The Book of Knowledge of Ingenious Mechanical Devices

The Book of Knowledge of Ingenious Mechanical Devices

(Kitāb fī maʿrifat al-ḥiyal al-handasiyya)

by

Ibn al-Razzāz al-Jazarī

Translated and annotated

by

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To my dear wife Pat *whose constant encouragement*
and support
made this undertaking
possible

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FOREWORD

To judge by the dictum of al-Jāḥiẓ (d. A.D. 869), 'Wisdom has descended upon these three: the brain of the Byzantine, the hands of the Chinese, and the tongue of the Arab', in the great age of the ʿAbbāsids the subjects of the Caliph felt no special competence in technology. By the later thirteenth century, however, Yuan China was learning from Muslim engineers. Can it be that during the intervening four hundred years there was technological advance in Islam? If so, how much of it was generated internally, and how much depended on borrowings from China, South Asia, the medieval Greeks and the Franks? What aspects of the mechanic arts flourished, what were neglected, and – in each instance – why was this the case? How was engineering integrated with, or isolated from, other aspects of Muslim culture?

The topic is full of enigmas. Why, for example, having taken over papermaking from the Chinese, did Islam – which used waterpower for grinding grain – never (so it seems) adopt the Western use of waterpower for pulping the rags from which paper was made? Why, having invented the world's first operative windmills in Sijistān, did Islam fail to spread them more widely? Why was it so resistant to printing with moveable type, even after this useful art had been borrowed from the West by its Christian and Jewish minorities?

In my own explorations of medieval European technology, I have been constantly handicapped by the dearth of scholarly material available on comparable Near Eastern activities. How could one be sure that anything was original in the West so long as we had so little solid information about Islam? The texts of al-K͟hāzinī edited by N. Khanikoff, and of the Banū Mūsà edited by M. Curtze, together with a scattering of studies by B. Carra de Vaux and others, were not very enlightening. From the fragmented and exasperating articles of Eilhard Wiedemann, it became clear that al-Jazarī's machine book was the greatest neglected monument.

Some years ago I went to Istanbul to look at the remaining superb miniatures of the badly mutilated Mamluk manuscript in the library of ʿAya Sofia. Western scholars had thought that conical valves first appeared in Leonardo's drawings, but al-Jazarī's pictures show them. Similarly, segmental gears first clearly appear in al-Jazarī; in the West they emerge in Giovanni de' Dondi's astronomical clock finished in 1364; with the great Sienese engineer Francesco di Giorgio (d. 1501) they entered the general vocabulary of European machine design. Of particular importance, also, is the first unequivocal description of metal casting in closed mould-boxes with green sand, a method not used in the West until the end of the fifteenth century. These examples, and others, suggest Muslim transmission of Hellenistic, Far Eastern, and indeed Muslim inventions to the West. On my return I kept telling my lamented colleague Gustave von Grunebaum that the engineering relations between Islam and the West could never be understood until al-Jazarī was edited; and he kept replying, 'Who knows enough both of technology and of Arabic to do it?'

At last a professional engineer, sophisticated in Arabic and learned in Islamic history, has accomplished the task. Since this is a pioneering venture, it may well contain errors: these, if they exist, will be corrected as other texts are edited and special subjects investigated. The essential fact is that Dr. Hill, by preparing this volume, has laid a massive cornerstone for the building of a new historical topic: medieval Islamic engineering.

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PREFACE AND ACKNOWLEDGEMENTS

My main objective in composing this book has been to present a faithful translation of al-Jazarī's work, together with accurate reproductions of the original illustrations. I have also provided explanatory notes and drawings to assist the reader to arrive at a full understanding of the construction and operation of the devices. I realise, of course, that the essential part of this book is the translation of the text and I have felt keenly the responsibility of presenting this English version, especially since there is no published edition of the original, readily available for comparison. In any case, much of the importance of al-Jazarī's work lies in its value for historians of technology, many of whom have no knowledge of Arabic. I can only say that I believe that my translation, while doubtless not free from errors, to be free from any which would seriously distort the meaning or obscure vital information.

For the rest, I have dealt briefly with the works of other medieval Islamic writers on technology, in the light of our present knowledge, in order to arrive at a tentative evaluation of al-Jazarī's position within his own cultural milieu. I have also touched upon the works of classical, Byzantine and Chinese writers, where such works impinge directly upon al-Jazarī's subject matter. In doing so I have been acutely conscious of the inadequacy of my general knowledge of the history of technology. I have not attempted to rectify this inadequacy by studying the subject in depth, but only those aspects of it which are relevant to the present work. The necessity for making al-Jazarī's work easily available to scholars overrides other considerations, and cannot wait upon my further education.

It would be a long task to express my gratitude to all those who have assisted me in the preparation of this book. I am nevertheless sincerely grateful for the co-operation and encouragement which I have encountered whenever I have asked for help or advice. I have carried out this work in my spare time, with only infrequent contacts with scholars of similar interests. Such contacts as I have had, together with a great deal of rewarding correspondence, have raised my spirits and strengthened my resolve, as well as providing me with valuable information and insights.

Professor Lynn White Jr. of the University of California, Los Angeles first prompted me to undertake this work, and has since sustained me with advice, encouragement and friendship. It was through him, moreover, that I was introduced to a number of scholars working in related fields. For all this I am extremely grateful. With Dr. Joseph Needham, Master of Gonville and Caius College, Cambridge, I have had several fruitful exchanges of views, and have thus been able to benefit from his immense store of knowledge of the technological culture of China. I am fully appreciative of the value of these discussions. My thanks are also due to Professor Cyril Stanley Smith, of the Massachusetts Institute of Technology, for his comments on the significance of al-Jazarī's description of his metal-casting techniques.

I could not have written this book without having first acquired some competence in Oriental studies. I remember with gratitude my first guide in Arabic history, Mr. F. R. C. Bagley, of the School of Oriental Studies, University of Durham, and then a long and fruitful association with the School of Oriental and African Studies, University of London. In particular, Professor Bernard Lewis passed on to me some small part of his profound understanding of Arabic history, and guided me towards an appreciation of the techniques of historical investigation. My debt to him is acknowledged with gratitude. I would also like to thank Professor T. M. Johnstone, who was kind enough to assist me in elucidating several of al-Jazarī's more difficult passages, and Mr. J. D. Pearson and the Library staff, from whom I have always received courteous and efficient service.

The reproductions of the illustrations from the Graves 27 manuscript are an essential feature of this book. I am grateful to Mr. N. C. Sainsbury, Keeper of Oriental Books in the Bodleian Library for granting permission to publish these photographs, and to the Photographic Department of the Library for the high quality of their work. I would also like to express my gratitude to all the museums, art galleries and private owners who have provided material for my researches, and especially to those who have given permission for publication of photographs from the Istanbul manuscripts.

Mr. Neil Rutherford, of the Central School of Art and Design, London, was kind enough to discuss metal-casting techniques with me and to show me work in progress in the foundry. This was of considerable assistance to me in arriving at an understanding of al-Jazarī's description of metal-casting.

Mrs. Nina Fuller, as usual, made a highly competent job of the typescript, and for this I offer my thanks.

Mr. R. J. Law of the Science Museum, London, and his colleagues in the Newcomen Society performed a service for me which leaves me greatly in their debt. They brought my work to the attention of Dr. J. L. Verbeek of the D. Reidel Publishing Company, thus ensuring that it would see the light of day. It is a fitting conclusion, therefore, for me to express my gratitude to Dr. Verbeek and other members of Reidel's staff, for their courtesy to me, and for the efficiency with which they have carried through the publication, and for the fine quality of the production.

LIST OF ILLUSTRATIONS

1. Complete set of illustrations referred to in the text

Al-Jazarī makes reference to 173 illustrations in his text, Fig. No. 174 being a list of 21 letters of the Arabic alphabet with their equivalent symbols from the secret alphabets. In order to present this work in accordance with al-Jazarī's intentions it was therefore necessary to reproduce all these illustrations, from simple line drawings and thumbnail sketches to full page paintings. Only two of the original set are missing from the Bodleian Library Graves 27 manuscript and these omissions have been supplied by unaltered photographs from the Bodleian Library Fraser 186 manuscript (Fig. Nos. 128 and 133). Two of the illustrations in the Graves 27 manuscript are very faint line drawings, and the figures were therefore produced by making tracings from the photographic copy of the original (Fig. Nos. 42 and 142). All the other illustrations are unaltered photographs from the Graves 27 manuscript.

Some of the illustrations are shown in the original lying on their sides, with lettering and captions also turned through a right angle. To make for easier reading most of these have been reproduced in upright positions. These are Fig. Nos. 53, 56, 59, 66, 67, 80, and 122.

2. Plates

Plates I to XXXII will be found between pages 207 and 238.

Note: credit lines are not given in the following list, but are shown below the individual Plates. In most cases the wording of the credit lines has been prescribed by the owners.

3. Explanatory Drawings

Part I

Introduction

1. Al-Jazarī – his life and environment

The name of the author of this work was Badīʿal-Zamān Abū al-ʿIzz Ismaʿīl b. al-Razzāz al-Jazarī. Badīʿal-Zamān means 'Prodigy of the Age' and was applied to other well-known men – to al-Hamadhānī for instance. Ibn al-Razzāz is translated by Sarton[1] as 'son of the rice-merchant', assuming a derivation from *ruzz*, which means 'rice'. There appears to be no sound basis for this translation; the name may in fact be of Syriac or Aramaic origin.[2] The appellation 'al-Jazarī' refers to his homeland, al-Jazīra or Mesopotamia, which lies between the upper reaches of the Tigris and the Euphrates.

All that we know of his life is contained in his own statement in the introduction to his work. He tells us that, at the time of writing his book, he was in the service of Nāṣir al-Dīn, the Artuqid, king of Diyār Bakr. He had then spent twenty-five years in the service of the family, having served the father and brother of Nāṣir al-Dīn before him, and the first year of his service to the family was 577 (1181/82 A.D.) according to the Oxford MS, and 575 (1179/1180 A.D.) according to both Leiden MSS. His book was thus completed in 1204 or 1206 A.D. The brother of Nāṣir (reigned 597/1200–619/1222) was Quṭb al-Dīn (581/1185–597/1200), and their father was Nūr al-Dīn Muḥammad (570/1174–581/1185).

The Artuqids[3] were a Turcoman dynasty descended from Artuq, a general who served Malik Shāh, the Seljuq Sultan, at the end of the 5th/11th century. They were divided into two main branches, descended from two sons of Artuq – Ilghāzī and Sukmān. Al-Jazarī's masters belonged to the Sukmān branch of the family. The Artuqid princes maintained, during the 6th/12th century, a precarious autonomy in Diyār Bakr in the face of more powerful neighbours, notably the Seljuqs, the Byzantines and the Crusaders. Their position might have been more secure had they not contended among themselves for possession of towns and territories in Diyār Bakr. With the advent of Saladin the autonomy of the Artuqids came virtually to an end. Nūr al-Dīn Muḥammad, the first of al-Jazarī's masters, felt if prudent to come to terms with Saladin, and in 577/1181 was awarded the town of Āmid as a fief. It was at about this time that al-Jazarī entered the service of the family. The door described by al-Jazarī in VI, 1 was for the King's palace at Āmid, and it is legitimate to suppose that this town was the seat of government during al-Jazarī's years of service.

Ibn Jubayr visited the Jazīra in 580/1184. It appears to have been a prosperous and fairly peaceful region at that time, although travel was rendered hazardous by marauding bands of Kurds. Quṭb al-Dīn was then ruler of the cities of Dunaysar, Dārā, Māridīn and Raʾs al-ʿAyn. Ibn Jubayr makes a deprecatory reference to the numerous petty princelings of Diyār Bakr, whom he compares to the kings (*mulūk*) of Arab factions in Spain. He remarks that they assumed honorific titles connected with religion (*al-dīn*), but that none of them deserved such titles except Ṣalāḥ al-Dīn (Saladin) himself. From the time of al-Jazarī's entry into the service of this Artuqid family until the completion of his book, his masters were thus no more than vassals of Saladin and his Ayyubid successors. It can be assumed that conditions during this period were fairly quiet, and allowed al-Jazarī to pursue his vocation in peace.

2. The Manuscripts

There are a number of manuscripts of al-Jazarī's work. Four of these, the first four mentioned below, were used for the present translation.

1. BODLEIAN LIBRARY, OXFORD

MS. Graves 27

This is referred to throughout this book as the 'Oxford MS'. The translation was made from this MS, the other three being used as controls, and to rectify mistakes and supply omissions. Only one passage of any length is omitted from this version, this comprising the end of Section 2

[1] Sarton II, 632.
[2] I am indebted to Professor T. M. Johnstone of the University of London for his comments on this name.
[3] For Diyār Bakr and the Artuqids see:
Cahen in *JA* 1935, passim,
Cahen in *E.I.*, article 'Artuḳids', pp. 662–667,
Ibn Jubayr (1), pp. 237–250;
Runciman, Vol. II (in index under 'Ortoqids').

and the beginning of Section 3 of Chapter 6, Category IV. Otherwise mistakes and lacunae are infrequent.

As the scribe stated in the conclusion, it was written in 891/1486 from a copy dated 742/1341. The script is a clear *naskhī*, not difficult to read, although diacritical consonantal points are frequently omitted. The letters used on the drawings are taken from the normal Arabic alphabet, whereas in the text numbers are often written in *abjad* form. (*Abjad* is the system whereby each letter of the Arabic alphabet is assigned a numerical value.) Except in a few cases the illustrations are well drawn.

2. LIBRARY OF THE UNIVERSITY OF LEIDEN

No. Or 656 in *Handlist of Arabic Manuscripts*, compiled by P. Voorhoeve, 1957, pp. 194–195.

This is a copy of the Oxford MS. Chapter 1 of Category VI is deliberately omitted. At the beginning of this category are the words: 'Chapter 2 of Category VI. I have omitted the first chapter because it is of no utility. It is the construction of a door...'. The manuscript ends with this passage:

'This marvellous book, uniting knowledge and practice, of use in the construction of *ḥiyal*, and attributed to Badīʿ al-Zamān Abū al-ʿIzz Ismāʿīl b. al-Razzāz al-Jazarī, was written on 4 Jumādā II, 606. My master the *shaykh* said: "I copied it from a copy in the handwriting of Shaykh Shams al-Dīn Ibn Abī al-Fatḥ al-Sūfī, [dated] 891". I made this copy from the [above] mentioned copy in the handwriting of my master, *Shaykh* Muḥammad al-Mahwarī, in 969 [1561 A.D.].'

Many of the drawings are missing, and after the first two chapters all representations of human or animal figures are omitted. The writing is in *naskhī* script which is not so easily legible as that of the Oxford MS. Letters or drawings are from the normal alphabet. This MS was only of limited value, but because the scribe had sometimes repaired errors and omissions in the Oxford MS it was not without its uses.

3. LIBRARY OF THE UNIVERSITY OF LEIDEN

No. Or. 117 in the *Handlist*.

This manuscript is incomplete. On the last page the scribe has written:

'I have omitted the 46th Chapter, i.e. the first chapter of the sixth category, which was concerned with the construction of a door in the city of Āmid, because of its small usefulness, and [because] the author gave it a lengthy treatment.'

At the bottom of the same page, in another hand, is written:

'The 45th Chapter, i.e. the last of the 5th Category is not in it, nor are the 46th and 47th, i.e. the first and second of the 6th Category. Also missing are the six chapters at the beginning of Category II.'

Actually part of II, 1, and part of II.6 are included. Also it is really the 4th chapter of Category V, not the 5th, which is missing. The 5th has been re-numbered as the 4th. A note in Arabic at the side of the passage in question points this out.

Parts of the text are very difficult, if not impossible, to read. It is written in a crabbed *naskhī*, the words crowded together, and even the legible parts are not as good as the Oxford MS. The drawings, which are marked with the letters of the secret alphabet, are very bad indeed.

4. CHESTER BEATTY LIBRARY, DUBLIN

MS. 4187

This manuscript has many pages missing, and all the folios are stained and damaged at the edges. There is no chapter of the whole work which is absolutely complete. There are 86 loose folios; earlier, soft, light-brown paper with large clear *naskhī* script (71 fol.) and later coarse white paper with a variety of *naskhī* hands (15 fol.). On fol. 16b there is a date, 730 A.H./1329 but this is not certain since the sentence recording this date is written in a different kind of ink, and seems to have been added later. Several full page drawings bear comparison, for skilful execution, with the best of the Istanbul miniatures (see below). The following are particularly worthy of mention: the Man on Balcony from the Elephant Clock, I, 4 (Fig. 59 in this book); the Beaker Clock, I, 5 (Fig. 60); the flumed beam water-raising machine with crank, V, 4 (Fig. 137). The other drawings from the earlier section are quite good, and often follow the textual description more closely than those in the Oxford MS. The drawings from the later section are poor, but in general readable. All the illustrations are marked with the letters of the secret alphabet.

Despite its fragmentary condition this manuscript was of considerable assistance in elucidating difficult passages in the Oxford MS. The writing is clear, with few mistakes, and omission of diacritical points is not so common. And as stated above, the drawings often follow the text faithfully.

Other Manuscripts

A number of miniatures from two manuscripts, dated 1315 A.D. and 1354 A.D. respectively, both originally in Istanbul, have found their way into public and private collections in Europe and the U.S.A. Photographs of 32 of these miniatures from the two MSS are shown here in the Plates. These miniatures are well known to those concerned with Islamic Art, and a considerable literature has grown up around them. A full bibliography of this literature is not included in the present work since many of the papers in question are very brief, and are concerned with one or two miniatures. A lengthy bibliography is given in Coomaraswamy (1), with further, more recent information in the Freer Gallery Folder Sheets Nos. 30.71–30.77, 32.19, 42.10, particularly Nos. 30.71 and 32.19.

Brief details of these manuscripts are as follows:

5. DATED 715 A.H./1315

This manuscript, formerly in Istanbul is now dispersed. It has been described by M. Aga Oglu, who assigned a Syrian provenance to it.

As can be seen from the examples included in this book the drawings are skilfully executed, and the writing, a fine *naskhī*, is very clear.

6. DATED 756 A.H./1354

What remains of this manuscript is in the library of the Topqapu Serai, Istanbul, No. 3606. M. R. Riefstahl established that it was written in Egypt.

Again, the drawings are most attractive and the calligraphy is excellent. One can only regret that neither manuscript, in its entirety, is any longer available for study.

7. LIBRARY OF TOPQAPU SERAI, ISTANBUL

No. 3472.

This manuscript was described by Ivan Stchoukine as being the earliest of all the copies of al-Jazarī's work, dating from the first half of the 13th century. From the reproductions given in Stchoukine's paper it seems to be a fine manuscript, with excellent illustrations. Fig. 3, for instance, showing the palace door, gives far more detail than the equivalent drawing in the Oxford MS (Fig. 142).

8. BODLEIAN LIBRARY, OXFORD

MS. Frazer 186.

A Mughal copy dating from the 17th century. This is quite well written, but not so good as the Graves MS. The illustrations, which are usually marked with the letters of the secret alphabet, are in general well drawn.

9. BIBLIOTHÈQUE NATIONALE, PARIS

Arabe 2477.

Second part of al-Jazarī's work. Dated 890 A.H./1485. Illustrations in colour.

10. BIBLIOTHÈQUE NATIONALE, PARIS

Arabe 5101.

Eighteenth Century MS in *nestaʿlik* script. It is without illustrations, for which, however, the spaces have been reserved.

11. BIBLIOTHÈQUE NATIONALE, PARIS

Suppl. pers 1145 and 1145a.

Persian translation of al-Jazarī's work made in 1291 A.H./1874 by Ibn Molla Mehdi Agha Baba Shlin Zani.

This list is based upon present information, but it may not be exhaustive. After all, none of the writers on the al-Jazarī MSS mention the important Dublin MS. Now that so many of the miniatures are assembled in one work for the first time, it is to be hoped that this may encourage an historian of art to make a comparative study of the illustrations in all the manuscripts, not simply of those from the 1315 and 1354 manuscripts, or of those which happen to be assembled in a given collection.

3. Translation and Illustrations

It was not an easy matter to decide upon the best means of setting out this work so that it would be of the greatest service to readers from various disciplines. About one question, however, there was no doubt in my mind at all: it had to remain as close as possible to the original in style, content and presentation.

At the outset I made the decision that my work would be, as far as possible, a rendering of the Oxford Graves 27 manuscript, this being the oldest complete (or almost complete) manuscript. The handwriting is clear, better than that in either Leiden manuscript, and as good as that in the Dublin manuscript, which is in any case fragmentary. The same applies to the illustrations – indeed, from a technical standpoint, these are better than those in any of the other manuscripts. Errors and omissions are infrequent, the only major lacuna occurring in Chapter 6 of Category IV; (as mentioned in the notes to that chapter, this lacuna was filled by making a translation from the Leiden or 656 manuscript). Although consonantal points are frequently omitted, this rarely presented any difficulty, since the words usually be identified from the technical context. It was therefore possible to establish an almost complete text, apart from the lacuna mentioned above, from the Oxford Graves 27 manuscript, and only in a very few cases was it necessary to have recourse to the three other manuscripts.

Textual variants and omissions supplied from other manuscripts have not been noted. This decision was not taken lightly, but I believe it to be right. Variations, as mentioned above, are infrequent, but their inclusion would have been distracting for the non-Orientalist reader. In any case, to give a complete picture, it would have been necessary to assemble all the extant manuscripts and part manuscripts, and collate them. This task would have added at least one year to the time taken to prepare this work and in the end very little of substance would have been achieved. The illustrations are a different matter, since the other versions sometimes supply important correctives and mistakes in the Oxford drawings. In such cases the variant version has been noted.

The translation presented no special difficulties, and has been kept as close to the original as possible, if allowance is made for the totally different structure of Arabic as compared to English. The English is straightforward, even pedestrian,reflecting the same qualities in the original, apart from two passages in rhymed prose (*saj*ʿ), one at the beginning of the work, one at the beginning of Category VI. In transliterating words I have followed the system adopted by the *Encyclopaedia of Islam*, 2nd Edition, with two exceptions: 'q' instead of 'ḳ', 'j' instead of 'dj'. For the single letters used for identifying parts on drawings, the same system has again been used, with two further exceptions: for *lam-alif*, rather than write *la* I have used 'p'; for *ayn*, since the hook normally used for this letters does not look well in isolation, I have used 'x'.

There are three unusual, but not solecistic, grammatical usages in al-Jazarī's Arabic. One is his use of *matà*, normally an interrogative participle, as a conjunction meaning 'when'. The second is his use of *law* (if), which as a rule introduces hypothetical conditional clauses, to introduce possible conditional clauses – often its meaning approximates to 'when'. Thirdly, he sometimes uses the third person feminine plural of the personal pronouns, '*hunna*', usually reserved for persons, in agreement with the plurals of inanimate objects.

A number of al-Jazarī's technical expressions have different meanings in literary Arabic or in modern Arabic. Some are of foreign origin and some are not to be found outside the works of medieval technologists. I therefore adopted the practice of translating these words into the modern expression for the object which they describe. Thus *rub*ʿ became a 'float-chamber', *dastūr* a 'flow-regulator' and so on.

In Category I I have diverged from the expressions normally used to identify the two types of hour. The time division which we use nowadays, twenty-four hours to a complete day, is usually called an 'equal' hour. The hour which is obtained by dividing daylight and night hours by twelve is usually called a 'temporal' hour. I do not consider that these terms give a precise enough meaning, and hence I have used the expressions 'constant hour' and 'solar hour' respectively. I am aware that the Arabic words are accurately translated by the more conventional expressions, but nevertheless I consider my departure from them justified.

Bearing in mind that it was the intention to present a close rendering of the Oxford Graves 27 manuscript, the illustrations posed a special problem. It would have been possible to have erased the Arabic identifying letters and the captions from negatives of the drawings, substituted Roman letters, and reproduced photographs in the work from these 'doctored' negatives. This would have had the merit of making reference easier for the non-Arabist. It would, however, have meant that the negatives were no longer a faithful reproduction of the originals, and much of their intrinsic interest would have been lost. After consultation with Mr. N. C. Sainsbury, Keeper of Oriental Books at the Bodleian Library, it was therefore decided to reproduce photographs of the illustrations, in black-and-white, as they appear in the original. These all appear in the English text in positions which closely approximate to their positions in the manuscript. They are numbered consecutively, and the captions, where these occur, are given in translation beneath the illustrations, with their locations on the illustrations indicated.

Obviously some further aids were required to enable readers to correlate text and drawings, and arrive at a full understanding of the construction and operation of the devices. Firstly, as a matter of course, I made orthographic or isometric drawings, reconstructed from al-Jazarī's text and drawings, wherever I felt that these would help to clarify his descriptive matter. These are, in a way, translations and, in the same way as written translations, may embody misinterpretations or faulty readings. Nevertheless, it is felt that on the whole they represent faithfully, and in modern guise, the designs of al-Jazarī. Some chapters are provided with a number of such drawings, some with one, some with none; they appear with the notes for the individual chapters.

Secondly, line drawings of some of the illustrations have been made, and inserted in the text close to the originals. This has been done in order to show the Roman letters which correspond to the Arabic ones. In certain cases numbers have been added to indicate the position of the captions; these numbers are then used as identifiers for the captions, which are given in translation below the figures. These line drawings have been provided only for those illustrations which carry a number of Arabic letters. The mistakes and omissions in the lettering of the illustrations, when compared with the instructions in the text, have not been noted except in extreme cases, e.g. when all the letters are missing. When, however, letters are mentioned in the text but omitted from the illustrations, these have been added in parentheses, if their position can be decided with some confidence. At the end of Part II, two sets of keys to the Arabic alphabet will be found. One of these was provided by al-Jazarī or by the scribe: it shows in the small circles, 21 letters of the Arabic alphabet (out of 29, including *lam-alif*) which he used on his drawings. With each letter two symbols are shown, and these are the letters of the 'secret alphabet' equivalent to the Arabic letter. These symbols are not used in the Oxford MS, but can be seen on the photographs from the Istanbul MSS.

Immediately following this I have given the same 21 Arabic letters, with their equivalent transliterations in Roman letters. Consonantal points are seldom written on the letters in the illustrations but can usually be identified from their shape. Of the 21 letters used, there are only two which can be confused because of the omission of these points. These are *ḥ* and *j*. One can always be certain that *j* is intended if it is given in conjunction with the letters *a b* and *d*, but otherwise my selection is arbitrary.

Finally I have given the *abjad* letters, with their numerical equivalents, up to fifty. Al-Jazarī frequently uses this system in the text, but on the drawings it is used only for the main illustration in each chapter, which are numbered from one through to fifty in this way, generally in large letters at the top of the drawings.

4. Modern works on al-Jazarī

By far the most important contribution to our knowledge of al-Jazarī's work was made by Eilhard Wiedemann, a physicist with a knowledge of Arabic, in collaboration with Fritz Hauser, an engineer. Eilhard Wiedemann (1852–1928) made the study of Islamic science, medicine, mathematics and technology his life's work, and in these fields his writings are of great importance. Unfortunately he never saw fit to publish his results in book form, and his many articles are scattered among a number of learned German periodicals, most of which are now very difficult of access. The articles which he wrote for the Erlangen Society are now, as indicated in the Bibliography, assembled in two volumes, which include a foreword, indexes, and a complete list of his writings. Some articles on technology are to be found in these two volumes, but all of those which he wrote in collaboration with Hauser – on al-Jazarī, the Banū Mūsà, the pseudo-Archimedes, and Ibn al-Saʿātī – remain in their original periodicals.

I am most happy to acknowledge my debt to the work Wiedemann and Hauser, particularly as an invaluable guide to original and derived sources, and as a secondary control for the elucidation of difficult passages. I am especially grateful for the care which Wiedemann expended in deciphering the less legible parts of the manuscripts, which I was thus enabled to read with comparative ease. (In the Oxford MS of al-Jazarī, however, these passages are infrequent.) It can safely be said that, were it not for the work of Wiedemann and Hauser, the Islamic contribution to the progress of technology would have remained almost unknown.

The six separate Categories of al-Jazarī's work were dealt with by Wiedemann and Hauser in seven articles in various learned periodicals. These articles have several merits, and in particular they give a fairly clear understanding, to anyone with some measure of technical knowledge, of the design, construction, and operation of each of the devices. In most cases the original drawings are faithfully reproduced, the identifying Arabic letters being transliterated and the captions translated. Many of the technical expressions and unusual words are given in transliteration as well as in German translation. Footnotes provide additional information and explanations, and orthographic drawings are sometimes supplied as an additional guide to understanding.

This having been said, however, it must be admitted that the usefulness of these articles is diminished by several defects, not the least of which is their inaccessibility. Perhaps the most serious deficiency lies in their treatment of the text and in the unevenness of the presentation. Sometimes the text is given as a fairly faithful translation (e.g. in the Clock Category), but even in these cases the translation is sometimes abridged. Admittedly, the authors almost always make it clear that this has been done, but their judgment of the significance of abbreviated or omitted passages is not always sound. In these translations, moreover, sentences were interpolated by the authors without any indication that this had been done. Apart from Category I and parts of Category VI, the remainder of the articles are shortened paraphrases of al-Jazarī's text. In general, therefore, a faithful reproduction of the original has not been presented, and the idiosyncrasy of the author has been lost. More serious still, there are omissions of significant sentences, and some notable errors in interpretation and translation. There are also a few cases where a passage which is obscure in Arabic remains obscure in German. In this present work, no attempt has been made at a continuous comparison with the work of Wiedemann and Hauser, because this would have lengthened the book considerably, without adding much of value. Where, however, there are important divergences between our interpretations these have been recorded.

The only other work of any note on al-Jazarī is the treatise of A. K. Coomaraswamy (1). This is written from the viewpoint of an historian of art and contains some interesting information about the miniatures from the 1354 Istanbul MS. For an understanding of the working of the devices Coomaraswamy relied entirely upon the writings of Wiedemann and Hauser. There are a number of other works which are concerned with the al-Jazarī miniatures from the Istanbul manuscripts; generally these are very brief.

There are two entries on al-Jazarī in Sarton (II, 510, 632–633) and a short discussion of his work by Winter (26f). Otherwise references are confined to discussions of individual devices in works of more general application such as those of Needham (1) (2) (3), White and Drachmann (2).

5. Islamic technology up to al-Jazarī

Sarton says of al-Jazarī's book: 'this treatise is the most elaborate of its kind and may be considered the climax of this line of Muslim achievement'.[1] Those who read this present edition of the book might therefore reasonably expect to be presented with a summary of Islamic technology up to the time of al-Jazarī, together with an appraisal of the work done by modern writers in this field. While it would be irresponsible not to attempt these tasks, it must be made clear from the outset that the material, both primary and secondary, is scattered and difficult of access, and by no means presents a picture of steady evolution – a picture that could be erroneously inferred from Sarton's statement.

First, it must again be emphasised that, apart from the writings of Wiedemann and Hauser, very little work has been done on Arabic technology, and that almost nothing has been attempted this field during the last fifty years. There is no general work which summarises the Muslim acheivement, and the scattered references in the works of general application by writers such as Mieli, Singer and even Sarton, serve merely to emphasise the paucity of information on this subject.

[1] Sarton II, 510.

In the General Notes at the end of this book the possible relevance of al-Jazarī's predecessors to the development of his technology is considered in some detail. The summary which follows, therefore, is confined to a brief discussion of the lives and writings of the few important technologists whose works are known to us at the present time. This summary must be regarded as preliminary and incomplete. This is not the place to attempt a full review of Islamic technology and, in any case, much research remains to be done before such a review could be undertaken with any confidence. Nor should such research be confined to the literary field. As far as I am aware, there has been no archaeological study of medieval Islamic technology, nor any detailed technical examination of those machines which still exist, such as the *norias* at Ḥamāt.

I have confined my attention, furthermore, to those writers who concerned themselves with mechanical technology, and this accounts for the omission of important works which deal with allied subjects, such as al-Khāzinī's *Book of the Balance of Wisdom* (which deals with weights, specific weights etc.).

BANŪ (SONS OF) MŪSÀ B. SHĀKIR: *Kitāb al-Ḥiyal*

The names of these three men were Abū Jaʿfar Muḥammad, Abū al-Qasīm Aḥmad and al-Ḥasan. They were brought up, after the death of their father, under the patronage of the Caliph Maʿmūn (198/813–218/833), and did most of their work under his successors.

Their work, which has not been edited in Arabic, is available in manuscript only. There is one in the Vatican (317) and another which is in two parts, one in Berlin (von Ahlwardt No. 5562) and the other in Gotha (Arab 1349). According to Wiedemann (W. H. 2, p. 268) there is also a copy of the Vatican MS in Gotha (No. 1349a). Seven devices are included in a Leiden Manuscript (Catalogue Vol. 3, 1019 168 Gol.). References to the Banū Mūsà will be found in Sarton I 560, Brockelmann Supplement I 856 and Winter p. 25f. The only detailed studies of the Banū Mūsà, however, were made by Wiedemann and Hauser – see W.H.2, 268–291; W.H.4; W.H.5; Hauser. There are also a number of references to them in the Beiträge, and these are listed in the indexes to the Aufsätze. In his book Hauser correlated the manuscripts, and gave abbreviated translations of the descriptions of each device with reproductions of the original drawings. He also gave explanatory notes and drawings. He makes only brief reference, however, to these devices which were dealt with elsewhere by himself and Wiedemann, so that for a complete examination of the output of the Banū Mūsà one requires all the works listed above.

In the present work use has been made of the Wiedemann and Hauser material together with a photographic copy of the Gotha 1349 manuscript. This seemed to provide adequate controls for making a brief appraisal of the Banū Mūsà's work, and to assess the extent of its influence on al-Jazarī.

There are 100 devices, including 7 fountains, 4 selftrimming lamps, an automatic musical instrument, a 'gas-mask' for approaching polluted wells and a mechanical grab for excavating in the beds of streams. The remainder, over four fifths of the total, consists of trick vessels for dispending liquids. In design and operation these are very similar to the devices described by Philon and Heron, and are almost certainly derived from these. Various effects are produced: for example, a wine dispenser which refills automatically, pitchers which dispense a measured quantity, pitchers from which different liquids may be drawn, vessels from which nothing may be obtained once pouring is interrupted, and so on. Use is made of pipes, siphons, jacketed siphons,[2] cone-valves, taps and air-holes; many of the devices are quite ingenious. The main differences between the Banū Mūsà devices and those described by the Greek writers, apart from the greater complexity of the former, is that the Banū Mūsà make use of properly fitted cone-valves, whereas Philon and Heron mention only crude clack-valves and plate-valves.

The descriptions of the devices are very brief – most of them occupy only a page of manuscript. Dimensions and details of construction are rarely given, the explanations being largely confined to descriptions of the design and operation of the finished articles. The drawings are simple line diagrams in one plane, almost invariably side elevations of the vessels, with the internals shown. Arabic letters are added to various parts of the drawings and these are referred to in the explanatory text.

[2] In a liquid container a narrow pipe *A*, both ends of which are open, passes through the floor of the container and rises vertically inside. A wider pipe *B* is fitted over *A*, its upper end a short distance above the top of *A*, its lower end a short distance above the floor of the container. The upper end of *B* is closed. When liquid is poured into the container it rises in *B* until it reaches the top of *A*, whereupon it discharges through *A* to beneath the floor of the container. This device is not used by al-Jazarī. One of its purposes was to produce air-locks and thus deliberately break the flow of liquid.

'ARCHIMEDES'

There are three manuscripts of this interesting and important work, and one fragmentary manuscript:

1. London, British Museum, Add. 23,391.
2. Paris, Bibliothèque Nationale, Catalogue von G. de Slane, No. 2468, p. 437.
3. Oxford, Bodleian Library, No. 954, p. 95.
   this is a fragment, and consists of the beginning of the work only.
4. New York Public Library. Indo-Persian, Spencer Collections, MS 2. Risāla-i-Ḥakīm Muḥammad.

For my research I have used photo-copies of Nos. 1 and 4. In my text, however, I have referred only to the London MS. I must digress at this point to say a few words about No. 4, which is referred to in the present work as 'New York MS'. Its existence was brought to my attention by Professor Lynn White of the University of California, Los Angeles. When the microfilm, which had been kindly sent to me by the New York Public Library, had been enlarged, I was delighted to discover that it consisted of a complete copy of the British Museum 'Archimedes' MS, a complete copy of British Museum 'Apollonius' MS, several chapters of the Banū Mūsà, and one of al-Jazarī's (No. II, 1). There are 38 leaves and 34 drawings. Unfortunately the Banū Mūsà chapters are badly smudged and almost illegible, but the remainder is clear enough, although it is written in the rather difficult Fārsī script. The manuscript is dated 1030/1620. As far as I known the contents of this manuscript have not been identified before.

The British Museum MS is written in a clear *naskhī* script, not difficult to read, and includes illustrative drawings. There are a few lacunae.

The clock of 'Archimedes' was first described by Carra de Vaux (1), with details of its construction and operation, together with examples of the Arabic text. The work was translated into German by Wiedemann and Hauser (W.H.8). from the London, Paris and Oxford manuscripts. They found that there were lacunae in the Paris MS, as well as in the London MS, but that the complete text could be re-assembled by using the two manuscripts.

Drachmann has written a valuable criticism of this clock, based upon the translation of Wiedemann and Hauser,[3] and comes to the conclusion that it was the work of a Muslim inventor who put together details from several sources, one of them doubtless Philon, another probably Heron. I see no reason to contest this opinion, in view of the many similarities between this clock and the devices of the two earlier writers. Since both Riḍwān and al-Jazarī acknowledge the derivation of their constant-flow clocks from that of 'Archimedes', we are safe in assuming that it is an important transmission between the classical writers and the later Islamic craftsmen.

There is no certain way of dating this work, but I suggest tentatively that the design of the cone-valve on top of the float in the float-chamber[4] may provide a clue. This type of valve is later than Heron and Philon, and does not occur in Vitruvius. As described in the 'Archimedes', however, it is a fairly crude component – merely a rounded knob (*zirr*) on top of the float. It is specified that it must enter the end of the bent-down pipe with ease, without sticking or allowing too much play. It is not called a 'ground-in valve' (*bāb maṯḥūn*) whereas this designation is used by the Banū Mūsà, al-Jazarī, Ridwān and in the *Mafātīḥ al ʿUlūm*. In all these works the plug and seat were conical and al-Jazarī and Riḍwān stipulate that they are ground together to a fit with emery. It may well be, therefore, that the 'Archimedes' is a very early Muslim work, written about the end of the 8th century. If this is the case the true cone-valve must have been developed in the first half of the 9th century, since those used by the Banū Mūsà appear to be properly machined components.

There is no general arrangement drawing but only a number of detailed sketches. These are drawn with ruler and compasses; the various parts are named, not marked with identifying letters. The description is quite brief and lacks al-Jazarī's clarity and precision. Only a broad description is given of the manufacturing and constructional procedures. It would therefore have been very difficult to have understood the construction and operation of this clock, had one not first studied al-Jazarī's work.

ABŪ ʿABD ALLAH MUḤAMMAD B. AḤMAD B. YŪSUF AL-KĀTIB AL-KHUWĀRIZMĪ: *Mafātīḥ al-ʿUlūm (The Keys of the Sciences)*

This work was written between the years 365/975–6 and 381/991–2, and is one of the few works containing technological information to have been published. It is essentially a vocabulary of

[3] Drachmann (2) 36–41.
[4] See al-Jazarī I, 1 (p. 21), and General Notes, (p. 276).

terms used in the sciences, the latter term being used in its widest sense, to include such subjects as linguistics, poetry and music, as well as medicine and the natural sciences.

The chapter which concerns us is on mechanisms (*ḥiyal*) – pp. 246–255 in the van Vloten edition – and this covers the lever, siege engines, and components used in water machinery. A clear, brief description of each component is given, together with some etymological information. The work is therefore of considerable value, since it gives definitions for a number of the parts used by al-Jazarī, and also, of course, gives us an indication of the state of technological development at the end of the 4th/10th century. Reference is made to several of the entries in *Mafātīḥ al-ʿUlūm* in the General Notes at the end of this book.

The chapter on *ḥiyal* was translated by Wiedemann, with copious notes, in I 188–228/VI 16–56.

RIḌWĀN

His full name was Fakhr al-Dīn Riḍwān b. Muḥammad al-Saʿātī, and he completed his work describing the clock at the Bāb Jayrūn in 600/1203. This work has not been edited in Arabic, and the only known manuscript is No. 1348 in the Forschungsbibliothek, Gotha. Fortunately this is an excellent manuscript, clearly written and with few diacritical points omitted; it is almost free of errors. This copy was completed in 961/1554, in Istanbul.

References to Riḍwān are to be found in Brockelmann I, 473 (6) and Sarton II, 631–632, but the only extended treatment of his work is by Wiedemann and Hauser (W.H.1, 167–272). This contains an introduction, giving the few details that are known of Riḍwān's life and environment, together with a history of the clock. There follows an abbreviated version of the work, partly in translation and partly in paraphrase: notes and explanatory and drawings are provided, although the latter are hardly sufficient to give the layman an adequate idea of the construction and operation of the clock.

Riḍwān is reported to have been a doctor, and also a man of letters who had mastered logic and philosophy. His lack of technical knowledge is clearly demonstrated by his presentation. The drawings are crude freehand sketches without reference letters, the names of the parts being written on the drawings. They are frequently impossible to understand without reference to the text, and there is much repetition – in many cases, when a new part is added, the entire assembly is redrawn. One might argue, of course, since the existing manuscript was copied out some 350 years after the book was written, that some deterioration from the original might be expected. It is indeed true that the finest paintings in the al-Jazarī manuscripts are to be found in the earlier versions, but their superiority lies in artistic merit rather than in clarity of detail. The later drawings follow the constructional details of the earlier ones very faithfully and indeed the clearest of all, from the technical standpoint, are those in the 15th-century Oxford manuscript. It seems unlikely, therefore, that the drawings in Riḍwān's original work were much superior to those in the Gotha MS.

The writing is discursive and imprecise – instead of proper specifications we are given a broad description of the construction of the clock, and of its components. Riḍwān often tells one what to do, without saying exactly how to do it. His mathematics seem to have been rudimentary: for instance he gives a value of 3 to π, whereas the usual value used by the Arabs was 22/7. Dimensions are given in many cases, but it is doubtful whether a full reconstruction of the clock could be made from these.

Despite these failings Ridwān's work is a valuable part of our scanty store of original material on Islamic technology. The clock contains materials and components which were also used by al-Jazarī, so that one is the more easily able to build up a picture of contemporary technology than from the work of al-Jazarī alone. It is also interesting to compare the technical vocabularies in the two works. Ridwān's vocabulary usually coincides with al-Jazarī's but there are a number of disagreements. Finally, Riḍwān's work has one merit, not possessed by his contemporary, and that precisely because he was not a technical man. He will sometimes describe the manufacture of small parts, pipes for instance, whereas al-Jazarī omitted such details, presumably because he felt they could be taken for granted.

6. Arabic translations of earlier works

Only a brief mention can be made of those writers, Greek and Byzantine, whose works were translated into Arabic. The *Mechanics of Heron* was translated into Arabic by Qustā b. Lūqā about 250/864, every indication being that this is a genuine and accurate translation.[5] Philon's

[5] Carra de Vaux (2). See also Drachmann (1).

pneumatics have also come down to us in Arabic, although we have no knowledge of the date or the author of this translation.[6] According to al-Kindī Heron wrote about geography and pneumatic devices, and he also made clocks and other instruments for the measurement of time.[7] Of Philon, al-Kindī says that he was skilled in the construction of water-wheels, mills, and ingenious devices (*ḥiyal*).[8] Even without this evidence there could be little doubt, from an examination of the devices of the Banū Mūsà, that these were derived directly from the works of Heron and Philon. And since al-Jazarī refers to the Banū Mūsà as one of his sources, our line of transmission, for trick vessels at least, is complete.

The treatise attributed to Apollonius, on the construction of a mechanical musical instrument, has been translated by Wiedemann (II, 50ff/XXXVI 20ff), using two manuscripts and the fragment of a third. As mentioned earlier, a fourth version is in the New York MS, and this appears to be a copy of the London MS. I have used the last-named as a control. The details of the manuscripts are as follows:

1. Paris, Bibliothèque Nationale. Catalogue von de Slane, p. 437, No. 2468.
2. London, British Museum. Catalogue as for 'Archimedes'.
3. New York. See under Archimedes.
4. Beirut, Library of Orthodox Christians. Wiedemann gives no other details, apart from saying that the beginning of the text is missing.

The work is entitled '*Construction of the machine of the flute player*, by Apollonius the Carpenter, the geometrician.' Al-Jazarī at the start of Chapter 7, Category IV, refers to this machine and names its inventor as 'Apollonius the carpenter, the Indian'. It seems highly probably that he is referring to the same man, and that 'Indian' is an error for 'geometrician' – '*hindī*' for '*handasī*'.

Wiedemann identifies the writer of this work with Apollonius of Perga, the geometrician, who flourished towards the close of the second century B.C. Certainly his works in geometry have come down to us in Arabic translations, and were presumably well known to the Arabs, but he seems to have been primarily a mathematician, not a craftsman. The treatise in question, moreover, has all the marks of being of Byzantine, rather than classical origin. The writer mentions Byzantine (*Rūmī*) mills, and he describes his clack-valves as being like the valves on a Byzantine naphtha-thrower (*Bāb al-Midfaʿ*). It seems probable, therefore, that he was a craftsman, working in Byzantium, whose treatise became known to the Arabs in translation.

[6] Carra de Vaux (3).
[7] Wiedemann I, 69f/III 228f.
[8] Wiedemann I, 71f/III 230f. This al-Kindī is not to be confused with the philosopher of the same name, but is Abū ʿUmar Muḥammad b. Yūsuf b. Yaʿqūb al-Kindī, who lived about 359/970 – see Brockelmann I, p. 149.

Part II

The Book of Knowledge of Ingenious Mechanical Devices

In the name of God the Compassionate the Merciful

Oh God, pray for, keep safe and bless our Lord Muḥammad, the seal of the Apostles, his family and his Companions. Praise be to God, creator of His work in the heavens, consignor of the secrets of His wisdom to the earths, which He made as a proof of His dominion, and as a certain sign of His omnipotence. I praise Him for the instruction he has given and I seek more of His increasing gifts and these are the manifestations of His wisdom, praise appropriate to some part of His beneficence and His abundant generosity. The grace of God be upon our Lord Muḥammad, the noblest type of humankind and upon his family and upon his followers, beneficence be upon them.

I have studied the books of the earlier [scholars] and the works of the later [craftsmen] – masters of ingenious devices with movements like pneumatic [movements], and water machines for the constant and solar hours, and the transfer by bodies of bodies from their natural positions. I have contemplated in isolation and in company the implications of proofs. I considered the treatment of this craft for a period of time and I progressed, by practising it, from the stage of book learning to that of witnessing, and I have taken the view on this matter of some of the ancients and those more recent [scholars]. I was fervently attached to the pursuit of this subtle science and persisted in the endeavour to arrive at the truth. The eyes of opinion looked to me distinguish myself in this beloved science. Types of [machines] of great importance came to my notice, offering possibilities for types of marvellous control.

The kings of my time and the philosophers of my epoch took an interest in me, and from this the seedling of my confidence bore fruit. I spent the nights of my industry and caused my sleeping ambition to stand up and awoke my sleeping genius. I was engrossed in diligence and consumed strength and passion. I found that some of the earlier scholars and sages had made devices and had described what they had made. They had not considered them completely nor had they followed the correct path for all of them, for every [part] of constructional knowledge was not verified in practice, and so wavered between the true and the false. So I assembled the divisions that they had separated and put forth branches from roots where they had been correct, and devised specimens which worked splendidly, light internally and externally. And when I found difficulty such as to lengthen the journey I hated [the thought] that my diligence might go the ways of the wind and that the trace of what I had made might be woven into the tapestry of the night without morning. So my soul asked of me to pass on a record of that to [someone] whom I would appoint to unroll his parchment and [whom] I desired to instruct. Then I turned aside from what I had resolved and abandoned my intention, apprehensive of the disapproval of a censurer directing a penetrating gaze.

I am in the service of the king al-Ṣāliḥ Nāṣir al-Dīn Abī al-Fatḥ Maḥmūd bin Muḥammad bin Qarā Arslān bin Dawūd ibn Sukmān bin Artuq, the king of Diyār Bakr, may God preserve him with those whom He chooses to preserve. That is following my service to his father and his brother, God sanctify their souls, before the kingship passed to him – a [total] period of twenty-five years, the first of them year 577. God, may He be exalted, has singled him out with distinctions of intelligence, high-mindedness, justice and probity, so that he surpasses in justice and probity the kings of the present age, and excels the lords of near and far in beneficence and graciousness. There is no subtlety of the subtleties of government that he has not mastered through the penetration of his intellect, and no mystery of the mysteries of learning that he has not understood by the height of his zeal. I never began to construct a device of mine without his anticipating it [i.e. its purpose] by the subtlety of his perception. He is completed by the refinement of his opinion and his wisdom.

I was in his presence one day and had brought him something which he had ordered me to make. He looked at me and he looked at what I had made and thought about it, without my noticing. He guessed what I had been thinking about, and unveiled unerringly what I had concealed. He said 'you have made peerless devices, and through strength have brought them forth as works; so do not lose what you have wearied yourself with and have plainly constructed. I wish you to compose for me a book which assembles what you have created separately, and brings together a selection of individual items and pictures'.

I followed the pattern he had imposed and accepted his judgement, for I had no recourse but to obey. I gave of my strength according to the required reading and I composed this book in which there are certain rents I have patched and basic matters the sub-divisions of which I have given and figures which I have designed. I do not know that I have had any predecessors in this, trusting in the generosity of those scholars who are expert in this. And those who have knowledge of aphorisms know that every man can accomplish only what he is capable of by his inborn ability. And he can spend only of the provision given him by God, and let no soul spare that which can benefit others. No soul is asked to go beyond its capability.

I assembled that in a book [lit. introduction – *muqaddima*] comprising fifty specimens, and it is divided into six categories. I have been thorough in description and in particulars. In what I have written I have used foreign names passed on by earlier people and adherence to these has continued until today; and other expressions made necessary by time. For the people of every epoch have [their own] language, and every group of scholars have technical terms understood among themselves, and conventions familiar to them. For every specimen (*shakl*) I have drawn a picture, and have marked it with letters for guidance, and have [also] put alternatives for these letters.

Category I	On the construction of clocks from which can be told the passage of the constant and solar hours – 10 Chapters [lit. specimens – *ashkāl*]
Category II	On the construction of vessels and figures suitable for drinking sessions – 10 Chapters.
Category III	On the construction of pitchers and basins for phlebotomy and ritual washing – 10 Chapters.
Category IV	On the construction in pools of fountains which change their shape, and of machines for the perpetual flute – 10 Chapters.
Category V	On the construction of machines for raising water from standing water which is not deep, and from a running river – 5 Chapters.
Category VI	On the construction of different, dissimilar things – 5 Chapters.

CATEGORY I

On the construction of clocks (*Finkān*) from which can be told the passage of the constant and solar hours by means of water and candles

Chapter 1 of Category I

A water-clock (binkām) from which can be told the passage of the solar hours; this is divided into 10 sections

Section 1

This contains an introduction, necessary in this case, and this is followed by a description of the outside appearance of the clock from which the passage of the solar hours can be learned.

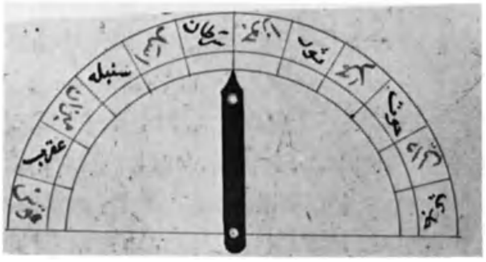


Fig. 1. Left to right around semicircle captions read: Sagittarius, Scorpio, Libra, Virgo, Leo, Cancer, Gemini, Taurus, Aries, Pisces, Aquarius, Capricorn.

I followed the method of the excellent Archimedes in distributing the twelve signs of the Zodiac over a semi-circle. A drilled onyx for the outlet of the water, mounted on a device, moved over these divisions. This was the fundamental basis of this work, or something similar, provided its divisions permit increased or decreased [flow]. He took a brass plate, and this is its picture [Fig. 1]. It is a semi-circle and he divided its perimeter into twelve equal divisions and wrote upon each division the name of a zodiacal sign. The first of these divisions is Capricorn, the last is Sagittarius, and at the top of the convexity is Cancer. He made its diameter horizontal, since the water outlet rises from [a point] opposite the centre of the semi-circle to the top of its convexity in 180 days and descends in the same time, because all the divisions of the zodiacal signs are equal. Hence [the flow] decreases as it [i.e. the outlet] rises and increases as it descends. If the outflow is at a certain division during the day, it will move to the opposite division (*naẓīr*) in the night of that day, so that in every day 12 [solar] hours will pass, and 12 hours in every night, corresponding to the latitude for which the instrument was designed. But when I made an instrument such as he [Archimedes] had described, it did not work correctly except for one day [in the year], namely the first day of Cancer. So I set it aside and searched for something else.

I discovered an instrument fabricated [at an earlier time] of which neither the maker nor the transmitter (*muṣanniʿ*) is known. This is a complete circle made from a circular plate, upon which two diameters at right angles are drawn, one from the head of Aries to the head of Libra, one between the heads of Capricorn and Cancer. These are marked *a*, *b*, *j*, *d*: the sign of the head of Cancer is *a*, of the head of Aries *b*, of the head of Libra *j* and of the head of Capricorn *d*. The diameter *ad* was divided into 180 equal parts, the ruler was placed on each division in turn parallel to the diameter *bj* and a mark made on the circle at each extremity, until all the divisions were made. The circle was thus divided into divisions which were broad [in proportion to their widths] at the heads of Cancer and Capricorn and narrow at the heads of Aries and Libra. This is the picture [Fig. 2]. That was a beautiful instrument for raising and lowering the water outlet according to the divisions of a straight line. I made an instrument to this pattern but it did not work correctly.

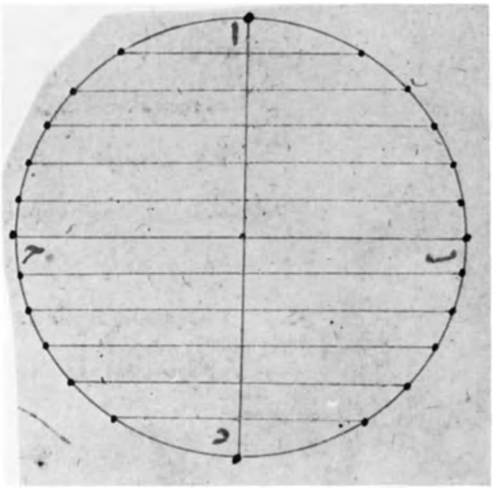


Fig. 2.

Archimedes described [another instrument] which he attributed to [a certain] al-Qajān or al-Qaṭān, and this is a complete circle divided into twelve equal parts, whereas he had used a semi-circle, but this [also] was incomplete.

I [therefore] turned aside from that and gave much thought [to the matter], whereupon it occurred to me to divide another circle according to the sun's inclination to the equator, and that the operation of this would be perfect. So I took a plate and drew a circle on it, and this is its picture [Fig. 3]. I drew on it two diameters at right angles, one between the heads of Aries and Libra, one between the heads of Capricorn and Cancer. Their signs are *a*, *b*, *j*, *d*: the signs of the heads of Capricorn and Cancer[1] are *ad* and the signs of the heads of Aries and Libra are *bj*. The diameter *bj* represents the equator, the centre of the circle is marked *e*, the greatest inclination [of the Ecliptic] is 23° 35′. Then from *e* [towards *a*] I made equal divisions representing 23° 35′. Then I placed the ruler on the position corresponding to the inclination [i.e. declination] of the first point of Taurus to the equator, namely 12° 18′, parallel to the equator. This begins from point *e*. At the edge of the ruler I made a mark on each side of the circle, the right-hand

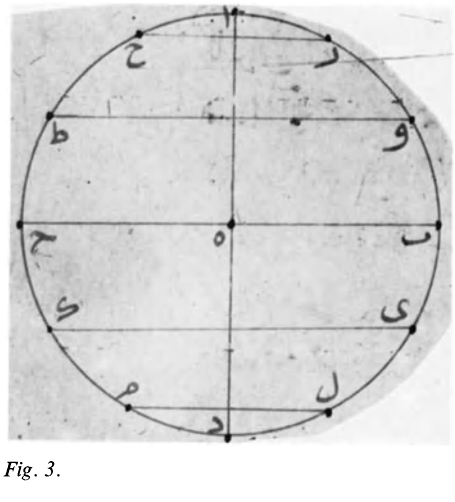


Fig. 3.

[1] These should be reversed, (*a*) is Cancer, (*d*) Capricorn.

mark being the first point of Taurus and the left the first point of Virgo. Then I counted out the full inclination of the first point of Gemini, which is 8°, placed the ruler at the end of this amount parallel to the equator, and made two more marks with the ruler on the outside of the circle, the right-hand one corresponding to the first point of Gemini and the left to the first point of Leo. I wrote at the first point of Taurus *w*, at the first point of Gemini *z*, at the first point of Leo *ḥ*, at the first point of Virgo *ṭ*. Thus I divided half the circle into approximately equal parts. Then from the centre-point *e* to the head of Capricorn I also divided according to the greatest inclination of the ecliptic, putting marks on the inclination of the first point of Pisces and the first point of Scorpio as I had marked the first half of the circle, similarly with the inclination of the first point of Aquarius and the first point of Sagittarius – *y, k, l, m*. The first point of Pisces was *y*, of Scorpio *k*, of Aquarius *l*, and the last point of Sagittarius *m*. The circle was now complete, with 12 Zodiacal signs, each divided into 30 parts. I used this instrument, but it did not function correctly and the measurements were false, the reason being that the earlier craftsmen were at fault. There was no alternative therefore but to proceed with practical work and experiment, using a method which I shall mention below, from which it will appear that the three designs given above are incorrect.

The Appearance and Method of Working of the Clock

The outside consists of a house, rising from the ground a distance of about twice the height of a man, comprising all that is required for telling the passage of the hours [Fig. 4]. In this house there is a door about 9 spans in height and $5\frac{1}{2}$ spans in width, which is closed by a wall of wood or bronze. Above the door, in a lateral straight line, are 12 doors, each of which has two leaves which are closed at the beginning of the day. Below these, and parallel to them, are 12 [more] doors, each with one leaf, which all have the same colour at the beginning of the day. Below the second set of doors is a frieze projecting one fingerbreadth from the face of the wall. At the side of the frieze is a crescent [moon] like a *Dīnār*. This crescent moves along the ledge in front of the doors to the [other] end of the ledge. In either side of the wall below the ledge, is a niche like a *miḥrāb*, and in each of these is a bird with outstretched wings, standing on its feet. Between the two niches are 12 roundels[2] made of glass, which are so arranged that they form a semi-circle with its convex side upwards. In front of each bird is a vase (*Qandīl*) supported on a projecting bracket, and in each vase is hung a cymbal. Below the wall several figures are situated – two drummers, two trumpeters and a cymbalist. Above the wall is a semi-circle with its convexity towards the top. Around its circumference are six of the 12 Zodiacal signs [i.e. visible at a given time], and below this is a sphere[3] carrying the sun, a golden roundel[2] and, below this, a sphere carrying the moon, a glass roundel.

As to its significance: at the beginning of the day the crescent moves in its regular imperceptible way along the frieze until it has passed one door and is between the first and second doors, whereupon the two panels of the first of the upper doors open and a figure, made according to the choice of the craftsman, comes out and stands as if he had suddenly emerged. Also, the first door which the crescent has passed turns over and changes colour, the two birds lean forward until they approach the two vases, and two balls are dropped from their beaks, each on to a cymbal, and the sound is heard from afar. The birds then resume their position. This happens at the end of every hour until the sixth, at which time the drummers drum, the trumpeters blow and the cymbalist plays his cymbals for a while. This occurs also at the ninth and twelfth hours.

The operation of the spheres is as follows: at the beginning of the day the centre of the sun will be in the appropriate degree of the Zodiac for that day, on the eastern horizon, about to rise. The opposite degree will be on the western horizon, about to set; whenever a degree rises its opposite will set. The sun climbs until noon, then descends until nightfall, when the sun's station will set, and the six signs that have been visible will disappear, and the six that have been hidden will appear.

Suppose that it is the day of Cancer – the sun will reach its greatest altitude, while on the day of Capricorn it will reach its lowest. At night the moon is seen in the Zodiacal sign and in the degree corresponding to that night [and in its appropriate shape]: if it is appearing as a crescent it will change [as the month progresses] to a full moon and if it is a full moon it will wane.

[2] For the twelve roundels the term *jāma* (small glass cup) is used, for those in the spheres *qurs* (disc). Both are translated as 'roundel' to distinguish them from the large disc which appears elsewhere in the structure.
[3] *Falak* – celestial sphere.

At the beginning of the night the first of the glass roundels will show light like a nail-paring (*qulāma*) which increases until it is filled with light, at which time an hour of the night has passed. This happens with the succeeding roundels until six are fully lit. Then the musicians do their duty as they do during the day, and similarly at the ninth and twelfth hours,[4] this being the last hour of the night, by which time all the roundels are filled with light. This is the picture of what I have described clearly. [Fig. 4]. God is all-knowing.

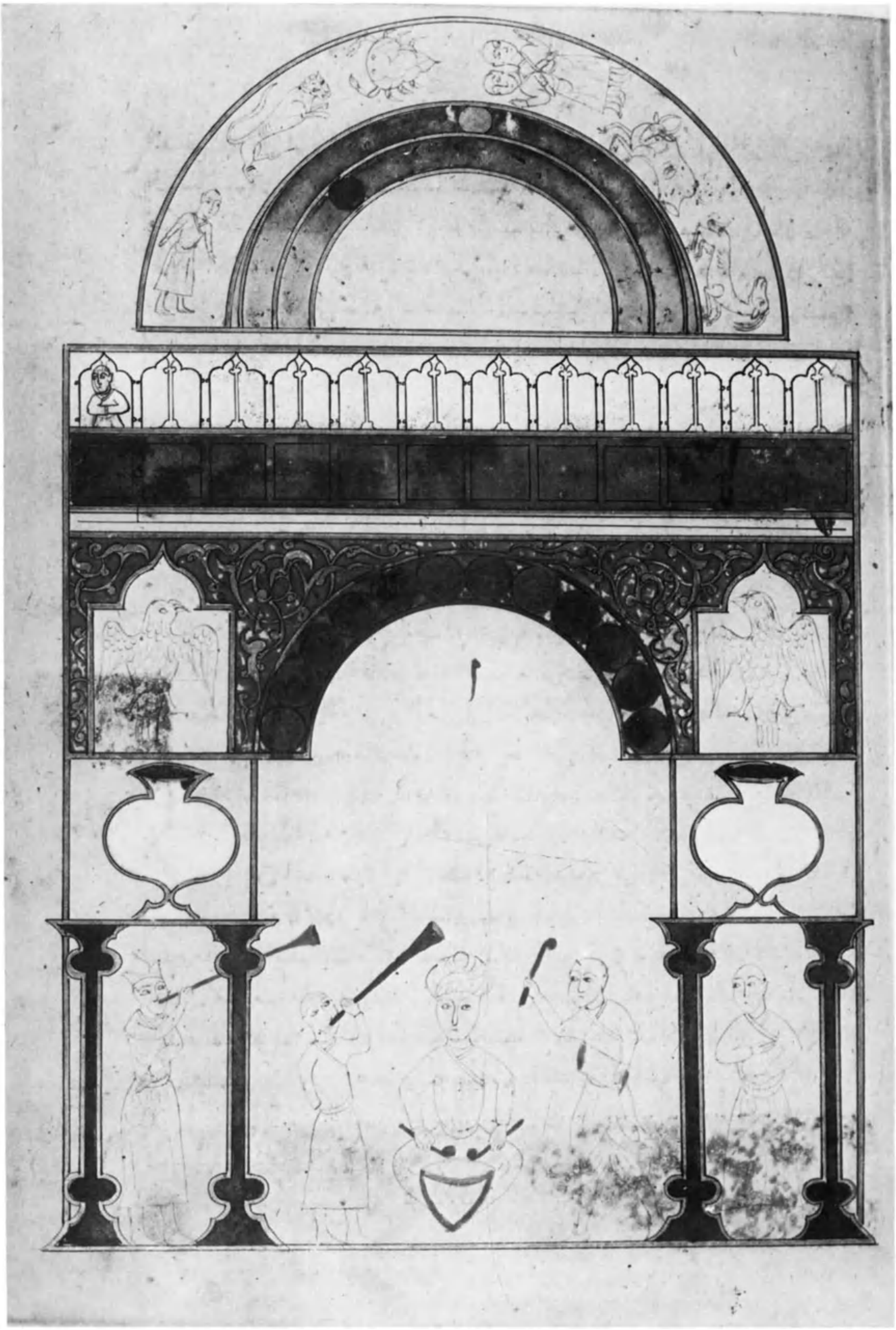


Fig. 4.

[4] See Sections 8 and 10, where it is stated that the musicians did not play at the ninth hour of the night.

Section 2

On the water reservoir

One takes a reservoir (*khizāna*) made of copper, about 6 spans high and $1\frac{1}{3}$ spans wide. It is filled with water which must all flow out of a hole in its bottom into an instrument connected to it, during the hours of the longest day in the latitude for which it is designed, which I specify to be the fourth region [30°–40°] where the longest day has 14 hours and 30 minutes. At the beginning of the day, in one constant hour 5 *kayl* must flow out of a single hole, and 5 *kayl* in the last constant hour of the day.[5] If the water is then poured back into the reservoir, in the night of the same day it will all flow out during the 9 hours 30 minutes of that night, and the same quantity will flow out in the first constant hour of the night as in the last.

Method of Construction of the water reservoir and its requisite water equipment

I begin with the construction of the vessel (*khābiya*) which is the reservoir (*khizāna*), its float (*tafāfa*), the tap connected to this vessel, the float chamber (*rubʿ*) and its float (*ʿawwāma*).

For the reservoir one takes four pieces of beaten copper and hammers them until each one assumes the shape of a kettle (*qidr*) or a *kayl* for crops, with vertical sides, and with top and bottom of equal width; they are about $1\frac{3}{4}$ spans high and $1\frac{1}{4}$ spans wide [Fig. 5]. To obtain a true shape, one takes a perfectly round disc of wood, that can only with difficulty be fitted into the vessel by hammering and making adjustments. Then four vertical lines are drawn on the inside of the vessel from top to bottom, each line opposite another, and each line is divided into about 10 equal divisions. Then water is poured into the vessel, until it reaches the first mark on each line, and then a measured quantity up to the second mark. Then one pours in a similar quantity; if this comes up to the third mark, all is in order, but if it is above or below this mark one must narrow or widen the vessel by hammering until it is correct. One proceeds in the same way until the last mark is reached, and for the other sections. The surplus from the top and bottom of each section is cut away until they resemble hoops,[6] except the last section which is not cut at the bottom, since this is the bottom of the container. Another is placed above it, and connected to it; outside the joint a ring of copper is fitted and firmly soldered. The same is done with the third and fourth sections to produce a single vessel with straight vertical sides [Fig. 6], in which is a tap which is described below. Its total length is seven spans, of which six are for the amount of

Fig. 5.

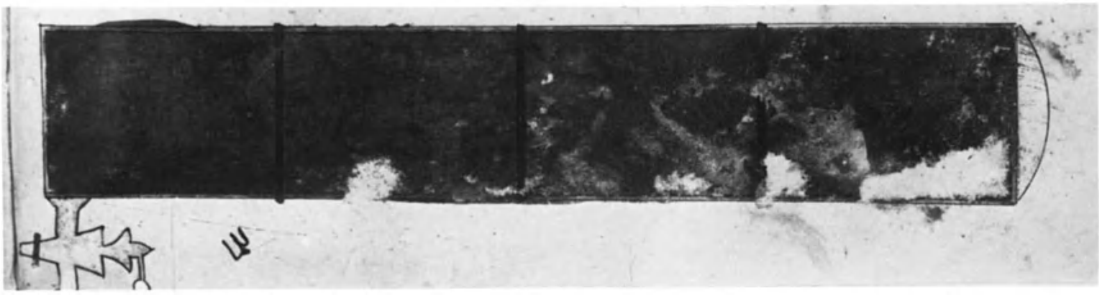


Fig. 6.

water known to be required, which is mentioned below, and one span, half of it for the unknown [quantity of] water in the bottom which is not discharged, and half a span at the top for the float. For the float (*tafāfa*) two pieces of copper are taken and hammered into oblate shape like a hollow turnip, so that one fits into the other. They are then soldered together at the joint. They should be of a width to enter the container with ease. In the centre of one of the circular surfaces a staple is fitted, with a ring, and near this point a hole is drilled of one finger diameter [Fig. 7].

Then one takes a tube of cast bronze, $\frac{1}{2}$ a span long, and wide enough to allow the index finger to enter; in the centre is a tap of good workmanship that opens and closes as required. One end of the tube is bent at right angles for about the length of half a finger – the open end of the bent [piece] should be wider than the tube at the angle. [Fig. 8]. The tap is fitted to the bottom of the reservoir. For the bent-down end a plug is prepared from cast bronze and is fitted to the inside and ground with emery on the lathe in the usual way. This is done with the greatest precision, since this is one of the most important and essential parts of the works. Every tap and ground

[5] See below, where the quantity is doubled.

[6] Shanbar, pl. shanābir (Persian).

valve is made in this way. This is the picture of the plug – conical, with a wide base [Fig. 9]. If it is pushed into the bent-down end of the pipe, and if it is not restrained by something, it will not be fixed, but free, because its base is wider than its head.

For the float-chamber a piece of copper is taken and hammered into a cylinder, like the reservoir. It is $1\frac{1}{2}$ spans high and four fingers wide. A hole is drilled in one side near the bottom, and into this [hole] a pipe in the shape of an index finger is fitted and firmly soldered. [Fig. 10]. Then for the float two pieces of copper are taken, hammered until they take the oblate shape of a hollow turnip and the two pieces soldered together. Its diameter should be of such a size that it fits easily into the float chamber without touching its sides. The base of the plug is now soldered to the centre of one of the circular sides of the float and it is then placed in water and observed. If it tilts to one side, the opposite side must be weighted so that it rides on the surface of the water without tilting. The float is shown with the plug. [Fig. 11].

Figs. 7, 8, 9, 10, 11. (Reading top to bottom).

Section 3

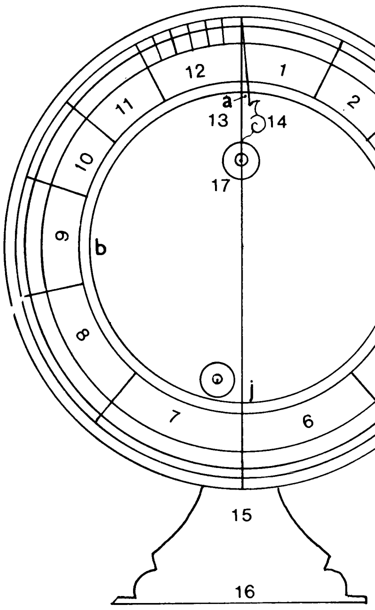
Method of Construction of the Flow Regulator[7]

For the flow regulator and for the water outlet one takes a strong brass plate and makes its

[7] *Dastūr*. This, with its basic idea of 'control or regulation', translates naturally to 'regulator' – and the instrument is indeed a flow regulator.

surface flat, so that a straight-edge[8] can be laid over it. It is circular with a diameter of $1\frac{1}{2}$ sp. In one of its quadrants is a projection about 3 fingers long[9] and this projection is formed into the shape of a base upon which the disc is upright. Then two diameters are drawn, not engraved, and one of them divides the base into two halves. Next one draws on the centre-point of the disc a circle with a diameter of one span. The marks *abjd* are made where this circle cuts the two diameters. Let *a*, opposite the base, be the first point of Cancer, *b* the first point of Libra, *j* the first point of Capricorn, *d* the first point of Aries. Then another circle *ḥ* is drawn outside this circle at sufficient distance for writing the names of the zodiacal signs between them. Another circle is drawn outside the circle, at sufficient distance to allow the divisions of 5 degrees to be written between them – this is marked *ṭ*; then another for writing the small divisions [i.e. degrees], marked with *y*. Then the space between the two circles reserved for the 12 signs is divided into 12 equal parts, without engraving, so that they can be erased when erasure is required. The divisions begin from *d*, the first point of Aries. Then the space reserved for the small divisions is divided into 360 equal divisions, without engraving. This is its picture. [Fig. 12].

On the centre-point *e* a circle is drawn inside and near the circle *abjd* and a disc is cut out with the dividers so that a ring remains. Then a plate is made from bronze, with a completely flat



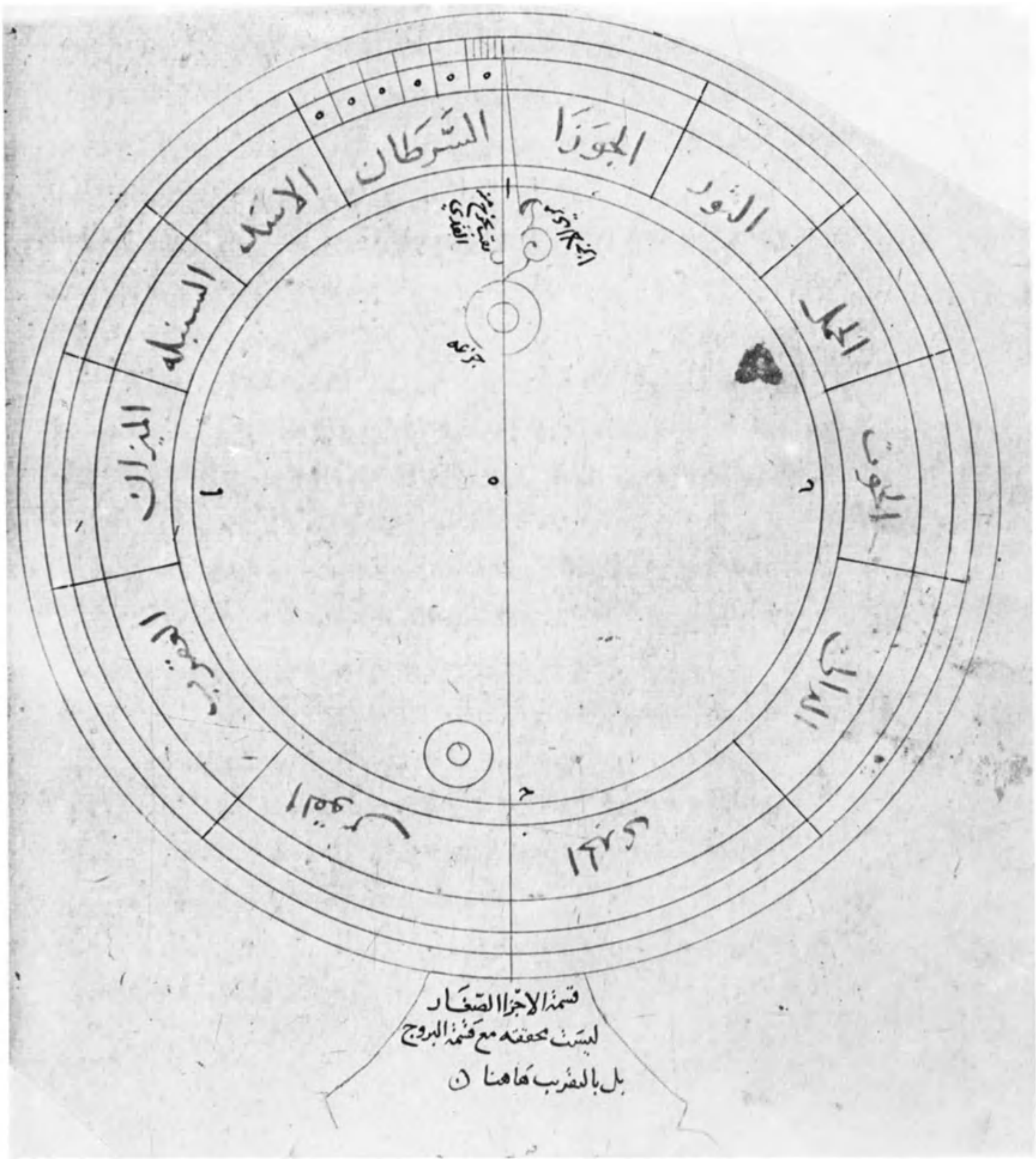
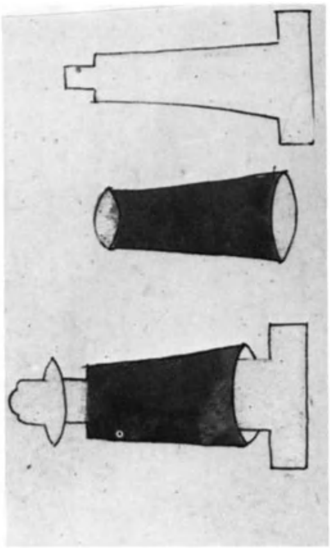


Fig. 12. (See line drawing for numbers giving positions of captions). 1–12: Gemini, Taurus, Aries, Pisces, Aquarius, Capricorn, Sagittarius, Scorpio, Libra, Virgo, Leo, Cancer. 13: Hole from which dirt is removed. 14: Division marker. 15: The division of the small divisions is not in exact agreement with the division of the Zodiac signs, but approximately so. 16: Footing of the flow regulator. 17: Onyx.

[8] *Mistara*. This can be 'ruler' but in this case the appropriate translation is 'straight-edge'.
[9] *Iṣbaʿ madmūm*. Therefore a total of only about $2\frac{1}{2}$ inches.

rim on which a straight-edge can be laid. When the plate is laid on the ring its circumference lies on the circumference of the ring, while the base is outside it. The inner perimeter of the plate has a smaller diameter than the inner perimeter of the ring. If the disc is now put back it will move freely, without being hindered at all by the edge of the plate. The surfaces of the disc and the ring are in one plane, as they were previously. The disc is now lifted from its position. A tube of cast bronze is taken, the length of an index finger [Fig. 14] and formed so that one end is broader than the other. For the tube a plug of cast bronze is made and the two are ground [to a close fit] so that no water can pass between – one must make certain of that. The two ends of the plug project from the ends of the tube and the narrow end is thin enough to allow a holding-ring[10] to be fitted to it, which is hammered on to [the plug] until it fits firmly around it and prevents it from coming out. When the plug is turned in the tube, it turns easily without coming out of the tube. The other end of the plug has a [round] base which is exactly at right-angles to the stem, so that if it is placed on a flat surface and rotated, the plug is always vertical. The plug is then drilled along its length to form a pipe, so that one has two pipes in one pipe. This is the picture of the tube [Fig. 14] of the plug [Fig. 13], and of the tube, plug and holding-ring assembled together [Fig. 15], to [give] a clear understanding. On the back of the disc a circle is drawn with the same diameter as the base of the plug; a radius is also drawn on the back of the disc corresponding to one of the non-engraved radii on the front, and both radii are now engraved. The base of the plug is now placed on the circle at the circle at the back of the disc, perfectly flat, and firmly soldered in position.



Figs. 13, 14, 15. (Reading top to bottom).

Then a hole is drilled through the base of the plug for half its diameter, until it meets the longitudinal hole. A test is then made: the jacket pipe is held firmly and the disc and plug turned together, with a pointer held opposite the rim of the disc to check its rise and fall; adjustments are made until it turns truly on its axis. A half-round pipe is now laid along the radius at the back of the disc, covering that radius and the hole in the base of the plug, and is soldered in position on the back of the disc and round the hole in the base of the plug. It is closed at the end near the edge of the disc.

Now one takes a copper tube 4 fingers long, and wide enough to allow the tube covering the plug to enter it for some distance, at which point it is soldered to the latter tube. This tube does not prevent the holding-ring from turning when the disc turns. Laying the face of the disc on the ground, some water is poured into the pipe covering the pipe covering the plug, and this flows from it through the hole in the plug then issues from the hole in the base of the plug into the [half round] channel on the back of the disc, but the water cannot flow out. This is the picture of the disc, with the base of the plug on it, and the pipe, so that it can be clearly understood [Fig. 16].

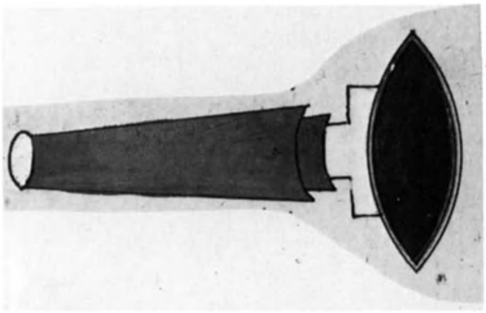


Fig. 16.

A hole is drilled on the centrepoint of the plate, through which is passed the tube covering the plug, and its tube, until the disc meets the face of the plate. The disc is now turned by itself and if it turns easily the pipe is then fixed firmly in position; if it rubs against the plate or its surrounding ring adjustments are made until it turns freely, and then the [final] firm fixing is made. On the front face of the disc a pointer (*shazīya*) is fitted at the end of one of the radii engraved in the surface, of such a length that it reaches to the small divisions. The other radius must also be engraved, so that one has a completely engraved diameter, and on this radius a fine round stud is fitted, with a projecting knob to hold when turning the disc on the plate. It is clear that when the disc is turned by the projecting knob, the pointer passes over the Zodiac, the circle assigned to the five-degree divisions, and the circle of the small divisions. It is set on the degrees of the sun and to degrees [diametrically] opposed to them.

Section 4

On the installation of the instruments and their interrelationships

A hole is drilled in the side of the reservoir near its base in which is fitted the tail of the tap so that the bent over piece faces down. The vessel is raised on a firm footing which is 4 spans above the floor of the House. The float chamber with its float inside is lifted until the top of the float chamber touches the tail of the tap and what is beneath it of the side of the reservoir, so that the bent piece of the tap is directly over the centre of the float chamber which then has a firm footing placed under it.

The pipe soldered into the bottom of the float-chamber is inserted tightly into the pipe in the plate and the joint is sealed with some wax. The pedestal of the flow regulator is facing the ground and the regulator is upright; a plinth of solid stone is placed beneath its pedestal. The reservoir is

[10] *Abshīzka.* No such word can be discovered in the dictionaries. 'Holding-ring' is the correct description for the fitting described and illustrated.

checked for tilting with the plumb-line and likewise the float-chamber. The verticality of the flow regulator is verified with the plumb-line, by passing its string over the first point of Cancer and the first point of Capricorn, so that the string is clear of the face of the regulator by an equal distance at the line of Cancer and the line of Capricorn, and divides the pedestal into halves.

Water is poured into the reservoir, the float being placed on top, for the required time [to fill it] and the tap connected to the vessel is opened and water flows from its bent-down piece into the float chamber, then into the plug on the back of the disc then into the [half round] channel on the back of the disc. The water has no outlet, so the water needs must rise in the float chamber and with it the float until its plug enters the bent-down end of the tap and closes it, whereupon the flow ceases until a hole is drilled in the face of the disc on the radius facing the channel, through to the channel, whereupon the water flows out from this hole. All the while water flows out the float sinks accordingly. If the division marker is at the first point of Cancer, and the hole in the disc therefore at its highest point, wherever this is in relation to the centre of the disc, the water will have its weakest flow. And if the division marker, I mean by this the pointer, is at the first point of Capricorn, the hole in the disc is at its lowest point, wherever this is in relation to the centre of the disc, the water will come out with the greatest force. A drilled piece of onyx is now fitted to the hole, so constructed that it allows a calculated quantity of water to pass through every hour, in a manner to be described.

It was mentioned earlier that the ring outside the disc was divided into 12 equal parts, not engraved, and the small divisions into 360 parts, not engraved, the indicator passing over these divisions in a complete year.

If the sun is in the first point of Cancer, then the indicator is at the first point of Cancer on that day and on the night of that day at the first point of Capricorn, which is the opposite [sign]. Then every day the indicator falls one degree from the first point of Cancer by day, and rises one degree from the first point of Capricorn by night. When it reaches the first point of Aries its position does not change in the day or in the night. These divisions are not dependable, and are not engraved, for reasons which will be mentioned below.

Section 5

On the division of the circle for the outflow of water

This is done by the *kayl*[11] of the water. I have prescribed the quantity of water in the vessel at 145 *kayl*. The latitude of the place for which the division is made is 36 degrees and the hours of its longest day are $14\frac{1}{2}$ so I divided 145 by $14\frac{1}{2}$ constant hours for the first point of Cancer, which is the longest day and obtained for each constant hour 10 *kayl*.

I now returned to the instrument on which I had marked 360 equal non-engraved divisions. [You will remember that it had] a radius on the disc with a channel behind it on the inside, a division marker on the face, and an outlet hole, connecting through to the channel, upon which was a drilled onyx. When the division marker was on the first point of Cancer I required that 10 *kayl* of water, measured by a level-instrument, should flow from the reservoir out of the hole in the onyx in exactly one constant hour.

To achieve this the hole was made narrow and widened with copper wire and emery until in one constant hour 10 *kayl* flowed from it. Then I divided 145 *kayl* by $9\frac{1}{2}$ constant hours for the first point of Capricorn and obtained for each hour about $15\frac{1}{4}$ *kayl*. I moved the indicator to the first point of Capricorn. If the calculated quantity flowed out in one constant hour, the outlet was not changed, but if more than the calculated amount then I moved the hole nearer the centre of the disc and lowered the Reservoir alone from where it had been by a like amount as I had moved the hole nearer the centre of the disc, and if less than the calculated amount flowed out I moved the hole away from the centre point of the disc and lifted the Reservoir alone from where it had been the same distance as I had moved the hole away from the centre point of the disc. In this way I found the position of the hole for which 10 *kayl* would flow from it in the constant hour when the marker was on the first point of Cancer, and $15\frac{1}{4}$ *kayl* would flow from it with the marker on the first point of Capricorn. The distance of the hole from the centre point was then about $4\frac{1}{2}$ fingers; the finger is 6 barleycorns laid belly to back. This latitude was 36° and for higher latitudes the outlet is moved farther from the centre and vice versa. Then I made a hollow house for the outlet from brass and fitted it around it on the diameter of the disc. Then I bored a large hole outside the outlet from which water could be poured into the channel and closed it with some wax. If some dust got into

[11] The required amount of water was about 4 cubic ft., 1 *kayl* therefore is about 1.35 pints or 0.78 litres.

the channel I took out the wax and removed it [the i.e. dust] so that the outlet was not hindered, then replaced the wax plug. On the side of the Reservoir I engraved a mark opposite the highest point of the float chamber to show the level of the float chamber in relation to the reservoir – it is important that this is done. Then I divided 145 *kayl* by 12 constant hours giving $12\frac{1}{12}$ *kayl* and this is for the first point of Aries and Libra. I moved the outlet point to the first point of Aries and more then $12\frac{1}{12}$ *kayl* flowed out in one equal hour. This shows the defectiveness of the three divisions mentioned previously, i.e. the division of the semi-circle, the division of the diameter and the division according to the sun's inclination. I then raised the outlet degree by degree until the flow was $12\frac{1}{12}$ *kayl* in one constant hour [which was at] 16 degrees from Aries. I made an engraved line at the marker position which cut the Zodiac circle, the 5-degree circle and the small division circle. This line was accurately the first point of Aries for this instrument after repeated trials. Next I divided 145 *kayl* by the hours of the first point of Taurus which are 13h. 12m., obtaining 11 *kayl* approximately; in one constant hour the calculated outflow corresponded to [a point] 10 degrees within Taurus. I made an engraved line at the face of the marker cutting the circles, as had been done for the first point of Aries, and this was truly the first point of Taurus, which was 17 degrees of the unengraved degrees of Aries through to 10 degrees of Taurus, i.e. 23 degrees for the sign of Aries. Now I divided 145 *kayl* for the hours of the first point of Gemini which are 14h. 12m. and obtained $10\frac{1}{5}$ *kayl* approximately and the point was found corresponding to this outflow for the last point of Taurus, and I made an engraved line at the face of the marker as I had done for the [first points] of Taurus and Aries; this line is truly the first point of Gemini and the last of Cancer[12] from respective sides. I now moved the marker to the first point of Cancer which was not engraved, and engraved it.

Now I moved the marker to the first point of Capricorn and engraved it. Now I divided the water for the hours of the first point of Aquarius and found the correct point according to the quantity flowing in one constant hour, which was 11° from Aquarius. I put the marker across the divisions and made an engraved line as before, and this was truly the first point of Aquarius. Now I divided the water for the hours of the first point of Pisces, whence the water outflow calculated for one constant hour occurred at 18 degrees from Pisces, and I put the marker there and made an engraved [cut]. From the lowest point of the circle with the regulator vertical on its pedestal to 11° of Aquarius is 41° of the unengraved degrees and this is the sign of Capricorn and I wrote 'Capricorn' there. From 11° of Aquarius to 18° of Pisces is the sign of Aquarius which is 29° of the unengraved degrees and I wrote 'Aquarius' there. From 12° of Pisces to 17° of Aries is the sign of Pisces which is 29° of the unengraved degrees and I wrote there 'Pisces'. From 17° of Aries to 11° of Taurus is the sign of Aries which is 29° of the unengraved degrees; from 11° of Taurus to the end of Taurus is the sign of Taurus which is 19° of the unengraved degrees and I wrote there 'Taurus.; from the last of Taurus to the first of Cancer is the sign of Gemini and I wrote there 'Gemini'. Thus I had divided half the circle into 6 unequal divisions.

In the remaining half of the circle I put the marker on the first point of Leo and engraved a line along its face and wrote between this line and the first point of Cancer, 'Cancer'. Then I put the marker on 20° from Leo and engraved a line along its face and from the first point of Leo to this line is the sign of Leo. Then I put the marker at 18° from Libra and engraved a line along the edge of the marker, and from this line to the last point of Leo is the sign of Virgo and I wrote 'Virgo' there. Then I moved the marker to 12° from Libra and engraved a line on its edge – from the last of Virgo to this line is the sign of Libra and I wrote 'Libra' there. Then I put the marker at 19° from Scorpio and engraved a line along its face – from the end of Libra to this line is the sign of Scorpio so I wrote there 'Scorpio'. From this line to the first point of Capricorn is the sign of Sagittarius so I wrote there 'Sagittarius', thus completing the division of the circle into the 12 signs. Each two diametrically opposite signs have equal divisions. Then I divided the 145 *kayl* to obtain [an amount corresponding to] the [end of the first] 5 degrees of Aries, and I made a mark where the correct quantity flowed out. I wrote between the circles reserved for the 5-degree divisions a '5' and divided the small divisions into five. I proceeded in this way, marking the divisions, until I had completed the regulator with 12 Zodiac signs, the 5 divisions and 360 degree divisions, namely the degrees. Then I erased the non-engraved marks.

The functioning of the regulator is as follows: when the Sun is in a degree of a sign, the marker on that day is on that degree and on the opposite, corresponding, degree in the night. If desired another circle may be drawn outside the circle of small divisions and the Rūmī months and days of the solar year marked on it, as I have done for two regulators.

This is the basis of the work. Individual parts may be omitted or added according to the place for which it is constructed. For mosques and shrines it may be limited to what is necessary for telling the hours; for the palaces of kings, what may be fitting, such as pictures and other things.

[12] Should read 'Taurus'.

Section 6

On the place in which the apparatus is erected and the functioning of its instruments

A House is erected which stands about the height of two men above the ground, its base area being 12 spans square. Opening into this is a door $5\frac{1}{2}$ spans wide and 9 spans high, which is closed by a wall of brass or strong wood. Across the top of the wall are twelve doors all of the same size, placed in a straight line; between each pair of doors is a post two fingers wide. Every door has two leaves (*miṣrāʿ*) of brass with hinges which move with ease. Under these doors and parallel to them are 12 doors, each with a single copper leaf, which has across its centre an axle whose ends project from the sides of the door and rest in two bearings half way up the posts in which they turn easily. One end of the door leaf is weighted, and this end is by nature towards the bottom. When the weighted end is lifted it is retained on the outside by a peg which prevents it from falling outwards, so that it falls by nature towards the inside. This [Fig. 17] is the picture of one door between two posts.

Fig. 17. Words on door read: 'Dominion is God's'.

Now one constructs below these doors a frieze one finger wide, like a ledge projecting one finger's width from the wall; it should run in a straight line across [the wall] and its vertical face is [also] one finger. Next a slit is pierced in the wall, running along the [top] edge of the frieze and the same height as the edge of the frieze. A crescent moon is made of gold, like a *dīnār*, as wide as the posts between the lower set of doors, or less. This is fixed to the end of a light iron rod which is as long as the doors are high. This is then bent to a right angle in the centre and the horizontal end pushed through the slit in the wall. The crescent moon, when it is placed erect in front of the first door post reaches half way up the door. If the door turns over it is not hindered by the crescent which stays in place.

Under the frieze two cavities similar to *miḥrābs* are made, one at each side of the wall, their highest points three fingers below the ledge; they are each two spans high and over one span wide. Two falcons are made of the lightest possible brass, with outspread wings and raised breasts [Fig. 18]. The head of each is pierced behind with a hole in which a ball of cast bronze weighing 40 dirhams can enter, and the neck is closed to keep the ball in its head. The upper beak and part of the head are detached so that the ball can come out easily; the beak and head are then connected with a very fine, easily moving hinge. Then one takes an iron bar one finger thick and one span long, one end of which is split and the two halves separated. In the centre a hole is bored into which an axle can easily be inserted, and the other end is also drilled. A hole is drilled in the centre of the *miḥrāb* and a $\frac{1}{2}$ finger long slit is made. In this slit the drilled rod is pushed until its axle in the hole in the centre comes square across the hole in the *miḥrāb*. Its ends are then fixed to the sides of the *miḥrāb*. When the rod moves it moves [only] up and down.

A copper tube is made of such a width that the thumb and forefinger pass round it; it is four fingers long and its ends are blanked off. The feet of the falcon are fixed to this tube, and near its ends two holes are drilled to receive the split ends of the rod. The falcon appears on the tube as if he were gripping a perch with his talons. The front of the falcon faces outwards and his back is towards the *miḥrāb*, and he stands on the pipe at right angles to the rod. The other end of the rod inside the screen wall is weighted with a lead weight attached to the rod with a chain 1 span long which goes into a hole in the end of the rod. This weight should be heavier than the falcon by 20 *dirhams*: the rod is like a balance, which will tilt if one end is heavier than the other. The weight lifts the falcon until its head touches the top of the *miḥrāb*, which holds it in place. Now a hole is made at the top of the *miḥrāb*, wide enough to allow the ball of above-mentioned weight to pass through. This opening lies close to the back of the head of the falcon, so that when a ball emerges from the opening it goes into the head of the falcon and remains above its neck. The falcon is then heavier than the [hanging] weight because the weight is heavier than the falcon by 20 *dirhams*. The falcon leans forward until its head is about two spans' distance from the top of the *miḥrāb*, the ball pushes its upper beak and falls out. The falcon is now lighter and returns to its position. Similarly with the other falcon.

Construction of the falcon's wings: each wing has a hinge in its centre connecting it to the back of the falcon and a string attached to the end of the spine of the wing, the other end of the string being fixed to the side of the *miḥrāb*. The colour of the string is the same colour as the *miḥrāb*. When the falcon leans forward its wings rise. There are thus two movements – one downwards, and the movement of the wings upwards; the tail also moves downward from its original position, by means of a hinge. This is beautiful [to behold].

In front of each falcon a brass vase is placed on a firm bracket which projects from the wall by such a distance that the ball from the beak of the falcon will fall into the vase. Across the top of each vase is a copper cross piece to which a cymbal of white bronze (*isfādrūh*) is hung, on to which the ball falls, making a sound which can be heard from afar. The ball then falls into the bottom of the vase, which has an opening which leads through the hollow bracket to the interior of the house, and the ball runs therein. Whoever wishes to use the passage of the ball into the centre of the house for a moving [device], will find it easy.

Between the two *miḥrābs*, 12 round holes are bored in the wall, into each of which is fitted a glass roundel. These roundels form a semi-circular line with its convexity facing upwards, the length of its radius being $1\frac{3}{4}$ spans. In the centre of the bottom of the screen the figures of two drummers are set, each with a copper drum in front of him. One of the arms of each figure has an axis at the elbow, the two ends of which are fastened in the sleeve of the figure's shirt: when the arm moves the motion is up and down. In the hand of this arm there is a baton (*sawlajān*) with which the drum is struck. A continuation leads from the elbow, in the form of a rod, through a long vertical slit in the wall, and this provides the downward and upward motion for the hand. Next a figure is made which holds a cymbal in his hand, and his right hand moves up and down like the drummer's hand. His back is also fixed to the wall, and the extension from his elbow leads inside through an aperture in the screen. The position of this cymbalist is to the left of the two drummers. To the right of them are the figures of two trumpeters, each holding a trumpet with the end in his mouth. This requires nothing in the screen for its functioning. This [Fig. 18] is the picture of one falcon, one vase and one figure – the picture gives all that is necessary for a clear understanding. No picture is needed for the trumpeter, since he makes no movement, and the sound of the trumpet comes from another source.

Fig. 18. Captions read: Upper: 'Balls' passage'; extreme right: 'weight'; right: 'channel for the balls to the inside of the house'; right centre: 'extension of the drummer's forearm'; left: 'axle upon which the arm moves'.

Section 7

On the means for imparting motion to all the things mentioned so far

Namely, the first and second doors, the crescent on the frieze below the second doors, the two falcons, and the nocturnal roundels, and nothing more, for anyone who wishes to limit himself to these alone. A door is placed in the house through which one can enter, and in the middle of the house a copper cistern is placed in which can be collected the water flowing from the reservoir, and [indeed] more than that. The water apparatus, I mean the reservoir, the float chamber and the upright regulator are erected and the reservoir should be on the right-hand side of the wall; the water from the outlet flows over hard ground into the cistern. Then one takes a round flat disc of strong dry wood like a shield, its diameter being $3\frac{1}{2}$ spans and half a finger nail (*ẓufr*) and its thickness two finger breadths. A diameter is engraved on one face, and on its centre a circle of diameter $3\frac{1}{2}$ spans is drawn. Then a second circle is drawn of diameter 2 spans. A cut is made from the edge [of the disc] along the diameter up to the line of the second circle of diameter 2 spans. The cut is then turned along the circumference of this circle until the line of the diameter is reached, and then the cut is turned along the line of the diameter to the edge of the disc, and the half of what lies between the two circles is removed. This is its picture after cutting [Fig. 19]: this first circle is *a*, the circle of diameter two spans is *b*, and on the two ends of the diameter are *jj* [not written]. The measurement, whatever its length, must be ascertained; it is measured with a ruler and preserved, until such time as it is required. An iron hoop (*ṭawq*) is now brought, as wide as the disc is thick, one finger thick, and of a length that will encircle half the circle of $3\frac{1}{2}$ spans diameter, that is $5\frac{1}{2}$ spans. The bar is bent into the shape of a semi-circle; there will be a surplus to the required length [for making the semi-circle] sufficient for each end to be turned inwards at an angle and placed on the wooden disc where the two pieces were cut from its diameter. These are firmly nailed, replacing the original cut away circle, which is now completed by the iron ring. This is a second picture [Fig. 20] after a square hole has been cut in the centre to take the end of an axle, which I shall describe.

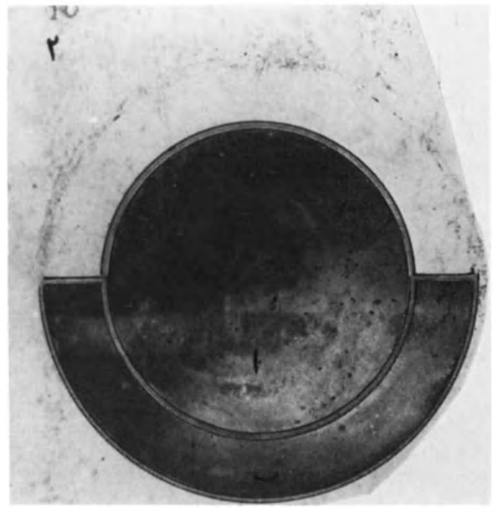


Fig. 19.

The axle is of solid wood, 4 spans long and of a thickness that can be encircled by two thumbs and two forefingers. One end is dressed square so that it can enter tightly the hole in the disc without protruding from its face. On the ends of the axle are nailed two iron 'acorns', around which it [i.e. the axle] turns. On the half circumference of the disc a channel (*nahr*) is made so that it becomes (as it were) a half-pulley. The depth of this channel, for [a length of] slightly over $3\frac{1}{2}$ spans is half a finger-nail, so that the back of the iron ring and the bed of the wooden channel coincide. This disc is then installed between two stable stanchions, under the 'acorns' of the axle, and its rotation is tested with the hand; if one side is light it is weighted with lead until it is balanced, and remains immobile in any position. A hole is bored inside the wall at the centre point of the semi-circle of glass roundels, and the 'acorn' at the end of the axle which carries the disc is inserted therein. The wall and disc are almost touching but the disc can turn and is not hindered by the wall. Under the 'acorn' at the other end of the axle a firm support is placed. If the completely wooden half of the disc is uppermost, then the glass roundels are

Fig. 20. Captions read: upper: 'the iron ring'; lower: 'the hole for the end of the axle'.

covered from inside, but if the iron ring is uppermost the roundels are not covered. When the disc turns gradually the roundels are covered according to [the distance] it turns.

A strong wooden board is now brought, as long as the wall is wide, plus two fingers at each end, and half a span in width, and free from warping. It is fixed along [the inside of] the wall in a straight line, two finger breadths below the slit of the frieze, and it has a rim at the other side to prevent anything placed in it from coming out. The name of this board, which is like a shelf (*raff*) is 'the Road of the Cart' (*maydān al-ʿajala*). Now one takes a piece of strong wood about 1 span long, of a width to fit into the Road of the Cart, or slightly less than that, about two finger breadths thick, and this is called 'the Cart'. In each end a staple and ring are fitted. Now four holes are bored in its surface facing the Road, and four rollers are placed in the holes, each roller having an axle which is firmly fixed in the appropriate hole, so that [the cart] moves on the rollers when lightly pulled. One pair of wheels runs along the wall, the other pair along the rim of the road. When the Cart is placed in the Road its top is level with the top of the frieze. The Cart is drawn along the Road until its centre is level with the beginning of the slit in the wall, where the crescent-moon made previously is located. The bent part of the moon's tail is firmly driven into the Cart. The crescent-moon is then in line with the first door and is not hindered from moving. Then one takes a flaxen (*kattān*, here wrongly *kabbān*) string, colours it, rubs it with some myrrh and twists it tightly. About 6 spans of it are taken and one end tied to the ring in the end of the Cart, the Cart being in position. The string is then passed over a roller at the end of the Road and its end hangs down; to this end a lead weight is attached which is heavier than the Cart, so that the Cart will be drawn backwards by the weight if there is nothing to prevent this. Another length of string is tied to the ring in the front end of the Cart, and the string runs along the length of the Road and its other end passes over a roller at the other end of the Road. The wooden half of the disc is now turned upwards to cover all the roundels, and the end of the string is tied to a strong ring on the diameter of the disc at the joint between the iron ring and the disc. The string must have no slack so that if the disc is turned downwards through the distance of a barleycorn the Cart will be pulled along the same distance.

Then a wooden disc is fitted to the other end of the axle, of the same thickness and diameter as the first disc. Nothing is cut from this disc, but the part which exceeds $3\frac{1}{2}$ spans is grooved, so that the diameter of this disc is the same as the diameter of the first disc. In the groove of this disc a firm ring is fixed opposite the diameter; what remains of the string is attached to it and wound once around the groove in the disc. This string was thus rigged differently from the string from the Cart to the first disc. The string is then led up to the roof of the house and passed over a pulley which is vertically over[13] the centre of the reservoir. From the pulley the end of the string is taken down and tied to the ring in the float. When the reservoir is filled with water and the float weighted with some sand poured into the hole by the side of the ring – the hole is then stopped with some wax – the pull of the string turns the disc. The string must have no slack in it, so that if the float sinks the distance of a barleycorn the two discs will turn a like distance and the Cart also will be pulled that same distance. I have described earlier that the level of water in the reservoir is $5\frac{1}{2}$ spans plus a $\frac{1}{2}$ span of water remaining in the bottom of the reservoir, to support the float after the outflow of the known quantity of water.

The distance of travel of the crescent-moon along the front of the doors is $5\frac{1}{2}$ spans and the diameter of the disc completed with the iron ring is $3\frac{1}{2}$ spans and the other disc is similar. When this disc makes half a turn it pulls it [the Cart] $5\frac{1}{2}$ spans so I say that when the reservoir is filled with the known [quantity of] water and the flow of water so arranged that it all flows out in the given day from the day's beginning to its end, it is very clear that as the water flows out the float sinks and pulls the disc. This rotates, and the other disc pulls the Cart according to the sinking of the float, and the sickle moon moves along the front of the doors. During its progress, whenever it has crossed one door and stands at a post between two doors, then one solar hour of the day has passed, and the wooden disc has uncovered one of the roundels. The uncovering [of the roundels] is of no benefit during the day – its value, as now described, is in the night. In the house there is a kindled lamp and when part of a roundel is uncovered the light shows in it from behind the wall, and when it is filled with light a solar hour of the night has passed.

Twelve figures (*shakhs*) of bronze or wood are now made, each figure being of a size to fill one of the upper doors, and made according to the choice of the craftsmen. Each figure is suspended from his head by a ring above the top of the door. On the back of the figure is a bronze plate, which is wider than the door, and prevents the figure from coming out; every figure is dealt with in like manner. Now one takes a wooden bar, its length greater than the width of the wall. This is erected behind the wall above the doors, its distance from the wall being equal to

[13] Lit. 'The fall of its stone is over'.

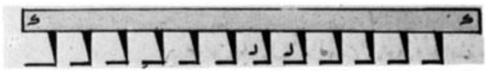


Fig. 21.

the height of one of the figures suspended in the doors. Opposite the centre of each door an iron hook (*ghurāb*) is fixed in the bar, its bent end pointing in the direction towards which the Cart travels. This is its picture [Fig. 21] – it has a *k* on each end of the bar and an *l* on the hooks. At the bottom of each plate on the back of the figures a smooth iron peg is firmly fixed, its length $\frac{1}{2}$ a finger. When each figure is lifted and the peg placed in the hook opposite the door of that figure, the head is hung above the top of the door, and the feet are held by the peg to the hook. The two door leaves are attached to each door by two light strings which are tied to the leaves and to the plate on the back of the figure. If the peg is lightly pushed from the hook in the direction towards which the Cart is travelling, the figure falls, opening the door leaves by its fall, and preventing them from closing again. He stands [there] as if he had come down from above. Then, above each of the other doors, one places a long iron weight, one half of it heavier than the other half. At its centre-point a hole is made into which an axle is inserted; the axle projects horizontally from the wall above a lower door. This is its picture [Fig. 22] – the heavy half is, of course, at the bottom, hanging over the door leaf and the light half is at the top, above the door. When the heavy half is lifted upwards from the door, and the heavy half of the door leaf is lifted up, and the weight placed against it, [while] the figure above this door is fixed by its peg to the hook, then the weight prevents the heavy end of the door leaf from falling. When the figure, held by the peg, falls, the plate on its back strikes the end of the weight, the end of the weight rises from the door, which turns over, and appears in a different colour. This happens with the remaining doors and weights.

Fig. 22.

Then a wooden piece is made, its length the same as the width of the wall; it is square [in section], its thickness 4 fingers and likewise [its depth]. On one face twelve vertical lines equidistant from one another are drawn, and on each line two separate holes are drilled, of such a size that the ball for the head of the falcon can go easily into them. By the side of each hole a groove is scooped out, slanted towards the hole, wide enough for one of the balls to be placed in it. The gradients of the holes are all inclined in the same direction, along the length of the wood. Near each pair of holes a lateral slit is made, deep enough to take a thin iron blade (*shafra*). This forms a division between the two balls lying in the grooves, and the holes. When the blade is removed from the slit the balls run into the holes. This is a picture of half the length of the piece of wood [Fig. 23]; it is marked with *b*, the holes with *j* and the grooves with *d*. Only one of the

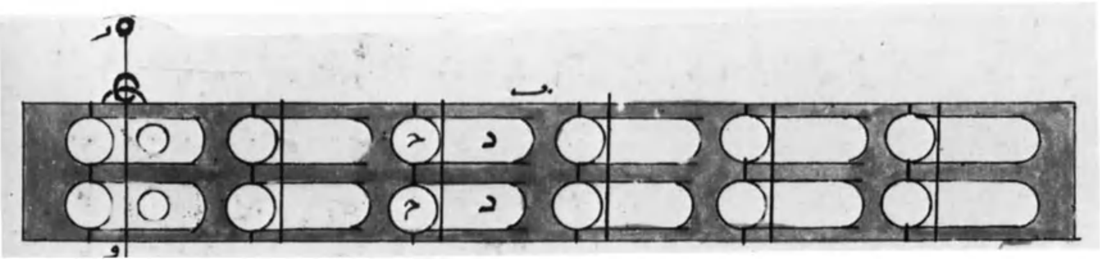


Fig. 23.

blades is shown. It is an iron blade, as long as the width of the wood, and its tail is one finger-length long. Between the blade and the tail is a hole with an axle in it, [the axle being] fixed into the side of the wood. The blade, marked with *w*, rotates upwards around the axle. The tail of the blade, marked *z*, also has a hole in its end. Two balls in two grooves are marked *ee*.

This wood is now installed parallel to the bar [carrying] the hooks, one span above it, but farther from the wall. The tails of the blades lie along the wall and each one is opposite the centre of one of the doors. Between the hole in the tail of each blade and the bottom of the plate on the back of the figure opposite the tail, a strong string is tied. When the figure is hanging by the peg to the hook, the string is slack. The blade is heavier than its tail and sits in the slit in the wood, preventing the two balls placed in the grooves from entering the holes. When the figure falls from the hook it pulls the string attached to the hole in the tail of the blade downwards; the blade is lifted from the slit, a sufficient distance to [allow] the two balls to move into the two holes, the grooves being inclined, and to fall from the two holes, into a [device] yet to be mentioned. Now a piece of wood is made, of the same shape as the wood with the holes, only thicker, and with one face convex. On the straight side, opposite the curved side, a straight line is drawn, dividing its length into two halves. On the centre of this line two marks are made laterally and on these marks two holes are drilled, each large enough to take a ball. In each half of the wood a groove is cut, sloping towards the centre, so that if two balls are placed in the ends of the two grooves they will roll along to the two holes in the middle and fall into them; similarly if two balls are placed in the two grooves at the other end of the wood they will roll along towards the centre and go into the two holes in the same way. This is its picture [Fig. 24]. The two ends of

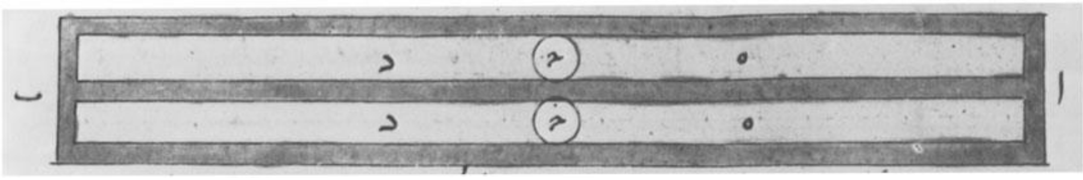


Fig. 24.

the wood are marked *ab*, the two holes are marked *jj*; the two grooves sloping from end *b* to the two holes are marked *dd*, and the two grooves sloping from end *a* to the two holes are marked *ee*. This wood is installed vertically beneath the wood with the holes in it, and is connected to it. When two balls fall from any two holes in the higher piece of wood into the two grooves in the lower, they roll along to the centre and come out of the two holes into something yet to be mentioned.

Two copper channels are firmly fixed into the two holes of this piece of wood and [each] to one of the holes at the top of the falcon's *miḥrāb*. It is evident that when the two balls come out from the two holes in the lower piece of wood into the two copper channels, neither will precede the other into the falcon's head, but will arrive together and strike [either falcon] at the same time. On the back of the Cart a [vertical] iron rod is firmly fixed which projects at a higher level than the hooks to which the figures are suspended. When the Cart passes the figures suspended on the hooks, then this rod pushes the end of its peg from the hook and the figure falls. This occurs for one peg after another until the Cart in its travel reaches the end of the Road, when the rod will have pushed all the pegs from the hooks.

This is the picture [Fig. 25] of the reservoir, marked *a*, the float, marked *b*, the tap *j* and its bent-down end, exactly over the centre of the float-chamber, *d* is the stopper of the float entering the bent-down end of the tap, while *e* is the mark of the regulator erected on its footing. On it [the regulator] is the onyx for the water outlet which is marked *w*. The Cart is marked with *z* and on its back is the rod *ḥ* which pushes the peg out of the hook, *ṭ* is the weight behind the Cart, the wooden disc completed with the ring is *y*, *k* is the balanced wooden disc on the other end of the axle, and from the groove in its rim a string rises to the roller in the roof of the house, then descends and is tied to the ring in the float.

One door [is also shown] with the back of a figure and the peg at its base holding it to the hook *l*, also a [lower] door with a board in it above which is a weight *n* preventing it from falling back inside. On the piece of wood for the balls *s* is a blade *x* which prevents the balls *p* from rolling towards the two holes, the piece of wood into which the balls drop *f* and in its centre the two connected channels *ṣ* which pass into the tops of the two *miḥrābs*. This is the picture of what I have described in the interior of the house. There are [other] things which it is not possible to depict – these are dealt with separately.

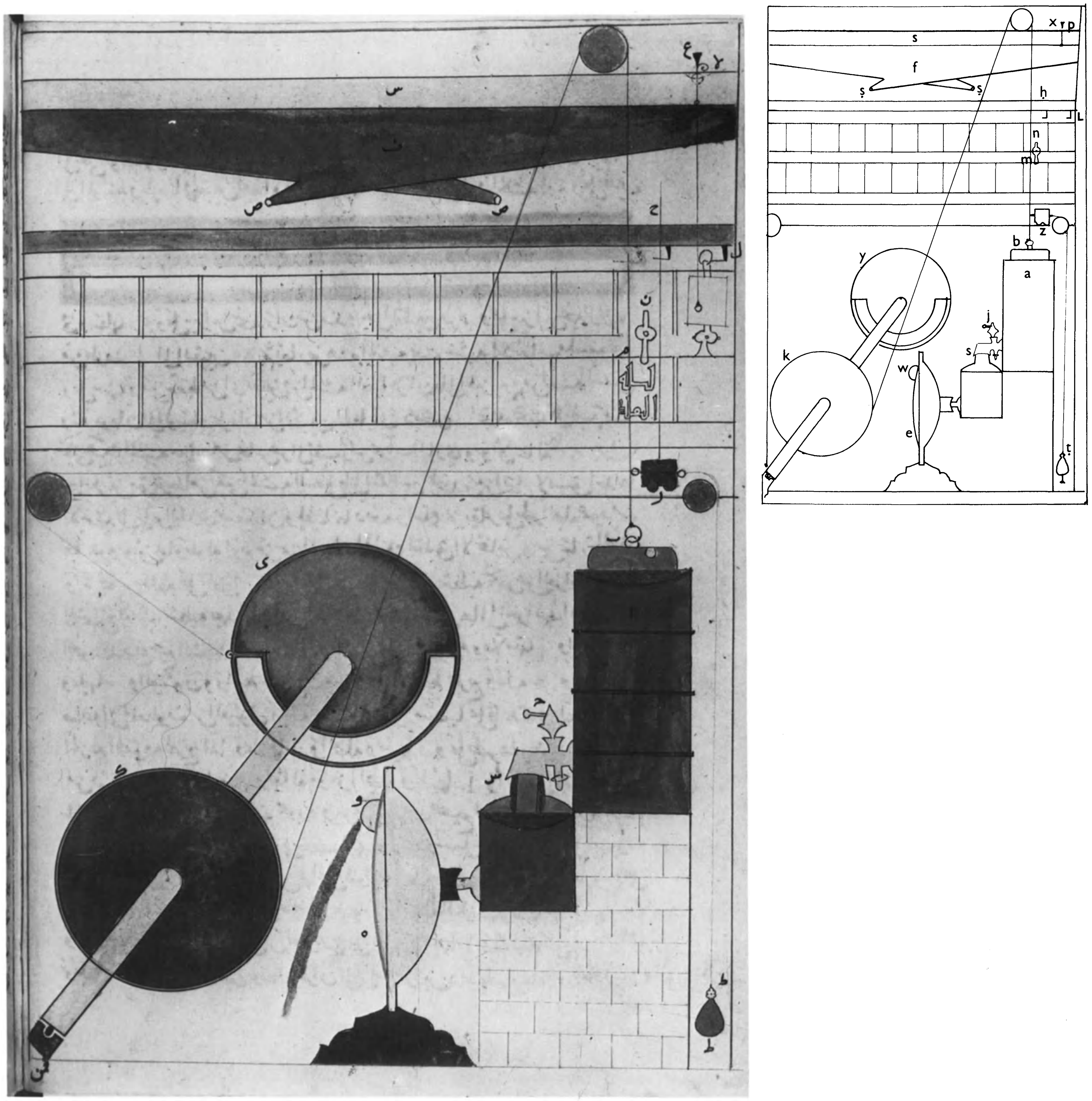


Fig. 25.

It is very evident that: the reservoir a is filled with the requisite quantity of water for the beginning of the day and the float b is in it on the surface of the water and the closed part of the wooden disc y is upwards and the Cart z is at the beginning of the Road, and the weight $ṭ$ which pulls it backwards is attached to it [i.e. the Cart]; the twelve figures have been raised and attached to the hooks l and each blade x is in the slit in the wood [made] for the balls, and a ball p has been placed in each groove; the lower doors m are tipped up with the heavy ends of each door upwards, restrained by the weight; all the faces of these doors being of the same colour. The outlet of water is set for that day to the [appropriate] degree of the sun and the reservoir's tap j is opened and the float-chamber s fills; the water issues from the outlet w, the float sinks pulling and turning with its tension the two discs [i.e.] the disc completed with the ring and the disc marked k, which are on a single axle. The Cart moves, and with it the crescent moon and the rod until, when the crescent moon has passed one door and is opposite the doorpost, the rod strikes the peg, the figure falls opening the two door-leaves and lifting the weight from the [lower] door, which turns over and [changes] to another colour. The blade is lifted from its slit, the two balls fall into the channels of the second piece of wood, and each ball comes out from the copper channel into the head of the falcon. Then they lean forward, the two balls fall from their beaks onto the cymbals, and the sound is heard from afar. The falcons resume their position and the two balls roll along a channel into the interior of the house. This occurs every hour until the 12 hours to sunset have passed. The water is poured back into the reservoir, and the division marker is moved to the opposite degree, but the figures, doors and balls are not lifted. The disc, however, is turned to mask the glass roundels and the lamp is lit – the glass roundels suffice for the night. At the beginning the first roundel a light like a barleycorn shows, then the light increases until the whole roundel is lit.

Section 8

On the means for imparting movements to the hands of the drummers and the cymbalist, and sound for the trumpeters

A copper axle is taken, longer than the distance between the cymbalist and the hands of the drummers by $\frac{1}{2}$ span. Near its end is a wheel with scoops (*kaffa*) like spoons (*mighrafa* pl. *maghārif*) so that then when some water falls on them the wheel turns. Then two firm footings are erected under the two ends of the axle, upon which the axle turns, being parallel to the hands of the drummers and the hand of the cymbalist. The wheel lies outside the ends of their elbows towards the position of the trumpeters, namely the right-hand side. Then one fits pegs to the axle opposite every hand – when the wheel turns the pegs push down the pieces projecting from the elbows, and then move away from these projections. The hand moves upwards from the drum and then falls into it, and likewise with the cymbal. For the right hand of the drummer two pegs are [provided] and for the left hand one peg, so that the drumbeats vary and the rhythm is correct. For the cymbalist there are three pegs, two of which are close together. Under the wheel a trough (*ḥawḍ*) is placed, raised from the ground on a firm base to [a position] near the scoops of the wheel. Water falling from the wheel's scoops drops into the trough.

Then one takes a copper vessel (*qidr*) of the same height as the base beneath the trough and of such a size as to hold the water that flows from the onyx in three hours of the hours of the first point of Cancer. Next a thin copper tube is brought that is longer than this vessel is high, and this tube is bent in the middle until the two ends almost meet, one end being longer than the other by half a link. This is called a siphon (*maqallab*) and also the Egyptian witch (*Ṣaḥḥāra Miṣriya*) [Fig. 26]. A hole is then made at the edge of the vessel and the bend of the siphon inserted in it so that the inside of the bend is level with the top edge of the vessel. The short end of the siphon almost touches the floor of the vessel, while the other end is outside and is lower than its floor. The siphon is securely soldered to the vessel. The vessel is covered with a copper cover, and is carefully and securely soldered so that no air or water can issue from it. This vessel is placed on the ground by the side of the base supporting the trough for the wheel so that the top of the vessel is level with the floor of the trough. The siphon is towards the cistern – water which comes out of it runs on to the solid earth, then into the cistern. The cover of the vessel near the trough and the floor of the trough near the cover are drilled and the two holes connected by a pipe both ends of which are firmly fitted in. This pipe should be slightly wider than the siphon.

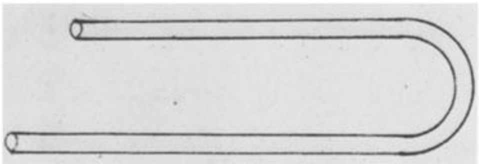


Fig. 26.

Then one takes a piece of pipe $\frac{2}{3}$ of a finger length long and so wide that it can be encircled by thumb and index finger – it is [thus] like a jar [*ḥuqq*]. At each end a cover is securely fitted. In the centre of one of the covers a hole is made shaped like the eye of a man, but smaller. Then a piece of copper pipe is taken, as long as the third of an index finger, and as light as possible.

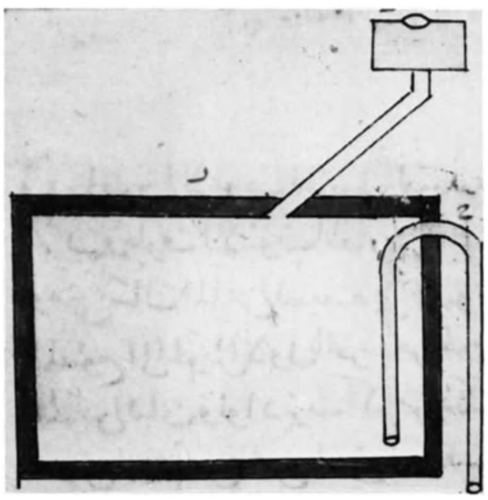


Fig. 27.

This is hammered until its circular shape is changed into the shape of an eye. This is inserted into the hole until it is near the [other] end of the jar, and is then securely soldered at the joint. The pipe is slightly narrower at the end inside the jar than it is at the point where it is soldered to the hole, and it should be as light as possible. Then a small hole is drilled in the centre of the other cover of the jar and on to this hole is soldered a pipe of length [equal] to [the distance] from the [centrepoint] between the two trumpeters to the vessel's cover. An aperture is made in the wall between the two trumpeters into which is inserted the end of the jar, without protruding to the outside of the wall. In the cover of the vessel a hole is made in the direction of this aperture into which hole is soldered the end of the pipe connecting with the lower cover of the jar. After this the soldering of the vessel and what is connected to it is tested [to ensure] that air does not emerge anywhere but through the pipe. This is the picture [Fig. 27] of the vessel, the siphon, and the jar on the pipe. From it one hears the sound of the trumpet. I refer [also] to the picture [Fig. 29] of the vessel, the trough and the wheel with the scoops. The vessel is *z*, the end of the siphon *j*, and the jar *ṭ*.

Now a piece of copper is beaten until it takes the shape of a long trough [also *ḥawḍ*], four fingers high and wide enough to hold the water that issues from the onyx in 9 hours of the hours of the first point of Cancer. In the centre of one end-wall of this trough, near its floor a hole is made, and in this hole a pipe [shaped] like a finger is soldered. In the floor of this trough, near the corners, are placed four lead weights [*sanja*] each weight one finger thick. Then a copper plate is brought, as wide as the width of the trough, and fitted over the weights inside the trough and firmly soldered around the perimeter of the trough so that the plate forms a second floor for the trough. This [second] floor is then divided transversely into three equal parts by two lines, upon which two plates of the same height as the trough are erected and firmly soldered in position. The trough has become three equal sized troughs. The whole trough is now placed on a firm base, with the pipe fitted to it directed towards the scoops of the wheel in the first trough. Then a hole is drilled in the floor of each of the three part-troughs each large enough so that the thumb can be inserted in it. The hole in the first part-trough, which is adjacent to the cymbalist, is near the second part-trough and the hole in the second part-trough is near the third part-trough, and the hole in the third part-trough is near its end. For each of the three troughs a ground-in, tight-fitting valve (*bāb*) is made. When the three troughs are filled with water none can flow into the bottom of the original trough. When the plug is lifted from the valve in the trough the water empties into the bottom of the original trough and flows out from the pipe on to the scoops of the wheel. Each plug is fitted with a ring.

Now one takes a copper plate with a vertical rim and a diameter of $1\frac{1}{2}$ spans. On the centre of the diameter of the plate is soldered a pipe 1 small span long and less than one finger thick, the end soldered to the back of the plate being narrower than the other [end]. Then one takes an iron stanchion $2\frac{1}{2}$ spans long, its end dressed so that it can be inserted with ease into the pipe on the back of the plate. This end is smoothed so that the plate can rotate easily around it. The other end is driven into the solid earth, at a distance of $\frac{1}{2}$ span from the front of the regulator for the water outflow, and made firm so that it cannot move. The pipe of the plate is pushed over the [other] dressed end [of the stanchion]. The plate is then horizontally on the stanchion and able to rotate. All the water that flows out from the onyx falls on to the plate.

Now the plate is drilled at its edge and a narrow pipe is soldered over the hole; [this pipe] reaches to the centre of the first of the three adjoining troughs. The pipe is higher than the trough and does not touch it. Then one takes a pipe about 1 span long and bores a hole in the centre through to the inside, and inserts the end of the pipe connected to the plate in this hole, so that [the second pipe] is at right angles to it and horizontal. Then the end of the cross-pipe opposite the end of the first trough, namely the one to the right of the plate, is blanked off. The water flows from the plate into the long pipe and then into the cross-pipe and from its open end into the first trough near the second trough. If the plate is turned to the left the water flows into the second trough, and if it is turned further the water flows into the third trough.

In each trough a copper cross-piece is now soldered transversely and a hole is bored in each one vertically over the centre of the plug of each ground valve. Now a stout string is tied to the ring in the valve plug of the first trough and the other end is passed through the hole in the cross-piece and lifted through the angle at the end of the pipe from the plate, namely the angle to the right of the plate. [From here] the end is raised to the roof of the house and passed over a pulley firmly fixed to the roof of the house. To the hanging end a lead weight is tied, which is heavier than the plug of the valve. The sixth figure is now attached to the hook and the weight is placed on its back – the string is slack at this time.

It is now very clear that: – the water flows from the onyx on to the plate, flows through the pipe connected to it and out of the cross-pipe and into the first trough which fills with water in three hours. The water then spills over the rim of the trough and runs over the solid earth into

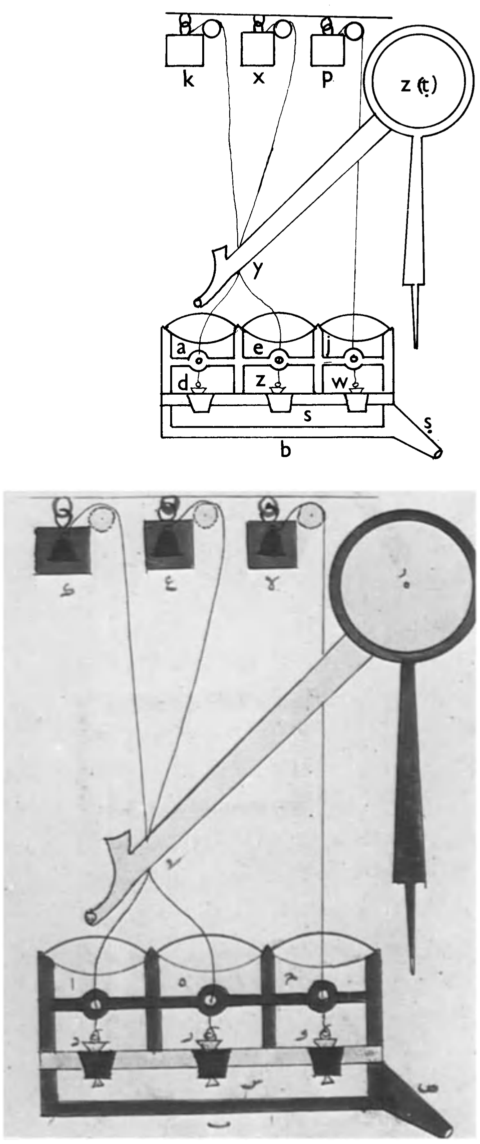


Fig. 28.

the cistern until 6 hours [total] have passed. The figure [then] falls down from the hook and the weight, which is heavier than the plug, falls from its back and pulls the plug upwards until it is stopped by the cross-piece in the trough. The water then runs out through the ground valve into the base of the original trough and out through the pipe on to the scoops of the wheel, which rotates. The hands of the two drummers and the cymbalist move. The connecting pipe between the wheel's trough and the vessel is filled with water and the air in the vessel is driven out through the pipe and the flute plays with a loud tone which is believed to come from the two trumpeters. When the vessel fills and the water rises to the bend of the siphon, the water flows out of the siphon's into the pond. The string from the plug has been passed through the angle of the cross-pipe at the end of the pipe from the plate, namely the angle on the side of the blanked-off end. The weight has fallen from the back of the figure and pulled the plug, bringing the string into a straight line. This turns the plate and with it the cross-pipe so that the water now flows from it into the second trough. Now a string is tied to the plug of the valve of the second trough, through the hole in the cross-piece of the trough, and is also passed through the angle of the cross-pipe with the first string; this string is at this time slack. It is lifted and passed over a pulley in the roof of the house and to the hanging end a weight is attached and placed on the back of the ninth figure, as was the case for the first trough and the sixth figure. Then a string is attached to the plug of the ground valve of the third trough, its end lifted and passed through the hole in the trough's cross-piece then over a pulley in the roof of the house and a weight tied to its hanging end and placed on the back of the twelfth figure. This string is not passed through the angle of the pipe since this is not necessary. This is the picture of the trough and the plate [Fig. 28]: – the floor of the original trough *b*; the second floor *s*; the first house (i.e. trough) *a*; the second house *e*; the third house *j*; the pipe from the floor of the trough *ṣ*; the plug of the valve of the first trough *d*; the plug of the valve of the second trough *z*; the plug of the valve of the third trough *w*; the weight on the end of the string coming from the plug of the valve of the trough, placed on the back of the sixth figure during the day, *k*; the weight on the end of the string coming from the valve of the second trough, placed in the back of the ninth figure, *x*; the weight on the end of the string coming from the plug of the valve of the third trough, placed on the back of the twelfth figure during the day *p*; and this string need not pass through the angle *y*.

On the picture of the axle and its pegs [Fig. 29]: – the three pegs on the axle which move one of the hands of the two drummers *jjj*; at the end of this axle, the wheel with scoops *d*; its trough *e*; in the trough is a pipe *w* connected to the air vessel; the air vessel *z*; the end of the pipe carrying the jar for the flute, *ṭ*; the end of the siphon *ḥ*.

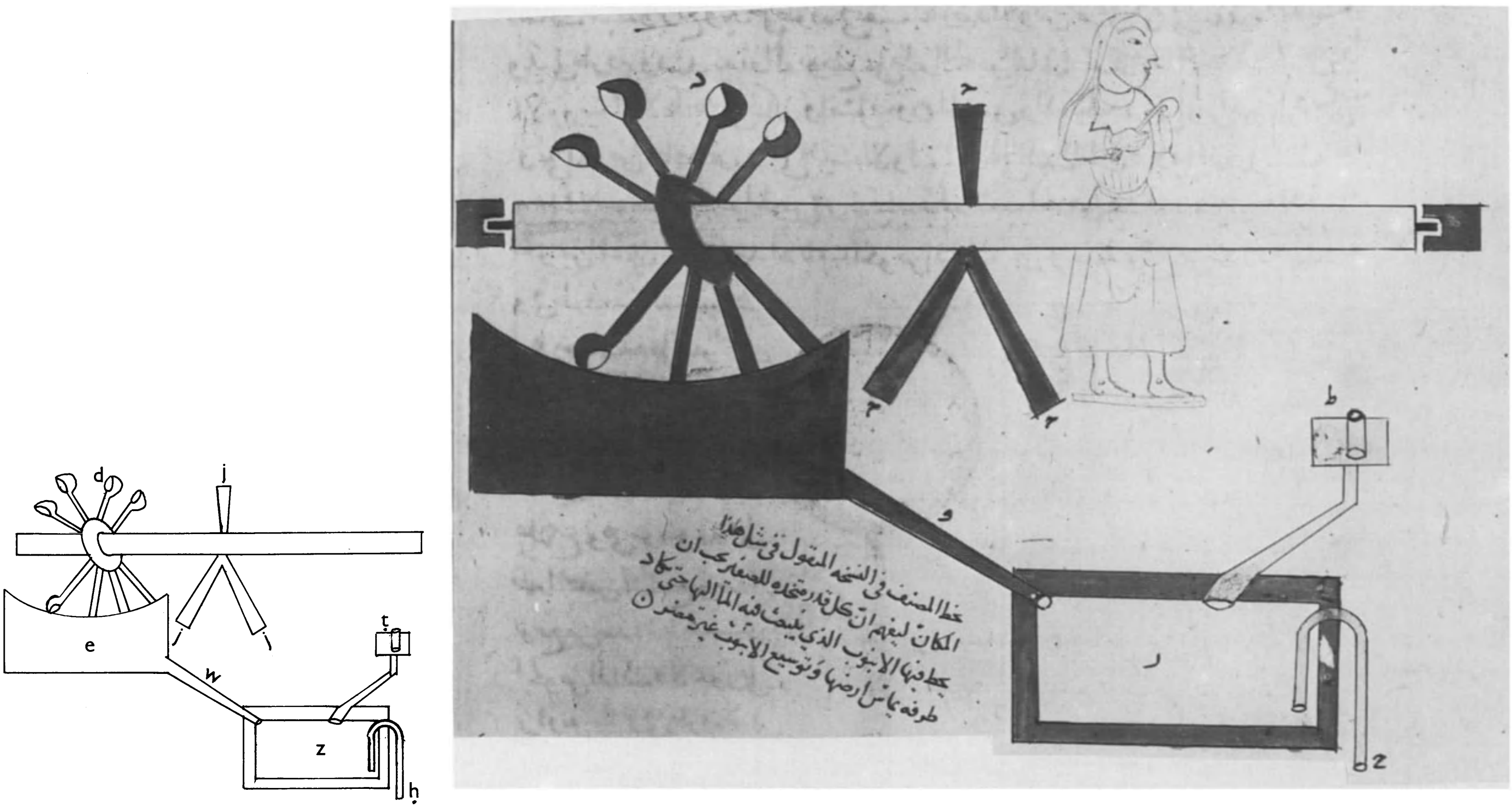


Fig. 29. Captions read: (in) the handwriting of the author, in the same positions: 'it is to be understood, (concerning) every vessel made for the whistle, that the pipe through which the water rushes into it should extend until its end almost touches its floor; the pipe should rest in position without injury'.

It is very evident that: the reservoir is filled with the requisite quantity of water with the float on its surface, and the figures are hung on the hooks, the lower doors are turned upwards, the balls are in the grooves, the blades preventing them from descending, the weight *k* connected to the plug of the first trough is on the back of the sixth figure and the string connected to the plug of this trough passes by day through the angle of the cross-pipe, and likewise at night through the angle *y*; the weight *x* connected to the plug of the valve of the second trough *e* is on the back of the ninth figure with the string also on the angle *y* at the cross-pipe; the weight *p* connected to the plug of the valve of the third trough *j* is on the back of the twelfth figure, and the string does not need to be on the angle *y* of the pipe. The water outlet is set to the sun's degree for that day and the water issues from the onyx on to the plate *ṭ* then into the first of the three troughs *a*, which fills with water in three hours of the day, and then, for three [more] hours the water coming into the trough spills over its rim in one direction and runs into the cistern. When the sixth figure falls down from the hook the weight *k* falls from it and pulls the string, opening valve *d*, whereupon the string tightens and turns the plate *ṭ* with the pipe so that the water outlet moves to the second trough *e*, which fills in a period of 3 hours. When the ninth figure falls the weight *x* falls from it and pulls the string, opening valve *z* of the second trough *e*, the string tightens (*tazannara*) and turns the plate with the pipe to the third trough, *j*, in which the water rises, filling it in three hours. When twelve hours are completed, with the movement of the crescent, the doors, the figures, and the two falcons, the weight *p* falls from the back of the twelfth figure pulling the string which opens the valve *w* of the third trough *j*, the water issues from it and the two drummers, the cymbalist and the two trumpeters do their duty as they did at the sixth and ninth hours. During the night the water is returned to the reservoir, the float being on its surface, and the division marker is moved to the opposite and corresponding (*naẓīr*) degree of the sun, which was the first point of Cancer [i.e. during the day]. The pipe attached to the plate is returned to the first of the trough sections and the sixth and twelfth figures are suspended to the hooks. The disc which covers the glass roundels is turned [back], and the weight connected to the plug of the valve at the first of the three troughs is placed on the back of the sixth figure and the string is passed through the angle of the cross-pipe. Contrary to the situation during the day, the weight connected to the plug at the valve of the second trough is on the back of the twelfth figure and the string of the plug is not passed through the angle of the pipe, this being unnecessary. The lamp is lit. Now I say that when the water flows from the onyx on to the plate then into the first trough, then [this] will fill in a period of two hours because of the depth of the water outlet. [This is] because the trough fills in three hours for the first point of Cancer and in two hours for the first point of Capricorn – there is a difference between these two. The water then spills over the top of the trough into the pond, and at the end of 6 hours, namely in the middle of the night, the sixth figure falls, the weight falls from its back pulling the string which opens the valve. The string tightens and turns the plate and its attached pipe so that the water outlet comes over the second trough, which fills in a period of two hours, and the water spills over the rim in one direction to the pond until twelve hours are completed to daybreak. Then the twelfth figure falls, the weight falls from its back, pulling the string, which opens the valve of the second trough. The two drummers do their service as was the case at the sixth hour. Now the roundels are filled with light, and the musicians have played in the day and in the night five times, namely noon, afternoon (*ʿAsr*), evening (*ʿIshāʾ*), midnight and at daybreak.

Section 9

On the construction of the spheres (falak) of the Zodiac, the Sun and the Moon

A piece of copper is taken and hammered until it assumes the shape of a round plate of diameter 5 spans. Its centre point is marked, and through this a circle is drawn [on the back] of the prescribed diameter, as accurately as possible. The surplus is removed, and the diameter is engraved. [On the front] a circle of diameter 4 spans is drawn around the centre point. Between this circle and the perimeter 12 equal divisions are made and in each division the appropriate sign of the Zodiac is drawn. The diameter [on the back] through the first point of Cancer and the first point of Capricorn is marked *bm* and on this diameter a second centre point is made, 5 divisions from the original centre point towards the first point of Cancer, assuming that the total diameter is 60 divisions. This was not always so, but is [something] I have introduced which is beautiful in its working: – the sun's disc rises and descends in the northern and southern signs of the Zodiac, and likewise the moon. Then a circle is drawn on the second centre point which touches the circle of 4 spans diameter at a single point at the first point of Cancer; it is at its greatest distance [from the first circle] at the first point of Capricorn; the first point of Aries and the first point of Libra are equidistant from it. This circle is then followed round with the dividers (*birkār*) until the Zodiac sphere is separated as an asymmetrical ring.

Then a second circle is drawn on the second centre-point at a distance of 4 fingers from the rim of the disc and this is cut with the dividers until it comes away as a symmetrical ring 4 fingers wide and this is the sphere of the sun. Then [yet] another circle is drawn on the second centre-point at a distance 4 fingers from the rim of the disc and this is cut with the dividers until it comes away as a symmetrical ring, and this is the moon's sphere. The remainder of the disc is left intact.

Now a light copper backing-ring (*biṭāna*) is taken for the moon's sphere; when fitted to it [the sphere], it lies inside the sphere $\frac{1}{2}$ a finger-nail at the outer [circumference] and projects $\frac{1}{2}$ a finger-nail at the inner [circumference]. Similarly a backing ring is fitted to the sun's sphere which projects for a $\frac{1}{2}$ a finger-nail at both sides. These [rings] must be accurately fitted and firmly soldered. Then six holes are drilled at even spacing (*mutaqābila*) around the outer rim of the backing-ring of the moon's sphere, through to the front face of the sphere. A nail is hammered into each hole, projecting from the backing-ring and flush with the front face of the sphere.

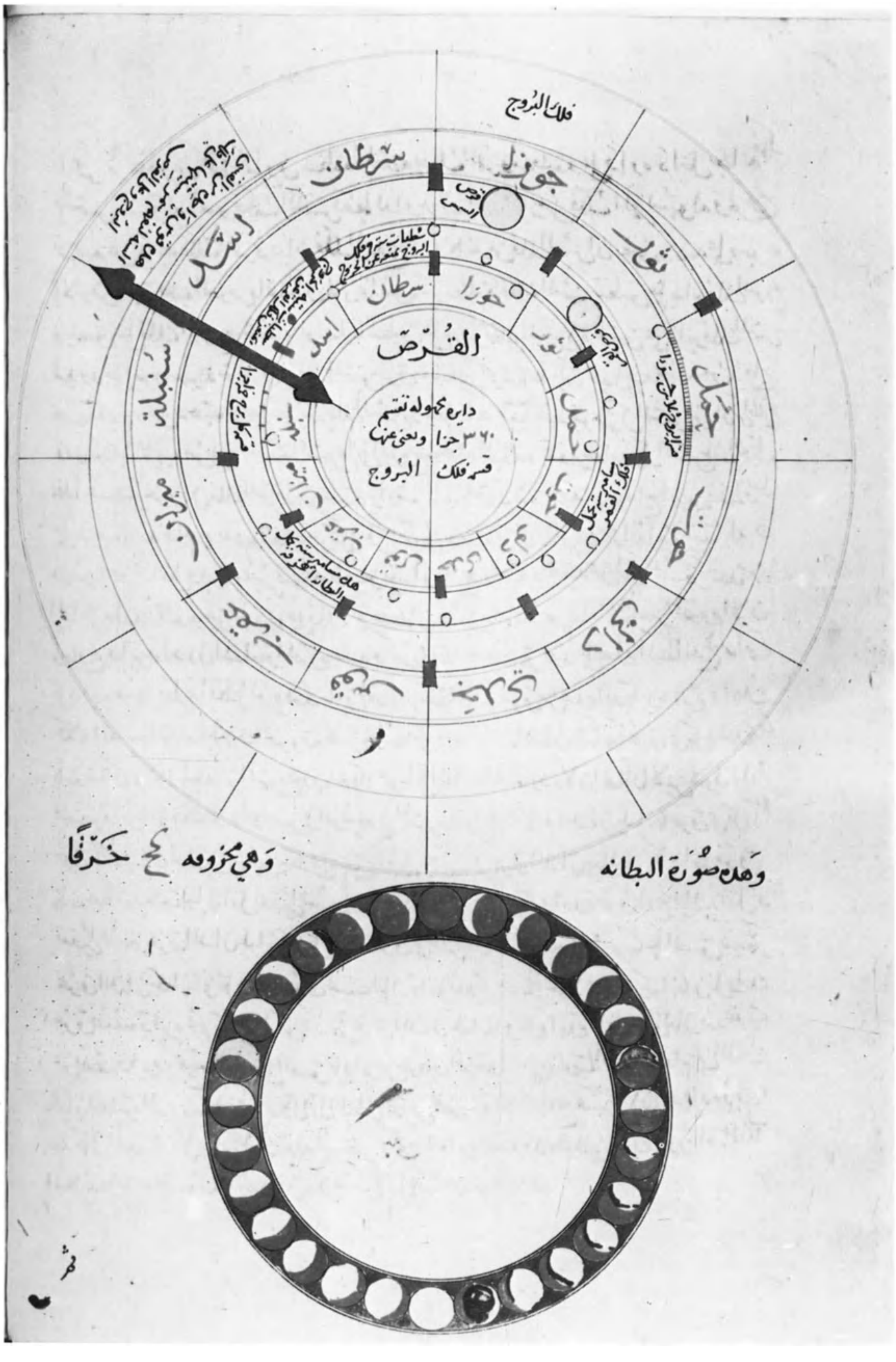
The disc from which the spheres were cut is now laid on a hard, level, horizontal surface and the moon's sphere is returned to its [original] position on the disc. The projection of the backing-ring then lies over the perimeter of the disc. Six evenly-spaced holes are drilled in the disc adjacent to the backing-ring and in each hole a nail is hammered which projects from the back of the disc and is flush with its face. When the moon's sphere is rotated by itself it turns easily around the nails, while the disc does not move. Between each pair of nails a [retaining] lug (*s̲h̲aẕīya*) is fitted to the disc; the lug projects over the inner circumference of the backing-ring but is not soldered to it – this therefore holds the face of the disc to the face of the moon's sphere. Now the sun's sphere is returned to its position next to the moon's sphere and the projection of the backing-ring of the sun's sphere lies over the circumference of the moon's sphere and is encircled by the six nails fitted to the outside circumference of the backing-ring of the moon's sphere. Now a lug is soldered between each pair of nails on the moon's sphere, the projecting end over the inside perimeter of the sun's sphere. If the sun's sphere is rotated by itself, it turns with ease around the nails on the moon's sphere and does not come away from the face of the moon's sphere. The sphere of the Zodiac is now put back in place around the sun's sphere, and lies on the surface upon which the disc and the two spheres are lying, since the projection of the circumference of the backing-ring on the sun's sphere is over the circumference of the Zodiac sphere. On the Zodiac sphere lugs are soldered whose projections are over the circumference of the backing ring on the sun's sphere but not soldered to the circumference of the sun's sphere, which turns with ease when rotated.

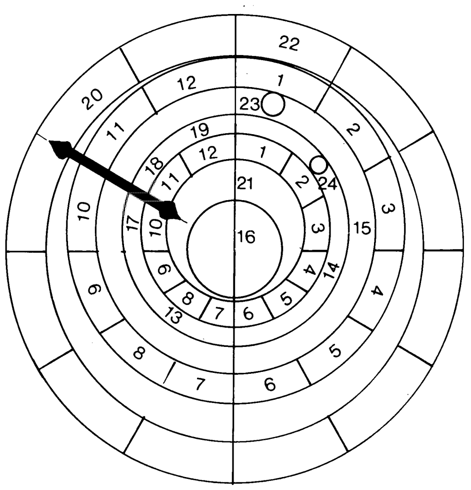
In the sun's sphere a round hole is bored, sufficiently wide to take a glass roundel with a gold leaf behind it. A clearly visible mark is now made on the back of the sun's sphere on a line passing through the centre-point of the sun and the upper centre-point; this mark is near the edge of the sun's disc, adjacent to the Zodiac disc, and is opposite the centre-point of the sun.

Then a round hole is bored in the moon's sphere wide enough to take a roundel of white glass and nothing more; a clearly visible mark is made on the back of this roundel, opposite the centre point of the moon. In the moon's sphere six evenly-spaced holes are drilled, which lie along its inner circumference, and in these [holes] nails are driven which are flush with the face [of the sphere] and project from its back. Then a light copper ring is taken which, when laid on the moon's sphere, is encircled on its inner circumference by the nails just mentioned, while its outer circumference lies inside the nails located there [already], and this is called a backing-ring (*biṭāna*). In this ring 28 circles, equidistant from each other are drawn, and each one has the [same] diameter as the moon. One of these circles is cut out completely, and from the circle [diametrically] opposite nothing is cut. The two circles adjoining [i.e. at either side of] the latter are each cut the shape of the crescent on the first night of the month, with the crescent curving towards the blank circle, since the right-hand crescent on the first night of the month is moving towards the full and the left hand [crescent] on the last night of the month is waning. The two adjoining these two are each cut to the shape of the crescent of the second nights and they are made opposite and symmetrical. The two adjoining these two are each cut to the shape of the crescent of the third nights, with less blacked out. The two adjoining these two are each cut for the fourth nights, with less blacked out. The two adjoining these two are each cut for the fifth night with less blacked out and their convexities symmetrical. The two adjoining these two are each cut for the sixth night, less blacked out. The two adjoining these two are each cut into semi-circles, with convexities symmetrical. The two adjoining these two are each cut for the eighth night with holes larger than a semi-circle, with the remainder symmetrical. Each pair of circles is cut to a larger size until the two circles adjoining the completely cut out circle are cut to almost full circles.

Thus from the crescent of the first night to the circle cut out completely there are 14 nights of waxing, and after that [nights] of waning up to the 27th night. The blank circle remains for two nights [Fig. 31].

This is the picture [Fig. 30] of the three spheres and the disc divided into various sections, as will be described, before the various parts are assembled.





Figs. 30, 31 (Upper 30; Lower 31). Fig. 30. (See line drawing for numbers giving positions of captions). 1–12: (Two sets): As 1 to 12 in Fig. 12. 13: These six nails carry the pierced backing-ring. 14: Six nails which carry the moon's sphere. 15: Division of the Zodiac signs into thirty parts. 16: Circle unknown (in diameter) divided into 360 parts; the division of the Zodiac's sphere is based upon it. 17: Division of each Zodiac sign into five parts. 18: Six lugs which prevent the moon's sphere from coming out. 19: Six lugs on the Zodiac's sphere which prevent it from coming out. 20: This is one of the six bows, for an understanding of the nailing of its horn onto the Zodiac's sphere and onto the disc. 21: The disc. 22: Zodiac's sphere. 23: Sun's roundel. 24: Moon's roundel.

Fig. 31. Caption above figure reads: 'This is the picture of the backing-ring which is pierced with 28 apertures'.

Then this backing-ring [with the phases] is laid on the back of the backing-ring for the moon's sphere around the nails which were fitted last. Then ['between' omitted] each pair of nails on the backing-ring of the moon's sphere a lug is soldered, whose projection lies over the surface of the pierced backing-ring. Four projecting nails, evenly-spaced, are fitted between the holes on the back of the pierced backing-ring, the projection being sufficient for them to be held and used by themselves for turning [the ring] with ease. The lugs prevent it [i.e. the phase backing-ring] from detaching itself from the moon's sphere. The connection of the three spheres, one to another, is now complete; they form, as it were, one piece, with their faces on the surface of the ground.

Six rods (*qaḍīb*) of iron are now taken, each weighing about 400 *dirhams*. Each one is bent until it takes the shape of an archer's bow. This is the picture [Fig. 32]. In every horn of the bows two holes are bored. The width of the bow of each rod [i.e. the chord of the arc] should be such that the face of one of the horns can be placed on the disc without touching the moon's sphere, when the face of the other horn is between the two perimeters of the Zodiac sphere, not touching the sun's sphere. Every bow is nailed with two nails to the Zodiac sphere and with two nails to the edge of the disc, with the arc facing upwards, and not touching the spheres of the sun and the moon at all. This is done for all the bows, and they are also all securely soldered with lead so that they support the Zodiac sphere on the [central] disc, [so firmly held that] the former has no movement relative to the disc. The bows are evenly-spaced around the disc.

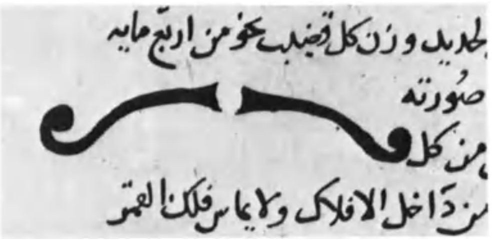


Fig. 32.

It is clear that there is a crescent-shaped section remaining inside the Zodiac sphere and bounded by the sun's sphere. Around this two circles are drawn, and in the space between them the names of the Zodiac are written; it is [also] divided into 360 parts. Near the outer perimeter of the disc one also draws two circles, in which the names of the Zodiac are written, and the space is divided into 60 'Fives'. The division of the Zodiac signs and the [small] divisions must be done before the bows are nailed in position.

The three spheres are now returned to their positions on the disc on the engraved diameter. Holes are bored through the disc on the centre-point of the whole [assembly] and on the outer centre-point. Then on the main centre-point a circle of optional diameter is drawn on the disc, and divided into 360 equal parts. The ruler is now placed between the two centre-points and a line drawn along its edge, between the two circles designated for the names of the Zodiac, on the sphere of the Zodiac. Thus the fabricator positions himself at the centre-point of the disc. Now he counts towards the left from the divisions on the back of the disc 30 divisions, places the ruler on the last division and in the main centre point, and draws a line between the two circles of the Zodiac sphere. Between this line and the line passing through the centre point to the Zodiac circle, which is the first point of Cancer, the word 'Cancer' is engraved. The ruler is not moved from the main centre point until the Zodiac is completed. Now a further 30 divisions are counted to the left, the ruler is placed on the last one and an engraved line is drawn along the face of the ruler between the two circles, and between the two lines 'Leo' is engraved. Then 30 [more] divisions are counted, the ruler is placed on the last of these, a line is drawn along the face of the ruler and 'Virgo' is written between the two lines. [One continues] in this way until 5 divisions are completed, whereupon a 5 is written on the outside of the circle – this method is of practical value to its user – and so on until 360 unequal divisions are completed on the circle of the Zodiac sphere. The heads of the companions of the writing [i.e. the letters] should be towards the side of the Zodiac signs [i.e. outside]. Similarly we draw lines in the space between the two circles on the perimeter of the disc designated for the signs of the Zodiac, this being divided into 60 parts. The method is this: whenever a line is drawn for the first point of a Zodiac sign on the Zodiac sphere, a line is drawn on the perimeter of the disc for the first point of a Zodiac sign, and whatever is written on the Zodiac sphere is written between the two lines [on the disc]. For the divisions the ruler is placed on 5 degrees on the Zodiac sphere, and a mark is made on the disc for a single division until the perimeter of the disc is completed with 60 unequal divisions. That is all there is to be said about the construction of the spheres, and their divisions, and their interconnections by the lugs and the bows. All the spheres must turn easily to the right or to the left. To the back of the sun's sphere and the moon's sphere, something is fixed for holding when the spheres are rotated.

Now an iron axle is made 5 spans long and of such a width that it can be encircled by thumb and forefinger; it must be completely straight and of constant cross-section and its ends are pointed. The main centre-point of the disc is then drilled and the end of the axle inserted in it [i.e. the hole], to project from the face the length of $\frac{1}{2}$ a Finger. The axle is soldered firmly to the disc, using as much lead as possible. It [the disc] must not tilt in any direction, and one must guard against tilting. One achieves this by supporting the axle on two stanchions and turning the whole [assembly] with a pointer set close to the Zodiac sphere, making adjustments until it is like a balanced wheel (*kharṭ*) as it turns. Observations are made and if one part of it is heavier than another, adjustments are made with lead between the pictures on the Zodiac sphere.

Then six bars of iron are brought and the end of each one is fixed to the back of the Zodiac sphere between two signs, and the other end to the centre of the iron axle. Care is [thus] taken to ensure that everything is stable – to this end I have made the work lighter by reducing the diameter of the Zodiac sphere from about 7 spans to 5 spans.

The faces of the disc and the spheres are painted in a colour like the colour of the heavens, and the pictures of the signs of the Zodiac are adorned with gold and other beautifying colours. In every sign of the Zodiac holes are bored to the number of its [accompanying] stars, approximately in their positions, large and small. These are filled with white, yellow and reddish glass to [suit] the colours of the stars.

At the other end of the axle a wooden disc 2 fingers thick is fitted, and a groove is made in the perimeter so that it becomes as it were a pulley – its diameter to the bed of the groove is $3\frac{1}{2}$ spans. In the bed of the groove 360 holes of equal bore and depth are made, equidistant from one another. Then one determines which of the holes is opposite the first point of Cancer in the Zodiac sphere, and this is marked with a clear sign. Then one counts from here 30 holes along the Zodiac and [at this point] also a mark is made – between the two 'sign of Cancer' is written, and so on for all the signs. Then one takes an iron nail with a hole in one end. This nail is of such a length that it penetrates to the bottom of the holes; [when inserted] it is firmly held in position.

This is all that is necessary for the construction of the spheres.

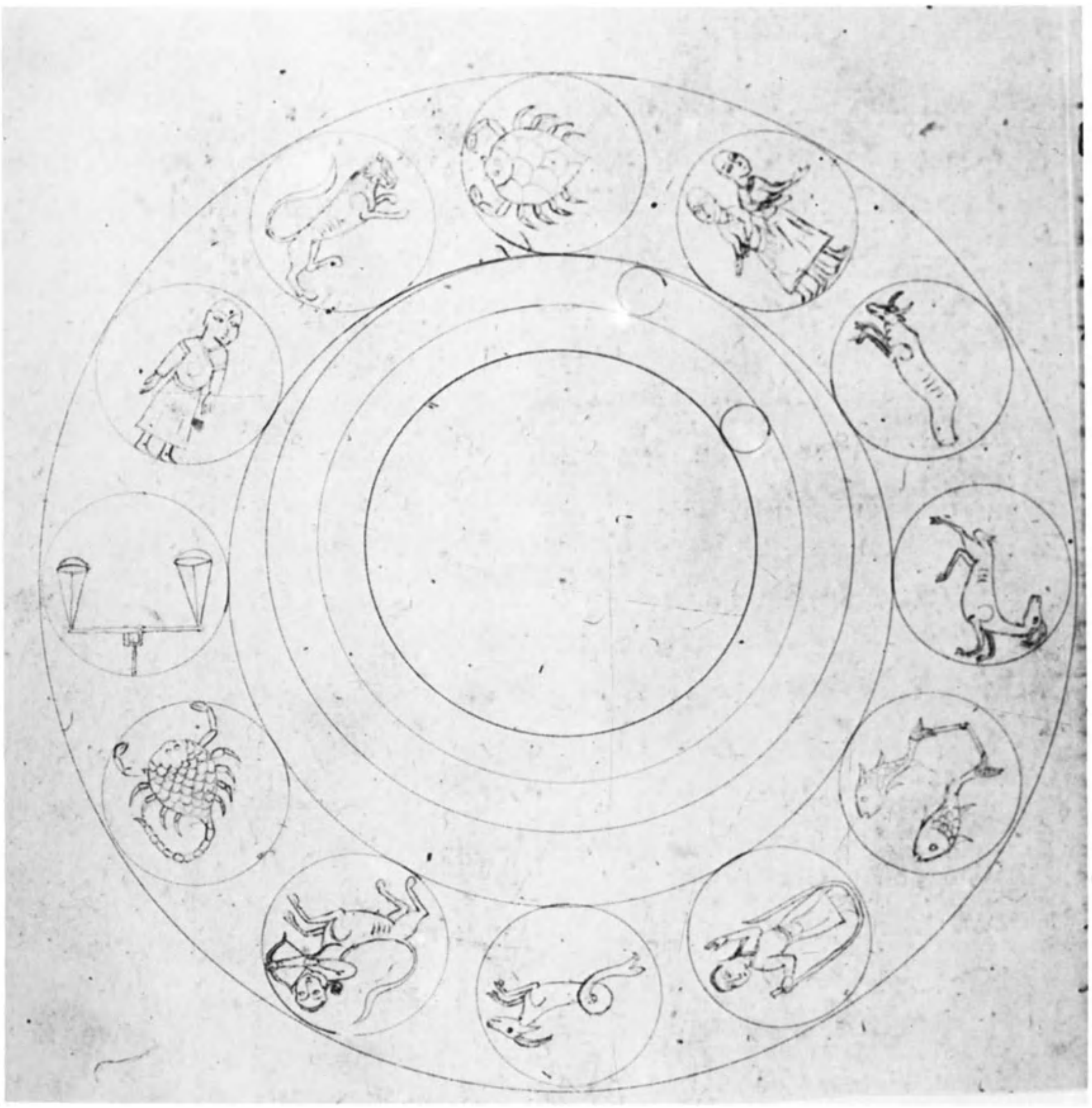


Fig. 33.

Section 10

On the place where the spheres are erected, and their functioning

A round opening is made in the upper part of the wall, as wide as the outer perimeter of the Zodiac sphere, and with the same circumference. The lower half of it is covered with a plate of copper or wood. At the half centre-point [i.e. the centre-point but with a semi-circle in mind] a small semi-circle is drawn and cut out [to form] a bearing for the end of the axle projecting from the face of the disc carrying the spheres. The diameter of the cover [of i.e. the lower large semi-circle] is horizontal and is the horizon for the signs of the Zodiac and the spheres. This half of the opening is painted in the same colour as the wall in which the opening is located.

The end of the axle at the face of the disc is laid in the place prepared [for it] in the centre of the plate, and the other end in a firm support in an iron bearing. It is evident that half the disc and the spheres surrounding it are always visible, so 6 Zodiac signs have risen and 6 have set. If the first point of Aries is on the horizon and [the disc] rotates, its degrees will rise and the degrees of its partner (*naẓīr*) will descend.

A strong cord is now tied to the ring in the end of the nail made for inserting in the holes of the wooden disc and the nail is inserted in the hole for the first point of Aries. [The string] is wound once round the disc from the top downwards and then taken vertically upwards; the string thus leaves the groove in the disc at the first point of Aries. The string is then passed over a pulley fixed securely in the roof of the house, then over another pulley vertically over the centre of the reservoir, and the end of the string is tied to the ring on the float, without any slack. The reservoir is full of the requisite quantity of water, as indicated by a clear mark in the reservoir.

The operation of these spheres: behind the spheres in the house there is a place where the servant [appointed] for this work stands. He sets the spheres, moves the nails from hole to hole, and sees that the sun is in the first point of Aries for the given day and the moon in the degrees of Taurus. The servant grasps one of the iron bows fixed to the Zodiac sphere in his left hand, while with his right hand he holds the sun's sphere and turns the sign on the centre-point of the sun until he brings it opposite the first point of Aries, which is marked on the back of the Zodiac sphere. Then he holds the sphere of the sun in position and brings the mark on the centre-point of the moon's roundel to the degrees of Taurus. Next he grasps the holder on the backing-ring [to the moon's phases] and turns it round the moon's sphere until the blank roundel of the 28 roundels is on the moon's disc, so that the moon is not seen at all on this day.

I have ordained that the nail is in the hole for the first point of Aries, that the reservoir is filled with water to the mark, that the day prescribed is the last of the month, the water outlet is on the first point of Aries, the pipe of the [dished] plated is on the first of the three troughs, the figures are suspended to the hooks, the [lower] doors are tipped up and all of one colour, and the crescent moon is on the frieze at the right-hand side of the wall; the string from the plug of the valve of the first trough is lifted through the angle of the cross-pipe and the weight is placed on the back of the sixth figure; the string of the plug of the second trough is also passed through the angle of the pipe and the weight is placed on the back of the ninth figure, the string from the plug of the third trough is lifted in a straight line and is not placed in the angle of the pipe and the weight is on the back of the twelfth figure; the balls are placed in the grooves and the blades in the slits.

This is what the operator of this plant must set in order at the beginning of the day at sunrise. From outside the house (lit: *ṣūra*) the centre of the sun's disc will be seen on the eastern horizon, about to rise, the moon will not be seen at all, 6 Zodiac signs have risen and the first point of Libra is about to set. The crescent moon takes its steady course until in its travel it has passed the first door, and its crescent is between two doors. Then the figure, suspended on the hook falls, the door turns over, showing another colour and the two falcons lean forward, each dropping a ball from its beak. Of Aries 15 degrees have risen, while 15 degrees of Libra have set; in the Moon's roundel no figures are seen – they are effaced. So it proceeds until the sixth hour, when the musicians do their duty, the sun reaches its highest altitude, and 3 Zodiac signs have set, 3 risen. At the ninth hour the musicians perform, and at the twelfth, when the sun's disc is on the western horizon, about to set.

The water that was in the reservoir is now collected in the cistern and the balls in two places in the floor of the house. Now the servant makes haste, and pours the water back into the reservoir through a strainer (*miṣfa*) in the top, then resets the pipe of the plate over the first trough. He hangs the sixth and twelfth figures, and puts the weight from the first trough on the ninth figure, passing its string through the angle of the pipe, and he puts the weight from the second trough on the back of the twelfth figure, without passing its string through the angle. He returns the crescent moon to the end of the frieze. He puts the centre-point of the moon on its degree for that night, and moves the backing-ring until the sickle-shaped hole is behind the moon's roundel. The nail in the [wooden] disc is moved to the hole for the first point of Libra for this night but the onyx on the sun's degree is not moved on this night. The glass roundels for the hours of the night are covered, the crescent-moon [on the cart] having been returned to the end of the frieze, and the solid part of the disc [with the iron ring] is uppermost. Inside the house two lamps are lit, one to the right of the house, one to the left, to spread the light over the iron bows fixed to the Zodiac sphere and to the disc. This is all the servicing needed for the night. The observer sees at the beginning of the night a light in the first roundel like a barleycorn, which [gradually] increases, and he sees the moon in its phase for that night until it sets. The roundels fill with light, and then it is midnight, and the sixth figure falls, the valve opens and the water falls on the wheels, and the musicians perform. The plate has moved, turning the water outlet on to the second trough which fills with water in three hours, as had happened with the first trough, and spills over the top for three [more] hours until the end of the night, when the twelfth figure falls and the musicians perform. Twelve roundels are then filled with light.

Then the servant makes haste to return the water to the reservoir and put everything in order as he had done the previous day, and so on for the days and the nights [throughout the year]. The water outlet and the nails are moved the same distance – in the day they are on the sun's degree and in the night on the opposite (*naẓīr*) of the sun's degree. The mark of the centre-point of the sun on the sun's sphere adjoining the back of Zodiac sphere is moved one degree each day. The mark of the centre-point of the moon opposite the circumference of the disc is moved at the start of each day from the prescribed degree of the Zodiac through 6 degrees and in the night of each day through one degree. The backing-ring is turned so that on the moon's roundel the correct opening for that night appears; the light from the two lamps shines through the roundel [showing] the shape of the moon as it is on that night. At the beginning of the day a piece of linen or a piece of white cloth is placed behind the opening in the moon's roundel, so that one can see the moon white, and in its appropriate shape for that day. I have made [the description] easier by saying: a string rises from the wooden disc on the end of the wooden axle [i.e. the axle with the cut-out disc at the other end] to the roof of the house, passes over a pulley, whence the loose end is tied to a ring in the float. The string from the nail goes round the groove in the disc pierced with holes then to a pulley in the roof of the house, and its loose end is also tied to the ring in the float. In practice the arrangement was different – I made it so for easy operation. What I did was to make two grooves in the disc at the end of the axle of the spheres. One groove was for the holes; in the other a ring was firmly fixed to which a string was attached and connected to the well-balanced disc on the end of the wooden axle. The entire functioning depended upon the rotation of the disc with the holes, and nothing was connected to the float except the string from the nail – one end [tied] to the nail, the other end to the float.

I have now said all that is necessary. Everything made of brass is stripped down (*tajarrada*), chiselling is applied where appropriate, and painting where appropriate. The visible parts are adorned. The brass is coated with oil of Sandarac and, since thought must be given to the drying [it is left] in the sun. Then the colour will last for a year, or fifty years. This is what I wished to describe clearly.

Now I will describe what I made, namely the water-clock of the drummers.

Chapter 2 of Category I

Being the water-clock of the drummers from which can be told the passage of the solar hours; it is divided into 5 sections

Section 1

Description of its outside appearance and operation

The visible part (*Ṣūra*) is on the outside of an alcove (*Ṣuffa*) or a handsome reception-chamber (*Īwān*) raised about the height of three men above the ground. It is a frieze (*Ifrīz*) like a ledge (*Raff*) projecting from the face of the wall about 4F. in a straight horizontal line. Along its edge there are 12 battlements and at the end of the ledge stands a man (*Shakhṣ*). His right hand is outstretched and his index finger points towards the battlements; when he moves behind the battlements his finger almost touches their points. Above the frieze and parallel to it are twelve glass roundels in a straight line [set] in holes [cut] through to the inside of the house. Below the centre of the frieze is a *miḥrāb* with a falcon in it, as in the first chapter, with a vase in front of it on a projecting bracket, with a cavity [in the wall behind], as [described] previously.

In the floor of the chamber is a platform occupying all the foreground, raised about the height of one man above the ground. On this platform are seven men: on the right two blowing trumpets, on the left two playing cymbals – the rest are drummers. The middle one has two kettle-drums (*Naqqāra*) while the two to his left and right each has a drum slung over his shoulder, its head tilted upwards so that it can be struck by a drumstick (*Ṣawlajān*) held in the right hand. The left hand is lowered on the other side [of the drum]. The one in the middle has a drumstick in each hand with which to strike the kettle-drums.

Now I say that at daybreak the man is at the end of the frieze and moves smoothly until he is behind the first of the twelve battlements, whereupon the falcon leans forward and casts a ball from its beak onto the cymbal in the vase, and the musicians play. This happens every hour as I have described.

It should be understood that the trumpeters, cymbalists and two of the drummers are standing on their feet, not touching each other or supported by anything, while the drummer in the centre is kneeling.

The situation in the night is that all the twelve roundels are [at first] completely lit. Then the edge of the first roundel darkens, [the darkness] increasing until the whole roundel is dark. At that time 11 solar hours of the night remain. The man moves along behind the battlements and is not seen, but every hour the sound of the cymbal is heard, since for this device the operation is the same in the night and in the day, nothing whatsoever being omitted [in the night]. When an hour has passed the musicians (*Nawba*) perform with a clamorous sound which is heard from afar. This is its picture [Fig. 34].

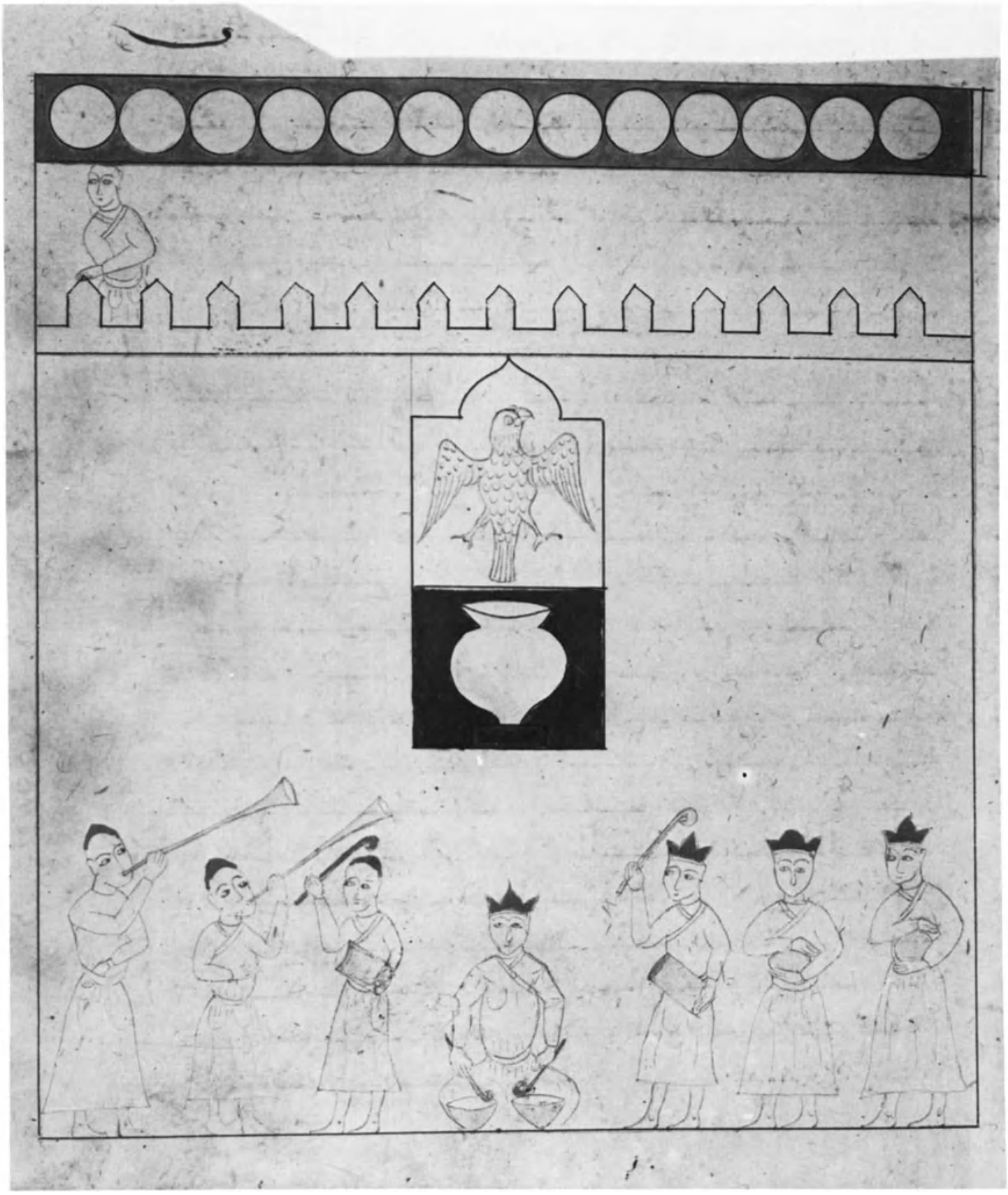


Fig. 34.

Section 2

On the water-instruments, and the functioning of the bucket (Kaffa) which fills and empties every hour.

Know then, that behind this chamber (*Īwān*) is a house which is raised above the chamber and extends beneath the platform. The platform is completely hollow. First I [must] mention that in this chapter there are types of instruments that were described previously in the first chapter. I will not discuss their operation and positioning at length, but will mention them briefly. Among these is a vessel [i.e. the reservoir] made as we described, its height 6 sp. and its width $1\frac{1}{3}$ sp. with a tap at the bottom as before.

Then an oblate float is made from copper, like a hollow turnip which floats on the surface of the water. It has in the centre of one of its faces a staple and a ring, and adjacent to the staple is a hole into which some sand can be poured to weight it. Then the float-chamber (*Rubʿ*) is made, the same shape as the reservoir, its length $1\frac{1}{2}$ sp. and its width 4F, with a float inside it having a plug which closes the bent-over end of the tap in the bottom of the reservoir. [One also makes] the flow regulator (*Dastūr*) for the water outflow as previously, omitting nothing from it. The reservoir is erected as described [before] with the float-chamber directly adjoining it and the flow regulator connected to the float-chamber – the drawing for that [assembly] was shown above.

Now for this device (*Shakl*) one makes a long copper trough about 4 sp. long, its side about 1 sp. high. It is called 'the trough of the bucket' (*Ḥawḍ al-Kaffa*). This trough is placed in front of the flow regulator so that the water which issues from the onyx falls into this trough. Then one takes a piece of copper and hammers it until it assumes the shape of half a hollow weighing-bucket (*Kaffa al-Mīzān*). Then, on the section which is cut away, [i.e. where the central cross-section of the complete weighing-bucket would be] a vertical plate is fitted at the same height as the side of the bucket, which now resembles half a drinking-bowl (*Ṭās*). It is wide at the top, narrowing towards the centre, and is longer than a semi-circle, and [looks] like half a boat. Below the rim of this bucket, near its end, two holes are drilled opposite each other – marked *bb*. An axle is inserted through the two holes, of sufficient length to protrude 1 F from each hole. The bucket should be large enough to contain the quantity of water which issues from the onyx in one hour when it is on the degree of the first point of Cancer, plus a little more. When the ends of the axle of this bucket are placed on two firm supports, and water is poured into it until it is almost full, it will remain stable. If a drop more water is added it will tilt towards its elongated end, and discharge its entire contents. Then it will return to its original position. This is the principle of this bucket. When I made this bucket, even though I did not know that I was the first to make it, I thereby rendered unnecessary many appliances of value in this craft.

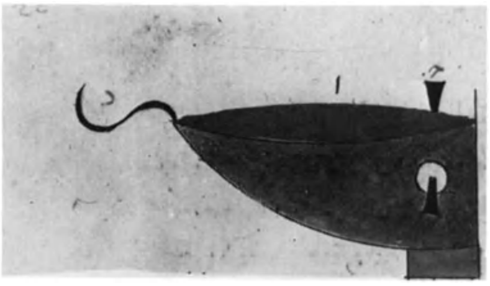


Fig. 35.

With the bucket freely balanced as before, the end near the axle, namely the back, is weighted with about 100 *dirhams* of lead, so that it will not tip when filled with water, but will remain in position. Something is [therefore] required to tip it in counteraction to the weight, [namely] a bar of copper on the end opposite the weight, turned upwards to form a bow with a single horn (*Sīya*). This horn is hammered into the shape of a circular plate, convex downwards. When a ball weighing 20 *dirhams* falls into this hollow horn, the bucket tilts and pours out all the water it contains. The ball rolls out of the hollow bow because the concavity is shallow, and the empty bucket returns to its original position. This [Fig. 35] is the drawing of the bucket, its axle, and the bow fitted to it. There are letters on the drawing; on the bucket *a*, on the two holes *bb*, on the ends of the axle *jj*, on the horn of the bow *d*, and on the weight on the fulcrum *e*.

The bucket is now placed in the trough in front of the flow regulator, resting horizontally on its fulcrum, the ends of its axle in two holes in the side of the trough. A hole is bored in the bottom of the trough for the insertion of a pipe, which is mentioned below. Then the bucket is filled with water from one hour of the first point of Cancer and a mark is made at the surface of the water, at the top of the vertical side. Above the weight a hole is made in which is fitted a thin horizontal pipe 4 F long, marked *w*. This is the drawing of the trough, marked *z*, with the bucket inside the trough [Fig. 36].

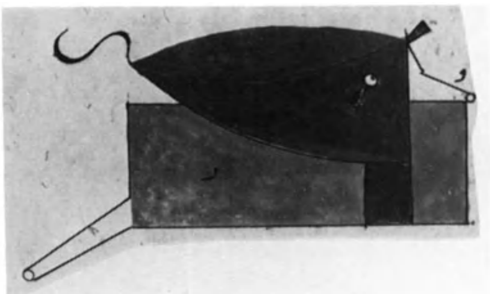


Fig. 36.

Section 3

At the beginning of this chapter it was mentioned that there is only one *miḥrāb* in the centre, one falcon and one vase on a bracket, the operation of these being the same as in the first chapter, so it is not necessary to go into this at length.

Above the *miḥrāb*, there is a frieze straight across the wall projecting 4 F from the face of the wall; it has an edging strip about 2 F high upon which are battlements, fashioned according to the choice of the craftsman. Then a slit is cut through the wall at the same level as the surface of the ledge. Inside the wall below the slit a cart track is installed as before, and a copper plate is nailed to the back of the cart which projects through the slit on the frieze almost as far as the edging strip upon which are the battlements. Then the figure of a standing man is made, who has his legs on the plate and his forefinger pointing to the tip of a battlement. Parallel to the frieze, and above it and the figure, are twelve holes in a straight line. In each hole is a glass roundel, the distances between each pair of roundels being equal. In this device the movement of the cart, [is as follows]; to the rear of the cart a string is attached, which passes over a pulley at the end of the track; to the hanging end a lead weight is attached to exert a pull on the cart from behind. A string is tied to the front of the cart which runs along the track, passes over a pulley at the end of the track, then up to the roof of the house and over [another] pulley which is vertically over the centre of the reservoir. Its end is tied to the ring in the float, [the string] having no slack at all. The reservoir is filled with the known quantity of water and when the tap is opened and the float descends the cart moves, and the figure with it. The length of the frieze and the roundels equals the height of the water in the reservoir.

The position with the roundels [is as follows]: at nightfall they are uncovered and the light from the lamp shines through the glass. I will now describe how they are covered so that they darken one after the other.

Near the first roundel a vertical axle is erected, one end of which [the lower] rotates in a bearing[1] set firmly in the end of the wall, and some distance away from it, another bearing is placed over the upper end [of the axle]. Then one takes a roll (*qimāṭ*) of smooth natural hide (*Udm* or *Adam*) wide enough and long enough to cover the roundels, and attaches its end to the vertical axle at the end of the roundels. The axle is rotated and the roll is wrapped round it like a roll of paper (*Darj*). The other end is attached to a rod which is erected in the middle of the top of the cart. It is very clear then that the cart with the rod is on the end of the track opposite the first roundel, and when the cart moves the roll unwinds, covering one roundel after another until all the roundels are covered. This is the drawing [Fig. 37] of the axle marked *y*, the two bearings *mm*, the roll *x* with its end in the rod on the cart *s*. [The roll] is unwound.

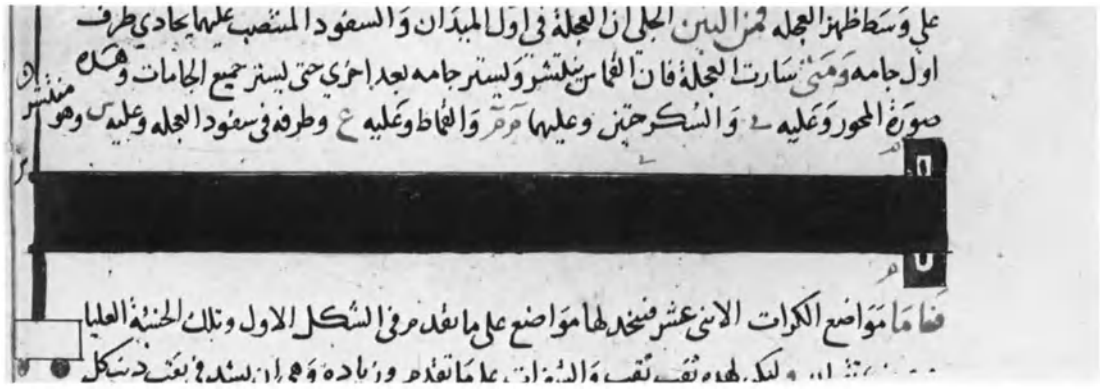


Fig. 37.

The 12 balls have places made for them like those in the first chapter except that in the upper piece of wood there is only one hole whereas in the other there were two. The blades are like they were previously. For the rest, one attaches a string 1 sp. long to the hole in the tail of each blade, and a lead weight, heavier than the blade, is tied to the other end. Running below the tails of the blades is a piece of timber with 12 hooks as was described in Chapter 1, with weights hanging from them. At the bottom[2] of each weight is a fine, smooth, long ring. This is the drawing [Fig. 38] of one ring in a weight on the end of one hook. The weight is marked *s*, the ring *ṣ* and the hook *x*. Then an iron rod with a smooth end is fitted to the top of the cart, and its end is bent over so that it passes below the hooks and above the weights which are suspended by the rings to the hooks. The bent-over end of the rod pushes one ring after another, and the weight falls, lifting the blade. The ball rolls down the groove, into the [wooden] channel, comes out of the centre of the wooden channel into the copper channel, then into the top of the *miḥrāb* and falls into the falcon's head.

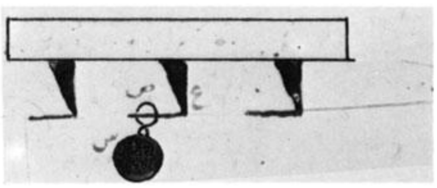


Fig. 38.

[1] *Sukurruja* = bowl or plate. Here evidently a bearing.
[2] Should read 'top', as shown in Fig. 38.

Section 4

On the construction of the men

Seven men are made from jointed wood; I shall describe the construction of one of five [percussion players] and one of two [trumpeters]. For the one of five one takes dry knot-free wood which is pieced together into the shape of the torso (*baṭn*) of a man, the back being hollow. The left thigh, lower leg and foot are joined to this, – they are not hollow. The right thigh, lower leg and foot are hollow, with a straight hole inside extending from the bottom of the foot through to the torso. For the right hand[3] a shoulder and [upper arm] up to the point of the elbow are made and fixed in position. From the point of the elbow a slit is made through to the hollow part of the torso – this is for the forearm. Then one makes a forearm, palm and fingers, which are clasped around a drumstick. A [piece] about 1 sp. [long] is separated from this forearm [i.e. there is a continuation piece] beyond the point of the elbow and a hole is pierced laterally at the end of the separation [i.e. where it joins the forearm]. In it an axle is inserted the ends of which rest in the slit made at the elbow, and the hand is mounted on this [axle] – when it moves it moves up and down. In the end of the extension inside the body there is a hole with an iron ring in it, to which [is attached] the end of a copper wire – the other end comes out of the hollow foot. When the man stands on his feet and the end of the copper wire is pulled down the arm moves upwards, and when the end of the wire is released the hand moves downwards by natural disposition. Now the other hand is made. With the drummers the face of the drum is held from underneath, and with the cymbalists, the edge of the cymbal is held in the usual place. A head is now made, adorned by the craftsman to the best of his ability, and painted in the colour of human skin. He is clothed in fine garments, which conceal the mechanism for the hand, with a headcovering such as musicians wear when on duty. Four men are made on this pattern – two trumpeters and two cymbalists. As for the drummer who leads them all, who is kneeling, his body is hollow, and his thighs also, the holes extending to the knees; the action of the hands is as described above, and each carries a drumstick. Then two trumpeters are made [standing] close together, in the hand of each of them a trumpet of the usual design, with the end in his mouth in the normal way. The trumpeters are placed on the right of the platform and a drummer with a drum is near them; next to him is the leader, kneeling with two large kettle-drums made of copper in front of him. Next to him comes a drummer with a drum and two cymbalists [all] in a line. The feet of each man are fixed securely – it is easy to do that. Beneath each foot in which there is the end of a wire, a slit is cut leading to the hollow interior of the platform, and beneath the knees of the leader there are two slits. The ends of the copper wires hang down inside the platform. Slung over the shoulders of the drummers are wooden drums, like the well-known drums.

Section 5

On the means for imparting motion to the hands of the drummers and cymbalists, and the instrument from which the sound of the trumpeters issues

A hollow axle is made of beaten copper as long as the chamber (*Īwān*) is wide, or somewhat shorter than that. Its ends are light. The axle is located in the hollow of the platform, vertically beneath the men's feet. On the end [of the axle] below the foot of the second trumpeter, a copper scoop-wheel of 2 sp. diameter is erected, strongly made with large hollow scoops [able] to withstand the weight of water which falls on them, as described below. A trough is installed beneath this wheel to catch the water falling from the scoops, and a hole is cut in this trough near the [first] trumpeter. Then a vessel (*qidr*) is made from copper, which has the capacity for the amount of water which fills the [tipping] bucket set in front of the flow regulator. A siphon is fitted to it like the one described in the first chapter for the flute. A hole is made in its cover, and between this hole and the hole in the bottom of the wheel's trough a pipe is fitted which is narrower than the pipe which discharges into the scoops of the wheel – which is mentioned below. Then another hole is made in the cover, narrower than the pipe which discharges into the vessel, into which a fine pipe is fitted which rises to the level of the platform and passes through the wall of the chamber to a small aperture (*Kūwa*) to the right of the first trumpeter. To the end of this pipe is fitted a jar (*ḥuqq*) for a flute, as described in the first chapter.

[3] *Yad.* Here as elsewhere the translation may be 'hand' or 'arm'.

Then a pipe is fitted to the hole in the bottom of the [tipping]-bucket's trough, which extends to and discharges over the scoops of the wheel. When the [tipping]-bucket fills with the [quantity of] water which issues from the onyx in one hour of the longest day, this is the least [quantity] of water of all the hours [in the year]. At this juncture the ball falls into the head of the falcon, thence onto the bracket[4] whence it rolls inside the house. A channel is provided for the ball leading from the bracket to the horn of the bow on the end of the [tipping]-bucket. So when the ball falls onto the horn the bucket tilts and empties all its contents into the trough underneath it, and the ball falls from the horn to the ground. The water flows from the bucket's trough through the pipe in its base onto the scoops of the wheel, turning the wheel. The water falls from the scoops into the trough, and flows through the pipe connecting the trough and the [air]-vessel, expelling the air in the vessel through the jar of the flute. The flute plays with a sound which is heard from afar. As the vessel fills the water rises to [the bend of] the siphon, and discharges through it into a cistern by the side of the vessel.

Now I will describe the means for imparting motion to the hands of the drummers, and I will do this for the movement of one hand [only]. Vertically beneath each hanging wire a mark is made. By one of these marks a straight, copper strip, beaten into the shape of a ruler (*misṭara*), is positioned. It is about $1\frac{1}{2}$ sp. long. One end is bent round to form a ring, which is attached to a staple fixed to something solid at the same level as the axle of the wheel. Then a hole is made in the ruler, a certain distance from the other end, and this hole and the end of the copper wire directly above it are connected by an iron ring. The ruler is thus raised to the level of the axle of the wheel, and is horizontal. The hand of the figure is heavier than the copper wire and the ruler which it supports. If the end of the ruler is forced downwards by something, the hand of the man moves upwards, and when the ruler is released from the thing which pushed it the end of the ruler will lift to its [original] position and the hand of the man will descend. Now, opposite the end of the ruler in a straight line from the axle of the wheel, a peg is fixed in the axle, its end as firmly fixed as the [end of] the ruler. It is of sufficient length for its other end to reach to the end of the ruler. When the axle turns the end of the peg presses on the end of the ruler which goes down with it for about 1 sp. and then comes away from it. Then one makes for this ruler, in addition to this peg, two other pegs whose ends are fixed to the axle on the opposite side to the first, and are opposite the end of this ruler. [i.e. they are in the same vertical plane as the first peg.] Since two of the three ends of the pegs are close together, the fall of the drumsticks on the drum is varied – [first] two raps then one rap – and likewise with the cymbal. In this manner the hands of the drummers and cymbalists are operated. [The positioning of] the pegs should be varied as much as possible. In this instruction it should be understood that the drum is tilted, so the axle for the hand of the drummer must also be tilted. The rise and fall of the hand of the drummer is not in a straight line from foot to head, but slanted from right to left. This is the drawing [Fig. 39] of one drummer standing on the platform marked *a*, the drawing of the axle, with the wheel on it, both marked *l*, and three pegs on the opposite side of the axle, marked *m*. The wheel's trough is marked *x*, the pipe connecting it to the flute's vessel is *w*, the flute's vessel is *q*, and on the end of the siphon leading from it is *ṭ*. There is a *j* on the jar of the flute, on the wire hanging from the drummers hand is *s* and on its end connected to the end of the ruler is *ṣ*. On the other end of the ruler, in a firm ring in a firm support, is *k*.

It is very clear that: the reservoir, marked *a* [Fig. 40] is filled with water at the beginning of the day, the water outlet is on the first point of Cancer on the flow regulator, marked *b*, and the water discharges from the onyx into the [tipping]-bucket in the trough, marked *y* and *j* respectively. The balls *d* are in the grooves in the wood restrained by the blades *sh̲* and the weights are on the hooks *e*.

The man is on the reverse of the drawing at the end of the frieze, moving smoothly, since he is attached to the cart, until, when one hour of the day has passed, his finger is near the tip of the first battlement. I mentioned previously that the glass roundels are screened by a roll of leather, which should be coloured *baqqam*[5] – red, so that [by day] they appear red, to match their darkness in the night. The roundels are marked *d* and the roll *z*. When a roundel is completely red, the rod pushes a weight, a blade lifts from a ball, which falls from the falcon's beak onto the cymbal, and the sound is heard. It rolls through the channel *ṭ*, falls onto the horn of the bow *s*, fixed to the end of the [tipping]-bucket *y*. The bucket is filled with water. If the hours have lengthened after some days then some of the water which falls into the bucket flows out of the pipe in the top, marked *j*, which is outside the trough of the bucket, and runs over the ground into the cistern. When the ball falls onto the horn of the bow, the bucket tips and discharges all

[4] Under the vase.

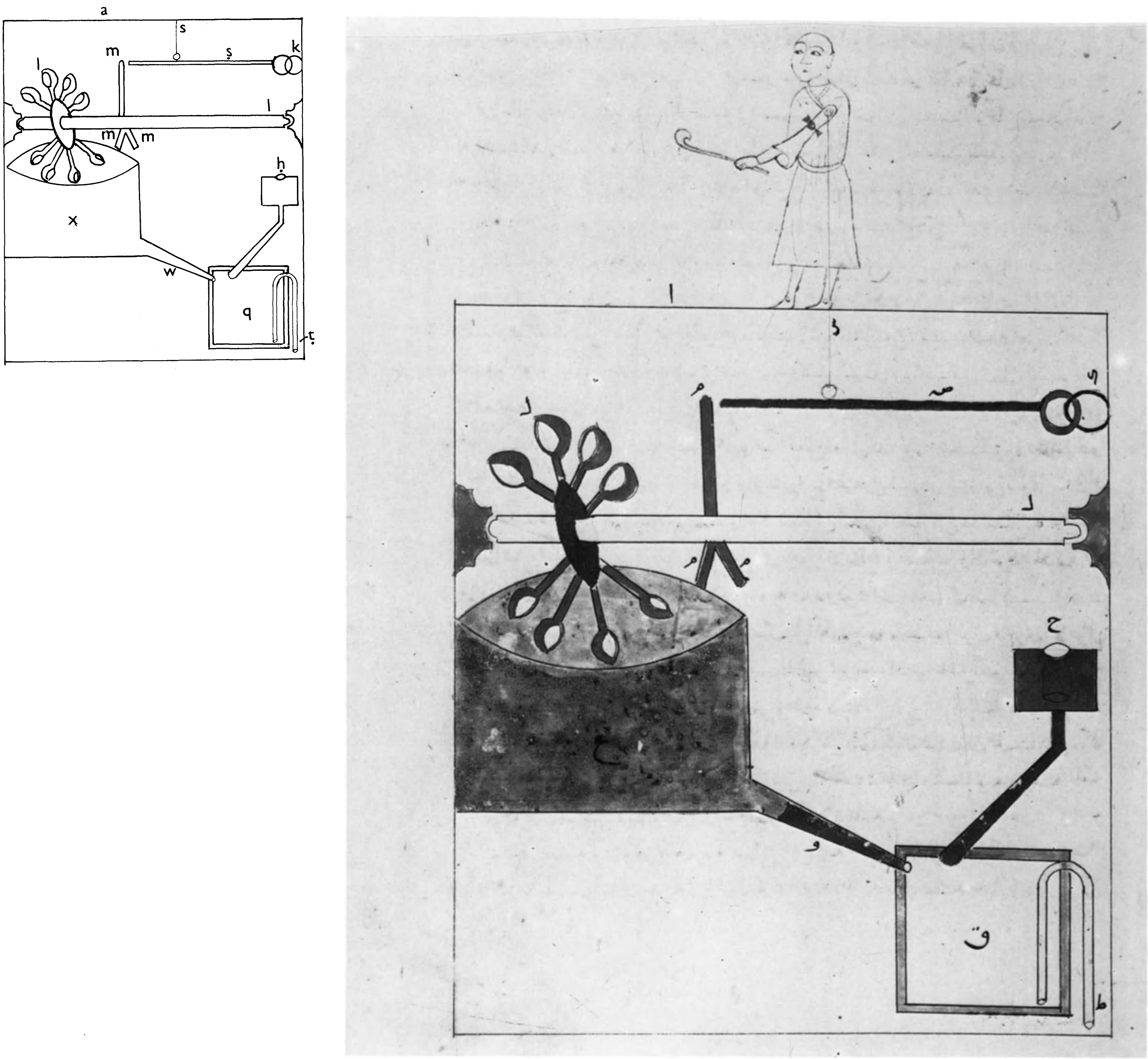


Fig. 39.

the water it contains into its trough. The water flows into the pipe *k* connected to the trough and into the scoops of the wheel *l* [Fig. 39]. The wheel turns with its axle, and the three pegs fitted to it, marked *m*, push the end of the ruler *ṣ*, moving the hand of the drummer up and down. The water collects in the wheel's trough *x* and flows through the pipe joining it to the flute's vessel *q*. The air in it [the vessel] is driven out through the pipe into the flute's jar *j*, which blows, and the blowing is thought to come from the trumpeters. There is no need to demonstrate the movements of the remainder of the hands of the trumpeters and cymbalists. Their description and mechanisms are similar to what was said above for a single hand – [namely] the axle, pegs, rulers and the wires hanging down from the extensions of the arms.

The members of the band perform as long as the water falls on the scoops of the wheel. Then their movements and the sound of the trumpets cease until water discharges from the [tipping]-bucket [again] when another hour has passed. So it continues until twelve hours have passed to sunset. The servant then pours the water back into the reservoir, moves the man to the side of the frieze, replaces the balls in the grooves, and the weights on the hooks, winds the roll and the axle, and turns the division marker [i.e. on the flow regulator] to the first point of Capricorn. He lights the lamp, whereupon the roundels are filled with light – whenever a roundel has darkened [completely] an hour of the night has passed. Then the falcon drops a ball, the musicians perform, and so on until twelve hours have passed.

The remarks [which follow] concern the reservoir, not the float-chamber and the flow regulator, for I say that the reservoir of this device is small and that a larger one is needed [only] when the quantity [of water] discharging into the bucket is increased, and the bucket is enlarged, so that the period during which the musicians play is lengthened.

This is what I set out to describe clearly. This [Fig. 40] is the drawing of that has been described, from inside the house.

Now I will describe a water-clock which I made for showing the constant hours. I have witnessed [the correctness] of its basic principle. It is the *Ṭarjahār*, of which there are various types.

[5] *baqqam* is sappan wood, originally from India and E. Africa. A red dye is obtained from it.

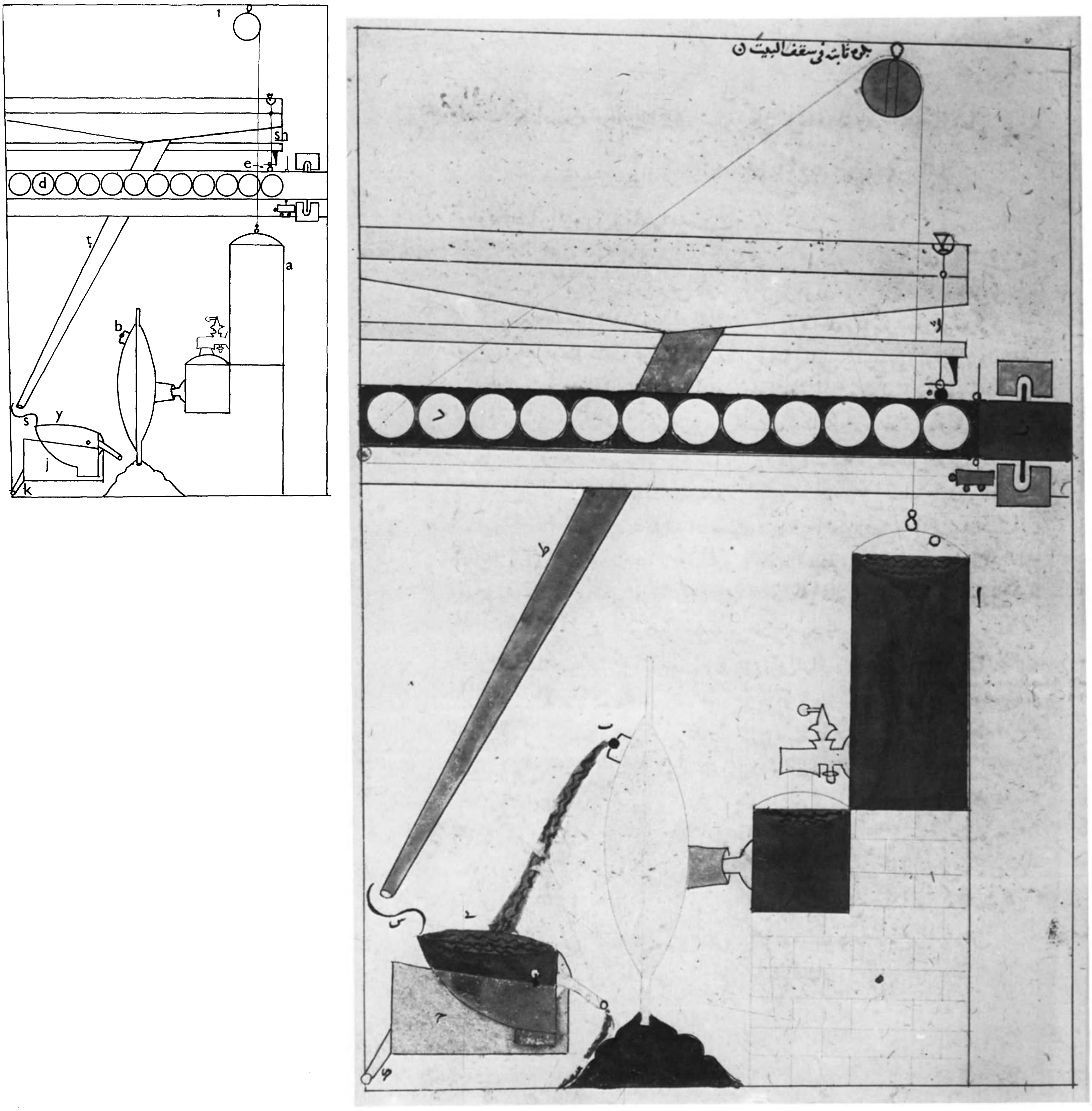


Fig. 40. Caption, at 1 on line drawing, reads: 'Pulley fixed to the roof of the house'.

Chapter 3 of Category I

On the water-clock of the boat, which is divided into six sections

Section 1

On its outside appearance and functioning

From it can be told the passage of the hours and their divisions. It is a boat of fine workmanship made of brass which rests on a footing raised about 1 small span (*fitr*) above the ground. It is about 3 sp. long and its breadth in the centre is $1\frac{1}{4}$ sp. The stern is covered over, the bow section (*ṣadr*) is open and lead-lined (*muraṣṣaṣ*) inside. Between the ends of the bow and stern sections [i.e. amidships] and over the sides [i.e. gunwales] is a square plate[1] with fretwork [around the sides] resembling battlements. In the four corners of the plate half-square pieces of brass are soldered and on each of these is a brass stanchion 3 sp. high and as thick as a thumb. On the stanchions is a square castle (*qaṣr*) of excellent workmanship around which are fretted battlements. Above it is a handsome cupola[2]. In the side of the castle facing the bow of the boat is a door containing a falcon – only its breast and head are visible. Between the centres of the two right-hand stanchions of the clock is a transom (*ʿiḍāda*), and likewise a transom between the centres of the two left-hand stanchions. In the middle of each of the transoms is a hole in which are [located] the ends of a thin axle. On the axle is the claw (*yad*) of a serpent (*thuʿbān*) which clutches the axle in the centre. Its tail curls round the axle like a circular ring and its head is stretched towards the falcon's breast, and its mouth is open as if it wished to swallow the falcon's head. Inside the plate, which is the balcony[3] of the boat, is a spherical-shaped section (*mikabba*) like a dome. On the dome is a platform (*sarīr*) upon which sits a man with a pen in his hand. Around him on the platform are 15 marks, like divisions. The functioning is [as follows]: at the beginning of the day the pen of the sitting man appears over the first of the 15 divisions, and it moves from division to division with an imperceptible motion. When the tip of the pen reaches the end of the divisions the falcon lets fall from its beak a solid ball (*bunduqa*) of cast bronze weighing about 30 *dirhams* into the mouth of the serpent. The head [of the serpent] rotates and sinks slowly until it reaches the bow of the boat; it casts the ball on to a cymbal in the bow of the boat, and it [i.e. the ball] remains in the bow of the boat. The serpent now rises back to its original position. The scribe's pen has returned rapidly to the first division, and one constant hour of the day has passed. Now the scribe moves his pen from division to division until he reaches the last division, the falcon drops the ball from its beak into the mouth of the serpent, which slowly sinks, and dropping the ball onto the cymbal, returns to its position. This happens every hour until 24 constant hours of the day and night have passed. A decrease of hours in the day is compensated for in the night and a decrease of hours in the night is compensated for in the day. This is the drawing [of the clock] [Fig. 41].

[1] *Milban* – A flat tray for carrying and storing bricks.
[2] *Qubba*. Is translated 'cupola' to distinguish it from the dome-shaped section on the platform below.
[3] *Shurfa*. Here this does not mean 'battlement'. One could almost translate it as 'the bridge'.

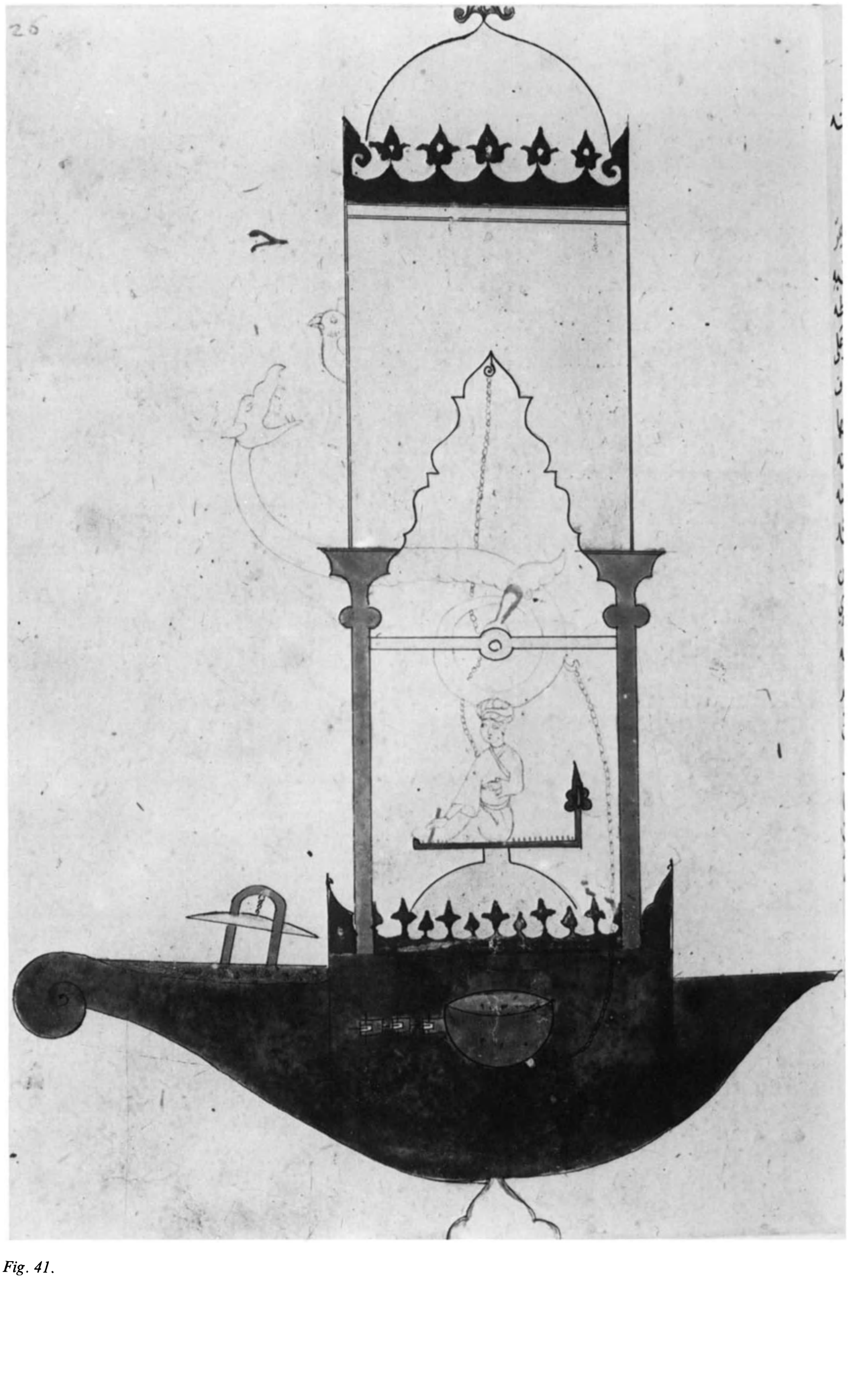


Fig. 41.

Section 2

On the construction of the boat, the dome, the stanchions and the serpent, the castle and the cupola

A piece of brass is taken and hammered into the shape of a well-made boat, and fixed on a support (*kaʿb*) like the base of a table. The stern is covered with a neat plate and its interior is tinned. At the end of the stern section a plate is fitted from bottom to top and [similarly] a plate is fitted at the end of the bow section from bottom to top.

The boat is 3 sp. long and its width at the highest point in the centre is $1\frac{1}{3}$ sp. The distance between the two vertical plates at bow and stern is equal to the width at the highest point, so that one has, in the centre of the boat, a single square trough.

Around the top of the trough a well-constructed battlement of fine fretwork is erected. Then in each corner of the trough, at the foot of the battlement, a half-square plate is soldered, so that the top of the trough becomes octagonal. In each corner, inside the battlement, [i.e. on the plates just mentioned] one places a triangular base with a vertical pipe one finger long in its centre, and these bases with their pipes on them are firmly soldered in position.

For the bow of the boat a rod is made, bent into a semi-circle with its convexity upwards, and its ends [fixed to] the sides of the boat. On this is hung a cymbal, upon which the ball drops, and then into the bottom of the bow of the boat, where the balls are collected. All that I have described is of best quality brass and [also] everything that is mentioned below for the visible parts. Now one takes four hollow cylinders each about 3 sp. long and of the thickness of a thumb. For the end of each cylinder a piece of pipe is brought, part of which is inserted into the cylinder and soldered in position. The projecting part is inserted into the pipe on the base in one of the corners [of the battlement] so that the cylinder is vertical on the base. A piece of cast bronze is fitted to the top of the cylinder, and this resembles the capital of a column – at the top there is a male [spigot]. In the centre of each cylinder is a finely-chiselled sphere. All the cylinders are made in this way.

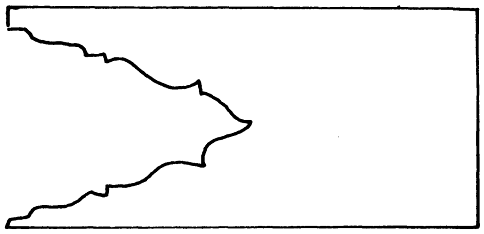


Fig. 42.

Inside the battlement and on top of the trough is fitted a rounded section like a dome, and above the dome is a kind of platform. On the pillars a square-shaped castle is erected. On its lower part is a cover, curved towards the inside, with chiselled corners; at the bottom corners are feet, decorated with gold (*mushadhdhar*) and underneath each foot is a hole into which is inserted the male [spigot] at the top of the stanchion. Around the perimeter at the top of the castle there is also a fretted battlement, and inside this battlement, above the castle, is a painted cupola. On top of the cupola is a fitting which is held when lifting or putting down [the clock].

In the face of the castle, towards the bottom, a handsome door is made.

On the construction of the castle: one takes 4 plates of this pattern [Fig. 42] places them together at right angles, and makes the joint between each pair with lead. The lead is used in abundance, from inside, with careful workmanship so that the lead is not visible from outside.

The serpent is made from a slender piece of brass 3 sp. long and 4 F wide at one end. The other end is pointed like a *Shūzaka* [?]. The brass is rolled into the shape of a pipe[4], one end being open and broad, the other narrow end closed. It is filled with black lead[5] and bent into the shape of a circular ring of 4 F diameter. Then one takes another pipe about 1 sp. long, one of its ends [of such a width] that it can be inserted into the end of the ring, and the other end narrower than that. It is filled with lead, and bent slightly in the opposite direction to the curvature of the ring. Then the lead is removed from this pipe only. A head is made for it like the head of a serpent, the pipe is soldered to the ring, and the head to the narrow end of the pipe. For the joint between the ring and the pipe two hands are made, each hand as long as the half-diameter of the ring. They are soldered to the right and to the left of the joint. The ends [lit. shoulders] of each hand are covered by a wing which is joined to the shoulder. Beneath the palms of the hands an axle is fitted, whose length is the same as the distance between two pillars. Between each pair of pillars, right and left, a transom is erected, the ends of which rest in holes in the centres of the stanchions. In the centre of the transoms are holes in which the ends of the axle are inserted. This is a separate drawing of the serpent [Fig. 43].

Fig. 43.

4 Lit. The pipe is rolled.

5 'Black' lead is lead, 'white' lead is tin.

Fig. 44.

Section 3

On the construction of [the equipment] which is inside the trough, namely the float (Tarjahār), and what is connected to it, and the ball inside the float which moves the scribe to the right and to the left.

One takes a brass float, as light as possible, in the shape of a hemisphere, its diameter at the top being 4 F. Near its centre point a hole is made.

Now three links (*narmādaja*) are made and joined together with pins. This is the drawing [Fig. 44] of the links, marked *j*, *d*, *e*. The one marked *e* is soldered to the float at a point 1 F below its rim, the end of the one marked *j* is inserted in a strong staple in the plate which divides the trough from the bow of the boat, so that the float rests on the bottom of the trough. The links are [thus] connected to the side of the trough, near the top, by the hinge mentioned above. Water is poured into the trough, nearly up to the staple. If the float with the links attached is lifted, the water in it will be emptied out, and if placed on the water it will float on the surface on an even keel.

Near the centre point of the float, but outside it, two rings are fitted, opposite each other, on a line that passes through the centre point. To each ring the end of a light triangular[6] chain is fixed, each chain about 1 short span long. The ends of the two chains are joined together by a fine ring, and also connected to the ring is the end of [another] light chain about 3 sp. long. When the float sinks in the water in the trough, and the end of this chain is pulled upwards, the float is lifted and all the water in it is emptied out to the last drop, and when the chain is released it floats evenly on the surface of the water.

In one side of the dome near the top a hole is made through which the chain can move with ease. This is the drawing [Fig. 45] of the float connected by the links to the hinge in the side of the trough.

Fig. 45. Captions read: Top: 'ring'; right: 'this rod is inside the bowl'.

Now I will describe how the scribe turns to the left and to the right. One takes a piece of pipe, its length half the length of a finger and of a width that can be encircled by thumb and forefinger. It has flanges (*ṭabaqa*) on each end, and the whole pipe should be as light as possible. A hole is made in the centre of each flange and a light axle passed through them, one end of which projects from the flange the length of a barleycorn and the other end the length of a finger. In the centre of the pipe a strong ring is fixed, and to this ring the centre of a silk cord 3 sp. long is tied. Then a hole is drilled in the centre of the platform to the inside of the dome, into which the long end of the axle in the piece of pipe is inserted from inside the dome, and projects above the platform. The flange of the pipe almost touches the dome [i.e. the underside of the platform]. Beneath the short end of the axle a cross-beam is erected and its ends are fixed to the dome. On this cross-beam a bearing (*kharaza*) is placed into which the short end of the axle is inserted, so that it turns easily on the support. Then one takes a very light pulley in a light channel (*bayt*) and fixes the channel firmly to the dome opposite the ring in the pipe. The end of the string tied at its centre to the ring is passed over the small pulley, and to this hanging end a lead weight of 5 *dirhams* is tied. Another small pulley is brought and its channel fixed to the dome opposite the [first] small pulley. The other end of the string is passed round this pulley. Now a solid ball of cast bronze (*ṣufr*) weighing 20 *dirhams* is made and a hole drilled through its centre. In the hole an axle, narrower than the hole, is inserted and the ends are bent into a half-ring so that the ball can turn without touching the half-ring. The end of the string, passed over the second small pulley, is tied to the junction of the ends of the axle, in the centre of the half-ring, which half surrounds the ball.

6 Having triangular links.

This is the drawing [Fig. 46] of the pipe, which is a pulley with its ring – they are marked *w*; the ends of the axle, one of them on the cross-beams – this end is marked *k*; the other end *w*, projecting above the surface of the platform; the string over the two pulleys, marked *j*, *d*, with a weight on one end, marked *ṭ*; on the end with the ring and the ball is a *y*. The string with the ball and the weight is wound once round the pulley, namely the piece of pipe, which is called the big pulley, inside the dome. This is [written] so that it is clearly understood.

It is evident that the ball is heavier than the lead weight. The ball is protruding [i.e. its string is extended]; the string of the weight is wound round the big pulley and the weight is near the small pulley over which is the string of the weight. If the ball is lifted up in the hand the weight will descend and the big pulley and the axle will turn.

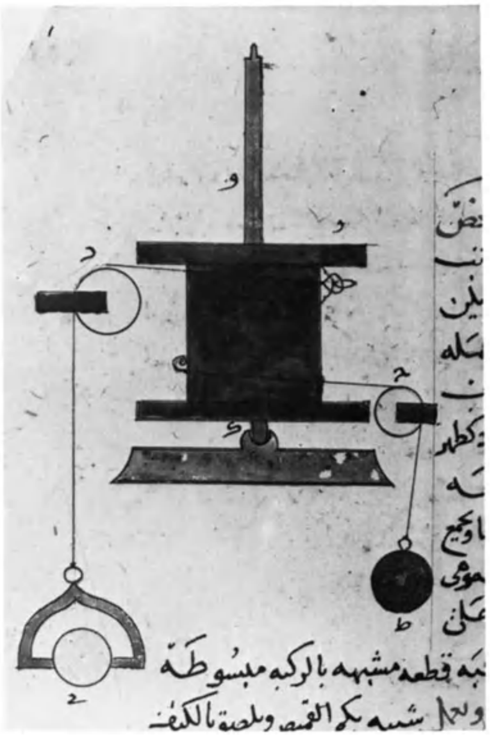
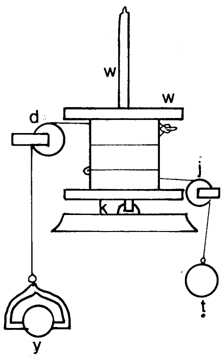


Fig. 46.



Section 4

On the construction of the scribe and what is connected to him

From jointed copper [by assembling copper components] a sitting scribe is made. One of his knees is on the ground and is raised vertically. He should be elegant because of his position on the platform and the dome. The method of constructing him is the one I have used for constructing light figures: one takes a piece of tube, as light as possible, of the length of a sitting man and forms it into the shape of the back and belly of a human being. In the position of the neck and shoulders a light piece shaped like the shoulders is soldered. A cylindrical head is made with a narrow neck and a broad face, painted as beautifully as possible. A turban is made for it like half a ball, ribbed like a turban. The turban is soldered to the head and the head [to the space] between the shoulders. For the knees, a piece like an extended knee is made and soldered in [the appropriate] position, and another like a raised knee is soldered in position. A [piece] like the sleeve of a shirt is made and soldered to the right shoulder; in this is part of the forearm, and the palm and the fingers, grasping the pen which points downwards. The left sleeve and hand rest on the raised knee. At the bottom of the pipe, [which is shaped] like a man, a cover is fitted with a square hole in the centre to take the end of the axle which projects above the surface of the platform – [this end] is also square [in cross-section]. The scribe turns on the axle when the big pulley turns. The three pulleys are inside the dome above a plate and the strings of the weight and the ball pass through two holes in this plate. The float is then placed on the surface of the water in the trough and the dome is placed over the trough; of necessity the ball descends into the centre of the float, which supports it. The string of the ball is slack until the weight sinks and tautens the string of the ball. Then the scribe is placed on the platform and the end of the axle fits tightly in the hole in the plate underneath him. The tip of his pen is on the platform outside the first point.

The water enters the float through the hole bored at the side of its centre point, and all the while the float sinks with the ball, the pulley turns, with the axle and the scribe. On the platform the point of the pen describes the arc of a circle while the float fills with water, but before it is submerged. This arc is divided into 15 divisions by means of a calibrated water-clock (*ṭarjahār*), [each division] for one degree [of latitude]. If the end of the chain attached to the float rises through the slit in the dome, it lifts the float and the water in it is emptied out, whereupon it floats evenly on the surface of the water. The ball is lifted in the float, the weight descends and the scribe's pen returns to the first division of the arc.

The two ends of the axle upon which is the claw of the serpent are now placed in the holes in the transoms. Its circular part is filled with lead, and the tail, the thin part, is towards the front. The heavy part is in the middle, and when it is placed in the transoms the head rises until the edge of the lower lip reaches the falcon's breast, because the serpent is connected to his [own] lower part. Its mouth is as wide open as possible, showing its two fangs. Now one takes the end of the chain connected to the float which rises from the slit in the dome. In it there is a hook which is placed in a strong ring attached to the back of the serpent. Part of the back of the serpent has been channelled out, and in each side of this groove are very fine teeth, separated from one another, which prevent the chain from coming out of the groove. If a ball of 30 *dirhams* weight falls into the mouth of the serpent, its head moves and sinks slowly, the chain winds around its back, raising the float from the bottom of the trough. The serpent's fangs prevent the ball from falling out of its mouth until its head approaches the bow of the boat, at which point the ball drops onto the cymbal. The serpent's head is lightened and the float pulls it and raises it until its lip is on the falcon's breast, and the empty float is on the surface of the water.

Section 5

On the construction of the falcon, the place for the balls in the castle, and the channel for discharging each ball into the falcon's head

The head and breast of a falcon are made as far as its middle; the upper beak and part of its head are detached, enough to allow a ball of about 30 *dirhams* weight to pass through. Its head and its beak are connected by a very light hinge. In the shoulders of the falcon two holes are made, opposite each other, in which an axle is inserted, and its ends sit transversely in the posts of the door of the castle. In the back of the falcon's head a hole is made through which the ball can enter. Its head and shoulders are separated by a hollow plate in which the ball rests – when the falcon tilts it is ejected from its beak. Inside the house and opposite the back of the falcon's head a channel is erected which leads from the back part of the castle to the head of the falcon, without impeding the movement of the falcon. The width of this channel should be such that a ball can move easily through it – its sides are vertical. In the centre of the channel a sector (*miqṭaᶜ*) for the balls is made as follows: in the centre of the channel a mark is made and a ball is laid on it. Two marks are made on one side of the channel, the distance between them equal to the diameter of the ball, and two marks are made opposite them on the other side of the channel. Then four slots are made in both sides of the channel through these marks from the rim of the channel to its base, the holes being wide enough to take the blade of a knife. Then a blade is made from iron or copper, a hole is bored at the root of its tail, and the end of the tail is bent round into [the shape of] a ring. An axle is inserted through the hole in the blade, and the blade is fitted into the two opposing slots in the channel [on the side] facing the head of the falcon. The axle is on the side of the channel and is firmly fitted at that point. The blade [rests] on the floor of the channel [owing to] the weight of its end. When a ball is placed in the end of the channel it rolls down until it is stopped from dropping into the head of the falcon by the blade. If the tail of the blade is pulled down, the blade turns on the axle, its end is lifted from the bed of the channel, and the ball rolls down into the head of the falcon. Another blade is made and placed in the other two slots in the sides of the channel, in a similar manner to the first blade, and the ends of its axle are fixed. In the end of this blade there is a hole. The axle of the first blade is marked *a* [Fig. 47] its head is marked *b*, the ring in its tail is marked *j* and the head of the second blade is marked *d*. Now I say that the head of the first blade, marked *b*, is lowered and its tail, marked *j*, is raised. The head of the second blade, marked *d*, is raised from the bed of the channel and its tail, which has a lead weight [fixed to it], is lowered. The end of a chain is attached to the end *d* of the [second] blade and the end of [another] chain is attached to the ring *j* in the end of the tail of the [first] blade. The ends of the two chains are brought together, below the channel, and attached to a light ring. If the ring is pulled down the first blade is raised from the bed of the channel and the second blade is lowered to the floor of the channel. If the ring is released the first blade descends to the floor of the channel and the second blade rises from the floor of the channel. When a ball is placed in the end of the channel it rolls down until it is stopped by the first blade, and if a second [ball] is put in, it will stop by the side of the first, and another will rest against the second, and so on until the channel is filled with balls. If the ring is pulled down, the second blade descends between the first ball and the second ball, and the first blade lifts away from the first ball which rolls into the head of the falcon, while all the balls in the channel are held back by the second blade. If the blade is released the first blade descends and the second lifts away from the balls. All the balls roll down and the second ball takes the place of the first. The same thing happens each time the ring is pulled. This is the drawing [Fig. 47] of the channel, the blades, and the balls in the channel. [Another] channel is erected at the end of the first channel, to the left of the castle near its side. This channel should hold 15 balls – it is soldered in position.

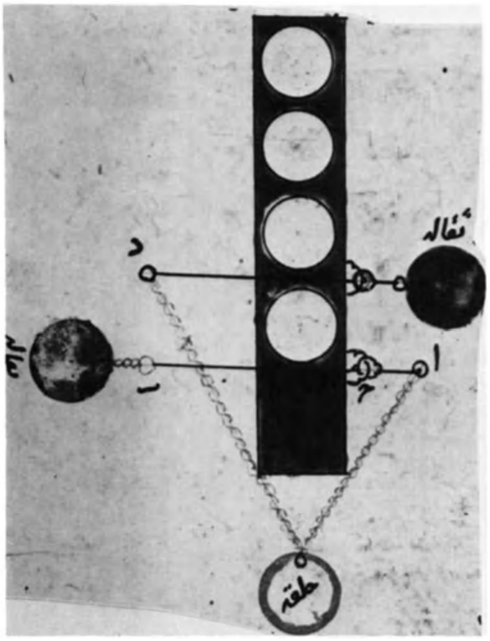


Fig. 47.

Section 6

On the connection of the chain on the float to the emplacement (qiṭāᶜ) of the balls, the fixing of the mouthpiece [Jazᶜa] to the hole in the float. The completion of the water-clock (finkān) and its method of operation.

A rod (*mīl*) is fitted to the rim of the float across its diameter. In the centre of this rod is a hole in which is a chain. Its end passed through a hole in the plate inside the dome, then through a hole in the face of the platform behind the scribe. It then [goes] through a hole in the base of the castle and is attached to the ring in which are the ends of the two chains from the blades. When the float has sunk to the bottom of the boat, the chain has pulled the ring to its lowest position and there is no slack whatsoever in the chain. Now an onyx with a fine hole is mounted on the hole in the float and sealed [around] with some wax. It is tested with a level instrument or with a calibrated water-clock, until, by widening the bore, it corresponds to one hour.

The ball is in its seat [in the float] and the chains are connected to it [i.e. the float].

All the outside parts are then scraped (*jarrada*), such as the boat, the base, the dome, the columns, the serpent, the castle and the cupola. The underside of the castle is painted as are the falcon and the serpents. The clothes of the scribe are painted. The usual colours are used, and everything is painted that requires painting, with various colours.

It is very clear that water is poured into the trough, marked *a*[7] at the beginning of the day until the water reaches four marks on the sides of the trough, which are the base-line for the apparatus, namely the main mechanisms of the clock, which are [as follows]: – the rod and the float and the chain *b* attached to the ring in the float coming out through the slit in the platform – its end rises to a ring *j* in the back of the serpent; the chain *d* attached to the centre of the rod across the top of the float and emerging from a hole in the base of the platform, rising past the side of the serpent, which it touches, to a hole in the centre of the base of the castle, its end then being attached to the ring in which are the ends of the two chains from the blades *e*. This ring is not pulled until the float tilts, and the rim of the float and the rod are level with the surface of the water. The pen *w* of the scribe is outside the first division of the divisions of the hour. In the channel *w* in the castle 15 balls have been placed. The water flows through the hole in the onyx into the float and the scribe turns to the left, his pen on one division after another. The progression of the day can be told from the number of division of the hour, until, when 15 divisions have been reached, the float sinks and the blades are pulled. One ball goes into the head of the falcon *ṭ* [and then into the mouth of the serpent][8] which is overweighted and sinks slowly. The chain from the float winds onto its back and the float is lifted, emptying out everything that is in it, except the ball. For this there is a lug (*ʿātiq*) fitted to the rim of the float on the side of the links which prevents it from coming out of the float. The scribe *y* has returned to his right, and his pen is outside the numbers. Then the serpent drops the ball over its fangs onto the cymbal *s*, then lifts its head halfway up, whereupon the chain from the float pulls it and lifts its head until it touches the breast of the falcon. The float with the ball in its centre is level with the surface of the water – one constant hour of the day has passed. This is repeated for every hour until the day time hours of that day[9] are complete at sunset. The balls which have collected in the bow of the boat are returned to the channel and the operation goes on during the night as it had during the day, until 24 hours of the day and night have elapsed. And this is what I wished to elucidate.

Now I will describe a water-clock which I constructed, namely the water-clock of the elephant which brings together many devices, which we have [at other times] made separately.

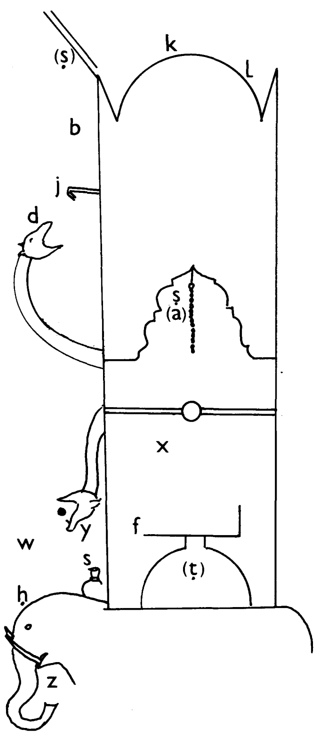
7 None of these letters is shown on this illustration in any of the available MSS.
8 Omitted in the text and supplied in the translation to make sense of what follows.
9 Translation is made difficult, as in similar passages in this work, by the lack of two words in English for 'day', one for the daylight hours, and one for the full solar day of 24 hours. Arabic has *nahār* for the former, *yawm* for the latter.

Chapter 4 of Category I

The elephant water-clock from which can be told the passage of the constant hours. It is divided into 15 sections

Section 1

On the outside appearance of the elephant water-clock



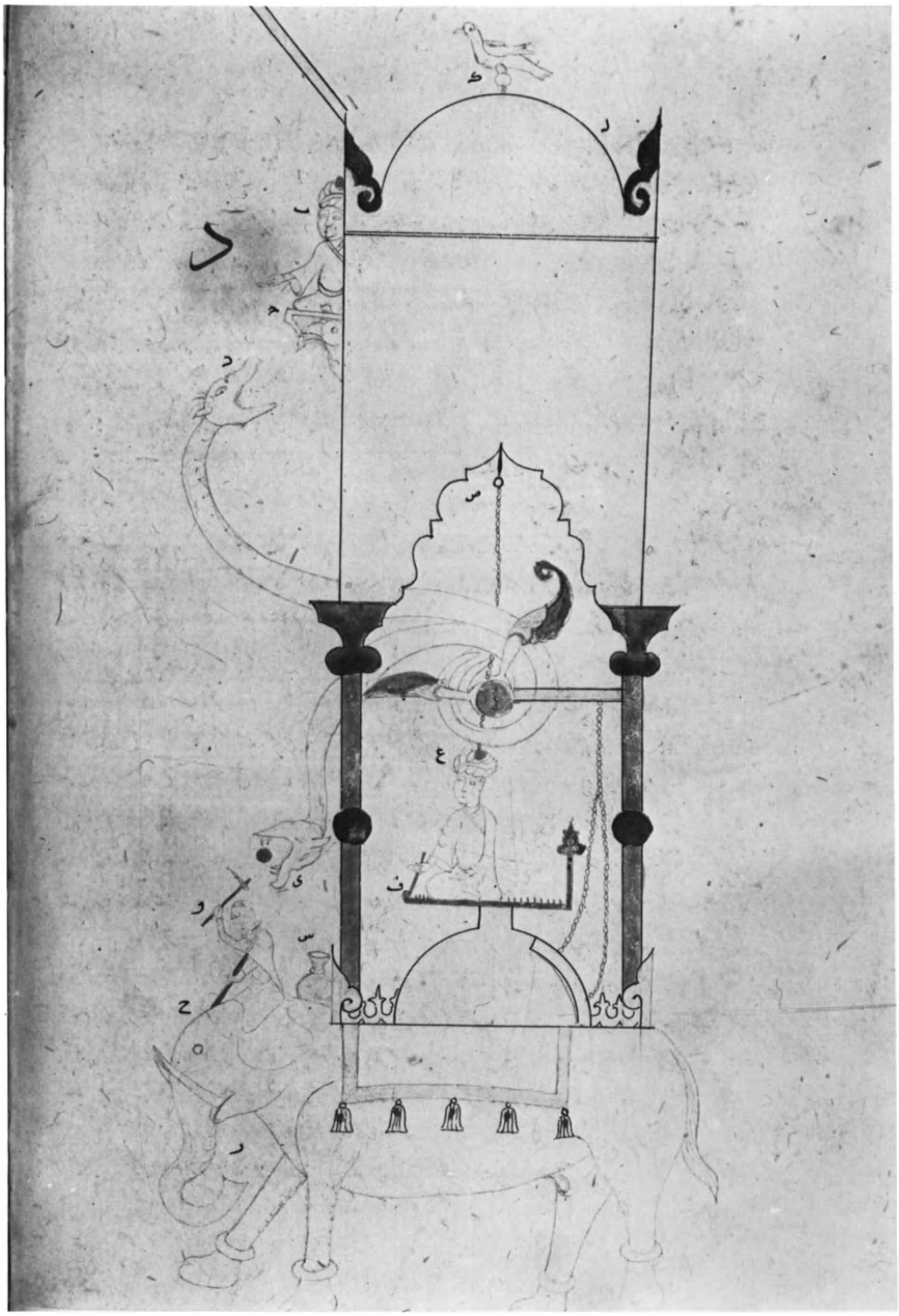


Fig. 48.

I have made many varieties of water-clocks using the perforated float (*tarjahār*) at different places and at various times and finally have combined them in a single clock, namely,the elephant water-clock, whose appearance I shall [now] describe. It is a complete elephant, with a man mounted between its shoulders, like a mahout (*fayyāl*). In his right hand is an axe (*fās*) which is lifted above the elephant's head and in his left hand is a mallet (*midaqqa*) resting on the elephant's head. On the elephant's back is a strong dais (*sarīr*) square in shape, surrounded by a balustrade (*darābzīn*), and on its shoulders two handsome vases (*qadaḥ*) are firmly [fixed]. At each corner of the dais is a pillar, and above the four pillars is a castle above which is a cupola (*qubba*) with a bird above it. In the side of the castle facing the elephant's head is a handsome balcony[1] projecting from the lower part of the castle. A man sits on this balcony; on his left and on his right are the heads of two falcons, emerging from apertures in the castle. The man sitting on the balcony is tilted over on his right thigh and his right hand is placed on the beak of the right-hand falcon, as if preventing it from opening its beak. His left thigh is lifted from the floor of the balcony and his left hand is lifted from the beak of the left-hand falcon. At the top of [this] side of the castle is a semicircle, its convexity uppermost, and around its perimeter are 15 holes, each as wide as a medium (*mutawassiṭ*) *dirham*. These holes are covered from inside the castle by a flat silver ring, completely circular, half of which is white, the other half black. Transversely between the centres of the pillars is an axle on which are two serpents, the claws of each one grasping the axle, its tail around the axle like a ring, its head tilted backwards, the mouth open as if to swallow the head of the falcon. In the centre of the dais is a dome and above the dome is a kind of circular platform upon which a man sits. In his right hand is a pen and in front of him on the surface of the platform is an arc of a circle, divided into $7\frac{1}{2}$ degress. This [then] is the appearance of the elephant water-clock, the significance of which I will now describe.

Section 2

On what is seen from the working of this clock

I say that everything is set in order at the beginning of the day: the holes are covered with the black [part of the ring], the tip of the scribe's pen is outside the numbers of the degrees and moves with a regular notion to the left until the tip of the pen is opposite the first degree, at which point one degree of the 15 degrees of a constant hour of the day has elapsed. So it continues until it [the pen] reaches $7\frac{1}{2}$ degrees, namely half an hour. Then the bird whistles on top of the cupola and rotates; half of one of the holes has turned white; the figure sitting on the balcony lifts his hand from the beak of the right-hand falcon, shifts on to his left thigh and places his left hand on the beak of the left-hand falcon. A ball drops from the beak of the right-hand falcon into the mouth of the right-hand serpent, which descends slowly with it [i.e. with the weight of the ball], until its head reaches the right-hand vase on the shoulder of the elephant. It discharges the ball into the vase and then rises to its [original] position. With his right hand the mahout gives the head of the elephant one blow with the axe, which was raised [before that], and raises his left hand, with the mallet in it, and strikes the head of the elephant with it. The right hand lifts to its original position and remains there. The ball emerges from the breast of the elephant and falls on a cymbal suspended in its belly, with an audible sound. [The ball] comes to rest in a flat-bottomed container between the elephant's legs, which is tilted towards the top of the elephant's trunk. The scribe turns back quickly to the right and the tip of his pen is again outside the numbers.

He then moves again to the left until he has completed $7\frac{1}{2}$ degrees, the bird whistles and rotates, and one hole has turned completely white. The man sitting on the balcony lifts his left hand from the beak of the left-hand falcon and shifts over to his right thigh and [places] his [right] hand on the head of the right-hand falcon. A ball runs from the beak of the left-hand falcon into the mouth of the left-hand serpent which slowly sinks with it, until it is deposited on the vase in the left shoulder. The mahout strikes the elephant in the same way as he struck it the first time. The ball falls on to the cymbal [and then into] the container between the elephant's legs. It is known that one constant hour of the day has passed, because one hole is completely white, and two balls are collected in the trough, and from the degrees [passed by] the scribe's pen. The same thing happens at every half-hour until $14\frac{1}{2}$ holes are white and 29 balls are collected in the container, for the $14\frac{1}{2}$ hours of the longest day in the fourth region [of latitude]. And as the day time decreases, the night time increases by a like amount.

[1] *Rawshan:* a Persian word meaning 'window'. Here it can be taken as meaning a balcony below a window-like aperture.

The balls are returned to the channel, the black [semi-circle] of the ring is [placed] over the holes once more, and the operation continues during the night until 24 hours of the day and night are complete. Now I will begin with the elephant, and its method of construction.

Section 3

Construction of the elephant and the dais

A sheet of copper is taken, about $3\frac{1}{2}$ sp. long and about $1\frac{1}{2}$ sp. wide. Its sides are bent round until they meet, and then they are joined together.[2] [The plate] is hammered until it takes the shape of the belly, back and two flanks of an elephant. Then another piece [of copper] is taken and hammered until it assumes the shape of the rump and thights of an elephant, and this is soldered to the perimeter of the belly and back. Then another piece is taken and hammered until it assumes the shape of the breast and shoulders of an elephant and this is soldered to the perimeter of the belly and back. Then one makes its forelegs and hind legs [lit. two hands and two legs], in the shape peculiar to an elephant, which are soldered securely [in position]. [Uneven parts] are made good with lead, projections and surplus pieces removed by filing.

Then a head is made, complete except for the ears, and fitted neatly into its place on the breast, and fixed, but not rigidly.

Then a square dais is made from brass. It has legs, and around its perimeter is a balustrade, with fretwork of fine manufacture and sure workmanship. The width of this dais should be such that it reaches from the back of the elephant's rump to end of the shoulder joint. It is placed on the elephant and securely attached. Copper cords are fitted to it and tied below the belly of the elephant like girths (*ḥizām* pl. *ḥuzum*), for an adornment. It appears to be tied to the back of the elephant.

Section 4

On what is fitted inside the elephant, and its method of operation

One takes a float (*ṭarjahār*) of beaten brass which is worked into the shape of a hemisphere. Its diameter is such that it can move inside the elephant without touching its sides. Its rim is divided by four equally-spaced marks, and a line is drawn on the outside from each mark to the centre-point. On the centre-point a circle of about one short span diameter is drawn, cutting the four lines. Then three hinges are made, and connected together by two pins, around which they can move freely. The length of the three hinges is one finger length; one of them – the first – is short. [i.e. shorter than the other two links]. The end of the third is bent around a light axle. This is the picture of them [Fig. 49]. The short one of the three is attached to a line on the outside of the float, one fingerbreadth below its rim. Then a hole is made in the float near its centre-point, colinear with the [centre] line of the hinges. On the intersection of the circle and the two other lines two staples are firmly fixed, and to each staple is attached the end of light chain with triangular links, about one short span long. The ends of the two chains are connected by a light ring. If this ring is pulled towards the rim of the float it should reach the mark opposite the hinges. Neither of the two chains is longer than the other by the slightest amount.

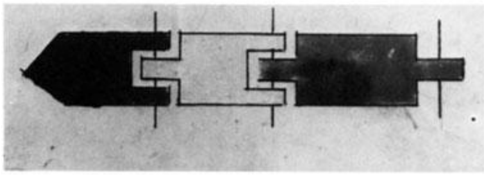


Fig. 49.

This is all that is attached to the back of the float, and can be clearly understood. This is the picture [Fig. 50] of the float and the connections on its back. There are signs on it: the sign of the three hinges is *m*; the sign of the ring connecting the ends of two chains is *l*; *q* is marked on the intersections of the circle and the two lines, where the staples are [fixed] in which are the ends of the two chains; the axle which joins the end of the three hinges to two staples yet to be mentioned is marked *ṣ*. An additional item is required for this float, which will be described [later].

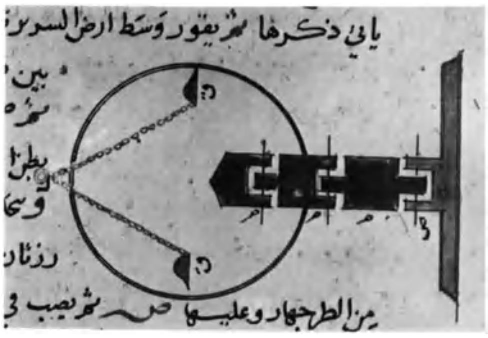


Fig. 50.

The floor of the dais is formed into an octagonal shape [i.e. aperture], as wide as possible.

Now a plate is erected between the belly and the breast of the elephant, forming a partition, and is securely soldered. Then another plate is erected as a partition between the thighs and belly of the elephant, so that the belly of the elephant forms a trough. The float is placed in the belly of the elephant. In the partition between the belly and breast of the elephant, two-thirds of its height [from its base], two staples are fixed in which are inserted the ends of the axle, marked *ṣ*, which is fitted to the end of the three hinges. Then water is poured into the inside of the

[2] *Laḥama*. This could mean that they were soldered. Probably, however, they were clamped, and soldered when the plate had been hammered into shape.

elephant, until it is near the two staples. If then the ring at the end of the two chains is pulled upwards the float will be lifted and will discharge the water it contains, and if the ring is released the float will rest evenly on the surface of the water. The float [when it is lifted] does not reach the back of the elephant, but [remains] below it.

Section 5

On the construction of the dome above the floor of the dais, the platform above the dome, the scribe above the platform and his movement

A dome (*makabba*) is made from brass, of noble shape and fine workmanship, its upper part is cylindrical, of one finger length diameter. Then a skirt[3] is made for the outside of the dome, like the rim of a plate. The circumference of the skirt is divided into eight sections and marks are made on them. The ruler is placed between two marks, a line drawn along its edge and a cut made along the line, and so on for the rest of the marks. Its perimeter becomes an octagon which fits tightly inside the balustrade of the dais.

Then one takes a flat brass disc, its diameter less than one short span, and erects a light balustrade around half its perimeter, so that it resembles a bench.[4] It is then placed on top of the dome, the balustrade towards the rump of the elephant, its centre point displaced from the centre-point of the dome by a distance of one thumb-width towards the head of the elephant; it is then fixed in position. A hole is drilled in the centre of the disc[5] which penetrates to the top [of the cylindrical section] of the dome, and the centre-point of the dome is bored from inside to meet [the hole in] the disc. Now I will describe what rotates the scribe to the left and to the right, and the method of his construction. One takes a piece of copper pipe, as light as possible, one finger's length long, and of a width that can be encircled by the thumb and the forefinger. There are flanges at either end, through the centres of which an axle is passed, which projects the length of a barleycorn from one flange and the length of half a finger from the other; it becomes, as it were, a pulley. A fine staple is soldered to its centre, to which is tied the middle of a strong silk string 3 sp. long. The long end of the axle is inserted in the hole in the centre of the platform until the flange of the pipe almost touches [the top of] the dome; the end of the axle protrudes from the floor of the platform less than $\frac{1}{2}$ F. Below the short end of the axle a cross-beam is erected and soldered firmly to the sides of the dome. On the cross-beam a bearing (*kharaza*) is fitted which holds the end of the axle in position and [allows it] to rotate freely. Opposite the staple in the pipe a small pulley is fitted, in a small channel (*bayt*) soldered to the side of the dome. Another pulley like this one is taken, and its channel soldered to the side of the dome; it is opposite the first, so that if one placed a ruler on the grooves of these pulleys its edge would pass through the staple in the big pulley. The end of the string, tied at its centre to the staple in the big pulley, is placed over one of the small pulleys and a weight of 5 *dirhams* is tied to its end. The pulley is given a complete turn so that the string with the weight on the end is wound around it. Then the other end of the string is passed over the groove of the other pulley. A ball weighing about 30 *dirhams* is made from cast bronze, its diameter is bored and a rod[6] passed through it, on which it rotates freely. The end of the string is tied to the rod. It is clear that this ball and the rod are heavier than the weight and that if the ball descends the weight rises until it touches its pulley, and if the heavier [mass] rises the weight descends, turning the big pulley and its axle.

Then the figure of a man is made from jointed copper or from papier-mâché.[7] He is sitting with his right thigh on the ground, and in his right hand is a pen with its tip pointing downwards. His left thigh is raised with his left hand resting on it. In his underside, near his back, a square hole is cut to take the end of the axle protruding from the platform, which is also square, so that the axle and the scribe move together. The underside of the scribe does not touch the floor of the platform. The three pulleys inside the dome are closed in by a plate which is fitted in position [beneath them]. In it there are two holes through which the strings from the weight and the ball pass. This is the picture [Fig. 51] of the dome with the pulleys in it, and of the scribe on the platform.

[3] *Shafa*. Lit. 'lip'.
[4] *Dakka*. Also translated as 'platform'.
[5] Actually this hole must be slightly off-centre.
[6] *Mirwad*. Literally a small stick for applying kohl to the eyelids.
[7] *Kāghadh maʿjūn bil gharā*, Paper, pulped, and glued.

Section 6

On the construction of the mahout and that [apparatus] which moves his hands, which is inside the elephant's breast

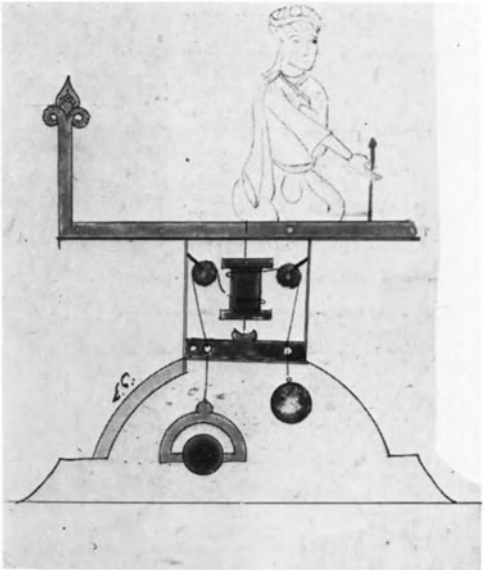


Fig. 51.

A shift (*qamīṣ*) with a short hem and short sleeves is made from copper; the shift rises vertically from the hem. A head is made for the mahout like the head of an Indian with abundant hair on the head and with a beard.[8] The neck is placed on the shift and fixed to the aperture. A right hand is made for him up to the end of the upper arm, which holds a light, handsome axe. A hole is bored across the elbow, and two holes are bored laterally in either side of the sleeve of the shift at the position of the elbow. The upper arm is inserted in the sleeve until the hole in the elbow is opposite the two holes in the sleeve. An axle is inserted in the two [holes] and fixed to either side of the shift, so that the hand moves only up and down on the axle. In the end of the upper arm a hole is bored. The left hand is made in the same way – it holds a mallet.

Now a slit is made between the shoulders of the elephant, narrower than the hem of the shift, and the hem of the shift is laid over it and fixed, but not firmly. The head of the elephant is removed and a hole is made in its breast as wide as the elephant's neck; if it has no neck then a hole is made between its forelegs as an outlet for a ball. Then a light spoon (*milʿaqa*) is made with a short handle. A hole is bored transversely through the root of the handle, another at the end of the scoop and another at the end of the handle. In the hole at the root of the handle an axle is inserted and its end is soldered firmly to the partition between the belly and breast of the elephant. The spoon is thus across the breast of the elephant with its scoop to the left of the elephant and its handle to the right. The hole in the end of the handle and the hole in the right upper arm are connected by a thin iron rod, the ends of which are formed into rings which move freely in the holes. The hole in the end of the scoop and the hole in the left upper arm are connected by a chain. Since the end of the axle in the hole at the root of the spoon is rigidly fixed to the partition, the spoon rotates about it. Its handle is made heavier than its scoop, so the [right] upper arm of the mahout is pulled [down] and the hand with the axe is raised. The mallet is heavier than the [left] arm and rests on the elephant's head. If a ball is placed in the scoop of the spoon it becomes [over] weighted and descends; the mallet rises and the right hand with the axe in it descends. The ball runs out into the hollow in the elephant's breast then through the hole made between the elephant's forelegs, and falls on to the side of a cymbal hanging from the elephant's body. Thence [it runs] into a tray with short sides and a flat base, near the elephant's trunk, where the balls are collected side by side. Then the hand with the axe in it is raised and the hand holding the mallet descends. The work is carried out to perfection while it is free [i.e. before the head is fixed] because it cannot be done after the head of the elephant is returned to its place. The hem of the shift is now soldered at the front and at the back. Legs are now made for the mahout – the thighs are below the hem of the shift, while the knees, lower legs and feet remain visible below the elephant's ears. The head of the elephant is now put back into place and firmly soldered. Two ears are made for it and attached to the shoulders, as in the picture [Fig. 51]. I have shown a picture [Fig. 52] of the breast of the elephant and [the equipment] which operates his hands [i.e. the mahout's hands]: – the breast of the elephant and the hole *ḥ* from which the ball emerges; the spoon, with the hole *ṭ* at the root of its handle through which is a rigid axle [fixed] in the breast of the elephant; the hole *y* in the end of the handle, carrying the end of the rod; the other end of the rod *k* connected to the end of the mahout's upper arm; the axle *l* in the upper [right] arm of the mahout; the hole *m* in the end of the spoon, in which is one end of the rising chain, its other end being in the hole *n* in the end of the upper [left] arm of the mahout; the hole *s* in his upper [left] arm, with an axle through it; the two pipes *x* leading from the vases into the spoon. This is a clear picture of [all] that.

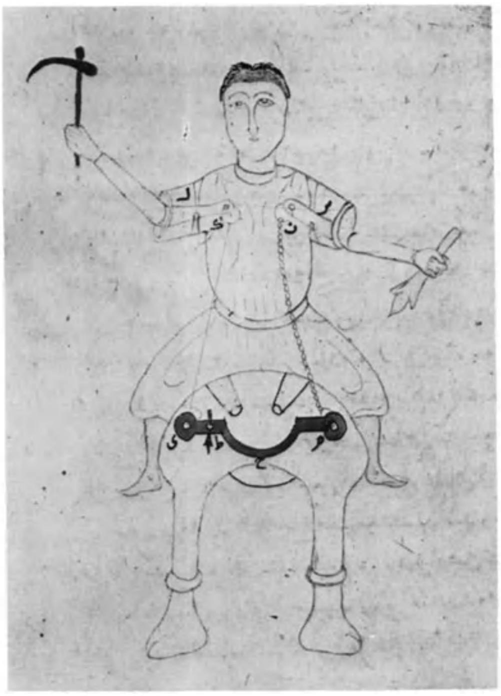
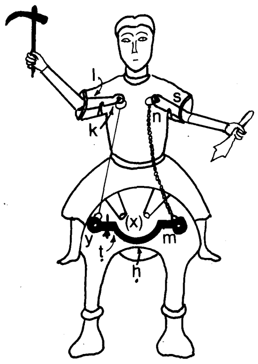


Fig. 52.



Section 7

On the construction of the four pillars; in the centre of each pair of pillars is a cross-beam

Four pillars, like pipes, are made from brass, each about 3 sp. long and of the width of a thumb. Inside them are pieces[9] of wood to stiffen them. In the centre of each is an engraved ball, and at the top a support of cast bronze to carry the feet of the castle. Above this support is a male [spigot] which is inserted tightly into a hole, in the foot of the castle. Then in each corner of

[8] The beard is not shown in Oxford, Istanbul 1315 or Leyden MSS. It is shown in Dublin MS.
[9] *Nushshāba*. Lit. 'arrow'.

the dais inside the balustrade, four bases, in the shape of half-squares, are fitted, so that they are not in the way of the dome when it is placed inside the dais. Then one fixes to each base a piece of pipe, as long as one finger, and of such a width that it fits tightly into the bottom of the pillar. The bases are then soldered securely. Each pillar is then lowered on to a base, and the base is marked with the [same] mark as its pillar. Then a transom is fitted between the centres of the two pillars on the right-hand side of the elephant, its ends in holes in the pillars. In the centre of the transom is a hole. Then another transom is fitted to the two pillars on the left-hand side of the elephant. The appearance of the pillars was shown previously on the complete drawing [Fig. 48].

Section 8

On the construction of the castle, upon which is a cupola and the heads of two falcons

One takes a brass plate about $1\frac{1}{2}$ sp. long and about 1 sp. and 2 F wide. Its surface is made flat [with] a straight-edge and its lower section chiselled out[10] like an arch – its appearance is [shown] in the complete picture [Fig. 48]. Three plates are completed to this design. Then one takes another plate which is one short span longer at the top. A semicircle is drawn [at the top] with its convexity uppermost, and the part outside the semi-circle is cut away. In the perimeter 15 holes are bored, close to one another. The heads of the falcons are also on it [this plate] and three holes, yet to be mentioned, are bored in it. Two apertures are made in the bottom of this plate, near the corners. The head of a falcon is placed in either aperture; its upper beak is detached and then connected with a light hinge. The head is large enough to allow a ball to come out of the beak. The back of the neck is soldered to the inside of the plate, the neck being open so that the ball can pass into it, and then emerge from the beak – the head [itself] does not move. In the bottom of the plate two holes are bored, each hole near one of the apertures for the falcons' heads, then another hole, in the centreline of the plate, higher than these two holes. An *s* is marked on the plate [Fig. 53] which is level with the tops of the three plates mentioned above. The semi-circle with the [15] holes is marked *x*, on the heads of [each of] the two falcons is an *f*, and on the two holes at the same level at the bottom of the plate *ṣṣ*. [One also sees] the floor of the castle, and the chiselled legs beneath it. The hole in the centre, above the two [holes] is marked *q*. This is the picture [Fig. 53] of the plate and what is in it, showing the positions of the three holes.

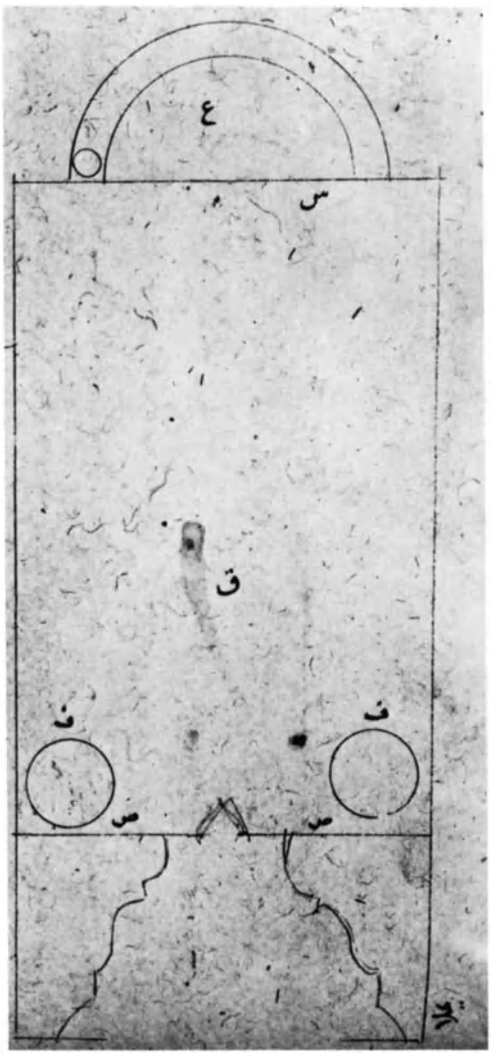
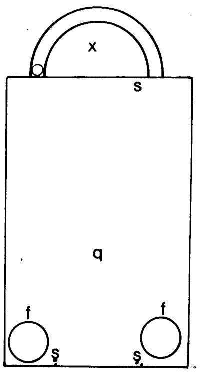


Fig. 53.



Then the four plates are erected at right angles to one another to form a square castle, with a semi-circle at the top of one side. Each plate is soldered to another in a craftsmanlike manner, with no lead visible outside, but with plenty inside. The inside of the legs are extended with stepped brass plates which continue the line of the chiselling of the legs and make the centre of the floor of the house deeper, for aesthetic [effect], so that it appears like a roof.[11] At the bottom of each leg is a triangular plate which is bored, so that the male [spigot] at the top of the pillar enters it tightly. Then a brass cupola is made in a shape pleasing to the craftsman. On top of it an ornamental ball is placed and drilled from above into the interior of the cupola. The skirt of the cupola is turned in and cut to the shape of a square which fills the top of the castle to an exact fit – it can be removed and replaced.

Section 9

On the construction of the channel in which the balls move and come to a halt, then emerge one after the other, now to the head of the right-hand falcon, now to the head of the left-hand falcon

One takes a channel with a flat floor and vertical sides, its length about 1 sp., and fixes it inside the castle below the highest point, by the right-hand plate of the castle. The end of the channel near the back plate of the castle is higher than the other end so that a ball can come out from it towards the front of the castle. It is soldered in this position. It is called the first channel. Then one takes another channel similar to the first and closes one of its ends. The craftsman places this channel in front of him with the open end towards him; at the other end, in the side of the channel to the right of the closed angle [i.e. end], he makes a hole through which a ball can pass. The hole reaches the bottom of the channel. Then on the back [underside] of the channel beneath the opening a vertical side [i.e. plate] as large as the opening is fitted. The corner [i.e. joint]

[10] *Shadhdhara.*

[11] i.e. Extension pieces are added to the legs to raise the apex of the arch.

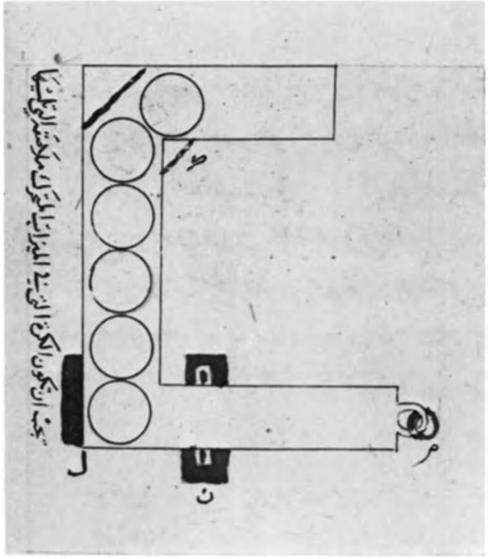
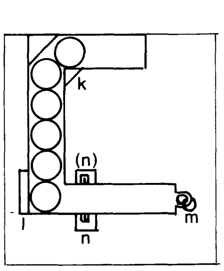


Fig. 54. Caption at left reads: 'The ball which is in the moving channel must be in contact with its follower'.



between the opening and this plate is made smooth. Furthermore, on the back of this channel one fixes a cross-axle near the opening, its position being two thirds of the [length of the] channel from the open end. At the end of the channel which is not closed, a staple is fixed with a ring through it. This channel is called the moving [channel]. This channel is placed at a right angle to the first channel, the opening in the moving [channel] at the end of the first [channel], the floors of the two [channels] in the same plane. The ends of the axle of the moving channel are placed in firm bearings on a firm base, upon which the channel can move up and down. The closed end is weighted so that it is naturally at rest, the closed end being slightly lower than the open end. If a ball is placed in the first channel it rolls through it into the opening and comes to rest against the closed end. It can move freely in it [the channel], which is no wider than it [the ball].[12] Then if another ball is placed in the channel it will roll in it and come to rest at the end of the first channel, against the first ball. If now the ring in the staple fixed to the end of the moving channel is pulled down slightly, this channel will move, the end with the ring in it will descend, the closed end will rise and the ball will roll away from it and fall out from the end with the ring in it. The next ball will be held back by the rising of the closed end because of the plate fitted below the opening. When the ring is released the closed end will by its weight return to its position, and the ball will enter it and come to a halt against the closed end in the place of the first ball.

I have drawn a diagram showing the square [outline] of the castle [Fig. 54] and in it a drawing of the first channel with the moving channel across its end. On the end of the first channel is a *k*, on the closed end of the moving channel is an *l*, on the ring at the open end *m*, on the two ends of the axle underneath it *nn*. It is evident that when a ball is placed at the end *k* of the channel, namely the first, it will roll through it rapidly and pass through the opening into the moving channel and come to rest at its closed end *l*. A second ball will rest against it, until the first channel is filled with balls. Then if the ring *m* is pulled down, this channel will move about its axle *n*, the closed end will rise and the ball will move and fall from the end with the ring to a point in the centre of the floor of the castle. The other balls will be held back when the closed end rises by the plate fitted below the opening. When the ring is released, the closed end descends, all the balls move towards it, and one ball settles in it in the place vacated, while the remaining balls rest against its side in the first channel. This happens for every downward pull of the ring.

I have been repetitious in this section so that there shall be no obscurity in what is described below.

Section 10

Construction of the trough into which the balls fall, from which they pass into a channel and fall to the right and to the left

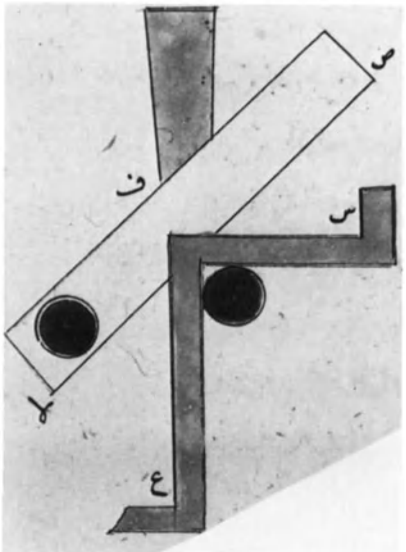
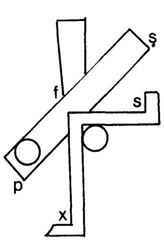


Fig. 55.



A round trough (*ḥawḍ*) is made, its diameter less then one small span, with a flat bottom and a vertical rim of one finger's breadth. It has a spout[13] through which a ball can emerge from it. When a ball falls into this trough it moves towards the spout. This trough is installed on two cross-beams inside the castle so that it is underneath the end of the moving channel, with the spout towards the front of the castle. When a ball falls from it [i.e. the channel] into the trough, it is towards the side of the trough, not in its centre, and emerges from the spout into [something] which will be described. Now one takes a piece of channel about 1 sp. long of the same pattern as the first channel, and closes the ends so that they become as it were one side of it [the channel]. It is then bent backwards in the centre to a right angle, the two legs being equal. An axle is fitted normal to the inside of the angle and firmly soldered, its ends projecting from the sides of the angle. Then a pipe is taken, shaped like a finger, in which is inserted a lead ball weighing 5 *dirhams*, which can move freely inside it. Both its ends are closed. The centre of this pipe is soldered to one end of the axle which is across the angle; if the ends of the axle are placed on firm supports they will move on them. Of necessity the ball will stay in one end of its pipe. The half of the channel on the side of the ball is [nearly] vertical, while the other end is level and almost horizontal, or rather its closed end has descended from its angle [i.e. is tilted slightly from the vertical]. When a ball is placed in [this] side of the angle it runs to the closed end which becomes heavier and tilts until it is vertical while the half that was vertical becomes horizontal. The ball leaves the closed end and the lead ball is in the other end of its pipe. If a ball is placed on the other side of the angle it will roll to the closed end of the half-channel which will be weighted and tilt, the lead ball will return to its original position and the half that was vertical

[12] i.e. the ball is a running fit in the channel.

[13] Lit. proboscis – *Kharṭūm*.

at first will be vertical [again]. The ball will come out of the closed end which was a vertical end and is now horizontal. The two ends of the channel are *s*, *x* [Fig. 55], there is an *f* on the angle and on the end under the spout, and on the two ends of the pipe of the ball are *ṣ* and *p*. The name of this channel and the pipe and ball is the Balance (*Mīzān*) and this is their picture [Fig. 55].

This Balance is installed inside the house in a manner which I shall [now] describe. A bearing is erected under the spout and another bearing opposite it, in the front face of the castle. The end of the axle carrying the pipe of the ball is placed in the bearing in the face of the castle and the axle in the bearing under the spout, so that the Balance moves freely in the two bearings. It is understood that the lead ball does not remain in the centre of its pipe but in one of its ends. I prescribe that it is in end *p* and that leg *x* of the channel is nearly vertical and leg *s* is nearly horizontal or rather that end *s* is dipping down from its angle *f*. When a ball falls in and out of the trough of the spout, it falls to the side of angle *f* and runs to end *s* which rotates and tilts until it [the leg] is vertical. The ball comes out of end *s* into a trough at the bottom of the castle which points towards the head of the right-hand falcon. The ball has settled in end *ṣ*, leg *x* has become horizontal and end *x* then is tilted away from angle *f*. When a ball falls into the trough of the spout, still moving, it emerges from the spout and falls to the side of angle *f* and runs to end *x* which rotates and tilts until it is vertical [i.e., the leg]. The balls emerge from it into a channel pointing to the head of the left-hand falcon. This happens for every ball which falls into the trough with the spout.

Now one erects for this channel a [second] axle. One end projects from the face of the castle through the middle hole *q* of the three holes [see Fig. 53] and the other end is in a bearing on a firm base on the floor of the castle. To this axle two curved projections (*shaẕīya*) are fitted with a small gap between them.[14] To the axle on the channel a broad peg (also *shaẕīya*) is fixed, the end of which comes between the two projections on the [second] axle. When the channel tilts to the right the peg below the channel pushes the left-hand projection on the axle and the axle rotates to the left. When the channel tilts to the left the peg of the channel pushes the right-hand projection on the axle which rotates to the right.

I have repeated the picture of the channel, with additions [Fig. 56]: – the peg, on which is *y* and the drawing of the [second] axle and the two projections. On the axle is a *ṭ* and on the two projections *ḥ* and *z*.

I have made clear the movement of the Balance and the movement of the axle in front of the Balance. Now I will describe what covers the holes, and the movement [required] for that.

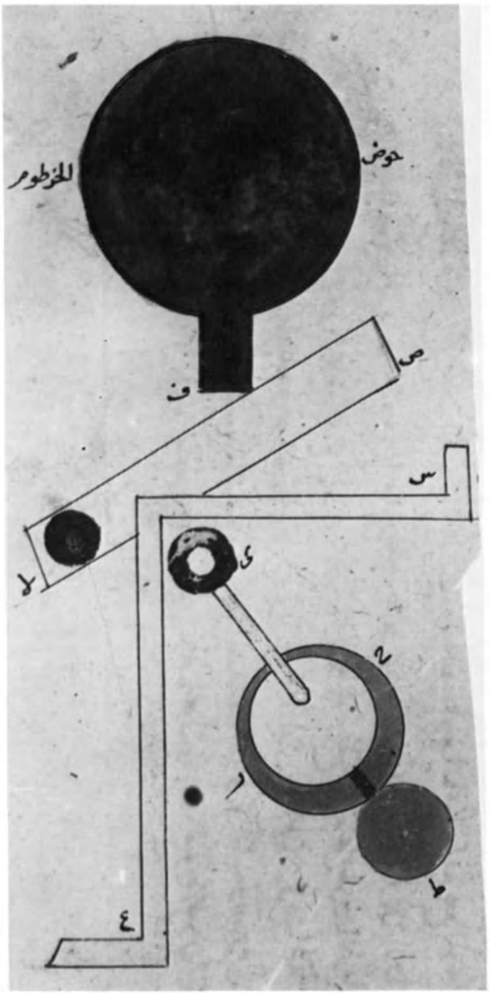
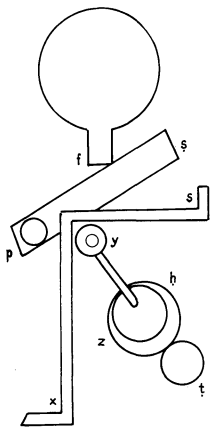


Fig. 56. Caption each side of trough reads: 'Trough of the spout'.



Section 11

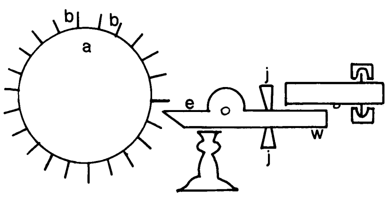
Construction of the ring, which is half white and half black, and which covers the apertures; construction of its movement; construction of the wheel upon which the bird on the castle's dome rotates; completion of the channel for the balls

One takes a fine ring of silver, its diameter the same as the diameter of the circle of holes, its width the [same as the] diameter of one hole, and [a little] more than that. For half of it the silver is blacked over. Then a copper disc is taken, its diameter the same as the diameter of the ring. Its surface and circumference are made perfect, and it is then laid on the back of the silver ring to match exactly, and firmly soldered to it. An axle is fitted to the centre of the disc, the ends of which project from its face and from its back. In the centre of the circle of holes a hole is then drilled from inside the castle which does not penetrate to the face of the castle. In it is inserted the end of the axle from the front of the disc, i.e. the one upon which is the ring. The other end, on its rear, is in a cross-beam, the ends of which are fixed in two corners of the castle. The ring now covers the holes and when it rotates it does so with ease, upon the disc. Then, on the half-perimeter[15] of the disc coincident with the white part of the ring, 30 teeth (*dandānjah*)[16] are fitted at right angles to the circumference. Each tooth has the shape and the length of a barleycorn, and they are equidistant from one another. Let the holes be covered by the black half, the white half with the teeth being underneath. Now two links are taken and connected by a pin [to form a hinge], in such a way that when one rotates about the other there is no restriction in one direction, but in the other direction it cannot rotate, and remains colinear [with the other]. One [link] is longer than the other. In the longer link an axle is fitted crosswise, near the hinge-pin, on the inflexible side. This is the drawing [Fig. 57]: on the longer [link] is a *w* on the shorter an *e* and on the two ends of the axle *jj*.

Fig. 57.

[14] *qarīb ma baynahuma.*
[15] Note that in Fig. 58 the whole perimeter is toothed.
[16] *Dandān* means 'tooth' in Persian.

Then the end of the short [link] is placed between the first and second teeth of the disc, and the end of the long [link] beneath the end of the moving channel [see Fig. 54 and text above]. The ends of the axle are placed in two firm bearings, one in the right-hand plate of the castle, the other on a cross-beam which does not impede the movement. The flexible side is uppermost, the non-flexible side underneath. Now I say that when the ring at the end of the moving channel is pulled down a set distance, it is prevented from descending below the set distance. Then it [the end of the channel] forces down the end of the long link *w* which descends by a known distance, while the end of the short link *e* rises by a known distance. Therefore the tooth at the end of the short link rises by a known distance – namely half the diameter of a hole. The disc moves and the white [part of the ring] rotates over half the first hole. When the moving channel returns to its position, its end lifts from the end of the [long] link, that light end rises and the end with the pin in it descends – this [end] is weighted with lead and so sinks because of its weight. The short [link] comes out from between the first and second teeth and enters between the second and third. This happens every time the ring at the end of the moving channel is pulled. I have shown the drawing [Fig. 58] of the disc marked *a* and the teeth, marked *b*, to which I have added the drawing of the links and the moving channel for clear understanding.



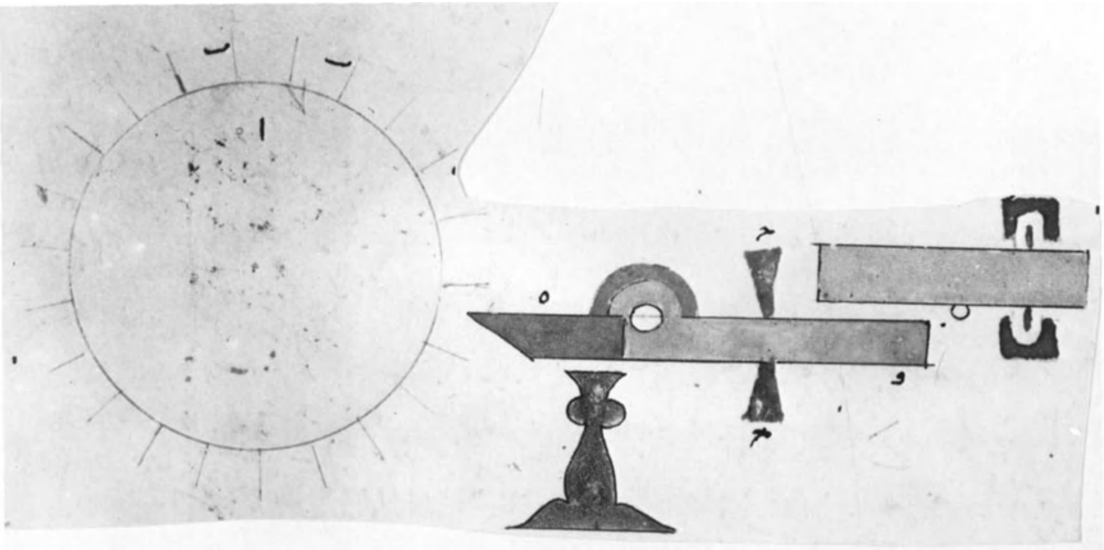


Fig. 58.

Now I will describe the functioning of the wheel, [mounted] inside the castle on an iron rod, the end of which emerges through a hole in the ball erected at the top of the castle's cupola.

One takes an iron rod, its length [the distance] from the base of the trough with the spout to the hole in the cupola's ball, from which it projects half a finger's length. Now one makes a wheel with short, slanting blades[17] and inserts through its centre-point the end of the rod, so that it projects $\frac{1}{2}$ F. This end is placed in a firm bearing [fitted] around the centre of the trough with the spout, and the other end through the hole in the cupola's ball, and protruding from it. On this is fitted the figure of a bird, made according to the choice of the craftsman from papier mâché. It is clear that when the ball drops from the moving channel onto the blades of this wheel it makes some rotations. The ball then falls into the trough and comes out of the spout.

Then the end of an iron wire is tied to the ring in the moving channel – the other end hangs down. A hole is made in the floor of the castle through which the end of the wire is passed. It is bent to the shape of a hook, which [hangs] below the lowest part of the castle.

Now one fits a second channel to the end of the first channel near the back of the castle; it goes screw-wise to the right-hand side of the castle, then to its front, then to its left, and rises to the inside of the cupola. A ball is placed in the moving channel, with another next to it [in the first channel], then another, touching one another, until the balls number 29, corresponding to the longest day in the fourth zone of latitude – 2 balls to each hour. This is what is required inside the house. I have dealt with this at length, and exhaustively, so that there will be no difficulty in constructing it. Whoever wishes to fabricate this must use patience and long thought, must change shapes [i.e. of individual parts] and pay attention to the fitting together of the [various] components, because of the restricted space. Soldering and jointing require painstaking ingenuity, and the ease of movement of the axle ends [must be ensured]. [Parts] may be made heavy, where this causes no harm, but lighter where lightness is necessary. Testing must be carefully carried out – practical skill is the essential basis of the construction.

[17] *Rīshāt* – lit. 'feathers'.

Section 12

Construction of the balcony and the man sitting thereon

One takes an oblong brass plate, [its sides in the ratio] one to two. Its long side is [the same as] the distance between the two holes bored in the bottom of the front of the castle. On one long side and around its edges a handsome chiselled balustrade is fashioned so it takes the form of a balcony. To the other long side two flat rods are fixed and inserted tightly in the two holes *ṣṣ* [Fig. 53] at the bottom of the front face of the castle. The long side without the balustrade is level with the bottom of the castle. Thus it is a balcony.

Then one makes from jointed copper the shift (*qamīṣ*) of a sitting man: both knees are raised from the ground [to a position] between the vertical and the horizontal. Feet are made for him and soldered to the hem of the shift in the position of the feet; also two hands with the palms towards the rear and their backs facing forwards, the fingers separated. They are soldered to the sleeves in this wise. Then a dark-[coloured] head is made. The neck is drilled through at the bottom from back to front and an axle inserted through it, the ends of which are soldered in the cavity in the shift, at the back and in front. The neck has an extension piece which goes down inside the shift – it is weighted with lead, so that the head moves to the right and to the left. A hole

Fig. 59.

is then drilled in the back of the shift, into which is tightly inserted the end of the axle protruding from the hole *q* [Fig. 53] in the centre of the face of the castle, so that the back of the shift almost touches the face of the castle, while the legs do not touch the floor of the balcony. It was mentioned above [see Figs. 56 and 4.3] that the peg on the balance pushes this axle, which is inserted in the back of the shift, to the right and to the left. If the right leg is flat, with the thigh on the balcony, his left knee is raised, the head inclined to his left and his right hand stretched out with the fingers lifted off the head of the left-hand falcon, the right leg of the Balance being level. Then I say that when a ball falls from the spout it drops on to the right leg of the Balance which tilts and becomes vertical. The axle and the man then rotate together to the left, his fingers are raised from the back of the falcon and the ball falls from the beak of the right-hand falcon. At this point the fingers of the man are on the beak of the left-hand falcon and his [i.e. the man's] head is tilted to his right, while his left thigh and the left leg of the Balance are horizontal. Then if another ball drops on it, it tilts and becomes vertical, the left hand of the man lifts off the beak of the falcon, he returns to his right, and the ball falls from the beak of the left-hand falcon.

I show a picture [Fig. 59] of the front of the castle, the heads of the falcons, the man on the balcony, and some of the holes covered with black, some of them white.

Section 13

Construction of the two serpents upon an axle, the ends of which rest in two holes

One takes a thin brass plate $2\frac{1}{2}$ sp. long and cuts one end to a tapering[18] point; the width of the other end is 4 F. This is rolled into [the form of] a pipe and soldered. It is filled with lead and then bent round in a circle until the ends almost meet, [forming] a ring with diameter piece 1 sp. long, the width at one end [the same as] the width of the ring, the other end narrower than that. It is formed into a pipe, soldered, filled with lead, and bent into a wide arc in the opposite sense to the ring. The lead is then removed. The serpent's head and claws are made in the manner described previously in the third chapter. Two serpents are made like this, and the claws of these serpents are bored through transversely to take an axle, upon which they rotate. An axle is made from iron to span between the transoms at the centres of the columns. In the centre of this axle a copper pulley is fitted which has a groove 1 F wide, its diameter being the same. It is soldered in position. Either end of the axle is then passed through the two claws of a serpent, with ease, until their claws touch the surface of the pulley. It was mentioned above that the back of the serpent is heavier than its tail, and that it is wound around the axle. Its head is raised, the mouth open as if it wished to swallow the head of the falcon. The edge of its lower lip is touching the front of the castle, and the upper lip is spread, with the two fangs bared. It should be understood that there is no set design (*ḏābiṭ*) to which the fabricator can refer for the construction of the serpent. Depending upon the size of the clock a correspondingly large model is made from paper, and he works from this. During construction [the serpent is] made heavier or lighter, coiled or opened out until it is similar to a balance, which tilts with a small weight. Its shape should be as handsome as possible. When the serpents are completed they are placed on the axle and the ends of the axle are placed in holes in the two stable transoms.

To the end of each of the two chains [in the float – Fig. 50] a light ring is fitted, and each ring is fixed to a staple in the back of a serpent. The float is in the belly of the elephant. At this point the chain is not slack, so that when the head of the serpent tilts, because a ball has dropped and fallen into it from the head of the falcon, the chain winds around the groove in the back of the serpent. When its head has descended to the beaker, the float discharges the water it contains. When the serpent raises its head and returns to its position, because the ball has left its mouth, the float rests on the surface of the water. It is empty, except for the ball, which does not come out because it is prevented from doing so by a small lug fitted to its rim on the same side as the hinges.

Section 14

Construction of the Instrument which whistles; one believes that this is the voice of the bird on top of the cupola

One takes a light, hollow, copper ball in which one makes a medium-sized hole. To the rim of

[18] *Mashūzka* (?)

the hole a pipe is fitted which is narrower than the hole – it is one finger long, but may be shortened as required. One blows gently in the end of the pipe, and moves the pipe and alters its position until the sound becomes louder. The pipe is then soldered in position.

Then a disc is made from copper, as light as possible, its diameter less than the diameter of the top of the float. It is made, hollow [i.e. concave on the underside] and is provided with a vertical rim 1 F deep. It is placed convexity uppermost (*makbūb*) on top of the float, its edge touching the edge of the float in one point opposite the hinges. It is soldered in that position. Between the rim of this cover and the rim of the float is a crescent-shaped opening; across from the rim of the float to the rim of the cover three brackets (*shazīya*) are fitted to support the cover on the float. Then an aperture is cut in the cover from its centre-point towards its side in the direction of the rump of the elephant, so that the string from the ball can pass easily through it. Around this aperture [on the inside of the cover] a partition is fitted with sides as [high as] the sides of the cover, and is soldered securely. Near the centre of the cover a hole is bored in the disc and the end of the pipe of the whistle is fitted vertically around its rim. To the centre-point of the cover a staple is fitted to which [is attached] the end of a chain about 5 sp. long. The [other] end of it goes through a hole in the centre-point of the dome, up between the two serpents and over the groove of the pulley. It has a ring, into which is placed the hook suspended from the ring in the moving channel.

The float is in the hollow in the belly of the elephant, the chain has pulled the end of the moving channel to the lower limit of its travel, the chain being taut due to the weight of the float and the strength of its pull. Now I say that when the empty float is on the surface of the water the ball of the whistle almost touches the plate in the dome which covers the pulleys. When the float has sunk the ball of the float is above the surface of the water, and no water enters it.

A piece (*kharaza*) of onyx with a fine hole is fitted to the outside of the hole in the float with some wax. It [the float] is placed on the surface of the water inside the elephant, and [the operation] is checked with a level instrument until the water passing through the onyx sinks the float in a period of half a constant hour. This is [done] by widening the [hole in the] onyx with a copper wire and emery until the required result [is obtained].

Section 15

On the construction of the two vases on the shoulders of the Elephant, the hanging cymbal, and the preparation of the water-clock

One takes two vases (*qadaḥ*) in the shape of a lamp (*qandīl*), the diameter at the top being just the length of an index finger, less towards the bottom. Then, at the top of the elephant's shoulder a hole is made into which is inserted a pipe which descends into the breast of the elephant and points towards the scoop of the spoon, which was constructed for the movement of the mahout's hands. This pipe is soldered in position. In the bottom of each vase a piece of pipe is fitted, the length of half a finger and wide enough for a ball to pass through with ease. This pipe is inserted tightly into the downpipe in the shoulder of the elephant. When a ball falls into the vase it descends to the bottom of the pipe, then into the scoop. The other vase is constructed in the same way. Then one makes a cymbal of white bronze which has a staple and a ring in its centre. It is suspended by the ring to a staple inside the elephant, so that the ball drops on to the edge of the cymbal.

As for the preparation of this water-clock: the servant betakes himself to the elephant, marked *ḥ* [Fig. 48], lifts the dome *ṭ*, and pours water into the belly of the elephant until it reaches four marks which I have used for the movement of the serpents. [The water should be] neither higher nor lower than them [i.e. the marks]. The float is in the hollow of the belly of the elephant and the water reaches its rim [the float's rim], simultaneously with [the beginning of] the downward motion of the end of the moving channel. He replaces the dome in position – the ball which moves the scribe has then descended into the centre of the float through the aperture in the float's cover. He then lowers the head of one serpent, marked *y*, until its upper lip touches the rim of the vase, marked *s*. Then he removes his hand from it and the serpent rises to its position, [at which point] the water in the float has been discharged and it rests evenly on the surface of the water, carrying the ball which is at the bottom.

This is at the beginning of the day: the scribe *x* is turned to his right and the tip of his pen is on the platform *f* outside the first number of the $7\frac{1}{2}$ degrees; he then rotates.

The holes *ṣ* are covered by the black half of the silver ring, having been turned [to that position] from outside the castle by the tip of the finger. The bird *k* is lifted from the rod and then the cupola *l* from the castle, the balls are placed in their channels in the castle, and the cupola and the bird are put back in place.

It is very clear that: the water enters the float through the hole in the onyx, and as the water rises the ball in it [i.e. the float] descends, rotating the pulley which turns the scribe. He turns to the left until the tip of his pen reaches the first division of the degrees, when one degree of 15 degrees of a constant hour of the day has passed. And so on for one degree after another until half an hour has elapsed, whereupon the float sinks and the air in its cover is impelled into the whistle, which whistles. The chain *a* connected to the bottom of the castle is pulled, which pulls the end of the channel. There is one ball in it which falls on to the wheel [mounted] on the bird's rod, which rotates; then it descends on to the horizontal right leg of the balance, tilting it to the right. The man *b* sitting on the balcony is leaning to his left with his left hand on the head *j* of the left-hand falcon. He lifts it from the beak and a ball falls therefrom into the mouth of the left-hand serpent *d* which becomes heavy and descends with it [i.e. the ball], which is prevented from coming out by the fangs until the upper lip touches the rim of the left-hand vase. It falls therein, and the mahout *w* strikes the elephant's head with the axe then with the hammer. Then the ball drops between the front legs of the elephant, falls on to the cymbal suspended in its [fore-]belly, then into a trough *z* beneath the elephant's trunk.

The serpent returns to its position and the scribe to his right, rapidly; half of one hole has turned white. The float has emptied itself and rests on the surface of the water. [Again] the scribe's pen moves to the left from one degree to another until half an hour has passed. The float sinks, the bird whistles, and rotates, and one hole is completely white. The man lifts his right hand from the falcon's beak and leans to his left, placing his hand on the beak of the left-hand falcon. A ball falls from the beak of the right-hand falcon and falls into the mouth of the right-hand serpent, which slowly sinks with it [i.e. the ball], until it falls into the right-hand vase. The mahout strikes the head of the elephant with the axe and with the hammer, the ball falls on to the cymbal and into the trough. One constant hour of the day has passed, two balls are in the trough, and one hole is white. This happens every half hour until the number of hours of a [given] day for that degree [of latitude] are completed.

At sunset the balls are returned to their place in the castle to do service on the night as they did during the day, until 24 constant hours of daytime and night have elapsed.

Everything made of brass is scraped bare, and that which requires painting is painted – i.e. the elephant, the mahout, the serpents, the scribe, the man sitting on the balcony, the heads of the two falcons, and the bird. This is what I set out to describe clearly.

Now I will describe something [else] I made, namely the beaker water-clock.

Chapter 5 of Category I

The Beaker (Kaʿs) Water-Clock
From it the passage of the constant hours, and their divisions, can be told. It is divided into three sections

Section 1

Description of its outside appearance and function

The king, Ṣāliḥ Abū al-Fatḥ Maḥmūd, may God assist Islam by prolonging his life, proposed that I should make for him an instrument having no chains, balances or balls[1], not liable to rapid change or decay, from which could be told the passage of the hours and the divisions of the hours without inconvenience. It should be of handsome design and suitable for journeys or for settled residence. I considered the matter and made, according to his suggestion, what I shall now describe. I constructed it [as follows]: it is in the form of a beaker resting on a base. On top of it is a flat cover, around the perimeter of which is a chiselled balcony. On the balcony is a handsome horizontal ring divided into $217\frac{1}{2}$ divisions, each fifteen divisions representing a constant hour. On the cover is a bench upon which is a scribe holding a pen, its tip on the ring outside the first division. This moves with a regular, almost imperceptible motion, from the beginning of the day until the tip of the pen reaches the first division, at which point one division of 15 divisions of one constant hour of the day has elapsed; and so on, division after division, until 15 divisions are completed, when a constant hour of the day has passed. This is its appearance and its function [Fig. 60].


Fig. 60.

Now I will describe the construction [of the beaker] and its base. One takes a piece of brass and hammers it until it takes the shape of a beaker with a narrow bottom and a wide top. A straight-edge can be laid from its rim to its round angle [i.e. to the edge of the lower perimeter]. The diameter at the top is about 2 sp., the diameter at the bottom is about 1 sp. and it is about 2 sp. high. Then on the centre point of the beaker [at the bottom] a small circle is drawn, and inside this circle, towards the centre point of the beaker, an extension 2 F thick is erected. A hole is then drilled in the beaker, offset from its centrepoint, and an onyx bush (*kharaza*) with a very fine hole is fitted to it on the outside of the beaker. The beaker is then filled with water, which must all flow out of the onyx in about $14\frac{1}{2}$ constant hours. Then a copper ruler is made and erected vertically on the centre-point inside the beaker. A second ruler is placed across the top of the beaker and along its face, and on the vertical rule a mark is made, which is the height of the beaker – the surplus is not removed. The non-surplus part is divided into $14\frac{1}{2}$ equal divisions. The end with the half division is fixed at the centre-point, inside the beaker, so that it [i.e. the ruler] is completely vertical. Then the beaker is filled with water and the outflow of the water in the space of one constant hour is observed with a reliable instrument. If it sinks to the second mark the top of the beaker is correct. Then the water is emptied from the beaker and water is poured [back] into it until it reaches the half division on the ruler. Its discharge is observed and if it flows out in the space of half an hour to the end of the ruler, then the bottom and the top of the beaker are correct. If they are not correct, one must return to it [the beaker], hammering to widen it or make it narrower, [proceeding] in this manner until the bottom, the top and the onyx are correct.

Then a base is made for it: a piece of brass is hammered until it takes the shape of a round basin (*ṭast*) with a flat bottom. Its diameter is $2\frac{1}{2}$ sp. and its vertical sides are about 1 sp. [high]. A cover is made for it which is domed in the centre. At the centre is a projection like a disc over which the bottom of the beaker fits tightly. A round hole is made in the centre of the disc large enough for a hand to be passed through it. The cover is fitted to the base so carefully that the joint can scarcely be seen. Two handles are fitted to it for picking it up and setting it down.

Section 2

Construction of the lid for the beaker, and the movement for the scribe

A flat cover is made for the beaker and a round seat is constructed in its centre, its diameter one small span less than that of the cover. Then the surface of its upper part, in reality its floor, is

[1] As in the four preceding clocks.

made level. Then a light, hollow, pulley is made from copper, 1 F wide, with a groove. The diameter of the groove is a function of the [length of] the divided ruler – being $4\frac{2}{3}$ parts in length. In the bed of the groove a small staple is fitted, and to the staple the ends of two smooth chains, connected to each other, are attached. The length of each chain equals the divisions of the ruler, with about two divisions in addition. For the pulley an axle is made which is fixed through its flanges. One of its ends projects from its flange the length of a barleycorn, the other end the length of half a finger. The centre of the seat is then bored, and the end [of the axle] is inserted in the hole from inside the seat until the pulley's flange almost touches the underside of the seat. Under the short end [of the axle] a cross-beam is erected with a firm bearing in which the end of the axle rotates. Two small pulleys are fitted in channels fixed inside the sides of the seat, on opposite sides of the groove of the large pulley.

Then a light, hollow float is made, oblate like a turnip, of such a diameter that it can enter the seat with ease. One third of it is cut away, so that it becomes as it were a turnip with one third cut off. A plate is soldered to the [remaining] two thirds to close up the cut. A hole is made in the curved side at the centre in which the divided ruler is inserted with ease – the hole goes through the other side [also]. Then a pipe is made, joined together in the shape [i.e. cross-section] of the ruler. It is inserted between the two holes, its ends are soldered securely to the faces of the float and the projecting ends are cut off. The float may [also] be made complete, without cutting anything from it; in the place which was [previously] cut away a round pipe is inserted between the two faces, and its ends soldered. The weight passes through this, and when the ruler is inserted in the [other] pipe, it [the weight] moves freely in it. The float is checked to see that no water enters it, otherwise the whole system will be useless.

A staple is fitted to one of its [i.e. the float's] faces. This is a sectional drawing [Fig. 61] of the float *y*; the cut, marked *l*; the hole *m* and the staple *s*.

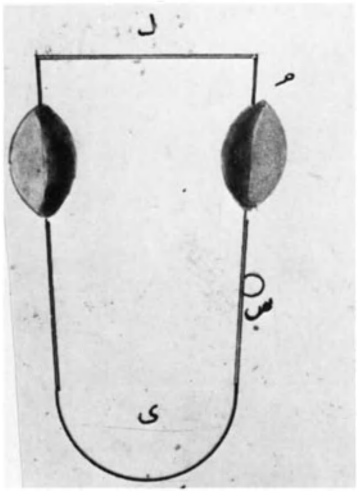


Fig. 61.

The upper end of the ruler is pushed into the hole in the float and slides easily through it until the float rests on the curved section at the bottom of the beaker. One of the chains from the large pulley is now passed over the groove in one of the small pulleys, and its hanging end is attached to the staple in the float. It has no slack in it at all. Then the other chain is wound once around the groove of the large pulley, passed over the groove of the [other] small pulley and a weight of cast bronze weighing 10 *dirhams* is attached to its end. When this weight descends the float rises and it does not touch the float because it is on the side of the third cut away from the float. The end of the extension of the ruler, above the divisions, touches the cross-beam installed under the end of the large pulley. The cover is fitted tightly to the rim of the beaker and soldered securely in position. Its rim is turned down over the rim of the beaker to conceal the joint. Around the perimeter of the cover a well-made, chiselled balcony is fitted. Handsome handles are made for the beaker for lifting it and setting it down.

Section 3

On the construction of the scribe

A very elegant sitting man is made from jointed copper. He sits on the seat, his right knee flat on the floor, and in his right hand is a long pen. His left knee is raised and it is grasped by his left hand. He should be dark [coloured]. He has two wide sleeves. A hole is made in his underside, in which the end of the axle of the large pulley which projects from the floor of the seat is tightly inserted. The hole is square – he almost touches the surface of the seat. Then a light brass ring is made, as thick as a thumb and wide enough to go round the top of the balcony. It is laid on top of the balcony and connected to the cover by lugs. The tip of the scribe's pen passes over the centre of the ring's width, almost touching it. A light cross-piece is now laid between the edge of the ring and the edge of the seat; in its centre is a hole with a staple and a ring, to which a plumb-bob (*shāqūl*) [is attached] with a sharp point which almost touches the cover. Then the base of the beaker is placed on a level surface, and the bottom of the beaker is fitted to it – it does not move but sits tightly in it. A hole is made in the beaker's cover in which the wide spout [*bulbula*][2] of a funnel (*qimaʿ*) can be inserted. One takes a funnel, places it in the hole in the cover, and pours water into the beaker until it is full. The limit of the water can be told from a hole in the side of the beaker – when a small quantity of water issues from it, the beaker is known to be full, with the water level up to the cover.

The tip of the plumb-bob is now observed, and a mark made on the cover vertically below it. The tip of the pen is [also] observed and a mark made on the ring opposite it. From the time the

[2] Oddly enough, *bulbul* is the word for 'plumb-bob' in modern colloquial Syrian Arabic.

water is poured in observations are made with a level-instrument or sinking-float (*ṭarjahār*) until one constant hour has elapsed, and at the completion of an hour a mark is made opposite the tip of the pen. [One proceeds] in like manner until the water has discharged from the onyx into the base connected to it, and reached the level of the curved section at the bottom of the beaker. Some water remains in the bottom of the beaker, supporting the float, but this remainder is not [included] in the known [quantity] of water which discharges in 14 hours and 30 minutes. The ring has thus been divided into $14\frac{1}{2}$ divisions. Across the first division a line is engraved, and on the first division 'one constant hour' is written, the second [division] is the second [hour], the third the third [hour] and so on, untill all the divisions are written on up to $14\frac{1}{2}$ [divisions].

Then one takes a graduated *ṭarjahār* which is placed on the water, the beaker being full, and the scribe's pen over the first mark, so that this mark is hidden. When the water rises in the *ṭarjahār* to the first mark, a mark is made opposite the tip of the pen, and so on for the remaining divisions until 15 divisions are completed between the two lines, for 15 degrees, i.e. one constant hour. [One proceeds] in this way, dividing the remaining hours; between the lines dot-like marks are engraved on the ring. This is the drawing [Fig. 62] of the beaker *a*, its base *b*, the onyx *j*, the ruler *d*, the float *e*, the weight *w*, the cross beam *z*, the large pulley *ḥ*, and the small pulleys *ṭṭ*. A section of the balcony and the ring with tip of the scribe's pen *y* [is shown], and the hole *k* in the top of the beaker.

It is very evident that: the beaker is filled with water at the beginning of the day until it reaches the level of the cover, and discharges through the hole in the onyx; the float is raised, touching the cross-beam, and the weight is hanging down as far as the bottom of the beaker; the tip of the scribe's pen is outside the first degree. The water passes through the hole into the base of the

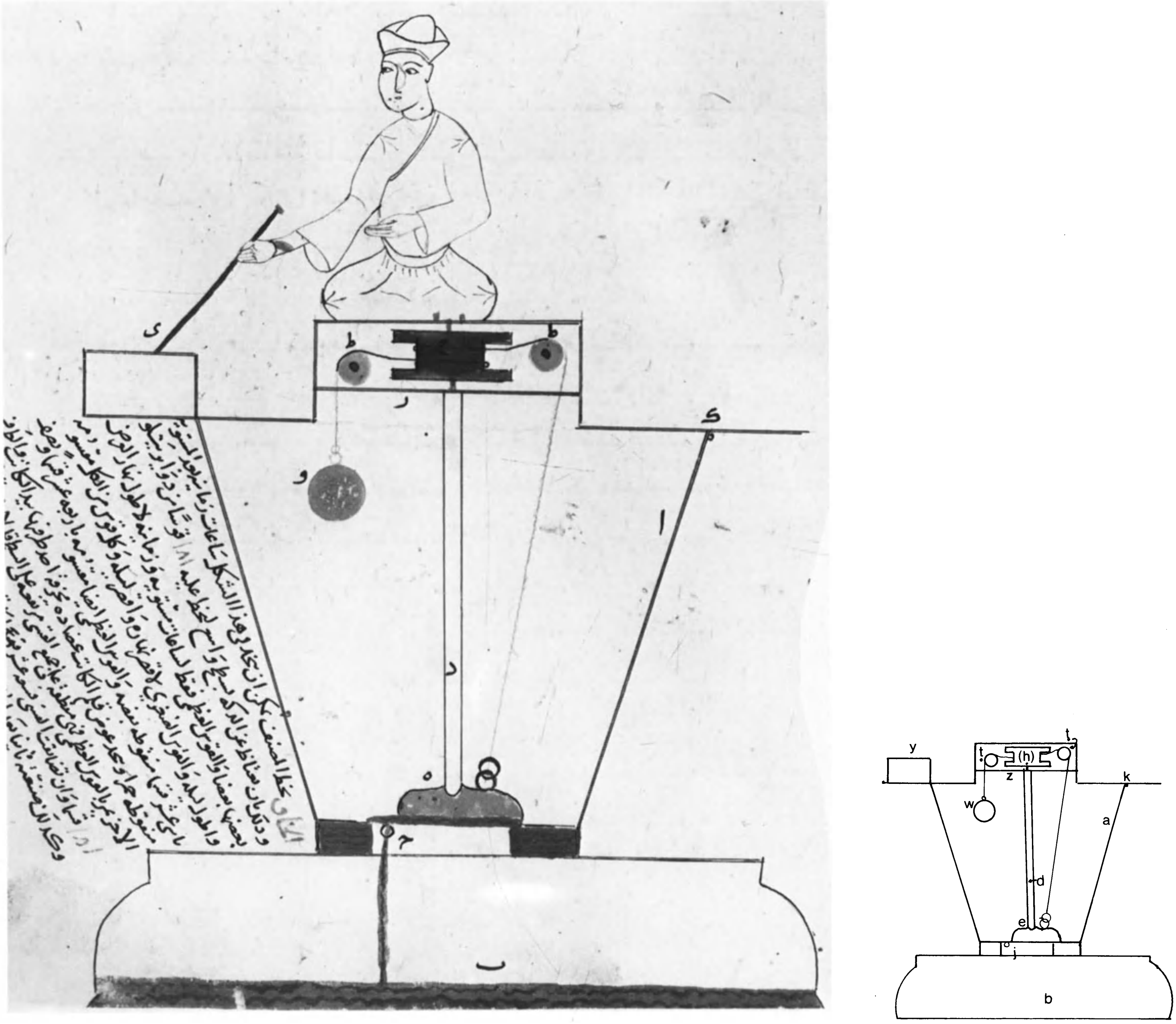


Fig. 62. N.B. The writing on the sides, some of which is omitted in the figure, is translated in the text.

beaker, the float sinks and the weight rises, the large pulley rotates and with it the scribe. The tip of the pen moves until it is over the first mark, when a degree of the day [i.e. 4 minutes] has passed, and so on until 15 degrees are completed, namely a complete constant hour, and so on until 14 hours and 30 minutes are complete at sunset, which is for the longest day in the fourth region [of latitude]. Then the water is returned quickly to the beaker from the base – the base holds the same amount of water as the beaker. The scribe returns to his right and his pen is opposite the beginning of the first degree. Then he moves as he did during the daytime until sunrise, and the tip of his pen moves until it completes 9 hours 30 minutes for the night of that day, [making] 24 hours altogether. Thereafter a decrease in the daytime is increased by night and a decrease in the night is increased in the daytime.

Then what should be scraped bare is scraped, what should be painted is painted, and it is decorated in the best manner possible. This is what I set out to describe clearly.

Now I will describe [something else] that I made, namely the water-clock of the two peacocks, after an additional section which is written on the drawing.[3]

Addition to the written text:

It is possible to include in this device, the solar hours as well as the constant hours. This is done by replacing the seat by a wide plate upon which 181 arcs of a circle are drawn, close to each other. The largest arc only is for the constant hours and the solar hours of the longest day of the latitude, and for its longest night, while the smallest arc is for the shortest day and the shortest night. Each arc is divided into 12 sections, marked in silver, and the largest arc is also divided in $14\frac{1}{2}$ sections, coloured red.

In place of the scribe's pen one takes a pointed crosspiece, one end of which is in the scribe's hand, and the other end passes over the largest arc and covers all the arcs, raised slightly above the surface. It is divided into 181 divisions. If the arcs are too narrow, then 10 arcs are combined, so that each arc represents 10 days and 10 nights. I made this a second time after completing the book. This short summary can be understood by those who are concerned with this craft.

It should be understood that if the numbers start on the largest arc, they are incomplete in the smallest arc, and their commencement on the smallest arc lags behind the largest arc; similarly if they start first on the smallest arc.

[3] The section which follows appears in the Oxford MS, the Leyden Or. 117 MS and the Dublin MS. The text is written on the sides of Fig. 62.

Chapter 6 of Category I

The water-clock of the peacocks, from which can be told the passage of the constant hours; it is divided into 6 sections

Section 1

Description of the exterior of the clock and its operation

This device should be [erected] over a fountain (*Shadurwān*)[1] with a pool. The first [part] of the picture [Fig. 63] is like a *miḥrāb*, at the base of which is a ball of diameter 1 small span, and on the ball is a peacock made of hollow jointed copper, as light as possible. His tail is erect and spread out as if he is making a display. Above this *miḥrāb* is a *miḥrāb* in which are two young peacocks, each standing on one side of the *miḥrāb* as if they are quarreling. Above the *miḥrāb* is a *miḥrāb* under which is a ball, smaller than the first ball, upon which stands a peahen, daintier

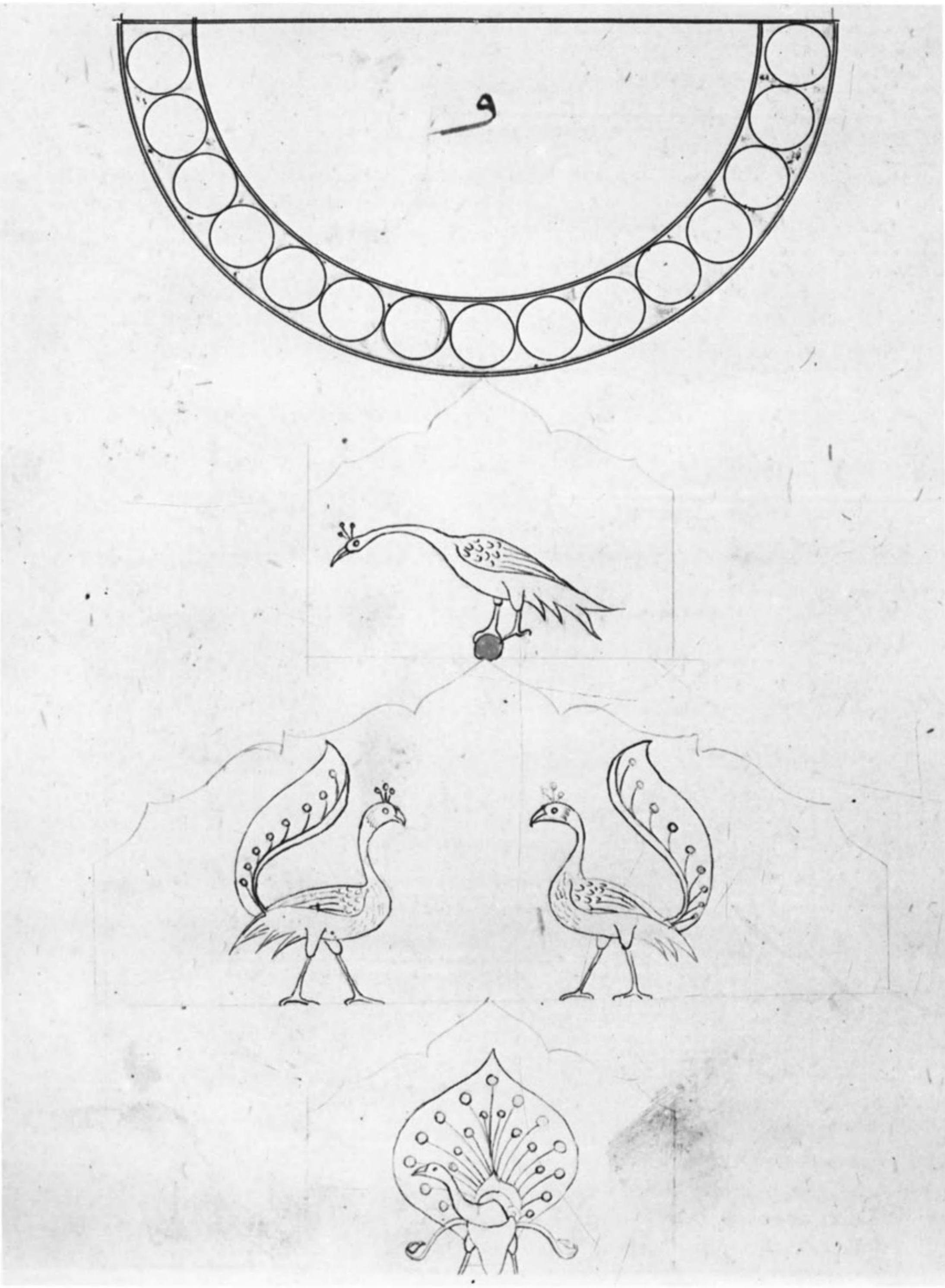


Fig. 63.

[1] See Wiedemann, I, 287/x, 322.

than the male. Her neck and beak are stretched out towards the right hand pillar of the *miḥrāb*. Above this *miḥrāb* is a semi-circle with its convexity at the bottom. Arounds its perimeter are 15 glass roundels. This is its picture [Fig. 63].

The functioning, namely the purpose, [is as follows]:

The beak of the peahen is at the right-hand pillar of the *miḥrāb* at daybreak. Then she turns away from it towards her left until her beak is near the left-hand pillar, at which point half a constant hour of the day has elapsed. Half of the first roundel is then red, the two chicks squabble and emit a loud whistle, and the peacock turns slowly as if displaying himself. That lasts a little while. Then the peahen returns to her right, her beak by the right pillar. This happens at every half hour until sunset – the [number of] roundels which turn red corresponds to the number of hours in that day. Nothing is changed in the night except that instead of the red [colour] the roundels are filled with light, according to the hours in that night. This is the picture of what I have described [Fig. 63].

Section 2

On the construction of the water apparatus in a house which is erected behind the fountain, its top above the roundels

One takes a deep vessel (*Ṭās*) that holds 20 *Mann* [about 40 lbs total] of water; if the water exceeds that [amount] it overflows from an opening in its wall. At the side of the vessel, near its underside, an onyx mouthpiece is installed at an angle to the vertical, from which a known [quantity of] water discharges. This vessel is placed on a firm base, and checked to see that it does not move from its position. Water flows into it continually with the same rate of flow as the discharge from the onyx. If there is a small quantity more it issues from the hole in its wall – it is not required. The discharge from the mouthpiece flows into a [tipping]-bucket (*kaffa*), yet to be described. For the [tipping-] bucket one takes a vessel with extended sides, wide in the centre. (This is a picture of the vessel [Fig. 64] after $\frac{1}{3}$ of it has been cut off, for a clear understanding.) One third of the vessel, which is not required, is cut away, and two thirds remain. A vertical plate is erected where the cut was made, up to the level of the rim, after the two severed sides have been brought close together. [One thus obtains] a long profile instead of a circle. The two severed sides are vertical, so it becomes like two thirds of a boat. This is its picture after cutting, with the vertical plate where the cut was made [Fig. 64]. Then an axle is fitted across the sides of the [tipping]-bucket, at the top, one third of its length from the [vertical] end. Its ends project from the sides, and they are firmly soldered. Then the centre of the axle is cut out inside the two walls of the [tipping]-bucket, and it is discarded. The two ends remain in place and the bucket rotates around them, – when it is filled with water [it tips] forward and when it empties [it tips] back. The capacity of this bucket is 20 *Mann*. The tip of the bucket is marked *f* [Fig. 65], the vertical plate at its rear end is marked *ṣ*; there is a *q* on the ends of the rigid axle at the top [of the bucket] near its rear end. When the ends of the axle are placed in bearings on two firm supports it rotates about them. The bucket is weighted at its rear end, where the point of balance is located; when water is poured into it almost up to the top it does not tilt towards its forward end. Then if [the quantity] is increased by a single *dirham* it tilts towards its tip and discharges all the water it contains, and tips back to rest upon its rear end. Then a copper trough with vertical sides is made, large enough to accommodate the bucket with the ends of its axle on the rim of the trough, which rests upon its own floor. The trough is tilted forward, while the bucket is horizontal for the whole of its perimeter. The bucket should fill and empty from the flow from the vessel's onyx in the space of half a constant hour – if the [outlet] hole requires enlarging it is enlarged. A hole is made in the front of the trough, near its base, and a pipe connected to it – this is mentioned below.

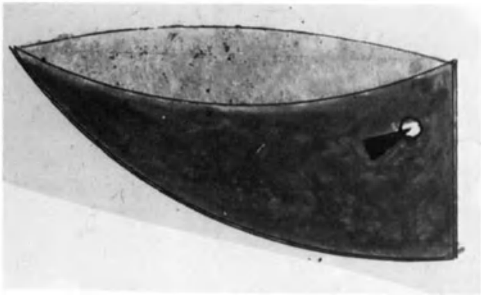


Fig. 64.

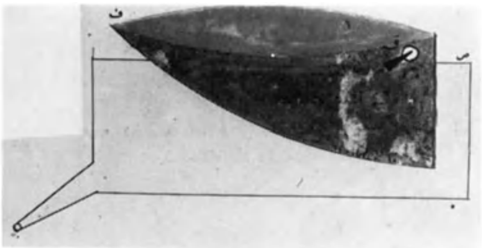


Fig. 65.

Section 3

On the construction of the peacock and the movement which causes him to make a display every half hour

One takes a copper ball of diameter 1 small span, which should be as light as possible. Then one takes a thin iron axle about 3 sp. long and solders the ball firmly on its end so that it [i.e. the ball] does not oscillate when the axle turns. Then a vertical hole is bored in the centre of the floor of the *miḥrāb*, leading to the interior of the house, and the other end of the axle is lowered through it until the ball almost touches the floor of the *miḥrāb*. The hanging end of the axle is placed in a firm bearing on a firm transom. To this end a toothed wheel of about 2 sp. diameter is fitted; it is a circular copper plate with equally spaced teeth around its perimeter. Then one takes an axle 2 sp. long and fits to its end a wheel of 3 sp. diameter, having large scoops. Then one fits another wheel, a small one of 1 small span diameter, to this axle by the side of the [scoop-] wheel. It is a plate with teeth around its perimeter. The teeth are evenly spaced, and the distance between the teeth is the same as the known distance between the teeth on the wheel fitted to the ball's axle. The end of this axle which carries the wheel is placed on a firm stanchion opposite the fountain. The teeth of the last-mentioned small wheel on the axle of the scoop-wheel mesh with the teeth on the wheel fitted to the lower end of the axle carrying the peacock's ball. When the scoop-wheel rotates towards the right-hand side of the fountain, the ball's wheel, together with the ball, also rotates towards the right-hand side of the fountain.

Then a peacock is made from copper, his tail raised and spread out as if he is making a display. His feet are placed on the ball and attached with secure soldering. He has no inclination in any direction, but when turned in any direction stands upright. I have drawn a picture [Fig. 66] of the bucket's trough and its position in the house. At the bottom of the trough is a pipe *p* which discharges the water which falls from the [tipping]-bucket on to the scoops of the wheel. The [tipping]-bucket, which is in the trough, is marked *ḥ*; its axle, the ends of which are in firm bearings on the rim of the trough, is marked *a*. In the hollow in the [tipping]-bucket is a float *f* with a staple in its centre to which a strong string is attached. The end of the string rises up and is passed over a pulley *b* which is about 1 sp. higher than the [tipping]-bucket. The ends of the axle of the pulley are firmly [fixed] in a stable transom. The vessel on its footing discharges through the onyx *ṣ* into the [tipping]-bucket. The vertical axle for the ball of the peacock is marked *e* at the top, the ball in the *miḥrāb* is marked *j*. The wheel, i.e. a large plate with teeth at the bottom of the axle, is marked *q*. The end of the axle, rotating in a firm bearing on a transom, is not shown in the drawing because it is covered by the wheel. The end of the axle of the scoop-wheel, on a firm transom near the [tipping]-bucket's trough, is marked *d*. The other end *x* near the back of the fountain is in a firm bearing (*mukḥula*) upon which it rotates. The vertical scoop-wheel *k* is on this side, almost touching the back of the fountain. Behind the scoop-wheel on the axle is the toothed wheel *w* which turns the ball.

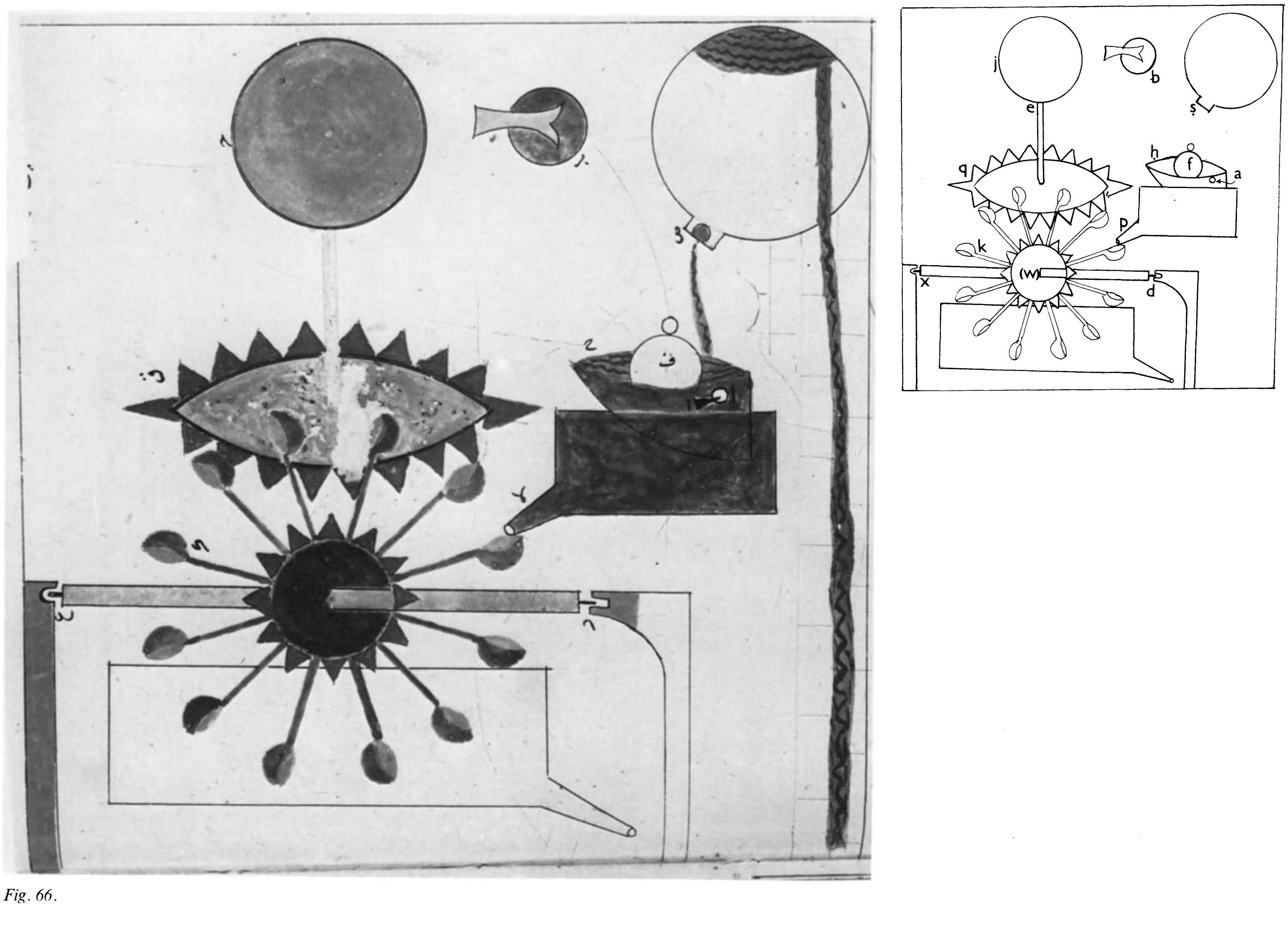


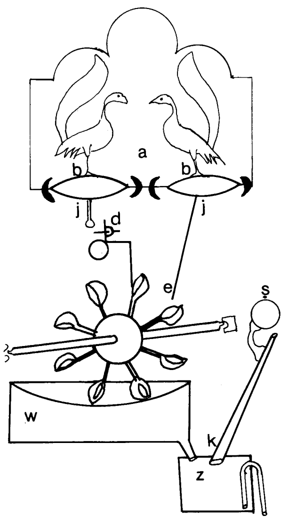
Fig. 66.

Now I say that the water flows from the onyx on the vessel into the [tipping]-bucket and the float rises slowly. The string attached to it is slack, it is to be connected to a pulley which is mentioned later – it is on an axle which carries the peahen. When the [tipping]-bucket is full it empties into its trough and the water discharges through the trough's pipe and flows over the scoops of the wheel which rotates rapidly and turns the wheel of the ball according to its width and the narrowness of that which rotates it [i.e. according to the gear ratio of the two wheels].

Section 4

On the construction of the two chicks in the miḥrāb, the action which makes them [seem to] quarrel, and the mechanism for the whistle

Two peacock chicks are placed in the second *miḥrāb*. Each one is upright and its feet grasp a short axle which is thick [in the centre] and narrow at the ends, which rotates in a bearing in the floor of the *miḥrāb*. The chick's tail is near the pillar of the *miḥrāb* and its head is towards the centre of the *miḥrāb*, with the neck curved and the head forward. Then below the centre of the *miḥrāb* a slit is made down into the house and in this slit is [inserted] an iron rod about 2 sp. long. One of its ends is inserted in a hole [bored] cross-wise in the axle and its tip is bent round so that it cannot come out. The other end hangs down inside the house and is flattened, like a poker (*Siṭām*). The position of the chick on the axle is adjusted so that it does not tilt in any direction until it is struck heavily by the weight of the iron rod, which forces it down.



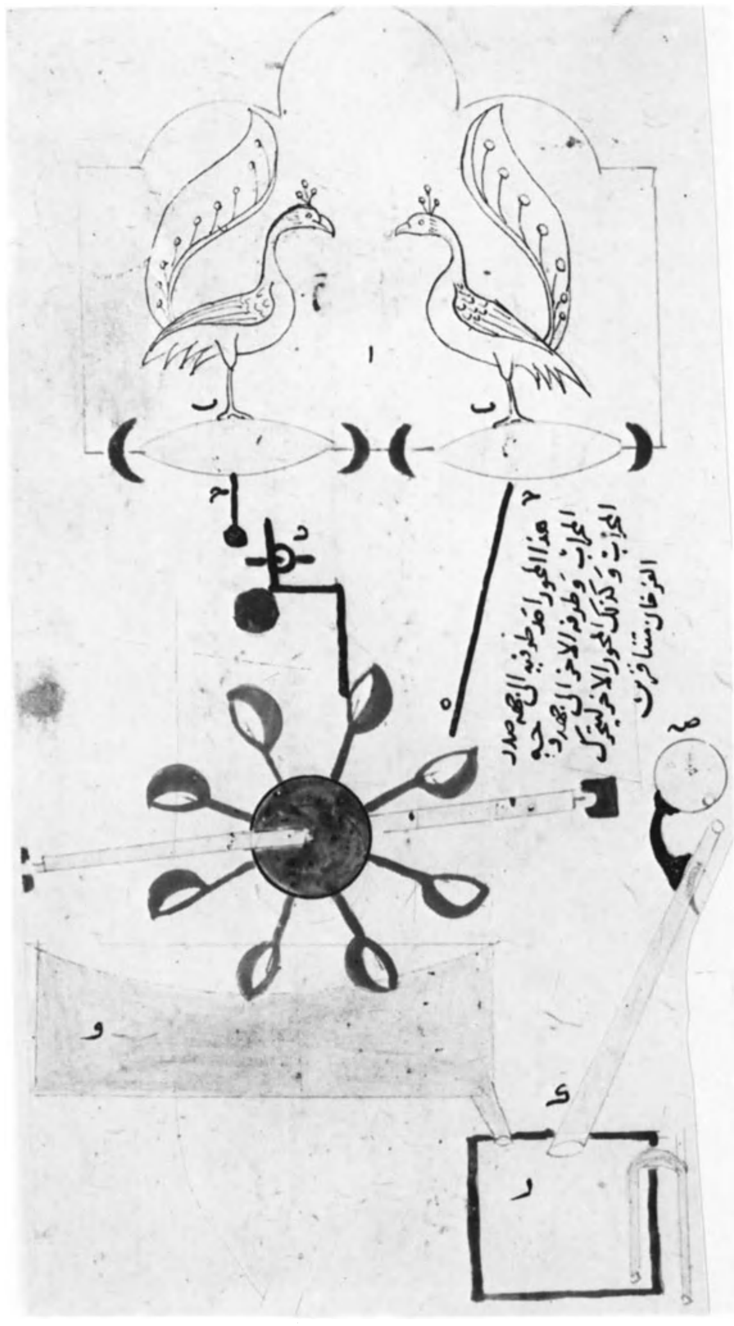


Fig. 67. Caption reads: 'One end of this axle is towards the inside of the miḥrāb, and the other end is towards the front of the miḥrāb – and so the other axle moves the two chicks in opposition'.

Then one places near the face of the suspended poker the end of a light iron rod about 4 sp. long. A hole is made 1 sp. below this end [of the light rod] in which is inserted an axle which is fixed to the back of the fountain. Then the rod is bent to an angle 1 sp. below the hole, and then bent [again] so that its end comes between two scoops of the scoop wheel. When the wheel rotates, the rods move and they move the chick. Then the other chick is constructed opposite this chick so that there is about 1 sp. between their beaks, as mentioned above. To activate this second chick, instead of the bent rod and the rod above it, there is a single rod, the end of which is also between two scoops of the wheel. A drawing is used to demonstrate the mechanisms for the chicks because it is clearer than a description. This is the drawing [Fig. 67] of the two chicks, the axles, the rods, and the scoop-wheel with the trough underneath it. Water which falls on the scoops of the wheels discharges from it [i.e. the trough] into the whistle's vessel. The *miḥrāb* is marked *a*, the chicks are marked *bb*, [written] on the axles under their feet, and the lower ends of the rods hanging down from the axles are marked *jj*. A *d* is on the rod which moves the poker, i.e. the bent rod which moves rod *j*, whose end is between two scoops of the wheel. The rod which is not bent is the longer one since it is as long as the two other rods together – there is an *e* on the end of it which lies between two scoops at the top of the scoop-wheel. When this wheel turns the chicks squabble, and the water flows from the trough *w* beneath the wheel into the whistle's [air-] vessel *z* whose construction was described in Chapters 1 and 2. The air is expelled into the pipe *k* into a whistle-ball *ṣ* at the end of the pipe. It [i.e. the whistle-ball] is inserted in the roof of the first *miḥrāb*. It is not visible, but its sound is heard, and is thought to come from the two chicks.

Section 5

On the construction of the peahen and the motive force for her

A peahen is placed in the third *miḥrāb* with her feet [fixed] firmly on a ball at the bottom of the *miḥrāb*. One takes a copper ball on top of an iron axle about 1 sp. long, and makes a hole in the floor of the *miḥrāb* which goes through into the house approximately in line with the top of the second *miḥrāb*. The end of the axle is pushed through it until the ball almost touches the floor of the *miḥrāb*. To the lower end of the axle a hollow copper pulley of about 1 sp. diameter is fitted: it should be as light as possible. In its groove is a staple. Below the end of the axle, on a firm stanchion, is a firm bearing in which the axle rotates. Then the string from the float is lifted vertically to the groove of the pulley mentioned earlier, which is a short distance above the [tipping]-bucket. Then [it is passed] over another pulley directly above this one and on a level with the staple in the pulley which is on the ball's axle. The string is wound once round the first of the colinear pulleys and is then brought across [over the second pulley] and is tied to the staple in the large pulley, being given a complete turn around it. It is then passed over another small

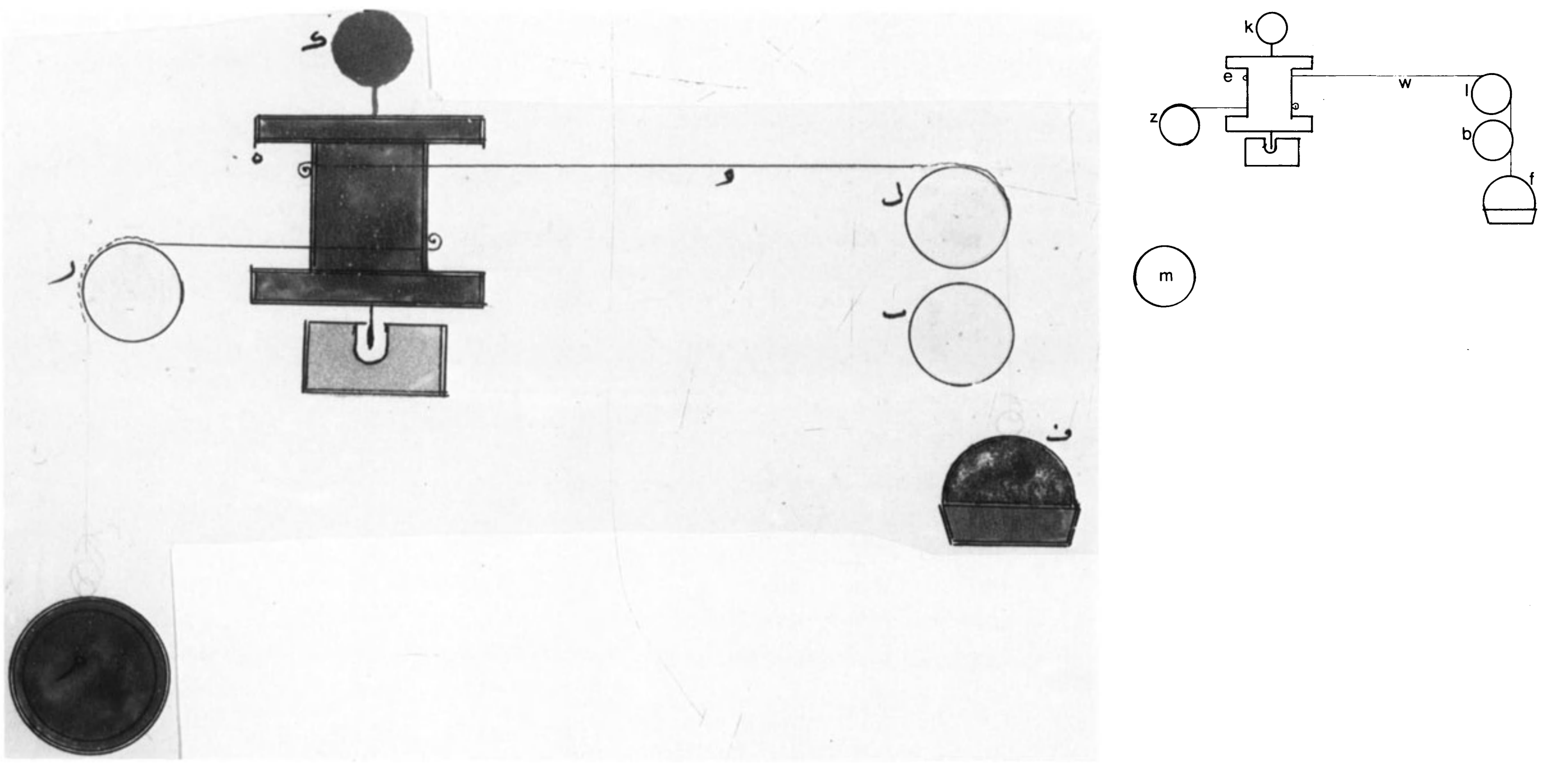


Fig. 68.

pulley which is in a firm bearing on a projecting bracket. Its end is attached to a lead weight weighing 50 *dirhams* – the float is heavier than this. The feet of the peahen are fixed firmly to the ball and her beak is then touching the right-hand pillar of the *miḥrāb*. When water falls into the [tipping]-bucket the pulley and the peahen rotate slowly until the bucket tips and discharges its contents. At this juncture the pulley and the ball with the peahen on it have turned and the beak has reached the left-hand pillar. When the water content of the bucket is discharged the float sinks rapidly to the floor of the bucket and the peahen and her beak return rapidly to the right-hand pillar. The pulley closest to the bucket prevents the float from coming out of the bucket.

This is the picture [Fig. 68] of the float *f*, the string *w*, the pulley *b* above the bucket, the second pulley *l*, the large pulley *e* with the staple and the string attached to the staple, the small pulley *z* on the same level as the staple, the weight *m* on the end of the string, and the ball *k*.

Section 6

On the construction of the roundels, what covers the roundels, and the moving mechanism for that

At the side of the bucket's trough two stable stanchions are erected, and they carry a copper axle. On this is a wheel, i.e. a copper plate of about 2 sp. diameter, having 29 teeth around its curcumference. On one face of the plate a circle of $1\frac{1}{2}$ sp. diameter is drawn, upon which an annulus (*Iṭār*) of the same circumference and 1 F wide is fixed. Its edge is bent outwards so that it becomes as it were the groove of a pulley. A staple is fixed to it. Near the tip of the bucket, over its rim, a hinge [consisting] of two links is placed, [the links] turning about an axle. They rotate, one around the other, in one direction but in the other direction they do not rotate but remain in a straight line. One is longer than the other and the combined length of the two is one small span. The end of the longer one is soldered to the rim of the bucket at right angles to the direction of the wheel. The short end is between the first and second teeth of the wheel. At this point the bucket is full of water. When its tip tilts and descends the hinge flexes downwards, leaves its position between the first and second teeth and comes between the second and the third. The bucket empties, its tip rises and the hinge lifts the second tooth to the position of the first tooth. This happens every time the bucket sinks and rises. Then one makes a pawl (*ṭāriḥ*): it is a flat piece of a ruler 1 sp. long and as wide as a thumb. Its end is bent round on itself to form a narrow lateral hole, in which an axle is inserted, the ends of which are fixed in a stable transom [sited] above ground level near the bucket. The other end is placed above the teeth of the wheel. About 1 F of this end is bent down to a right angle, and this bent section rests between two teeth and prevents the wheel from turning back in the direction of the bucket. Whenever the wheel turns away from the bucket the bent-down part comes out from between two teeth and [enters] the following pair.

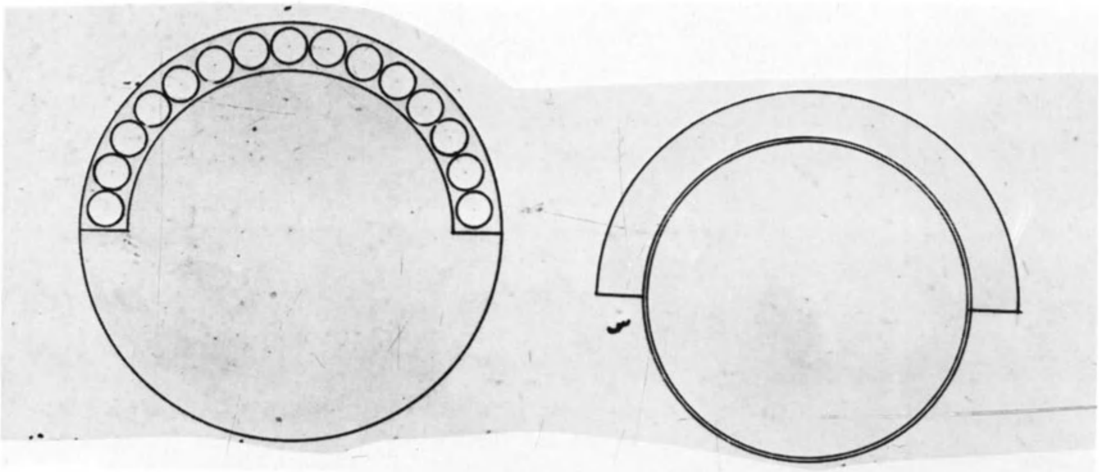


Fig. 69.

Then the end of a string, which is mentioned later, is attached to the staple in the groove of the wheel. Then one makes a thin wooden disc, constructed from many pieces of wood placed one upon the other, so that it does not warp at a later time. Both its faces are made flat, then a circle is drawn around its perimeter of diameter $4\frac{1}{2}$ sp., and then a second circle of diameter 4 sp. The edge of the disc [i.e. outside the first circle] is removed. On half [the perimeter] of the disc between the two circles 15 holes are made, almost touching one another, and into each hole a flat glass roundel is fitted. Now a [half-] round door is made in the house above the three *miḥrābs* and this disc is erected on it with the roundels towards the bottom; the diameter of disc is horizontal and the circumference [of the door] surrounds it. The centre of this disc is bored from its inside [face] until [the hole] almost penetrates to the visible side. Then another disc is made in the same pattern as the first disc. The section between the two circumferences on half this disc is cut out and removed from the disc. This is the picture of the first disc with 15 roundels on half its perimeter, and the second disc with the position of the discs cut out and removed from it. [Fig. 69] [This is shown] so that it is clearly understood.

If the cut disc is placed over the disc with the roundels, with the cut downwards, the roundels will not be covered; if the cut is turned upwards then the roundels will be covered. Then one fits to the cut disc an axle, as long as the distance between the disc with the roundels and the position of the tip of the tipping bucket. The end of the axle is flush with the face of the disc – it does not project from it at all. In it is a light, short, iron 'acorn' which is fitted into the centre of the disc with the roundels. Then on the other end of the axle a wooden disc is fitted, grooved like a pulley, its diameter from the bed of the groove 3 sp. A diameter is drawn on this disc corresponding to the diameter of the cut disc, and marks are made in the bed of the groove on the diameter. On the two marks holes are made. On the end of the axle an acorn is nailed and placed in a firm bearing on a firm transom.

Then one takes a strong cord and ties its end to a hole in a nail, which is of such a size that when inserted in one of the holes in the groove it will remain by itself.[2] The nail is inserted in the left-hand hole in the groove, the roundels being uncovered. The string is lifted up over the groove and its other end hangs down in the direction of the wheel connected to the [tipping]-bucket, namely the toothed wheel with the pulley-like annulus on its face. The end of the string is tied to the staple. The staple is then not on the bucket's side, but is on the other side of the wheel.

Now I say that: the [tipping]-bucket is filled with water and the end of the hinge is between the first and second teeth; the roundels are uncovered. When the bucket tilts and discharges its contents, its tip rises, the hinge lifts the first tooth and the wheel turns. The string connected to the grooved disc gives a pull and it [the disc] rotates, together with the axle and the cut-away disc, and half of one of the roundels is covered, and so on for every filling and emptying of the [tipping]-bucket. I have drawn a picture [Fig. 70] of the [tipping]-bucket with the hinge *d* attached to it, the short link *q* between the teeth, the pawl and its bent down end *x*, the annulus like a pulley with a staple *y* on it, the string *b* connected to it. The disc is on the end of the axle and the string is in its groove, reeled half-way round it. When the toothed wheel turns through one revolution, this disc turns through half a revolution – being double the diameter – and all the discs are covered. It is not necessary to illustrate the disc with the glass [roundels] in it or the cut away disc which covers and uncovers the roundels, since the drawing of them is shown separately above.

This [described so far] was for the daytime. The space between the two circumferences on the cut away disc is coloured red, and whenever half a roundel is covered it appears red from outside.

The situation by night: the nail is moved from its hole to the other hole and the roundels are covered at the beginning of the night and half a disc is uncovered every half hour – it starts from the right by night and by day. All the servant of this device has to do is to move the nail at nightfall and at daybreak, turn the disc and the toothed wheel, and light the lamp.

It is very evident that: at daybreak the roundels are uncovered and colourless, the nail having been moved, and water flows from the onyx *ṭ* of the vessel *ṣ* into the [tipping]-bucket *ḥ*, lifting the float *f*. The beak of the peahen moves from the right-hand pillar of the *miḥrāb* to the left-hand pillar. When she has reached it the [tipping]-bucket has filled and it [then] discharges into its trough (*m*) in which is the pipe *p*. The bucket returns to rest, by its movement lifting the hinge *d* which turns the toothed wheel *j*. The string *b* pulls the disc *a* and with it the cut-away disc *s*; half a roundel is covered and appears red. The pawl *x* has come out of the position it was in and entered another – preventing the movement of wheel *j* in the direction of the [tipping]-bucket, this being the sole function of the pawl. The hinge has dropped from the pair of teeth it was in to the following pair. The water falls from the pipe *p* on to the scoops of the wheel *k* which turns, moving the rods *de* which move the quarreling chicks. The water flows into the trough of wheel *k* and runs through the pipe *e* connected to it [the trough], its [other] end being connected to the whistle's vessel *d*:

The air in it is expelled into the pipe with the whistleball *ṣ* at its end. The sound of the whistle is heard and it is thought that it is from the chicks. The small toothed wheel *z* rotates, with the rapid rotation of the scoop-wheel, turning the wheel *n* fitted to the bottom of the axle carrying the peacock's ball, with a slow uniform rotation. The peacock displays himself at leisure. Half an hour of the day has passed. It is the same during the night; in the roundels, instead of red, light appears. The water that discharged from the whistle's vessel through the siphon is not required.

[2] i.e. The nail is a push fit in the hole.

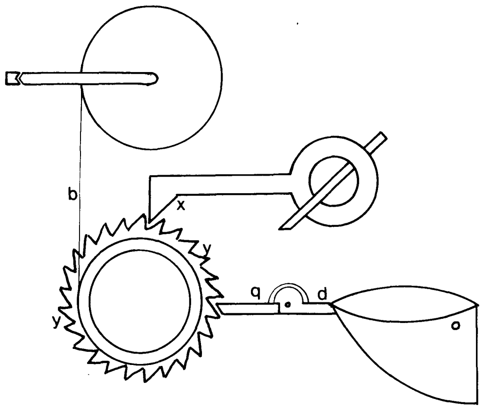
Then the brass fittings, such as the balls, are rubbed clean, things that need painting are painted, e.g. the peacocks, in their natural [colours]. Everything is coated in oil of Sandarac.

The operation of this device can be adapted for the solar hours, [using] the reservoir, the flow regulator, the [tipping]-bucket, and the scoop-wheel which turns the peacocks' wheel to operate the rods.

I have drawn a picture [Fig. 70] of the toothed wheel with the pawl between two teeth; the [tipping]-bucket with the end of the hinge on its tip and the other end between two teeth; the grooved disc which turns the cut-away disc; the annulus on the surface of the toothed wheel, in which is a staple, with one end of the string [tied] to it; the other end is connected to the nail inserted in the holes in the groove. The design of this clock has been shown in separate detailed drawings. There is no need to assemble them [in one drawing].

If there is no continuous water supply for the vessel then a large cistern is made, with sufficient capacity for feeding the vessel. The water is returned to the cistern at daybreak and nightfall.

Now I will describe a candle-clock which I made.



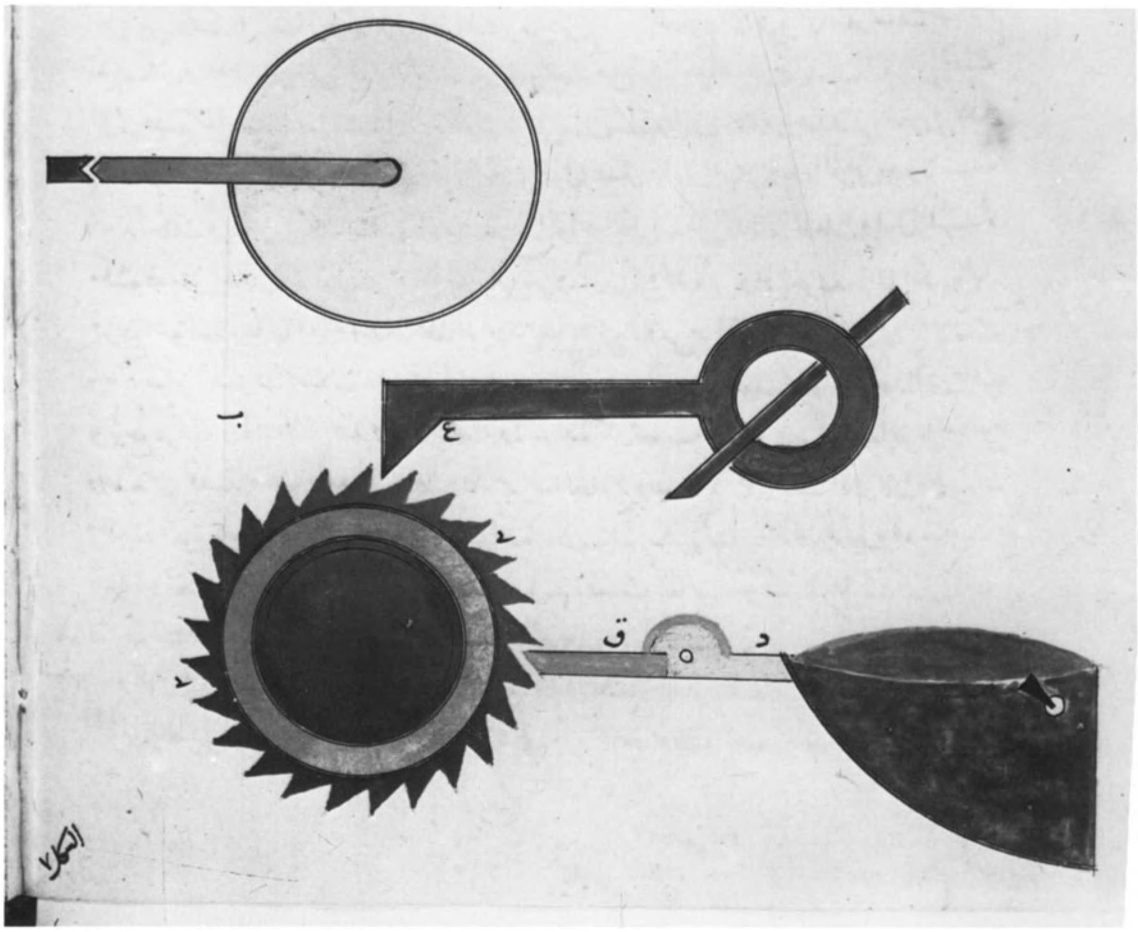


Fig. 70.

Chapter 7 of Category I

The candle-clock of the swordsman from which can be told the passage of the constant hours, from a candle. It is divided into three sections

Section 1

I say that I have never come across a work by anyone on candle-clocks and have never seen a completed [example of such a] clock. I heard tell, however, of a candle-holder with a brass candlestick on it in which was a wax candle whose wick went through a hole in a cross-piece at the top of the brass candlestick. Near the foot of the candlestick was the head of a lion. When a constant hour had passed from the lighting of the candle a ball fell from the mouth of the lion on to the bottom of the candle-holder. I kept thinking about making a device like the above without adding anything or altering the principle, but I did not know the principle upon which [the device] mentioned [was constructed]. So I made what I shall [now] describe.

Its appearance and working principle: It is a tall brass candle-holder of fine workmanship, upon which is a brass sheath about 3 sp. long. Near its foot is a falcon, erect up a perch (*Kundura*). Its back and the back of its head are against the sheath and its wings are outspread. Towards the top of the sheath is a bracket projecting about the length of a finger from the sheath and on this is a black slave (*ghulām*). His legs are hanging down and in his right hand is a sword, [held] across his chest. His left hand is on the bracket. On the candle, towards its tip, is a cap, hollow underneath, with the wick projecting from it.

Its working principle: the wick is lit at nightfall, and part of it has burned away, [another] part rises to take its place. When a constant hour has passed the falcon lets fall a ball from its beak on to the floor of the pedestal of the candle-holder, and the slave strikes the wick with his sword, removing the portion that has burned away, and so on for every hour until morning. The passage of the hours of the night can be told from the number of balls.

I will describe its fabrication: a tall candleholder is made – its height and that of its tube[1] is about $1\frac{1}{2}$ sp. Then a sheath is made for the candle about 4 sp. long, of a width aesthetically appropriate for this length. A hole is made in the lower end of the tube, into which the lower end of the sheath is inserted until it reaches the ground. The sheath is soldered to the tube and the tube to the candle-holder – the sheath projects $2\frac{1}{2}$ sp. from it [i.e. the pedestal].

Then a candle is made from pure wax, weighing 160 *dirhams*, about $1\frac{1}{2}$ sp. long. Its wick weighs 2 *dirhams* and is made from clean thread. The thickness of this candle from top to bottom must be exactly the same [i.e. it is of exactly uniform cross-section]. Then the wick is lit [and allowed to burn] for a short while. It is then extinguished and the length of the candle measured accurately. Next the wick is lit [again] before the top of the candle has cooled or the wax congealed around the wick. From this ignition of the wick a period of one constant hour is measured with a level instrument or *ṭarjahār*. When the hour has elapsed the wick is extinguished and the length of candle which has burnt away in the hour is calculated: the measurement of the length melted is taken accurately with a standard ruler, and this length is marked 13 times on the candle – making 14 hours in all. Two further lengths remain, which will not be burnt away, and after that any surplus on the candle is cut away.

Then a second sheath is made from copper, as long as the candle, and wide enough for the candle to be inserted in it easily. It is not soldered, but its edges are bent outwards longitudinally so that the candle is visible lengthwise for the width of one finger. The two edges are approximately at right angles [i.e. to the circumference]. When this sheath is inserted in the first sheath there is a gap 1 F wide between them, and the edges of the second sheath touch the inside of the first. This is the drawing [Fig. 71] of the circle of the first sheath *e*, of the second *ḥ* and the circle of the candle *y*. The edges of the sheath *ḥ* are soldered to the first sheath lengthwise outside the gap. Then at the top of the second sheath two holes are made [diametrically] opposite each other, to the right and to the left of the gap, and in these are fitted two small pulleys made of cast bronze which turn on axles the ends of which are fixed firmly to the outside of the second sheath. Then one takes a black lead weight of about 400 *dirhams* of a width to be inserted easily into the first sheath, and ties to two holes in opposite sides of the top of the weight the ends of two strings. The weight is placed in the lower end of the sheath and the ends of the strings are passed over the pulleys inside the second sheath. Then a piece of copper is shaped to the form of a weigh-scale dish, with a flat circular bottom and vertical sides. The bottom of the candle is

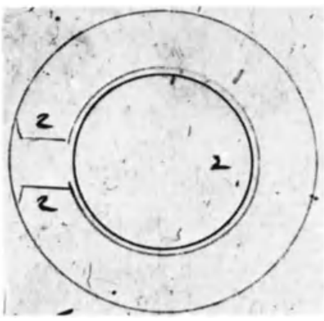


Fig. 71.

[1] Barbakh. A short pipe of relatively large diameter.

fitted to it by trimming off from the perimeter of the candle the thickness of the wall of the dish, so that both are in the same plane. Two strips (*zarfīn?*) with holes in them are fixed to its sides, opposite each other, and the end of a string is tied to each of these holes, so that this dish is [suspended] horizontally, in the second sheath, about two candle-lengths below the top of the sheath [i.e. the holes at the ends of the strips are at this level]. Then if the bottom of the candle is placed on the dish and pressure exerted on the top of the candle, the candle will descend and the weight will rise the length of fourteen parts of the candle. When the pressure is released the candle will rise part by part until 14 of its parts have risen above the top of the sheath, while two parts will remain below.

Then a cap (*ḥuqq*) is made from cast bronze, of a width to fit the first sheath; the thickness of its base [i.e. top, when inverted] is $\frac{1}{2}$ F and the height of its sides 1 F. It is fitted to a mandrel and adjusted for correct rotation. Its base is indented from outside and a round hole is made in its centre wide enough for a thumb to be inserted [in it]. A slot is made to the half-way point in the rim of the cap from outside – the rim fits tightly over the first sheath for half its width and its lower part is open at the top. There is a hindrance from inside the sheath which prevents it from being detached from the sheath except when it is turned to the right.[2] Then the cap is lifted from the top of the sheath and the candle is placed in the dish and pushed down. Then the inside of the cap is placed on the top of the candle with the wick protruding through the hole in the base [i.e. top] of the cap. The perimeter of the cap is pushed on to the sheath up to half the [width of] the rim of the cap, which is slotted for the sheath, and turned until the hindrance prevents it from coming off.

When the wick is lit the cap gets hot, the wax melts and collects around the wick. The flame grows large and rises to about 1 sp. Whenever the fire burns away part of the candle it rises by and equivalent amount.

Section 2

On the construction of the channel which carries the balls and of the falcon

A channel is made from copper as long as fourteen parts of the candle and as wide as a little finger. This channel is then divided into 14 equal parts and to each division a partition is fitted equal in height to the sides, and is soldered in position, so that the channel is divided into 14 chambers (*bayt*). When this channel is placed in the gap [between the sheaths] with the chambers towards the candle, it rises and descends freely. Then one takes 14 solid balls of cast bronze, each weighing about 12 *dirhams*. A ball is placed in each chamber, and the channel with the balls in it is inserted in the gap between the two sheaths and the candle, with the balls and the candle in contact. The bottom of the channel is level with the bottom of the dish. The top of the channel has a ring by which it is suspended to a hook in the top of the first sheath. The cap is returned the top of the candle and turned so that the hindrance prevents it from coming off.

It is very clear that when the wick is lit and when one part of the candle has burned away, the candle and the dish lift off the lower end of the channel of the balls by the height of one chamber. The ball does not remain in this chamber, since the candle and the dish were [all that was] restraining it, so the ball falls inside the first sheath. This is the picture [Fig. 72] of the channel with one ball in it.

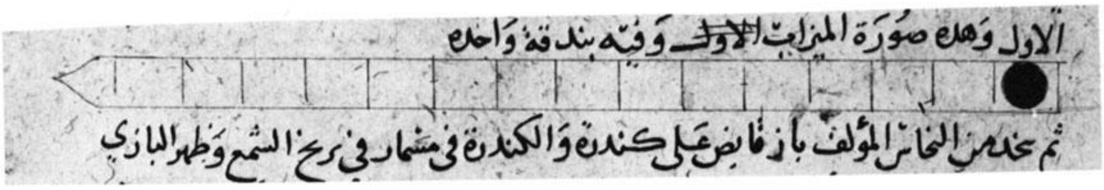


Fig. 72.

Then, from assembled copper [parts], a falcon is made, upright upon a perch, the perch being on a peg on the candle's tube. The back of the falcon and the back of its head are against the side of the sheath. Its wings are outspread. Its lower beak moves about an axle in its neck, [the axle] having a weight which lifts the [lower] beak so that it joins the upper beak. There is a round hole in the back of its head and another in the sheath, through which a ball can pass with

[2] The original, from the words 'A slot is made...', is somewhat obscure. Obviously, however, al-Jazarī is describing a bayonet fitting. This is made a little clearer in the sentence beginning 'The perimeter of the cap...'.

ease into the falcon's head. It pushes [open] the beak with is weight, passes through, and falls into the pedestal of the candle-holder.

Section 3

On the construction of the bracket, of the slave, and of the movement for the sword-hand

A bracket is made from jointed copper, having two sides at right angles. The side upon which the slave sits is shorter than the side which adjoins the sheath. This is the detailed drawing [Fig. 73] of it. A hole is made through it 2 F wide. The length of the side *s* adjoining the sheath is about 1 sp., and the length of the side upon which the slave sits is one small span. A round hole is made in the wall of the sheath, which is located under the lower end of the balls' channel.

Then a piece of channel is made, wider than the balls' channel and double its depth. This is fitted inside the sheath, with the closed end on the far side of the sheath from the hole in the sheath behind the falcon's head, and the other end below the lower end of the balls' channel. When one of the balls drops into this channel it goes into the falcon's head.

Then the long side of the bracket is placed against the wall of the sheath, the bottom of its foot over the hole [in the sheath] The top of the bracket is one small span below the top of the sheath. It is fixed, but not soldered.

On top of the bracket a hollowed-out slave is placed – the hole goes through to the hole in the bracket. His legs hang down and his left hand is on the bracket. In his right hand is a sword which moves from right to left about an axle [fitted] slantwise in his hollow sleeve. The extension of his elbow is in the hole [in his body] and has a hole in it to which a weight [is attached] which is heavier than his hand and the sword. The hand and the sword lie cross-wise towards his left. Also in the hole in the extension of the elbow is the end of a string which goes up to [a point] below his left shoulder. It is passed over a pulley [located] there and hangs down into the hollow in the slave, and through to the hole into the bracket, thence into the interior of the sheath. The end of this string is divided into two parts which are connected to the sides of a copper pouch,

Fig. 73.

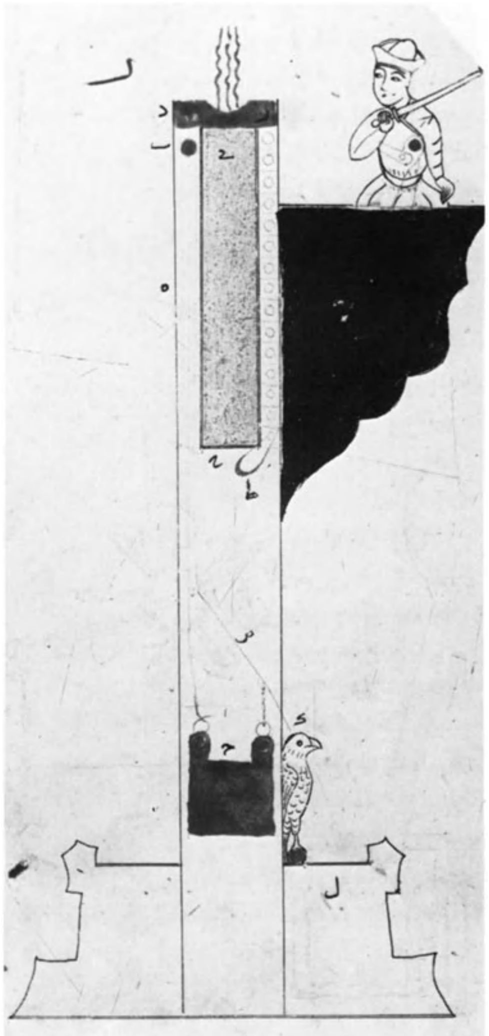
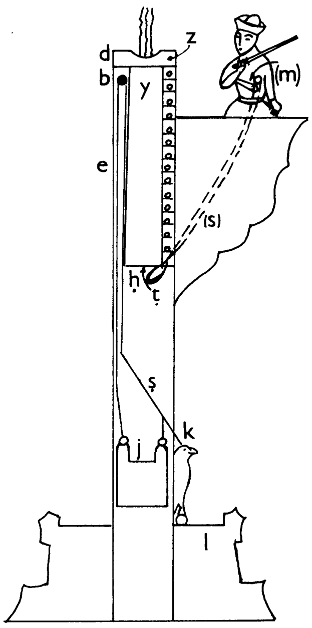


Fig. 74.



in the shape of the pouch of a trebuchet[3] – it is as light as possible and not deep. It is placed in a predetermined position in the channel connected to the falcon's head under the balls' channel. When a ball drops from the ball's channel, it cannot avoid the pouch on the ends of the string, which it strikes forcefully, giving it weight. The string pulls the slave's hand upwards to the left [the arm therefore goes downwards to the right]. The sword strikes the end of the wick forcefully, and it falls off. This movement [was perfected] after arranging and calculating and [after] repeated trials: the pouch should be set at the same level as the closed end of the channel and opposite the hole in the back of the falcon's head. [The ball] runs out of the pouch into the falcon's head. The weight pulls the slave's hand, lifting it from the wick, and the pouch returns to its previous position. This is its picture [Fig. 74].

It is very evident that: the graduated candle *y* and its dish *ṭ* are placed in position and pushed down in the sheath *j*, i.e. the second one; the balls' channel *z* with its gap *ḥ* is positioned, the balls in contact with the candle and the back of the channel touching the inside of the first sheath *e*; the cap *d* has been put on to the candle and the wick is protruding from the hole in the bottom [i.e. top] of the cap. The weight *j* is raised when the candle is lowered and the dish *ṭ* is held by two strings, connected to it and passed over the pulleys *b*, the two ends being joined to the weight. When the candle is lit at nightfall, the fire melts its wax and the candle is lifted by the weight, the dish lifts off a ball, and a constant hour of the night has passed. The ball falls into the pouch attached to the string *s* which is connected to the extension of the hand of the slave *m*. The ball then descends in the pouch until the pouch is at position *ṣ* whereupon the ball rolls down and goes into the falcon's head *k*, and then falls into the pedestal of the candle-holder *l*. The slave has struck the wick with his sword and cut off the burnt-away section of it, and the pouch has returned to its original position. This happens at every hour until the end of the night. The balls have collected in the pedestal of the candle-holder to the number corresponding to that night.

This clock (*Minkāb*) is not designed for hours other than the [hours] of the fourth region, where the longest [day] has fourteen hours and the shortest nine hours.

After it is assembled, the parts to be scraped are scraped, and the parts to be painted are painted, e.g. the slave and the falcon. The paintwork is cured in the sun, so that it will last a long time. This is what I wished to describe clearly.

[Now] I will describe a clock which I made with a candle.

[3] *Kafla al-manjanīq*. See notes.

Chapter 8 of Category I

From which can be told the passage of the constant hours and their divisions by means of a candle. It is divided into three sections

Section 1

Description of its outside appearance and functioning. It gives the hours and their divisions

I came upon a clock made by Yūnus al-Asṭurlābī which had the appearance of [the clock] described above in the first chapter.[1] A cross-beam which had a hole in its centre for the wick replaced the cap which I used to hold the candle down, and I discovered that the wax flowed into the interior of the sheath and over the instruments inside the sheath. Truly, the construction with the cross-beam did not work at all. I found that the weight was in a different position from where I had placed it, and the two pulleys with the weight's string passing over them were halfway up the sheath. [There was] a rod upon which the candle rose upwards. This gave much trouble; for this reason the design was useless, its failure being due to the overflow of the wax.

So I made what I shall [now] describe: it is a candle-holder upon which is a brass sheath; at the bottom of the sheath is an upright falcon on a perch, with its back, and the back of its head, against the sheath. To the right of the falcon on the pedestal of the candle-holder is a dais with a scribe on it, having a pen in his hand, which is on the fifteen divisions of a complete circle [marked] on the face of the dais. This is its picture [Fig. 75].

Its functioning: the graduated candle is placed in the sheath at sunset and balls are placed in the falcon's beak up to a total of 15 balls. The scribe's pen is then outside the first degree. The candle is ignited and has a larger flame than a candle standing by itself since [in the latter case] the wax collects around the wick. The scribe's pen moves until its tip is opposite the first mark, namely one degree, whence it can be told that one degree of one hour of the night has passed. When the pen has reached the end of 15 degrees the falcon drops a ball from its beak into the pedestal of the candle-holder. So it goes on until the night is over: balls are collected in the pedestal of the candle-holder to the number of hours in that night. Similarly with the scribe's pen – [moreover], this shows the degrees, which the balls do not.

Section 2

On the construction of the sheath, the weight, and the place for the balls

The place for the balls differs from the one in the previous [lit. first] chapter, where it was needed for moving the slave's hand.

A sheath is made from brass in the shape of a candle, about 4 sp. long. A hole is made in the tube of the candle-holder and the lower end of the sheath is pushed down into it until it touches the ground, where it is fixed firmly without soldering. The tube is soldered securely to the candle-holder. A hole is made half way up this sheath, through which a ball can pass. At the lower end of the sheath a falcon is placed, made like the previous one, and a hole is made in the back of its head so that the two holes coincide. Then a channel is made long enough to stretch from the hole in the sheath to the bottom of the sheath. It is soldered in position. If a ball is placed in the falcon's beak and pushed inside, it will fall into the top of this channel and come out at the bottom. Now another channel is made, as long as $14\frac{1}{2}$ divisions of the candle [see previous chapter]. In it are 14 hollow balls like little bells (*juljul*), touching one another. There is no gap between them [and the channel] which should not be so narrow that they are damaged during movement. The height of its sides and the width of its bed are slightly greater than the diameter of the balls.[2] Then a staple with a ring in it is fitted to the back of the channel at the top. It is closed at the lower end, and the other end is inserted into the top of the other channel, which is fixed inside the sheath, near the hole, so that the upper end of the channel with the ring coincides with the bottom of the hole. This channel, which has been pushed down in the other one, is prevented from descending below this point by a bracket [lit. a hindrance – it is on the bottom of the first channel], which is fixed so that it [i.e. the second channel] cannot move. When the

[1] Not the first, but the seventh, chapter of this work.
[2] i.e. the balls are an easy running fit in the channel.

ring is pulled upwards this channel rises freely, but moves only directly up and down in the [first] channel. Then a ball is put into the beak of the falcon and pushed inside, where it falls through the second channel and comes to rest in its bottom; then another, which rests against the first, then another which rests against the second, and so on, up to the number of 14 balls, the top of the 14th ball being level with the bottom of the hole in the back of the falcon's head. If the ring is pulled up by a distance equal to the diameter of one ball, the highest ball will roll down and pass through into the falcon's head, force [open] its lower beak, and fall into the bottom of the candle-holder. Then if the ring is pulled up [again] by a distance equal to the diameter of a ball, another ball will fall, and so on until the closed end of the ball's channel is level with the bottom of the hole in the falcon's head, at which point the 14th ball comes out. Thus the place of the balls, and their discharging from it has been explained.

Now a weight of 400 *dirhams* is made, with a groove (*nahr*) in its centre like a channel. It is placed inside the sheath, with the channel in its groove, which does not prevent it [i.e. the weight] from moving freely up and down. Then two staples are fixed to its top, opposite each other to the right and left of the groove, and the ends of two strings are tied to them. Inside the sheath, to the right and to the left of the hole for the balls, two pulleys are fitted in firm housings [fixed to the side] of the sheath. The ends of the two strings attached to the weight are brought up the wall of the sheath and passed over the grooves of the pulleys. The ends are brought together and attached to a hole in the end of an iron rod, which is two divisions larger than the [14] divisions of the candle. The end of this rod to which the strings are tied is pushed down into the weight's groove,[3] and it rests lightly against the balls' channel. Then the weight is raised by a distance equal to the length of the candle.

Then, on the upper end of the rod, a copper disc of the same width as the bottom of the candle is placed. A hole is made in its centre through which the end of the rod is passed, projecting about a finger-nail. It [the disc] is soldered firmly and horizontally in position [i.e. on the rod]. On its rim, on the same side as the falcon's head, a hole is made, to which a staple and ring are [fitted]. This ring and the ring at the top of the ball's channel are joined together, whereby the ball's channel is at its lowest level, the rod is at its lowest level, and the weight is at its highest level. The rod is prevented from rising by the hand. When it is released it rises gradually, the weight descends and the balls' channel rises, and ball after ball passes through to the falcon's head.

This is quite different from the first model: had we made the balls' channel to the previous pattern, it would not have worked [lit. would be impossible].

Section 3

On the construction of the scribe on the platform and his moving mechanism

A square or circular platform with feet is made from brass and placed upon the surface of the candle-holder. A scribe is made from jointed copper of a size appropriate to his situation. He is sitting with his right knee on the ground and in his right hand is a pen with its tip pointing downwards. His left knee is erect and is grasped by his left hand. He is dark [coloured] and has wide sleeves. In his underside a non-circular hole is made.

Then a hollow copper pulley is made, as light as possible, as described above [i.e. in previous chapters] – it is a piece of pipe with flanges, of such a width that a string the length of $14\frac{1}{2}$ candle divisions makes exactly one turn around it. In its centre is a staple. An axle is passed through it, one end of which projects the length of a barleycorn and the other the length of a finger. The centre of the platform is bored through to the face of the candle-holder. From the interior of the candle-holder the long end of the axle is passed through a hole into the hole in the platform, from which it protrudes [sufficiently to allow it] to be inserted in the hole beneath the scribe. Beneath the other end of the axle a cross-beam is erected upon which is a bearing which has [something] on it, to prevent the end of the axle from leaving its position.

A smooth slit is made in the sheath from its base to the level of the top of the candle-holder, in which a string can move. Two light pulleys are erected in suitable housings inside the candle-holder, one of them on a level with the top of the slit in the sheath, the other opposite that. The grooves of the two pulleys and the staple in the large pulley are then in one straight line. Then one takes a strong silken thread and ties the centre of it to the staple in the pulley. One end is passed over the pulley which is near the slit in the sheath and is then tied to a ring at the bottom of the large weight. The other end is passed over the other pulley, having first been wound once

[3] i.e. in a sliding fit.

around the large [pulley], and is tied to a lead weight of about 10 *dirhams*. When the [large] weight rises the large pulley and the axle rotate, and the small weight descends.

The scribe is placed on the axle in the platform, almost on the surface of the platform, with his face towards the falcon. The tip of his pen, almost touching the platform, is on the circumference of a complete circle which surrounds the scribe. Then a mark is made, but not engraved, on the circle opposite the tip of the pen. On top of the disc fitted to the end of the rod a candle is placed which has a hole in its centre to receive the tip of the rod. Its weight and its length and the weight of its wick were given previously [in Chapter 7] and it is of uniform cross section. Its top is pushed down until it disappears inside the sheath, whereupon a cap [such as was] described in the previous chapter is placed on its upper end and turned so that the hindrance prevents it from coming off. Then the top of the pen is observed [to see] whether it is opposite the first mark, as it should be. Then the first mark is erased and the circle divided into $14\frac{1}{2}$ divisions and on the first division is written 'one hour' and on the second 'second [hour]' and so until $14\frac{1}{2}$ hours are completed. Then each division is divided into 15 degrees or if the divisions are narrow, into five, so that there is a mark for every three degrees.

It is very evident that when the graduated candle *a* [Fig. 75] is placed in the sheath *q* on its disc *b* and pushed down, the weight *ṣ* rises from the bottom of the sheath because the strings attached to it are passed over the two pulleys *jj* and their ends are tied to the bottom of the rod *d* which supports the disc *b*. It [i.e. rod *d*] passes through the middle of weight *ṣ* as this is channelled out – in its channel is this rod and also the ball's channel, in its sheath, its top connected to a staple *e*. The end of the string which turns the scribe is attached to the bottom of weight *ṣ*, the other end [passes] over a small pulley, around the large pulley, then over a light pulley *s* to the weight *z*, which is towards the bottom. The scribe is on the axle of the pulley which projects from the surface of the platform *n*. The cap *ḥ* is positioned on the top of the candle and turned so that the hindrance prevents it from coming off the top of the sheath, and the wick *m*, protrudes through a hole in its face. When the wick is lit at nightfall the fire burns away the candle, the weight descends and the rod rises together with the candle. The disc pulls the ball's channel up until a degree [i.e. 4 minutes] of the night has passed. The scribe's pen has moved to one degree [mark] and then [it moves] to another until 15 degrees are completed, when one constant hour of the night has elapsed. In the channel the highest ball has risen until it is level with the hole in the back of the falcon's head *l*, at which point it rolls out and falls from the beak into the pedestal of the candle-holder *ṭ*. So it goes on until morning, when balls will have collected in the candle-holder to the number of the exact hours for that night, and the scribe's pen is on the degrees of a [certain] hour.

When [all] this is assembled the base of the candle-holder is covered with a plate of like diameter, which is soldered to it. That which needs scraping is scraped; the scribe and the falcon are painted, and [the parts] are oiled as before.

This is what I wished to explain clearly, and this is its picture [Fig. 75].

[Now] I will describe a clock which I made, namely a candle-clock.

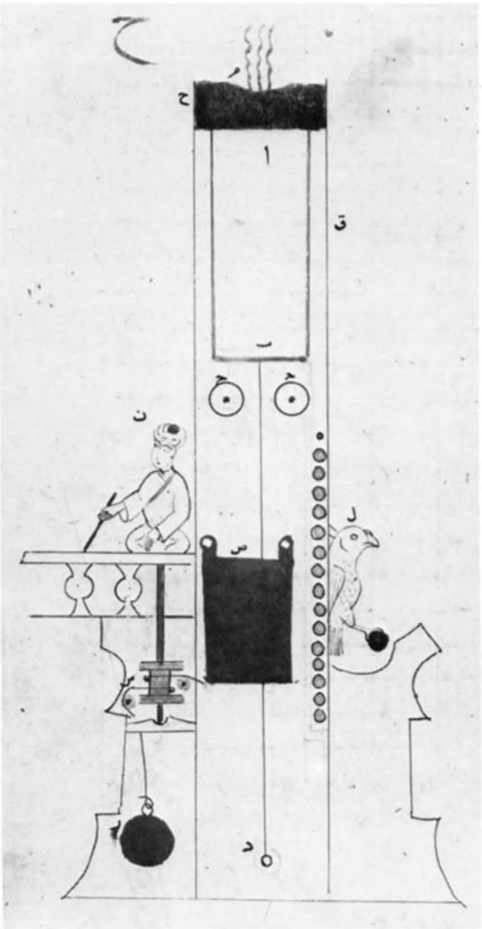
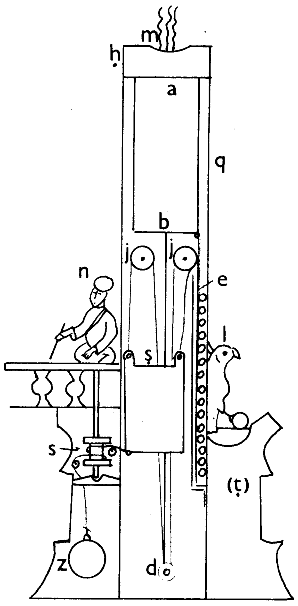


Fig. 75.



Chapter 9 of Category I

From which can be told the passage of the constant hours by means of a candle.
It is divided into 2 sections

Section 1

Description of the outside of the clock and its functioning

It is a candle holder on which is a brass sheath, with an upright falcon on a perch at its lower end. Its back and the back of its head are against the sheath, and its lower beak moves as described previously. To the right of the falcon on the surface of the candle-holder is a man kneeling on his right knee. His forearm is on the [other] upper arm with part of his hand and fingers on his shoulder. On his shoulder is a short post (*daql*) which he holds with his right hand. On top of the post is a disc upon which is a sitting monkey, its face towards the side of the sheath. It clasps its knee to its breast with its left paw. Its right paw is outstretched, and the index finger is on one of the points of 218 points, on a straight line along the side of the sheath. Between each 15 points is written '[first] hour' 'second' 'third' and so on up to $14\frac{1}{2}$ hours.

Its functioning; the graduated candle is placed in the sheath and the balls [are pushed] through the falcon's beak into the channel. The wick is lit at the beginning of the period and the monkey's paw is on the first mark. The monkey's keeper (*qarrād*) lifts the monkey up the post gradually until its finger reaches the second point, namely one degree of a constant hour, and so on until its finger reaches the first hour-mark, when an hour of the night has passed. At that moment the falcon drops a ball from its beak into the bottom of the candle-holder, and the post has risen by one division of the candle. This continues until the end of the night. The time elapsed in the night can be told from the hours and degrees.

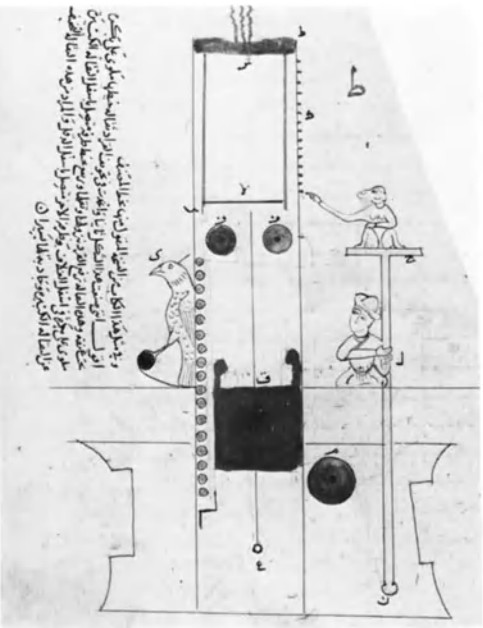
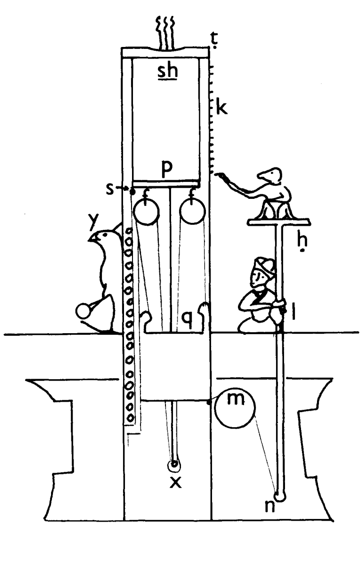


Fig. 76.



Section 2

On the construction of the monkey's keeper and the post, and the lifting mechanisms

The [following] are made as described previously: the candle-holder, the sheath and the falcon; the two pulleys and the weight in the centre of the interior of the sheath; the channel which covers the ball's channel, inside which is the ball's channel; the balls.

Construction of the monkey's keeper, the monkey, and the mechanisms for lifting the post: from jointed copper the figure of a man is made, resting on his right knee with his left knee erect and his left elbow on his left thigh. His right hand is on the [opposite] upper arm with part of its palm on the shoulder. A hole is made in him from the palm, through the elbow and forearm, through his groin into the interior of the candle-holder. The hole is wide enough to take a thin copper post on top of which is a neat disc. On it [i.e. the disc] is a sitting monkey, put together from light copper [pieces], clutching its knee to its breast with its left paw. Its right paw is outstretched with its finger on the side of the sheath. The keeper's hand grasps the post, which moves freely through it. Inside the candle-holder a pulley is installed for [connecting to] the hole in the post, in a firm housing soldered to the back of the pedestal. When the post descends in the hole [in the pedestal] it almost touches the pulley's groove. A hole is then made at the lower end of the post to which the end of a strong string is attached. The other end is passed over the pulley through a slit made in the sheath lengthwise from the bottom of the sheath to the top of the pedestal, and then tied to a staple at the bottom of the weight. The slit is smooth and narrow.

It is very evident that when the graduated candle (*sh*) is placed in the sheath *k* on the disc *p* and the candle is pushed down, the weight *q* rises from the bottom of the sheath *k* because the strings connected to it are passed over the pulleys *ff* and their ends are tied to the bottom of rod *x* supporting the disc *p*. It [rod *x*] goes down through the middle of weight *q* – this rod and the ball's channel pass through the groove in weight *q*. The top of the ball's channel is connected by a staple *s* to disc *p*. The string whose end is tied to the lower end *n* of the monkey's post, passes over the pulley *m* which is in a firm housing inside the candle-holder, and its other end is tied to the bottom of weight *q*. The keeper *l* is sitting on the pedestal of the candle-holder, and his hand grasps the post which passed freely through it. On top [of the post] is the disc *ḥ*, upon which is the monkey, its finger on the side of the sheath on a line marked with the hours and their divisions.

The cap *ṭ* has been placed on top of the sheath *k* and turned so that the hindrance prevents it from coming off the sheath.

The candle is lit at nightfall and as it burns away the weight sinks and the candle rises. The string connected to the bottom of the post pulls it upwards together with the monkey, whose finger moves from mark to mark until an hour has passed. The hole in the back of the falcon's head *y* is then level with the first ball in the channel, [the ball] rolls out and falls into the falcon's beak, comes out, and drops into the pedestal of the candle-holder. So it continues for every hour until the end of the night. Balls have collected in the pedestal of the candle-holder for the number of hours of that night and the monkey's finger is on the appropriate degrees and divisions.

Then what requires painting is painted, such as the monkey, its keeper, and the falcon, and what requires scraping is scraped. [The exterior] is coated with Sandarac oil. The paintwork is cured in the sun for [some] days continuously.

And this is what I wished to describe clearly. I have drawn this picture of it [Fig. 76].

[Now] I will describe what I have made namely the candle-clock of the doors.

[The following addition to Chapter 9 is written by the side of Fig. 76 in the MS.]

This was taken from [another] copy of this work, in the author's writing:

I say that I made a second model of this device in which I placed a weight in the keeper's hollow body, its strings passing over a pulley below his neck. This weight raised the monkey as it sank. It was also lifted by the string, one end of which was connected to the lower end of the large weight, its other end passing over a pulley at the bottom of the sheath and then attached to the lower end of the rod. The purpose of this light weight was to lessen the load slightly for the large weight.

Chapter 10 of Category I

The clock of the doors, from which the passage of constant hours can be told by means of a candle. It is divided into two sections

Section 1

Description of its outside appearance and functioning

It is like the previous model, from which nothing is omitted except the keeper and the monkey. The additions are as follows: around the perimeter of the candle-holder fourteen doors are erected, each with two leaves. When a constant hour has passed from the lighting of the wick, a ball falls from the falcon's beak and the door opposite the falcon opens, and a figure emerges, [made] according to the choice of the craftsman. At the second hour the second door opens, at the third [hour] the third door, and so on – at every hour a door.

The construction of these doors and the mechanism for opening the leaves to display the figure: a pulley is made 1 F thick, and of such a width that a string as long as 14 divisions of the candle can be passed around it. An axle is passed through it, the ends projecting a short distance only. This candle-holder should be taller than the previous one by a thumb's breadth. The sheath of known [size] is placed in the candle-holder. Its foot is above the bottom of the candle-holder by a distance equal to the increase in height of this candle-holder [i.e. a thumb's breadth]. A cross-beam of the same length as the diameter of the lower end of the candle-holder is placed on the ground and its ends soldered to the interior walls of the candle-holder. One of the ends of the pulley's axle is placed in a bearing on the centre of the cross-beam and the other end, also in a bearing, in the centre of the plate at the bottom of the sheath upon which the weight rests.[1] Thus this pulley is between the base of the sheath and the cross-beam, which rests on the ground. A staple is fixed in the centre of this pulley and the middle of a string is tied to it. Then a small pulley is placed in a firm housing soldered to the bottom of the sheath, its groove at the same level as the staple in the [large] pulley. The end of the string from the staple in the large pulley is passed under the groove of the small one up to the top of the candle-holder's pedestal, then over another pulley on the sheath, whence it is passed through a hole in the sheath and tied to a hole in the underside of the weight. Then another pulley is fixed at the bottom of the sheath opposite the first, its groove on a level with the staple in the large pulley. The other end of the string tied to the staple in the large pulley is passed through the groove of this pulley, lifted up, and passed over a small pulley, the housing of which is soldered to the back of the candle-holder's pedestal. To its hanging end a lead weight of 30 *dirhams* is attached. The string has been wound once around the large pulley, and at this point the weight is at the top, touching the groove of the pulley which is on the back of the candle-holder's pedestal. Now I say that when the large weight is raised, the string attached to it is slack, and wound around the large pulley. The small weight sinks until it is near the bottom of the candle-holder, its string unwinds round the large pulley, which makes a complete rotation. Now we fix to the perimeter of the large pulley a light iron rod, which is horizontal at the bottom and is then [bent] up vertically at right angles, until it is close to the top of the pedestal of the candle-holder. When the large pulley rotates, this vertical rod rotates with it.

Section 2

On the construction of the doors and the figures which emerge from the doors

This candle-holder is constructed as before [but] its upper perimeter for one third of its height is plumbed to the vertical. In this perimeter 14 doors are cut, equidistant from one another and of the same width and height. Two leaves are made for each door, with hinges that move freely. Then 14 brass plates are made, each plate the same size as the doors. On each door is the figure of a man, made according to the choice of the craftsman and painted according to the current fashion. When a plate is erected in a door the figure fills the door. Then a hook is fixed to the top of each plate and to the top of each door a staple – the hook hangs in the staple. At the bottom of each door a projection (*Shaẓīya*) is fitted. Then one makes a copper ring. This is the picture [Fig. 77] of these.

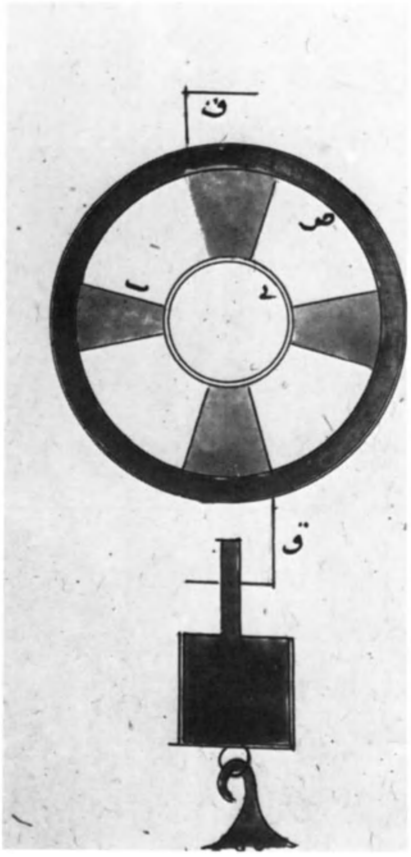


Fig. 77.

[1] i.e. The weight when it has completed its descent rests in the bottom of the sheath.

The circumference [of the ring] is divided into 14 parts and to each part an angle is fixed, the points of the angle all [pointing] in one direction. This ring, which is the same size as the inside of the candle-holder, is located in its interior below its highest point. It is fixed concentrically to the sheath by brackets. A door is opposite the end of each angle. Then each figure is suspended to an angle by the projection on the bottom of the plate. When the vertical rod connected to the large pulley rotates, it passes the ends of the projections and pushes each one off the angle. This is a separate enlarged drawing [Fig. 77] which shows it more clearly than the drawing of the inside of the candle-holder, where one thing is hidden by another: on the circumference are 14 angles, their ends all in one direction. In the centre of the ring is the drawing of the circle of the sheath, and between the ring and the sheath are 4 brackets with their ends soldered to the inside of the ring and to the outside of the sheath. [There is] the drawing of one figure from behind, namely a plate with a staple on its upper end hung on a hook on one of the fourteen doors; at the lower end is a smooth projection placed on the end of one of the hooks. The ring is marked *ṣ*, the hooks *q*, the sheath's circle *y* and the projections supporting the ring on the sheath are marked *b*. I have drawn a picture of the candle-holder [Fig. 78] inside which is everything that I have mentioned.

It is very clear that when the graduated candle *a* is placed in the sheath *ḥ* on the disc *b*, and the cap *s* is placed on it, weight *e* rises from the bottom of the sheath *ḥ* in which is the ball's channel *d*. The lower end *z* of the rod carrying disc *b* sinks down to the bottom of the sheath *ḥ* and the large pulley *w* is turned by the ascent of weight *e* since it is connected to its underside by string *p*. [This string] is passed over pulley *n*, then down to the groove of pulley *m*, and is passed around the groove of the large pulley *w*. The other end of the string goes under the groove of pulley *l* and is passed over pulley *ṭ* and is tied to the hole in the top of weight *j*. The balls are pushed through the beak of the falcon one after another and are collected in the channel until it is filled with 14 balls. Each figure is lifted and hung by the projection on its lower end to the angle opposite it. The door leaves are closed.

The wick is lit. the candle burns away and weight *e* sinks. Disc *b* lifts the balls' channel. String *p* pulls and turns pulley *w*, so that string *y* winds around it lifting weight *j* which is on its end. The thin rod *f* on pulley *w* turns with the rotation of the pulley until it touches the end of a projection on the bottom of a figure, pushing it until it is on the end of one of the angles, fitted to ring *s*, namely the angle opposite the head of the falcon *q*. When a ball drops out, the figure *p* falls, opens the leaves of door *k*, and stands there. So it continues for every hour until the end of the night. Balls have collected on the pedestal of the candle-holder to the number of the hours of that night. The divisions of the hour are not shown by this clock.

Then what should be scraped is scraped and what should be painted is painted.

This is what I wished to explain clearly.

There is another method of lifting the balls, as follows: a single channel is made and a longitudinal slit is made along its centre. At the bottom of the rod carrying the disc a poker (*siṭām*) is fitted with its tail fixed firmly to the bottom of the rod, and its disc inside the channel. When a ball is pushed into the falcon's beak it drops down in the channel and comes to rest on the face of the poker's disc, and so on, one on top of the other in the channel. When the rod rises the balls rise and fall into the falcon's head in succession.

Now I will describe what I have made, which is an Arbitrator for carousals. God is all-knowing.

End of first category

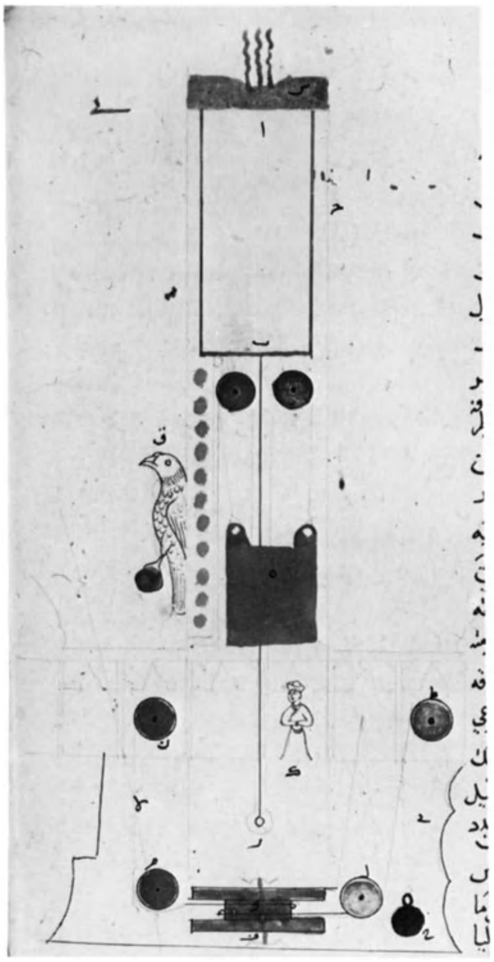
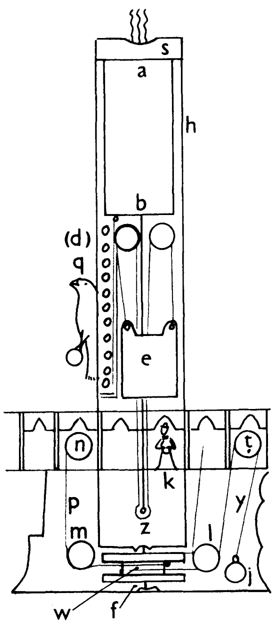


Fig. 78.



CATEGORY II

On the construction of vessels and figures suitable for drinking sessions

Chapter 1 of Category II

It is a goblet which arbitrates at[1] *drinking parties.*
[The chapter] is divided into two sections

Section 1

Description of the goblet and its functioning

It is a tall goblet made of silver or brass on a tall pedestal. On top of the goblet is a flat, fretted lid which is below the rim [of the goblet]. In the centre of the lid is a beautiful dome on top of which is a bird with an open beak. Below the rim of the goblet is a handsome spout. Its functioning: the steward[2] brings the goblet and sets it down in the middle of the assembly with the revellers around it. Then he pours the wine[3] slowly on to the lid from a wineskin or from a vessel with a narrow mouth. Whenever he pours the wine it flows through the lid's fretwork. The bird rotates and the whistle emits a shrill tone until the vessel is nearly full, whereupon he stops pouring. The bird comes to rest and stops whistling; its head is pointed towards one of the party, and the steward picks it up and hands it to the one opposite whom the bird has stopped. He drinks from the spout and if he empties all the wine it contains and hands it to the steward, he accepts it. If [however] any wine remains in it the bird whistles and the steward does not accept the goblet but tells him to drink what is left. If he drinks it all he [i.e. the steward] takes the goblet. If a mere 5 *dirhams* remain in it the bird will whistle. This will happen even if a hundred sips are taken from the goblet. [i.e. without emptying it completely.]

Section 2

A tall goblet is made from silver, supported by the shoulders of a slender pedestal. Then a flat lid is made for it in the centre of which is a handsome dome – both lid and dome are fretted. Then a silver duck is made, which is gilded and engraved where appropriate. It has two legs which move from the hip joint. Between the legs there is a square hole in its belly. – It should be understood that everything inside the goblet is made of tin (*raṣāṣ al-qalʿī*) and tinned copper. – Then the lid is removed and a flat cover is fitted to the goblet 2 F below its rim and its perimeter is soldered to the inner circumference of the goblet. In the cover, at the wall of the goblet, a long hole is made which penetrates through to the goblet. Then one takes a piece of channel as wide as the hole and long enough to reach from the cover to [a point] near the bottom of the goblet. It is put inside with its edges along the wall of the goblet, and is soldered to the wall of the goblet and to the perimeter of the cover. Its upper end is open, so that if water is poured over the cover it will collect and then flow into the channel, filling it, and then issue from the bottom of the channel into the goblet. When the goblet is tilted towards the channel the water will flow from the lower end to the upper end of the channel until it is all discharged.

Then a hole is made in the cover [diametrically] opposite the channel, its edge touching the side of the goblet. To this a pipe is fitted with one of its ends connected to the hole and the other reaching towards the centre of the fretted lid. On it is the ball of a whistle: when water is poured over the cover it flows down through the channel and displaces the air in the goblet, which is expelled through the pipe into the whistle's ball.

Then a wheel is made as I shall describe: it is a light copper disc, its diameter shorter than the diameter of the cover soldered inside the goblet. An axle is passed through it, one end of which

[1] Vb. *Ḥakama.* The noun *ḥakam* is used for the devices themselves. The basic meaning of the root *ḥkm* is judgement or arbitration. Presumably the words are used humourously, to describe these inanimate arbiters of the revels.
[2] *Sāqī.* Cup bearer. The word 'steward' is used to indicate the somewhat privileged status of these servants.
[3] *Sharāb.* Translated throughout as 'wine'.

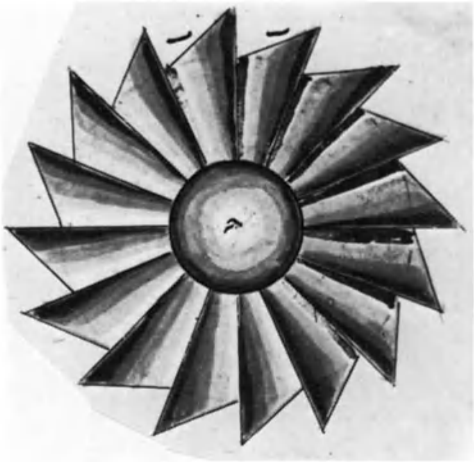
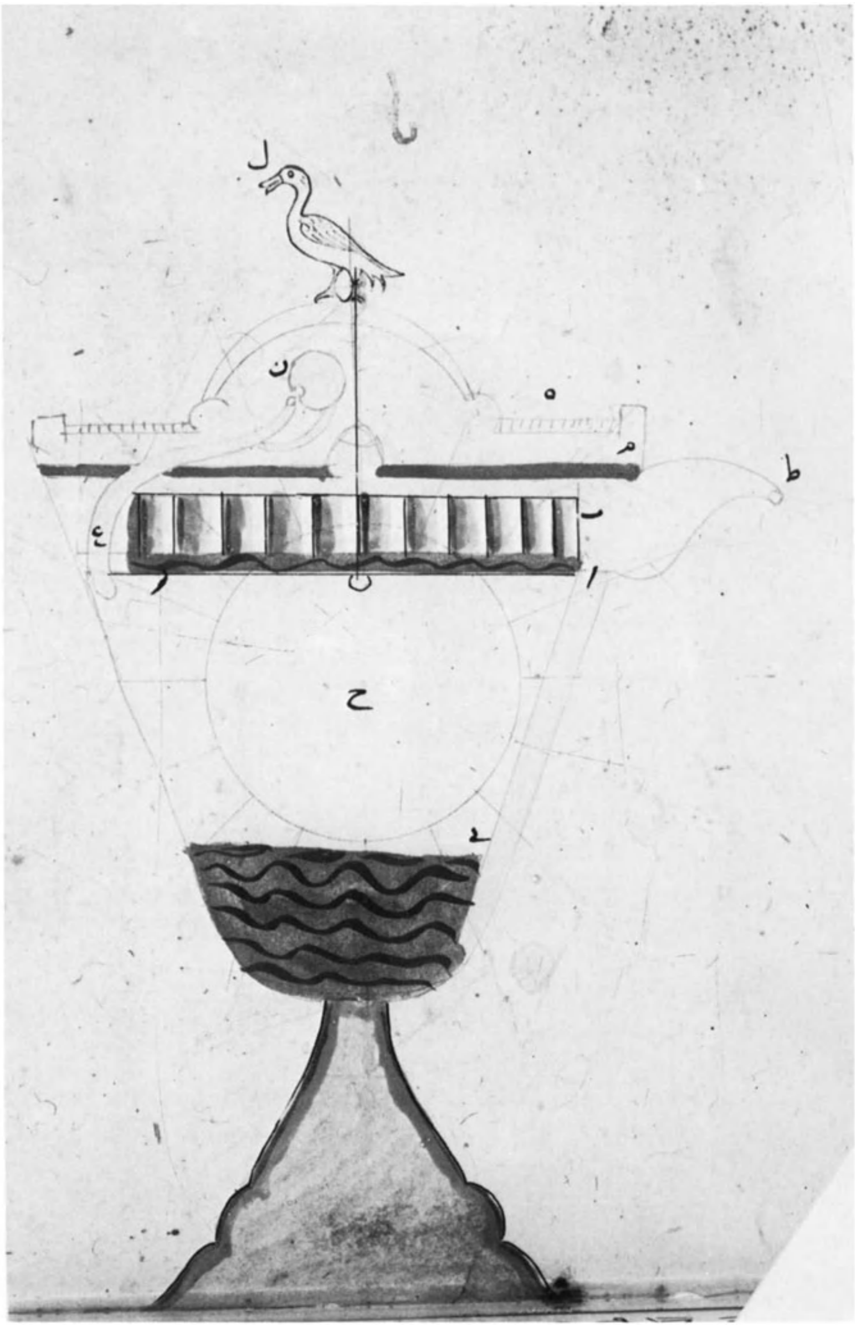


Fig. 79.

projects a barleycorn length from the face of the disc, the other end about a finger's length. About twenty marks are made around the edge of this disc and a cut is made from each mark towards the centre of the disc. This is the picture [Fig. 79] – the lines have been cut so that they are like vanes [lit. feathers]. There is *j* on the centre of the disc and *bb* on the tips of the vanes. Then the vanes are separated so that they form, as it were, a water wheel.[4] Now the short end of the axle of the water-wheel is placed on the centre of the cover, so that the vanes almost touch the cover.

Then another cover is made with a hole in its centre, the centre having a small upward protuberance. The upper end of the water-wheel's axle is passed through the centre of this cover, and the whistle's pipe through [another] hole in it. The perimeter of the cover is soldered to the goblet. The whistle's tube is bent so that the water wheel [can] be between the two covers with no impediment to its rotation. A hole is made in the upper cover through which water can flow on to the rim of the water-wheel. In the side of the goblet a hole is made between the two covers, and above the hole to which the channel is [fitted]. To this a fine spout is fitted which is vertical [i.e. normal to the goblet at the junction] and it is then turned down slightly. The silver lid made previously is now placed on the goblet, a little below its rim, and soldered in position. The whistle's ball is then near the top of the dome and almost touching the axle of the water wheel, since this goes up through a hole in the centre of the dome and protrudes sufficiently to be inserted in the hole in the belly of the duck, whose legs do not touch the dome. I have shown a picture of that [Fig. 80]. It is very evident that when wine is poured over lid *e* it flows through the fretwork on to the second cover and thence through hole *m* on to the vanes *b* of the water-wheel.



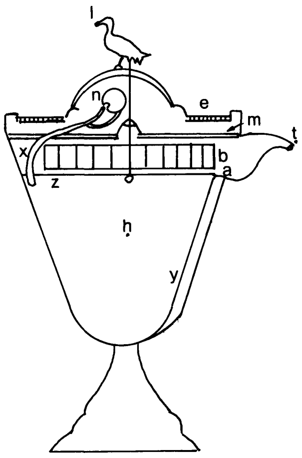


Fig. 80.

[4] *Surn al-arḥā'*

The water-wheel, with the duck *l* on its axle, rotates. The wine flows on to the cover *z* then into hole *a* whence it is sucked into the channel and issues from its lower end *y* into the goblet *ḥ*, driving the air from it through the pipe *x* into the ball *n*, which whistles.

When one drinks from spout *ṭ* some of the wine in the goblet the space it leaves is occupied by air, and when the wine flows back from the spout and from the top of the cover it drives out the air and the ball whistles, and it is thought that the whistling [comes] from the duck. So it continues until all the wine in the goblet is exhausted.

That is what I wished to describe clearly.

Now I will describe a goblet which I made which has additions to the first one.

N.B. *Notes for this chapter are included with the notes for Chapter 2.*

Chapter 2 of Category II

It is a goblet which arbitrates at drinking parties. I will describe its outside appearance and its functioning

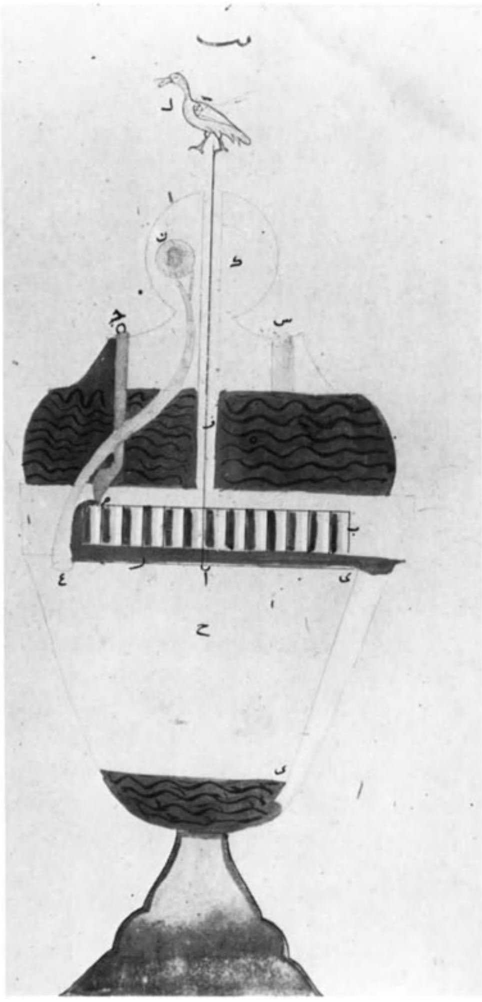
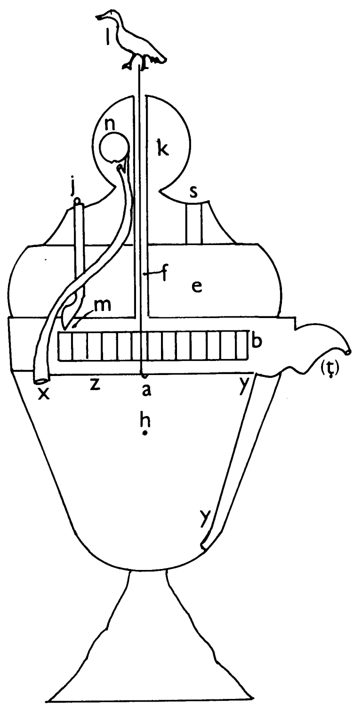


Fig. 81.



It is a silver goblet of the same pattern as the first goblet, except that its lid is not flat, but is a large dome rising from its rim. On top of the dome is a duck as before. The steward brings this goblet in his hand and stands until he is permitted to put it down, in the middle of the assembly. He puts it down and stands aside. The bird rotates and whistles for a little while and then comes to a halt opposite one of the party. The steward takes the goblet and hands it to the one opposite whom the bird stopped, for him to drink. If he finishes all the wine it contains the steward takes it from his hand and departs. If he drinks some and leaves some the bird whistles so that everyone in the party can hear it, and the steward does not take it from him but tells him to drink what is left in it. So he drinks it. And even if he drinks repeatedly but still leaves some wine in it, the bird will whistle.

Now I will describe its construction. I have drawn a picture like the first goblet up to the second cover *m*. In hole *m* is a ground valve *m* of sound workmanship. Then a dome is made, the width of its base [the same] as the width of the top of the goblet. Above it is a fretted ball which is raised above the top of the dome by a thick neck. On the centre of cover *m*, which is pierced to take the axle of the water-wheel, is a pipe through which the axle of the water-wheel passes; both [pipe and axle] go up to the top of the ball on the dome. This axle is longer than the first one – it goes above the ball and the duck is placed on it. The pipe for the whistle's ball goes up from cover *z* through cover *m* into the neck of the dome. The ball whistles inside the [large] ball.

Then a piece (*shazīya*) like a rod is made for the plug of valve *m*, and [this rod] protrudes above the dome in the fretwork below the neck. On its end is a staple in which is a small ring. This rod moves stiffly up and down in the dome's fretwork. Then the lower perimeter of the dome is soldered securely to the rim of the goblet. At the top of the dome a hole is made in which is inserted the stem of a very small funnel. A lid is made for it, having a staple and a ring which is [diametrically] opposite the ring at the end of the valve rod.

I have shown the picture [Fig. 81] of the goblet *ḥ*, the first cover *z*, and the end *y* of the channel connected to it. On the second cover, near the ground valve, is *m*, and on the centre-line of the pipe going up to the top of the ball is *f*. On the whistle is *n*. On the centre of cover *z* is the end *a* of the water-wheel's axle. The vanes are marked *b* and the tube on the centre of the cover is marked *f*. Inside it is the duck's axle, marked *k*. Below the tube's spout is *ṭ*, on the valve rod *j*, on the dome *e*, on the lid in the top of the dome with the ring in it *s*.

It is very clear that: lid *s* is lifted with valve *m* closed, and wine is poured into opening *s* until it fills dome *e*. The lid is replaced and the steward carries the goblet in his hand and waits until he is given permission to put it down in the middle of the assembly. He puts it down as if he wished to place it on the ground because it was [heavy] to carry, and lifts the ring of the valve rod without any of the assembly noticing. Then the wine flows through valve *m* on to the vanes of the water-wheel. Its axle rotates together with the duck. The wine is sucked down into the end *y* of the channel and comes out at the other end, displacing the air in the goblet which is expelled through pipe *x* into ball *n*. This continues until all the wine that was in the dome is in the goblet, and the duck stops opposite one of the revellers. The steward takes the goblet and hands it to the one opposite it [i.e. the duck] to drink. If he drinks all it contains the steward takes it, but if any is left, little or much, the steward does not accept it from him. And so on as long as there is any drink in it.

That is what I wished to describe clearly.

[Now] I will describe what I have made, namely an 'Arbiter' for drinking sessions.

Chapter 3 of Category II

It is an Arbiter for a drinking session. It is divided into five sections

Section 1

Description of the outside appearance of the Arbiter and its functioning, i.e. its purpose

It is a square dais, with sides about 2 sp. wide; it has short painted legs, and is surrounded by a fretted balustrade. On the dais sits a slave-girl (*jāriya*). In her right hand she grasps the neck of a bottle with its bottom resting on her right knee. In front of her is a goblet. Around the slave-girl,

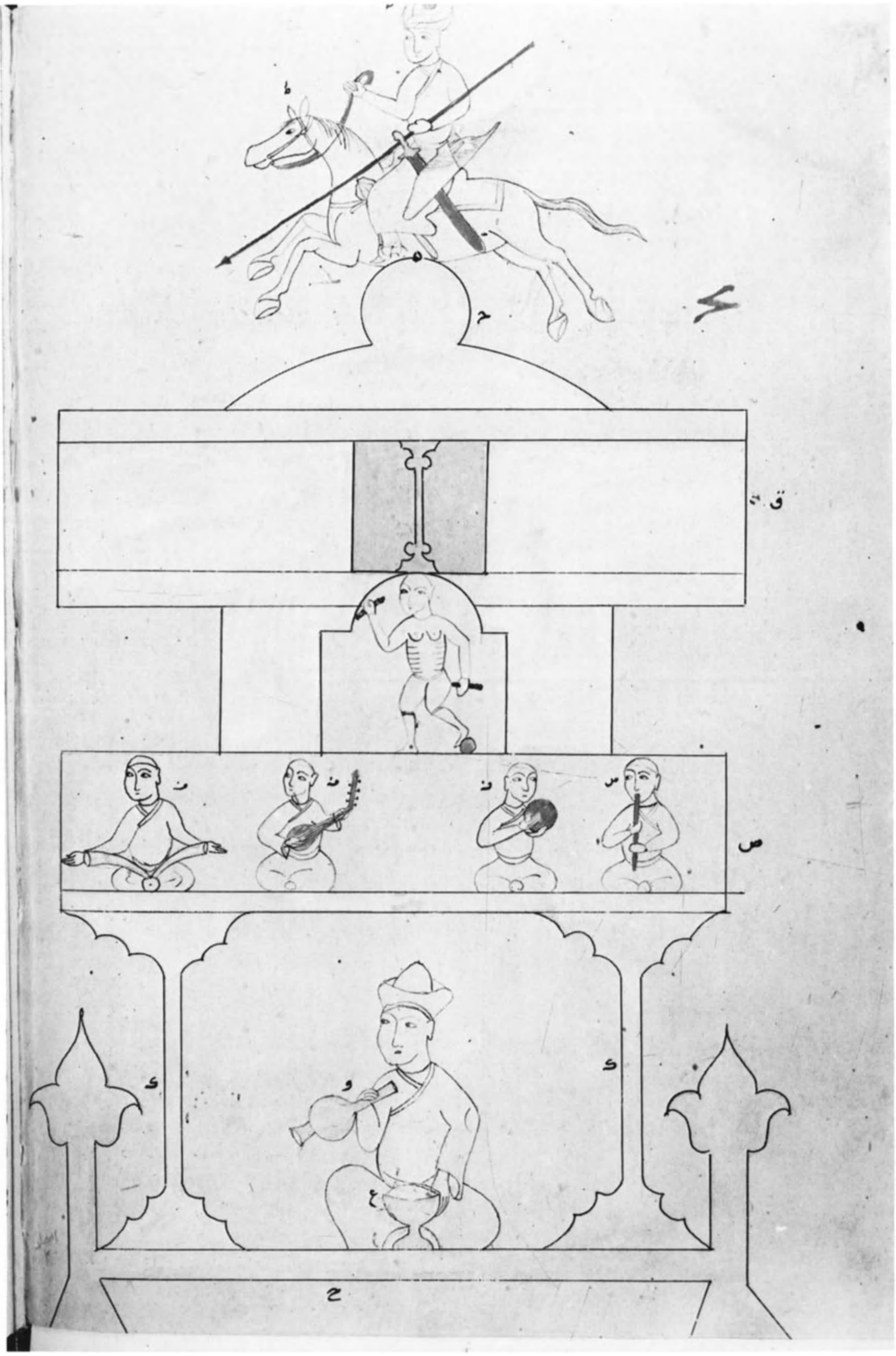
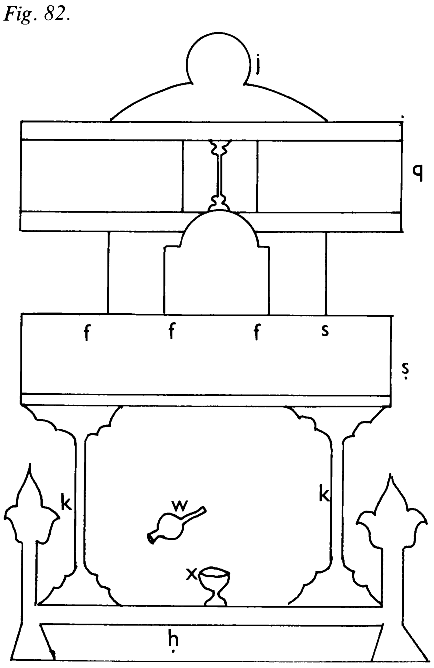


Fig. 82.



but not touching her, four exactly vertical columns each about 2 sp. long are firmly [fixed] to the floor of the platform at its corners, inside the legs. Above the columns a castle is erected, about $2\frac{1}{2}$ sp. wide. In its front face, near its base, is a balcony,[1] upon which are four slave girls. One holds a flute to her mouth, another holds a tambourine, another holds a lute, and the last has a drum slung around her neck by a strap. Above this balcony is a *miḥrāb* like a reception-chamber (*Īwān*) in which there is a [male] dancer on a ball. Above this castle is a castle which is wider than it. In its front is a door with two closed leaves. Above this castle is a dome upon which are a horse and rider. [The latter] carries a lance point downwards. This is the picture [Fig. 82] of the Arbiter.

Its functioning: it is taken into the drinking party in three parts – the dais with the slave girl on it, the castle with the four slave-girls and the dancer; the upper castle with the horse and rider. The pieces are placed one upon the other and [connected together] by male to female [joints]. It is then left in the middle of the assembly until a period of about 20 minutes has elapsed. Then it emits an audible musical sound and the horse and rider rotate slowly past the members of the assembly as if about to stop opposite one of them. The dancer makes a half turn to his left and [then] a quarter turn to his right. His head moves, as do his hands, each holding a baton. At times both his legs are on the ball, at times [only] one. The flautist plays with a sound audible to the assembly, and the slave girls play their instruments with a continuous regular rhythm, with varied sounds and drumbeats. [This continues] for a while and then the rider comes to a halt, with his lance pointing to one of the party. The slave-girls are silent and the dancer is still. Then the slave-girl tilts the bottle until its mouth is near the rim of the goblet, and pours from the bottle clarified, blended, wine until the goblet is nearly full, whereupon the bottle returns to its previous position. The steward takes it [i.e. the goblet] and hands it to the person towards whom the lance is pointing. [After the goblet is drained][2] the steward puts it back in front of the slave girl. This is repeated about twenty times, at intervals of about twenty minutes. Then the leaves of the door in the upper castle open and a man emerges from the door, his right hand indicating 'no more wine' and the left hand indicating 'two more goblets'.

If the head of the assembly chooses that more wine is poured into the reservoir in the upper castle, he gives the order, and it is poured in.

Section 2

On the construction of the dais and the columns on it; the slave-girl, her hand, the bottle and the goblet

A dais is made with feet of cast bronze, a deck of copper and a fretted balustrade of cast bronze, [all] of excellent workmanship. It is about 4 F above the ground, and is square, the length of one side being 2 sp. Then a slave-girl is made from jointed copper, sitting cross-legged on the dais. In her right hand is a brass bottle, which I shall [now] describe. A bottle is made in two pieces, one from the centre to the base, one from the centre to the mouth. They fit neatly together but are not soldered. Then to the inner rim of the upper half a copper disc is fitted. The disc, the inside of the half-bottle and the inside of its neck are tinned. The disc is then soldered firmly to the perimeter of the half bottle. When any liquid is poured into its upper end, it fills up. Then a narrow slit $\frac{1}{2}$ F wide is made in the disc from its centre towards the rim of the half-bottle. Then in the centre of the slit, from right to left across it, an axle is placed with its ends in two strong staples on the disc. Then one takes a pipe 1 sp. long and bends its end like a polo-stick (*ṣawlajān*). Half of this end is pushed through the slit in the disc, and the centre of the axle is firmly soldered to the inner radius of the crook in the pipe. The half-bottle then moves freely up and down around the pipe. This is the picture [Fig. 83] of the two halves of the bottle and the pipe: the upper half *w*; the end of the pipe inside the disc *z*; the disc and the ends of the axle *a*; the lower half of the bottle *j*, having a slit *m* in its side down to its base, in which the *ṣawlajān* can move easily.

Fig. 83.

Then a hole is made at the top of the slave-girl's right knee, which is raised above the ground. The hole runs from below the joint down to the underside of the dais. In this hole a pipe is inserted which is wide enough for the end of the *ṣawlajān* to be pushed tightly into it until the bottle almost touches the knee. The joint between them is made with lead. The lower half of the bottle is put back on the upper [half] with its slit facing downwards, the *ṣawlajān* being [free to] move in it. The bottom of the bottle is 5 *dirhams* heavier than its top and is held by gravity [lit. by nature] on the knee of the slave-girl. Its upper end is not erect but tilted. When wine flows up through the

[1] *Rawshan*. Lit. window (Pers.).

[2] The verb *saqā* means, for a person, the same as 'to water' means for cattle. The phrase in parentheses is therefore redundant in Arabic, since the verb *saqā* comprises the actions of the globet passing from hand to hand, the drinking of the wine, and the steward's receiving the empty goblet.

ṣawlajān into the top of the bottle it collects and weighs down the upper half which tilts. The mouth of the bottle sinks and wine pours from it into the goblet for as long as the wine rises through the *ṣawlajān*. When the flow of wine is cut off the top of the bottle is lightened by the outflow [of the last of the wine], so it rises and the bottle returns to its previous position.

Then four hollow brass columns are made each 2 sp. long. They have pedestals and capitals, the latter in alignment with the corner of the castle. Then each column is erected at a corner of the deck of the dais near the top of the feet of the dais, and is soldered firmly. No part of the columns touches the slave-girl. Then a hole is made in the deck of the dais into the bore of the column on the left-hand side of the slave-girl. This hole and the end of the pipe fixed in the knee of the slave-girl are connected by a channel, the edges of which are soldered securely to the underside of the deck of the dais, and its ends to the end of the pipe and to the hole under the column. When water is poured into the top of the column at the left-hand side of the slave-girl it flows into the channel, rises through the *ṣawlajān* and flows into the top of the bottle, since it has no outlet except the bottle.

Then a goblet is made from brass, tinned on the inside. Its capacity is 300 *dirhams*. This goblet is placed on the platform in front of the slave-girl, and her left hand appears to touch the rim of the goblet. Her right hand is made from thin copper, as light as possible. The slave-girl's sleeve is wide enough for the arm to be placed in it; there is an axle across her forearm around which it moves up and down. The palm and fingers are on the neck of the bottle, not soldered, but positioned to make it appear as if she is grasping it. When the neck of the bottle sinks the hand sinks with it, and when it rises [the hand] rises with it.

Section 3

Construction of the shells of the two castles, the dancer, the man in the second castle, the horseman and the horse

A rectangular castle is made from brass, as wide as [the distance] between two columns, and about $2\frac{1}{2}$ sp. high. It is [made] from four plates soldered firmly together. At the bottom of one of the plates, namely the front one, is a hollow like the top of a *miḥrāb*. There is a cover on the bottom, and on each corner is a piece of pipe which sits tightly in the top of a column, so that the castle is fitted neatly to the top of the columns. The top of the *miḥrāb* is around the slave-girl's head, but does not touch it.[3] Above the top of the *miḥrāb*, across the full width of the castle, is a balcony with a short, pointed balustrade. On the balcony are four slave girls made from jointed copper, their backs fixed to the castle. The one at the left side of the castle holds a flute to her mouth, the one next to her holds a lute, and the one next to her, at the right hand side of the castle, has a drum in her lap, slung round her neck by a strap.[4] The flute player makes no movement. The forearm of the tambourine player is in the sleeve of her blouse (*qamīṣ*) and moves up and down obliquely upon an axle [fixed] across the forearm. The end of the forearm slants down slightly and passes through a slit into the interior of the castle. Below it [i.e. the end of the forearm] is the end of a bar (*shaẓīya*) and this turns about an axle at its centre. Its other end is inside the castle, and is extended so that its movement is double. I have shown its picture [Fig. 84], in the opposite sense to that described.

Fig. 84. Caption at left reads: 'the rod' (al-shaẓīya).

The lute-player holds the neck of the lute to her thigh with her left hand. The fingers of her right hand are on the strings of the lute – the lute and its strings are made of copper. Her forearm is in the sleeve of the blouse and moves up and down around an axle. The extension of her forearm passes through a slit to the inside of the castle.

The drummer: the drum is made of copper and has a wire tied to either side which is slung around the neck of the slave-girl. The fingers of her left hand are on one face of the drum, which is slanted, and the fingers of her right hand are on the other face of the drum. The [right] forearm moves up and down in the sleeve with an obliquity corresponding to the obliquity of the drum. The forearm's extension extends through a slit into the inside of the castle and when something forces it down and then comes away from it, the hand lifts from the drum and then descends – and similarly for the hands mentioned previously.

Above the slave-girl's balcony a *miḥrāb* like a reception-chamber is made in the front of the castle, its height about 1 sp. Then a hollow ball, as light as possible, is made from papier mâché, and it has a square hole into which the end of an axle about one small span long is inserted, projecting 1 F from the floor of the chamber. Then the model of a dancer is made. It is a short

[3] The *miḥrāb* is not shown in the Oxford MS – i.e. Fig. 82, but appears in the Dublin MS.
[4] The tambourine player has been omitted.

paper skirt for which two legs are made: the right one moves on a ring which is inside the skirt and the left one is attached rigidly to the skirt, and its foot to the ball. Two hands grasping batons are made for him, and the forearms are in the sleeves and move on axles. The head is in the [collar] opening and moves about an axle in the neck the ends of which are fixed firmly to the collar.

On the upper perimeter of the castle projections are fitted, like a cornice, to adorn each face of the castle, for a height of 3 F.

Then above this castle [another castle] is erected, wide enough to overlap the top of the first castle, its height about $1\frac{1}{2}$ sp. In its front is a door with two leaves which open and close in a light kiosk (*bayt*) large enough for the figure of a man to stand in. His legs move on an axle the ends of which are in two bearings at the foot of the kiosk. He is made from jointed copper. His right hand is lifted, palm forward, [fingers] extended as if to say 'nothing left'. His left hand is [also] raised with the thumb, third finger and little finger closed, and the index finger and second finger extended separately as if to say 'two more'.

On top of this castle is a tall dome, on top of which is a ball, for lifting it and setting it down. A hollow horse is made from papier mâché upon which is a rider holding a lance – the tip of the lance points downwards. His other hand holds the horse's reins. Both [horse and rider] should be as handsome as possible. In the breast of the horse is a hole in which is the end of an iron rod $2\frac{1}{2}$ sp. long.

Section 4

Construction of the wine reservoir and its float, which moves the standing man; and the door leaves; construction of the [tipping]-bucket into which the wine discharges; of the mechanisms for the horse and rider, the dancer, and the hands of the slave-girls

A copper reservoir (*khizāna*) is made and placed in the second castle. It is placed on the floor of the castle, touching the inside of the castle on all sides, and surrounding the kiosk of the standing man on three sides. It rises above the castle into the place of the dome above this castle, so that when the dome is placed on the castle it [the reservoir] touches the inside of the dome. The top of the reservoir is open so that the wine can be poured into it. Now a thin pipe is fixed in the centre of the reservoir's floor from inside, stretching up to its top. It is soldered firmly and then a hole of the same diameter as the pipe is made in the centre of the floor of the reservoir through to the pipe. Then a float is made, according to the [method for] manufacture of floats described earlier. Holes are made in the centre of both its faces, and the holes are connected by a pipe, which is wide enough for the pipe on the floor of the reservoir to be inserted easily in it. It is soldered securely with its ends flush with the faces of the float. This float is placed on the pipe on the floor of the trough [i.e. the reservoir]. In one of its faces is a staple in which is the end of a string. The other end goes to the top of the reservoir's side where it is passed over a pulley, and hangs down between the side [of the reservoir] and the kiosk with the man in it. On the man's back is a rod, one end of which is soldered to his back; the other end passes through the back of the kiosk via a slit, which stretches up towards the top. There is a hole in the end of the rod to which is attached the end of the string from the float. And when the float is at the bottom of the reservoir, the standing man leans forward and opens the leaves, showing his head and part of his arms. When there is water [sic] in the reservoir and the float upon it, the string is slack, and the man goes back and the doors close upon him. When the water empties from the reservoir the float sinks and pulls the rod on the back of the man, who leans forward, opens the leaves, and shows himself.

Then a fine hole is made in the floor of the reservoir near the centre of the wall and the left hand side of the castle. On this hole, underneath the floor of the reservoir, a piece of pipe is fitted which is very narrow and prevents the water from flowing along the floor of the reservoir – it falls drop by drop into a place yet to be mentioned.[5] The inside of the reservoir, and the float, are tinned as is everything described below. This completes the [description of the] manufacture of the upper castle and its contents.

I have shown the picture [Fig. 85] of the reservoir *b*, the pipe *p* running vertically from the centre of its floor to its upper end, the float *y* inside it with a staple from which string *ṣ* rises to a pulley in the top of the reservoir's side. The end of the string goes down between the side of the reservoir and the man, and is tied to the end of rod *w* attached to the man's back. The man stands erect on an axle *s*. The hole in the bottom of the reservoir is marked *d*.

[5] This is not clearly expressed: the purpose of this pipe was to direct the water to a single point in the lower castle. See detail on Fig. 13.1.

Now I will describe the construction of the [tipping]-bucket into which water flows from the reservoir, and the flows out of the bucket into a trough underneath it, then on to the scoops of a wheel which turns the horse and the horseman – all this is inside the upper third of the first castle. A scoop-wheel is made of diameter 1 sp., each scoop in the shape of a semicircle [i.e. in plan] of a half a fingerlength diameter. A trough is made for this wheel so that it can rotate freely without touching any part of the trough – the trough should not be wide since the place for it is narrow. To the axle of this wheel, a wheel of diameter half a fingerlength is fitted, having eight teeth equally spaced around its perimeter. This trough is then installed in the top of the castle at the right-hand side, with the wheel's scoops below the top of the castle, the trough against the inside of the right-hand plate of the castle, and the small wheel towards the left-hand side of the castle. Two cross-beams are placed beneath the trough to support it. In the underside of this trough a pipe is fixed which faces the back of the castle – the pipe then runs laterally towards the left-hand side of the castle, to discharge on a wheel, yet to be mentioned, which is at the left-hand side of the castle.

Then an axle is made 1 sp. long, with a long hole in its end in which is inserted tightly the end of a rod, so that they both become a single axle. This hole is called the *mukḥula* [lit: kohl-jar]. At the other end of the axle is a disc, 4 finger lengths in diameter, with teeth on its perimeter, the distance between them the same as the distance between the eight teeth on the disc mounted on the axle of the scoop wheel. This end of the axle [i.e. of the large cogwheel] is on a cross-beam which is in the centre of the interior of the castle. On the cross-beam is a firm bearing. The teeth

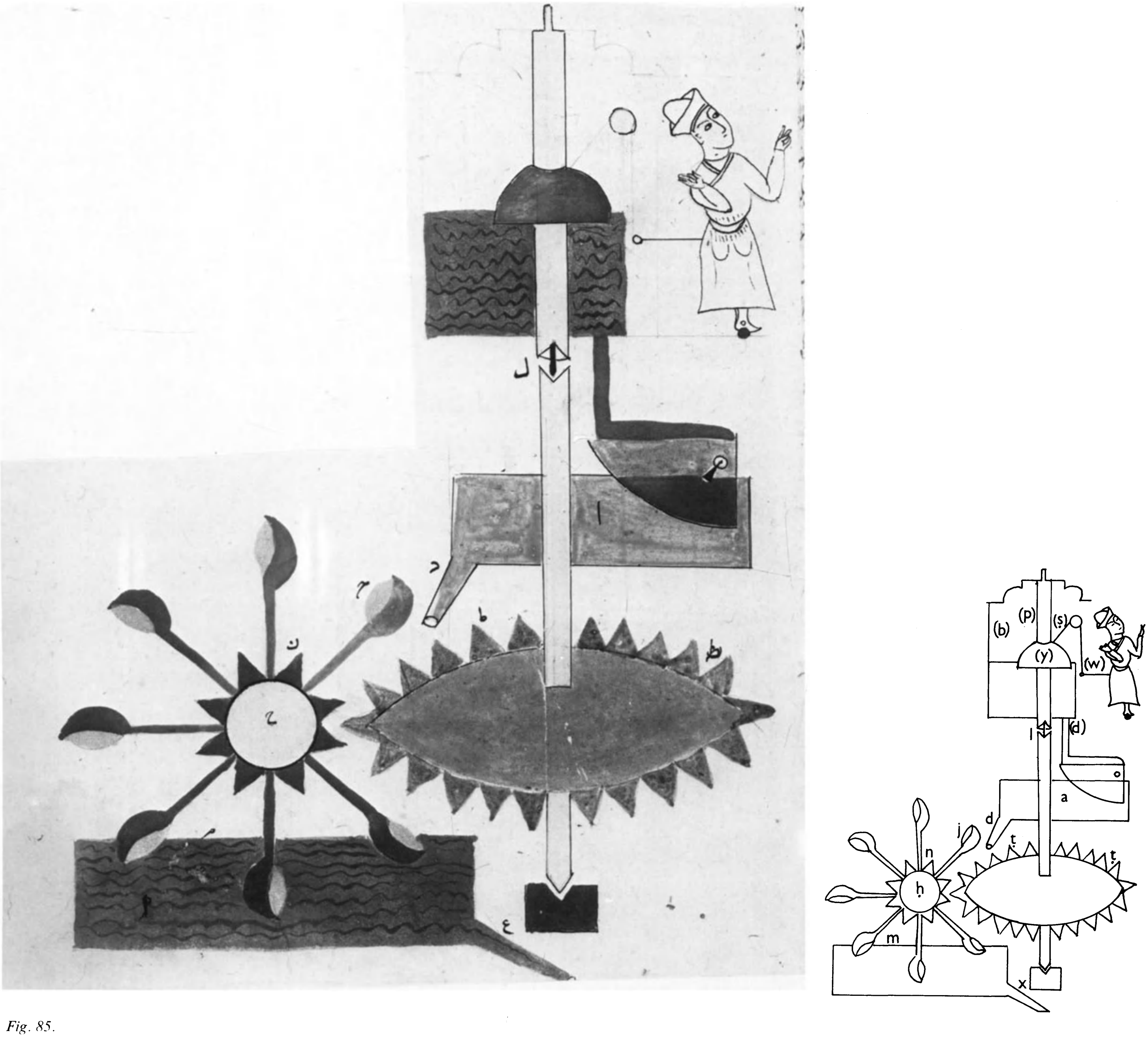


Fig. 85.

of this wheel – their number is unspecified – go between the eight teeth on the small disc on the axle of the scoop-wheel. The other end of this axle goes through a cross-beam in the centre of the top of the castle. The name of this wheel on the axle with the *mukḥula* on its end is 'the rider's wheel'.

Then a trough is made, its width half the width of the castle, and it is installed inside the castle on the left-hand side, its bottom almost touching the face of the rider's wheel. In the side of this trough, near the bottom, a hole is made which discharges on to the scoops of the wheel in the direction of the back of the castle. Then a [tipping]-bucket is installed in this trough, with the ends of its axle in the sides of the trough – its shape and method of operation have been described before. Its capacity is 300 *dirhams* of water. Its tip is towards the back of the trough and when it rests on its rear end in the bottom of the trough with its rim horizontal it is below the level of the top of the castle.

I have illustrated the scoop-wheel, and the ends of its axle, and adjoining it the small eight-toothed disc, on a separate picture [Fig. 85]. The rider's wheel is [also] separate – i.e. out of position. Its teeth should [in fact] engage with the eight teeth. It is horizontal and its axle is vertical. The trough in which is the [tipping]-bucket has the back of its floor almost touching the rider's wheel, and the trough's pipe discharges on to the scoops. On the scoop-wheel is *n*, on the disc and its axle *ḥ*, on its trough *m*, on the rider's wheel *ṭ*, on the *mukḥula* on the end of its axle *l*, on the tipping-bucket's trough *a*, on the pipe discharging over the scoops *d*, and on the pipe connected to the bottom of the scoop-wheel's trough *x*. This is the drawing of what I have mentioned. Then a scoop-wheel like the first wheel is made, in a trough like the first trough. On the end of the axle of the wheel a disc of one fingerlength diameter is mounted, having equally spaced teeth around its perimeter. It is on the end of the axle. Then a hole is made in the centre of the floor of this trough, narrower than the pipe connected to the trough of the first scoop-wheel. This trough is installed in the left-hand side of the castle, with about 4 F between its base and the bottom of the castle. It is supported underneath by a cross-beam. The pipe of the first trough discharges into the scoops of this wheel, and the water which falls from it flows out through the hole in its underside into [something] to be described. This trough is near the left side of the castle, while the disc mounted on the end of the wheel's axle is towards the right side of the castle.

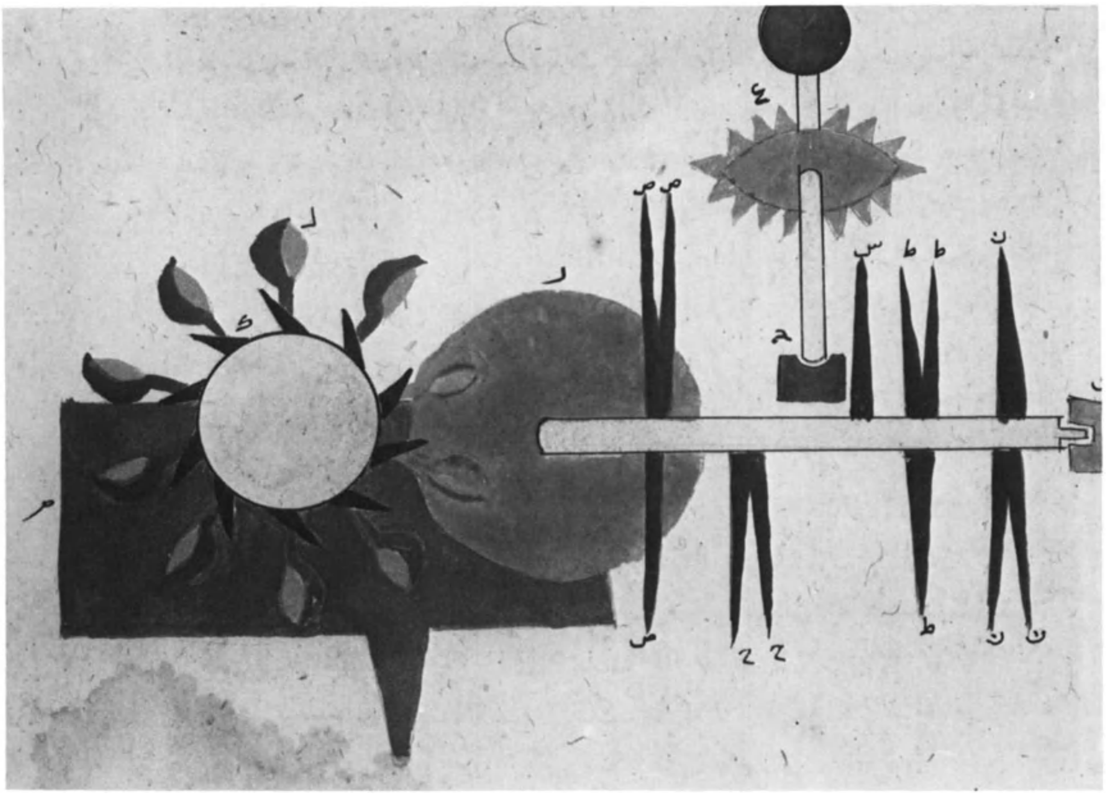
Then an axle is placed along the inside of the castle opposite the slave-girls' hands; its ends are in bearings in the right-hand and left-hand plates of the castle. At the left-hand end of this axle a wheel is mounted opposite the disc fixed to the end of the axle of the second scoop-wheel. The wheel is formed from two discs, each of one fingerlength diameter, and as light as possible; between the two discs is a gap 1 F wide, and thin cross pieces are fixed between the perimeters of the two discs, [spaced so that] the distance between them equals the distance between the teeth on the disc opposite this wheel, so that the disc's teeth enter between the cross-pieces on the wheel with the two discs. When the scoop-wheel rotates with the disc, the wheel with the two discs rotates on its axle.

Then on this axle, opposite the rod which moves the hand of the tambourine-player, a peg is fixed, the end of which falls onto the rod which moves the hand of the tambourine player, pushing it down [then] releasing it. The hand of the tambourine player moves down and up. Similarly a peg is fitted to the axle opposite the extension of each forearm, which moves them up and down for every rotation of the axle. It should be understood that one peg for each hand is not sufficient: there should be three pegs, two close together and one opposite the pair, so that the beats fall as two beats and one beat. I have now explained the mechanisms for the slave-girl's hands.

Now I will describe the mechanism for the dancer. An axle one small span long is made. Its end can be inserted tightly in the hole in the ball – [the tightness] is necessary. A disc like a *dirham* is fitted to the centre of this axle, with eight teeth, each one 1 F long, on its perimeter. In the floor of the reception-chamber a hole is made, through which the end of this axle is passed from inside the castle, projecting sufficiently for it to be inserted into the ball. Below its lower end a cross-beam is placed, one end fixed behind the luteplayer's left shoulder and the other end in the back plate of the castle. On the cross-beam is a firm bearing in which the end of the axle rotates opposite [i.e. normal to the axis of] the axle with the pegs. To the latter axle a peg is fitted whose end is between the teeth of the dancer's wheel on its right-hand side. When the axle with the pegs makes a half turn the peg first fitted turns the dancer's wheel about a quarter turn to its left. Then two more pegs are fitted to the axle with the pegs, to the right of the dancer's wheel. When these two pegs are vertically up the first peg is hanging down. When the two pegs make a half-turn the dancer's wheel will have made a half turn to its right by the time the pegs have disengaged from its teeth. Then the two pegs move down and the single one moves up into the teeth. It is clear that every rotation made by the axle with the pegs turns the dancer's wheel a quarter turn to its left and a half turn to its right. Then the ball and the dancer are mounted on the end of the axle.

I have drawn a picture [Fig. 86] of the vertical scoop-wheel *l* (I have given a picture of the first vertical scoop-wheel previously), the disc *k* on the end of its axle, and the trough *m*. The left-hand end of the axle with the pegs is on the trough of this wheel, and its other end *y* is in the right-hand plate of the castle. [Also shown are] the three pegs *n n n* for the drummer's hand; the three pegs for the lute-player's hand *ṭ ṭ ṭ*; the single peg *s* to the right of the dancer's wheel and the two pegs *ḥ ḥ* to the left of the dancer's wheel; the three pegs *ṣ ṣ ṣ* for the hand of the tambourine-player; the two discs *z* with the cross-pieces around their perimeter in which the teeth of the disc engage, the dancer's wheel *x* with the ball *e* on its end [i.e. on the end of its axle] and the dancer in the Īwān, and the lower end *j* of the axle of the dancer's wheel.

Then a cover is fitted to this castle to hide what is inside it. In the centre of the cover is a hole, from which protrudes the end of the axle, i.e. the *mukḥula*, of the rider's wheel. On the right-hand side of the cover is a concavity with a hole in it. Whatever flows into this concavity drips through the hole into the centre of the [tipping]-bucket.



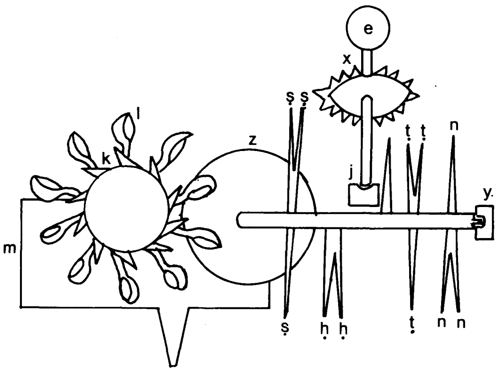


Fig. 86.

Section 5

On the construction of the flute and the production of the sound from the sleeve of the flute-player

A vessel is made, its height equal to the distance between the bottom of the castle and the bottom of the second trough in which is the scoop-wheel. Its capacity is 270 *dirhams* of water. Then one takes a siphon and places the inside of its bend through the wall of the vessel, with one end near the floor of the vessel and the other end one finger length below its base. Then a cover is made for it [i.e. the vessel] and soldered securely to it. A hole is made in the cover which is narrower than the pipe from the first trough[6] which discharges over the scoops of the second wheel. Then this hole is connected to the hole in the bottom of the second trough by some wax [i.e. to the pipe from the trough]. Then a second hole is made in the cover and the end of a narrow pipe is fitted to it, on the end of which is a ball. The ball is placed in the sleeve of the flute-player's blouse since this vessel is behind the flute-player. When water flows into the second trough it is sucked into the hole in the vessel, displacing the air that is in the vessel which is expelled through the narrow pipe into the ball of the whistle. When the vessel fills and the water rises above the bend in the siphon it discharges at the other side of the vessel into the column on the left-hand side of

[6] But the second trough if one includes the tipping-bucket's trough.

the slave-girl. There is no need to draw this vessel since its construction has been described repeatedly in earlier chapters. Whoever wishes to construct [this] should not fit the base [plate] to the castle before the mechanisms are complete, and until they have been tested for [several] days, with several [tests] each day. Then it is fixed, but not soldered. I made it and soldered its base [plate] securely. Then after 30 years something went wrong inside, and I had great difficulty in repairing it.

It is very clear that: the dome *j* is lifted from the upper castle *q* and clarified wine is poured into the reservoir of castle *q* until it fills. The float inside the reservoir, for moving the man, rises and pulls the man backwards, closing the door leaves on him. The dais *ḥ* supports the slave-girls, and upon it are the four pillars *k*, and above the pillars is the first castle *s*, rising above which is the second castle *q*. The dome is replaced, and the rod *e* for the rider passes through a hole in its top. The lower end [i.e. of the rod] enters the *mukḥula* in the axle of the rider's wheel. The horse and the rider *ṭ* are placed on its top. The wine drips through the hole at the bottom of the reservoir into the top of the cover of the first castle and flows through a hole in it into the [tipping]-bucket until this fills in part of an hour, when the contents of the bucket discharge all at once into the bucket's trough. Thence it flows onto the scoop-wheel, the toothed wheel rotates with it and turns slowly. The wine collects in the wheel's trough and flows from it onto the scoops of the second wheel. The toothed wheel turns with it, turning the wheel with the two discs and its axle *y*, upon which are the pegs for moving the hands of the slave girls. The wine flows from the trough of the second wheel and is sucked through its pipe into the whistle's vessel, displacing the air it contains, which is driven into the whistle's ball, which whistles, the sound being thought to come from the flute-player's flute *s*. The slave-girls *f* play their instruments until the wine has all run out and filled the whistle's vessel. The wine rises above the bend of the siphon and is discharged, falling through the pillar on the slave-girl's left, rising through the *ṣawlajān* and flowing into the top of the bottle *w*. This tilts and the wine flows from its mouth into the goblet *x* in front of the slave-girl, until the wine has all run out and filled the goblet. The top of the bottle rises. The steward takes the goblet and hands it[7] to the person towards whom the tip of the rider's lance is pointing. Then he puts the goblet back in front of the slave-girl. When the same period has elapsed a second time, the same procedure is repeated, and so on until the wine is nearly exhausted. The float in the reservoir has sunk, and pulls the string connected to the rod attached to the man's back. He leans forward heavily and opens the two leaves, indicating with his right hand 'no more wine' and with his left hand 'except two goblets'.

Then everything which needs scraping is scraped, and everything which needs painting is painted e.g. the rider, the horse, the man in the kiosk, the kiosk, the dancer, the doors, the balcony, the slave-girls [i.e. the musicians], the floor of the dais, and the [single] slave-girl. Everything is coated with oil of Sandarac and dried for [some] days in the sun. This is what I wished to describe clearly.

Now I will describe what I made, namely a boat the design of which was my invention.

[7] See note 2.

Chapter 4 of Category II

It is a boat which is placed on a pool during a drinking party. It is divided into three sections

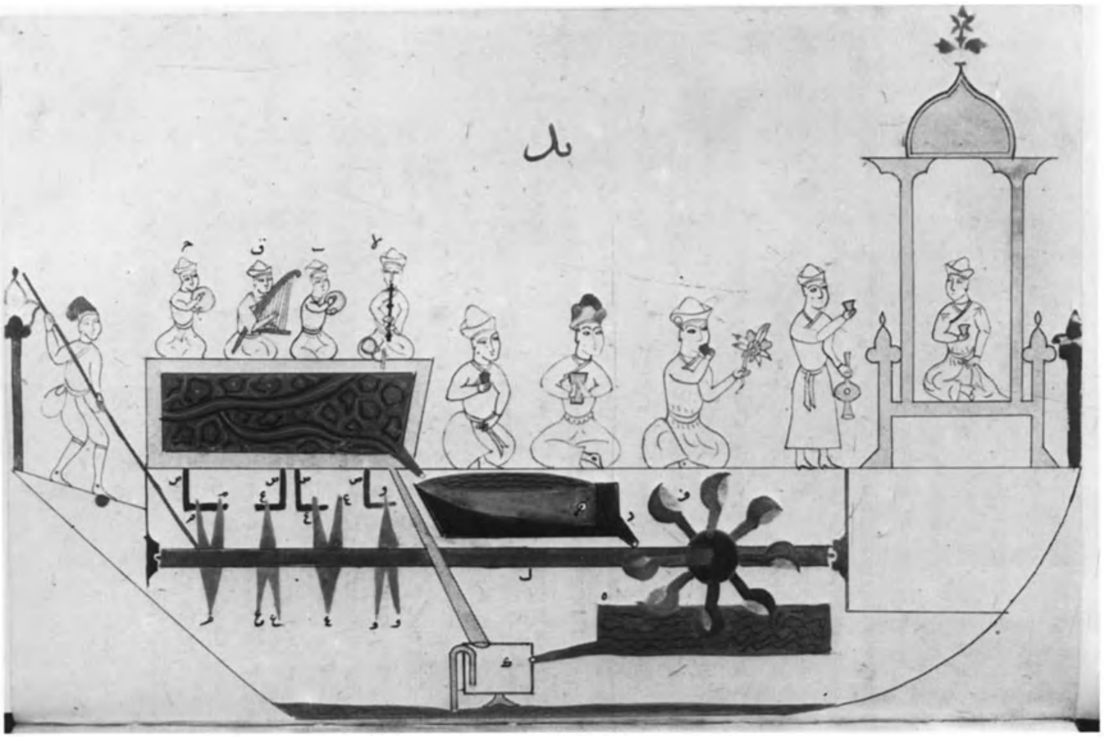
Section 1

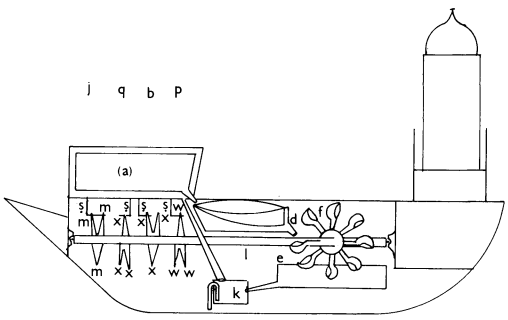
Description of the outside appearance of the boat, and its functioning

I say that I was commissioned by one whom it is impossible to disobey to construct a boat upon which were figures of boon-companions and of a company of female musicians and servants of the court. I did not discover a means of delivering any water to the boat or discharging any water from the boat and [therefore] constructed what I shall [now] describe.

It is a handsome boat made of wood, decked over. On its stem is a platform with a dome above it, and on the platform is the seated figure of the king, with his chamberlain (*ḥājib*) standing on his right at the back of the platform. On his left is the weapon-bearer, and in front of him is a slave holding a jug and goblet, as if serving drinks. Below this is a group of boon-companions sitting to the left and to the right. In their hands and in front of them are objects [such as are used] when drinking. On the stem of the boat is a platform, at the opposite end to the king, upon which are a flute-player, a harpist and then a tambourine-player. Behind the platform and the slave-girls is a standing sailor, holding the boat's rudder. On either gunwale of the boat is a sailor holding an oar. This is the picture of the boat and what is upon it [Fig. 87].

Its functioning: the boat is placed on the surface of a large pool, and is seldom stationary but moves in the surface of the water. All the time it moves the sailors move, because they are on axles, and the oars move it [i.e. the boat] through the water-until about half an hour has elapsed. Then, for a little while, the flute player blows the flute and the [other] slave-girls play their instruments with sounds that are heard by the assembly. Then they fall silent. The boat moves slowly on the surface of the water until about half an hour has passed [again]. Then the flute-player blows the flute audibly and the slave-girls play the instruments, as happened the first time. They do not desist until they have performed about fifteen times.





Section 2

Construction of the boat and the water-instruments fitted in the boat for producing the movements of the slave-girl's hands and the sound of the flute

A boat is made from very thin wood, about 7 sp. long and 3 sp. wide at its centre. Inside and outside it is decorated. A platform like a dais is fitted to its stem, with four columns on its corners carrying a dome [which is] as light as possible. Then the figure of the king is made from papier mâché, and likewise the figures of the boon-companions, which are hollow. As for the sailors: the figure of a naked sailor is made, covered where necessary by a cloth. An axle is placed beneath his feet, fixed to his feet, – its ends move about two firm bearings in the front of the boat. He tilts only backwards and forwards. He holds the boat's rudder in the usual manner, and this moves on a peg in the prow, to the right and to the left, the sailor moving with it constantly. Similarly the two other sailors on the sides of the boat, who are holding two oars [i.e. one each] with their blades moving in the water – the sailors [also] move.

The movement for the hands of the slave-girls, and [the instrument for] the sound of the flute: a copper reservoir, square in section, is made, with sides of 3 sp. and a height of $1\frac{1}{2}$ sp. The whole of this reservoir forms the platform. The slave-girls are on its roof and behind the slave-girls is an inlet hole for the water. Then a [tipping]-bucket is made, the construction of which has been described before. Its capacity is one-fifteenth of the capacity of the reservoir. A trough like the previous ones is placed beneath it, and the ends of its axle move [in bearings] in the sides of the trough. This trough and the [tipping]-bucket are placed under the reservoir towards the centre of the boat on a firm base, with the top of the bucket near the bottom of the reservoir. Below the outlet of the reservoir an axle is erected cross-wise, the ends of which move in bearings on the sides of the boat. Between this axle and the bottom of the reservoir is a gap of about 4 F. To the right-hand end of this axle a scoop-wheel is fitted, beneath which is a trough. [Water] discharges from a pipe in the [tipping]-bucket's trough over the scoops of the wheel. A hole is made in the bottom of the reservoir through which water drips into the [tipping]-bucket. When the [tipping]-bucket is full, it empties all the water that it contains into the trough beneath it, and this discharges from it through a pipe and falls on to the wheel's scoops. It collects in the trough beneath the scoop-wheel and flows from it through a narrow pipe into a vessel of the same capacity as the [tipping]-bucket. This vessel is made for the whistle, having a siphon and a pipe with a whistle-ball on its end which is placed in the hollow in the flute-playing slave-girl. This vessel has been described previously in several places. Water which discharges from it collects in the hull of the boat.

Section 3

Construction of the slave-girls on top of the platform, i.e. the reservoir, and the movement for their hands

The figure of a slave-girl flautist is made from jointed copper. She holds a flute with its end in her mouth. Her place on the platform is on the left. Next to her is a tambourine-player, then a harpist, then another tambourine player. Four marks are made on their stations and a hole the width of a *dirham* is made at each mark. Holes are also made in the floor of the reservoir vertically beneath these holes. A piece of pipe is inserted in each hole and the ends soldered to the floor and roof of the reservoir. Into the hole beneath the flautist is inserted the pipe with the flute's ball, the ball [entering] the hollow in the flautist, who is [now] placed in position and soldered to the platform. The sound issues from her sleeve. The right hand and forearm of the tambourine-player moves about an axle whose ends are fixed in her sleeve. The extension of the forearm is in her hollow [torso]. It has a hole in its end in which is a copper rod (*shaẕīya*) having a ring-shaped end which moves in the hole at the end of the forearm. The other end of the rod goes through the hole under the tambourine player, down beneath the platform, to [a position] close to the axle of the scoop-wheel. It does not touch it [i.e. the wheel] since it is near the prow of the boat, some distance away from it, and is level with the axle. Then the end of the rod is bent at right angles in the direction of the axle. To the axle a short peg is fitted, the end of which, when the scoop-wheel rotates, comes down on to the bent-up end of the rod for the hand, and presses it down. So the hand moves up and down. A single peg on the axle is not sufficient, so two pegs are fitted close to each other opposite this peg, so that the movement of the hand gives two beats and one [beat]. The axle in the sleeve for the forearm should be slanted so that the hand rises and falls obliquely and strikes the tambourine squarely, since the latter is raised obliquely. The other tambourine player is made similarly. The harpist is made like the others of jointed copper, and the harp is of copper with a copper frame and copper strings. It is placed on her left thigh, truly vertical [in one plane], with its top tilted towards the front so that the strings are tilted towards the front. Both her hands are constructed so as to move, with their fingers over the strings but not touching them. In the end of the extension of each of her forearms is a hole in which is a rod which hangs down like the rod made previously for the tambourine player. The two rods go down through a pipe underneath the harpist. For the movement of the right hand, three pegs are fitted to the axle which are similar to the single [peg] made for the tambourine player's hand. For the left hand one peg [is fitted] so that the movement of the two hands is different. A board is installed behind all the rods which descend from the slave-girls to prevent them from moving backwards.

I have shown a picture [Fig. 87] of the reservoir with the slave-girls on it, with the [tipping]-bucket's trough beneath it. Beneath that is the scoop-wheel at the end of the axle with the pegs, and beneath that is a trough from which the water flows into the whistle's vessel, the whistle's vessel being supported on a footing which rises from the floor of the boat.

[The drawing is marked as follows:] the reservoir *a*; the flute player *p* with the whistle's ball inside her; next to her the tambourine-player *b*, with the extension of her forearm and the top of the rod; the harpist *q* with the tops of the two rods in the extensions of her forearms; the [second] tambourine player *j* next to her; the bent-up ends *ṣ* of the rods hanging down from the slave-girls' hands; the pipe *d* of the [tipping]-bucket's trough; the scoop-wheel *f*; the trough of this wheel *e*; the whistle's vessel *k*; the three pegs *w* which move the rod for the tambourine player's hand; the six pegs *x*[1] which move the harpist's hands; the three pegs *m* which move the hand of the second tambourine player, the axle *l* which has the scoop-wheel on its end.

It is very clear that when the water reservoir, i.e. the platform for the slave-girls, is filled with water, this drips from its underside into the [tipping]-bucket. When the [tipping]-bucket has filled in the period of abour half an hour, it discharges its contents into its trough, and these flow on to the scoops of the wheel, turning the wheel on its axle, so that the pegs move the rods which hang down from the slave-girls' hands. The water is sucked down into the pipe which connects the wheel's trough to the whistle's vessel, displacing the air the vessel contains, which is expelled into the whistle's ball. (The whistle is shrill, like a flute; whoever wishes to construct a flute must use delicate ingenuity and fine workmanship, and should make a copper flute[2] instead of the ball's whistle). When the vessel is full and the water has risen above the siphon, it flows out from the siphon into the bottom of the vessel, whence it is returned to the reservoir on the following day. When I completed this boat and its contents, I placed it on the surface of the water, and it tilted and was unstable. So I added much weight to its bottom until it was upright in the water. This is its picture [Fig. 87] and this is what I wished to describe clearly.

[Now] I will describe what I made, namely a pitcher for wine.

[1] This contradicts the text above, where only four are mentioned.
[2] Presumably like the flute's 'jar' in Chapter 1, Category I.

Chapter 5 of Category II

It is a pitcher (baṭiya) for wine which is used in carousals, into which water and wines of [different] colours are poured; it has a valve from which each colour is drawn separately. It is divided into three sections

Section 1

Its outside appearance and functioning

It is a large brass pitcher $1\frac{1}{2}$ sp. high resting on a pedestal. It has a lid like a dome and on the dome is a ball with a projecting staple on top of it. It [i.e. the pitcher] has a valve near its bottom in the shape of the head, neck, breast and forelegs of a cow – up to the haunches. A man is sitting on a light disc on the cow's back, with his right hand outstretched, its index finger on the rim of the disc.

Its functioning: a jug containing aromatic wine (*sharāb raḥānī*) is brought, half the ball of the pitcher's lid is lifted off by the staple, and wine is poured from the jug's spout into the lower half of the ball, from which it runs down into the pitcher through a hole. Then the jug is filled with rose-coloured wine, which is poured in like the first one, then it is filled with yellow wine which is poured in like the second, then it is filled with red wine which is poured in like the third. Then it is filled with pure water and four jugs of water are poured in. The half ball is replaced. The steward takes the goblet and places it below the cow's mouth. Then he turns the man on the cow to a mark chosen by the recipient from the marks written on the semi-perimeter of the disc. Then the goblet is charged: if he wants aromatic wine, out it comes; if rosé, out it comes; if yellow or red, out it comes; if pure water [out it comes]. If desired the four coloured wines can be blended together, and dispensed with a like quantity of water, or one third of wine to two thirds of water, or a fifth part of wine to four fifths of water – according to choice. This is the picture of the outside of the pitcher, with lid, valve and pedestal [Fig. 88].

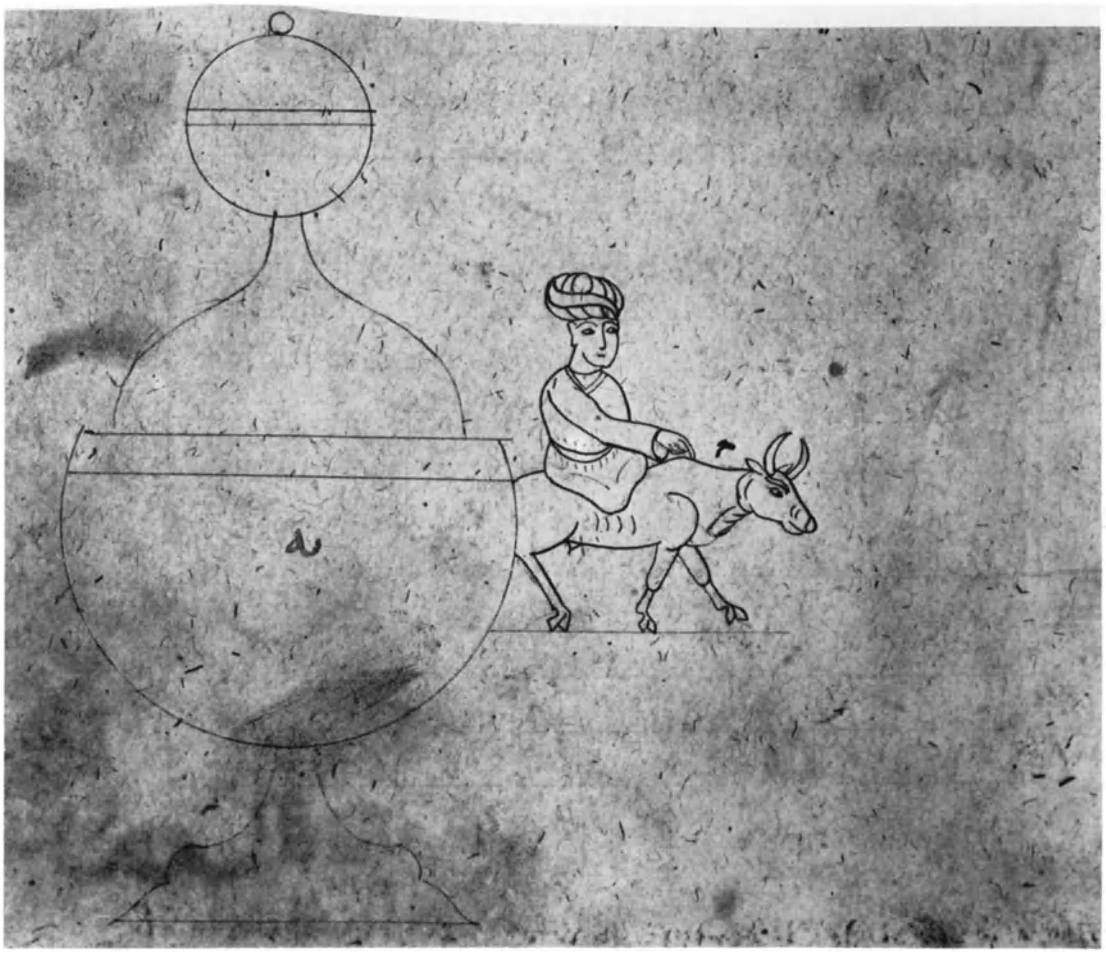


Fig. 88.

Section 2

Construction of the pitcher

One makes a large brass pitcher $1\frac{1}{2}$ sp. high, resting on a pedestal. Then a lid like a dome is made for the pitcher. On the dome is a ball cut into two parts, the [lower] half soldered to the neck above the dome. The other half of the ball has a projecting staple, a bird, or a similar [fitting] by which it can be placed on and lifted off the other half with a sliding fit. The lid and the pedestal are removed from the pitcher. Then a circle of the same diameter as the top of the pedestal is made on the outside of the pitcher and a round hole is cut on this circle so that the bottom of the pitcher is open. Then the position of the valve is marked and a hole made [at that position]. Then one takes a circular plate to fit the lower end of the pitcher above the hole for the valve, and its perimeter is soldered securely to the pitcher. This plate in fact is the floor of the pitcher. Then one takes a plate which, when placed upright on the floor of the pitcher, meets the floor and sides of the pitcher and rises above the pitcher in the shape of the lid. When the lid is placed on the pitcher it meets the whole [length] of the raised edge of the plate, just as it [i.e. the plate] meets the floor and sides of the pitcher. It [i.e. the plate] is soldered securely so that the pitcher is divided into two equal chambers, one of them facing the aperture for the valve. Then one takes another plate, of the same size and shape as the plate erected on the floor of the pitcher, and divides it lengthwise into two halves. Then another plate is made of the same size and shape as one of these halves, so that one has three halves. Then the three halves are erected inside the chamber, namely the one which does not have the valve hole beneath it. These are soldered, so that half the pitcher is thus [divided] into four equal chambers, and the other half is a single chamber above the valve hole. This is the drawing of the pitcher with a round hole in its bottom and a hole for insertion of the tail of the valve [Fig. 89]. Also separate drawings of the four plates which have the same profile as the pitcher [drawn] before installation. One of them, namely the complete plate, divides the

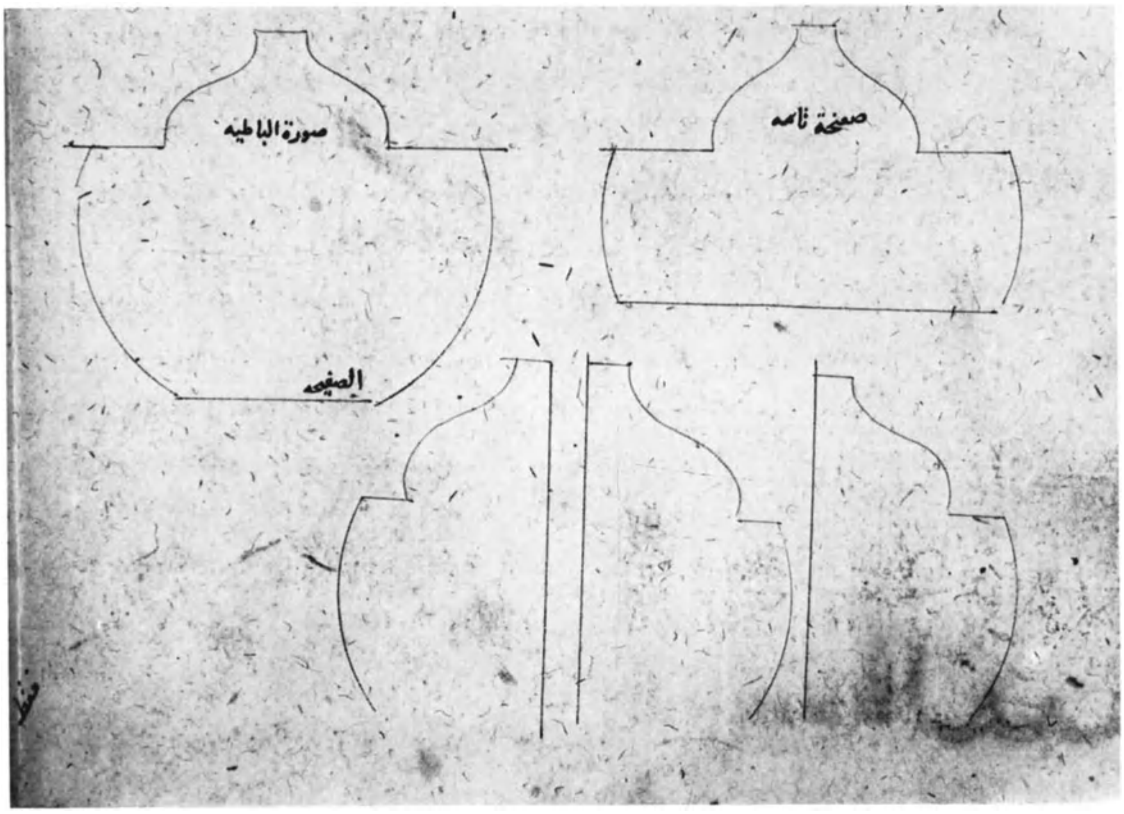


Fig. 89. Caption reads: Right: 'complete plate', left upper: 'drawing of the pitcher'; left lower: 'the plate'.

chamber into two halves, and the three half-plates divide half the pitcher into four equal chambers. The pitcher is marked *l*, the round hole in its bottom *m*. On the valve hole is *n*, and on the plate which forms the floor of the pitcher is *s*. On the complete plate is *x*, and on the three halves *f*.[1] I have shown the picture of the four plates separately to explain how they are fitted inside the pitcher with their upper parts above the rim of the picture, so that the description that follows is clear.

[1] These letters do not appear.

Then a copper cover is made which is inserted in the [neck of] the dome of the pitcher, and fits it neatly. Then the cover just made is taken out and is cut into two halves. One half is fitted to the large chamber of the pitcher, meeting the semi-perimeter of the pitcher and the upper edge of the complete [vertical] plate. Half the pitcher [thus] becomes a chamber, its upper end open at the neck of the dome for the area of half the area of the neck of the dome. If water is poured into the top of this chamber, filling it up to the top, none of it will leak out into another place. Then the other half of the cover is cut into four pieces and each piece fits tightly on to one of the four chambers. The area of the top of each chamber is one eighth of the area of the neck. When water is poured into each chamber separately until it is full, it will not leak out of it into the two adjacent chambers.[2]

When the five chambers have been securely soldered the dome is put back on the top of the pitcher without hindrance, since the necks of the five chambers [i.e. the tops of the five plates] form a circle which enters the neck of the dome. Then the half ball on the neck of the dome is lifted off and the perimeter of the five necks is soldered securely inside the neck of the dome.[3] I have shown the drawing of the plan of the neck with the tops of the five chambers around it. On the large chamber, the chamber for pure water, is written 'water', on the chamber next to it 'aromatic wine', on the next chamber 'rosé', on the next chamber 'yellow', and on the next chamber 'red'. [Fig. 90].

Fig. 90. Captions, reading clockwise from twelve o'clock: 'water'; 'red'; 'yellow'; 'rose'; 'aromatic'.

For the chamber with the aromatic wine a cover is made, i.e. a flat plate to fit the top of this chamber[4], and a hole is made in its centre in which the end of the little finger can be inserted. Then one makes a hollow copper ball (*jawza* – lit. walnut), as light as possible, solders to its top a light circular plate like a *dirham*, and solders to the centre of the *dirham* a vertical pin of length $\frac{1}{2}$ F. The bottom of the walnut is heavier than its top with the *dirham* and the pin. Then a cage (*bayt* – lit. house) is made for the walnut in which it moves freely up and down. The cage is [made from] two rods, one upon the other crosswise, their ends being bent up to make a four-barred cage around the walnut, longer than the latter. The ends of the rods are soldered to the back of the cover of the aromatic wine chamber, around the hole, so that the end of the pin passes through the hole and protudes slightly from the face of the cover. When the walnut rises the *dirham* covers the underside of the hole in the cover tightly. And when the walnut sinks to the bottom of the cage the *dirham* comes clear from the cover of the chamber. Then the cover is placed on the top of the aromatic [wine] chamber, so that the walnut and its cage are inside the neck of the chamber, and the perimeter of the cover is soldered securely to the top of the chamber. This is the picture [Fig. 91] of the cover *d* the walnut's cage with the walnut *s* in it, both on the back of the cover; the ends *k* of the rods; the *dirham a*; and the pin *ṭ* protruding from the face of the cover. I have also shown by the side of this drawing four pictures to illustrate the flow of the wine and the water into the five chambers.

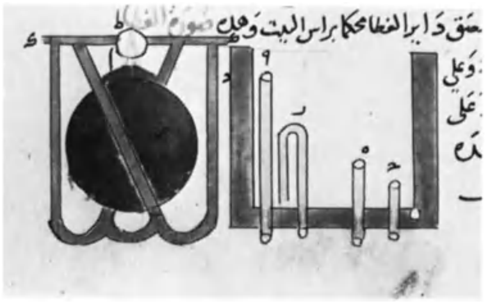
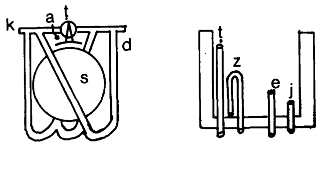


Fig. 91.



Then a cover is made for the rosé wine chamber, on its back a walnut in its cage. To the cover is added [i.e. additional to the fittings on the first cover] a piece of pipe 1 F long and as wide as the hole made in the centre of the cover. It is soldered around the hole in the face of the cover [and stands] upright. The second picture [Fig. 91] shows this pipe *j*. Then for the yellow [wine] chamber a cover is made, a walnut in its cage is fitted to its back and a pipe to the hole in this cover, as before. The length of this pipe is double the [length of the] pipe in the rosé chamber. The third picture shows this pipe *e*. Then for the red [wine] chamber a cover is made, on its back a walnut in its cage, and in its hole, instead of a pipe, is a siphon which is twice as long as the pipe in the rosé chamber. One of its ends is soldered around the hole and the other end nearly touches the surface of the cover. The fourth picture shows the siphon *z*. Then a cover is made for the water chamber with a hole in its centre. This does not have a walnut on its back, and in the hole is a pipe which is longer than the siphon of the red [wine] chamber. The fifth picture shows the pipe *ṭ*. Then one takes a jug of the same capacity as one of the four chambers, its spout the width of one of the holes in the covers of the five chambers, all these holes being the same width. The end of the spout and the hole in the centre of the half ball are also this width. Then the half ball is returned to the top of the neck and soldered, and a hole is made in its centre as before. It is clear that when the jug is filled with aromatic wine, which is poured into the half ball, it flows through to the middle of the neck and runs into the hole in the cover of the aromatic [wine] chamber until it is full. The walnut rises and the *dirham* comes against the underside of the cover, after which

[2] The preceding paragraph may be an interpolation, or a section written before it was decided to fit the ball valves described below. It would have been possible to translate the verb *alṣaqa* as 'solder' instead of 'fit'. The former is often its meaning, and may indeed have been the original meaning if this passage is out of place. But this would have made the subsequent fabrication impossible, since the tops of the plates have yet to be soldered to the sides of the dome. The reading given here implies that the plates were offered up, checked to ensure a close fit, and them removed. In fact the paragraph could be omitted without affecting the description. – See notes giving the sequence of fabrication.

[3] i.e. the upper outside edges of the dividing plates are soldered to the sides of the dome and its neck section.

[4] But the manufacture of these covers has already been mentioned – see Note 1.

nothing can enter the chamber, and nothing from later [fillings] can be mixed with it. Then the jug is filled with rose-coloured wine which is poured into the half ball, flows into the middle of the neck and rises until it reaches the top of the pipe in the cover of the rosé chamber, through which it flows into the rosé chamber. When this is filled the walnut rises and blocks the hole in the cover. Then the jug is filled with yellow wine which is poured into the half ball up to the neck. A little of the rose coloured wine remains in the neck which does not [however] spoil the colour of the yellow [wine], which rises in the neck until it reaches the top of the pipe of the yellow [wine] chamber. It flows through this into the yellow wine chamber until it is full, whereupon the walnut rises and blocks the hole in the cover. Then the jug is filled with red wine which is poured into the half ball. Something remains in the neck [from the previous pourings] which does not spoil the colour of the red [wine]. The wine rises up to the siphon of the red [wine] chamber and flows through it into the red [wine] chamber, taking everything that is in the neck to the last drop. Then the hole in the cover is blocked [by the valve]. Then the jug is filled with water which is poured out – there is no wine in the neck – and rises until it reaches the top of the pipe of the water chamber, through which it flows. Then three more jugs of water are poured in, making four jugs of water. The pitcher has [thus] been filled with water and with wine. Some water remains in the neck which will not spoil the colours of the wine if it is mixed with one of them.

One need not use a jug of this kind if one pours in the first colour until one hears it fall on to the bottom of the second chamber – similarly for the third, fourth and fifth. What flows in will not spoil the other colour in the chamber, because it is a small [amount]. Similarly there is no need for the walnuts, since when the chambers are full the colours cannot be mixed. But I made things easy for those without practical experience, who would be ignorant of the procedure if the jug and the walnuts were omitted.

Section 3

On the construction of the valve (buzāl)

The model of a handsome cow is made from cast-bronze, from her head to her haunches. In her middle, from back to belly a valve-seat (*buthūr*) is made, into which the plug (*dhakar*) is fitted and ground, according to the usual practice in the manufacture of valves. Then [the plug] is lifted out. When the valve seat is made [i.e. cast] it has a long slit from the breast to the shoulder-hump (*sanām*) of the cow which [then] passes through her neck and head into her mouth. In the valve-seat, opposite this slit six equidistant holes are made in a straight [vertical] line, through to the cow's rear end. Then the plug is put back into the seat and effaceable marks are made on it opposite the holes in the seat. Then the plug is placed on the mandrel and non-engraved lines are drawn on it between every pair of marks, with lines outside the first and last holes, making seven lines in all. Then, with the ruler, seven lines are drawn lengthwise on the plug the same distance apart as the lines made on it on the mandrel. This is the drawing [Fig. 92] of the plug with the lines on it, making squares (*bayt murabbaʿ*) with six holes made in them with the same bore as the holes in the seat – on each hole is *j*. Also [shown], for clarification, is the drawing of the holes in the seat, in a straight line, with *m* on each hole.

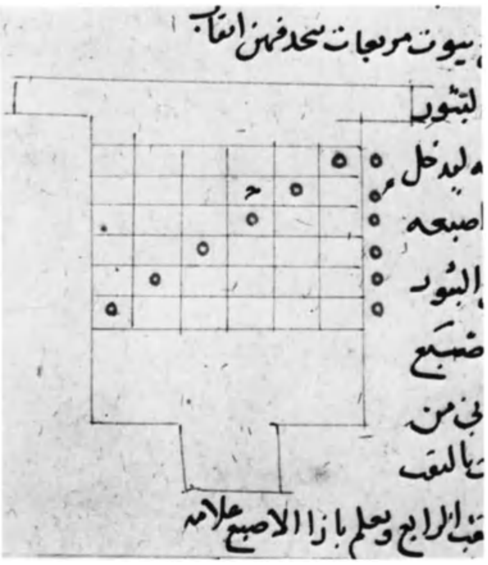


Fig. 92.

Then one makes a disc with a round hole in its centre through which the top of the plug can be passed. It is soldered to the cow's back. Then a seated man is fitted to the top of the plug with his finger on the edge of the disc. Then, before further assembly, the first hole, i.e. the highest, in the plug is aligned with the first hole in the valve-seat, the man's finger being on the rim of the disc on the left-hand side of the cow. A mark is made on the disc opposite the man's finger, and near it 'aromatic' is written. Then the second hole in the plug is aligned with the second hole in the seat, a mark is made on the disc opposite the finger, and near it 'water' is written. Then the third hole is aligned with the third hole, a mark is made opposite the finger, and near it 'rosé' is written. Then the fourth hole is aligned with the fourth hole, a mark is made opposite the finger and near it 'yellow' is written. Then the fifth hole is aligned with the fifth hole, a mark is made opposite the finger, and neat it 'water' is written. Then the sixth hole is aligned with the sixth hole, a mark is made opposite the finger, and near it 'red' is written. When that has been done, prior to assembly, the rear end of the cow is soldered to the aperture made for it at the bottom of the pitcher.

Then the bottom of the pitcher is turned uppermost. It has a round hole in it, and the position of the lower end of each of the five chambers has already been marked. A hole is made in the bottom of the aromatic chamber and this hole is connected to the first hole in the back of the cow by a pipe, the ends of which are securely soldered. A hole is made in the bottom of the rosé chamber and this hole is connected to the third hole in the back of the cow by a pipe, the ends of which are securely soldered. A second hole is made in the bottom of the water chamber and this hole is connected to the fifth hole in the back of the cow by a pipe, the ends of which are securely soldered. A hole is made in the bottom of the red chamber and this hole is connected to the sixth hole in the back of the cow by a pipe, the ends of which are securely soldered.[5] The round piece [cut from] the bottom of the pitcher is replaced and soldered – it is covered by the pedestal. The pitcher, the cover, the pedestal and the valve are scraped clean and everything is coated with oil.

I have shown the drawing of the pitcher [Fig. 93] with the drawing of the aromatic wine chamber inside it with the walnut in its cage at its upper end; the drawing of the pipe in the cover of the rosé chamber, the pipe in the cover of yellow chamber, the siphon in the cover of the red chamber and the pipe in the cover of the water chamber; the pipes from the bottom of each chamber to the holes in the valve.

It is very evident that: the valve is closed, the upper part *p* of the ball [Fig. 93] is lifted and a jugful of aromatic wine is poured into the lower half *q*. It flows over the cover of the five chambers and runs into the hole *z* in the aromatic chamber, because this is the lowest. This fills, the walnut rises, and the hole is blocked by the *dirham*. Then a jugful of rosé-coloured wine is poured in, which collects on the cover of the chambers, rising until it reaches the top of pipe *ḥ*, which is the shortest pipe, and the wine runs through it into the rosé chamber and the walnut rises and blocks the hole. Then a jugful of yellow wine is poured in, and it collects on the cover of the chambers and rises until it reaches the top of pipe *ṭ*, which is higher than pipe *ḥ*. The wine runs through it into the yellow chamber which fills, and the walnut rises and blocks the hole. Then a jugful of red wine is poured in and collects on the cover of the chambers until it reaches the bend in the siphon *y* whereupon the wine runs through it into the red chamber. Everything that remained in the half ball is drained. The walnut rises and blocks the hole. Then four jugfuls of water are poured in and it collects on the cover of the chambers until it reaches the top of pipe *k* and runs through it into the water chamber, which fills up.

Then the half ball is put back. When the steward wishes to draw aromatic wine he turns the finger of the man sitting on the back of the cow *n* to the mark 'aromatic'. The wine flows through pipe *a* into the valve. When he turns it to the mark 'rosé', [the wine] flows through pipe *b*. When he turns it to the mark 'yellow' [the wine] flows through pipe *j*. When he turns it to the mark 'red' [the wine] flows through pipe *d*. When he turns it to the mark 'water', [the water] flows through pipe *e* and when he turns to the second mark for the water, it flows through pipe *w*. I have also explained how to pour out a mixture.

This is what I wished to describe clearly.

Now I will describe what I made, namely a boon-companion.

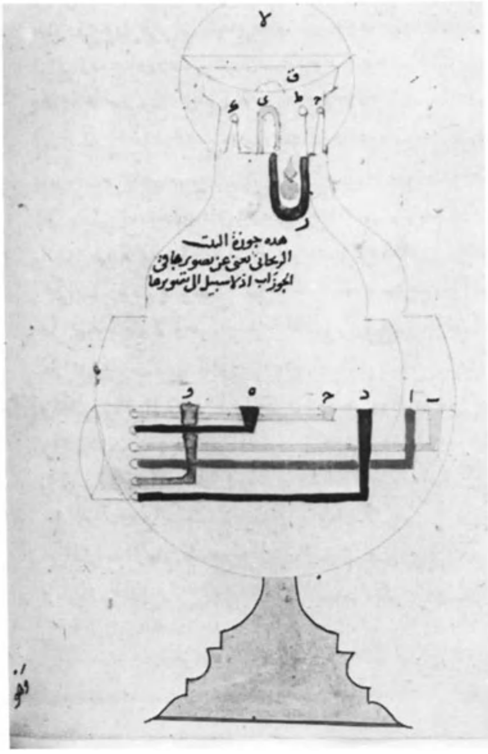
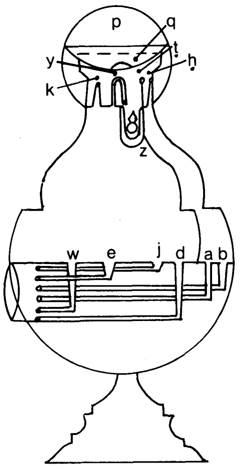


Fig. 93. Caption reads: 'This is the walnut of the aromatic chamber – its illustration refers (also) to the other walnuts, since there is no means of illustrating them'.



[5] Two connections have been omitted in the MS – from the water chamber to the second hole, and from the yellow chamber to the fourth hole.

Chapter 6 of Category II

Is the figure of a man, a boon-companion, who drinks the king's leavings, i.e. the wine left in the bottom of the goblet. It is divided into two sections

Section 1

Description of its outside appearance and purpose

It is a kneeling figure made of jointed copper. He holds a goblet in his right hand with fingers extended along its stem, and in his left hand he holds a waterlily by its stalk.

It was one of the customs of the kings in those days, when they were drinking, to leave some [of the wine] in the goblet and this, when it had collected, was drunk by a boon-companion designated for that duty. This boon-companion [i.e. the model] is placed in front of the head of the carousal. When he drinks a goblet the steward takes it, pours what is left in it into the boon-companion's goblet, and stands aside. When left by himself he [i.e. the boon-companion] lifts the goblet in his hand until its rim is between his lips [where it stays] for a while. Then he lowers the goblet from his hand and nods his head several times. This happens every time wine is poured into the goblet. His left hand moves and is observed by the head of the carousal until after a while it reaches a certain position.

Then the head of the carousal says to someone he wishes to make fun of, and who does not know the purpose of the boon-companion, 'So-and-so, take this boon-companion, who drinks wine and hides a secret. Put him on your knee, drink, and give him [wine] to drink.' So he takes him without argument, puts him on his knee, drinks and gives him drinks. He does not finish two or three goblets before [the boon companion] pours on to him all he has drunk since the beginning of the carousal, wetting his clothing. The wine flows beneath him, making him a target for laughter. This is appropriate at certain times, but it is more usual for the king, when he knows the boon-companion is about to discharge what he has drunk, to have him carried outside the company and given two or three goblets, so that he discharges what he has drunk. [Then] he is brought back into the company. This is his picture [Fig. 94].

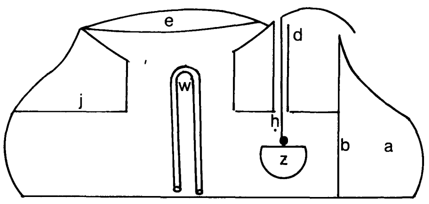
Fig. 94.

Section 2

Construction of the boon-companion

A human figure is made from jointed copper in the form of a five year old boy, squatting on his knees. This figure, like all such figures, has a shift. Some [figures] are constructed without legs, some with legs. On this figure the feet are not visible – the shift appears to be covering the legs. Then the shift is cut into two pieces: a piece from the waist down, and a piece from the waist up. In the lower half a vertical partition is fitted between the groin and the buttocks, like a tank. [N.B. the remainder of the tank is formed by the shift itself.] A flat cover, stretching from right to left, is made for the trough. Its length is divided into two halves. In the centre of the right-hand half a hole is made, as wide as a thumb, and above this hole a funnel is erected, with a spout as wide as the hole and a third of a fingerlength long. In the centre of the other half a hole is made upon which a pipe one fingerlength long is erected. Then a float is made with a flat cover in the centre [i.e. in the centre of an imaginary sphere]. On its cover is a staple to which the end of a string [is tied]. Then a fine siphon is made with one leg longer than the other. A hole is made in the floor of the tank directly below the funnel's spout, and the long end of the siphon is fitted vertically to this hole and soldered. The other end almost touches the floor of the tank. The float is placed in the tank, and the end of its string is passed through the vertical pipe which is on the hole in the plate. The [cover]-plate is placed on the tank, locating the elbow of the siphon halfway up the funnel's spout, with the perimeter of the plate fitted to the perimeter of the tank. This [Fig. 95] is the picture of the lower section *a*, the partition *b*, the cover-plate *j* with the pipe *d* on it, the funnel *e*, the siphon with its elbow *w* in the funnel's spout, the float *z* with the string *ḥ* in its staple, going up through the pipe *d*.

It is clear that when water is poured into the funnel it runs down into the tank, and the float, which is partly below the water surface because of its weight, rises until the water level reaches the cover. The water has not reached the bend in the siphon [but] if a little more water is poured into the funnel it will rise to the bend in the siphon, and all the water will be discharged



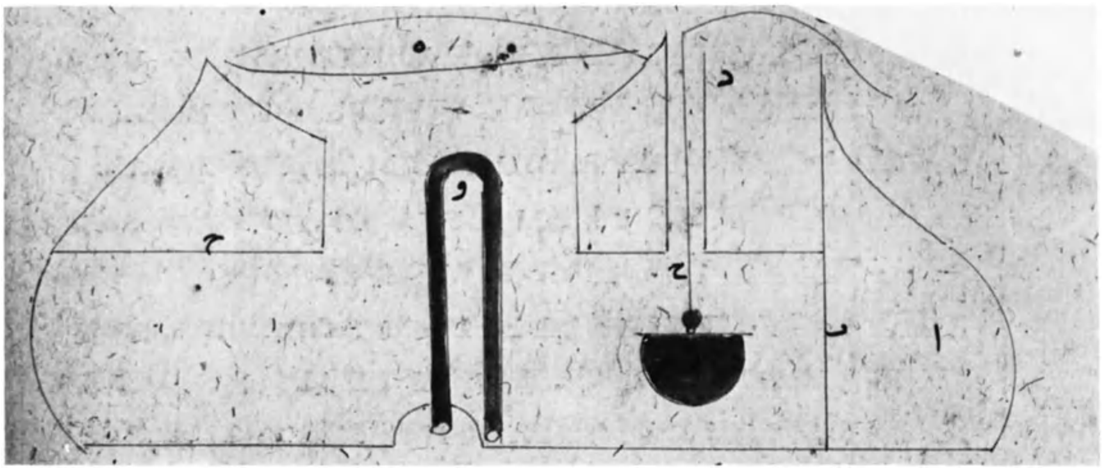


Fig. 95.

through the end of it which is in the floor of the tank. Then a head, dark-coloured or with a pointed cap (sharbush), is made in proportion to the size of the figure. A hole is made cross-wise at the bottom of the neck and an axle is passed freely through it, the ends of which are soldered to the collar of the shirt. The end of a rod, one fingerlength long, is fixed at the bottom of the neck and to the other end [of the rod] a weight is rigidly attached. The head therefore oscillates forwards and backwards. Then a right hand is made as appropriate, holding a goblet of brass or silver, as light as possible, with a flat cover in open filigree. The fingers are grasping its stem. In the stem is a hole which penetrates through to the hollow forearm, elbow, and upper arm. [At the end of the upper arm] is a jar which holds 20 *dirhams* of water. A siphon is made, one end of which almost touches the floor of the jar, while the other is outside, below the bottom of the jar. The inside of its bend is in the wall of the jar. It is fixed in position. A cover is made for the jar and fitted to it. A large hole is made in the centre of the cover, opposite the siphon, and the end of the upper arm is soldered to it, so that the upper arm is fixed without blocking the water inlet to the jar. Then an axle is fitted to the elbow around which the arm moves up and down inside the sleeve of the shift – it is a short sleeve. This is the picture [Fig. 96] of the arm *a*, the goblet *j*, the ends of the axle *e e*, the jar *w* and the siphon *z*.

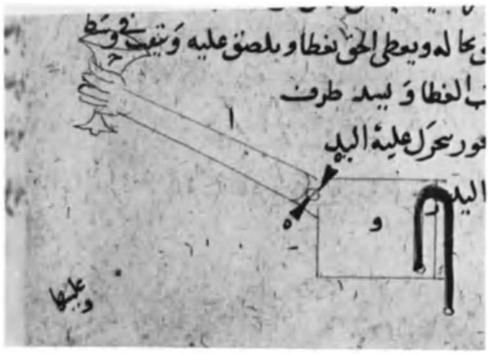


Fig. 96.

It is clear that when water is poured into the goblet it flows slowly from its stem through a fine pipe into the outstretched arm and collects in the jar for a while. The jar moves in the opposite direction to the hand and the goblet, since the hand and the goblet rise. The water rises to the bend in the siphon (which is a narrow siphon) and some of the water is discharged through it, whereupon the jar becomes lighter and rises. But the discharge of the water is not interrupted by the lifting of the jar, and flows out to the last drop. Then the arm is put into the sleeve of the shift and the ends of the axle soldered to the sleeve. The sleeve is wide at the hem, narrow at the axle and the arm should move without showing the axle – one should not find this difficult. I made it, concealing the ends of the axle, and the construction did not prevent the movement. The right end of the axle should be higher than the left, and when the goblet is in the hand its brim is tilted to the right. When it is raised to the man's[1] mouth it straightens up, because it is raised obliquely – one attends to this during fabrication. Then the left hand is made, which holds a water lily by its stalk. In its elbow is a hole with an axle in it about which it [i.e. the arm] moves up and down in the sleeve of the shift. In the upper arm is a staple. After the arms are made and placed in the sleeves a pulley is placed under the left shoulder in a housing soldered inside the shoulder, and then another pulley on a transverse axle fitted vertically below the hole in the elbow of the left arm. The end of the string from the float is lifted and passed over the pulley in the shoulder. It hangs down, and is passed under the pulley near the upper arm and is tied to the staple at the end of the upper arm.

The upper part of the man[2] is now put back on the lower part, and they are joined together. The float is on the floor of the tank, the string from its staple having been lifted over the pulley in the shoulder. It hangs down and is passed under the pulley near the upper arm and tied to the staple in the upper arm. The float is heavier than the arm, which is stretched out [upwards] with the stalk of the water-lily raised off the man's thigh. When water flows into the tank the float rises slowly and the hand with the water-lily sinks slowly. When the top of the float touches the cover of the tank the end of the water-lily's stalk almost touches the man's thigh joint. Then it is known that when the water in the tank is increased by a small amount, the water will rise in

[1] The word *rajul* (man) is used, although this is a five year old boy.
[2] See note 1.

the funnel's spout to the bend in the siphon, and all the water will be discharged rapidly through the siphon. As for the jar on the end of upper right arm – it is higher than the funnel, and what discharges from it [goes] into the funnel. I have repeated the picture [Fig. 97] of the upper and lower [parts] of the man, so that it is understood.

It is very clear that wine is poured into the goblet *k* [Fig. 97] almost filling it, then flows through the forearm *ḥ* of the boon-companion into the jar *z* on the upper arm. [The jar] becomes heavier and sinks, the wine rises to the bend in the siphon, which has *ṭ* on its end, the goblet *k* having risen until its rim is between the lips of the boon-companion – his head is pushed backwards slightly by the goblet. Then the wine runs from the end *ṭ* of the siphon into the funnel *j* and collects in tank *b*. Jar *z* then becomes lighter (the remainder of the wine is still discharging from the siphon) and it rises while the arm and the goblet sink. When the goblet leaves the lips of the boon-companion his head moves forward rapidly and oscillates several times and [then] comes to rest. The left hand *s* sinks all the while the wine is rising in tank *b*. Float *x* rises with the string connected to it, which is passed over the pulley *e* underneath the boon-companion's shoulder, and is then passed under the other pulley *m*, which is underneath the point of the elbow, then goes up and is tied to the hole *ṣ*. The water-lily *y* sinks in the hand until the bottom of its stalk almost touches the thigh of the boon-companion. So it goes on until the wine rises in the tank almost to the bend *n* in the siphon in the tank. And then, if the boon-companion drinks an additional glass or two glasses, the wine rises to the bend in the siphon and issues from its end *q* which is underneath the boon-companion, until no more wine is left in tank *b*.

That is what I wished to describe clearly.

[Now] I will describe what I made, namely a slave [ghulām] who is cup-bearer to the king.

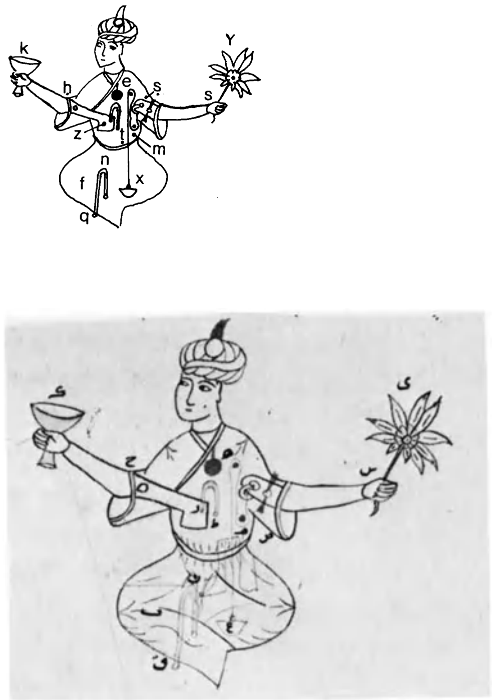


Fig. 97.

Chapter 7 of Category II

It is a standing slave holding a fish and a goblet from which he serves wine to the king. It is divided into three sections

Section 1

On the outside appearance and functioning of the cup-bearer

He is a standing slave, ten years old in appearance, dressed in a short jacket (*farajiya*) with a robe (*qabāʾ*) underneath it, and a cap (*qalansuwa*) on his head. In his right hand is a glass (*qadaḥ min zajāj*), the fingers curled around the bottom of the glass so that it can be taken out of his hand and put back. His upper arm [points] downwards, his forearm is extended, with the hand and glass slightly raised. His left hand is in the same position, but higher than the glass, and holds a silver fish. Its head is higher than the glass by about 4 F and its tail is downwards. He stands by the king's side until about one eighth of an hour has passed, whereupon the head of the fish tilts until it is near the glass, and clarified wine (*sharāb murawwaq*) flows from its mouth into the glass until it is almost full. Then its head lifts and the slave's hand with the glass sinks about one small span from its previous position. The king takes the glass from the slave's hand, drinks its contents, and puts it back in his hand, which has returned to its previous position. This happens at time intervals like the first, until the carousal is over and [the company] rises.

Section 2

On the construction of the figure

From jointed copper a figure is made with the appearance of a ten year old slave, standing on his feet. He is made from a plate, hammered thin – it is 4 sp. long and $1\frac{1}{2}$ sp. wide. Its ends are bent round and soldered so that it takes the shape of a cylinder. This is formed to resemble the lower part (*dhayl*) of a shift, from the hose to the waist, which is made slightly wider at the bottom by hammering. It is not circular but hangs down without concealing [the feet]. Then above this cylinder another one is made, and hammered into the shape of the belly and chest of a slave. Above this one fits the shoulders with a round hole like a collar between them. Then a head is made, i.e. a soldered cylinder. One end is wide – this is his head. The neck is made narrow by repeated hammering. [The head] is provided with a face, forehead and part of the neck. If the craftsman is not competent enough to make the face by hammering he can make [various] parts thicker with lead, e.g. the nose etc. The inside of the head, neck, shoulders and breast are tinned and also a plate which is fitted below the breast. Thus the breast, head and shoulders form a wine reservoir. The head is soldered securely to the collar. Then one takes a plate and fits it inside the skirt, 4 F above its hem. It is not soldered [yet]. Then to this plate one fixes legs, starting at the knee and [having] a lower leg and a foot – i.e. one makes a pipe in the shape of the lower leg and the knee. For the foot one takes a pipe with one end narrower than the other end and shapes it to resemble a foot. To its top one fits something resembling the top of a slipper (*khuff*) and to its underside one fits something resembling the bottom of a slipper. When the leg is completed, one imagines this to be a slipper. The other leg is made in the same way. Each leg is then soldered to the plate at the knee, the legs wide apart as is usual. The craftsman should not be afraid that the slave will tilt in any direction. I made him and placed the soles of the feet on the ground, and was afraid that he would tilt, but when he was standing erect he did not tilt at all. The plate with the legs [fixed] to it remains [untouched] until it is soldered. Then one makes from copper forelocks and two lovelocks (*dhawāʾib wa sudghān*) for the slave. Then two sleeves are made for the shift, cut short at the elbows; inside each sleeve a slit is made through to the torso.

I have described the fabrication of this figure to make its construction easy for the craftsman, having omitted to explain this in earlier chapters.

Section 3

Construction of the slave's hands and their mechanism, of the fish, and of the palm of the slave's hand through which the wine runs into the forearm and into the fish

A hollow right arm, hand and fingers are made in one piece, holding the bottom of the glass, the little finger preventing the glass from descending too much. There is an axle across the elbow in the sleeve of the shift, its ends firmly fixed. The end of the upper arm is weighted inside the torso of the slave, so that the arm and the glass are raised – they sink when the glass of known weight is filled with the known [amount] of wine. A light, hollow fish is made from silver. In its breast towards the head is a cavity [leading] towards outside, and from there to its middle is a cavity towards the inside. In its middle is a partition plate which prevents the wine from running into the half of the tail end. Then the left hand, with palm, fingers and part of the forearm is made, grasping the middle of the fish. The forearm is hollow and as light as possible – the hollow goes through to the hollow in the fish, near its head.

Then a trough is made and placed in the slave's body, its highest point almost touching the plate which divides his breast from his belly. The height of the sides of this trough is about 3 F. Then a [tipping]-bucket, as described in several previous chapters, is placed in the trough. Its sides are short, 1 F high, and its capacity is only about 60 *dirhams* of wine. When it is filled its tip tilts and it discharges its contents into the trough. Then the left arm is made, which is really the sleeve of the robe from the wrist and forearm up to the elbow. The elbow is inserted in the sleeve, one end of the elbow in the sleeve and the other end touching the side of the [tipping]-bucket's trough. A hole is made in the side of the trough into the hollow in the elbow and soldered to it. Then one takes a narrow pipe long enough [to reach] from the hole in the side of the [tipping]-bucket's trough to outside the forearm, namely the sleeve of the robe. Then the [part of] the forearm attached to the fish is placed loosely in the sleeve of the fish. Then a rod is fixed vertically to the end of the pipe, with a hole in its upper end. In this hole an axle is inserted cross wise, its ends soldered to the sides of the fish, which moves in the axle like the arm of a balance. The rod is soldered to the narrow pipe out of which the wine flows into the fish. This rod acts like the column of a balance. When the fish moves the forearm and the hand clutching the fish move in the sleeve of the robe. The fish is tilted [down] towards its tail. When wine discharges from the bucket's trough into the narrow pipe in the hollow of the arm, it issues from its end into the middle of the fish, and a small quantity of it collects in the breast of the fish, since this is hollow towards its underside. The head becomes heavier and sinks until it is near the glass. The wine flows into the glass, slowly because of the narrowness of the fish's mouth, until the glass is nearly full. The fish's head becomes lighter and rises, together with the arm, to its previous position.

Now the plate with the slave's legs on it is soldered to the inside of the skirt and the slave is stood up. Then he is painted with various colours, as is the jacket above the robe. A cap is placed on his head. If desired a fine shirt of some kind may be added, which is so light that when he wears it the movement of his body [i.e. the arms] is not impeded.

For a clear understanding I have shown a picture of the slave and what is inside him [Fig. 98]: – his right hand and the glass *p*, the axle *q* in its elbow, the weight *j* in its upper arm; the wine-reservoir *f* in part of his breast and his entire neck; the [tipping]-bucket's trough *ṣ* and the [tipping]-bucket *x*; the narrow pipe *ṭ* soldered to the bucket's trough and extending to the hollow in the fish; the rod *m* with a hole in its end in which the axle is [inserted].

It is very clear that when the cap is lifted from the head of the slave clarified wine, such as is drunk by kings, is poured into his head. (The wine reservoir, as [mentioned] previously and everything into which the wine falls is tinned.) The cap is put back on his head and the wine drips from the underside of the reservoir into the bucket's trough and flows through the narrow pipe into the breast of the fish, making it heavier. It tilts until its head comes down near the glass, pouring its contents slowly into the glass until it is almost full. It becomes heavier and his hand descends as if he were offering the glass to the king. The king takes the glass, drinks from it, and returns it to his hand, which has risen to its previous position. This continues until the wine reservoir is empty, whereupon the company disperses.

This is what I wished to describe clearly.

Now I will describe what I made, namely a man holding a goblet and a bottle, who pours wine from the bottle into the goblet, and drinks it.

Fig. 98. Caption reads: And in the author's handwriting: 'I have drawn the bucket in its trough, and a pipe extends from it to the breast of the fish; on its end is a rod upon which it (i.e. the fish) moves and through which is the axle'.
N.B. Caption is omitted from Fig. 98. It is beneath the figure in the MS.

Chapter 8 of Category II

It is a man holding a goblet and a bottle. He pours wine from the bottle into the goblet and drinks it. It is divided into two sections

Section 1

Description of its outside appearance and functioning

It is a standing slave holding a silver goblet in his right hand by the stem of the goblet. In his left hand is a bottle with its top pointing to the top of the goblet. Every one eighth of an hour wine flows from the bottle into the goblet. He lifts his right hand with the glass in it to his mouth so that the rim of the glass is between his lips [and holds it there] for a while as if drinking the contents of the goblet. Then the goblet leaves his mouth and his hand returns to its former position. In this model the bottle does not move, neither does it prevent the rise and fall of the goblet, although the latter rises close to it.

The construction of the figure was described in the previous chapter so there is no need to explain it here. The construction of the goblet: the top of the goblet is covered with a flat lid which is extensively filigreed. In the pedestal of the goblet is a hole which goes through to the palm of the man's hand, up his forearm into his upper arm to a jar connected to the underside of the upper arm. In it [i.e. the jar] is collected the wine which is poured into the goblet. The arm moves about an axle in its elbow. In the jar is a siphon and when the wine collects therein it rises to the bend in the siphon. [Meanwhile] the jar has become heavier and descends and the hand with the goblet rises to the man's mouth. The wine discharges through the siphon into the tank inside the man's body, and the wine collects on it. When the man is removed from the assembly the wine is extracted from his right sleeve. The construction of this hand was described more fully in a previous chapter [Chapter 6] than it has been described here.

Section 2

Construction of the left hand holding the bottle, of the wine reservoir and the [tipping]-bucket

It should be understood that the hands of this man are higher than the hands of the cup-bearer [in Chapter 7], so it is not possible to make the wine reservoir from the lower part of this man's chest. Instead, the wine reservoir is made in the upper third of this man's chest to his neck. [This space] and his head and neck under his cap are thoroughly tinned. In the top of his head is a slit through which the wine is poured into the reservoir. Its floor is a plate, beneath which is a trough with a [tipping]-bucket in it, whose construction has been described previously. The bucket's trough is short and is 1 F wide and the bucket is flat with low sides – it has a capacity of 20 *dirhams* of wine. In the floor of the reservoir a hole is made through which the wine discharges into the bucket. In the side of the bucket's trough is a pipe which is bent into the man's elbow. Its end emerges from the sleeve of the robe. A silver bottle is made, and the lower part of its neck closed by a plate so that wine cannot enter the main part of the bottle. A hand is made grasping its neck, and part of the hollow forearm – [the hole] penetrates to the neck of the bottle. The forearm is inserted in the sleeve and the end of the pipe [is inserted] in the neck of the bottle, where it is soldered; the bottle does not move.

Then this figure is made as beautiful as possible by painting with different colours and similar [decoration]. On top of the head a cap is placed, and he may also wear a shirt which does not impede the movement of his right hand.

I have shown a picture [Fig. 99] of this man: the hand of the goblet *j*, the axle *d* in his elbow; the jar *e* and the upper arm; the siphon *w* in the jar; the wine reservoir *z*; the trough *ḥ* and the [tipping]-bucket; the narrow pipe *ṭ* connected to the side of the bucket's trough and extending through the left hand into the neck of the bottle; the bottle *y*.

It is very clear that the cap is lifted from his head and wine is poured into the reservoir until it fills to the top of his head. Then his cap is put back on his head and he is brought into the assembly. After about an eighth of an hour about 20 *dirhams* of wine flows from the collar [i.e. the upper part of the body] into the goblet. His hand and the goblet rise until the rim of the goblet is between his lips where it remains for a while. Then the goblet leaves his mouth and his hand descends to its previous position. This happens every one eighth of an hour. The wine collects in the trough, i.e. his belly, and when the party is over the man is tilted on to his right-hand side and the wine in his belly flows out of his sleeve.

That is what I wished to describe clearly.

[Now] I will describe what I made, namely a dais with two *shaykhs* on it, who serve each other with drinks.

Fig. 99.

Chapter 9 of Category II

It is a dais upon which are two shaykhs, each holding a goblet, and a bottle from which he pours wine into the goblet of his friend, who drinks it. It is divided into two sections

Section 1

On its outside appearance and functioning

It is a long rectangular platform surrounded by a fretted balustrade; the height of its supports is about 4 F. On it are two old men facing each other. Each one holds a goblet in his right [hand],[1] and a bottle in the left, with the palm and fingers grasping the neck of the bottle, the top of which points towards his friend's goblet. On the corners of the dais are four columns each about $1\frac{1}{2}$ sp. high and above the columns is a castle about 1 sp. high. Above the castle is a handsome dome. The dais, as I have described it, is set down in a drinking party, and when about one eighth of an hour has elapsed one of the *shaykhs* pours wine from his bottle into his friend's goblet. His friend drinks it and nods his head several times. When about an eighth of an hour has elapsed [once more] the other *shaykh* pours wine from his bottle into his friend's goblet. His friend drinks it and nods his head several times; and so on until the company disperses.

[Now] I will describe the construction of the dais, the two *shaykhs*, the columns and the castle. A dais is made with a floor of copper and supports of cast bronze, the height of each support being about 4 F excluding its foot and its top. The centres of the supports are enclosed by plates which cover the underside of the dais. Near the bottom of the supports these plates are covered by a plate so that the dais becomes a tank with this [last mentioned] plate as the floor of the tank. Then a balustrade, fretted and painted, is fitted around the upper part of the dais. On the floor of the dais, near its corners, four hollow brass columns about $1\frac{1}{2}$ sp. high are erected. Above the columns is placed a brass castle, its long side four times as long as its short side, the same [length] as the dais, and about 1 sp. high. Above the castle, on its centre, is a small dome, having the same width as the castle. Around the upper perimeter of the castle is a fretted balustrade. What remains of the top of the castle at the sides of the dome is decked over, since the dome is in the centre of its upper surface.

Then two dark-complexioned *shaykhs* are made from joined copper, sitting cross-legged and facing each other along the dais. Each one holds in his hand, namely the right hand, a silver goblet with a highly filigreed lid. When water is poured [into it] it runs through its stem into the hollow hand and then into a jar with a siphon in it, as described [before]. The left hand grasps the neck of a bottle, the lower part of the neck being closed by a plate to prevent the water from running into the main section of the bottle. In the neck of the bottle is a hole in which is the end of a pipe. [The pipe] goes through the palm, forearm and elbow of the *shaykh*, is bent through into his body, is bent [again] beneath his skirt, and is inserted into the column on his left-hand side, from which [water] flows into it from above.

Section 2

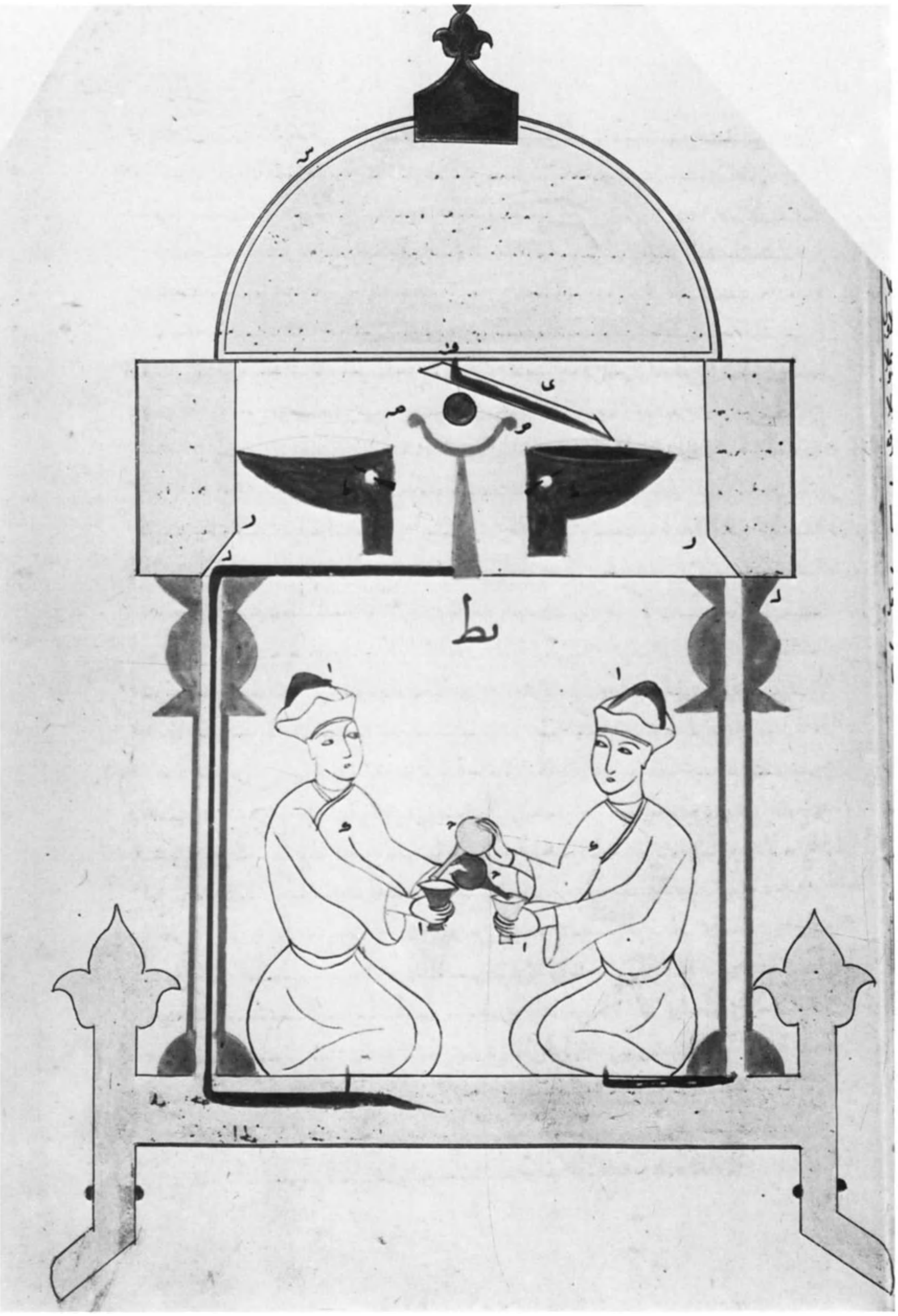
Construction of the reservoir for the water, and its discharge into the bottle of one shaykh and the bottle of the other shaykh alternately

A trough is made from copper, its sides 2 F high and the same area as the floor of the castle. A vertical plate is erected across the floor of the trough, dividing it into two halves. In each trough a [tipping]-bucket, as described previously, is erected, its capacity 20 *dirhams* of water. The back of each bucket is towards the plate which divides the trough into two. Then at the top of this plate in its centre two struts (*shaẓīya*) are fitted. One end of each strut is soldered to the plate and the other end projects a thumb's breadth above the plate. In it [i.e. the upper end of the strut] is a hole, so that an axle, yet to be mentioned, can rotate in the two holes. Between the two holes there is a gap. Then one takes a piece of channel, as light as possible, one fingerlength long. On its underside, in the centre, is a transverse [axle]. The ends of the axle are inserted in the holes in the two struts, and moves freely in them. The channel is then at right angles to the

[1] In Fig. 100 one holds the goblet in his right hand, the other holds it in his left – and vice versa for the bottles.

divided plate and its ends are directly above the rear ends of the two [tipping]-buckets. Of necessity one of its ends is tilted gently by its weight on to the near end of one of the buckets. When water drips into the channel it flows into this bucket which fills up. Its tip swings down and its rear end rises, lifting the end of the channel so that [water] which falls into the channel [now] drips into the other bucket. When this fills its tip swings down, its rear end rises and lifts the end of the channel which returns to its former position, and the water drips into the first bucket. And so on, as long as the water drips into the channel.

Then one makes a water reservoir for installing above the trough of the two buckets and the channel. It fills the castle and the dome and has a hole in its top[2] through which the water is poured. In its floor is a hole through which [the water] drips into a short pipe [then] into the



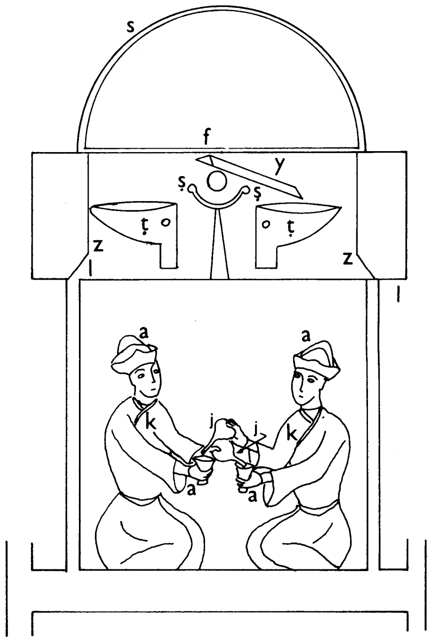


Fig. 100.

[2] Not clear. The hole may be in the dome.
[3] i.e. so that the water is directed into the channel.

channel so that the water does not run along the underside of the reservoir.[3] Then in the bottom of each of the two troughs a hole is made to which a pipe is fitted, the [other] end of which is connected to the vertical pipe in the adjacent column. The discharge into each trough thus flows into the end of the pipe connected to the neck of the bottle of each *shaykh*.

I have shown a picture of this: the platform, and the *shaykhs* with *a* on their heads and *a* on their hands; their elbows *k* which move on axles; the jars beneath their upper arms – no need to illustrate them since that was done previously; the bottles *jj* with the end of a pipe in the neck of each bottle; [the pipes] run from their hands to their elbows, then are bent down, emerge from beneath their skirts, [go] into the columns on their left-hand sides, then up to the tops *l* of the columns; two pipes *z* connected to the tops of the pipes in the columns and to the troughs *ṭ* of the buckets; the plate dividing the two troughs with the struts *ṣ* on it, the channel *y* which moves on the ends of its axle in the holes of the struts; the short pipe *f* from which the water drips into the channel from the underside of the reservoir; the reservoir *s*.

It is very clear that water is poured into the reservoir until it is full. It drips from the floor of the reservoir *s* into the channel *y* and runs through it into bucket *ṭ*. [Then] it flows from its trough into pipe *z* and descends through the column's pipe to beneath the *shaykh*'s skirt and rises through the pipe in his arm only as far as the elbow. [This is] because the bucket discharges 20 *dirhams* and the downpipe and the rising pipe are filled by 20 *dirhams*, so nothing from the first bucket flows into the neck of the bottle. The end of the channel has tilted towards the other bucket and water flows in it until it is full. It discharges its contents into the pipe of the other channel, and the downpipe and the rising pipe are filled only as far as the elbow of the other *shaykh*. The channel tilts [back] to the first bucket into which water flows until it is full. It discharges and the water runs out and flows into the neck of the bottle [up] to its mouth, and flows into the goblet whose capacity is 20 *dirhams*. [Then] it flows from the stem of the goblet through the hand into the jar until it is almost full. It [i.e. the jar] sinks, the hand rises with the goblet until the rim of the goblet is between the *shaykh*'s lips, where it remains for a while. The contents of the jar discharge from the end of the siphon on to the floor of the dais, then run down through a hole into the tank, i.e. the dais. His hand sinks and the goblet leaves his lips. His head had been backwards and [now] recoils rapidly and nods several times. The construction of the head was described above in the chapter on the boon companion [Chapter 6]. Things proceed in like manner for the other *shaykh*, and they go on drinking in turns until the water in the reservoir is exhausted. The company breaks up, the dais is lifted and the water is poured out of a hole in the tank near one of the columns.

When it has been completed according to my description the dais, the columns, the castle, and the dome are scraped, and the two *shaykhs* are painted in various colours as previously. Everything that has been scraped and painted is coated with Sandarac oil.

This is what I wished to describe clearly.

[Now] I will describe what I made, namely a female cup-bearer.

Chapter 10 of Category II

It is a slave-girl who emerges from a cupboard at intervals, holding a glass which contains wine. It is divided into two sections

Section 1

On its outside appearance and functioning

It is a cupboard made of wood about 7 sp. high and $2\frac{1}{2}$ sp. wide. It has a door with two closed leaves. This cupboard is by the king's side during carousals. It is of fine workmanship, and covered with variegated paintwork.[1] At the expiry of one eighth of an hour the leaves open on a slave girl standing in the door holding in her right hand a glass filled with wine and in her left a small towel (*mandīl*). The king takes the glass, drinks the wine it contains, puts the glass back in her hand and, if he wishes, wipes his mouth with the towel. Then he closes the [door] leaves on her. After an eighth of an hour the leaves open [again] and the slave girl emerges holding the glass. The king takes it, drinks, returns the glass to her hand and closes the leaves. This happens every one eighth of an hour.

I will describe the construction of the cupboard and the slave girl. A wooden cupboard is made of fine workmanship covered with variegated paintwork.[2] It has a door $4\frac{1}{2}$ sp. high and $2\frac{1}{2}$ sp. wide, which is raised slightly above the floor of the cupboard. Two brass leaves are made for it, which turn easily on their hinges. Then a hollow slave girl is made as light as possible from papier mâché, like a girl twenty years old. She stands on her feet. Then one takes a board 2 sp. long and as wide as the slave girl's foot is long. Then four rollers of cast-bronze are fitted at the corners of the board, in axles placed cross-wise in transverse slots at the corners of the board. When this board is placed on a flat surface which is inclined in one direction slightly, with its width in the direction of the slope, it will move rapidly on the rollers until stopped by something. The feet of the slave girl are placed across the board and secured to it. When the board with the slave girl on it is placed on a sloping surface with her face in the direction of the slope, the board and the slave-girl will move rapidly in the direction of the slope as long as they are not hindered by anything. Each of the rollers should be as I have described and of a width that can be encircled by the middle finger and thumb. At the centre they are a thumb's breadth thick, at the edge a barleycorn. This is the picture [Fig. 101] of the roller on its axle. Then two copper channels are placed on the floor of the cupboard, sloping gently from the back of the cupboard to its front, and are [then] made secure. When the slave-girl is lifted onto the floor of the cupboard with the rollers in the copper channels, she moves rapidly to the door of the cupboard and [then] stops.

Fig. 101.

Section 2

On the construction of the slave-girl's hand and its mechanism, the wine reservoir, the [tipping]-bucket and its trough

A right hand is made for the slave-girl from copper, as light as possible, with the palm and fingers appearing as if she were grasping a wine glass.[One also makes] her forearm and elbow, with an axle in the elbow upon which it moves up and down. Its [i.e. the axle's] ends are fixed inside her sleeve. In her elbow is an extension which sticks out like a rod; its end penetrates her back through a slit which extends upwards, and protrudes about one fingerlength from her back. A short length at its end is bent down. Then the slave-girl is pushed to the back of the cupboard until her arm, i.e. the one which is extended and which holds the glass, is inside the cupboard. Cross-wise behind the slave-girl is an iron bar, its ends fixed to the sides of the cupboard, so that the bent down angle of the rod which extends from the slave-girl's elbow hooks on to the bar. This prevents the slave-girl from moving to the door of the cupboard because this bent-down end is heavier than the slave-girl's hand with the glass, when it [i.e. the glass] is empty. When a known [quantity] of water falls into the glass it becomes heavier than the end of the rod, and the angle

[1] *Nuqūsh*. This could also mean carved figures.
[2] See footnote 1.

Fig. 102.

lifts off the bar. The slave-girl runs rapidly on the rollers and opens the leaves with her left hand, which holds the towel. The left arm does not move and is longer than the right [arm]. When the left [door] leaf is pushed with the left hand, the right leaf opens first, because it is above the left one, and it does not touch the glass.

Then a copper reservoir is made, the same width as the top of the cupboard, and about 1 sp. high. Its interior is tinned. On top of it is a hole through which wine is poured into it. On this is a wide pipe, rising above the hole in the top of the reservoir, and on this is a shaped cover. Then beneath this reservoir a trough is installed, in which is a [tipping]-bucket whose construction has been described before. Its capacity is 100 *dirhams* of wine. In the floor of the reservoir a hole is made with a short pipe on it through which the wine drips into the bucket. A wide hole is made in the floor of the bucket's trough in which is a short pipe which is [vertically] over the board and hence pointing to the glass, when the slave-girl is inside the cupboard and prevented from emerging. I have shown the picture [Fig. 102] of the slave-girl *a* inside the cupboard and the board beneath her feet on the rollers, two rollers being visible; her hand, holding the glass, which moves about an axle *j* in her sleeve, the rod extending from a long slit in her back, its end *b* bent down, and held by a bar *d* across it; the bucket and the bucket's trough *e*, in which is a pipe *w* through which the wine flows into the glass, the reservoir *z* with a hole in its bottom upon which is a pipe from which the wine drips into the bucket, the wine is poured into the top *k* of the reservoir.

It is very clear that when the reservoir is filled with wine it drips into the bucket which fills in the space of one eighth of an hour and empties its contents into the bucket's trough, which discharges all at once into the glass in the slave-girl's hand. The glass becomes heavier, the angle of the rod lifts off the bar, and the slave-girl runs [down] and pushes the left leaf with her left hand, which is holding the towel. The leaves open without touching the glass. She stands at her post. The king takes the glass from her hand, drinks its contents, and if he wishes, wipes his mouth with the towel. Then he puts the glass in her hand, presses it down, and pushes the slave-girl gently until she shops. He lifts her hand up, and the bent end of the rod hooks over the bar. This is not visible to the company – the most they see is that he puts the glass in the slave-girl's hand and closes the leaves. This happens about every one eighth of an hour until the company breaks up.

That is what I wished to describe clearly.

[Now] I will describe what I made, namely a ewer from which is poured hot water, cold water and mixed [i.e. luke-warm water].

CATEGORY III

Manufacture of pitchers, basins and other things

Chapter 1 of Category III

A pitcher from which hot water, cold water and mixed water is poured. It is divided into two sections

Section 1

Description of the outside appearance and its functioning

It is a pitcher of handsome workmanship with a handle and a spout. The slave brings it on a tray at the end of the meal and places it in front of the diner [*al-makhdūm* – lit. the one being served]. He lifts the pitcher from the tray and pours over the diner's hands moderately warm water, with which he completes his ritual ablutions (*wuḍū'*) or the washing of his hands. Then on the hands of the person whom he is putting to the test he pours hot water unbearable to the touch, so he cannot wash his hands. Then on the hands of the person whom he is putting to the test he pours very cold water, unbearable to the touch. Then he tilts the pitcher over [the hands of] the person whom he is putting to the test and nothing comes out of the pitcher. He pours out [warm water] to whomsoever he wishes in the company, and refuses it to whomsoever he wishes.

Now I will describe the construction of the pitcher. A brass pitcher of the most handsome design is made. One third of its neck [is left] and two thirds removed. There is no cover on its bottom. Then a copper plate is made to measure and inserted longitudinally in the bottom of the pitcher up to the third of the neck. Its perimeter is soldered securely to the inside of the pitcher. Thus the pitcher has been divided lengthwise from its bottom up to one third of its neck into two unequal chambers. Then another plate is made to the same pattern as the first and soldered to the inside of the pitcher like the first. There is a gap 1 F wide between the two plates, so the pitcher has become two equal chambers with a gap between them. When one of the chambers is filled with hot water and the other with cold the hot does not get cold and the cold does not get hot. I made a pitcher with a single plate and the hot got cold and the cold lukewarm. So I made it again with two plates and achieved the required result. The two plates are joined together inside the pitcher at two different [lit. opposite] points: one under the handle and the spout and the other place, higher than this, in the third of the pitcher's neck. The tops of the two plates are brought together and soldered, the top of each chamber [thus] being semicircular. It should be understood that neither plate is inserted into the bottom of the pitcher before its edges have been bent along lengthwise so that they are flat when inside the pitcher.

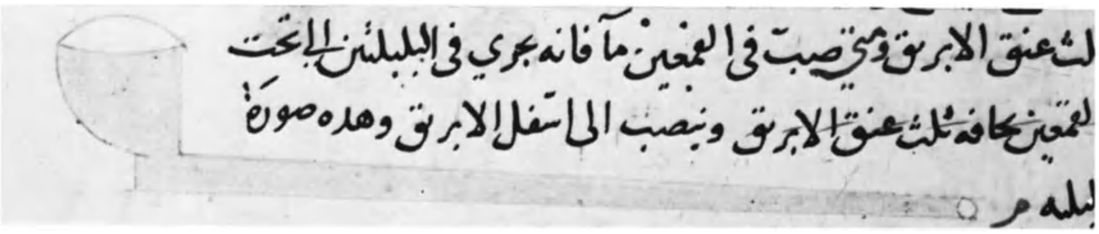


Fig. 103.

Then a funnel is made to be inserted in the top of the chambers [i.e. one such funnel to each chamber]. It has a semi-circular rim with a spout at an angle [to the funnel] the end of which extends to [a point] beneath the pitcher's spout and almost touches the side of the pitcher. Then another funnel is made to this design, and placed in the top of the other chamber with its spout also beneath the pitcher's spout. The edges of the two funnels are soldered to the perimeter of the one third neck of the pitcher. When water is poured into the two funnels it flows through the two spouts to [a point] beneath the pitcher's spout. The edges of the two funnels are soldered to the perimeter of the one third neck of the pitcher [sic. This phrase is repeated]. They discharge into the bottom of the pitcher. This is the picture [Fig. 103] of one funnel with *k* on its top and *m* on the end of its spout.

Section 2

Construction of the deflector, (ṣadafa) which discharges water into the two chambers; completion of the pitcher

In one of the two chambers a float is placed with a projecting lug (*zirr*) on its surface. Then on top of this chamber a cross piece is fitted, with a hole in its centre which the tip of the lug on the float enters with ease. When the funnel is filled with water the float rises until its surface touches the cross-piece on top of the funnel, and the lug rises above the cross-piece. Then in the other funnel a walnut [i.e. a small circular float] is placed. On top of it is a thin rod as long as the [complete] neck of the pitcher. Then the rest of pitcher's neck is replaced and a joint is made between the one third neck and the two thirds. Then one makes a copper disc, as light as possible, its diameter such that it can move easily in the neck of the pitcher. Its diameter is grooved slightly, so that if it is placed on a flat surface and water is poured on to its centre it will flow from the centre along the diameter to one of its edge. The name of this disc is the deflector (*ṣadafa*). Then a cross-axle is fitted to the diameter at the back of the deflector, which cuts across the grooved diameter [but on the other side of the disc]. The ends of the axle are placed in firm bearings inside the neck of the pitcher, so the deflector and the axle move freely in the bearings. One edge of the deflector is weighted underneath so that this edge rests on the float's lug, by nature. If water runs on to the centre of the deflector it flows into the funnel in which the float is [placed]. When the chamber and the funnel are filled, the float rises and its lug lifts the edge of the deflector, which rises. The other edge sinks into the other funnel and if water runs on to the centre of the deflector it will flow into the funnel which does not have the float. Then the bottom of each of the chambers in the pitcher is sealed with a separate plate which is securely soldered. To the bottom of the pitcher the usual kind of cover is fitted.

Then one makes a hollow handle and at the position of the handle two holes are made in the pitcher, each into one of the pitcher's chambers. Two pipes are fitted to the holes and brought through into the hollow of the handle, their ends penetrating to the inside of the handle's bend. They are soldered to the pitcher and to the bend of the handle. One of them is higher than the other. The handle is soldered to the pitcher and to its neck. Then a spout is made and placed in its position on the body of the pitcher. Around its lower perimeter on the body of the pitcher a mark like the outline of a ring is made. Half of this ring is on one of the pitcher's chambers and the

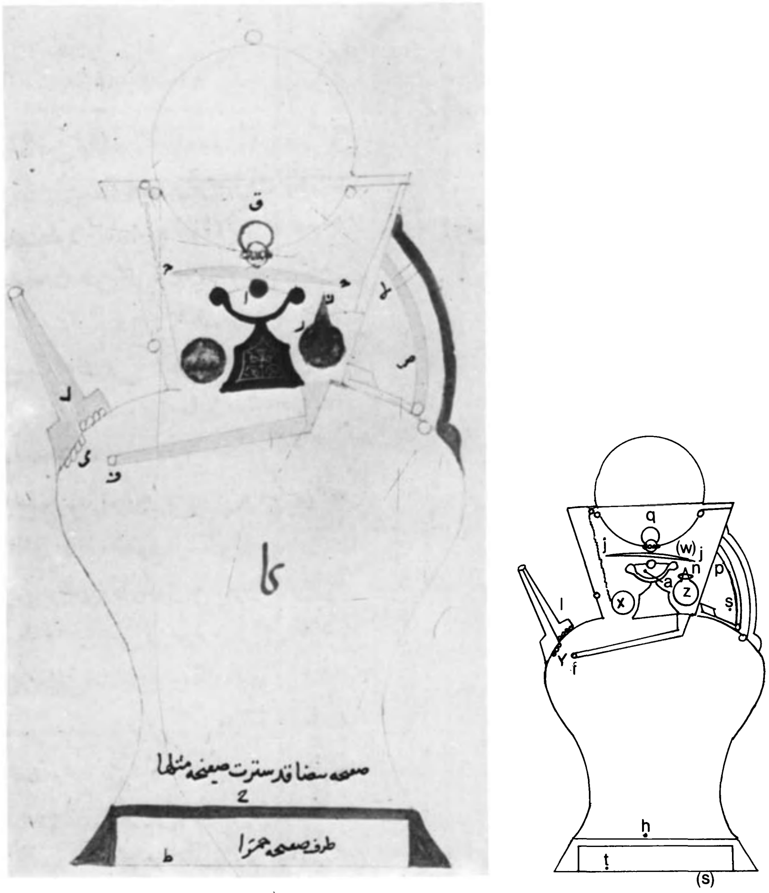


Fig. 104. Captions read: Upper: 'a white plate which has concealed a similar plate'; lower: 'the end of a red plate'.

other half on the other chamber. (The two plates are joined together below the mark, and below the handle, as [mentioned] before.) Into each chamber inside the neck about five holes are made, [one group of holes] opposite the other. [Then] the spout is soldered in place.

Then on top of the pitcher a plate is fitted, concave downwards like a funnel, with about seven closely-spaced holes in its centre through which the water flows into the centre of the deflector. [There are also] three holes on the edge of this funnel [i.e. the cover plate] to let out the air; through one of them projects the tip of the walnut's rod.

I have shown the drawing [Fig. 104] of the pitcher: the funnel *q* which discharges on to the deflector; the heavy side *w* of the deflector, and the ends of its axle *j*; the tip *a* of the float's lug; the cross-piece *n*, on top of the funnel, with the [lug of the] float in it; the float *z*; the end *f* of the spout from the float's funnel; the walnut *x* in the other funnel; the holes *y* which penetrate to the spout from the chamber with the float's funnel; the other holes *l* which penetrate through to the spout from the hot-water chamber, the hole from the cold-water chamber, with a pipe *p* on it the end of which goes through to the bend in the handle; the hole from the hot chamber with a pipe *ṣ* on it, the end of which goes through to the bend in the handle below the first; the plate *ḥ* [under] the cold chamber; the lower plate *ṭ* to the hot chamber; the cover *s* at the bottom of the pitcher.

It is very clear that the servant pours cold water into the funnel at the top of the pitcher and this falls on to the centre of the deflector and flows into the float's funnel until the chamber is full. The float rises and with its lug lifts the edge of the deflector, which tilts. The sound of it falling on the other channel is heard, so no more cold water is poured in after that. Then hot, almost boiling, water is poured in, which falls on to the centre of the deflector and runs into the walnut's funnel until the chamber is full. The walnut with the rod on it rises and the top of the rod rises above the top of the pitcher, and it is known that the hot chamber has filled, so nothing more is poured in. The servant knows the action of the two holes in the handle. When he closes with his finger the upper hole in the handle and pours, he pours hot water; when he closes the lower hole he pours cold water; when he lifts his finger off the holes the water comes out mixed, from both chambers; when he closes both holes nothing comes out at all.

That is what I wished to describe clearly.

[Now] I will describe what I made, namely a pitcher which discharges water from its spout while resting motionless on the floor.

Chapter 2 of Category III

It is a pitcher which the slave sets down beside a basin on a handsome pedestal in front of the King. Then the servant stands aside. A bird on top of it whistles, water issues from its spout for [the King] to perform his ritual ablutions before departing. It is divided into two sections

Section 1

Description of the outside appearance of the pitcher and its functioning

King Ṣāliḥ, may God double his righteousness, disliked a servant or slave-girl pouring water on to his hands for him to perform his ritual ablutions and he wished me to make [something] for pouring water onto his hands for his ritual ablutions. So I made for him a large pitcher of fine workmanship with a spout that was raised up [then] bent down, its end being almost horizontal. When it is required the servant brings it, puts it down by the basin on a handsome pedestal which is for raising it above the ground, and stands aside from it. A bird on its cover whistles for a while then the water begins to flow from a spout. [The King] performs his ritual ablutions – there is so much water that some is left over after his ablutions. The servant picks it up, pours water into it, waits for the necessary period, and brings it [back]. The operation which I have described then takes place [again].

I will describe its construction: a large brass pitcher of fine workmanship is made and divided by a plate into two chambers, a chamber from its middle to its bottom, and a chamber from its middle to its top. Then a narrow pipe of constant cross-section about 2 sp. long is taken and bent to form a siphon, with one end longer than the other. The long end points towards the outside. This is its picture [Fig. 105]. Then a hole is made at the position of the pitcher's spout and the

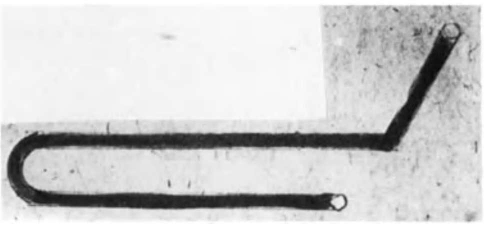


Fig. 105.

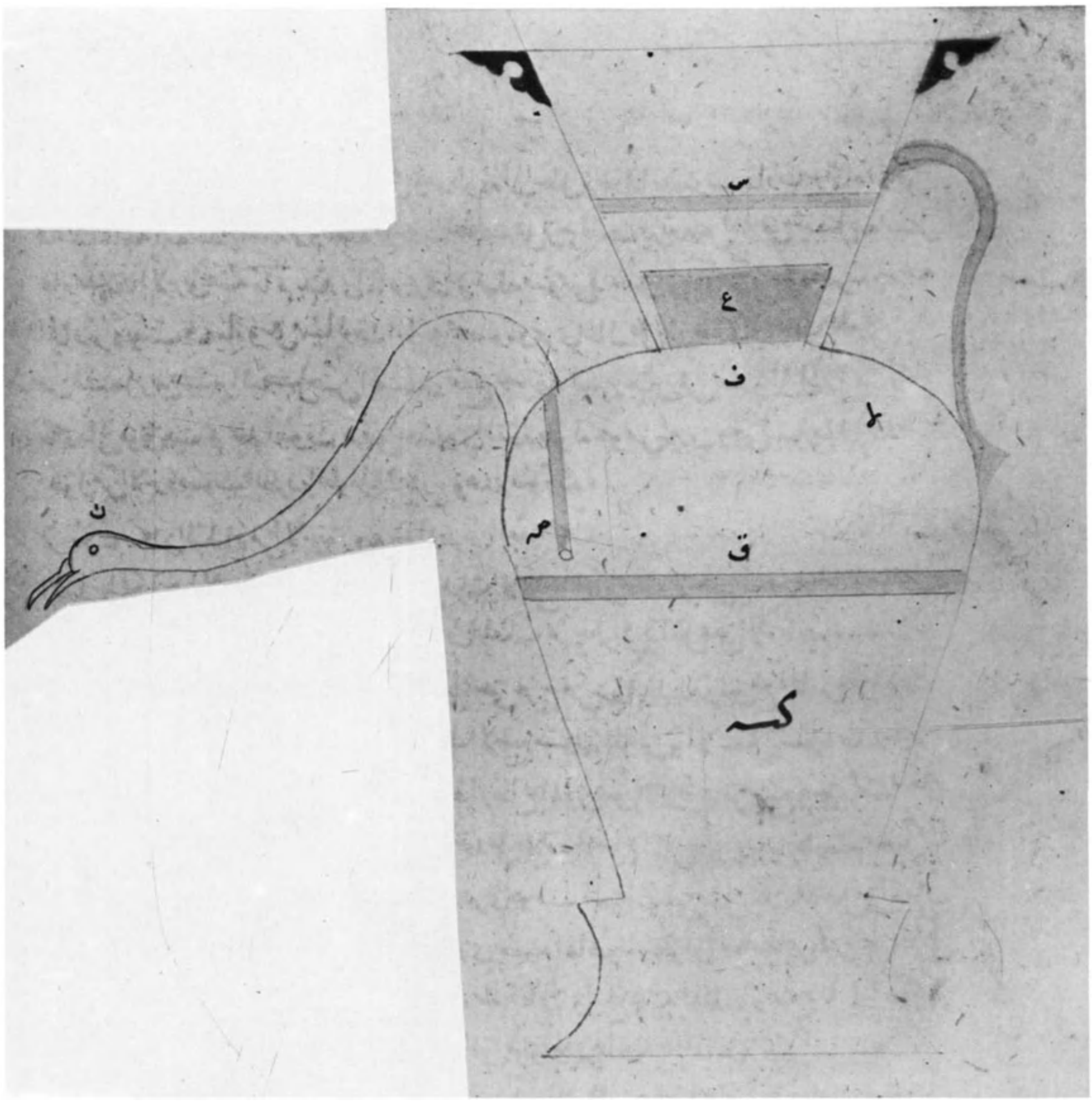
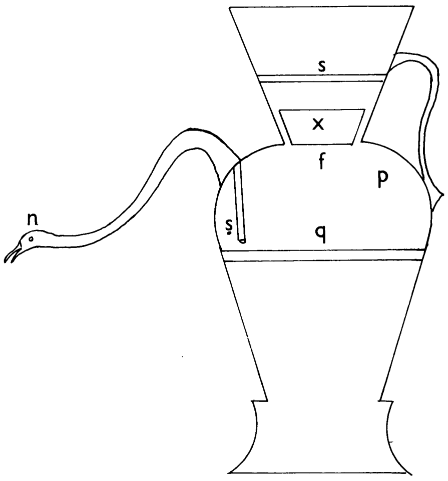


Fig. 106.



short end of the siphon is pushed inside the pitcher until it almost touches the floor of the upper chamber. It is soldered in position. Then the visible part of the siphon is coated with copper and lead until it resembles the neck of a duck, its head being at the end of the siphon. Then inside the neck of the pitcher a mark is made at the same level as the bend in the siphon. That is [done] by pouring water into the top of the pitcher until it comes out of the duck's beak. The mark is made where the water came to in the pitcher's neck. Then a float is made with vertical sides about $\frac{2}{3}$ of a fingerlength high. The top and bottom are flat. Its size is such that it can be inserted with ease in the neck of the pitcher, until its top is 1 F below the water-level mark. Then a crossbar is fitted beneath the float to prevent it from sinking below the prescribed [level], and a crossbar is erected at the water-level mark in the pitcher's neck to prevent it from rising. When water is poured into the top of the pitcher it flows around the float until the upper chamber of the pitcher fills. The water rises until it touches the bottom of the float, which rises. The person who is slowly pouring in the water observes the float until its upper surface touches the crossbar which is on the water-level mark, and he pours in no more after that. The water has then reached the bend in the siphon and a little more water is needed to rise around the float until it [i.e. the water] touches the crossbar which is above it, and to submerge it [i.e. the float]. At this juncture the water has risen above the bend in the siphon.

I have shown the picture [Fig. 106] of the pitcher and the plate which divides it into two chambers; the float at the bottom of its neck with a crossbar underneath it preventing it from descending into the body of the pitcher, since it [i.e. the float] rests upon it, and above it another crossbar, which prevents it from rising above the mark which is level with the bend in the siphon in it. [Other markings are as follows:] the plate *q* dividing the pitcher into two chambers; the crossbar *f* below the float *x*, with a crossbar *s* above it; the siphon whose end *ṣ* almost touches the plate which divides the pitcher into two chambers and its other end *n* in the duck's beak:

When the water in the pitcher is increased by an amount which raises it around the float, namely about 5 *dirhams* of water to a maximum of 10 *dirhams*, its rise around the float is $\frac{1}{2}$ F. If [therefore] about 10 *dirhams* of water is poured suddenly on to the contents of the pitcher, it rises around the float and up to the bend in the siphon. The water rushes out through the siphon, and the entire contents of the pitcher are discharged.

Then a handle is made for it and a cover is soldered to its base in the usual manner. This is the end of the section [lit. of the words].

Section 2

On the construction of the pitcher's cover from which water which rises around the float to the level in the siphon

A cover is made for the top of the pitcher like a dome with a pipe on its perimeter – this pipe does not move when lowered into the neck of the pitcher.[1] Its length is such that when the cover is fitted to the top of the pitcher its lower end almost touches the crossbar which prevents the float from rising. This pipe is divided into two chambers, one above the other. In the centre of the floor of the upper chamber is a valve, which I shall describe. It is a seat[2] having a plug which is fitted and ground in a workmanlike manner. In its centre a hole is made which slopes down, penetrating to [a point] near the bottom of the seat. On top of the plug is an upward extension like a rod the end of which protrudes through a hole in the top of the cover. This is a separate picture of the valve [Fig. 107]: the plug *w*, the upper ends *ṣ* of the hole through the seat, and its lower end *a*. The upper end of the hole is in the upper chamber, and its lower end, which is near the bottom of the seat, is in the lower chamber. When water is poured into the upper chamber, the valve being closed, it fills it and remains there. When the plug is turned and [the valve] opened the water runs into the lower chamber.

Fig. 107.

Now a [tipping]-bucket is placed in the lower chamber, of such a size that it can move freely therein. Water which flows from the valve [runs] into it and is discharged from it into the lower chamber, where it collects. In the centre of the floor of the lower chamber is a hole with the end of a siphon in it, which rises almost up to the bucket and is bent down so that its end almost touches the floor of the chamber. When water is poured into the upper chamber through a hole in the top of the cover, the valve being closed, the water collects in the upper chamber. When the valve is opened – its hole is very narrow – the water flows slowly from the upper [end of the] hole which is in the upper chamber and issues from the lower [end of the] hole in the lower

[1] i.e. it is a push fit in the neck of the pitcher.

[2] Here the valve is *fītūn* and the seat *tanūr*.

Fig. 108.

chamber. It falls into the bucket which fills and discharges several times. The water collects in the lower chamber until it reaches the bend in the siphon, which is wider than the siphon in the pitcher's spout. The water flows through the siphon and the entire contents of the lower chamber are discharged all at once. I have shown the picture [Fig. 108] of the pitcher's cover which is the under-cover (*biṭāna*) of a cover mentioned below. [The markings are as follows:] the undercover *p*; the pipe connected to it which is divided into two chambers, the lower chamber being marked with *z*; the extension *x* to the valve plug; the upper [end of the] hole *q*, in the valve, above the floor of the upper chamber; the lower [end of the] hole *a* beneath the floor of the upper chamber; the bucket *ṭ* which is in the lower chamber moving on an axle the ends of which are in the upper part of its chamber; the siphon *y* fitted to a hole in the centre of the floor of the upper chamber.

Then this pipe is inserted in the neck of the pitcher with the [domed] cover uppermost. In it is an aperture through which water is poured into it; the end of the valve-rod projects from the centre of the aperture. On this cover is another, of handsome design and workmanship, and the end of the valve-rod is soldered to the centre of the [second] cover from inside. When this cover is rotated it rotates easily, together with the valve-rod. The valve is shut and opened by this cover. Then a staple and ring are fitted to [the side of] the aperture in this cover in line with the handle of the pitcher. A mark is made at the top of the handle: – when the staple and ring are at the mark of the handle the valve is closed, and when the ring is moved to the right by rotating the cover the valve is opened. A [retaining] pin, which goes down into a slot in the top of the pitcher, is fitted to the undercover so that this does not move from its position. A hole is made by the side of the centre of the cover for filling the first chamber.

It is very clear that water is poured into the pitcher until it fills, and the float rises until it touches the crossbar in the neck of the pitcher. The water has not risen above the bend in the siphon of the spout, and nothing flows from it.

Water is poured into the upper chamber in the cover, with the valve closed, and the cover is placed on the pitcher with the two chambers down inside the neck of the pitcher. The basin is placed in front of the king with a handsome pedestal by its side. The servant brings the pitcher, holding it by its handle. He puts it on the pedestal and, unobserved, moves the ring on the cover with his thumb. Then he takes his hand off the pitcher's handle and waits. The valve has opened, and water flows into the [tipping]-bucket which fills and discharges repeatedly. The last time the bucket discharges the water rises to the bend in the siphon underneath and runs through the siphon and flows all at once over the float. The water rises to the bend in the spout's siphon and issues from the duck's beak until no water at all is left in the pitcher. It should be understood that everything that I made inside the cover – the two chambers, the valve, the bucket – are set in motion only when the servant stands aside from the pitcher. No water comes out of the spout. One waits for a while, and then the water flows.

Everything which I have mentioned can be dispensed with [if one proceeds as follows]: water is poured into the pitcher until the float is submerged. The pitcher is tilted towards its handle, and the servant carries it tilted in this direction. As he puts it on the pedestal he tilts it towards the spout, and then sets it down level. The water runs through the siphon, and there is no need for that which is in the neck of the pitcher. Or another method – which is to make only one chamber in the cover and a wide hole in the valve, wider than the spout's siphon. When the valve is opened the water flows into the neck of the pitcher, rises over the float and up to the bend in the spout's siphon, and issues from the duck's beak. It should be understood that as the water flowing over the float [becomes] less than the flow required to fill the spout's siphon, then the flow from the siphon [diminishes] correspondingly. When the water stops flowing over the float, the discharge of water from the siphon [gradually] ceases.

This is what I wished to describe clearly.

[Now] I will describe a slave which I made who pours water over the king's hands from a pitcher which he holds, and offers him a towel to dry his hands, and so on.

Chapter 3 of Category III

It is a slave who pours water over the king's hands for him to perform his ritual ablutions. It is divided into two parts

Section 1

Description of the outside appearance and functioning

It is a slave made of jointed copper, like a shift completed by arms, legs and head. He is standing and holds a pitcher in his outstretched right hand. On the pitcher's cover is a bird; the pitcher's spout rises and is [then] curved downwards, like the neck of a peacock. Its head, and the pitcher, are tilted towards the spout. His left hand is raised, the forearm almost touching the upper arm and in the palm of the hand is a towel hanging down over his clothing, a mirror and a comb. This slave is brought, when required, to the king for his ritual ablutions and placed by the side of a basin which is in front of the king. The servant stands aside from it, and the sound of a bird is heard, which whistles for a while. Then water runs from the spout, more than sufficient for his ritual ablutions. When he has finished his ablutions the slave stretches out his left hand until it is straight, and the king takes the towel, the mirror and the comb, and uses them as appropriate. Then he puts them back in the slave's hand, and the servant removes him; when required he brings him [back] and he performs as he performed before.

I described the construction of the figure itself in previous chapter, and it is not necessary to repeat that. The pitcher is made from brass, [its size] intermediate between small and large. It is divided by a plate into two chambers, a chamber from the waist down and a chamber from the waist up. One takes a narrow pipe about $1\frac{1}{2}$ sp. long and bends it into [the shape of] a siphon with one end longer than the other, with the long end made horizontal at the very end... [lit. levelled off slightly]. Then a hole is made in the body of the pitcher at the position of the spout in which the short end of the siphon is inserted until it almost touches the floor of the upper chamber. It is soldered securely in position. The visible part of the siphon is thickened with copper and lead so that it resembles the neck and head of a peacock, with its mouth open. Then a dome-like cover is made for the top of the pitcher – on the dome is a bird. The neck of the pitcher is closed by a plate so that no water can flow from it. Then two holes are made in the body of the pitcher at the position of the handle, through to the chamber. To one of these holes a narrow pipe is fitted and to the other hole a wider pipe.

Then a hollow right arm is made, which is [in effect] the sleeve of the shift emerging from a sleeve wider and shorter than itself. On it is a hand holding the handle of the pitcher. This hand does not move, but remains completely still and rigid. Then the handle is placed over the two pipes fitted to the body of the pitcher at the position of the handle, so that the ends of the pipes pass through the handle, into the palm of the slave's hand and from his palm into his sleeve. The handle is soldered to the body and to the neck of the pitcher in the usual way. The narrow pipe extends through the slave's sleeve as far as the upper arm of the sleeve, and a small whistle's ball is fitted to its end. The treatment of the wide pipe is described below. The left arm is a narrow sleeve in which is a hand grasping a small mirror, which can be lifted in the hand. Over it [i.e. the hand] a towel is also placed. Between the index and middle fingers is a gap in which are two teeth of a comb with a little spike between them holding the comb. This arm moves in a short, wide sleeve about an axle in the elbow extension [of the arm]. A finger's length of the extension is bent upwards at a right angle inside the hollow in the slave almost touching his waist. This is the picture [Fig. 109] of the left arm. On the end of the extension of the elbow is a fixed weight which raises the hand together with the mirror, comb and towel. On the end of the weight is a hole l, and the axle is marked z. There is no need to draw what is in the right hand.

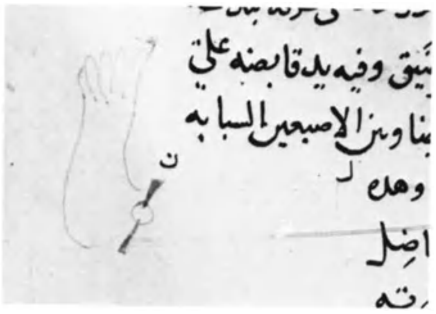


Fig. 109.

Section 2

On the construction of the reservoir for the water, its outlet, and the mechanism of the left hand

A reservoir is installed in the breast of this slave, extending lengthwise through the right-hand $\frac{2}{3}$ of the breast and part of his belly near the right hand. The $\frac{1}{3}$ of the breast towards the left hand is left for the movement of its elbow extension and the weight. On the top of this reservoir, towards the right arm, a pulley in a firm housing is fitted at the edge of the reservoir. Then a valve is made

Fig. 110.

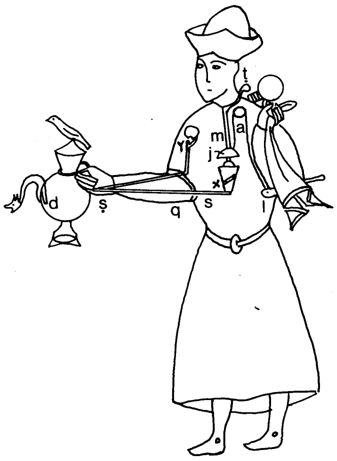
with a seat and a plug. On top of the plug is an extension, one finger-length long, which stretches from the bottom to the top of the reservoir. This valve is drilled obliquely towards the lower end. This is a separate picture [Fig. 110] of the valve, for a clear understanding: the seat and the upper end *ṣ* of the hole, the lower end *a* and the end *m* of the extension from the plug. An opening is made in the floor of the reservoir in line with the centre of the slave, and the valve seat is inserted therein so that the upper end of the hole is in the reservoir and the lower end of the hole is outside the reservoir. The perimeter of the valve seat is soldered securely to the floor of the reservoir. The extension to the plug rises vertically up to the centre of the slave's neck. The reservoir fills if water is poured into it with the valve closed, since the water has no outlet, and if the valve is opened the water issues from the lower end of the hole. Now a small pot (*ḥuqq*) is made, placed over the visible part of the valve and against the bottom of the reservoir, and its perimeter is soldered firmly to the underside of the reservoir. When water issues from the valve's pipe it fills the pot, since there is no outlet for it. Then a hole is made in the side of the pot in the direction of the right hand and the end of a pipe is fixed to the hole. [The pipe] extends through the narrow sleeve and meets the wide pipe which comes from the body of the pitcher through the handle and the palm of the slave's hand to the end of his narrow sleeve. The two [pipes] are soldered securely together. When water is poured into the reservoir with the valve open it discharges from it into the pot and flows through the pipe and into the upper chamber in the pitcher. The latter is covered above the top of the siphon.

The air in the pitcher therefore has no outlet except the hole in the body of the pitcher inside the handle, [this hole] having a pipe in it which goes to the slave's upper arm with a whistle-ball on its end. So the air is emitted through this pipe into the whistle. The sound emerges from the narrow sleeve and from holes made in the folds of the jacket. Then a medium sized float, pierced through the centre, is made, as described before.[1] The end of the valve rod [lit. the plug's extension] is inserted in it so that it rests on the valve seat. It [i.e. the float] has a staple on its [upper] surface to which the end of a string [is tied]. The other end is lifted, passed over the pulley fitted to the edge of the reservoir, and hangs down. It is tied to the hole in the weight on the extension to the left elbow, while the arm is extended.

The arm is raised, and it descends again when the float pulls the end of the elbow extension. When water is poured into the reservoir the float ascends on the surface of the water, and the hand is lifted close to the shoulder. It stays there until most of the water has issued from the reservoir, whereupon the elbow extension is pulled and the arm rotates slowly until it is stretched straight out.

Then a handle is fixed rigidly to the end of the valve rod. It is bent down slightly, then its end is bent up vertically. It emerges from the back of the slave's neck-socket between the collar of the jacket and the neck. To the end of this handle a projecting knob is fixed, by which it is held and rotated to open and close the valve. Then a head is made for the slave as [described] previously.[2] In the top of it is a round hole through which water is poured into the reservoir. Then the lower end of the neck is placed on the neck-socket of the jacket and its perimeter is soldered, except for [part of] the neck between neck and collar, to [allow for] the movement of the handle.

Fig. 111.



I have shown the picture of the slave [Fig. 111] and everything inside him and inside the pitcher: the water reservoir *z*; the valve plug *m*; the end *n* of the hole in the valve in the reservoir, the float *j*; the string *a* passed over the pulley; the end *s* of the elbow extension, the axle *l* in the left hand; the hole *x* in the bottom of the valve, the pot *p*; the hole *q* in the side of the pot having the end of a pipe in it which goes through into the body of the pitcher, and this pipe *ṣ* at the end of the sleeve; the whistle's pipe *y*; the plate *f* which divides the pitcher into two chambers; the siphon's end *d* inside the pitcher, the end *ṭ* of the handle which has a projecting knob for turning the valve rod to open and close [the valve].

Then to the hole in the centre of the slave's head a filter is fitted, having a strainer, and a spout in its centre through which [passes] a thin rod. This has a plate like a *dirham* on its upper end which prevents it from disappearing downwards, and a plate like a *dirham* on its lower end which prevents it from rising above the funnel's spout. The purpose of this funnel is to conceal what is inside the water reservoir. The purpose of the rod in the spout of the funnel is that when water is poured into the funnel, and reaches the required level in the reservoir, the float lifts the rod, so it is known that the water in the reservoir is complete, and no more is poured in after that. The funnel is soldered so that its rim is level with the top of the slave's head, upon which a cap is placed.

It is very clear that water is poured into the funnel, the valve being closed, and the water rises in the reservoir until the rod moves upwards. No more is poured in after that. The slave remains

[1] e.g. Chapter 5 of Category I, Chapter 3 of Category II.
[2] e.g. Chapter 7 of Category II.

in that condition until he is summoned, whereupon the [human] slave brings him, carrying him with his left arm under his left armpit and the right [arm], over his right shoulder. He sets him down on his feet by the side of the basin, and in raising his [i.e. the servant's] right hand he turns the projecting knob and opens the valve. The servant stands aside from him. The water runs from the valve into the pot, thence through the pipe into the pitcher. The air is driven into the whistle, the ball whistles, and it is thought that the whistling comes from the bird's beak. If the water did not rise [so high] I would have put the whistle in the bird's body, but this was impossible. The whistling lasts a while, until the water in the pitcher has risen to the bend in the siphon. It discharges from the bird's beak and the king performs his ritual ablutions. When it [i.e. the pitcher] is almost empty, the left hand holding the towel, mirror and comb, inclines from its nearly vertical elevation, and stretches out straight, towards the king. He takes the towel to dry himself, the mirror to look at his face and the comb to comb his beard. Then he puts them all back on the slave's hand, which lifts.

Then the pitcher is scraped, everything required painting is painted and given several coats of Sandarac oil.

That is what I wished to describe clearly. One should not fear that the slave will tilt. I was apprehensive in case he tilted, and prepared a device which I placed under his feet. He did not tilt at all.

[Now] I will describe what I made, namely a peacock which discharges water from its beak for ritual ablutions.

Chapter 4 of Category III

It is a peacock which discharges from its beak water for the master [lit. the one served] to perform his ritual ablutions

It is a peacock in the attitude peculiar to the peacock. Its neck is erect with the head lowered, its beak extended and open, its tail erect, but not spread out in display. This peacock is brought when required into the ritual ablutions, and the servant puts it down upright on a handsome pedestal by the side of the basin, in front of the person being served. Then he stands aside from it. Water pours from its beak, sufficient for him to perform his ablutions, while [the servant] stands aside.

Its construction: a peacock is made from jointed copper, hollow as far as the beginning of its neck. Then a siphon is made with one end longer than the other. The short end is inserted in its belly until it almost touches the belly's floor, the bend of the siphon raised to resemble its neck. The other end of the siphon comes down towards the peacock's breast. All the visible section of the siphon is coated with copper and lead so that it takes the shape of the neck and head of a peacock, with the beak open. Then a hollow tail is made for it, raised and gathered in, not spread out. The tail is divided half way up by a plate, so that the upper half of the tail forms a separate chamber, while the lower half is connected to the cavity in the belly and breast.

Then in this plate is fitted a valve, as described in both chapters on the slave.[1] It is a seal and a plug, [the latter] having an extension on top which reaches to the top of the peacock's tail. When this tap is closed and water [is poured in] at the top of the peacock's tail, the chamber fills and the water has no outlet. If the plug is rotated slightly, the valve opens and the water in the chamber flows into the peacock's belly. That [i.e. the connection of the plate to the tail, and the valve to the plate] is fixed securely by soldering. Then a cover is made for the end of the peacock's tail. This is lifted when water is poured into the tail and then replaced; one cannot tell that it is a cover. Then a hole is made at the top of this cover from which the end of the valve rod protrudes. A projecting knob is fixed to it, crescent shaped like the pretty feather of a peacock. This can be pushed in and out of the hole in the top of the cover.

Fig. 112.

I have shown the picture [Fig. 112] of the peacock: the end *f* of the siphon in its beak, and the other end *z* on the floor of its belly; the plate *ṭ* dividing its tail; the hole *m* at the bottom of the valve; the other end *s* of the hole, above the plate; the end *e* of the plug in the upper part of the tail; the cover *n* through the centre of which the valve rod projects.[2]

It is very plain that the cover is lifted, the valve being open, and water is poured into the top of the tail and runs into the belly of the peacock, until it rises to [a point] beneath the bend of the siphon. The plate in the peacock's tail is the level of the top of the siphon, and to raise the water to this level a little more water is required. The valve is shut and then water is poured into the tail above the plate until the chamber is full. The cover is put back on the top of the tail.

When the master wishes to perform his ablutions he tells the servant who brings the basin and [places] by its side a handsome pedestal. Then he brings the peacock, holding it by its neck with his left hand and by the tip of its tail with his right hand. He turns the crescent [i.e. the end of the valve rod] and [water] flows through the siphon into the peacock's beak. The master performs his ablutions and completes them – there is more water than he requires. The [servant] takes the peacock away and fills it, so that it is ready when called for.

When it is constructed as I have described, it is painted in the colours of a peacock and coated with Sandarac oil. That is what I wished to describe clearly.

There is another way to [do] that, which is to omit the valve and the chamber in the tail and to pour the water into the top of the tail while it is tilted backwards, so the water does not reach the bend in the siphon. The servant brings it, [still] tilted backwards and when he places it on the pedestal he tilts it forwards. The water rises to the bend in the siphon and rushes out through the beak.

Now I will describe what I made, namely a basin for blood letting (*fiṣād*). It is based upon [the work of] a predecessor, which was simply a sphere for collecting the blood. I have excelled him with various designs.

[1] Chapters 2 and 3. In fact one is a pitcher, the other a slave (*ghulām*).
[2] Some of the letters are missing, some are out of place.

Chapter 5 of Category III

It is the basin (ṭast) of the Monk, from which can be told the quantity of blood which falls into it. It is divided into two sections

Section 1

The outside appearance and functioning of the basin

It is a deep, circular basin with a flat rim. Its diameter at the top is about 2 sp. It rests on a pedestal about 1 sp. high and 4 fingerlengths wide.[1] In its centre [i.e. the centre of the basin] is a tower (*manāra*), the same height as the side of the basin and of appropriate thickness. On top of the tower stands a monk holding a staff, with the bottom of the staff on the basin's rim. On the rim of the basin the numbers up to 120 are marked and written. When this basin is required it is placed in front of the patient[2] with the bottom of the staff outside the first number. When one *dirham* of blood falls into the bottom of the basin the bottom of the staff moves to the first number, i.e. one *dirham*. And so on, *dirham* after *dirham* until 5 *dirhams* are completed, at which juncture the bottom of the staff has reached the mark upon which 'five' is written. Then *dirham* after *dirham* up to 10 *dirhams*, when the bottom of the staff will be on the mark upon which 'ten *dirhams*' is written. And so on for 20 *dirhams* and 30 *dirhams* up to 120 *dirhams*, according to the quantity required to be extracted from the patient.

The construction of the basin, the tower and the monk: a basin is made from brass about 4 F deep and about 2 sp. wide with a horizontal, exactly circular rim. Then a pedestal is made, 4 fingerlengths wide and 1 sp. high, and is soldered under the basin. An opening is made in the centre of the basin in which a finger can be inserted, and the floor of the basin is made concave downwards so that any liquid falling into the basin collects and runs down into the hole. Then a hollow brass tower is made, as high as the side of the basin and of appropriate width. The top of the tower is flat and its lower end is on four feet which lift it above the floor of the basin. Then the figure of a standing monk is made from jointed copper, with a hooded cloak (*burnus*) on his head since he is a Christian, and in his right hand a staff.

Section 2

On the construction of [the apparatus] which conducts the blood from the basin, and that which turns the monk

A receiver (*jaʿba.* lit. quiver) is made, i.e. a copper tube four fingerlengths long and wide enough to be encircled by the thumb and middle finger with a gap 1 F wide left between their tips. A cover is placed on its bottom, namely the bottom of the receiver, and soldered [to it]. This receiver must be accurately [made]; of a single width from top to bottom – the ruler touches its sides from top to bottom.[3] Then a second receiver is made, so that the first can be inserted in the second in a sliding fit.[4] It is shorter than the first and its name is 'the quiver's sheath'. It has no cover, but both its ends are open. One of its ends is soldered to the underside of the basin, around its central opening. Then the first receiver is inserted in the one soldered to the basin so that its rim touches the underside of the basin, and its lower end is towards the bottom. When water is poured into the basin it collects and [then] goes through the opening in the centre of the basin into the receiver, where it collects, having no outlet. Then a float with a flat bottom is placed in the first receiver. A hole is made in its top, and a staple is fitted [to this hole] in its top to which the end of a stout string is tied. The other end is passed up through the opening in the centre of the basin into the hollow interior of the tower, as [described] below.

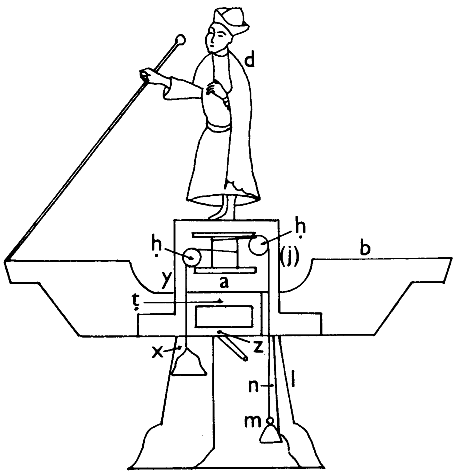
Then one takes a measuring vessel, its capacity 5 *dirhams* of blood. Into the receiver, the float being on its floor, twenty four measures of blood or milk are poured, and a mark is made inside the receiver at the level reached by the blood. Then one takes a string, as long as [the distance] from the floor of the receiver to the blood-level mark. A pulley is then made, as [described] previously, around which this string makes exactly one turn. To the groove of this pulley a staple is

[1] Four fingerbreadths would be too small – see notes.
[2] *Al-mafṣūd.* lit. – the one to be bled.
[3] i.e. it is of uniform cross-section.
[4] Lit. Between easy and tight.

fitted, and through it [i.e. the pulley] an axle is passed, one end of which protrudes from the pulley's flange about the length of a barleycorn and the other end the length of a small span. Inside the lower part of the tower a cross-beam is fixed upon which is a firm bearing, and the short end of the pulley's axle is placed in the bearing. The long end goes through from a hole in the centre of the deck of the tower, and protrudes about 1 F. The end of the string attached to the float's staple is brought up through the hole in the centre of the basin into the hollow in the tower, and is passed over a small pulley which is in a firm housing inside the tower, its groove in line with the staple in the large pulley. Then it is tied to the staple in the centre of the [large] pulley and is given a single turn around the pulley. [Then] it is passed over another small pulley, the housing of which is fixed inside the tower, with its groove in line with the staple in the large pulley. The end of the string hangs down through a hole in the floor of the basin, which is near the opening into the pedestal. To it a 20 *dirham* lead weight is attached, the top of which touches the underside of the basin. Above the weight a short piece of pipe is fixed to the floor of the basin to prevent blood from running into the hole. When water flows into the receiver, the float rises, the weight descends, and the large pulley makes a single rotation when the water rises to the mark in the receiver. Then a hole is made in the underside of the monk's right foot in which is inserted the end of the axle projecting from the deck of the tower – they are both square [i.e. the hole and the end of the axle].

I show the picture [Fig. 113] of: the basin *b*; the monk *d*; the tower *j*, the large pulley and its axle *a*; the two small pulleys *ḥ*; the cross-beam *ṭ* below the pulley; the opening *z* through which the blood flows, and which has a pipe through which the float's string passes; the short pipe *y* fixed above a hole, down which the weight's string passes; the sheath *l* soldered to the underside of the basin – inside it is the receiver *n*; the float *m* in the bottom of the receiver; the weight *x*, at the end of the hanging string, touching the underside of the basin.

It is very clear that all the floor of the basin is moistened with about two *dirhams* of water and a single measure of blood is poured into it from the measuring vessel. The bottom of the monk's



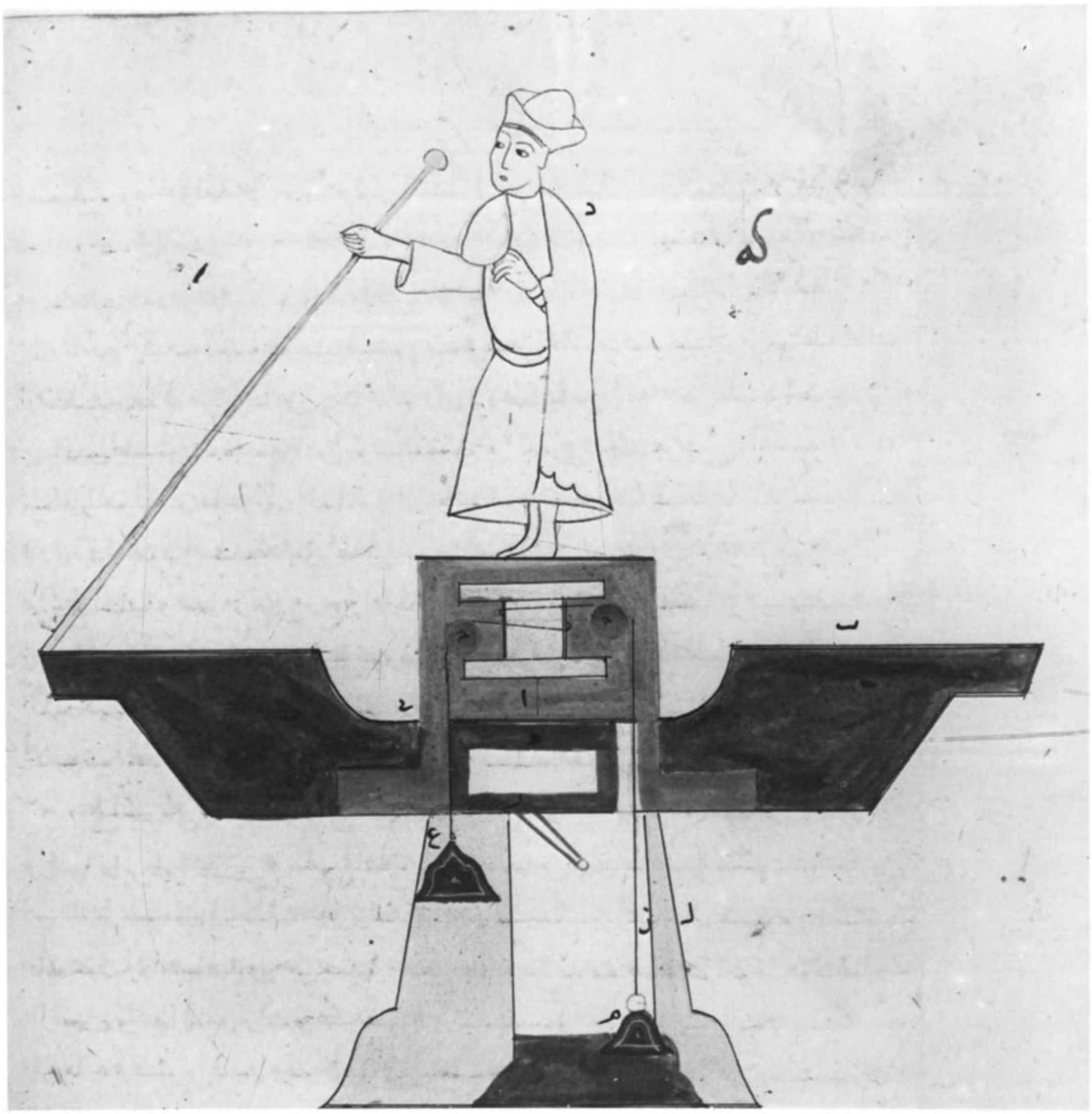


Fig. 113.

staff is outside the first number, and [then] the monk moves and rotates until the bottom of his staff is over the 5 *dirham* mark, the float having risen, the weight having sunk. This happens every time [blood] is poured into the basin until the monk's staff reaches 120 *dirhams*, when 24 measures have been completed in the basin. The basin is lifted, the receiver pulled out of the sheath, and the blood poured out of it. Both it and the basin are washed, and the receiver is put back in the sheath. A cover is fitted to the bottom of the pedestal so as to cover the weight etc. In the cover is an opening through which the receiver can be inserted and withdrawn. On the bottom of the receiver is a hook the end of which goes into a staple on the cover at the bottom of the pedestal – the receiver is turned, and comes out of the staple when rotated in the opposite direction.

When the construction is complete according to my directions the bowl and the pedestal are scraped, the monk is painted in various colours, and [everything] is coated with Sandarac oil as [described] previously.

That is what I wished to describe clearly.

[Now] I will describe another basin which I made for blood-letting.

Chapter 6 of Category III

It is the basin of the two scribes for blood-letting, from which the quantity of blood which it holds can be ascertained. It is divided into two sections

Section 1

Description of its outside appearance and functioning

It is a basin resting on a pedestal and on the floor of the basin are four columns upon which is a platform with two scribes on it. One of them is sitting inside a circle upon which are the numbers from one to one hundred and twenty and he is holding a pen whose tip is outside the first number. The other scribe is sitting at the corner of the platform. In his left sleeve one can see the end of a board upon which a single mark [is visible]. In his right hand is a pen whose tip is on the board above the first number. The basin is placed in front of the patient, the scribes facing him, and about two *dirhams* of water are poured into the floor of the basin. He is bled, and when one *dirham* of blood has run into the basin the pen of the [first] scribe moves to the first number, upon which '*dirham*' is written. The board rises from the sleeve of the second scribe until the tip of the pen is opposite the first mark, upon which *dirham* is written. So it goes on, *dirham* after *dirham* until the tip of the [first] scribe's pen is opposite the ten-*dirham* mark, and until the board has lifted from the sleeve of the second scribe and the tip of his pen is opposite the ten-*dirham* mark. This continues until 120 *dirhams* of blood, or less if desired, have collected in the basin. Then the basin is lifted, the receiver with the blood in it is removed, drained, and washed, together with the basin. The receiver is put back in its place.

Its construction: a basin is made from brass, not having vertical sides but being [dished] like a plate – when water is poured into it then it collects in the centre. A 1 sp. high pedestal is made for it as previously. A hole in which a finger can be inserted is made in the centre of the basin. Over this hole something is placed to conceal it, such as a small dome with much openwork, which does not impede the flow of blood into the hole. On the centrepoint of the dome, which is [also] the centrepoint of the basin, a circle is drawn of the same width as the basin's pedestal and on this circle two marks are made which divide the circle into two halves. At these marks, inside the circle, two holes are made which penetrate to the interior of the pedestal. The width of each hole is such that a finger can be inserted in it. Two columns, each about 1 sp. long, are erected on these holes. Near them, on the floor of the basin, two other similar columns are erected, so that the four columns are positioned in a long quadrilateral [i.e. a trapezium]. A kind of hollow, long quadrilateral, platform is placed on the four columns, with a balustrade of fine workmanship around its perimeter. The platform has a cover like a deck. The length of the cover is divided into two halves. A centre point is made on one of these upon which the largest circle possible is drawn. Inside it another circle is drawn, and the space between the circles is divided into 120 divisions; or one writes *dirham* in the first division, 'ten' on the tenth division, and so on at similar intervals up to one hundred and twenty. As mentioned below, a hole is made at the centre point.

Then on the corner of the other half of the cover, on the half of the basin clear of the columns, is placed a handsome hollow man made up from copper [plates]. His left knee is raised and the palm of the left hand rests on it. Part of the palm is above the top of the knee, with the fingers outspread. The thumb is placed between the forefinger and middle finger. There is a gap between the forefinger and the [other] two [digits] in which is a light board of beaten [brass] which moves freely. Vertically beneath the gap between the fingers a slit is made in the side of the knee, and this appears to be in the hollow of the man's sleeve, because his sleeve is wide and part of it hangs down over the side of his knee. Then in the [cover] plate below the slit in the knee a slit is made which is wider than the slit in the knee. The cover is placed in position on top of the platform. Below the slit in the [cover] plate a slit is made in the floor of the platform which penetrates to the right-hand column of the two columns on the circle.

I have shown the picture of the floor of the basin [Fig. 114] and the circle with the two columns on it: the right-hand one *a*, the left-hand one *b*, the two other columns *m*, the small dome *j* on the pierced centre point of the circle.

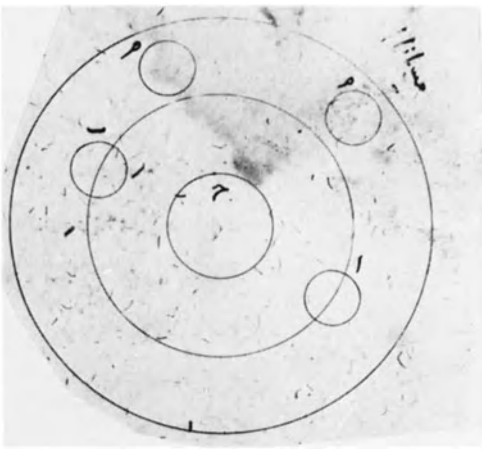


Fig. 114.

When a board like a sword is passed through the scribe's knee and the gap between the fingers, it goes down through the slit in the platform's cover, and the slit in its floor, into the column, through the slit in the basin down into the interior of the pedestal. A right hand is made for him holding a pen, the tip of which is opposite the left thumb and almost touches a board, which is mentioned below. Then another scribe is positioned as [described] above, holding a downward pointing pen in his right hand. A non-circular hole is made in his underside.

Section 2

The mechanisms for the scribes

To the underside of the basin below the right-hand column a sheath is fixed inside the pedestal as before. In the sheath is a receiver and in the receiver is a float. Below the hole in the centre of the basin a deflecting channel (*ṣadafa*) is fixed, through which the blood runs into the receiver – the end of this channel enters a hole in the top of the receiver's sheath. Then one takes a brass rod, as long as [the distance] from the top of the float to the gap between the scribe's fingers. Half of this rod is beaten into the shape of a sword, and the other half is left as it is. The other half is like the top of a board. Then, as before, the height of blood inside the receiver is measured. Then near the top of the board, on its face, a mark is made. And a second mark is made on the face of the board so that the distance between the two marks equals the height of the blood in the receiver. Then 120 divisions are made between the two marks; on the first mark at the top of the board '*dirham*' is written, on the tenth 'ten *dirhams*', and so on above each junction up to 120. The rod should weigh about 10 *dirhams*. The end of the rod is soldered to the top of the float, at the side. The top of the board is then between the scribe's fingers and the tip of the pen is on the face of the board above the '*dirham*' mark. If 120 *dirhams* of blood are poured into the floor of the basin, the board will rise until the tip of the pen is on the last of the numbers, namely 120 *dirhams*. Then the cover, with the scribe soldered firmly to it, is lifted off. A mark is made in the side of the board at the level of the floor of the platform, and a hole is made [at this mark].

The end of a stout string is put through the hole and passed over a small pulley, the groove of which almost touches the side of the board. Then one makes a pulley, its groove of such a diameter that a string passed [once] around it is equal in length to the height of the blood in the receiver. An axle is made for the pulley, one end of which protrudes from the pulley for the length of a barleycorn and the other end the length of half a finger. A bearing is fixed to the floor of the platform vertically beneath the centre of the numbered circle, in which is placed the short end of the pulley's axle – the other end is in a hole in a crossbeam, which prevents the end of the axle from coming out of the bearing. When the cover is put back in its place on the platform the end of the axle goes through the centre of the numbered circle and protrudes 1 F from the surface of the cover. A staple is fixed in the pulley's groove, and the string is tied to it after having been given a complete turn around the pulley. The rest of the string is passed over a small pulley above the top of the left-hand column. A hole is made in the platform through to the left-hand column and the end of the string hangs through it into the basin's pedestal, where a weight of 30 *dirhams* is attached to it. At this juncture the weight is near the bottom of the pedestal.

The cover with the scribe soldered to it is returned to the top of the platform – the cover is fixed to the platform at several points but not soldered. A cover is fixed to the bottom of the pedestal as before. The [other] scribe is put back on to the end of the pulley's axle, with the tip of his pen outside the first of the numbers on the circle. The receiver is empty and the float is on its floor.

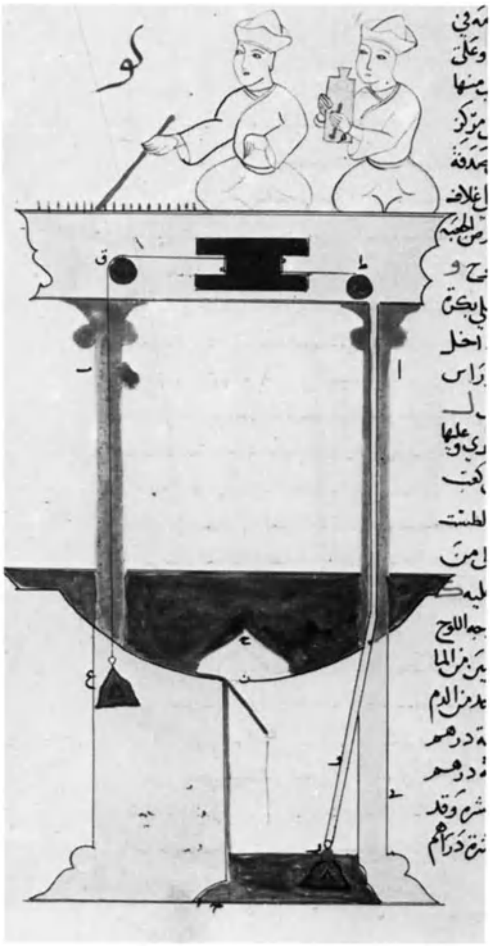
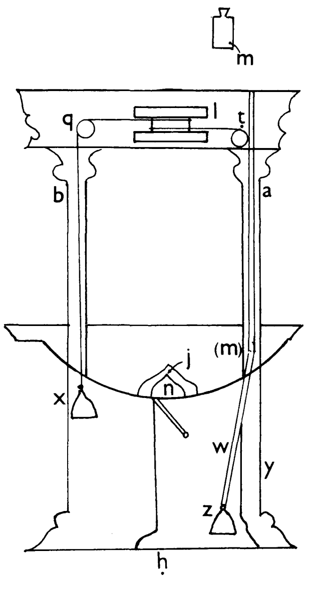


Fig. 115.



I have shown the picture [Fig. 115]; of the basin: the right-hand column *a* and the left-hand column *b* with the one near it concealed and likewise the fourth; the dome *j* on the centre of the basin with a hole beneath it through which the blood descends, and below the hole the deflecting channel *n* through which the blood runs into the receiver; the receiver's sheath *y* and the receiver *ḥ*; the float *z* in the floor of the receiver; the rod *w*, i.e. the board, soldered to the float; the end *m* of a string in a hole at the bottom of the board; the small pulley *ṭ* above the top of the right-hand channel, inside the platform; the large pulley *l* with a vertical axle – the end of its axle protrudes from the surface of the platform, and has the scribe on it; the small pulley *q* above the top of the left-hand column, with the rest of the string passed over it; the weight *x* on the end of the string in the basin's pedestal.

It is very evident that: the basin is placed in front of the person who wishes to be bled, with the half [of the basin] clear of the columns opposite him. He is face to face with the scribe *k* in the circle, and the scribe with the board is on his right, with the face of the board towards him. The floor of the basin is wetted with about 2 *dirhams* of water. Bleeding commences and a *dirham* of blood falls into the floor of the basin. The tip of the pen of the scribe in the circle rotates to the *dirham* mark, the board rises and the tip of the [other] pen comes into line with the *dirham* mark. So it goes on, *dirham* after *dirham* until ten have flowed, and the tips of the two pens are where 'ten *dirhams*' is written. This continues as long as the blood falls into the basin up to 120 *dirhams*, or less if desired. Then the blood is extracted from the receiver, which is washed together with the basin, and remains ready for when required.

When it has been completed according to my description, that which requires scraping is scraped, the two scribes are painted in various colours, and everything is coated with [Sandarac] oil.

That is what I wished to describe clearly.

[Now] I will describe what I made, namely [another] basin for blood-letting.

Chapter 7 of Category III

It is the basin of the Reckoner (al-ḥāsib) for blood-letting from which the quantity of blood collected can be ascertained. It is divided into two sections

Section 1

Description of the outside appearance of the basin and its functioning

It is a basin with four columns on its floor. On the columns is a platform and on the platform are two scribes, one of them inside a circle, and the other having a board in his sleeve, as in the previous chapter. In the side of this platform is a fort (*burj*) with a door in it in which can be seen the head and the breast of a man. This basin is placed before the patient. Facing him are: the half [basin] outside the columns; the face of the scribe in the circle; the face of the board and the right-hand side of the other scribe; the face of the man in the door. When a *dirham* of blood falls into the floor of the basin it collects and goes down the hole in the basin's face. [Then] the pen of the scribe moves to the first number, i.e. a *dirham*, and the board of the second scribe rises from his sleeve until the tip of his pen is level with the word '*dirham*', and so on to complete 10 *dirhams*. At this juncture the man in the fort shows his right arms from the elbow to the hand, the fingers indicating[1] 'ten'. And so on, with the two scribes passing *dirham* after *dirham* together, up to the completion of 20 *dirhams*, whereupon the man covers the hand which had indicated 'ten' and reveals the one indicating 'twenty'. This continues, and whenever the numeration reaches a [major] division [i.e. every ten *dirhams*] the man covers a hand and reveals the one showing that [amount], until 120 [*dirhams*] are completed.

The construction of the basin and its equipment: a brass basin like a plate is made as described in the preceding chapter, including the pedestal; the columns; the platform; the two scribes; the divided circle; the three pulleys; the string attached to the bottom of the board, passed over the small pulley, wound around the large pulley – whose axle projects from the scribe's deck; the dome in the centre of the basin, beneath which is a hole through which the blood flows into the deflecting channel and thence into the receiver; the float and the weight. Nothing must be omitted from the previous [design], and there is an addition, which I shall mention. It is a fort, with a man inside it. One can only see his head, his breast, and his right arm up to the elbow joint, pressed to his side. His left hand holds his beard.

Section 2

On the construction of the fort, the man, the mechanism for his right hand, and for the indication of the [ten dirham] divisions

I mentioned previously that the shape of the platform was a long rectangle, with its deck and floor twice as long as they are wide. It is about 4 F deep. The platform is on columns [resting] on one half of the basin, while the other half has nothing on it, so that the blood can fall into it. [A fort] is added to the platform of the shape [just described], part of which is below the platform and part of it above. In its hollow [interior] is a vertical wheel of 4 F diameter – the fort is about 2 F wide. Above the fort is another small fort, in which an open door is [located] above the half of the basin outside the columns. These two forts should be of pleasing appearance and should harmonize with the platform. I made this, and I put projecting supports on the two columns under the two [forts] so that the platform and the forts looked like a single castle, with one part of it on top of the other. Around the two forts are painted battlements. One places in the door of the small fort the head of a dark man with a large beard. His elbow is raised and rests on the threshold of the door. His beard, and his forearm pressed to his upper arm, are of such a width that they [almost] cover his breast leaving an opening in the breast through which hands rotate on a wheel, described below.

At the right-hand side of the threshold is a downward-facing aperture like a window in which can be seen the right forearm up to the elbow. Between this forearm and the window there is a gap. Then a circular wheel is made on an axle which is as long as the platform and the fort are broad. On the circumference of the wheel are twelve arms, each consisting only of a palm, a

[1] Verb ʿaqada. It is used in the sense of a manual sign language for indicating numbers.

hand, and a forearm. [i.e. the forearm and hand with the palm towards the front]. The first indicates 'ten', the next 'twenty' and so on by equal stages up to 120. They are spaced equidistantly, and the palms all face the same way, i.e. towards the surface of the wheel which is facing the aperture. This wheel is on one end of the axle and on the other end is a pulley around which a string is wound whose length equals the distance risen by the blood. This wheel is then installed inside the fort. One end of its axle rotates in a firm bearing on the back of the fort, and the other end in a firm bearing half way up the front (lit. side) of the fort. One arm is then visible, representing the right arm of the Reckoner. When the wheel turns towards the Reckoner's left the arm that had been visible disappears behind the beard and the [left] arm. Then another arm appears – whenever the wheel turns one arm disappears and another appears until the wheel has completed one rotation, when all the arms will have appeared and disappeared.

Then one takes a string, longer than the string in the previous chapter, and ties its end to a hole in the bottom of the board. It is passed over the small pulley whose groove almost touches the board, then passed once around the pulley fixed to the end of the wheel's axle, being attached to a staple in this pulley. Then it is given one turn around the vertical pulley upon which is the scribe, then passed over the small pulley above the top of the left-hand column.

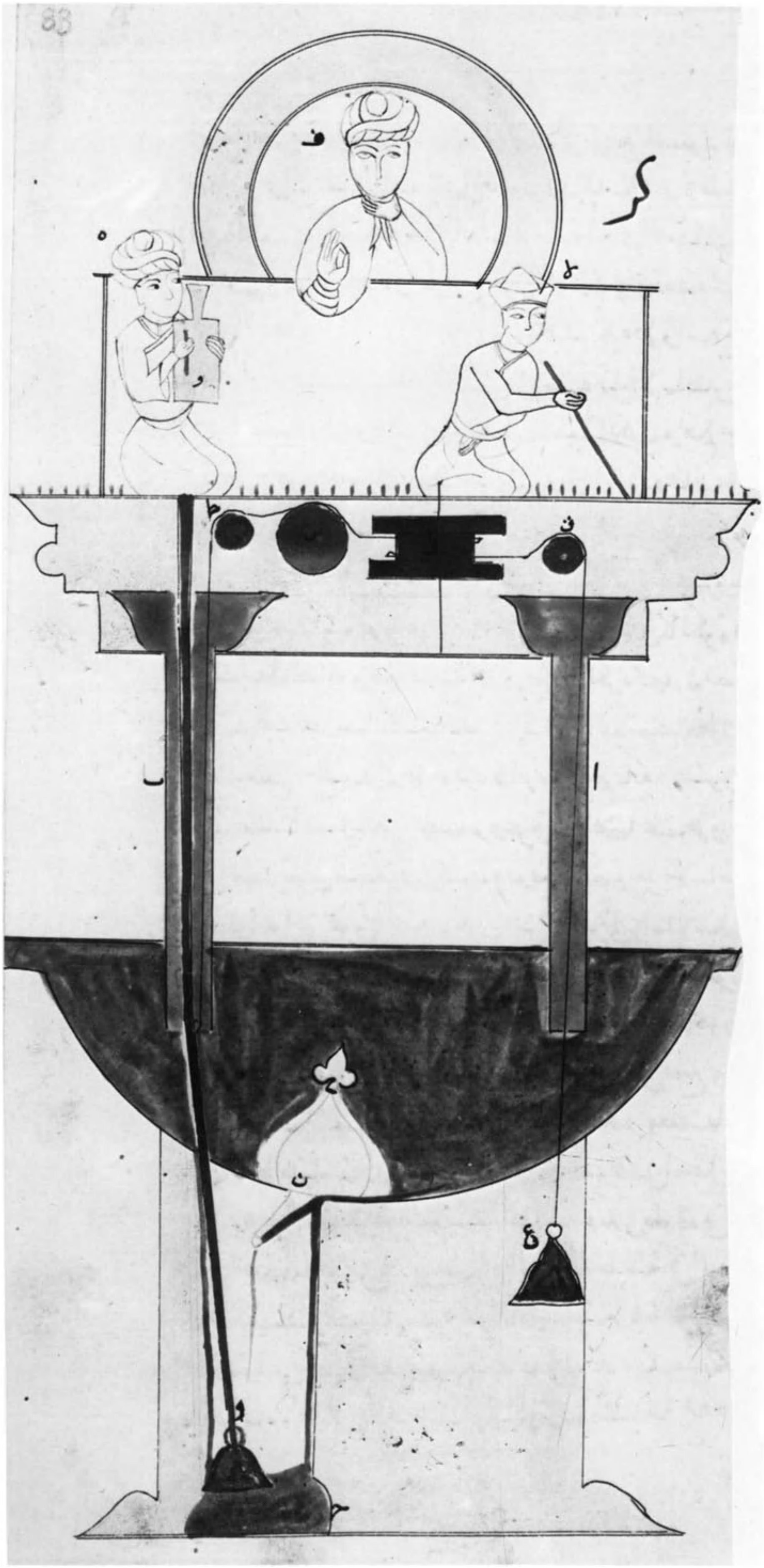
The end of the string hangs down the column into the basin's pedestal where a weight is attached to it, the top of which touches the underside of the basin. At this juncture the float is resting on the floor of the receiver, and none of the hands is visible in the aperture. The Reckoner is standing, holding his beard, and his right arm is hanging down with none of it visible except the point of the elbow.

I have shown the picture [Fig. 116] of the basin, the pedestal, the columns, the platform, the two forts rising above the platform with the large fort [also] projecting beneath the platform, having inside it the wheel for the arms, and the float in the reservoir. [The parts are marked as follows]: the receiver *j* the float and the board *w*, the small pulley *ṭ* above the top of the column, the large pulley *s* on the end of the wheel's axle, with the string wound once around it; the large vertical pulley *l* for rotating the scribe; with the string wound once around it; the small pulley *q* above the top of the left-hand column, with the string passed over it hanging down inside the column; the weight *x* on the end of the string; the right-hand column *a* and the left-hand *b*; the dome *ḥ* on the floor of the basin, the deflecting channel *n*; the scribe *e* with the board; the scribe *f* in the circle; the Reckoner *p*.

It is very clear that this basin is brought before the patient, and facing him are: the half [basin] outside the columns, the face of the scribe in the circle, the face of the Reckoner and the face of the board. When a *dirham* of blood falls into the floor of the basin the scribe's pen moves until it is on the first number, i.e. one *dirham*, and the board rises until the tip of the pen is level with the first number, i.e. one *dirham*, and so on until ten *dirhams* are completed. The Reckoner's arm has not [yet] appeared in the aperture but it appears [now] and indicates 'ten'. The scribes move over one *dirham* [after another] until 20 *dirhams* are completed, whereupon that hand disappears and another hand appears, indicating 'twenty' – as if [the Reckoner] is showing his hand, and then changing its gesture. So it goes on until the blood in the basin amounts to what the patient has chosen – up to a maximum of 120 *dirhams*.

When the construction is complete the basin, the columns and the platform are scraped, since they are all [made] of brass. The two forts, the two scribes and the Reckoner are painted. The Reckoner is dressed in clothes which are all of one colour. The arms on the wheel and the palms of their hands should be the same colour as the clothes.

This is what I wished to describe clearly. The picture of that is shown opposite [Fig. 116]. [Now] I will describe a basin I made for blood-letting.



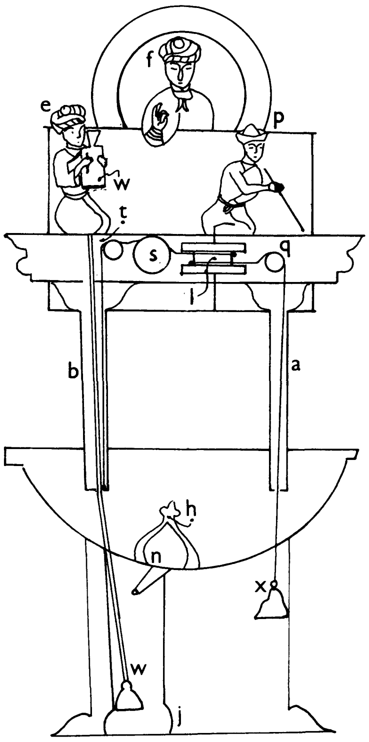


Fig. 116.

Chapter 8 of Category III

It is the basin of the Castle from which the amount collected therein can be ascertained. It is divided into two sections

Section 1

Description of the outside appearance of the basin, its contents, and its functioning

It is a brass basin like a plate resting on a pedestal and having six columns on its floor. On the columns is a castle with 12 doors, each door having two leaves, and one of them higher than the [other] eleven. The roof of the castle is flat, and there is a scribe in its centre surrounded by a circle upon which are numbers from one *dirham* to 120 *dirhams*. In his hand is a pen as if he were holding it on the board.[1] Its functioning is [as follows]: when this basin is required for use it is placed in front of the patient with the door leaves closed, the scribe's pen outside the first number on the circle, and the scribe's pen towards the patient. The face of the board and the large door of the 12 doors are also facing the patient. When, after the floor of the basin has been moistened with a little water, a *dirham* of blood falls into the basin the scribe moves and the tip of his pen reaches the first number, i.e. one *dirham*. And so on until ten *dirhams* are complete, whereupon the leaves of the large door open on a door as large as one of the eleven doors. In it is the figure of a standing boy, as far as the waist, his right hand indicating 'ten'. Above this door is a window of the same measurement as the height of the [door] leaves.[2] In it is a hand indicating 'ten' in agreement with the boy's hand. The scribes continue to register the same measurements [lit. they continue to agree together] until 20 *dirhams* are completed, when the leaves of the second door open on the door, in which is a boy indicating 'twenty' with his right hand. The hand which was in the window indicating 'ten' disappears and a hand indicating 'twenty' appears in it. So the two scribes continue together *dirham* after *dirham* until 30 *dirhams* are completed, whereupon the leaves of the third door open on the door, in which is a boy indicating 'thirty' with his hand. And so on until 120 *dirhams* are completed, by which time all the leaves have opened on the doors, and the hands in the window have succeeded one another for a complete [round].

I decided to make two scribes because the scribe in the circle rotates and [then] his pen becomes invisible to the patient, and the scribe's back turns towards the patient's face, while the board is not concealed from him at all. And I decided to make the hand in the window, since the patient sees the large door and [the doors] adjacent to it but does not see the remainder of the doors. So he sees the hands in the window instead of the doors and the boys' hands.

I described previously the construction [of the following]: the basin; the pedestal; the receiver's sheath; the hole in the centre of the basin with a filigreed dome above it, a deflecting channel below the hole through which the blood flows into the receiver; the receiver in the sheath; the construction of the scribe holding a pen which points downwards, there being a square hole in the underside of the scribe.

Section 2

Construction of the six pillars and the castle on top of them

On the centre point of the basin's floor a circle is drawn, having the same width as the pedestal, and six equidistant marks are made on its circumference, so that two marks are diametrically opposed. On every mark a column is erected with a handsome base and a capital of fine workmanship. Then for the castle one takes a plate 3 sp. long and about 1 sp. wide and solders its edges together to form a cylinder. Then it is hammered to take the form of a twelve-sided castle. In every side a small door is opened, with its long side vertical. Above one of the doors an aperture like a window is made. For every door two leaves on light, easily-moving hinges are made. For the door with the window above it, however, leaves are made which are longer than the [other] leaves, so as to cover the window.

A bottom [plate] is made for the castle which is soldered neatly inside the castle, and battlements are fitted around its perimeter. A flat cover is made for it, on the centre point of which a

[1] Obviously there is a sentence missing.

[2] i.e. the door leaves cover both door opening and window. The door opening is the same size as the other eleven doors.

circle is drawn and divided into 120 divisions. Outside the circle, on the edge of the cover, a scribe is placed with a board, as before. A slit is made in the cover below the slit in the scribe's knee, and a slit in the floor of the castle vertically below the slit in the cover, and of the same width as the slit in the cover. The castle is placed on the columns and a hole is made in the floor of the castle above the top of the column which is above the receiver, and a hole is made in the floor of the castle above the top of the opposite column, below which is the string from the weight, in holes [through the basin and bottom of the column]. A board is fixed to the float as before. It rises through the column which is above the receiver to the inside of the castle and up into the scribe's knee as if emerging from his sleeve.

An axle is made as long as [the distance] from the floor of the castle to the cover of the castle. It goes through a hole in the centre point of the cover and projects from it about 1 F. A bearing is fixed to the centre point of the bottom of the castle in which the bottom of the axle rotates. On it a large pulley is erected – its description and the method of constructing it were given previously. Its thickness is such that a string as long as the rise of blood in the receiver can be wound round it. A hole is made in the bottom of the board to which the end of a string is [tied]. It goes over a small pulley at the top of the weight's column and its end hangs down through the column into the pedestal where a weight of about 30 *dirhams* is attached to it. The float is then resting on the floor of the receiver while the top of the weight is touching the underside of the basin.

Then 12 plates are made, [each] large enough to cover one of the doors in the castle. On each plate the head, breast and belly of a boy are placed. A hand, namely the right hand, indicating a number, is made for him. The first indicates 'ten', the second indicates 'twenty', and so on at like intervals up to 120. The left hand is over his belly; or hanging down. At the top of each plate a staple is fitted, and above each door a hook. The figures are suspended to the doors, and they hang down, one next to the other. To the bottom of each plate is fixed a rod, like half a needle. Then a light ring is made, one finger's length in diameter, and on its circumference 12 light angles are fixed. This ring is fitted to the pulley's axle, half way up the castle, and it is supported on three legs fixed firmly to the sides of the castle. Then each plate is lifted with the finger from outside the castle and the needle laid on an angle. To the axle a rod is fitted, the middle section of which passes the ends of the needles, pushing one needle after another, so that the figures fall down and open the doors with their hands, since these are proud of their bodies [i.e. the figures are in bas-relief with the hands uppermost]. Then a ring is made, its diameter less than the width of the castle, and 12 ivory hands are fixed to its perimeter, each hand up to the centre of the forearm. Each hand indicates a number as before, and the forearm is fixed inside the copper sleeve of a shift. All the arms are soldered to the perimeter of the ring equidistantly, with the signs [for the numbers] in succession. Then a light cross bar is made as long as the diameter of the ring and its ends are fitted to the ring. The [position of] the centre point of the ring is located on this crossbar, and marked. A hole is made [on the mark], through which the top of the pulley's axle is passed, so that the hands are in line with the window. The hand which is to the right of the window should indicate the first 'ten'. The cross bar is soldered firmly to the ring. The cover, upon which is the scribe with the board, is put back on the top of the castle, and fixed at two or three points. The top of the board is visible in the scribe's sleeve and the tip of his pen is on the face of the board. Then the other scribe is placed on top of the axle of the pulley and pushed down until his underside almost touches the surface of the cover. The tip of his pen is outside the first number. The figures are hung on the angles and the doors are closed.

I have shown the picture of the basin [Fig. 117] and what is connected to it: the receiver *j*, the float and the board *a*; the small pulley *s* above the board's column, over which the string from the board is passed, the large pulley *x* around which the string has been given one turn; the small pulley *n* over which the string goes through the weight's column into the pedestal; the weight *q* on the end of the string; one figure *e* in the large door, after having descended from the angle; the ring *ḥ* for the angles; the ring *m* with the hands, with one hand on the ring behind the windows *ṭ*. It should be understood that the board moves in the corner of the castle and is outside the ring, which it does not touch.

It is very clear that: the basin is placed in front of the person who wishes to be bled, as previously. The floor of the basin is moistened with two *dirhams* of water. He is bled, and a *dirham* of blood falls into the floor of the basin. The scribe's pen moves, and the tip of the pen comes in line with the word *'dirham'*. The board rises and the tip of the scribe's pen comes level with the word *'dirham'*. And so on until ten *dirhams* are completed, whereupon the long leaves open on a door in which is the figure of a boy indicating 'ten', and upon the window in which is a hand indicating 'ten'. The scribes move on together from *dirham* to *dirham* until twenty *dirhams* are completed. The next pair of leaves open on a door in which is a figure indicating 'twenty' with his hand, and the hand that was in the window indicating 'ten' disappears, and a hand indicating 'twenty' appears. This continues until all the leaves are open on the doors, and 120 *dirhams* of blood have flowed into the basin. [The basin] is lifted and the receiver removed as before, and washed together with the basin. It is taken away until it is needed again.

When it has been constructed according to my description, that which requires scraping is scraped and that which requires painting is painted, such as the figures etc. Then everything is coated with Sandarac oil.

That is what I wished to describe clearly.

[Now] I will describe what I made, namely as basin for washing the hands – one of a number of basins which I made.

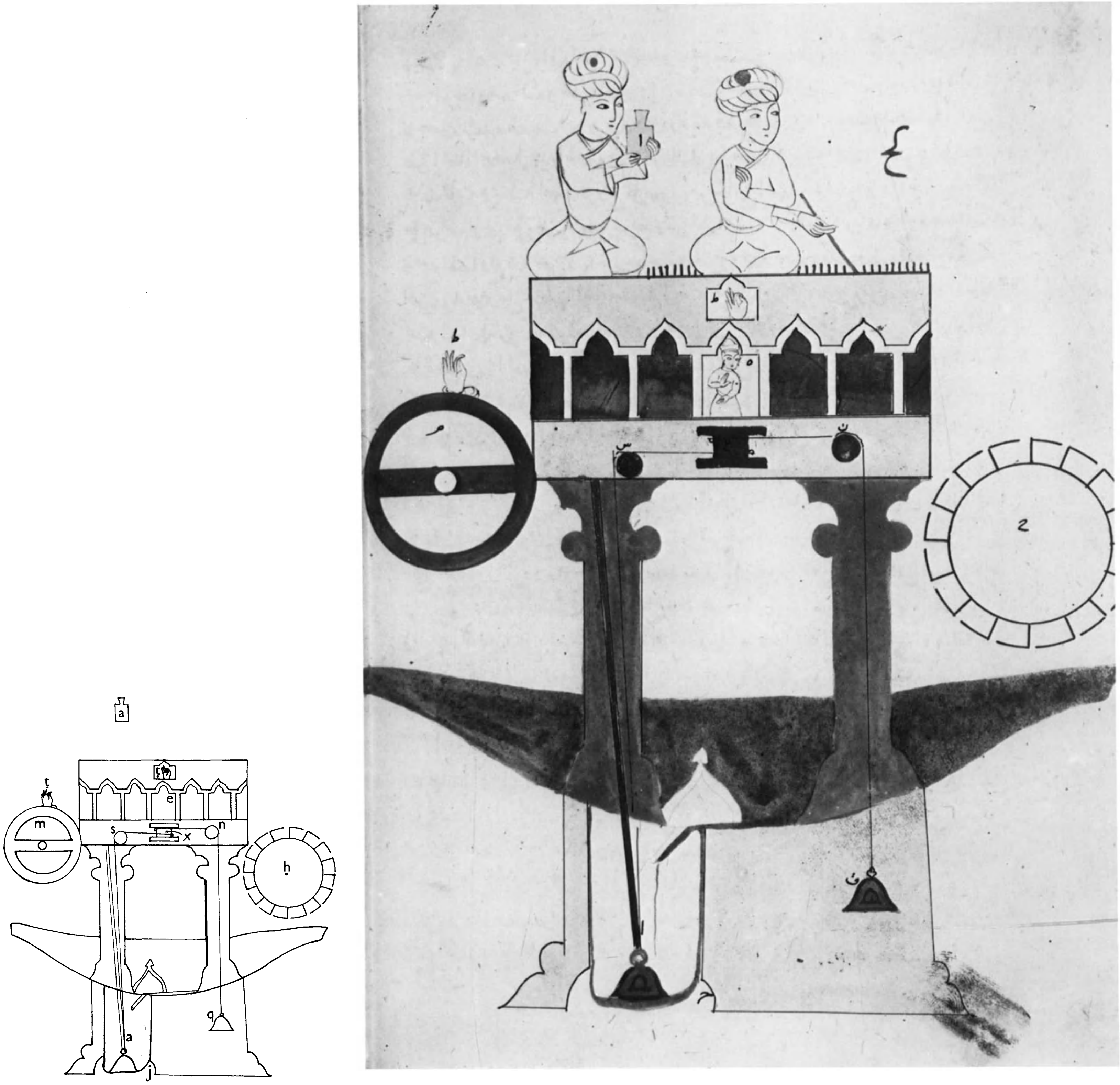


Fig. 117.

Chapter 9 of Category III

It is the basin of the peacock for washing the hands. It is divided into four sections

Section 1

On the outside appearance of the basin, and its functioning

It is a basin resting on a pedestal. On the floor of the basin are four columns which support a square-shaped castle. On the roof of the castle is a standing peacock with tail erect, its neck stretched out in a curve, its beak pointing to the floor of the basin, at the front of the castle. In the front of the castle, i.e. on the same side as the head of the peacock, are two doors, each having two closed leaves.

Its functioning: when the master[1] wishes to wash his hands or perform his ritual ablutions, the servant brings the basin [and places it] in front of him, with the head of the peacock facing the master. The servant stands aside and the peacock begins [to work], pouring a small quantity of water from its beak on to the master's hands. Then the leaves open on the door at the right of the castle and a slave emerges from it holding a jar containing vegetable soda (*Ishnān*), from which he [the master] takes what he requires. The water flows while he is washing, and when he has finished washing the flow of water ceases. Then the leaves open on the door at the left of the castle and a slave emerges holding a towel, for him to dry his hands. All the while the water is flowing it runs first into the basin and then into the basin's pedestal. In the pedestal is a closed tap. When the basin is taken away from him [i.e. the master] and removed from the company, the tap is opened and the basin is tilted towards the tap, to extract all the water is contains. When this has been done the tap is closed and the basin is put aside until such time as it is required for use.

Section 2

Construction of the basin, the four pillars, the castle on top of them with the two doors in its front, and the two slaves

A basin is made of brass with a wide floor and a vertical rim, its top slightly dished. The floor of the basin is divided into two halves and on one of the halves four columns are erected, each about 1 sp. high. Two columns are erected on the centre of the basin's floor and two on the corners of a square. Two holes are made below the two columns which are at the edge of the basin, penetrating through the floor of the basin into the two columns. If some water is poured into the floor of the basin it will rise in the floor of the basin because it has no outlet. Then, in the base of the right-hand column of these two columns, an opening is made into the floor of the basin, through which [opening] water falling into the floor of the basin can discharge.

Then a rectangular castle is made, wider than the square of the columns [i.e. wider than the side of the square formed by the feet of the columns] and about 1 sp. high. Two adjoining doors are opened in the [front] face of the castle, each door nearly as high as the castle. For each door two leaves are made, on hinges which move easily. Then the castle is fixed to the tops of the columns, the face with the doors on it towards the empty half of the basin. Then a slave is made from jointed copper, standing on an axle on the floor of the castle behind the right-hand door. The ends of the axle are on bearings, in which it moves freely towards the front and back of the slave. The height of the slave is such that he moves in and out of the door without hindrance. The slave is holding a small jar of fine workmanship in which some vegetable soda is placed. A bar [*sahm.*, lit arrow] is fixed rigidly to the axle, and it reaches to the top of the right-hand column, which has the opening in its foot for the water to fall through. The slave is tilted towards his rear, with the hand and the jar behind the door leaves, which are closed. The bar on the axle has a flat end, and this is touching the floor of the castle and over the centre of the column. There is a hole in the floor of the castle which goes through to the hollow of this column, whose foot has the opening in it. So if a rod rises from the column it will lift the end of the bar and tilt the slave forwards, who will push the door leaves with the jar he is holding. They open and he emerges from the door

[1] *Al-makhdūm.* Lit. He who is served.

and stands where he is. Then another slave is made, like the first, behind the left-hand door, standing on an axle. This has a bar on it the end of which extends to the centre point of the top of the other column on the edge of the basin – [this column] has no opening in its foot. A hole is made in the floor of the castle which goes through into the hollow of this column. If the end of a rod rises from it [i.e. the top of the column] it will lift the end of the bar, tilting the slave forwards so that his hand which holds the small towel opens the leaves. He emerges from the door and stands where he is.

Section 3

Construction of the basin

A pedestal is made, the width of its top equal to the distance between the columns, wider than that at the bottom, and about 1 sp. high. This pedestal is soldered underneath the four columns so that it is underneath half the basin – one need not fear that the basin will tilt. Then two holes are made from inside the pedestal, through the floor of the basin into the hollows of the two columns. A medium sized float is made, like a hollow turnip as [described] previously. For this float a chamber is made like a vertical jar, its height twice the thickness of the float, and wide enough for the float to be placed in it, and to move freely. Then a flat bottom [cover] is made for the pedestal, and this cover is cut into two halves. One half is fitted over the half of the pedestal below the two columns which are on the edge [of the basin], and its perimeter is soldered securely to the perimeter of the pedestal. The float's chamber is placed inside this half of the bottom of the pedestal, vertically beneath the column with the aperture in its foot, and is soldered to the bottom of the pedestal so that it cannot move out of position. Then a light rod is fixed vertically to the top of the float. Its length is such that it extends from the float, when this is resting in [the floor of] its chamber, up through the column with the opening in its foot, and almost touches the end of the bar on the axle of the slave who is holding the jar with the vegetable soda [in it]. When water is poured into the floor of the basin it flows from the hole in the floor of the basin into the chamber of the float, causing it to rise, until the rod lifts the end of the bar on the axle, which tilts the slave. So he opens the door leaves. Then a hindrance is made for the float which prevents it from exceeding that level, and coming out of its chamber. It stays where it is, at the top of its chamber. Then another float is made with a short, vertical rod on top of it. This float rests on the cover of the floor of the pedestal, and [the rod] is inside the left-hand column which is at the edge of the basin. The [other] half of the bottom of the pedestal is put back in position and its perimeter soldered securely to the perimeter of the pedestal. Then the cut is soldered securely. Water is poured into the floor of the basin and it flows through the opening in the foot of the column into the float's chamber, which fills up. The float rises and the rod lifts the rod on the axle of the slave who holds the jar with the vegetable soda. The water flows over the chamber of the float into the bottom of the pedestal and the other float rises. Its rod is short and does not touch the end of the bar on the slave's axle until the pedestal is full, and until the water in the peacock is exhausted. And at that juncture the float's rod touches the end of the bar on the axle of the slave who holds the towel. He tilts, pushes the leaves, emerges from the left-hand door and stands where he is.

Section 4

On the construction of the peacock and what is connected to it. It stands on the roof of the castle

A hollow peacock is made from jointed copper, large enough to contain the water that is dispensed for ritual ablutions. It is in a standing position, the neck curved down from its centre to its lower end. Its beak and its head are slightly lower than its belly. In its neck is a narrow siphon, one end of which is on its back and the other end on the floor of its belly. Then one makes for it a round hollow tail, the width of the cavity such that a finger can be inserted in it. This tail is erected at the rear end of the peacock, as if he were making a display. Then an opening is made between the cavity in the tail and the cavity in the peacock so that if water is poured into the top of the tail it will flow into the interior of the peacock's body. The tail is then divided half way up by a thin plate so that the tail becomes two chambers. If water is now poured into the top of the tail the upper half will fill since the water has no outlet. In the centre of the plate which divides the tail into two chambers a hole is made, in which the tip of the little finger can be inserted. A ground valve is made on this hole, watertight and of sound workmanship. The plug goes down into the seat from above. On the plug is a rising rod, the end of which is bent towards the back

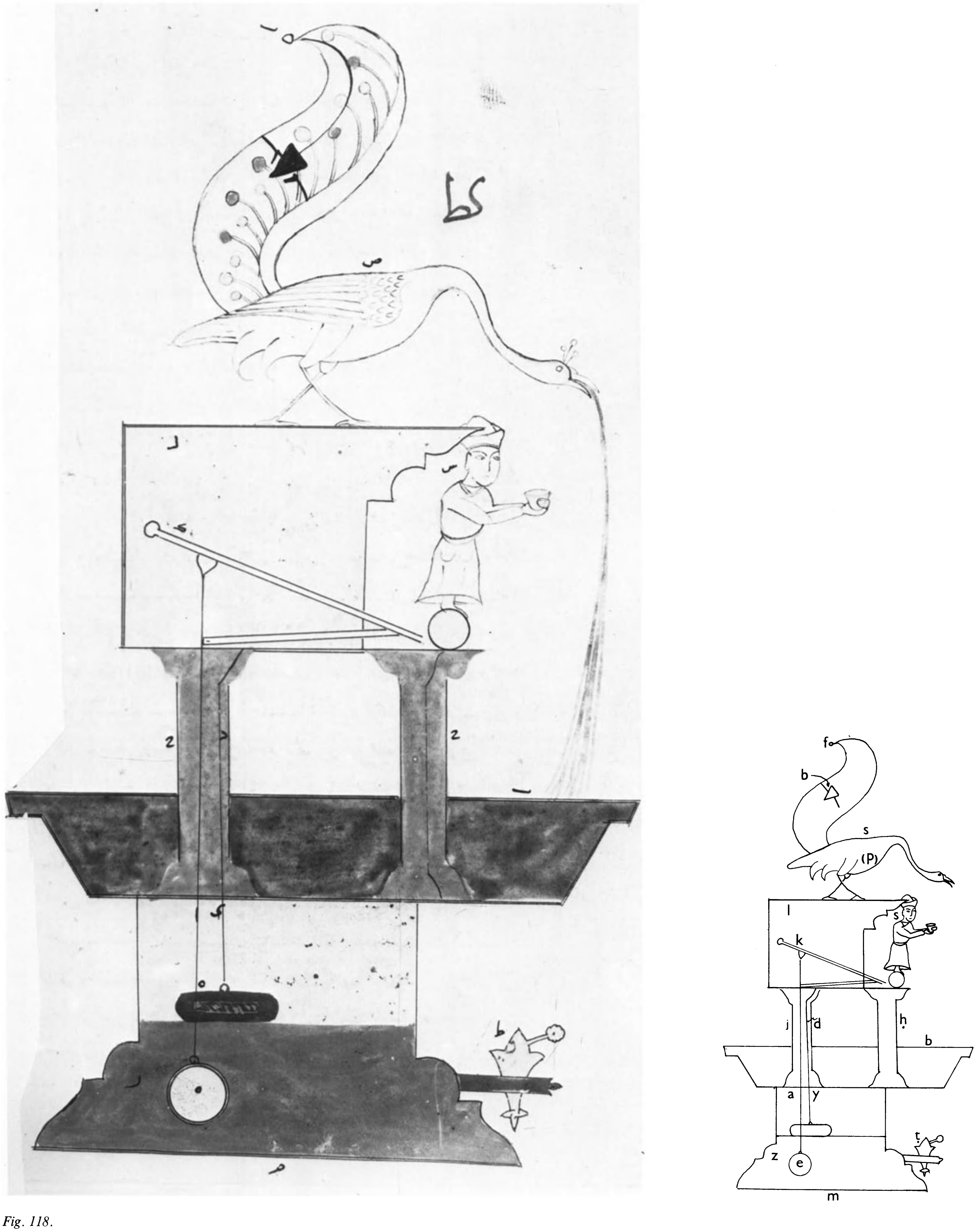


Fig. 118.

of the tail. In it is a ring which moves upwards stiffly in a narrow slit. In the top of the tail a wide aperture is made through which the water is poured. There is a cover on it, and when this is in position the join cannot be seen. When the cover is taken off and the ring lifted, the valve opens. Then water is poured in at the top of the tail until the body of the peacock and half the tail are filled, and water rises through the ground valve, this being observed visually. At this juncture the water has not reached the bend in the siphon in the peacock's neck but is slightly below it. Then the ring is pushed down stiffly in the slit, closing the valve, and water is poured into the upper half of the tail until it is full. Then the ring is pulled up, opening the valve and the water [from the lower chamber] mixes with the water [from the upper chamber] and rises above the bend in the siphon. The water issues from the peacock's beak because the ground valve is wider than the siphon. This [flow] continues until all the water in the body of the peacock is discharged. Then the peacock's legs are placed apart on the roof of the castle and soldered securely. The head of the peacock is towards the front of the axle so that it discharges into the empty half of the basin [i.e. the half outside the columns].

I have shown the picture [Fig. 118] of that: the basin *b*; the two columns *ḥ* on the centre of the basin; the column *j* on the edge of the basin with an aperture in its foot, and the other column *d*; the pedestal – its tap *ṭ* and its bottom *m*; the float's chamber *z*, the float *e* and on its top a rod *a*, which goes up through the column with the aperture in its foot; a second float on the surface of the water on the top of which is a rod *y* which goes up through column *d*; the castle *l*; the figure of one slave *s* holding the jar with the vegetable soda and standing on an axle on which is a bar *k* the end of which extends to the top of the column with the aperture in its foot; the other slave holding the towel is hidden but there is no need it illustrate him since he is of the same pattern; the peacock *ṣ* with the end of the siphon is his beak and its other end *p* in his belly; its tail is divided into two chambers and in the plate between the two chambers is a ground valve with a plug *b* on which is a rod whose end is bent to the outside of the tail and has a ring *f* on it.

It is very clear that: the cover on the peacock's tail is lifted off and the ring is pulled up, lifting the valve's plug. Water is poured into the top of the tail until the body of the peacock is filled to [a level] half way up the tail, and the water rises over the ground valve, whereupon the ring is pushed back to where it was before. The rest of the tail is filled with water and its cover is replaced. When the basin is called for the servant places it in front of the master, pulls the ring quickly without anyone noticing, and waits. The water mixes, one part with another, and rises above the bend in the siphon and issues from the peacock's beak on to the master's hands. The water flows, and runs down through the aperture in the foot of column *j* and fills chamber *z*. Float *e* rises and rod *a* rises, lifting bar *k*. The slave tilts and emerges from the door and stands [there]. The master takes vegetable soda from the jar – the water is running – and performs his ablutions until he has finished washing his hands. The [rest of] the water runs from the floor of the basin into the pedestal until it is almost full. Float *y* has risen and [now] the bar on the axle of the slave holding the towel rises. [The slave] tilts, opens the leaves, emerges from the door and stands where he is. The master takes the towel, dries his hands, and returns the towel to him. The servant takes the basin, opens the tap, and tilts the basin towards the tap until there is no more water in the pedestal or in the float's chamber. Then he closes the tap and puts the basin aside until such time as it is required for use.

On completion of what I have described the basin, pedestal and castle are scraped, the peacock and the slaves are painted in various colours, and everything is coated in Sandarac oil and cured by drying in the sun.

That is what I wished to describe clearly.

[Now] I will describe what I made, namely a basin for washing the hands.

Chapter 10 of Category III

It is the basin of the slave and is divided into two sections

Section 1

Description of its outside appearance and functioning and the construction of the dais (kursī) and the slave

It is a square-shaped dais about 1 sp. high and 2 sp. by 2 sp. in area. On it is a kneeling slave holding a pitcher in his right hand and a towel and comb in his left, which is raised, covering his upper arm. On the corners of the dais are four columns which support a handsome castle with a dome on top of it and a bird on top of that. Directly beneath the pitcher is a half basin, soldered to the dais – many basins are positioned like that. In the floor of the basin is a handsome, crouching duck, its tail pressed against that side of the basin which adjoins the dais. Its neck is raised then bent [down] from the middle so that its beak touches the floor of the basin. So much for its appearance, now for its functioning: the servant fetches it and brings it in front of the master, the bird whistles and water pours from the pitcher's spout. He [i.e. the master] performs his ritual ablutions until they are completed. The water collects on the floor of the basin and the duck drinks it all. The slave extends his hand with the towel and the comb. He takes the towel and dries himself with it, uses the comb and puts it back on his hand. The servant takes the basin away from the company. In the side of the dais is a tap, and he opens it to extract the water, all of which was drunk by the duck.

A square-shaped dais is made from copper, 1 sp. high and 2 sp. by 2 sp. in area. Upon it is placed a kneeling slave holding a handsome brass pitcher in his right hand. This pitcher is divided in the middle into two chambers, a chamber from the middle down and a chamber from the middle up. It is closed at the top by a plate. Two holes are made below the handle, and [two pipes] are fitted to them: one pipe goes from the handle through the palm into the upper arm of the slave and a whistle's ball is fixed to it; and a pipe which goes through the palm and is bent down at the slave's elbow and terminates below the slave's skirt, for the time being. At the position of the spout a hole is made, in which the end of a siphon is inserted until it almost touches the [dividing] plate. It rises one finger's length inside the body of the pitcher and is then bent down until its end is lower than the end which is inside the pitcher. The visible part is adorned, and resembles the head and neck of a peacock – or something similar.

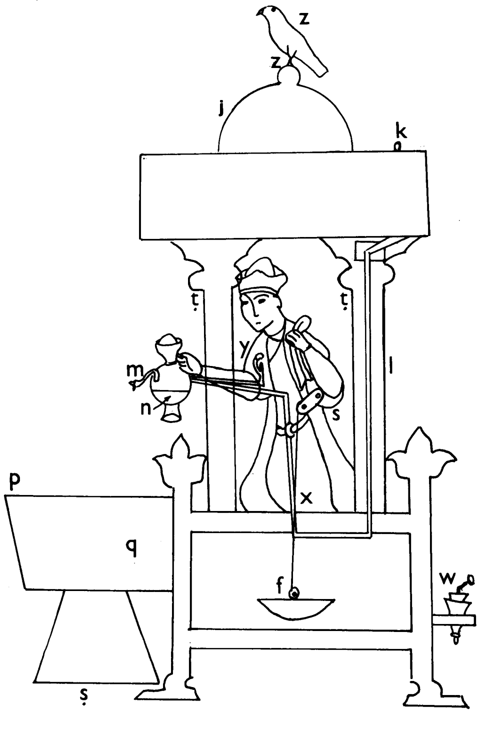
The left hand moves on an axle, the ends of which are fixed firmly in the sleeve at the elbow. The extension of the elbow goes into his cavity and on it [i.e. the extension] is a staple which is mentioned below. Then four columns are placed on the corners of the dais, each column slightly higher than the slave's head. Above the columns a handsome castle is installed, above which is a dome, and on the dome is a dainty bird. This castle is thoroughly soldered, to serve as a tank. A cover is placed on top of it. To the floor of the castle a pipe is fixed which goes down through the right-hand column which is behind the slave, is turned under the deck of the dais and rises into the hollow of the slave. Its end is connected to the end of the pipe which comes up from the pitcher's handle and [goes] through the palm and sleeve of the slave. This pipe should be the same width as the pitcher's siphon so that water does not rise into the whistle's ball. If some water is poured into the castle it runs down through the pipe then rises through it and flows into the pitcher. It drives out the air which is in the pitcher, and this has no outlet except the pipe which rises from the pitcher's handle into the upper arm of the slave, and which has the whistle on it. This whistles and the whistling is thought [to come] from the beak of the bird on top of the dome.

Then a float is made, as described in a number of previous chapters. In the centre of its [upper] circle a staple is fixed, to which is [attached] a chain or a stout string. It is placed on the floor of the dais and a hole is made in the deck, vertically below the staple in the extension of the slave's left arm. The chain is lifted through the hole in the deck of the dais into the hollow in the slave and its end is attached to the staple on the extension of his arm. When the float is resting on the floor of the dais its weight pulls the extension of the slave's elbow and lifts his hand with the towel and comb until his palm and fingers almost touch his shoulder. When water runs into the dais the float rises and the slave's hand sinks.

Section 2

On the construction of the basin and its contents

A basin is made shaped like half a basin, having a wide floor and short sides, with a pedestal which rests on the ground. Its diameter adjoins the dais and it is at the same level as the dais. It is soldered securely to the dais. Then a handsome duck is made, having no legs. When it is placed on the floor of the basin its neck rises as far as the middle [of the neck] and is then bent down



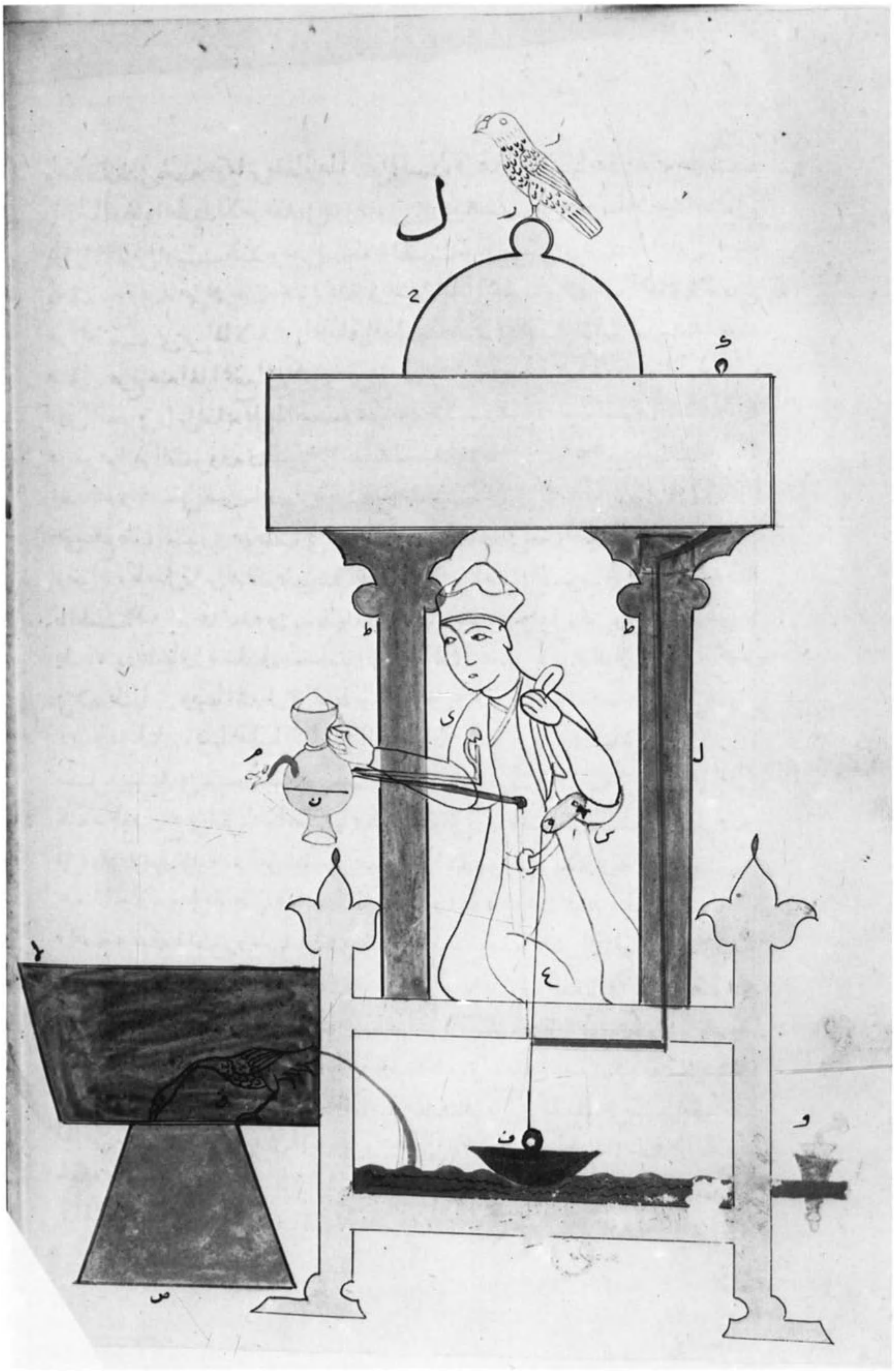


Fig. 119.

until its beak touches the basin's floor. A narrow siphon is inserted in its neck – one end of the siphon is the tip of the beak. The other end goes through its rump, through the side of the basin into the hollow of the dais, and is brought down a little lower than the level of the basin's floor. It is firmly soldered to the basin and to the dais. When water is poured into the floor of the basin it rises until it covers the bend in the duck's neck, [whereupon] it runs through the siphon into the hollow of the dais. No water can leak out of the basin, because the siphon is securely soldered to the basin. To the side of the basin near the bottom a tap is fitted from which, when it is opened, the water collected in the dais can be extracted.

Than an upright valve (*faythūn*) is fitted to the upper end of the pipe which descends from the floor of the castle, as follows: it is a valve seat (*tanūr*), half of which is [pushed] down over the end of the pipe, while the other half rises above the floor of the castle. In it is a plug which has an extension [rod] on its top which goes up to the top of the castle; and which has something on its end for turning the plug. In the centre of the [side of] the seat a hole is drilled laterally, as far as the centre [line] of the plug. Then a hole is made lengthwise through the plug from its underside to meet the hole from the seat. When water is poured into the floor of the castle it runs down through the hole in the valve into the pipe. When the extension on the top of the plug is rotated a little, the valve is shut and nothing flows from it into the pipe.

I have shown the picture of that [Fig. 119]: the basin *p*; the duck *q* with a siphon in its body; the dais *ṣ*, with the float *f* inside it, upon which is a staple connected to the extension to the slave's arm by a chain *x*; the slave's hand *s* which moves on an axle in his sleeve, and which has a towel and a comb in it; then the pitcher – the plate *n* which divides the pitcher into two chambers; the spout *m* in which is a siphon going down into the upper chamber, its end almost touching the plate; the pipe *l* connected to it [i.e. the pitcher] which goes up from its handle, through the palm and sleeve of the slave, down through his hollow, turns under his skirt along the dais, and rises through column *l*; the top of the valve and its plug's extension *k* which goes up to the top of the castle; another pipe *y* which rises with this [i.e. the above mentioned] pipe from the pitcher and terminates at the end of the slave's upper arm, with the whistle's ball [fixed] in its end; three columns *ṭ*; the castle *j*; the dome *z* with the bird *z* on top of it.

It is very clear that: water is poured into the castle while valve *k* is closed; the whole assembly is placed in front of the master and the servant opens valve *k* without being noticed, and then stands aside. The water descends and rises in pipe *l* and flows into the pitcher, covering the end of the siphon. The air in the pitcher is driven out and rushes through pipe *y*. The ball whistles and it is thought that the whistling comes from the bird's beak. This continues until the water rises above the bend in the siphon and flows out of the peacock's beak over the hands of the one who is performing his ritual ablutions. It collects in the basin until the water in the castle is almost exhausted, whereupon the duck drinks all the water that is in the basin. The slave holds out his left hand, with the towel and the comb. He [i.e. the master] dries himself and uses the comb, then puts them back into his hand. The servant takes the basin outside the company, opens the tap, and drains the water out of the dais.

That which requires painting is painted, that which requires scraping is scraped, and everything is coated with [Sandarac] oil.

That is what I wished to describe clearly.

[Now] I will describe what I made, namely a fountain which changes its shape at known intervals.

[End of Category III]

CATEGORY IV

On fountains which change their shapes (tabaddala) at known intervals, and on perpetual flutes

I did not follow the system of the Banū Mūsà, may God have mercy upon them, who in earlier times distinguished themselves in the matters covered by these subjects. They made the alternation with vanes turned by wind or by water so that the fountains were changed at every rotation, but this is too short an interval for the change to appear [to the full effect]. Then in two designs they used a pipe like an almost horizontal balance arm. The water flowed through it into a tank and then into the fountain. To part of the pipe a small tank was fitted, into which a small quantity of water dripped, filling it in a known period. The end of the pipe became heavy and tilted, and the contents of the small tank discharged all at once into another tank. In this was a pipe which discharged [the water] from it [i.e. the tank] in the same time as was taken to fill the first tank. It seems that the pipe tilted on completion of a known weight, namely the last drop which fell into the first tank; when the weight decreased by a small amount the pipe rose to its original position. The time during which it was tilted was not long enough for the water in the tank be completely evacuated. I do not know whence this confusion [came], from the original or from the copy.

Chapter 1 of Category IV

It is the fountain of the two [tipping]-buckets and is divided into two sections

Section 1

Description of its construction

It is a fountain in a pool: the water shoots up from it in a single vertical jet for the space of one constant hour, then it changes and shoots up for the space of an hour in six curving jets.[1] Then it changes back and emits a single jet, and so on, for as long as the water flows into it.

I will describe its construction: some distance away from the pool a high house is built into which the water flows, and from which it [flows] into the fountain. Then a tank is constructed and divided into two tanks *j*, *x*. From the floor of tank *x* a wide pipe *l* is run into the pool, and rises from its centre [a height] of about 6 sp. On top of it a brass sphere is fitted into which the water flows, and in which it collects. In its upper circumference six holes are made, facing the pool, and in the centre of the [ring of] holes a large hole is made. Then a narrow pipe *e* is run from the floor of tank *j* into pipe *l* and then up until it projects slightly from the hole in the centre of the sphere. They [i.e. the pipe *e* and the sphere] are soldered together.

Then one takes a pipe 4 sp. long and bends its ends. An axle is fitted underneath it, at the centre, and this [rests] in bearings on a firm support which is fixed on top of the partition between the two tanks. In the centre of the pipe, on the opposite side to the axle, a kind of funnel is fixed and soldered in position. In its bottom an opening is made which penetrates through to the bore of the pipe. Two holes are made in the pipe on either side of the axle, and two small pipes are soldered to them, and these have calibrated orifices on their ends. The [main] pipe does not rest horizontally on its axle, but tilts towards one [or other] of the two tanks. Suppose it is tilted towards tank *j*, then on the tilted end is *y*, on the other small pipe connected to it is *m*, on the axle is *d*, on the second small pipe is *q*, on the raised end is *w*, and on the funnel is *z*. This is the separate picture [Fig. 120] of this pipe, for a clear understanding.

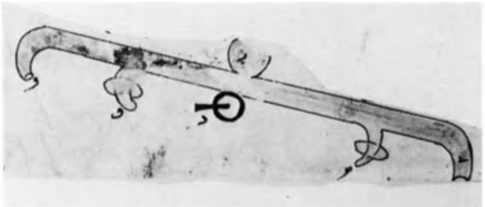


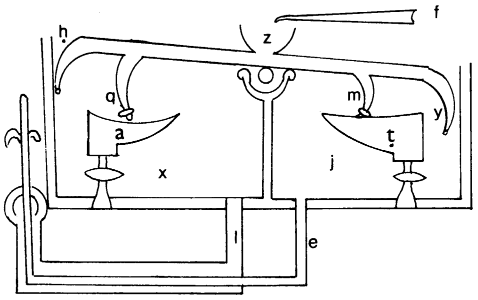
Fig. 120.

Then a supply channel *f* is made which discharges water into funnel *z* – not too much and not too little, but in a quantity that suits the capacity of the fountain. When water flows into funnel *z*, it runs through the tilted end *y* of the pipe and also through the small pipe *m*, and these discharge into tank *j* and into [tipping]-bucket *ṭ* [respectively]. When this end lifts the other end *ḥ*, tilts and water runs through it, and also through the small pipe *q*, and they discharge into tank *x* and bucket *a* [respectively]. The [tipping]-buckets lift the ends of the pipe alternately.

[1] Al-Jazarī uses various descriptive terms for the shapes produced by his fountains. In this case the single jet is a *qaḍīb*, literally 'stick'. The curving jet is a *ṣawlajān*, literally 'polo-stick'.

Section 2

Two [tipping]-buckets are made from copper – I have described the shape of the bucket and its movement on its axle in a number of places previously. The capacity of the bucket should be 5 Ba<u>gh</u>dadī *raṭls* of water. Each bucket is placed in a horizontal position under one of the pipes *m*, *q*. Pipe *m* discharges into bucket *ṭ*. A known quantity of water discharges into it from the onyx [orifice] at the end of pipe *m* in one constant hour. When it is full it tilts and empties the water it contains into tank *j*. Its rear end lifts pipe *y* by means of a rod connected to it. The large pipe tilts and discharges into tank *x*, and pipe *q* discharges into bucket *a*, which is underneath it, and which fills with the known [quantity] of water which issues from the onyx in pipe *q*. Then it empties the water it contains into tank *x*. Its rear end lifts pipe *ḥ* by means of a rod connected to it, and the water discharges once more into tank *j* and into bucket *ṭ*. And so on, as long as water flows through the supply channel. This is its picture [Fig. 121].



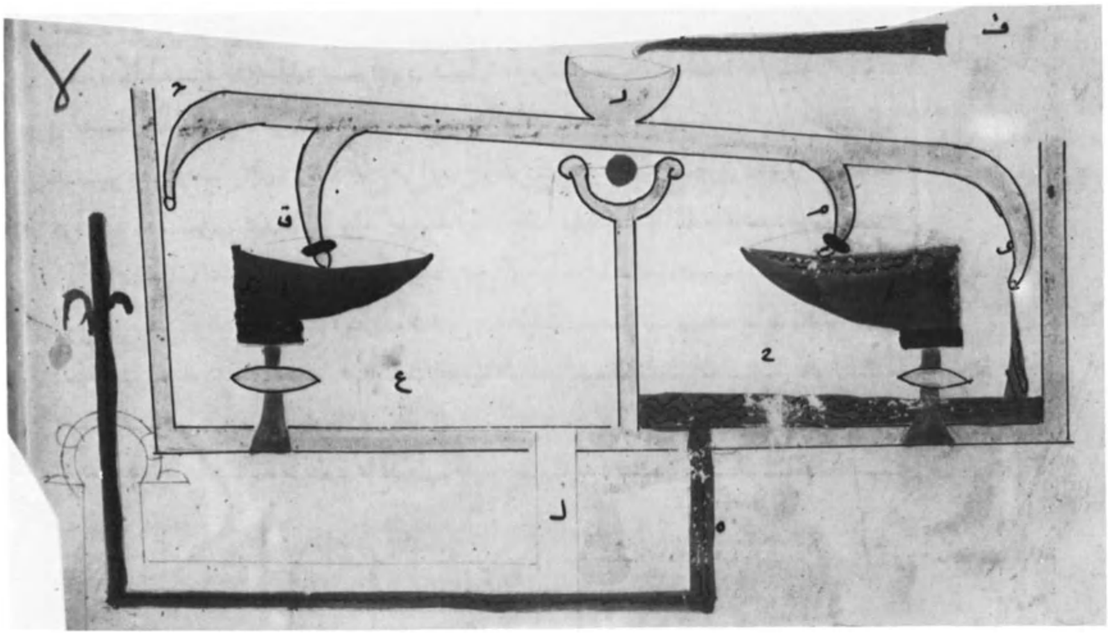


Fig. 121.

It is very evident that: water runs from channel *f* into funnel *z*, then through pipe *y* into tank *j*, and then through pipe *e* into the fountain *n*, and comes out of its head like a stick [i.e. in a single jet]. Some of the water discharges from pipe *m* into bucket *ṭ* which fills in the space of one hour. Then it empties the water it contains into tank *j*, and its rear end lifts pipe *y*. The water runs from pipe *ḥ* into tank *x*, then through pipe *l* – to gush out in six jets from the sphere. Some of the water flows from pipe *q* into bucket *a*, which fills in one constant hour. Then it discharges the water it contains, its rear end lifts pipe *ḥ* and the water flows once more into pipe *y*. And so on, as long as the water flows through the supply channel.

That is what I wished to describe clearly.

Now I will describe what I made, namely two fountains which change shape in one pool.

Chapter 2 of Category IV

It is two fountains, and two [tipping]-buckets and a [balance] pipe, with four outlets

I will describe what I constructed, namely two alternating fountains in a single pool or in two pools. For the space of one hour one emits a single jet and the other six arcs; then they change over and the one that was a single jet emits six arcs, and the one that was six arcs emits a single jet. And so on, as long as the water continues flowing.

I have repeated from the previous chapter the [supply] channel *f* into two tanks *x*, *j*. Two adjacent pipes lead from the floor of tank *j*: pipe *e* into fountain *s*, and then into the sphere, whence it issues in arcs; and pipe *p* into fountain *n*, from which it issues as a single jet. And two pipes [lead] from tank *x*: pipe *l* into fountain *n*, where it issues from the sphere in arcs; and pipe *ṣ* into fountain *s*, emerging as a single jet. This is their picture [Fig. 122].

It is very evident that: water flows through channel *f* into funnel *z* and discharges from pipe *y* into tank *j*; then from tank *j* through pipe *e* into fountain *s*, whence it shoots up in arcs, and through pipe *p* into fountain *n*, shooting up from it in a single jet. Some of the water drips from pipe *m* into bucket *ṭ* which fills in the space of one hour, then empties its contents into tank *j*. The projection on its rear end lifts pipe *y* – this rises, pipe *ḥ* descends, and water discharges from it into tank *x*. From tank *x* [it runs] through pipe *l* into fountain *n*, whence it shoots out in arcs, and through pipe *ṣ*, into fountain *s*, whence it shoots out as a single jet. And so on, as long as the water flows through channel *f*, which is the supply channel.

That is what I wished to describe clearly.

Now I will describe what I made, namely an alternating fountain.

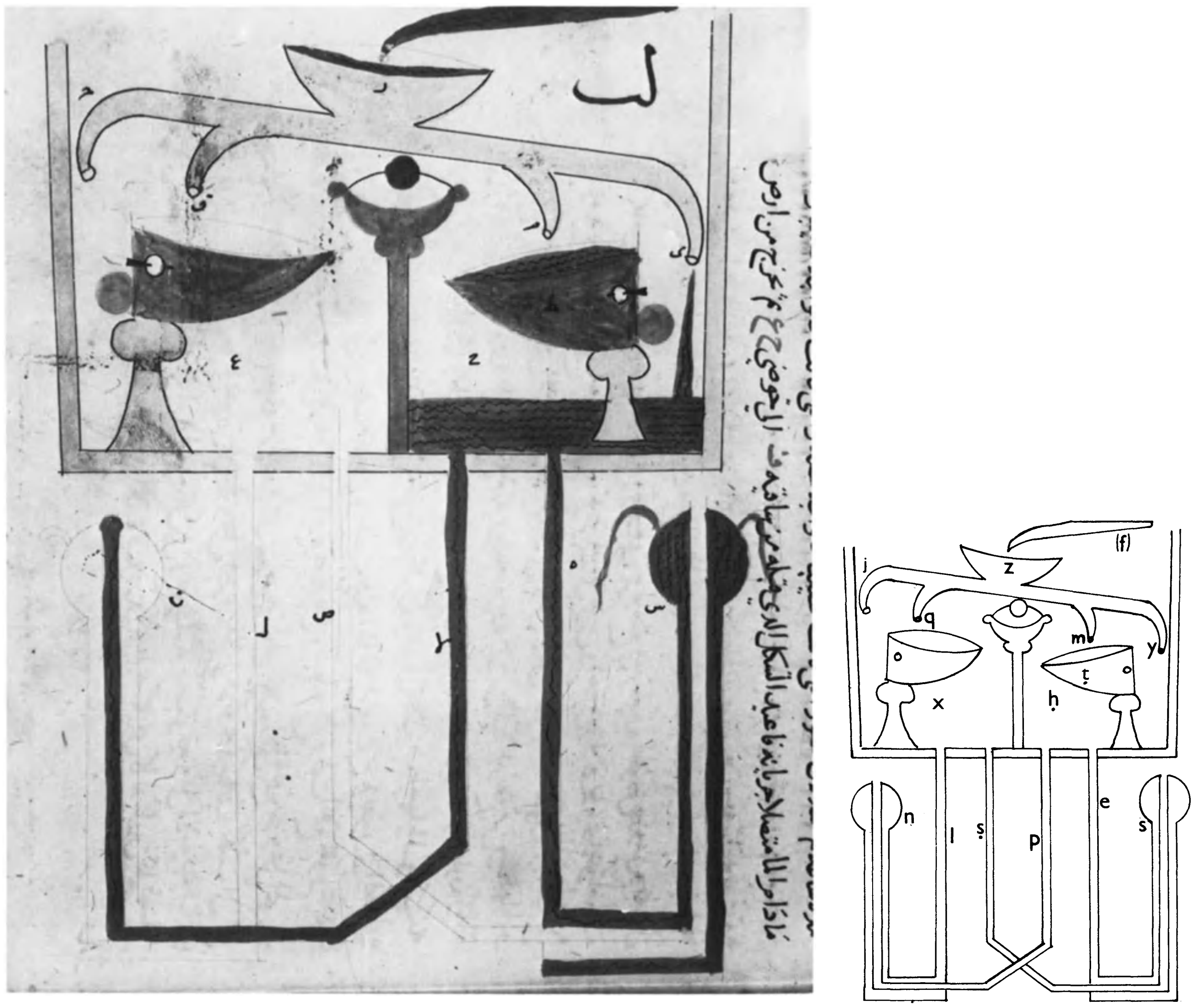


Fig. 122.

Chapter 3 of Category IV

It is the alternating fountain of the two floats. It is divided into two sections

Section 1

I will describe what I made, namely an alternating fountain which throws up an arc for the space of quarter of a constant hour, and [then] throws up [something] like a lily-of-the-valley (*sūsan*), as I shall describe.

As previously, a house is constructed some distance from the pool, in which two tanks *ṣ*, *s* are installed, with a partition between them. Then a float is made with a projecting knob on top of it, and it is placed in the side [lit. corner] of the tank at *ṣ*. Then a barrier is erected to prevent it from coming out of the corner. It can move freely, but only up and down. Then another float is made and placed in the side of the other tank at *s*. Then in the floor of tank *ṣ* a ground valve is fitted, through which water can run into pipe *l*. On the rising end [of pipe *l*] is fixed a vessel,[1] the top of which has a small aperture in its centre, through which a [second] pipe rises which emits water in an arc. The end of this pipe [i.e. pipe *x*] is level with the top of the vessel. Then a copper [fitting] shaped like the top of the vessel is fixed around the end [of pipe *x*], so that water issues between the rim of the vessel and the end of the pipe in the shape of a lily-of-the-valley. In the floor of tank *s* a ground valve is fitted through which water can run into pipe *x* and shoot up in the fountain like an arc.

Then a pipe 3 sp. long is made, with a funnel fitted to its centre. Beneath the funnel is an axle upon which the pipe moves – it [i.e. the axle] is on a firm support which is on top of the partition between the two tanks. [The parts are marked as follows on Fig. 123]: the funnel *j*; the axle *d*; the end *ṭ* of the pipe above tank *ṣ*; the other end *m*.

Then a supply channel is made which delivers [water] into the funnel through a calibrated pipe *y*, [at a rate] which fills one of the troughs in quarter of a constant hour.

Section 2

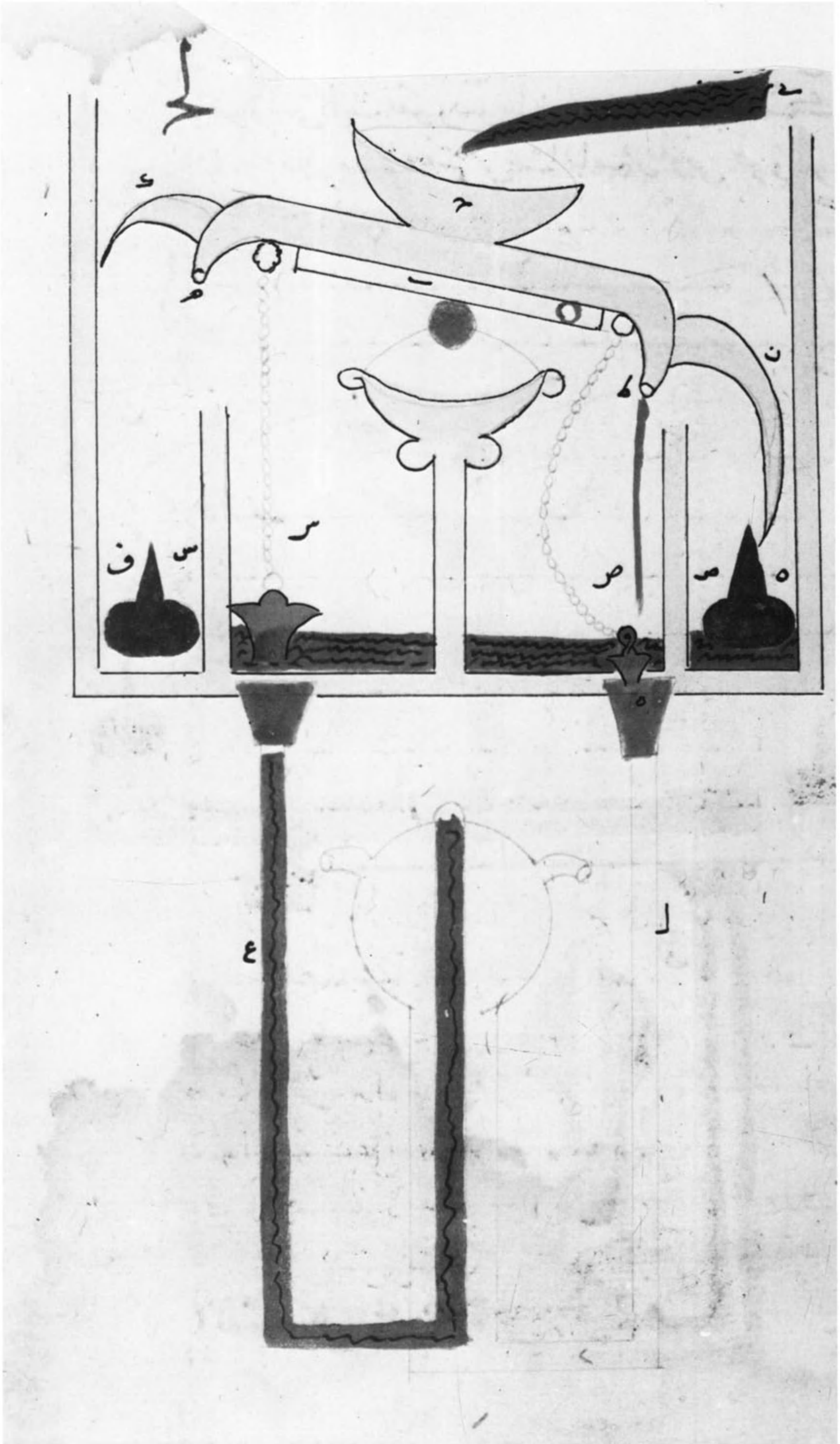
To end *m* and *ṭ* of the pipe two extensions like *dīnārs* are fitted, each extension in line with the knob on a float. At each end of the pipe, a little way back from the water outlet, a staple and a ring are fitted, vertically above the ground valve in the floor of the tank. The ring and the valve-plug are connected by a chain of appropriate length. When the end of the pipe rises the valve opens, and when it descends the valve closes. Then a copper cylinder (*jaʿba*, lit. quiver) is made, its length 2 sp. A lead ball is placed in it, and both ends of the cylinder *b* are closed. It is placed longitudinally on the pipe so that their centre points coincide and so that it touches funnel *j*. It is soldered firmly to the pipe in [that] position. This is the picture of what I have mentioned [Fig. 123].

It is very clear that when the end *ṭ* of the pipe is down, the valve of tank *ṣ* is shut and water flows from pipe *y* into funnel *j* and runs from pipe *ṭ* into tank *ṣ*, which fills in the space of quarter of an hour. Float *e* rises and with its knob pushes extension *n*. This rises, end *m* sinks, and the ball which is in the cylinder moves into [the end of the cylinder] near end *m*. The valve of tank *ṣ* opens and the valve of tank *s* closes. Water runs into it and it fills in the space of quarter of an hour, in which time [all] the water from tank *ṣ* is discharged into the fountain, where it shoots out as a lily-of-the-valley. Float *f* rises and with its knob pushes extension *k*, which rises. End *ṭ* sinks and the ball returns to side *ṭ*. The valve of tank *s* has opened, and the water runs through pipe *x* and shoots out in the fountain like an arc. And so on, as long as water flows from pipe *y*.

That is what I wished to describe clearly.

[Now] I will describe what I made, namely two fountains which alternate at known intervals.

[1] *Burniya*. A large earthenware or stoneware jar.



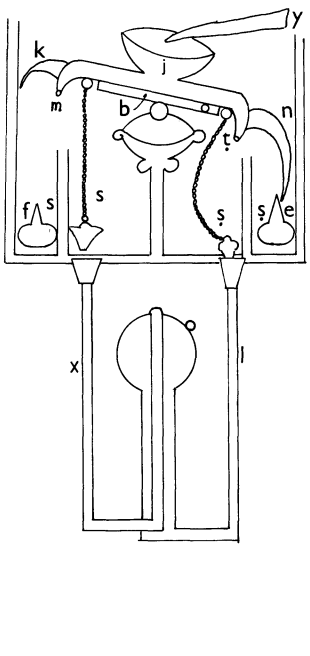


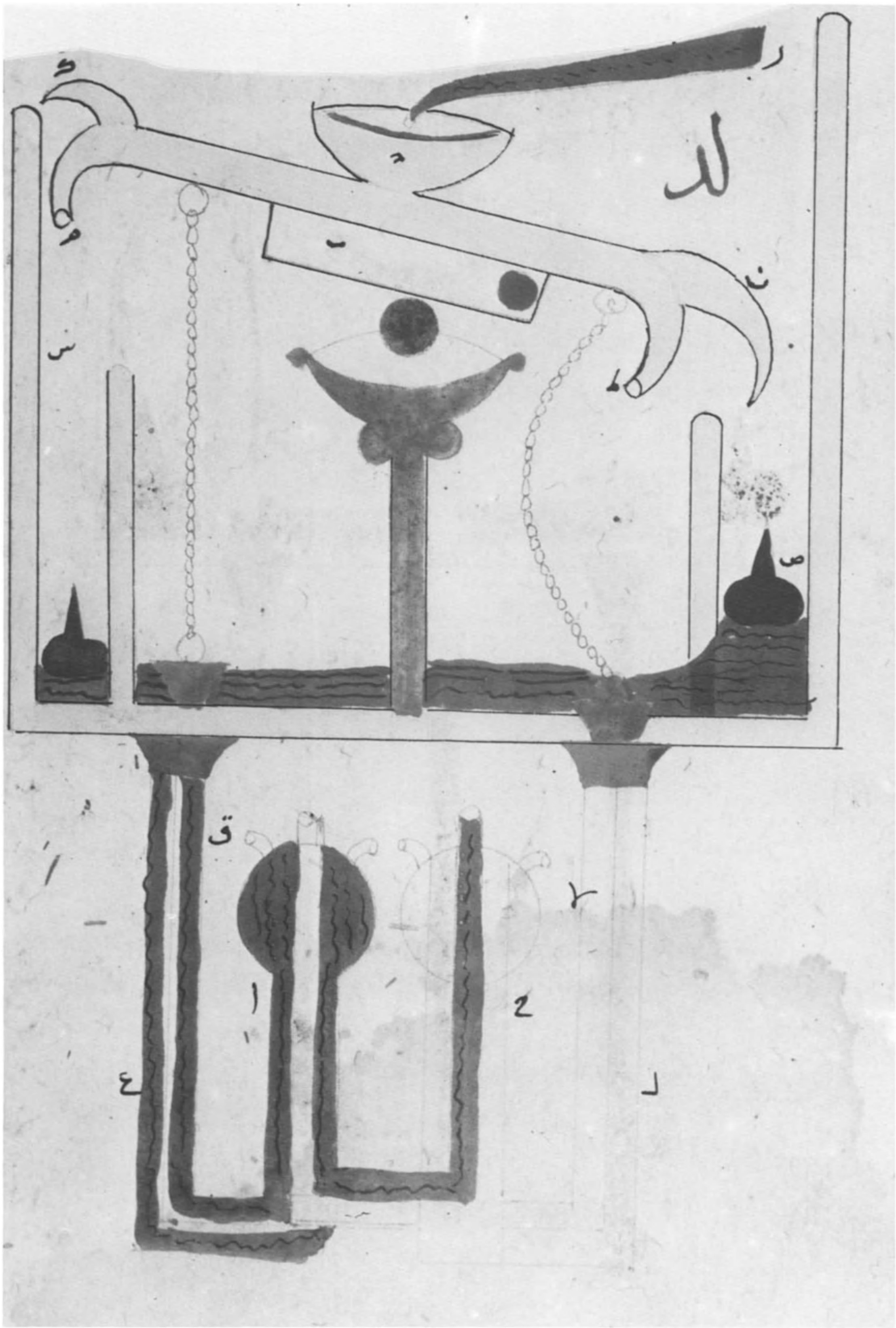
Fig. 123.

Chapter 4 of Category IV

It is the two fountains of the two floats

I will describe what I made, namely two fountains, one throwing up a lily-of-the-valley, and the other an arc for the space of quarter of an hour. Then they change – the one that was throwing up a lily-of-the-valley emits an arc, and the one that was throwing up an arc emits a lily-of-the-valley.

I repeat the previous chapter word for word up to and including the two ground valves. Underneath the valve of tank *ṣ* pipe *l* is divided into two parts along its [entire] length: part *p* into foun-



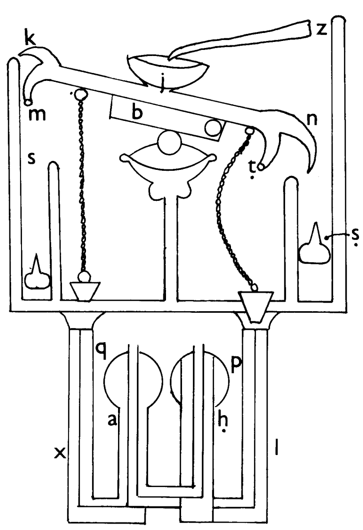


Fig. 124.

tain *a* to shoot up as an arc and part *l* into fountain *ḥ* to shoot up as a lily-of-the-valley. Then, underneath the valve of tank *s*, pipe *x* is divided into two parts: *x* into fountain *a* to shoot up from it as a lily-of-the-valley, and part *q* into fountain *ḥ* to shoot up as an arc. This is the picture (Fig. 124) of what I have described.

It is very clear that when water flows from pipe *z* into funnel *j* it discharges from end *ṭ* into tank *ṣ*, the valve of which is closed. Water collects in it for the space of quarter of an hour. Its float rises and with its knob pushes extension *n*, so end *ṭ* rises, end *m* sinks and water discharges from it into tank *s*, the valve of which has been closed. The water from tank *ṣ* rushes out of the valve in the space of quarter of an hour, through pipe *l* and into fountain *ḥ*, shooting up from it as a lily-of-the-valley and through pipe *p* into fountain *a*, from which the water shoots up in an arc. This continues until tank *s* fills, [whereupon] the float rises and with its knob pushes extension *k*. End *m* rises, end *ṭ* sinks and the valve of trough *s* is opened. Water rushes out of it into pipe *x* and shoots up from fountain *a* as a lily-of-the-valley, and through pipe *q* into fountain *ḥ*, shooting up from it in an arc. And so on, as long as the water flows through pipe *z*.

That is what I wished to describe clearly.

[The following paragraph is an addendum to Chapter 4.]

I say that there is a second design for this model, whereby it is possible for one of the fountains to throw up a 'tent'[1] and a single jet, and the other fountain [to throw up] six arcs. Then they alternate continuously.

I have shown the picture of that in a single drawing [Fig. 125] which takes the place of the other one, as follows: the water flows through pipe *e* from tank *ṣ* into sphere *m* and shoots up from it through 6 pipes *z* like section of bows, which pass through the shield (*daraqa*). Inside the sphere's pipe is pipe *ḥ*, carrying water from tank *ṣ*, and this shoots out of its top with force and is met by the barrier of the shield, and descends from its perimeter like a tent. Inside this pipe is pipe *a* through which water flows from tank *s*. It [i.e. pipe *a*] protrudes above the centre point of the shield and emits a single jet. This device is not included in the fifty devices.

That is what I wished to describe clearly.

[Now] I will describe what I made, namely a fountain which changes shape every half constant hour.

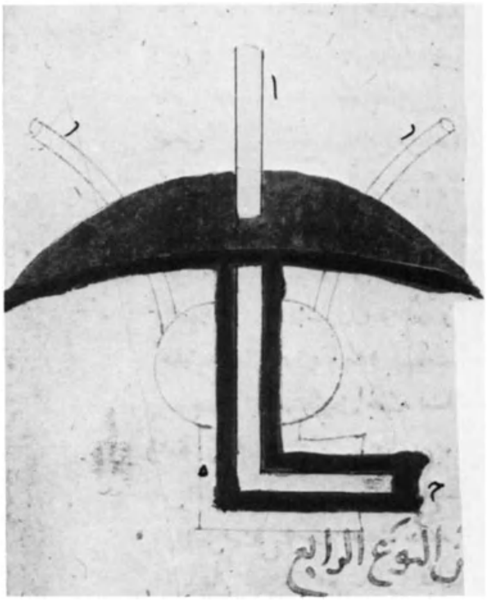


Fig. 125.

[1] *Khayma*. Its shape is explained in this paragraph and in the next chapter.

Chapter 5 of Category IV

It is the fountain of the bowl (ṭarjahâr) which changes shape at known intervals. It is divided into two sections

Section 1

I will describe what I made, namely a fountain which emits a tent for half a constant hour then changes, and emits a tree for half an hour, and so on, as long as the water flows into it.

Some distance from the pool a house is built, from which the water flows into the fountain. In the house a vertical tower (*burj*) is erected with a tank on top of it. On its underside is a channel, square in shape [i.e. in cross section]. It runs along the ground. Its end is closed and behind it [i.e. in the channel near this end] are two co-axial apertures, one in the top and one in the bottom. To these apertures ground valves are fitted, and between them is a plug, the ends of which are machined to fit into them: one end closes the lower valve and one closes the upper valve.

The tank is marked *b*, the tower *j* and the channel *x*. To the tower a small, almost horizontal pipe *k* is fitted, on the end of which is a drilled onyx *y*. The lower valve is marked *ṃ*, the upper valve is marked *ṭ* and the plug is marked *w*. On its upper end is the end of a chain, mentioned below – its other end is marked *l*.

Then below valve *m* a long pipe is fitted which rises in the centre of the pool. On its end a brass 'citron'[1] *q*, with an opening in its top, is firmly [fixed]. Then above the upper valve a pipe *s* fitted, which is taller than the tower and the tank. The chain rises up [through this pipe] with a length to spare. At the bottom of this pipe is a hole upon which is a pipe *f*. This is bent down, runs along [for some distance] goes into the citron's pipe, and comes out of the top of it [i.e. the top of the citron]. Between it and the top of the citron there is a gap right round. Then to the top [of pipe *f*] a cover is fitted, and in the cover a hole is made in which the little finger can be inserted. Around it are a number of closely spaced small holes, so that together they produce a fountain like a tree. Then a slightly concave disc is made, 1 sp. in diameter, with a round hole in its centre through which pipe *f* is passed, so that it [i.e. the disc] almost touches the top of the citron. The concavity of the disc faces downwards. It is soldered in position to pipe *f*.

Then a copper cylinder is made about 2 sp. long. A lead ball weighing about 2 Ba<u>gh</u>dadī *raṭls* is placed in the cylinder, the ends of which are [then] securely closed. It is suspended at the centre by a strong staple [attached] to a firm staple *n*. The cylinder is marked *p*, *e*. The end *l* of the chain, which hangs out of the top of the pipe, is connected to a ring in end *e* of the cylinder.

Section 2

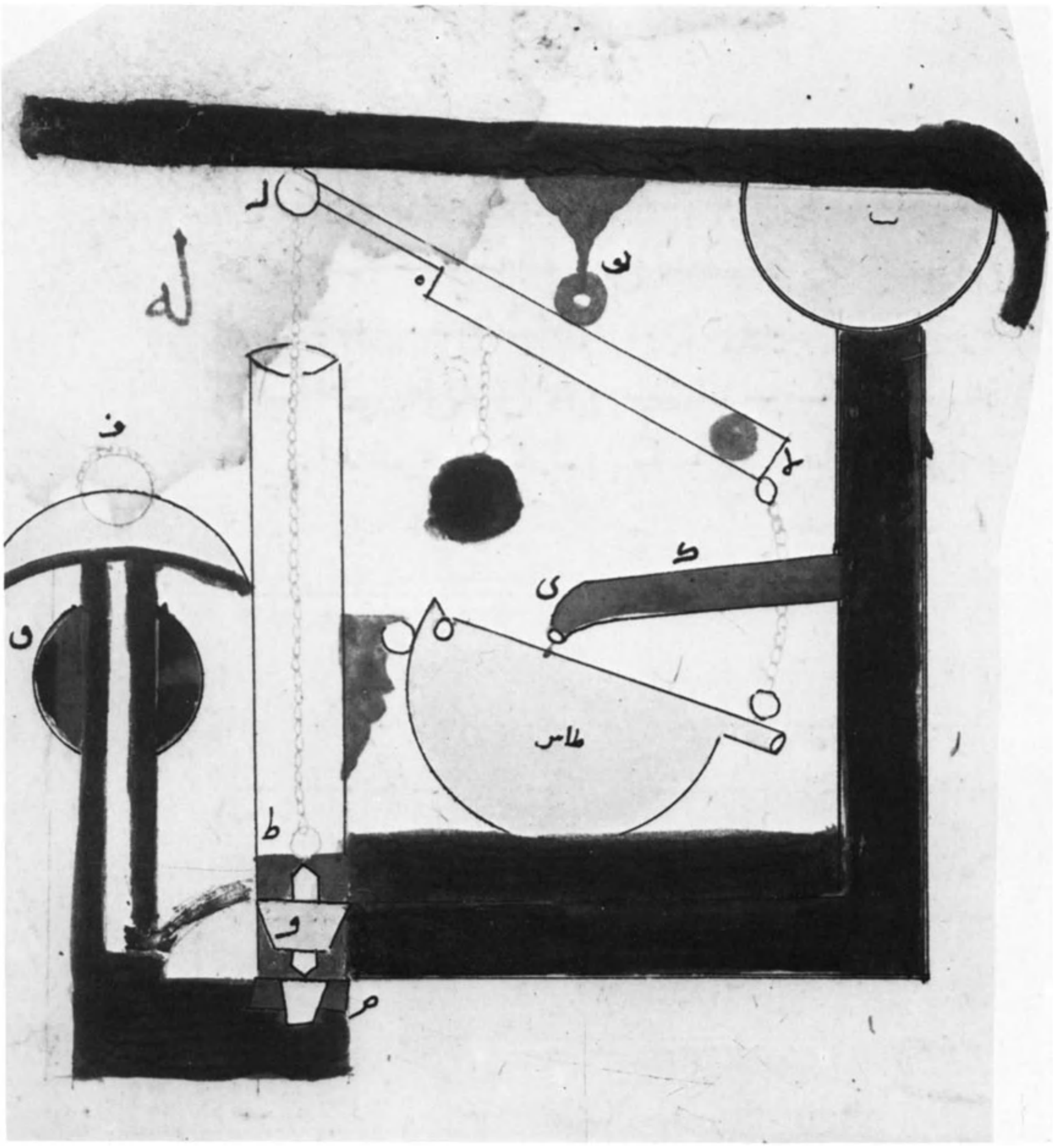
A small bowl (*ṭâs*) is made, its capacity about 2 Ba<u>gh</u>dadī *raṭls* of water, and its top is closed with a plate, the two being soldered securely together. To the rim of the bowl, at *ṣ*, a ring and staple are fitted, and [diametrically] opposite them a ring and staple are fitted to the cover of the bowl at *z*. Then ring *z* is attached to a strong staple on the pipe *s* which has the chain inside it. Ring *ṣ* on the bowl's cover and ring *p* on the end of the cylinder are connected by a chain, which is just long enough for the purpose when the ball is in end *e* of the cylinder and the bowl is suspended on the two rings with its cover horizontal. In the cover, near *z* is a hole: water which drips from the onyx in pipe *k* runs to this hole, *z*, and flows into the bowl, which fills in the space of half an hour, and [this] becomes heavier than the ball, which is in end *e*. It runs along into end *p*. Plug *w* lifts and closes valve *ṭ*. Then a hole is made in the rim of the bowl at *ṣ* and to it a drilled onyx is fitted, from which the water in the bowl discharges in a period of half an hour. The ball and the empty bowl are then heavier[2] than valve *w*, so end *e* of the cylinder is overweighted and moves, lifting the bowl until its cover is horizontal. This is its picture [Fig. 126].

It is very clear that water flows from tank *b*, filling tower *j*. Water drips from the onyx of pipe *k* on to the cover of the bowl, and collects in the bowl. Water flows from the tower through valve *ṭ*, since valve *m* is closed, and the water rises through pipe *f*, which is above the citron, and shoots out like a tree. When the bowl is full it becomes heavier than end *e* of the cylinder, together with the ball and the valve plug. So it descends until its bend [i.e. the circumference near end *ṣ*]

[1] *Utrijja*. Evidently a small vessel shaped like this fruit.
[2] Should be 'lighter'.

touches the ground and the water it contains flows out in the set time. Valve *ṭ* is closed and the water flows out of the pipe of valve *m* and issues from the perimeter of the hole in the citron around the pipe [i.e. the hole is around pipe *f*]. The shield blocks its way, and it descends to the pool in the shape of a tent. This continues as long as the water is flowing into tank *b*. That is what I wished to describe clearly.

[Now] I will describe what I made, namely a fountain which changes shape at known intervals.



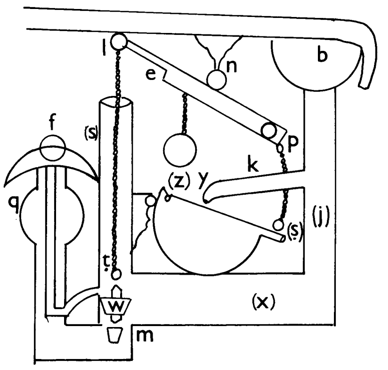


Fig. 126.

Chapter 6 of Category IV

It is the fountain of the two [tipping]-buckets which changes shape at knows intervals. It is divided into three sections

Section 1

I will describe what I made, namely a fountain in the centre of a pool from which the water shoots up for a period of half a constant hour in an arc in one direction; then it changes and the water shoots out like a tent for a period of half a constant hour. Then it changes back to an arc, and so on, for as long as the water flows into it.

Its construction: some distance from the fountain a handsome house is built, into which the water runs and from which [it discharges] into the fountain. Then at the side of the house a tank is erected, its floor 10 sp. above the floor of the house. Then in its underside a hole is made and a pipe is fitted to it, which holds the same amount of water as the tank. The pipe descends to the floor of the house, and runs horizontally along the floor of the house for about 10 sp. Then this end of the pipe is securely closed. Along [the pipe] from the blank end a wide hole is made in it [i.e. the pipe] at the top, and a similar hole opposite it at the bottom. Then a ground valve is made and the seat is fitted to the lower hole. The plug of this valve has two ends, an end to close the valve at the bottom, and an end to close an upper valve, yet to be mentioned. Then one takes a copper pipe 12 sp. long, and inserts in one end of it a ground valve, machined to the upper end of the plug made for closing the two valves. To the top of the plug a chain about 15 sp. long is fixed, and its other end is passed through the ground valve fitted to the end of the pipe and pulled out of the other end [of the pipe]. This pipe is erected vertically and the end with the ground valve in it is above the aperture made in the end of the horizontal pipe. The connection between the two is strongly made with secure soldering. At this juncture the plug is at the bottom, in the lower valve. For this I have shown a separate picture [Fig. 127]: the tank *a*, and the pipe *b* coming down from it for 10 sp., and running along the ground horizontally for 10 sp. – it has *j* on its closed end; to the right [lit. behind] of this end in the underside is a hole in which is a ground valve *d*, and opposite it is a hole upon which is the vertical pipe, with ground valve *e* in it; the plug *w* is between the two valves, and on its top is a chain which goes up through the valve and the pipe *z* – its end is higher than the pipe. It is evident that water flowing into the tank runs down pipe *b* into pipe *j* then up into pipe *z* for 11 sp., since the tank is 1 sp. and the pipe coming down from it is 10 sp., so the water does not rise to the top of pipe *z*. The water has no outlet, but if the chain is pulled up to open valve *d* and close valve *e*, the water issues from this valve and runs through the pipe into the pool and rises into a fountain, yet to be mentioned, where it gushes out like a tent.

Then in pipe *z*, i.e. the vertical one, a hole is made above the valve fitted therein, and to this hole a pipe is connected which is bent down and [then] runs along to the pool. It is inserted into the tent's pipe and rises up inside it until it protrudes from the top, where the water is emitted in an arc when the chain drops and closes valve *d*. This pipe is marked *ḥ*.

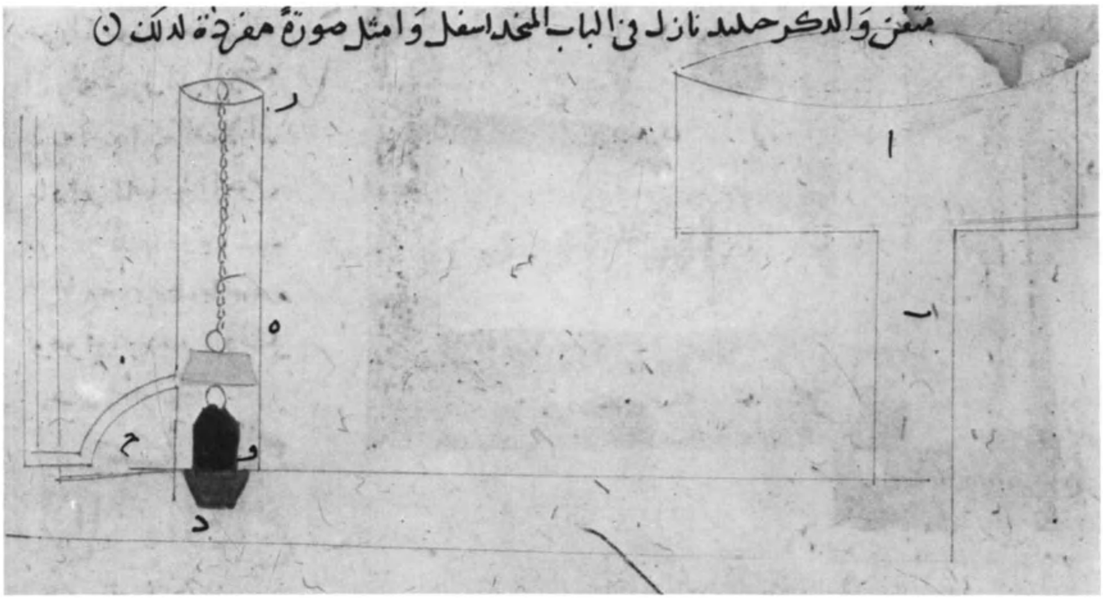


Fig. 127.

Section 2

Construction of the cylinder like a balance for opening and closing the valves: it is on a firm stanchion

At the bottom of the house, on top of the pipe running along the floor, a firm stanchion is fixed close to the vertical pipe, the height [of the latter] being about 13 sp. Then a copper cylinder is made, about 2 sp. long, and a lead ball of about 50 *dirhams* [weight] is inserted in it in a running fit. Both ends of the cylinder are closed. Then an axle is fitted at its centre which does not penetrate to its hollow. The ends of the axle are placed on firm supports on the stanchion so that this cylinder is aligned with the pipe on the floor of the house. One of the ends of this cylinder is directly over the point where the chain leaves the vertical pipe, and a ring is fitted to it to connect it to the end of the chain. When the lead ball is in the end where the ring is, it [i.e. this end] is tilted downwards, almost touching the vertical pipe. The chain is slack and the plug is in the lower valve, which is closed,[a] so the water does not enter it. When the end of the cylinder lifts away from the vertical pipe, the lead ball rolls to the other end and the chain rises and pulls the plug upwards; the lower valve is opened and the upper valve is closed.

When this is completed and made perfect a narrow pipe is fixed to the top of the cylinder – each end of it is bent down and extends a short distance beyond the end of the cylinder. The tip of the spout of a funnel is fixed to the centre of this pipe, the centre of the funnel having a hole in it which goes through to the bore of the pipe. When water is poured into the funnel it flows into the pipe and comes out of that end of it which has descended with the cylinder, since the pipe is fixed to the cylinder. Whichever end of the cylinder tilts, the pipe tilts with it, and the water runs out. I have shown a picture [Fig. 128] of the stanchion *ṭ* and the cylinder with the pipe on it. The cylinder moves on an axle *y* and inside it is a lead ball *k*. On one end of the pipe is a ring to connect it to the chain *l*.[1] The two projecting ends of the pipe, which are open, are marked *m*, *n*. On its centre is a funnel *s*.

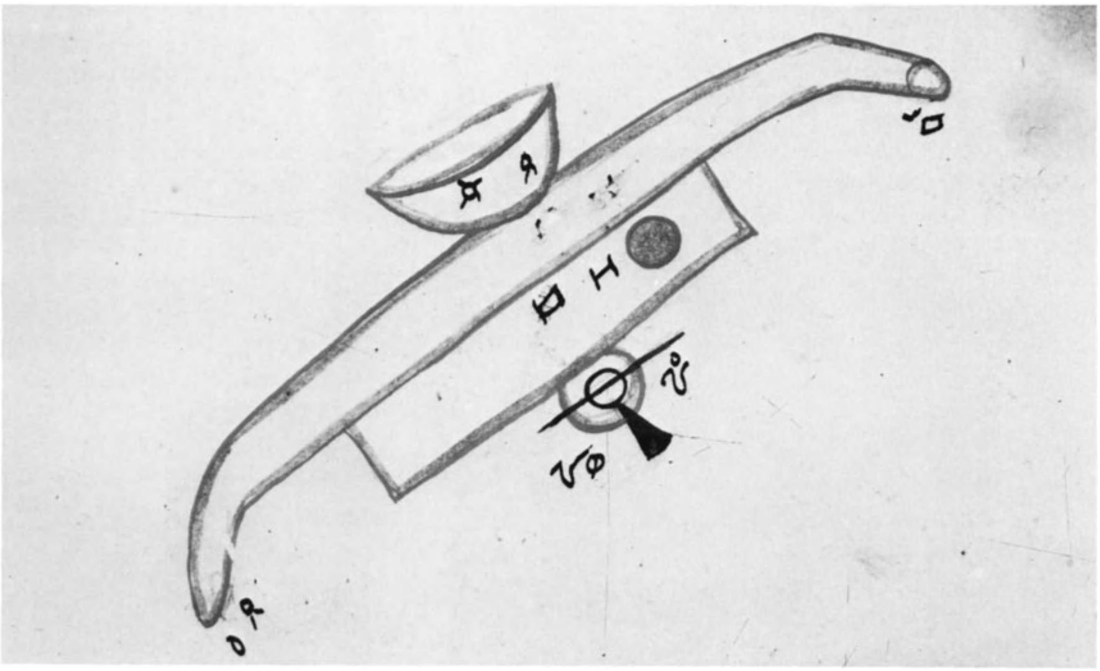


Fig. 128.

Section 3

On the construction of the outlet for the water into the funnel, and of the two tipping-buckets into which the water falls

As mentioned previously, the water passes through the constructed house, so it is necessary to take some of it before its arrival at the tank, through a narrow pipe which discharges into a bowl (*ṭās*), in the underside of which is a pipe with an orifice on its end. The water flows from it into the

[a] Lacuna in Oxford MS begins here.

[1] Note that earlier the ring was said to be on the end of the cylinder.

funnel fixed to the pipe and the cylinder. The quantity issuing from the orifice in the space of half a constant hour is 2 *manns* of water. The surplus over the capacity of the bowl flows continuously over its rim in one direction – it is not needed. Then two [tipping]-buckets are made from copper. The shape and manufacture of this bucket have been mentioned previously in a number of places. Two *manns* of water should fill and tilt each bucket. Each bucket is placed beneath one of the outlets at the end of the funnel's pipe, with its rear end towards the centre of the pipe. It moves on its axle, the ends of which are in two bearings fixed to two firm supports; its other end is on one of the buckets.[2] When the known quantity of water flows into it, it tilts and its rear end rises and lifts the end of the pipe which is discharging water into it. It discharges the water it contains and returns to its former position. The lead ball has rolled to the other end of the cylinder and the water flows into the other bucket. When the known quantity of water has collected in it, it tilts, its rear end rises and lifts the end of the pipe which is discharging water into it. The ball returns to the other end of the cylinder and the water flows into the other bucket. This discharges its contents and returns to its former position – and so on, as long as the water flows. I have shown a complete picture of that [Fig. 129], inside the house, and also the fountain, which is a pipe with a pipe inside it, as previously, rising in the centre of the pool. It [i.e. the fountain] is made of brass and it has a brass vessel (*burniya*) at the top, with a narrow upper end. The inner pipe projects a finger's length from the top of the vessel, and around it is a narrow gap. Then a disc is made from brass, about 1 sp. in diameter; it is slightly concave and has a round hole in its centre. This is fitted tightly to the inner pipe projecting from the top of the vessel so that there is a narrow space between it [i.e. the disc] and the top of the vessel. It is soldered in that position, with its convexity uppermost. When the water flows through the first pipe it emerges with force from its mouth around the second pipe, and onto the concavity of the disc. The water spreads out and falls into the pool like a tent, as if a number of beautiful candles, which are not extinguished by the water,

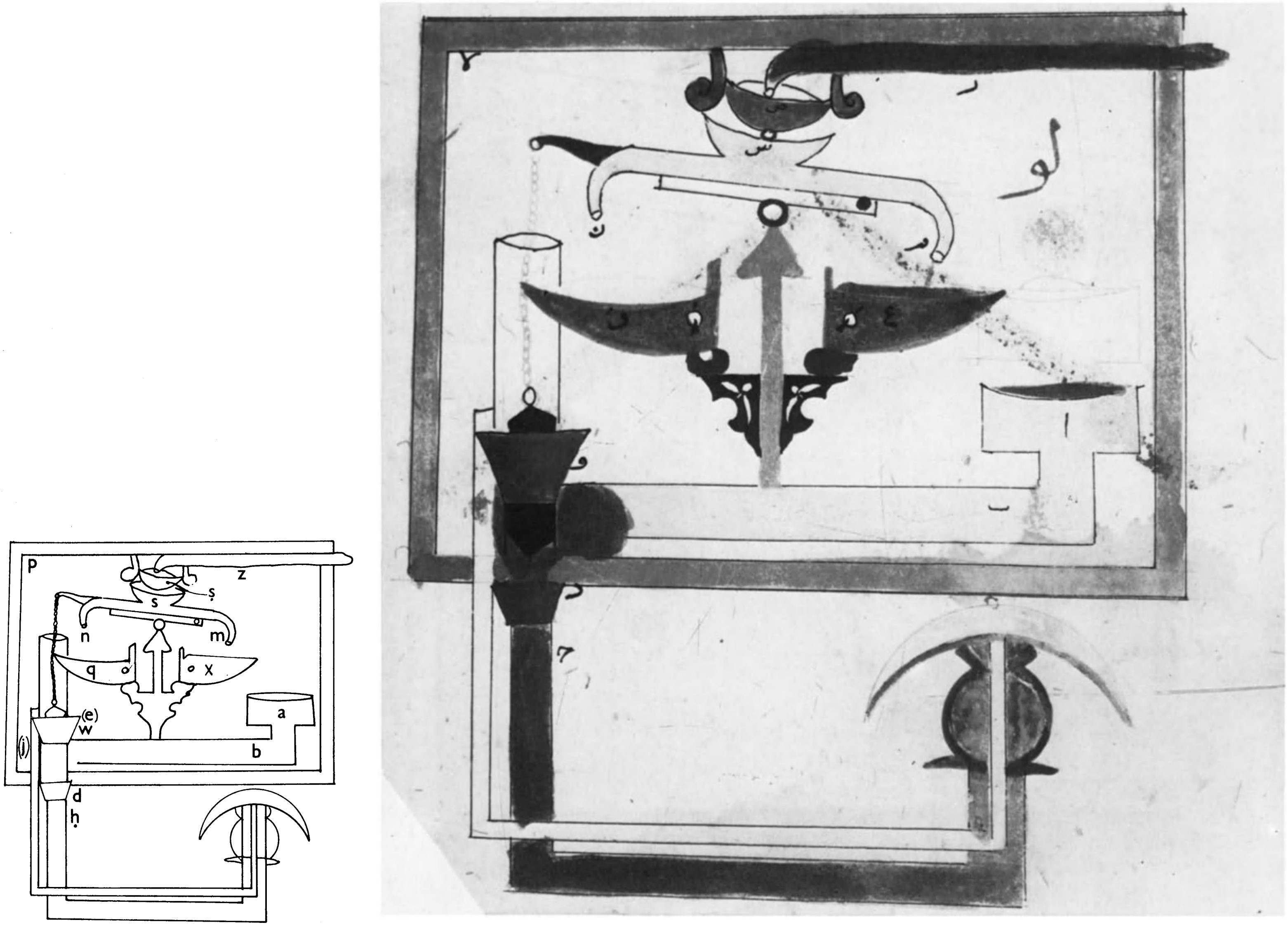


Fig. 129.

[2] Not very clearly put: this describes the usual arrangement for supporting these devices, on two half axles, each soldered to one side of the bucket.

had been lit around the fountain. When the valve of this pipe is closed and the valve of the inner pipe is opened the water shoots out in a single jet and falls into the pool at one point. I have shown a picture of the house and all it contains [Fig. 129].[b] The house is marked *p* and the tank *a*. The water flows from the tank through pipe *b*. Valve *d* is open and the water flows from it through pipe *ḥ* into the vessel, and out of its top into the disc; it is dispersed and comes down like a tent. The water at the top runs through pipe *z* and flows into bowl *ṣ* and from it into the pipe with the orifice on it into funnel *s*. Then it flows from the end *m* of its pipe into bucket *x* which fills in the space of half an hour. When the complete amount of water is in it, it tilts, and its rear end rises and lifts pipe *m*. The ball rolls along in the cylinder and the water comes out of the other end *n* of the pipe into bucket *q*. The chain has become slack, so plug *w* goes down into valve *d*, which closes. The water rises through valve *e*, flows through pipe *j*, then rises and shoots up in a single jet. The water has also risen in the chain's pipe, without reaching the top of it, because the fountain is at a lower level than that. After the lapse of [half] an hour the bucket fills and tips up, the pipe and the cylinder rise together, and the water flows into the other bucket. Valve *e* has closed and valve *d* has opened. And so on, as long as the water runs into the tank, and provided that the construction is strong and secure.

That is what I wished describe clearly.

Now I will describe what I made, namely the perpetual flute.

[b] Lacuna in Oxford MS ends here. (See notes)

Chapter 7 of Category IV

It is an instrument for a perpetual flute with two spheres, for two trumpeters, one of whom is silent while the other blows, then the one that was blowing falls silent and the one that was silent blows. Also the flautist plays continuously on the pool, [where] there are figures of various types of musicians. I have not described this, but I have described the instrument for the flute, for the earlier [workers] made many mistakes [in its construction].

I came across a well-known paper by Apollonius the Indian carpenter: he made a wheel which turns slowly and opens water outlets upon the completion of half a rotation. This period is shorter than required, unless the wheel is slower in its rotation than one imagines. I also examined another old instrument, about which I found no written report, but a drawing. In this the flute is like a *nāy* having eight holes, with [rods] like moving fingers on them. In the drawing there are eight tanks, seven ground valves and four wheels with teeth, and he mentions a wheel which opened water outlets slowly. And I say that even if the wheel caused a number of rods to fall in succession it would not be slow enough to display the changes of shape [adequately]. I [also] examined a paper written in Baghdad in year 517. A.H. by the eminent inventor Hibat Allah b. al-Ḥusayn al-Asṭurlâbī, in which he makes a real innovation. Its design is [as follows]: it has a cylinder with a lead ball in it, an arm like a lever-arm, two buckets suspended in chains, three tanks, six ground valves, and two pipes like the end sections of bows, which come out side by side from the tank. It is a well-known instrument.

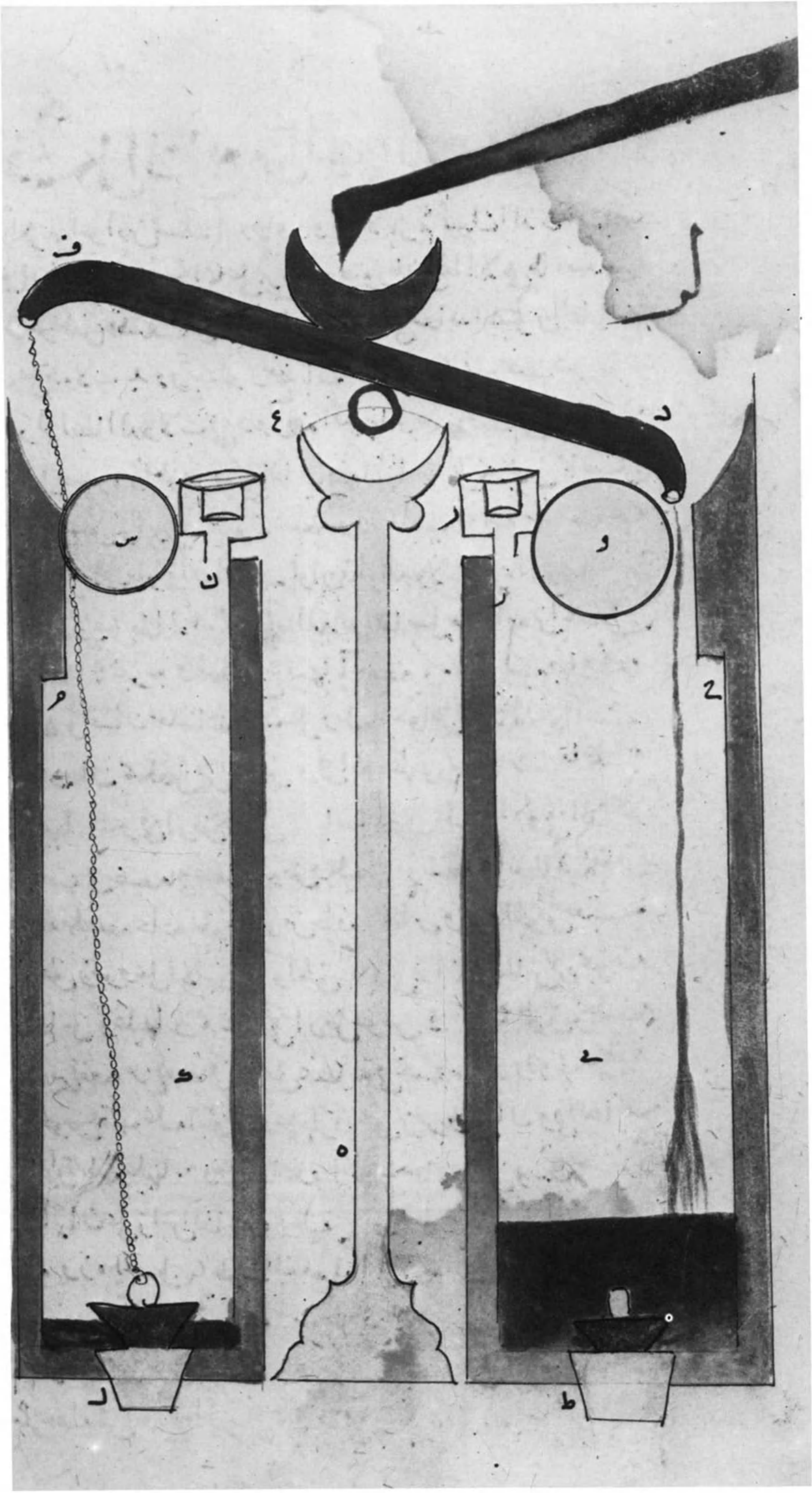
I will describe what I made, namely two adjacent tanks *y*, *k*. In the floor of tank *y* is a ground valve *ṭ* the plug of which has a chain which goes up through a hole *ḥ* in a concavity in the tank's cover. The cover is shaped like a semi-circular bowl, and its rim is soldered to the rim of the tank. Between the rim of the bowl and the rim of the tank is a narrow hole upon which is a pipe with a flute's jar *z* on its end. In the bowl is a light, hollow, sphere *w* the [lower] half of which almost fills the bowl. Then a ground valve *l* is fitted in the floor of trough *k* and on the valve's plug is a chain which goes up through a hole *m* in the underside of its cover; [the hole] is in a concavity in the corner [of the cover]. Between the rims of the bowl and the tank is a hole upon which is a pipe with a flute's jar *n* on its end. In the bowl is a sphere *s*.

Between the two tanks is a firm stanchion *e* and on the stanchion is a transverse pipe with a bush in its centre, drilled to take an axle *x* the ends of which are firmly [supported] on top of the stanchion. The ends of the pipe are marked *d*, *f*. End *d* is tilted and rests on ball *w*. It [i.e. end *d*] has a staple on it which is attached to the end of the chain arising from the plug of valve *ṭ* which is down in its seat. On top of the middle of the pipe is a funnel *j*. End *f* is raised above sphere *s* and has a staple on it which is attached to the end of the chain rising from the plug of valve *l*, which is lifted out of its seat [Fig. 130].

Water flows through the supply channel *ṣ* into the funnel, runs out of end *d* into the bowl and is sucked down through hole *ḥ*. Valve *ṭ* is closed so the air in tank *y* is expelled and streams through pipe *z*. The jar therefore plays like a flute continuously until tank *y* has filled. The water rises in the bowl, and a little of it lifts the sphere which presses against end *d* and lifts it. End *f* sinks and closes valve *l*. The water runs into the bowl and is sucked down through hole *m*. The air in tank *k* streams through pipe *n* and the jar plays like a flute until tank *k* is filled. The water rises in the bowl and a little of it lifts sphere *s* which presses against end *f* and lifts it. End *d* tilts. Tank *y* has emptied, so the water runs into it, valve *ṭ* having closed. The jar plays like a flute. And so on, as long as water flows from the supply channel. There is no harm in adding a cylinder with a lead ball in it to pipe *d*.

This is what I wished to describe clearly.

[Now] I will describe what I made, namely an instrument for a perpetual flute with two [tipping]-buckets.



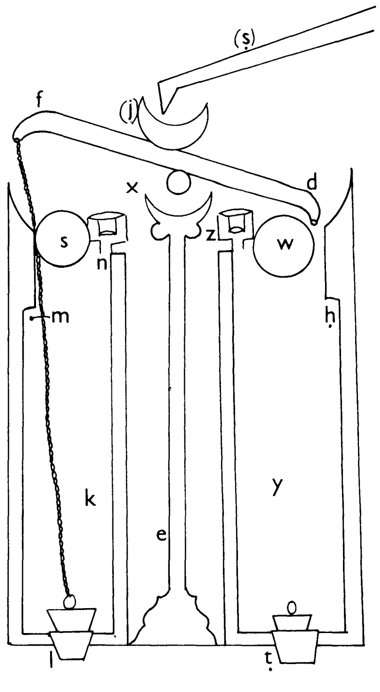


Fig. 130.

Chapter 8 of Category IV

It is an instrument for a perpetual flute, with two [tipping-] buckets

Two adjacent tanks *a*, *p* are erected. To tank *a* a siphon is fitted, its end almost touching the floor. Its bend is in the top of the tank and it is brought down outside the tank so that its end *b* is lower than the tank's floor. To this tank a flat cover is securely soldered and two holes are made in it: hole *ḥ* in which there is the spout of a funnel *d*, and hole *e* in which there is a pipe with a flute's jar or a flute's whistle on its end. To tank *p* a siphon *q* is fitted, as described [above]. The top of the tank is covered with a flat cover in which are two holes: hole *ṣ* in which there is the spout of funnel *f*, and hole *x* in which there is a pipe with a flute's jar or a flute's whistle on its end.

Then two [tipping-] buckets are made – their shape and their movement have been described before. [Each] one moves on an axle near its rim and near its rear end, and the ends of the axle are firmly [supported] on firm supports. Water drips into the bucket and when it is filled with a known amount its front end becomes heavier and tilts, and it evacuates the water it contains. [Then] it returns and balances [once again] about a point below [its rim] at the rear end, with its rim horizontal. Bucket *w* is placed over funnel *d* and the ends of its axle are secured to two firm supports. When water flows into this bucket it tilts towards its front end and discharges its contents into funnel *d*. Then another bucket is made to the same design and erected over funnel *f*. When water flows into this bucket it tilts towards its front end and discharges its contents into funnel *f*. [Then] it returns and balances [once again] about a point below [its rim] at the rear end, with its rim horizontal.

Then a small elongated tank *j* is made, and in its short sides near its floor two light pipes *z*, *l* are fitted. An axle is fixed underneath this tank, in its centre, upon which it moves in the direction of its pipes *z*, *l*. The ends of the axle are located on top of a firm stanchion *k* which is erected between the two tanks *p*, *a*. When tank *j* tilts in the direction of pipe *z*, this [latter] rests on the rear end of bucket *w*. Then a supply channel *y* is made for discharging the water into tank *j*. I have shown a picture of [all] that [Fig. 131].

It is very clear that the water runs from channel *y* into tank *j* and issues from it through pipe *z* into bucket *w*. This fills in a known period and tilts, discharging its contents into funnel *d*, and these are sucked down through spout *ḥ* and collect in tank *a*. The air in tank *a* is driven out, once the end of the siphon has been covered, and the air streams through pipe *e* into the flute's jar, which plays like a flute. When bucket *w* tips, its rear edge lifts pipe *z*, so tank *j* tilts and the water flows into bucket *s* from pipe *l*. The water has risen to the bend of siphon *b* and flows out of its end to the outside of the tank, the flow continuing until there is no water left in *a*. When bucket *s* is full it tilts and discharges its contents into funnel *f*, and these are sucked down through spout *ṣ* into tank *p*. The air in it is driven out and streams through pipe *x* into the flute's jar. Bucket *ṣ* has lifted pipe *l*, so tank *j* tilts and discharges into bucket *w*, and the water evacuates from tank *p* through siphon *q*. And so on, as long as water flows through channel *y*.

That is what I wished to describe clearly.

[Now] I will describe what I made, namely an instrument for the perpetual flute, with a balance.

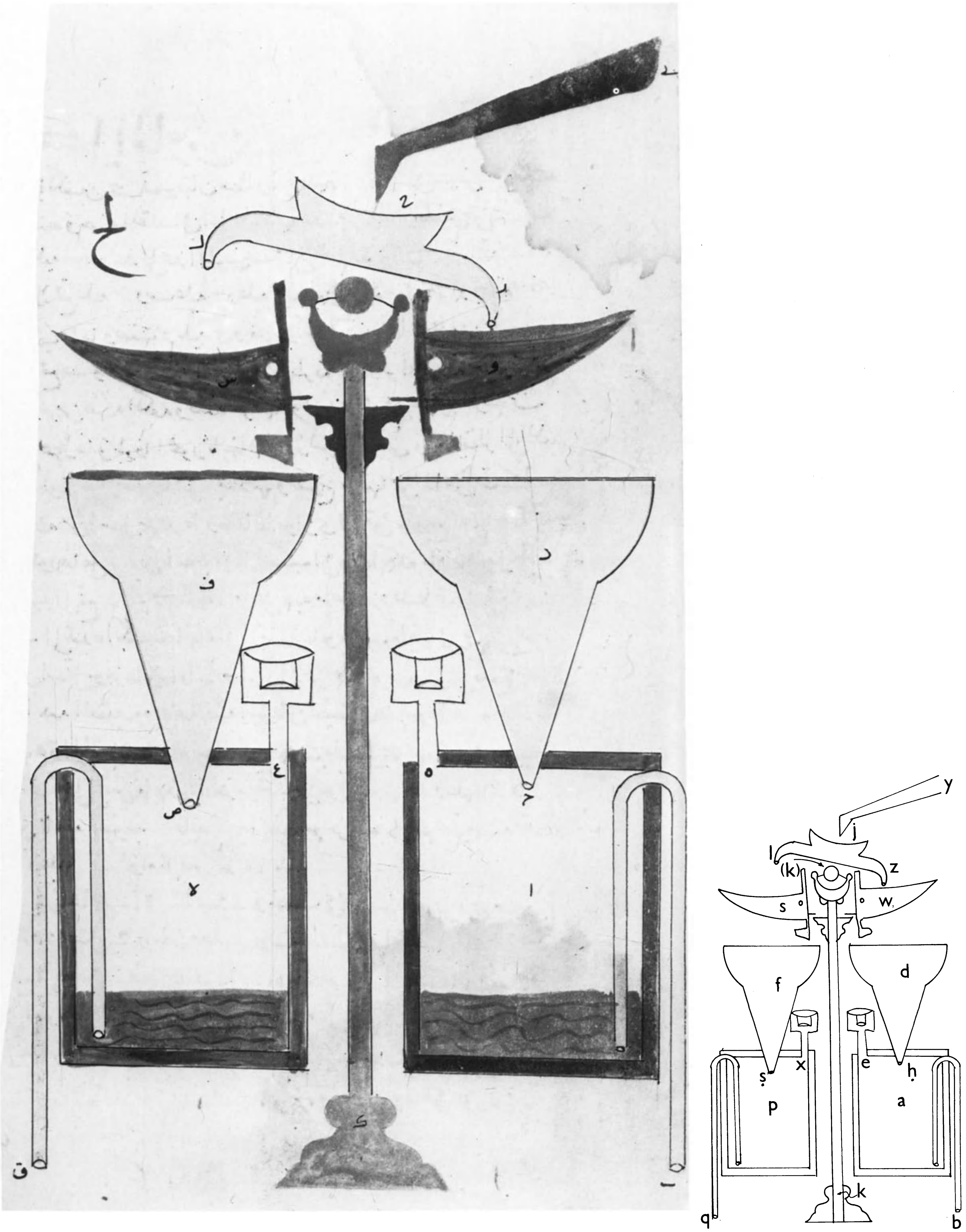


Fig. 131.

Chapter 9 of Category IV

It is an instrument for the perpetual flute, with a balance

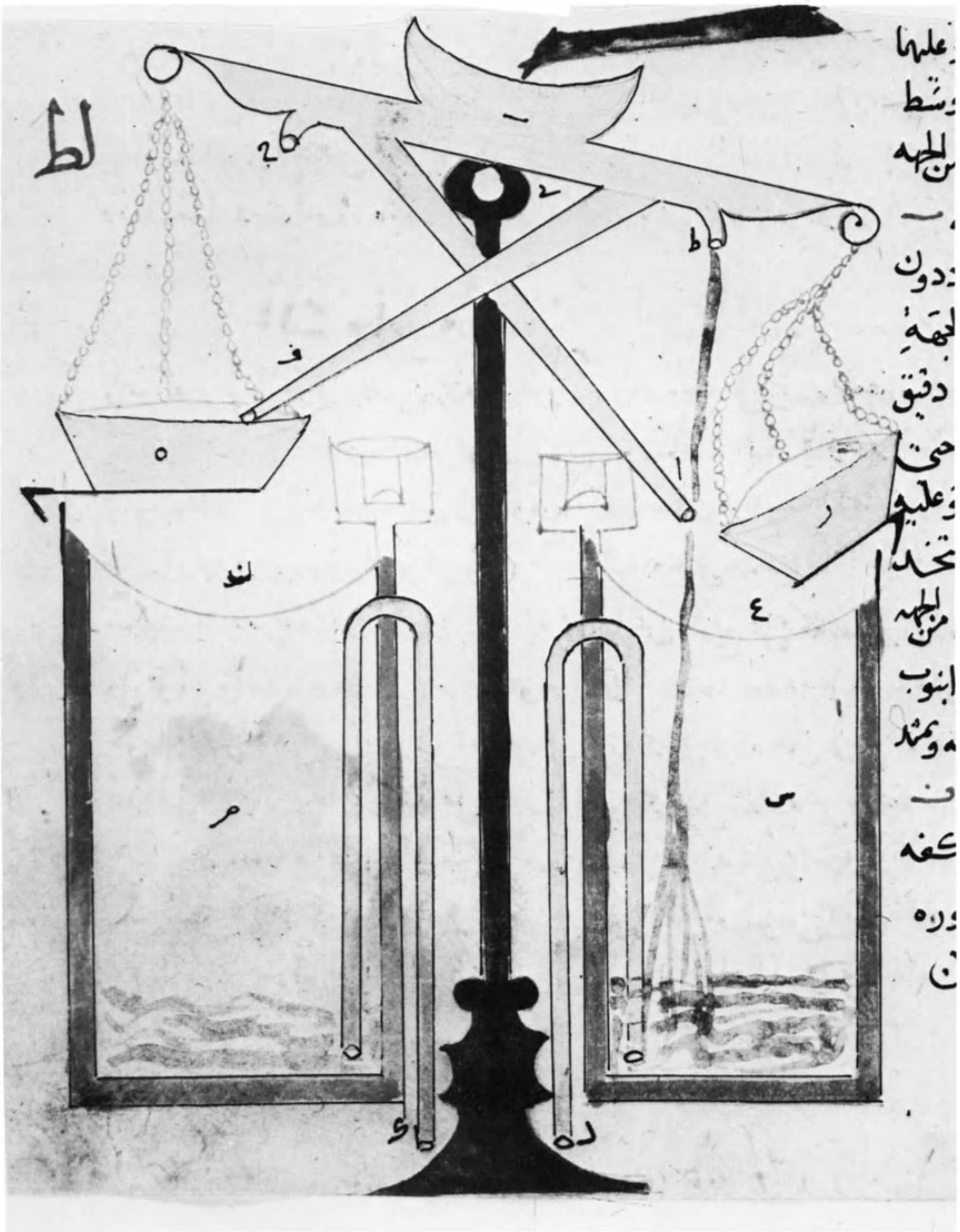
A tall tank is made and divided across by a curved plate so that it becomes two tanks, an upper one *x* one third [of the complete tank] and a lower one *s*, two thirds. Then another tank is made, as I have described, and divided into two tanks: the lower one *m*, i.e. two thirds and the upper one *n*, i.e. one third. The tanks are placed close together. In tank *s* siphon *l* is fitted, and in tank *m* siphon *k*. Then a hollow pipe *y* is made as a balance-arm, its two open ends *ṭ j* being bent down. On top of end *ṭ* is an extension with a ring on its end in which are three chains carrying a weighing bucket *z*. On end *j* is an extension with a ring in it and three chains carrying a weighing bucket *e*. Underneath the arm in its centre is an axle the ends of which are firmly [supported] on top of a firm stanchion which rises between the two tanks. A funnel *b* is also installed at the centre of the arm, on the top.

Underneath the arm, inside end *ṭ*, a narrow pipe is fitted which stretches downwards so that its end *a* is above bucket *z*. Then inside end *j* another narrow pipe is fitted which stretches downwards so that its end *f* is over bucket *e*. I have shown a picture of [all] that [Fig. 132].

It is very clear that water flows through the supply channel into funnel *b* and runs through end *ṭ* of the pipe because it is tilted towards tank *x* and is directly above it. It drips through hole *f* into tank *s* and the air in it is driven out and streams through pipe *p*, which has the jar on it. This plays like a flute. Some of the water runs through pipe *f* and its end discharges at a low rate of flow into bucket *e*. Bucket *e* fills in the same time as trough *s* and part of tank *x*. Bucket *e* becomes heavy and sinks. On its rear end, extending behind it, is a bracket (*s̲h̲aẓīya*), the end of which is bent down. When the bucket sinks the angle of the bracket bears against [lit. touches] the side of tank *n*, so the bucket tilts and evacuates its contents into tank *n*. The bucket remains in its tilted position. When water flows from end *j* into tank *n* it runs through hole *ṣ* and falls into tank *m*. The air in it is driven out and streams through pipe *w* which has the flute's jar on it. Some of the water flows through pipe *a* and issues from its end into bucket *z* which fills in the same time as tank *m* and part of tank *n*. The contents of tank *s* have discharged through siphon *l*. Bucket *z* becomes heavier and sinks. On its rear end, extending behind it is a bracket, bent down [at the end]. When the bucket sinks the angle of the bracket bears against the side of tank *x*, so the bucket tilts and discharges its contents into tank *x*. The water in tank *m* discharges through siphon *k*. And so on, as long as the water flows through the supply channel.

That is what I wished to describe clearly.

[Now] I will describe what I made, namely an instrument for a perpetual flute.



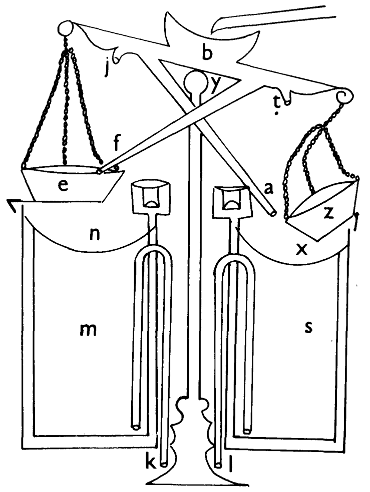


Fig. 132.

Chapter 10 of Category IV

It is an instrument for a perpetual flute, with two floats

A large tank *a* is made and its top is covered with a plate soldered securely to its rim. On top of the tank's plate a small tank is placed, with a hole *p* in its corner. In the side of the large tank there is a pipe *j* with a flute's jar on its end. Also in it [i.e. the large tank] is a siphon *ṣ* rising from its floor to [a point] above its top, and coming down outside, its end lower than the floor of the tank. In the floor on the cover is a float *e* with a rod on top of it which passes through a ring *x* on a cross bar. This [i.e. the ring] prevents it from moving out of position, but it moves freely up and down in it. Then another tank *b* is made according to this description. On the hole in the corner of the small tank on its cover is *q*; *d* is marked on the pipe in its side [i.e. in the side of the large tank] with a flute's jar on its end; on the bend in the siphon of this tank is *f*; on the float above the cover of this tank is *w*; on top of it is a rod *s*, which is kept in position by a ring on a crossbar.

Between the two tanks is a firm stanchion *m* on top of which are the ends of an axle. On the axle is a pipe *l*, the ends *ḥ ṭ* of which are bent down. On pipe *l* is a funnel *n*, and on its ends are extensions like curved *dīnārs* directly above the rods on the two floats [Fig. 133].

It is very clear that water flows from the supply channel and falls into funnel *n* and flows through end *ḥ* of the pipe because it is tilted towards tank *k* and float *e*. It runs through hole *p* into tank *a*, driving the air from it, which streams into pipe *j*. The flute plays until the water rises to the level in the siphon *ṣ* – hole *p* is narrower than end *ḥ* [of the pipe]. The water rises in the tank of float *e*, the float rises and lifts extension *ḥ* with its rod, pipe *l* tilts and discharges from end *ṭ* into tank *z* and float *w*. Water runs through hole *q* into tank *b*, driving the air from it, which streams through pipe *d* into the flute's jar, which plays like a flute until tank *b* is filled. The water rises to the bend in siphon *f*, and in the tank of float *w*, which rises, lifting the extension of end *ṭ* with its rod. The water in tank *a* has evacuated through siphon *ṣ*. Then the water runs away from end *ṭ* which comes away from the tank *b*. And so on as long as the water flows from pipe *l*.

[End of Category IV]

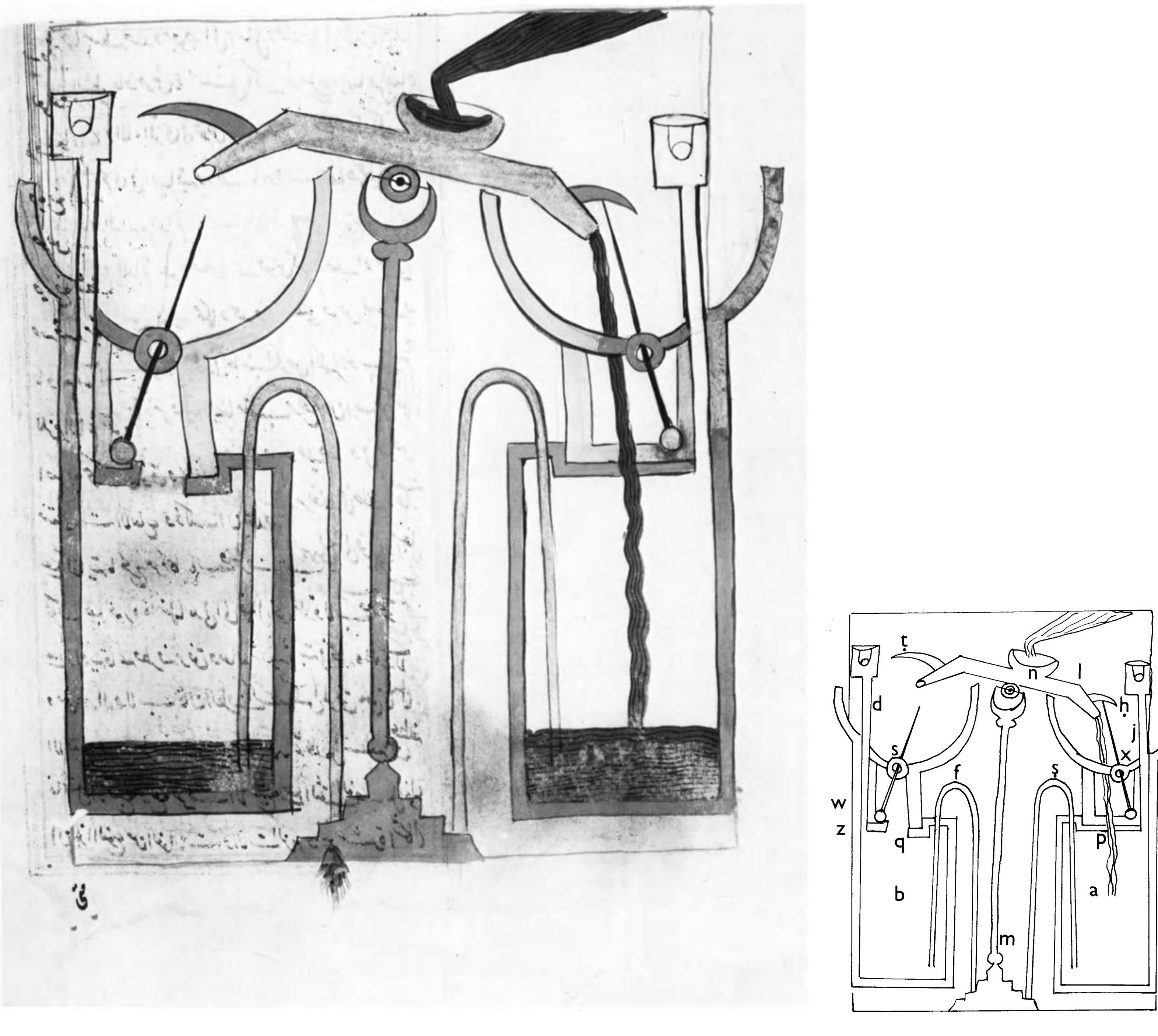


Fig. 133.

CATEGORY V

On machines for raising water from pools, and from wells which are not deep, and from running streams

Chapter 1 of Category V

On machines for lifting water from a pool to a higher place by an animal (dāba) who turns a lever-arm (sahm)

I have shown the picture of that after the text of the next chapter.

One repairs to a pool of water – it is marked *a* on the drawing – and two strong stanchions *k*, *l* are erected in it. On top of the two stanchions an axle is installed, its ends on the stanchions. In its centre is a wheel *y* [consisting] of two rings, and between these are cross-rungs at a spacing of about one small span between each pair. Also on this axle is the stem *m* of a wooden ladle (*mighrafa*) which has a capacity of about 30 Baghdadī *raṭls* of water, or more. Its stem from the axle to the scoop is a channel which is filled with water when the scoop rises from the pool, until it is slightly above the horizontal. Then the water runs through the ladle's stem and discharges into an irrigation channel (*sāqiya*). The scoop is marked *ṭ* and the end of its stem *ḥ*. Above this axle is another axle *n*, its ends on bearings on upward extensions of stanchions *k*, *l*. On this axle is a quarter-wheel *s* with teeth, their spacing the same as that of the cross-rungs on wheel *y*. On the end of axle *n* is a toothed wheel *x*, and between its teeth are the teeth of a wheel *w* on a vertical axle, on top of which, parallel to *w* is a lever-arm *j*. At the end of the lever-arm is a connection[1] to the animal *e*. This is its picture [Fig. 134]. It is very clear that when the animal turns with the lever-arm he rotates wheel *w* which turns wheel *x* and quarter-wheel *s*, which turns runged wheel *y*. Scoop *ṭ* is immersed in the water and it lifts, full of water. On completion of a quarter rotation of the axle the scoop of the ladle is horizontal and the water it contains runs through its stem and discharges from its end *ḥ* into an irrigation channel at that point. Then the teeth of quarter-wheel *s* disengage and the scoop descends again to the pool with great force, and re-submerges in the water, remaining thus while axle *n* performs $\frac{3}{4}$ of a rotation, whereupon the first tooth of quarter-wheel *s* enters the rungs of wheel *y*, rotating it and raising the scoop of the ladle, filled with water, until axle *n* has completed a quarter rotation. The ladle's scoop has risen to the horizontal and its contents flow through its stem into the irrigation channel. The quarter rotation is complete and teeth *s* disengage from the rungs of wheel *y*. The scoop is overweighted and falls into the pool. And so on, as long as the animal moves round.

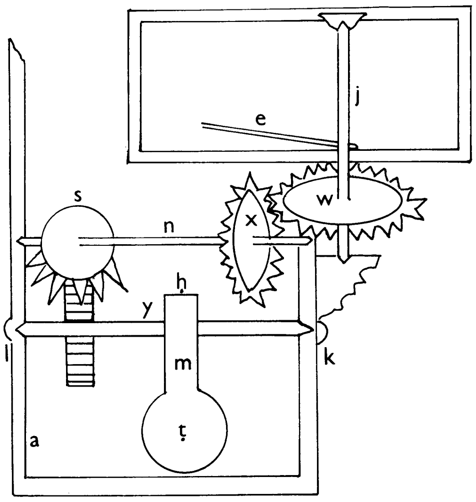
That is what I wished to describe clearly.

[Now] I will describe what I made, namely this model but with the addition of one, two and three extra ladles.

[1] *Ribāṭ*. A tie or connection. This denotes a fairly simple method of tying the animal to the lever.

Chapter 2 of Category V

It is a machine for raising water from a pool or a well by an animal who rotates it. I have shown a picture of it opposite the picture of the first machine, to let it be understood. I will describe it: one repairs to a pool which is not deep – on the drawing it is marked *a*. In it are erected three stanchions *p*, *ṣ*, *q*, stanchion *ṣ*, the middle one, being shorter than stanchions *p*, *q*. Then on stanchions *p*, *q* an axle is placed, upon which is a wheel *f* with cross-rungs like the rungs of ladders. By its side, also on the axle, the end *x* of a ladle's stem is fixed. The scoop is marked *ṣ*. Then on stanchions *ṣ*, *q* an axle is placed, upon which is a runged wheel *n* and by its side, also on the axle, is fixed end *m* of a ladle's stem. The scoop of the ladle is marked *l*. Then on the two stanchions *p*, *q* an axle is placed which is directly above [the centres of] wheels *f*, *n*, and on the former is fitted a quarter-wheel *k* with teeth, opposite the runged wheel *f*. Then [another] quarter-wheel *y* with



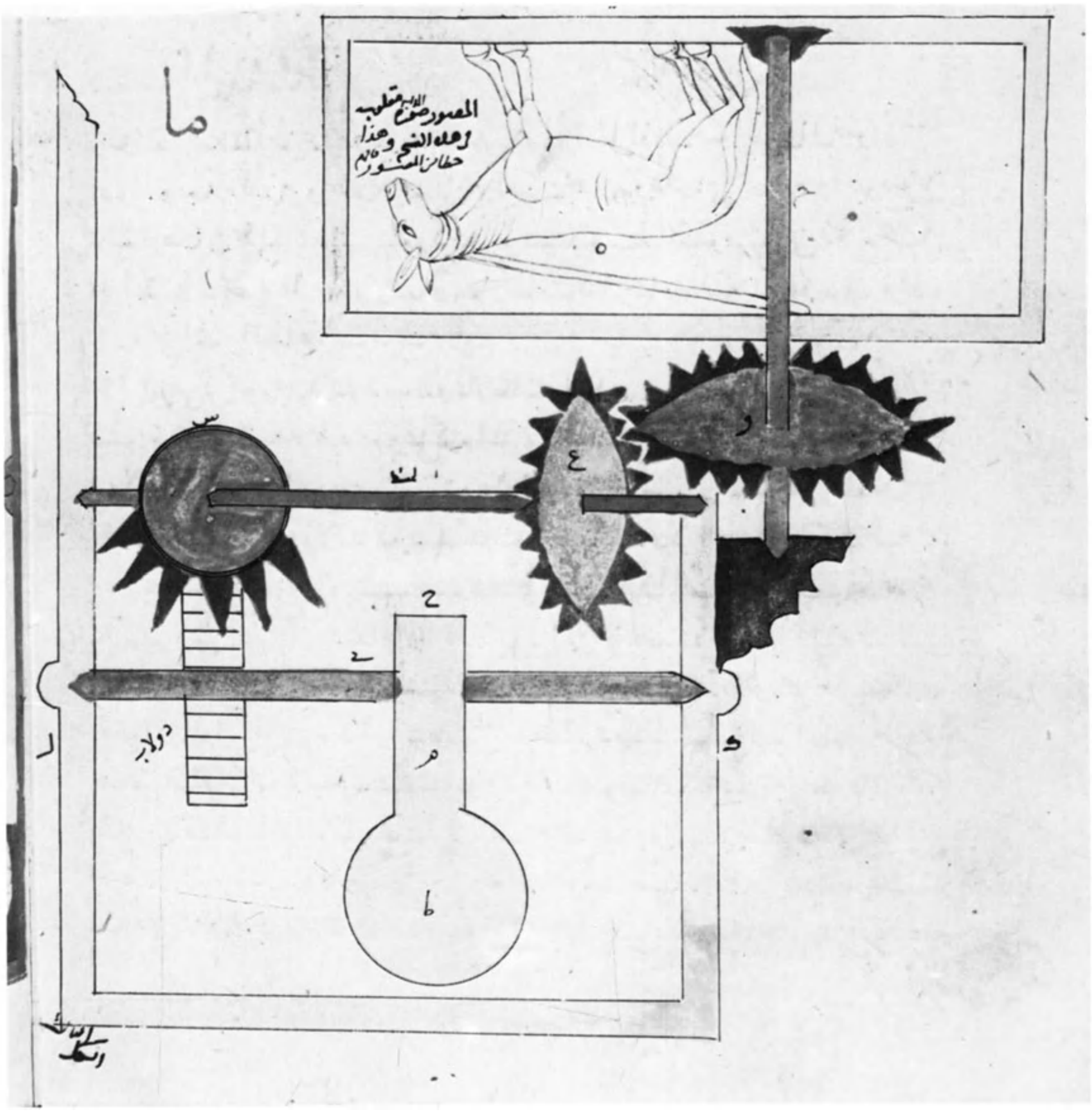


Fig. 134. Caption by animal reads: 'The artist has drawn the animal upside down in this Section. This is a mistake by the artist – understand!'.

teeth, opposite runged wheel *n*, is fitted to it [i.e. the upper axle]. Then on the end this axle a cog-wheel *ṭ* is fitted, its teeth meshing with the teeth of wheel *ḥ* which is on a vertical axle. On this axle is lever-arm *w*, connected to an animal who moves round and turns wheel *ḥ* with the lever-arm [Fig. 135].

It is very clear that the animal moves round with lever-arm *w*, rotating wheel *ḥ* so that wheel *ṭ* rotates. The teeth of quarter-wheel *k* are between the rungs of wheel *f* and turn it. The scoop of ladle *s* rises, its contents flow, and discharge from end *x*. The teeth of [wheel] *k* disengage from wheel *f*. Scoop *s* falls under gravity [lit. with its weight] back into the water and submerges. Between quarter-wheel *k* and quarter-wheel *y* there is a quarter of a revolution, so when the quarter revolution is completed the teeth of *y* descend into the rungs of wheel *n* which makes a quarter of a revolution, lifting scoop *l* until the water it contains is discharged from its stem *m* into the irrigation channel which is connected to the other one [i.e. the channel mentioned in Chapter 1]. Then quarter-wheel *y* disengages and its axle makes a quarter of a revolution until the teeth of quarter-wheel *k* mesh with the rungs of [wheel] *f*. And so on, as long as the animal moves round.

Now scoop *s* is up when scoop *l* is down, and it is possible to make this model with four runged wheels on four axles, every axle having a ladle. [All] that is turned by a single animal, through wheel *ḥ*. On its axle[1] are four quarter-wheels, and each ladle is lifted by a quarter-wheel. And this model is self-regulating at a single weight [i.e. loading system] – neither lighter nor heavier than what is required.

There is a greater idle movement in the first model than in the two models just mentioned – three quarters of a revolution in the first model compared to half a revolution in the second model.

That is what I wished to describe clearly.

[Now] I will describe what I made, namely a machine for lifting water from a pool [to a height of] about 10 sp.

[1] Actually on the axle at right angles to it.

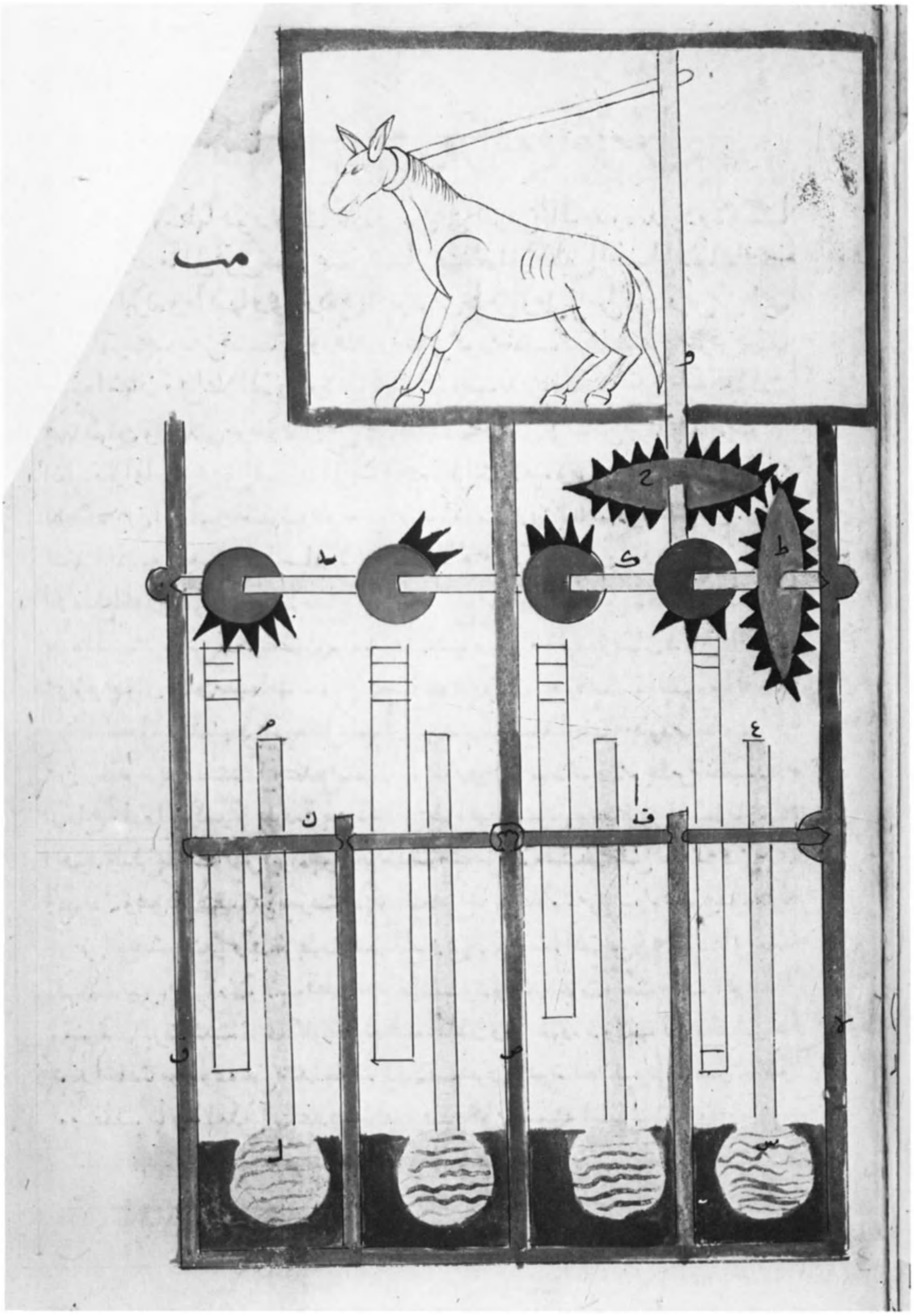
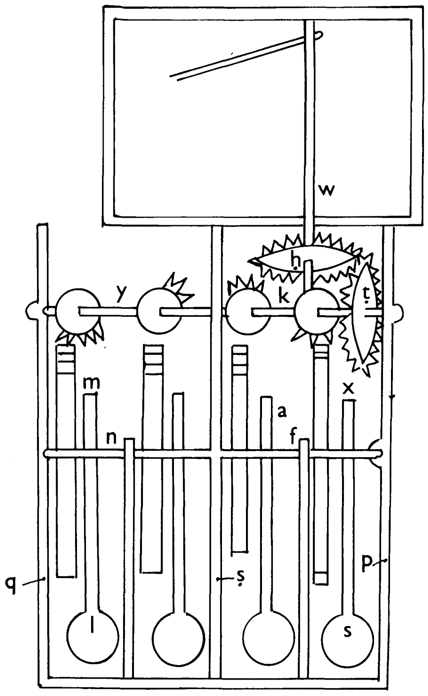


Fig. 135.



Chapter 3 of Category V

It is a pool with a hollow pillar in its centre upon which is a disc. On the disc is the figure of a cow who turns a wheel about 10 sp. above the pool of water. It is divided into two sections

Section 1

I will describe the appearance of the pool and its contents

It is a pool in the centre of which there is a copper pillar with a copper disc on its top. On the disc is a wooden cow which moves round and turns a lever-arm on a vertical axle, which is about 8 sp. higher than the disc. On top of the axle is a toothed wheel which turns a Sindī wheel which has two ropes on it carrying jars (*kūz*). The ropes go over the back of the wheel and are immersed in the water of the pool in the usual manner. The water discharges from the jars into an irrigation channel inside the wheel, and the water runs therefrom into wherever is desired. It has been stated that the vertical axle is about 8 sp. long and on top of it is a wheel which turns a Sindī wheel of about 4 sp. diameter. For this plant comprises two machines, one of which raises some of the source water to a level higher than the pool. The other [i.e. the one described here] is beautiful to behold, with upper wheels, splendid craftsmanship, elegant shapes, and handsome design. The ropes are silken, the jars delicate and painted with various colours, as are the wheels, the cow and the disc.

Section 2

On the construction of what I have described

A handsome square pool is made, its floor a copper plate, its sides [made] of marble. In the centre of the pool a hole is made on which is a vertical, hollow, copper pillar of the [same] height as the side of the pool. On its end is a copper disc of about 2 sp. diameter, with an opening in its centre through to the hollow in the pillar. Beneath the floor of the pool is a cavity of sound workmanship, about 8 sp. deep. In the floor of the cavity, which is like a small chamber, is an outlet for the water which runs into it. Then a thin iron stanchion is made, its length about 12 sp. The end of this stanchion is passed through the hole in the centre of the disc, through its pillar, and down to the underside of the pool. To its [lower] end a toothed wheel of 4 sp. diameter is fitted. Below the end of the stanchion is a support which rises from the floor of the chamber. Then a 3 sp. long axle is made with a toothed wheel on its end which meshes with the toothed wheel on the end of the iron axle. On the other end of this axle [i.e. the 3 sp. long axle] is a wheel of about 7 sp. diameter, having scoops which are as large as possible so that they carry as much as possible. I have shown the picture of what I have described and what I am about to describe [Fig. 136].

I say that [the equipment is as follows:]: the pool *s* with a thick pillar *x* in its centre with a disc *n* on its top, in which is a hole through which the iron stanchion *y* [passed]; wheel *a* is on that end of it [i.e. the stanchion] which is in the chamber underneath the pool; in the chamber is the scoop-wheel *ḥ* and on the end of its axle is wheel *ṭ*; the water flowing into the pool discharges from it through pipe *e* – about $\frac{2}{3}$ of the water which runs into the pool flows on to the scoops, turning the scoop-wheel; wheel *ṭ* turns wheel *a* and stanchion *y*.

[Now] I will describe the construction of the cow on top of the disc, a wheel at the upper end of the stanchion, and the Sindī wheel upon which are the two ropes and the jars: to stanchion *y* a turning lever (*sahm madār*) is fixed at right angles, and is as long as the radius of the disc. It is marked *k*. Then a dainty wooden cow is made, hollow and as light as possible. A strong collar fixed to the cow's neck, connects it rigidly to the lever, so that the lever supports the cow, and her forelegs and hinds legs about a barleycorn's thickness above the disc. When the stanchion rotates together with the lever, the hooves of the cow *l* do not touch the disc. Then a toothed wheel *b*, of about 2 sp. diameter is fixed to the top of the stanchion.

A Sindī wheel *d*, about 4 sp. in diameter is now made, its axle is short, and on its end is a toothed wheel *q* of about 3 sp. diameter. The teeth of wheel *b* mesh with the teeth of wheel *q*. Then one takes two silken cords, each of such a length that when it is laid over wheel *d* with its ends joined together, its free length hangs down almost touching the floor of the pool. Then one takes copper jars, each one large enough to hold about 30 *dirhams* of water. It is longish, and of constant cross section. Two diametrically opposite staples are fitted to its top, and, in line with these, two staples to its bottom. The two cords are attached to them [i.e. to the staples], and then placed on the wheel – the staples on the cords are marked *f*.

When the manufacture of everything has been completed according to my description, such as the wheels, the axles, the jars, the channels, and everything made of copper and other [materials], they are painted with coloured pigments which have been formed into a paste on the grindstone with pure linseed oil. Then the water will not harm them or change them for a long time.

An *ṣ* is marked on the position of the discharge channel, at the end of the axle carrying the Sindī wheel. It is not necessary to illustrate the wooden structure which is built on top of four light columns erected around the pool.

It is very clear that the water flows into pool *s* and discharges from it through pipe *e*, turning wheel *ḥ*. So wheel *ṭ* turns wheel *a*, stanchion *y* and cow *l*, and wheel *b* turns wheel *q* and wheel *d*, which has the jars on it. These hang down, almost touching the floor at the pool, so when wheel *d* rotates the full jars rise and discharge into channel *ṣ* and thence into the place selected.

That is what I wished to describe clearly.

[Now] I will describe what I made, namely a machine for raising water from a shallow pool or from a shallow well.

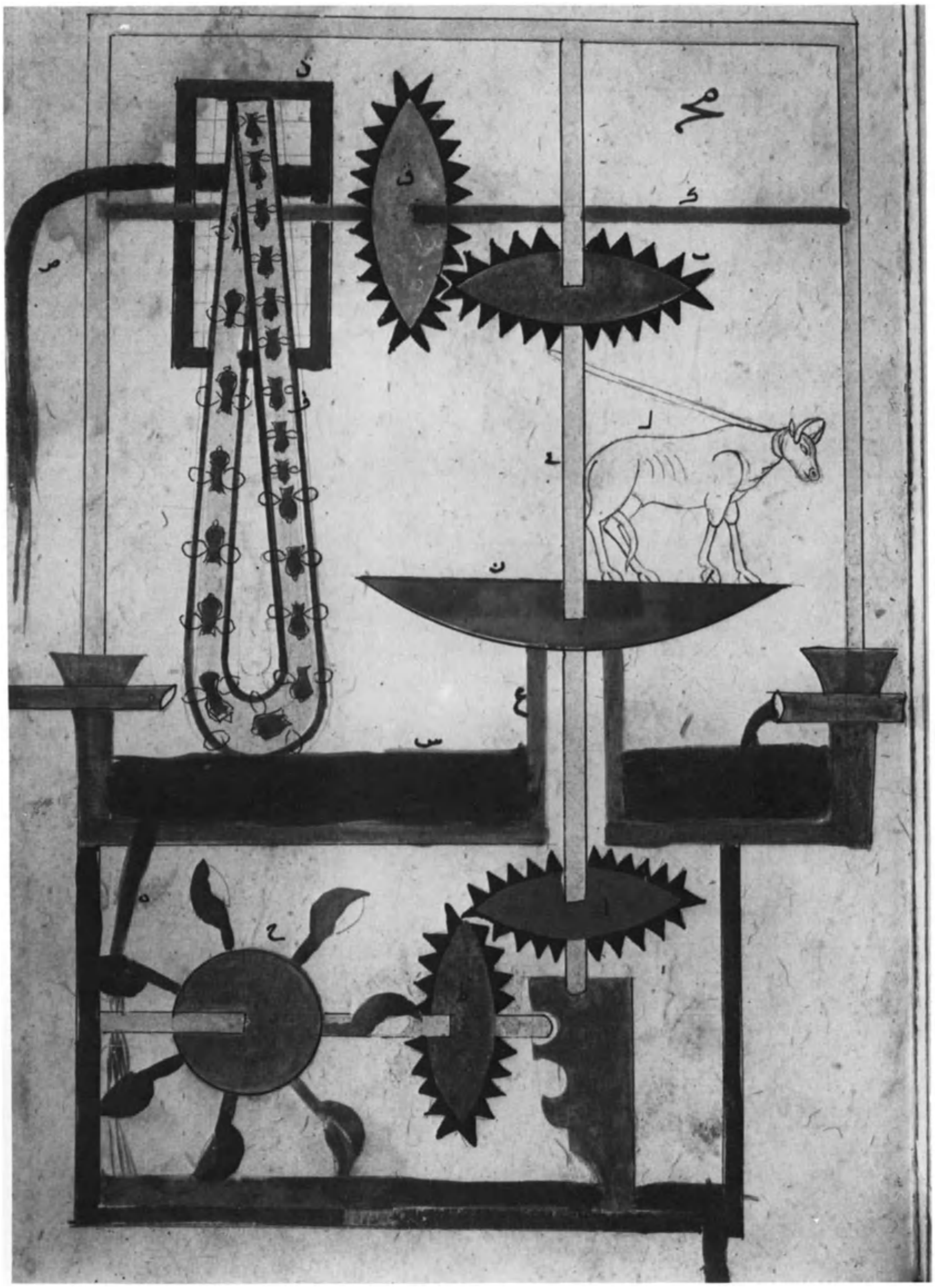
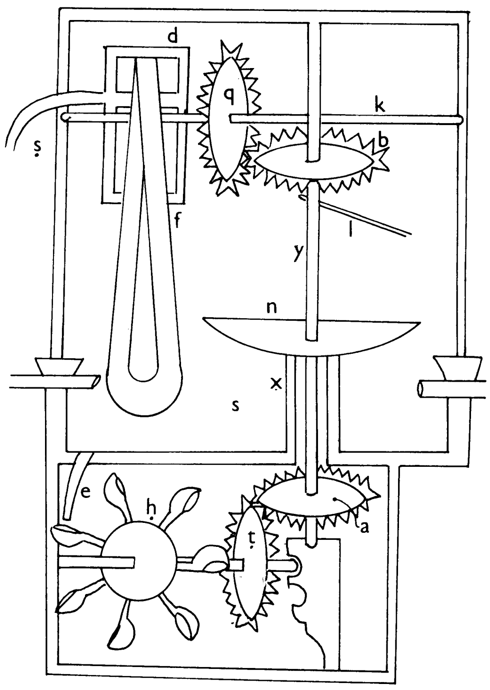


Fig. 136.



Chapter 4 of Category V

It is a machine for raising water from a pool

Section 1

It is a well with a recess in one side which is 10 cubits high in a straight line from the top of the well to the surface of the water in the well. I have shown the picture of that: the well *s*, the surface of the water *x*, the long side *d* of the recess. Then at the top of the recess a toothed wheel *ṭ* of 6 sp. diameter is installed. The ends of its axle are marked *a*, *y* and at end *y* is a vertical lever-arm *j* bent at its end to a right angle. On the end of the lever-arm is a dowel[1] *b*. End *a* of the axle is on a firm support on the ground. End *y* [which is bent to] a right angle does not have an end which rotates in a bearing but instead it has a firm support inside the angle at *z*, and this has a restraining collar which prevents the axle from lifting out of it. Then a wooden ladle is made with a capacity of about 50 *raṭls*. Its stem *d*, which is a channel, is of such a length that it stretches from the surface of the water to the top of the recess, with 2 sp. to spare. Its scoop is marked *k* and the end of its stem *m*. In it [i.e. at *m*] is a hole carrying an axle *ṣ*, the ends of which are in bearings in which they rotate, and from which they cannot emerge. In the stem of the ladle a long slot *n* is made, twice as long as lever-arm *j*, in which the dowel on the end of the lever-arm can move freely. The dowel has a flange (*ṣafīḥa*) on it [in front of the slot] and a flange on it behind slot *n*.

Above wheel *ṭ* a toothed wheel *ḥ* of 3 sp. diameter is installed. [The lower] end of its rotating axle is in a firm bearing *q* on the ground and on its upper end is a transverse lever-arm *l* with a strap on its end which connects it to the neck of an animal *e* who turns the lever arm.

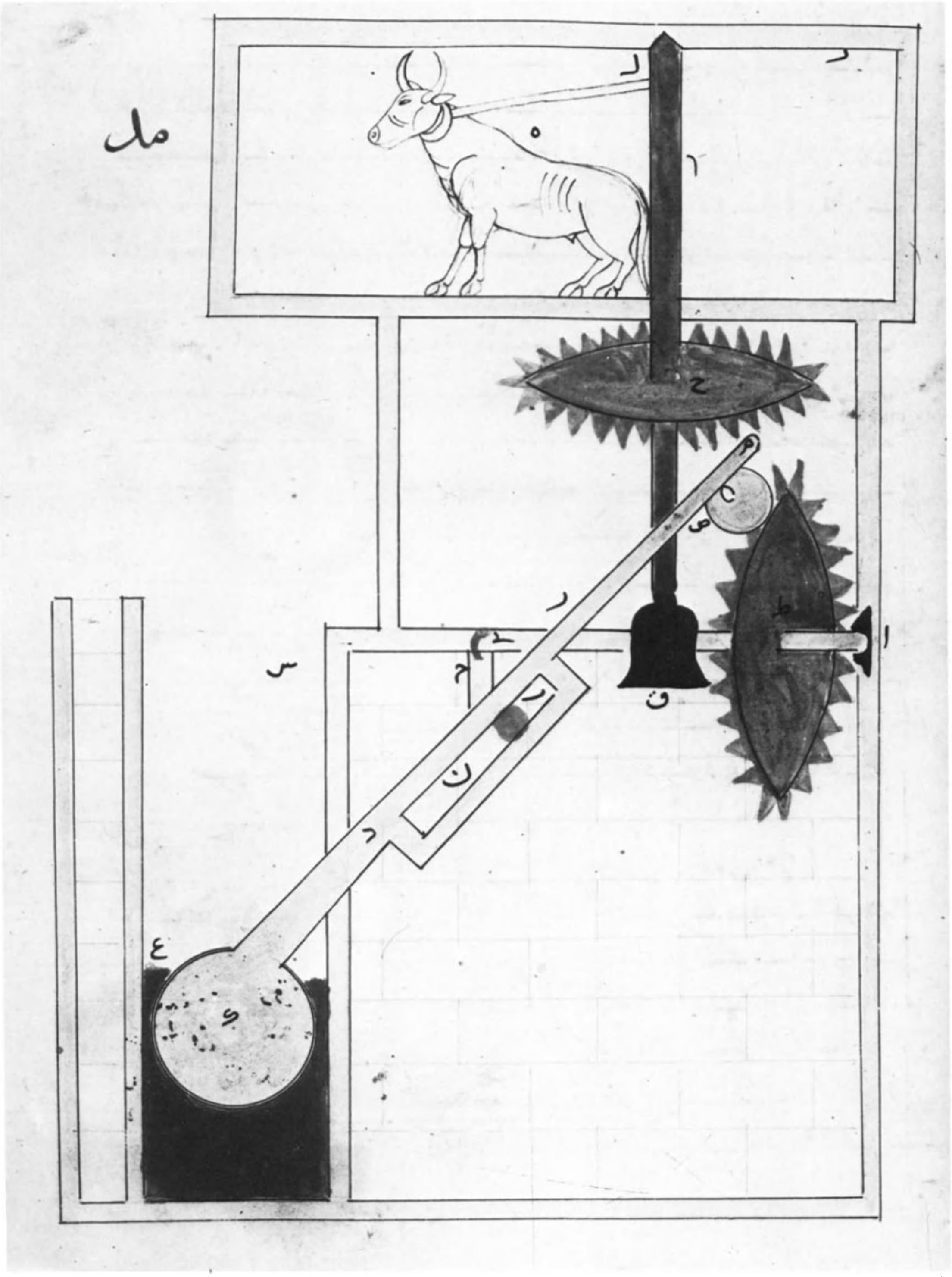
It is very clear that when animal *e* turns lever-arm *l* wheel *ḥ* rotates, turning wheel *ṭ*, axle *a*, *y* and lever-arm *j*. Dowel *b*, in slot *n*, is at its lowest position, and scoop *k* is immersed in the water. When lever-arm *j* describes a half revolution on its axle the ladle lifts its scoop past the horizontal and the water runs through its stem and discharges into an irrigation channel which leads away in the chosen direction. Lever-arm *j* rises to the vertical and then descends for a complete half revolution of the axle until the scoop is fully immersed in the water [Fig. 137].

It should be understood that when the dowel of the lever-arm is at its lowest position it is in the centre of the ladle's slot, and down in the slot. When the axle makes a quarter of a revolution the dowel moves along the slot to end *d*, while the ladle is rising. At the end of half a revolution the dowel is at its highest point, and is in the centre of the slot in the ladle, and up in the slot. At the end of three-quarters of a revolution the dowel is at the end of the ladle's slot at *b*, and is sinking with the ladle. At the end of a complete revolution the dowel returns to its position in the centre of the slot, and has descended to the bottom, and the scoop is immersed in the water.[2]

That is what I wished to describe clearly.

[Now] I will describe what I made, namely a machine which lifts water about 20 cubits from running water.

[1] *Watad.*
[2] The concept is not clearly expressed in the preceding paragraph. See notes pp. 265–266.



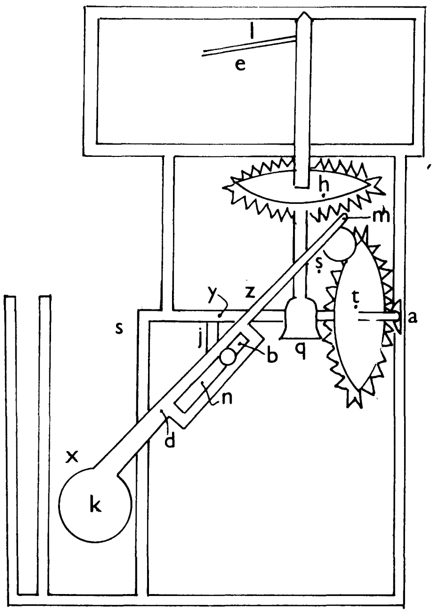


Fig. 137.

Chapter 5 of Category V

It is a machine which raises water about 20 cubits from running water by means of a wheel. It is divided into three sections

Section 1

I say that this model can be made in two versions. The first is to make a vaned wheel, which is the machine's drive, on a vertical axle. The vanes[1] are turned by the water as millstones[2] [are turned]. It [i.e. the vaned wheel] is on the lower end of the axle, which rotates in a bearing in the usual way. The upper end rotates in a firm ring. At the extremity of this end is a disc with a flat surface, and on the edge of the disc is a vertical dowel. This dowel is the activator for the device for raising the water. I have shown a picture of these vanes, with the disc above them and the dowel on the disc [Fig. 138]: the vanes *ḥ* which are slanted; the ring *s* in which the upper end of the axle rotates; the disc *q* on top of the axle's upper end; the dowel *f* on the side of the disc.

The second version: a wheel with paddles[1] is fitted to the end of a horizontal axle, some of its

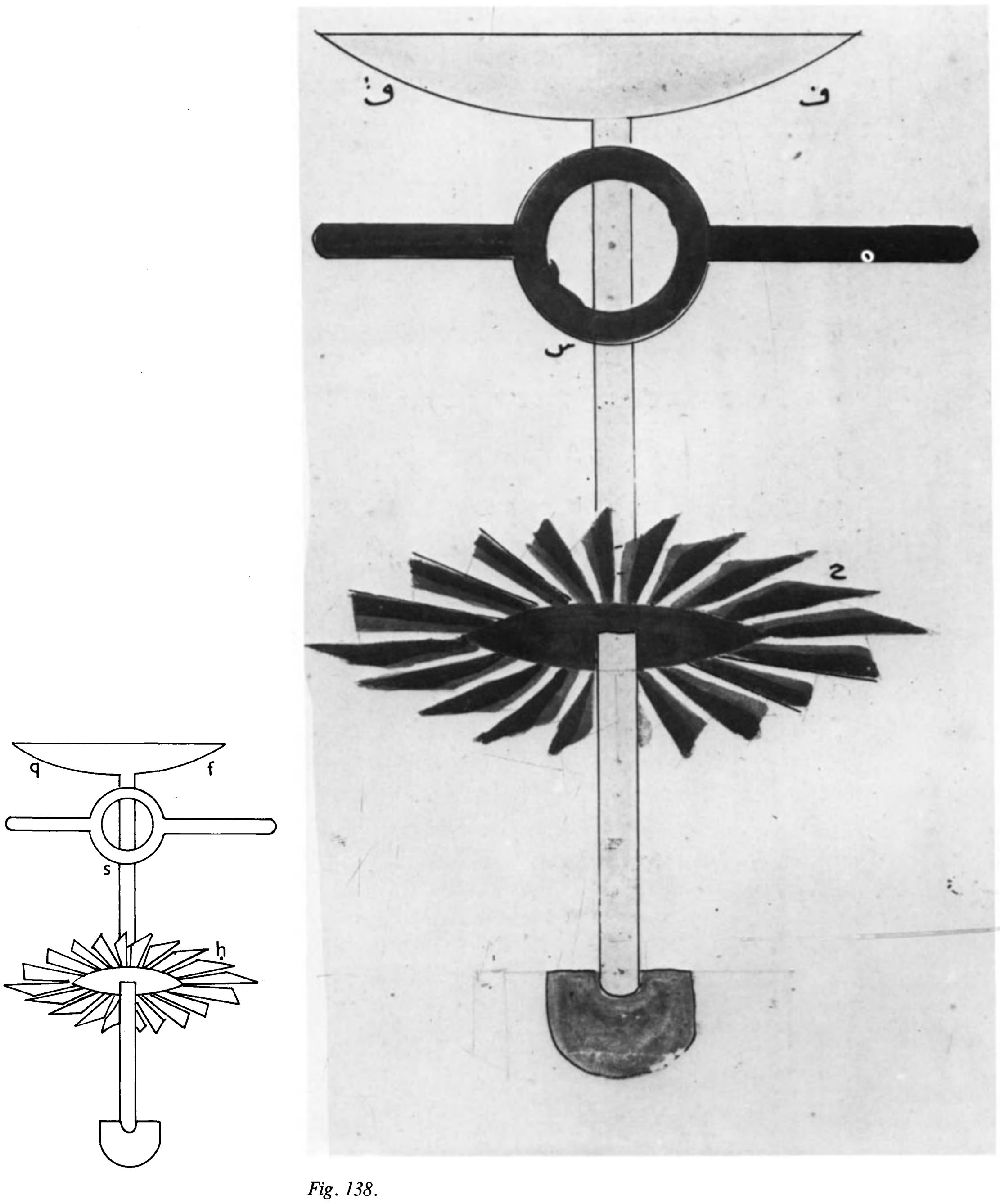


Fig. 138.

[1] *Janāḥ* pl. *ajniḥa*. The same word is used in both cases. Its literal meaning is 'wing', but it has been translated as 'vane' for the first wheel and 'paddle' for the second.
[2] *Arḥā*ʾ.

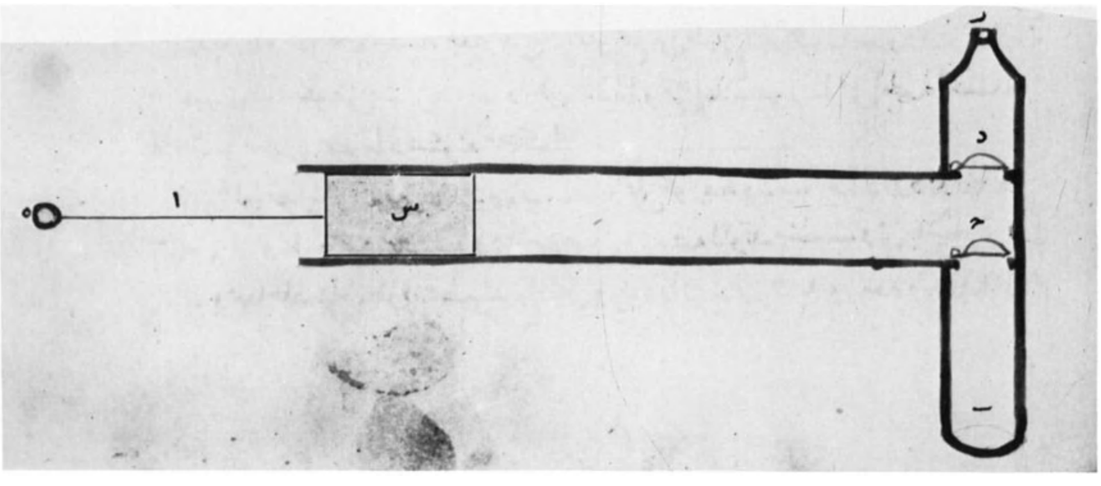
paddles immersed in running water. On the other end of it [i.e. the axle] is a toothed wheel which turns, with its rotation, a disc which has teeth on its perimeter. On its side is a vertical dowel which operates the machine. I have shown a picture of that [Fig. 139]: the paddle-wheel *s*; the toothed wheel *x* which turns a disc on the upper end of its axle, the lower end of which is in a bearing. Below its upper end is a ring in which it rotates, and on its extreme end is the disc *l*, and on the side of the disc is a vertical dowel *d* which operates the machine.[3]

Fig. 139.

As for the machine: a triangular box is made, its side about 8 sp. long and its thickness [lit. height] 2 sp. It should be of mulberry wood. Its corners are marked *ḥ*, *x*, *s*. Below its upper side a disc is installed on the end of the axle, the other end of which is in a bearing in the floor of the box. Underneath the disc is a ring in which the axle rotates. On the circumference are teeth which project from the box. The disc inside the box is marked *w*, and the teeth which emerge from the side of the box are marked *s*. On the face of the disc, and normal [to it] is a dowel [fixed] in a hole. Then a lever-arm (*sahm*) is made, one end of which has a hole with a strong nail through it, which is [fixed] to corner *x* of the box. The other end has a longitudinal slot in it, as long as the diameter of its circle [i.e. as long as the diameter of the disc]. The end of the disc's dowel passes through this slot and is on the far side of the box from angle *ḥ*, and is in the end of the slot [i.e. as drawn on Fig. 141]. The centre of the slot is marked *l* on the left and *e* on the right. [Suppose, for example] that lever-arm *q* is tilted neither towards *ḥ* nor towards *s*, but is exactly between the two: [then] when disc *w* takes a quarter revolution from direction *ḥ* towards direction *s* the disc's dowel moves towards direction *s* and lever-arm *q* tilts with it, and this is the limit of its travel. The movement of disc *w* continues until it has made [another] quarter revolution, at which point the dowel has moved to direction *x* and the lever-arm has moved back to the centre. When the disc makes another quarter revolution the dowel moves to direction *ḥ*, and lever-arm *q* has tilted [in that direction also], which is the limit of its inclination in direction *ḥ*. When the disc has made a complete revolution the dowel has returned to its starting point, and the dowel and the lever-arm are on the centre.

Section 2

A copper cylinder (*burj*, lit. tower) is made, as long as the diameter of the disc, and in cross-section it is a circle of diameter about 1 sp. One of its ends is closed. In its side, near the closed end, an opening is made upon which is fitted a pipe $1\frac{1}{2}$ sp. long. At this end, where it joins the cylinder, a light circular plate is joined by a hinge on its rim to the closing plate on the end of the cylinder. It can only move upwards, and is called a clack-valve (*raddāda*). Then on the end of the cylinder opposite this pipe an opening is made upon which is fitted a wide pipe which then [becomes] narrow. Where it joins the cylinder is another clack-valve, and this also only moves upwards. Then one takes an iron rod about $2\frac{1}{2}$ sp. long. [One of its ends is bent to form] a ring, and on the other end are two discs – it passes through holes in their centres. The distance between the two discs is 3 F, and the width of each disc is such that it can be inserted easily into the cylinder. Hempen cord is coiled around in the gap between the two discs, turn after turn, until the gap is filled. This end, with the two discs, is inserted tightly into the cylinder. The bore of the cylinder is made as smooth as possible to facilitate the movement of the discs and the hemp. I have shown a separate picture of the cylinder and its connections [Fig. 140]: the cylinder *a* with a pipe *b* on



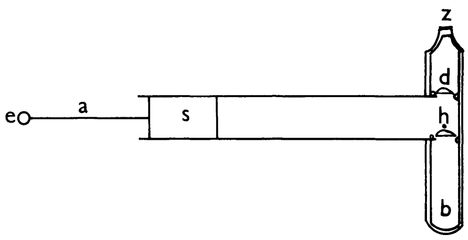


Fig. 140.

[3] Refer to Notes.

its open [should be 'closed'] end in which is a clack-valve *j*; this pipe is on the underside, and opposite it on the top is a pipe *z* which is wide [at first] and is narrow towards its upper end – in it is clack-valve *d*; the iron rod with a ring *e* on its end and on its other end two discs with hemp *s* between them. This machine is like the ejectors of naphtha (*zarāqāt al-naft*) except that it is larger than that. When the end of pipe *b* is placed in the water and ring *e* at the end of the rod is pulled the two discs and the hemp move to the end of the cylinder; clack-valve *j* lifts, clack-valve *d* closes and the air sucks up the water from pipe *b* and fills cylinder *a*. When rod *e* is pushed clack-valve *j* closes and the water is expelled, clack-valve *d* lifts, and the water rises forcefully through the narrow pipe *z* to a height of about 20 cubits, which is the length of the pipe. Then another cylinder with its connections is made according to the above description: the cylinder *ṭ*, a pipe *p* with clack-valve *y* in it; opposite this on the upper side a pipe which is wide and then narrow, with clack-valve *ṣ* in it; the rod, one of whose ends is a ring, and on the other end are two discs with hemp *n* between them.

When this has been completed, a hole is made in the floor of the box on side *ḥ*, and pipe *b* from cylinder *a* is lowered through it for half its length, and it is fixed firmly in position. Cylinder *a* is placed on two supports and made secure. Then pipe *d* is brought out from the top of the box and bent round to a central position. Then a staple is fixed on the centre-line of the slot in the lever-arm *q*, at the side, on point *e*, and this is linked to the ring at the end of rod *e*. Similarly the other cylinder is installed at side *s* of the box. Then a staple is fixed at the centre-line of the slot and this is linked to the ring at the end of rod *l*. It is clear that when lever-arm *q* moves to the left water discharges from cylinder *ṭ* through pipe *f* and water rises through pipe *b* into cylinder *a*. And when the lever arm returns to the right water discharges from cylinder *a* through pipe *z*, and water rises through pipe *p* into cylinder *ṭ*.

Section 3

One fits a paddle-wheel *k* to the end of a horizontal axle, on the other end of which is a wheel *m* with teeth, which mesh with the teeth of disc *w*. The paddles *k* are in running water which turns them. The ends of its [i.e. the paddle wheel's] axle are on firm supports in the stream. Then the box is positioned near wheel *m*, and pipes *b*, *p* are immersed in the water. The box is fixed firmly in position so that it cannot move at all. A cover is fitted to it, and weights are placed on this so that it cannot alter its position. The ends of pipes *z*, *f* are joined together, and a narrow vertical pipe about 20 cubits long is fixed on top of them. The water issues from the top of it [and is led away] in the chosen direction.

It is very clear that when wheel *k* rotates, wheel *m* on its axle turns the teeth of disc *w* which has lever-arm *q* on its face. In the lever-arm is slot *e-l* in which is the vertical dowel, and on either side of the slot are staples *e*, *l* in which are the rings of the piston-rods.[4] When disc *w* rotates, its dowel rotates with it, turning lever-arm *q* to the right and to the left. Rod *e* is pushed and rod *l* is pulled for half a revolution. Then rod *l* is pushed and rod *e* is pulled until the revolution is completed. Rising water enters the cylinder on the pull-[stroke] and water discharges through pipes *z*, *f* and rises through the pipe to which both [pipes] are connected. Clack-valve *d* prevents the water from returning to cylinder *a* and clack-valve *ṣ* prevents the water from returning to cylinder *ṭ*. Clack-valve *j* prevents the water from descending to the stream through pipe *b* and similarly clack-valve *y* prevents it from descending to the stream through pipe *p*.

That is what I wished to describe clearly.

[Now] I will describe what I made, namely a door of cast brass.

[End of Category V]

[4] *Quṭb al-zarāqa*. lit. the pivot of the ejector.

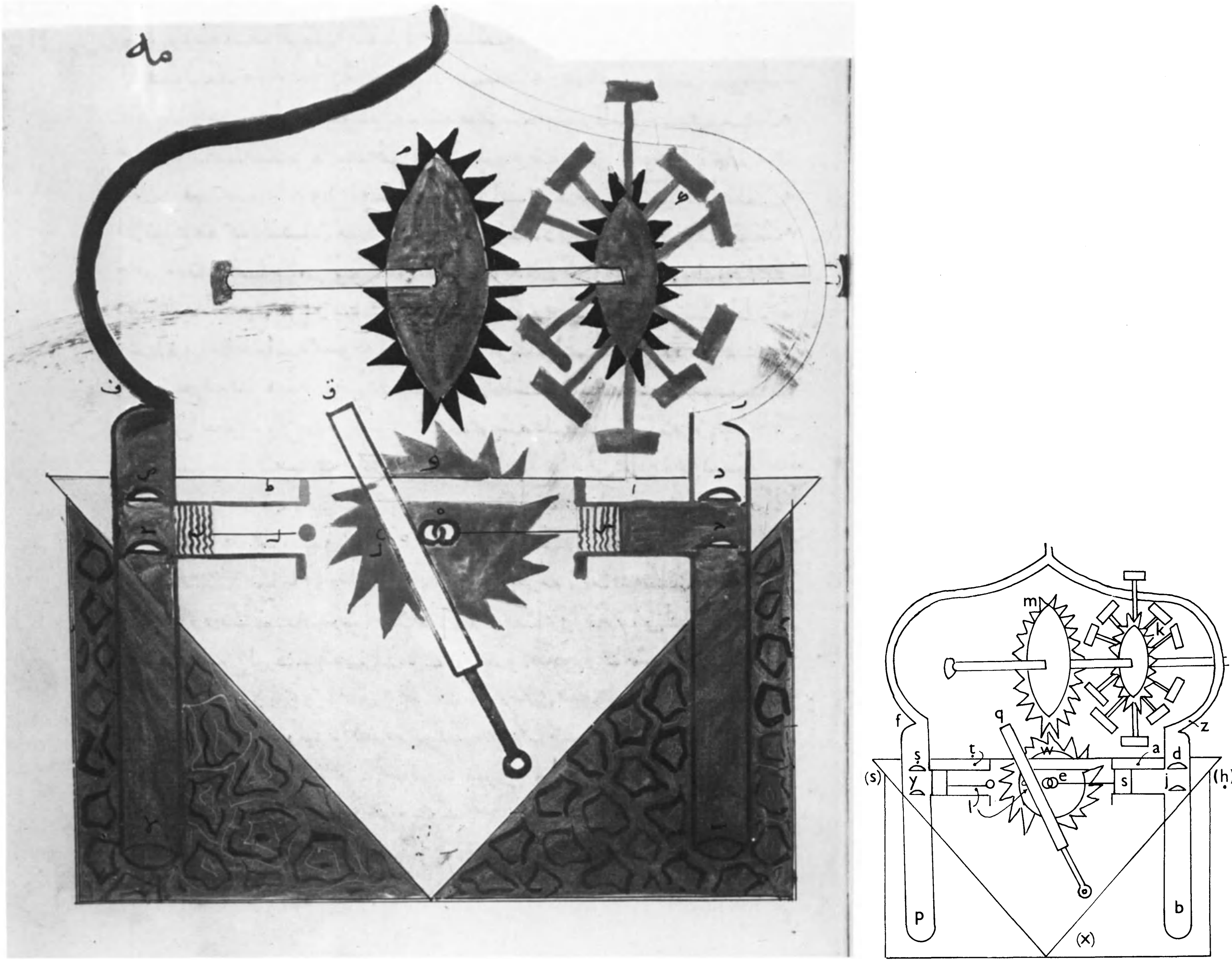


Fig. 141.

CATEGORY VI

It is heterogeneous, and consists of dissimilar designs, [described] in five chapters

Chapter 1 of Category VI

It is a door made of cast brass for the king's palace in the city of Āmid. It is the chef-d'oeuvre, to view it saddles are strapped on. Truly it is the pearl, the orphan, a priceless possession.[1] *It is divided into three sections*

Section 1

I shall describe the outside appearance

It is a door with two leaves, each leaf about 18 sp. long and about 6 sp. broad. Its centre is a lattice-work[2] in two linear [motifs], one a hexagonal line, the other an octagonal line, which are

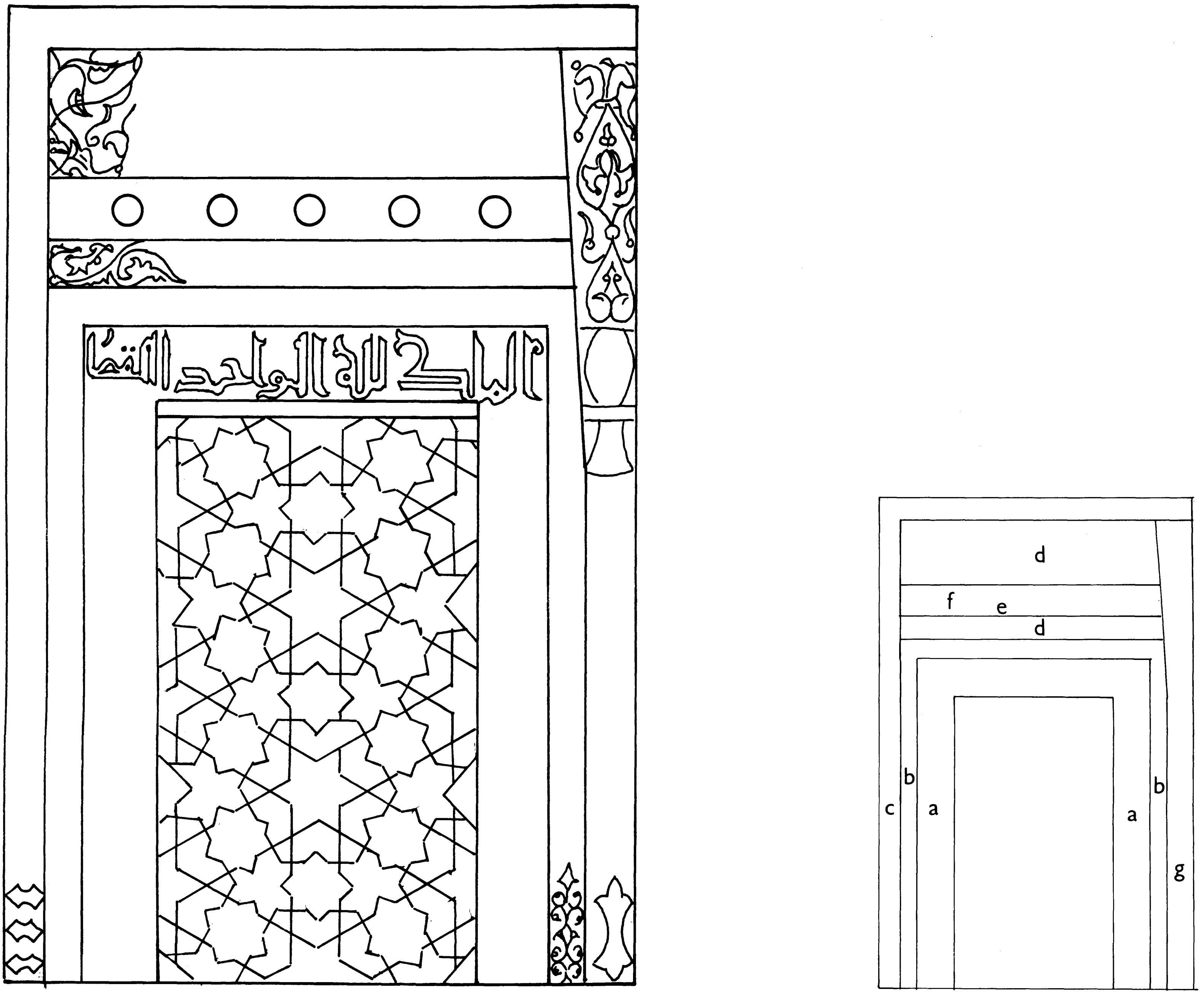


Fig. 142. N.B. The figures added to the line drawing occur neither in the text nor in the original drawing.

[1] The preceding two sentences are in rhymed prose – *saj*ʿ – which accounts for the ornate style.
[2] *Shabaka*. Lit. net.

[made from] bars, 1 F broad and thicker than that, with flat [edges], between which is a round moulding [*khayruzān* – lit. bamboo]. In the centre of its stars [*khatim* – lit. signet ring] are hollow decorated domes, and leaves of various kinds with intertwined stems. The leaves are turned away, one from the other, and the background is engraved. There are [also] decorated almonds, inlaid with silver and red copper. This lattice-work is bounded by writing in the Kufic script [*a*] with intertwined letters, and between the letters are intertwined leaves, the background of the leaves being engraved. Below the engraving is a brass plate, engraved with fine spirals. This writing is bounded by a polished border [*b*] of brass and red copper adorned with two leaves, one yellow and one red, with no stylus marks between them. This strip is bounded by a strip of cast brass [*c*] – its shape is shown in the drawing [Fig. 142].

Towards the top of the door-leaf is a brass plate [*d*], and on it there is a strong transom [*e*] of cast brass in which there are closely-spaced large nails [*f*] of excellent workmanship.

On the right-hand leaf is a closing-style, namely the nose (*anf*), [*g*] and I will describe its design: its centre is about 10 sp. long and is composed of a half-pipe with small pipes on either side of it; part is painted and part inlaid with silver, and between this there are intertwined leaves; the background is engraved. The two ends of the style are rectangular and their sides are decorated but not engraved. The two faces [of the ends] are each decorated with two leaves of different colours, one made from brass, the other from red copper. These two leaves are identical in size and are intertwined, in the manner of leaves made from wood.

I have shown the picture of the [upper] half of one leaf. In drawing it I have not aimed for completeness. My purpose was to present a [general] arrangement so that it can be understood in the whole and in detail. One realises that there is obscurity in the representations of solid bodies, but in the imagination one can fit one thing to another, view it from an angle, dissect it, and thus assemble it step by step. All the drawings which I have made are simple, so that they give a clear picture. I show a drawing of part of what I have described, as I have done with the drawings in the other chapters, split into its separate parts.

Section 2

Construction of the lattice-work

For the entire lattice-work, with the exception of its border, I cut out three pieces, i.e. [wooden] patterns, comprising a pattern for the hexagonal star with sharp corners [Fig. 143d], a pattern for the octagonal star with sharp corners [Fig. 143c] and a pattern for the filler [piece], like a quadrilateral almond-shape with sharp corners [Fig. 143b]. Then I made iron nails [Fig. 143a]

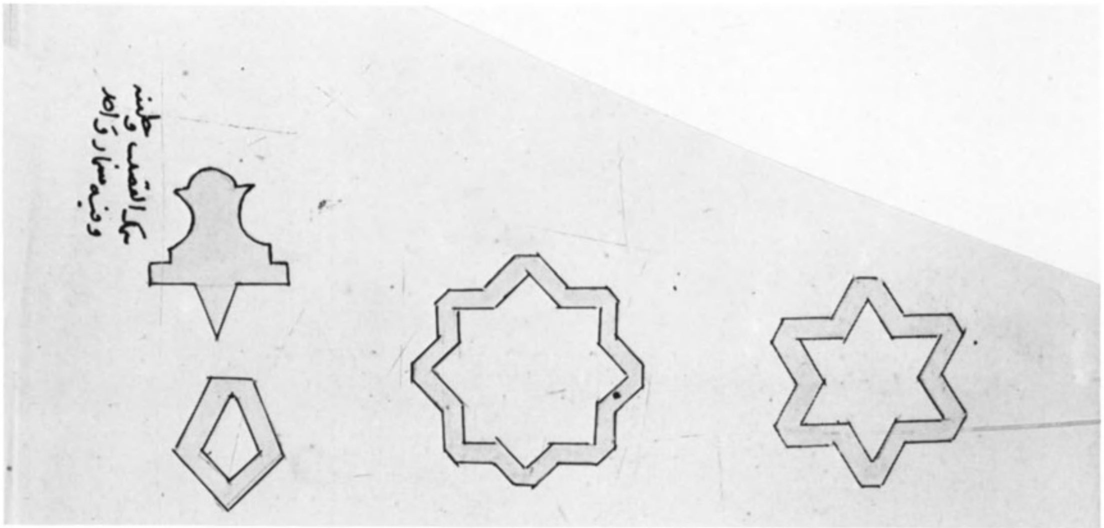


Fig. 143. (left upper (a); left lower (b); centre (c); right (d)). Caption by (a) reads: 'Thickness of the rod and its opening (?), in which there is one nail'.

each one 4 F long, its top not flat but shaped like a small date kernel [laid] across the top of the nail. Then I took an impression of the hexagonal pattern in the sand, as the founders do in the foundry (*ālat-al-Ṣabb*). Then I lifted the pattern from the sand and into the impression of its underside I pushed 12 nails so that the [date] kernel at the top of each nail almost touched the sand, but with a narrow gap left between it and the sand. Then I put the parts of the apparatus together again and poured the molten brass into the forms, covering the heads of the nails so that it became a hexagonal star. Then, as [just] described I made the octagonal [stars] and the filler [pieces] with patterns, until sufficient were completed for the two leaves. I finished that off by filing, scraping etc.

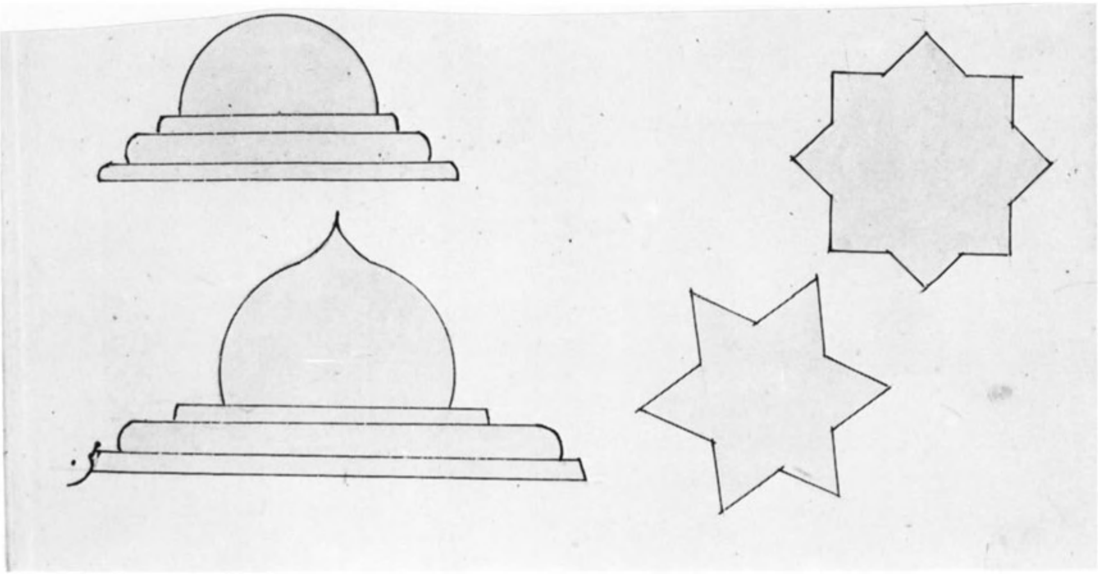


Fig. 144. (Left upper (a); left lower (b); right upper (c); right lower (d)).

Then I made for every star a dome[3] from cast brass, surrounded by angles[4] [which fitted] inside the angles of the stars. The upper faces of the angles are flat and at the same level as the bars of the lattice-work. Between the angles surrounding the dome and the bar of the star there is a gap.[5] The sides of the dome's angles fit the sides of the bar, as is usual in carpenters' work for filling in joinery (*kārzawān*).[6] Then I adorned the dome with leaves of various kinds as the carpenters do, with grooving (*ḥafr*), chiselling (*tanjīr*) and with inlaying (*tafzīʿ*), and by intertwining the stems. I chiselled the background of the leaves, taking the greatest pains.

Then I placed in the quadrilaterals, filler [pieces] with flat surfaces and vertical sides to fit the sides of the bar,[7] and as high as the thickness of the bar. Then I made three-angled saddle-shaped fillers[8] to span between the stars and the quadrilaterals, each filler as high as the thickness of the bar, its side flush with the side of the bar. Then I made 'humped' (*musannam*), saddle-shaped fillers[9] with flat surfaces to span between the stars and the quadrilaterals. In the centre of each triangle is a [decoration like] a rose projecting from its surface. The surface is adorned, with a black background. Then, to surround the lattice-work and complete the stars and quadrilaterals, bars are made with nails in them as [described] previously for the casting of the stars. In this lattice-work half-stars, quarter-stars and smaller pieces do not occur, apart from [a few] half-stars. I have shown a picture [Fig. 143] of a hexagonal star, an octagonal star and a quadrilateral; and a picture [Fig. 144] of one raised dome and another of a flat dome; and quadrilateral three-angled and saddle-[shaped] fillings [Fig. 145]. It is to be understood that each dome, three-angled

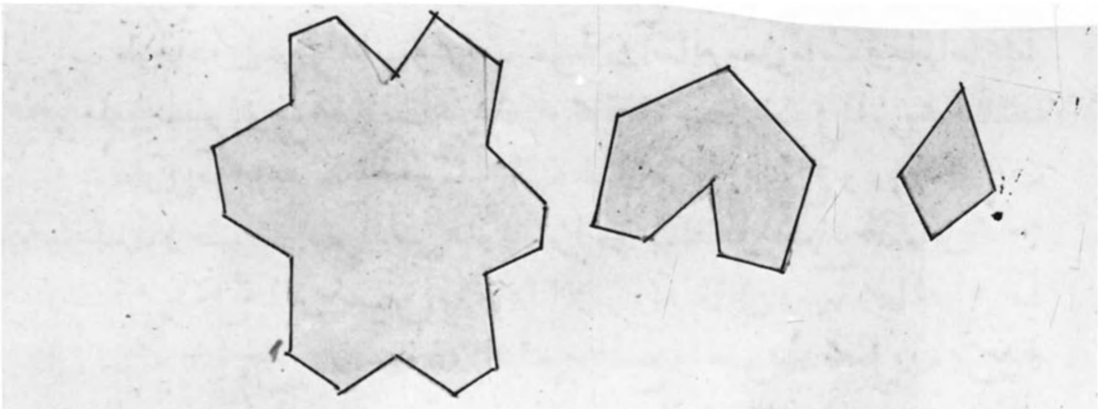


Fig. 145. (Left (a); centre (b); right (c)).

[3] Fig. 144a and b. Fig. 46.1A and B.
[4] Fig. 144c and d.
[5] Presumably a tolerance to allow for fitting.
[6] The Persian word *kār* means 'work' and zawān '*tooth*'. The compound is not given in the dictionaries, but may refer to some kind of cabinet work. (Wiedemann and Hauser 7, p. 221, Note 3).
[7] Fig. 145c. Fig. 46.1C.
[8] Fig. 145b. Fig. 46.1E.
[9] Fig. 145a. Fig. 46.1D.

filling and quadrilateral filling has a flat border which is half the width of the bottom of the bar, so that the bar rests on the borders of each dome, filling, and three-angled [filling].

Section 3

Manufacture of the border from brass and red copper

Fig. 146.

exposed the face of the plate by filing and scraping, and it assumed this form [Fig. 147a]. Then I I made a brass plate and chiselled it to this design [Fig. 146]. Then I made a wooden pattern for this plate, thicker than it [i.e. the plate]. Then I made an impression of the pattern in sand in the casting box. I lifted out the pattern and placed the chiselled brass plate in its impression; melted red copper and poured it thereon. [The plate] was coated up to the thickness of the pattern. I then

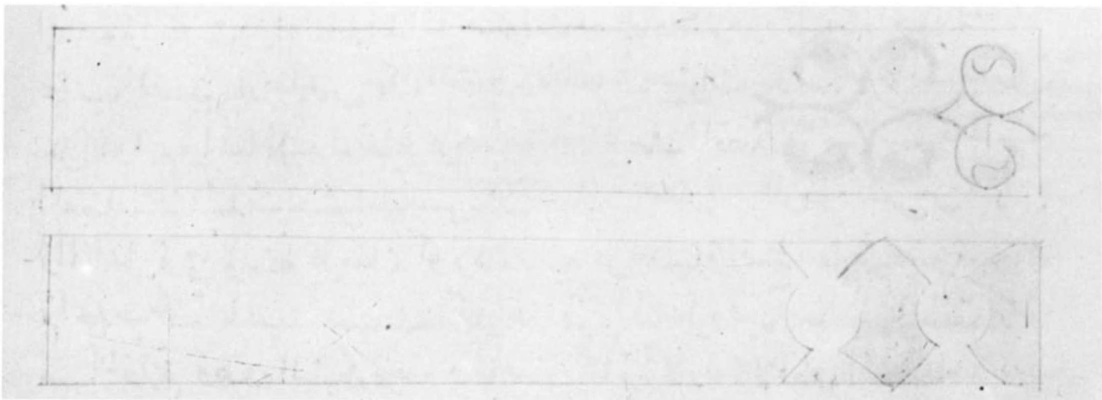


Fig. 147. (Upper (a); lower (b)).

fitted the end of one plate to the end of another so that the fitted joint was hardly visible, and I made marks on them.[10] Next I made plates of cast brass with projecting places on their backs in which nails were [fixed], as I had fixed them in the bars. This is a picture [Fig. 147b] of one plate. Each plate has a vertical edge which adjoins part of the side of the door-post.[11] For each end of each door-leaf I made a cross-beam[12] of cast brass, like a channel, its length less than the width of the door, its width about 3 F. Its ends are concealed [i.e. covered by the door-styles]. Its surface is almond pattern, and so fabricated that large conical nails can be fitted to the groove, and so on. Then I made for each end of each door-leaf a brass plate as long as the width of the leaf and about 1 sp. wide.[13] I painted it and filled in the background of the painting with black. Then I made for each leaf a ring [i.e. a knocker] from cast brass in the shape of two connected serpents, the head of one facing the head of the other. Their mouths are open as if they wished to devour the neck and head of a lion. This lion's head and neck are the extension of an iron staple which is nailed to the door. The fangs of the serpents are in two holes in the lion's neck,

[10] These are the components for the border – *b* in Fig. 142.
[11] These are the components for the style and rails – *c* in Fig. 142.
[12] *e* in Fig. 142.
[13] *d* in Fig. 142.

and the ring rotates about these. This is the picture [Fig. 148] of the ring and the lion's head. The manufacture of the closing-style, i.e. the nose:[14] for its middle [section] I made a hollow wax pattern shaped like a long half-pipe with a flat back, and on its back I also made wax protuberances, in which I buried nails. I covered the inside and the outside of this [pattern of the] closing-style with clay, and then burnt the wax away from the clay – as done by the masters of this craft – and replaced it with molten brass. Then I removed the clay, smoothed it by filling, and inlaid it with silver so that it gleamed. In between the silvered portions were leaves of different kinds, like grasses, and animal heads: I encrusted the leaves, intertwined the stems and finished [all] that with scraping.

Fig. 148.

For either side of it [i.e. the style] I made a piece of cast brass 4 sp. long, rectangular in shape [i.e. cross-section], wider at the end than where it met the [centre-section of] the style, to which it was closely fitted. There were nails on its rear. Both sides sloped gradually outwards. Its surface was decorated, namely with leaves, whose tips were intertwined and turned away [from one another]. Then I placed wax leaves upon these leaves, positioning them precisely, nothing omitted and nothing added, entwining the stems with one another in [symmetrical] opposition and the tops of the leaves in [symmetrical] opposition. Then I placed this in a large sand mould, and took the impression. I cut away the wax from the outside of the leaves and burnt it off from inside, leaving the place of the wax empty. I then replaced it with red copper. I then cleaned these leaves and made them into various shapes with styluses, with scraping etc. I joined these two pieces, i.e. the ends [of the style], to its main section. I showed the drawing of this closing-style earlier, in the drawing of the door-leaf [Fig. 142]. This is [best] understood by studying the drawing, not from what I have described, for I have abbreviated the description.

That is what I wished to describe clearly.

[Now] I will describe what I made, namely an instrument like a ruler from which the centre-point of three points on the surface of a sphere or on an horizontal surface, can be determined. It also sets out angles.

[14] Fig. 142 *g*.

Chapter 2 of Category VI

It is an instrument by means of which the centre-point of three points of unknown position, lying on the surface of a sphere, may be precisely determined; also [for three points] on a horizontal surface, provided that they are not in a straight line; the other angles in [general] use, acute and obtuse, may be also determined with its. It is divided into three sections

Section 1

On the purpose of the instrument, and its construction

I say that $\frac{2}{3}$ of a circle, $\frac{1}{3}$ of a circle, an arc of a circle, or more or less than these, can pass through any three points lying on the surface of a sphere. When I mentioned this, some people denied it, and demanded that I should fix one foot of the dividers on the centre point and pass the other leg through the three unknown points [implying that] there was an error in that.

The straight line joining two of the points is divided at its centre by a mark, upon which a line is erected making two equal angles with the first line. Similarly a line is drawn between the second and third points and on its centre a mark is made, upon which a line is erected making two equal angles with the first line. Where the lines cross is the centre-point.

I made an instrument for that to facilitate the determination of the required centre-point, and the determination of all the angles in [general] use, acute and obtuse. This is [the method]: we take a brass ruler of [adequate] thickness, about 3 sp. long: in the centre of the ruler is a projection in the shape of a semi-circle. I have shown a picture of this [Fig. 149]: the ends of the ruler are

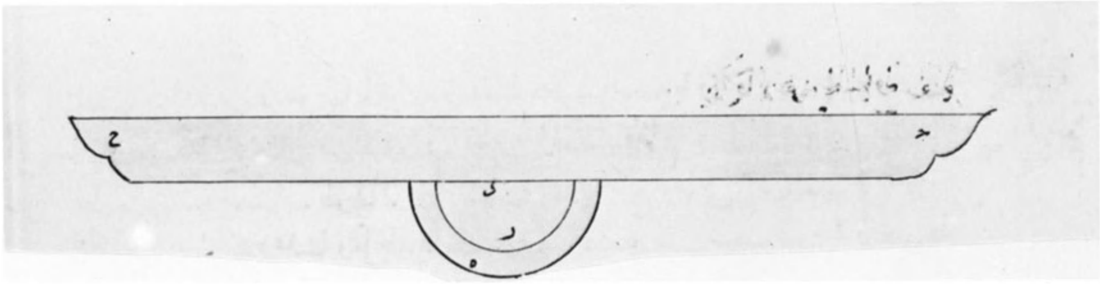


Fig. 149.

marked *j*, *h* and the centre point of the semi-circle *y*. On centre-point *y* a semi-circle *z* is drawn, a short distance inside the perimeter of the [first] semi-circle. The edge of the ruler is verified [for straightness]. Then from centre point *y* on the second drawing [i.e. referring to Fig. 151] a line *n* is drawn which divides the semi-circle into two halves, and which finishes at the ruler's edge, dividing its length into two halves. The intersection of the semi-circle with the end of the line is marked *f*. Then the face of the ruler from line *n* to the end *j* of the ruler is divided into as many divisions as possible, and from line *n* to end *ḥ* it is divided in the same way as from line *n* to end *j*. Between every five divisions a '5' is written on the ruler.

Then an alidade (*ʿadāda*) is made, about $1\frac{1}{2}$ sp. long, and as wide as five divisions of the ruler. Near one of its ends, a projection is fitted, a very small semi-circle is drawn on the projection, and a narrow hole is made in its centre-point. In the end of the alidade nearest the semi-circle a hole is made – the distance between this hole and the hole in the centre-point of the semi-circle equals the distance between centre-point *y* and semi-circle *z* on the ruler. This is a picture of the alidade

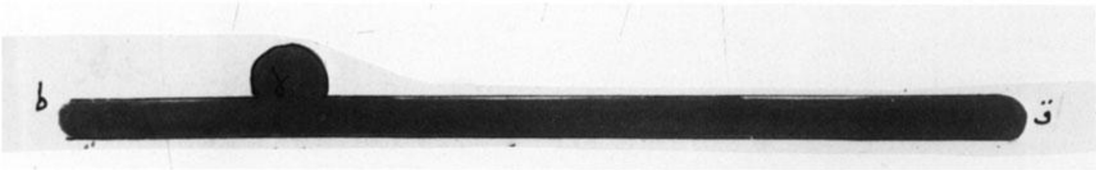


Fig. 150.

[Fig. 150]: on the pierced end of the alidade is *ṭ*, on the hole in the centre of the semi-circle is *p* and on the other end is *q*. In the two holes [i.e. holes *y* and *p*] a nail is inserted, and its ends are hammered gently until they bend down over the ruler and the alidade, in such a manner that when the alidade is moved over the ruler it rotates truly. Then the alidade is moved over the ruler until its edge with the semi-circle on it is on line *n* of the ruler, and the alidade is at right angles to the ruler. At this juncture the end of the drill is placed in hole *p* and a hole is made on circle *z* and through line *n*. The drill is lifted out and a nail is inserted tightly in the hole. On its end is a protruding piece for lifting it out and for inserting it. This is the complete picture [Fig. 151].

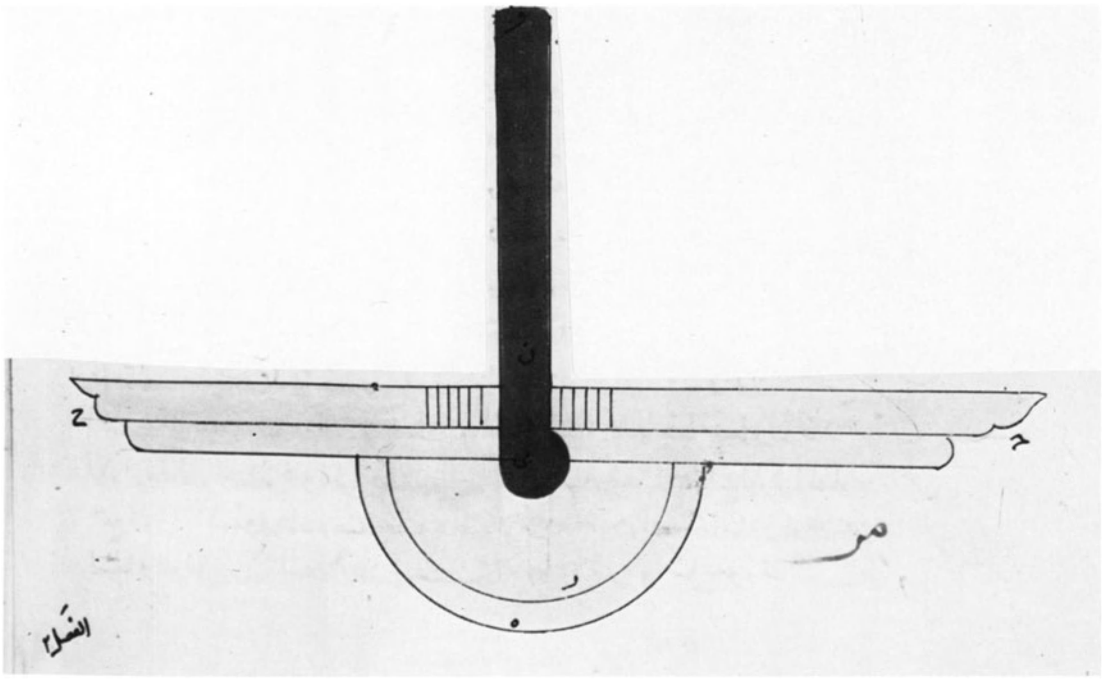


Fig. 151.

Section 2

Use of this instrument for determining the centre-point: either for determining the centre-point of three points of unknown position in the surface of a sphere, with precision; or for determining the centre point of three points of unknown position on a horizontal surface, with the exception of one case, i.e. when the points are in a straight line.

Consider the points *a*, *b*, *j* to be on the surface of a sphere or on a horizontal surface [Fig. 152]. The ruler is laid on points *a*, *b* and the alidade is near the centre of *ab* and towards the space [lit. hollow] between the three points. The divisions are to the right and to the left of the alidade. The ruler is moved until the edge of the alidade is exactly in the centre of the two points, whereupon a line is drawn along the edge of the alidade. Then the ruler is moved to points *b*, *j* and adjusted to bring the edge of the alidade exactly in the centre of points *b*, *j*, whereupon a line is drawn along the edge of the alidade, cutting the first line. The intersection is the centre-point of the three points. This is the picture of the three points [Fig. 152]: through them are two lines drawn along the edge of the alidade, intersecting in *y*. If one foot of the dividers is placed on the intersection, the other foot will pass through the three points.

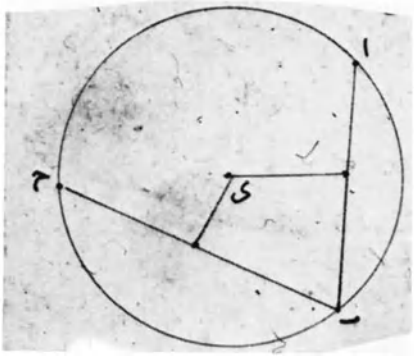


Fig. 152.

Section 3

Use of this instrument for setting out different angles

When the alidade is at right angles to the ruler, right angles can be set out with it, without altering it. Then one takes a flat board, the edge of which has been made true with the ruler. The angle of an equilateral triangle is drawn on it, the edge of the board being one of its sides. Then the ruler is placed against the edge of the board. The nail is removed from the holes in the alidade and the ruler. The alidade and the ruler are moved until the edge of the alidade is aligned with the side of the triangle. Then the drill is placed in the hole at the end of the alidade and a hole is made through the ruler's semi-circle. The nail is inserted in this hole, and the alidade on the ruler is now showing two angles, i.e. the angle of an equilateral triangle. From this one can obtain a sextuple acute angle and a sextuple obtuse angle.

Then an acute quintuple angle is marked on the edge of the board, the edge of the ruler is placed against the edge of the board, the nail is lifted from the hole of the triple [angle] and the ruler and the alidade are moved until the alidade is on the side of the quintiple [angle]. The drill is placed in the hole in the alidade and a hole is made through the ruler's [semi-] circle. The nail is inserted in it, and the alidade on the ruler is now showing two angles – a quintuple acute angle and a quintuple obtuse angle. [One proceeds] in this way for whatever angles are chosen. On every hole on the ruler's semi-circle one writes the name of its angle. To the end of the nail the end of a light chain is attached, the other end of which is attached to a staple on the semi-circle, so it [i.e. the nail] is permanently retained.

That is what I wished to describe clearly.

[Now] I will describe what I made, namely a brass lock on a chest.

Chapter 3 of Category VI

A lock for locking a chest by means of 12 letters of the alphabet

Section 1

The earlier [workers] in this craft made locks for locking and opening by means of the letters. Among them were [those that] locked by means of 4 letters on 4 circles, by 2 letters on 2 circles, and by 6 letters on 6 circles. I made a chest (*ṣundūq*) and made a lock on its lid, as I shall describe. It is four circles on a long rectangle and inside this circle is [another] circle. Between them are sixteen lines and between the lines are sixteen of the twenty-eight letters. I have shown the picture of the top of the lid [Fig. 153] with the circles on it, and cylinders cut out, [leaving] round holes.

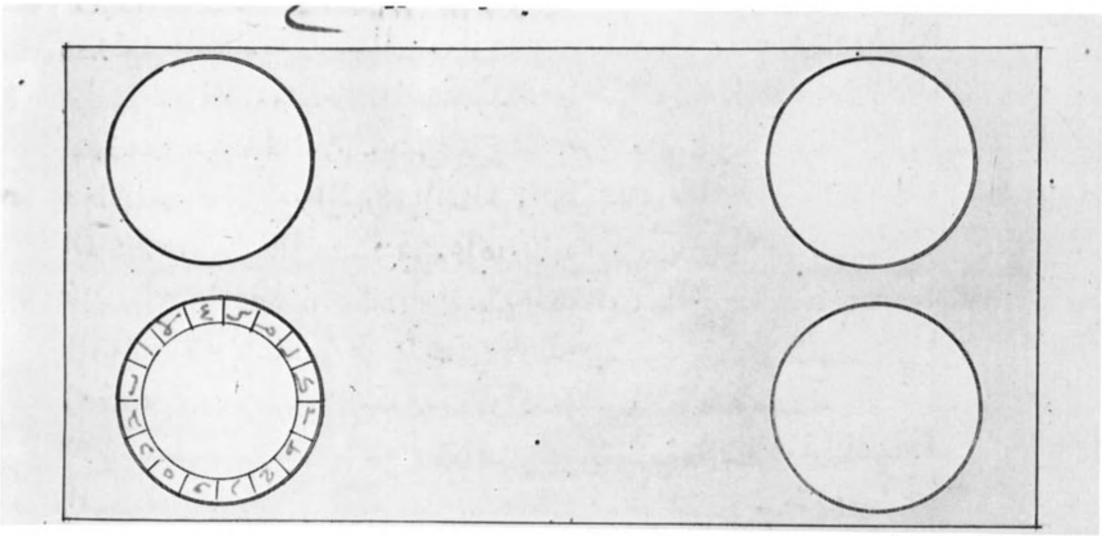


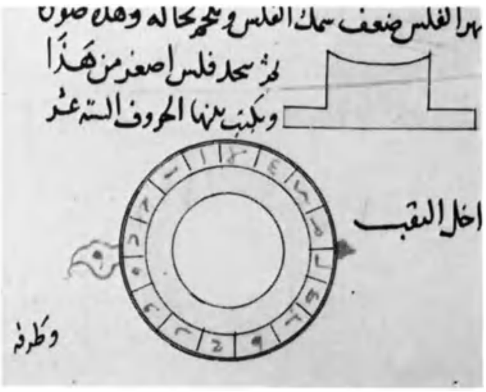
Fig. 153.

A disc (*fals*) as thick as the lid is made to fit each hole. Inside the perimeter of the disc a circle is drawn and [the space] between the circle and the perimeter is divided up by 16 lines between which 16 letters are written. To the edge of the disc a dainty 'almond' [i.e. an almond-shaped projection] is fitted, half of it on the face of the disc and half of it outside its edge. Opposite it on the edge of the disc is a bird's head, for holding when rotating the disc in the hole in the lid. The head of the almond passes over the letters like a division indicator,[1] as does the bird's beak. Both prevent the disc from sinking through the hole. A wide hole is made in the centre of this disc. This is its picture [Fig. 154]. Then a projecting cylinder is fitted to the disc's hole, filling it. One of its ends is flush with the face of the disc and the other end protrudes from the underside of the disc for twice the thickness of the disc. It is soldered in position. This is another picture [Fig. 155] of the side view of the disc with the cylinder in it.

Fig. 154.

Then a smaller disc than this is made and a circle is drawn inside its circumference. A wide hole is made in its centre. This is its picture [Fig. 156]. A projecting cylinder is fitted to this hole, filling the inside of the hole. Its end is flush with the face of the disc and its other end projects from the underside of the disc for four thicknesses of the disc. Then an almond is fitted to its edge [i.e. the edge of the disc], half of it on the surface of the disc and half of it outside its edge, to pass over the letters on the first disc. Opposite this almond on the other edge of the disc a projecting knob is fixed, for holding and turning. When the cylinder of this disc is inserted into the cylinder of the first disc, it rotates therein with ease. This is the picture of the second disc [Fig. 157] with the cylinder in it.

Then a brass rod is made, half a finger's length long, and of such a thickness that it can be inserted in the cylinder of the second disc. On top of the rod, at right angles, is an almond with a pointed tip. When the rod is inserted in the cylinder of the second disc the almond lies over the face of the disc, and the tip of the almond passes over the letters which are marked on it. This is a separate picture of the rod and the almond [Fig. 158] I have drawn a picture [Fig. 165] of the



Figs. 155, 156. (Upper 155; lower 156).

[1] e.g. on an astrolabe, or on the flow regulator described in Chapter 1, Category I.

Figs. 157, 158, 159, 160, 161. *(Reading top to bottom).*

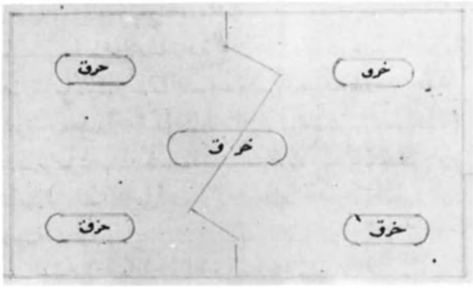


Fig. 162. All the words read 'aperture'.

first disc in one of the lid's holes, the second disc on top of it, and the almond's rod through it [i.e. the second disc]. When the bird's head on the first disc is grasped and the disc twisted to the right and to the left, it rotates together with what is on it. When the knob projecting from the second disc is grasped in one hand, while the head of the bird is grasped with the other hand to prevent the first disc from turning, the second disc rotates when it is twisted. When both discs are held and the almond [on the rod] is twisted by itself, it rotates. Then, on the end of the cylinder which projects from the back of the first disc, 16 notches (*ḥazz*) are made, so that [something] like teeth can enter them. This is the picture [Fig. 159] of a disc with a notched cylinder on it.

Then a disc of medium thickness is made and a hole is made in its centre to take the end of the notched cylinder. In this hole is a radial tooth [pointing] in the direction of the centre-point. A triangular notch is cut in the edge of this disc opposite the tooth. This is its picture [Fig. 160]. Then this disc is pushed on to the end of the cylinder of the first disc, the tooth fitted to it entering one of the notches in the cylinder [where it is held] firmly in place. The face of the disc is flush with the end of the cylinder. Then 16 notches are made in the end of the cylinder of the second disc, and a disc is made of the same dimensions as the second disc[2] which is on the cylinder of the first disc. A hole is made in its centre and a tooth fixed to it. When the end of the cylinder of the second disc is inserted in the hole of this disc it is rigidly connected, since the tooth fixed to the disc's hole enters one of the notches of the cylinder. The face of the disc is flush with the end of the cylinder. A triangular notch is made on the edge of this disc opposite the tooth – in the same way as on the previous disc. Then another disc is made, of the same size as one of the two discs [just] made. In its centre a hole is made, in which is inserted the rod with the almond on its end. Inside its perimeter [i.e. the disc's perimeter] 16 holes are made and a triangular notch is made in its edge opposite one of the holes. This is the picture of this disc [Fig. 161]. Then, a disc is made, smaller than this disc and a square hole is made in its centre. The bottom end of the almond's rod is made square, to be inserted immovably in the disc's hole. In this [last] disc a hole is made in line with the 16 holes in the disc when it rotates below [should be 'above'] it. In this hole a strong nail is fixed which enters one of the holes easily. A slot is made in the end of the rod in which a cotter (*faras*, lit. horse), yet to be mentioned, can be tightly inserted.

Section 2

For the interior of the lid a plate is made which covers the four holes with a little to spare. Four marks are made on the plate on the centre-points of the holes in the lid. Long slots, [all] running in the same direction are made on these marks. The width of each slot is such that the cylinder on the end of the first disc can pass through it, and move freely in the slot. Then a slot, running in the same direction as the four slots, but narrower than one of those slots, is made in the centre of the plate. Then this plate is cut into two pieces, in the manner shown in the drawing [Fig. 162]. This is the drawing of the plate, with slots on it, and cut [in two]. Then in each slot in the plate we insert the discs made for it, six in number, with the almond's rod through them, as described above.

Now one makes an earring (*qurṭ*) of fine workmanship on the end of a rod like the rod of the almond. A hole is made in the centre of the lid on the centre-[line] of the four holes, and the earring's rod touches the surface of the lid. The earring can move, and when it is twisted it turns – the shoulder is in contact with the surface of the lid. This is the picture [Fig. 163] of the earring on the rod. Then a medium sized disc is made, a square hole is made in its centre, and the end of the earring's rod is made square so that it fits tightly into it. A slot is made in the end of the earring's rod for the insertion of a cotter. To the edge of the disc 4 teeth are fitted as I have shown in this drawing [Fig. 164].

I have shown the mounting of the discs in one hole [in the lid], one fitted over another [Fig. 165]: the rod of the almond with a cotter on its end retaining the discs; the side view [lit. thickness] of the plate inside it, and the side views of the discs one upon another; and the side view of the lid with a hole in it, in which is a disc – both are at the same level and are marked *a*; the side view of the disc *b* above the disc in the hole; above it is an almond *j*; the side view of the plate *ṭ* inside the cover; the side view of the disc *ḥ* on the end of the cylinder of the first disc; the side view of the disc *x* on the end of the cylinder of the second disc; the side view of the small disc *m* on [the rod of] the almond – [the rod] has a retaining lug *q*[3] on it; the end *n* of the almond's rod in whose slot is a cotter *k* which holds everything [in place]. In every hole in the lid there is a similar assembly.

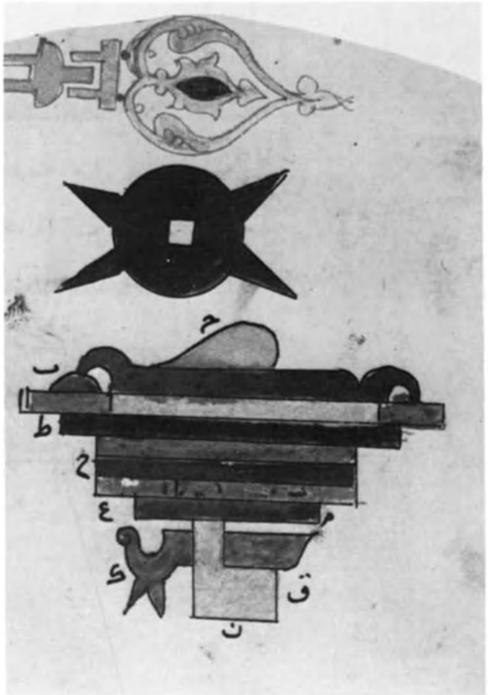
[2] i.e. the third disc to be made.
[3] *Samād.*

I have shown the picture of the inside of the cover [Fig. 166]. On the surface of the plate, opposite each of the holes with discs in them, is a projecting lug [lit. almond]: when the triangular notches on the sides of each disc are all in line, and the plate is drawn [apart] by the earring, the plate's lug enters the notches in the three discs and the lock is opened. When the large earring fitted to the centre of the lid is turned in the opposite direction, the lock shuts. The tip of the almond on the rod is opposite one of the letters written on the small disc which is underneath the almond, the tip of the almond of this disc is on one of the letters written on the disc underneath it, namely the one occupying the hole in the lid, and the almond of this [last-mentioned] disc is on one of the letters of the lid's circle. These three letters, the first of which is on the uppermost disc, are recorded. Similarly for each circle on the lid, so that the total number of letters is twelve. The four lugs are on two halves of the plate. [The parts are marked as follows]: the two halves of the plate *ḥ*, *x*; in each of the holes *a*, *b*, *j*, *d* there are four discs, one upon the other, their notches (i.e. of three of them) all in alignment, with a small disc *e* above them; the extension of the almond's rod with the cotter *ṣ* in it; in the centre of the plate is the end of the earring's rod on which is a disc with four teeth *y*, *m*, *e*, *z* on its perimeter; on the end of the rod is a cotter *f* which fixes the disc to it;[4] on the plate, by each tooth are projecting pegs *l*, *l*, *k*, *k*; on the side of the plate are two hooks *q*; on the ends of the plate at *ḥ*, *x* are two ring-shaped projections *s* on the ends of which are two rods with cotters through them – the rods pass through two holes in the ends of the lid.

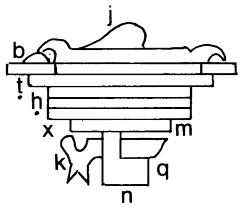
On the side of the lid is an opening through which a latch enters, and this rotates about a hinge [lit. 'its second sister'] which is on the side of the chest, to bring it [i.e. the latch] between the two hooks. This latch has an aperture in which the ends of the hooks engage, thus locking the chest.

On [one of] the two halves of the plate, opposite the three notches in the three adjoining discs, a triangular projecting 'almond' [i.e. lug] is fitted to the plate.[5] When the plate is moved towards the notches the lug fills the notches. The tip of the rod's almond is on one of the letters of the uppermost disc, the almond of the uppermost disc is on one of the letters of the disc underneath it, and the almond of the latter is on one of the letters of the lid's circle. Similar lugs are fitted for every three notches, making four lugs in all, for twelve notches. The tips of four almonds and [the pointers of] eight discs are on twelve selected letters, and the lock at this juncture is open.

It is very clear that when the earring in the centre of the lid is turned to its right[6] the two halves



Figs. 163, 164, 165. (Reading top to bottom).



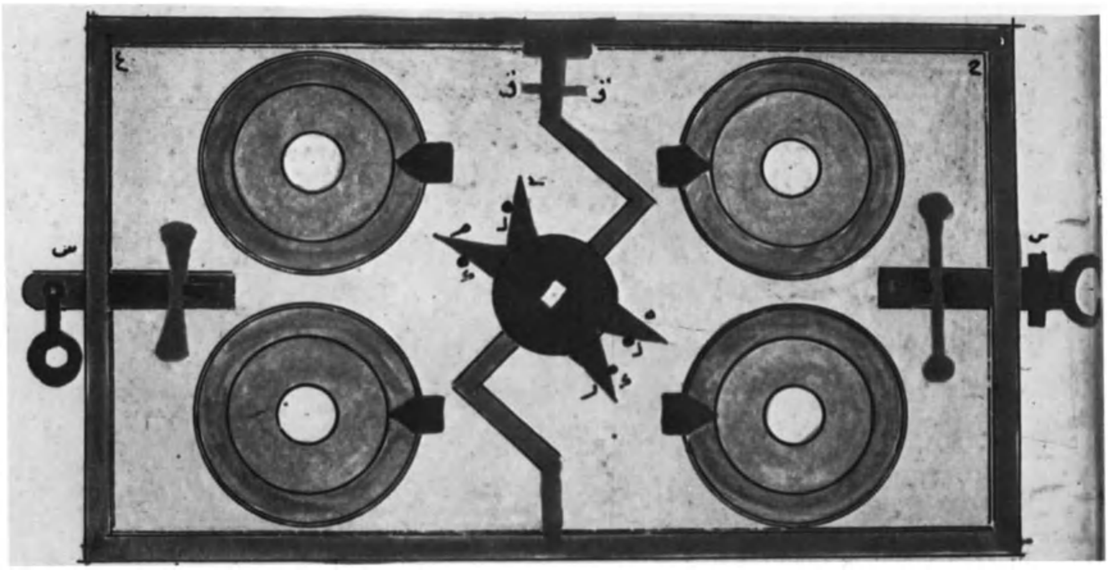
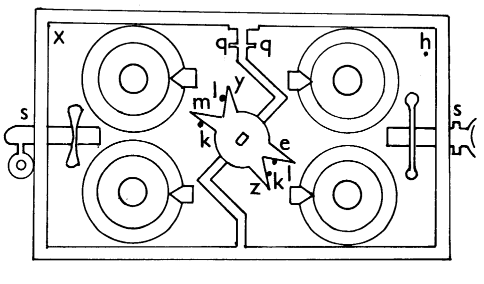


Fig. 166.



of the plate are joined together and the ends of the hooks are in the hole in the latch. The lock is [thus] closed. The tips of the almonds are moved away from the letters which they were on, so that the notches of the three discs go out of alignment from one another. Then, if the rings on the ends of the lid are pulled the lugs will not engage in the notches of the discs. The lock will therefore not open, unless the tips of the almonds are returned to the letters which they were on, bringing the notches into alignment. [Then if] the two rings are pulled the four lugs fixed to the two plates will enter the notches and the lock will open.

That is what I wished to describe clearly.

[Now] I will describe what I made, namely bolts on a door.

[4] Refer to notes.
[5] These lugs have already been described.
[6] To the left when viewing the lid from above.

Chapter 4 of Category VI

Which is four bolts on the back of a door. It is divided into two sections

Section 1

I will describe what I made – the appearance of the bolts and their functioning

They are four bolts made from wood or from iron, on the back of a door, but placed in four different positions. They are locked and opened by a key. One closes to the right, one to the left, another upwards and another downwards. There is no place in the four bolts through which an evildoer can enter. When the key is withdrawn from the hole in which it is inserted to open and close the bolts, the nearest point of the bolting mechanism cannot be reached by the hand to move the bolts up or down, right or left. They do not move, opening or closing, and nothing can move them except the key.

The construction: one takes two wooden bolts, slightly shorter than the width of the door, and two bolts slightly shorter than the height of the door. The bolts made for the width of the door should each be square in shape [i.e. in cross-section]. A mark is made at one third of its length and a mark is made 2 F from the other end. I specify that the thickness of the bolt is 4 F. Two cuts are made on the two marks for a depth of half the thickness of the bolt and what lies between

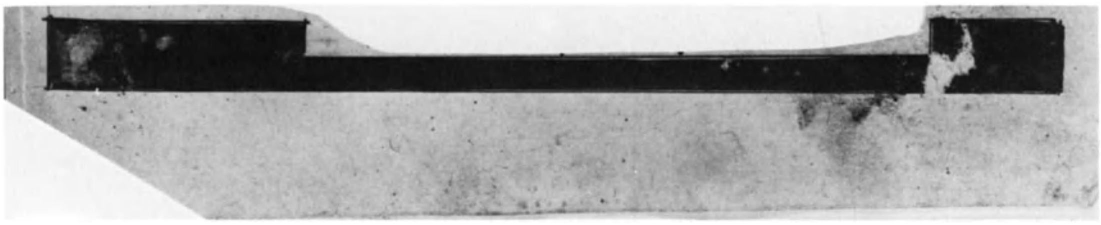


Fig. 167.

the two cuts is cut away from the bolt, so that it is recessed. This is its picture [Fig. 167]. The other bolt is made to the same pattern. The long bolts are each made 2 F thick and 4 F wide. About 10 notches, i.e. triangular teeth, are cut in its short side [lit. in its thickness]. This is the picture

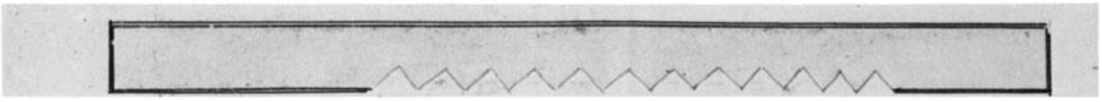


Fig. 168.

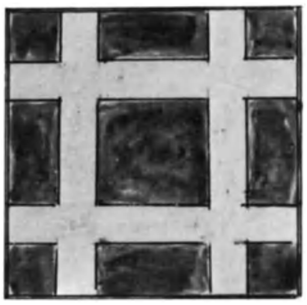


Fig. 169.

[Fig. 168] of one bolt – the remaining bolts are notched in the same way.

Then a wooden tray, called the beehive (*qafīr*) is made, 4 fingers[1] thick, and grooves are cut in it to take the bolts crosswise – this is its picture [Figs. 169, 170]. The positions of the long bolts are marked *q*, *m* and the positions of the short bolts *ṣ*, *x*. They [i.e. the short bolts] are on top of the long bolts, so that the short bolts on top of the long ones are flush with the face of the tray, or rather the face of the tray is slightly higher. The teeth of the bolts face the centre-point of the tray. This is a picture of the four bolts in the tray, in position on top of the tray [Fig. 170].

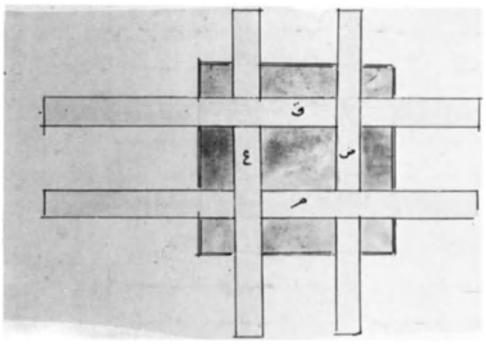


Fig. 170.

Section 2

Manufacture of the pulley (bakra) which opens and closes the bolts

A pulley is made from cast bronze, without a groove, and its perimeter is serrated with the file into triangular teeth with the same spacing as the teeth of one of the bolts. This pulley should be as thick as two bolts, i.e. 4 F. In the centre of this pulley a medium sized hole is made, around which is a short cylinder. A narrow slit is made along this hole. On the other side of the pulley [from the cylinder] is a projection like another pulley, smaller in diameter, $\frac{1}{2}$ F thick. Its perimeter

[1] This must mean 4 fingerlengths – see notes.

is toothed as in the drawing – this is the drawing of the pulley [Fig. 171] with teeth *b* on its circumference. The teeth of the small pulley are marked *a* and the hole with the narrow slit in it is marked *j*. When this pulley is placed in the centre of the tray between the four bolts its teeth mesh with the teeth of the four bolts. And when the key, which is an iron rod with a tongue (*s̲hazīya*) on it, is placed in the pulley hole, it goes right through the pulley, and [the tongue] fills the narrow keyway in the pulley's bore. When the key is turned the pulley rotates and pushes each bolt in one of four directions. The teeth of the small pulley at the back of the tray: – an iron blade (*mis̲hqāṣ*) is set against them, namely a sharpened bow-shaped strip with a hole in its end by which it is fixed by a nail to the back of the tray; the other end of the spring enters the teeth of the small pulley. Behind the blade is an opening. When the blade is pushed backwards its end comes away from between the teeth. There is a hole in the centre of the blade through which the key passes, pushing it [i.e. the blade] out of the teeth; when twisted it [i.e. the key] turns the pulley.

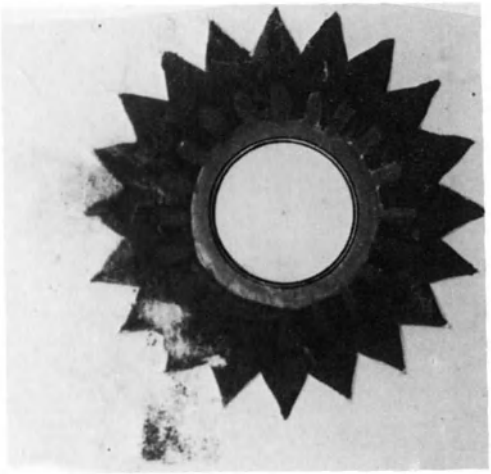


Fig. 171.

This is a picture [Fig. 172] of the blade and of the key and of the pulley in the centre of the tray, inside the bolts: the top *b* of the tray; the two long bolts *ḥ*, *m*; the two short bolts *d*, *z*; the pulley *w*; the blade on its own *e*; the key *a*.

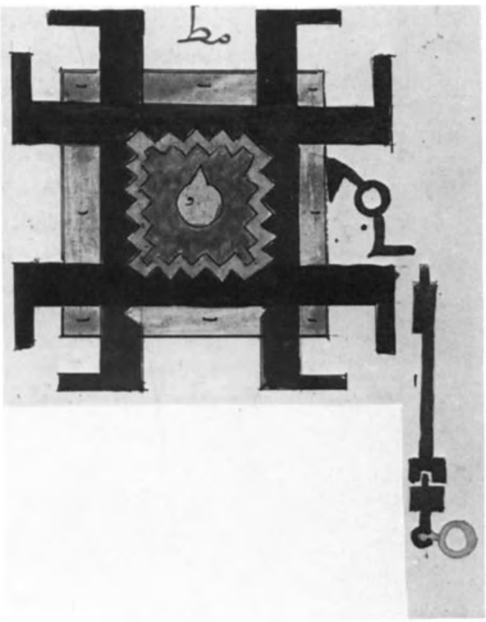


Fig. 172.

It is very clear that when the key is inserted in the hole in the pulley, bolt *ḥ* is pushed towards *ḥ*, bolt *m* is pushed towards *m*, bolt *z* is pushed towards *z* and bolt *d* is pushed towards *d*. The bolts are [then] closed – they open in the reverse [direction].

When that has been fabricated holes are made in the four corners of the tray. A hole is made in the centre of the back of the door, in which the cylinder fitted to the pulley can be fully inserted. It [i.e. the hole] is completed with a smaller drill than the first so that the key can be pushed through it into the door. Then the bolts and the tray are placed on the back of the door and the tray is fixed with four strong nails.

That is what I wished to describe clearly.

[Now] I will describe what I made, namely a handsome boat from which can be told the passage of a constant hour.

Chapter 5 of Category VI

It is a handsome boat from which can be told the passage of a constant hour. I will describe the outside appearance of the boat, and its functioning

It is a very handsome boat made of brass. In the boat is a man, standing and leaning on a handsome oar, the blade of which is on the floor of the boat and its upper end[1] in his left hand, across his chest. In his right hand is a pipe, its end in his mouth. In the floor of the boat is a drilled onyx bush, through which the water passes into the boat. When it is placed on the surface of the water it fills and submerges in the space of one constant hour. When it submerges the sailor plays the pipe. The water is emptied out of the boat's hull and placed [once more] on the surface of the water – and so on at every hour. I made that to do the duty of a *ṭarjahār*. Using a *ṭarjahār* requires persistence, to observe it while it fills. If the observer forgets about it, it may sink without him noticing, so he does not know how much time has elapsed. So I made this device so that he will know from the pipe that the boat has sunk, and will wake from his doze at the sound.

I will describe its construction: a boat is made from brass $1\frac{1}{2}$ sp. long and appropriate width, with a flat floor, and vertical sides, in the attractive semblance of a boat. Then a sailor is made, i.e. a copper shift with short skirt. Two legs are fixed to the skirt of the shift. To it [i.e. the shift] hands are fixed, the left hand holding the end of the oar across his chest, as if he were leaning on it. The blade of the oar is on the floor of the boat. A light, hollow head is made for him. In his neck a short pipe is placed on the end of which, inside the hollow of the head, is a pipe's ball. On his head is a round cap (*kumma*) in which there are five holes, spaced out and concealed by the cap's

Fig. 173.

[1] In the text the 'head' of the oar is in the boat, the 'lower end' in the man's hand. This is probably not a mistake – the 'business' end of a tool is considered as its head, and the handle as its lower end.

fold. A right arm is made for him, holding the pipe with its end in his mouth; the hole of his mouth and the hole in the pipe coincide. The sleeves of the shift are securely closed, as is the neck in the collar of the shift. Then this sailor is erected on the floor of the boat, taking care that he does not tilt the boat in any direction. Having made sure of that, one solders his feet securely to the floor of the boat. The blade of the oar is also soldered to the floor of the boat. The hem of the shift should be slightly below the rim of the boat.

When that is completed a hole is made in the floor of the boat and an onyx bush with a narrow hole is fitted to it. Then the boat is placed on the surface of the water and observed with a *ṭarjahār* or with a level gauge. The hole in the bush is made wider until the water which passes through it in one hour fills the boat until it sinks. I have shown the picture of the boat *l*, the sailor *s* standing in the boat, with a pipe *ṭ* in his mouth [Fig. 173].

It is very clear that the boat is placed on the surface of the water and the water enters the hole in the bush until the perimeter of the shift's skirt touches the surface of the water. The air in the hollow of the shift has no outlet, and when the boat sinks together with the sailor the air rushes through the neck into the whistle's ball, and this emits a whistling which wakes the sleeper from his light sleep. The height of the vessel in which the boat is placed, and the depth of water in the vessel are such that the sailor sinks as far as his shoulders. No more than that, otherwise the water will enter the whistle's ball and damage it. That is what I wished to describe clearly.

In this five chapters I have described roots which have many branches and great usefulness. When the descriptions are mastered, from them many more [things] may be created. I have omitted to mention many devices which I invented, for fear of obscurity or ambiguity. In what I have mentioned there is information for him who seeks information and profit for him who has zeal.

[End of Category VI]

[Concluding passage to the Oxford Graves 27 manuscript]

'This glorious work, combining theory and practice, useful for the manufacture of ingenious devices, written by Badīʿ al-Zamān Abū al-ʿIzz Ismaʿīl b. al-Razzāz al-Jazarī with the blessing of God, may He be exalted, was completed [i.e. the copying of it] at noon on Sunday the blessed, the 28th of excellent Ṣafar, one of the months of the Arabic year 891 [5th March 1486]. The date of the copy from which it was taken was 4.26 of the year 742 of the Hujra [9th October 1341].[1] Similar [copies] were made after that. This copy [i.e. the latter] is taken from a copy in the handwriting of the author – the letters and their variants, and the drawings of the devices are as he drew them with the ruler (*bi ḍabṭihi*) and freehand (*bi khaṭṭihi*) – the mercy of God, may he be exalted, be upon him. He completed [his work] on the 4th of Jumādā II, year 602 [16th January 1206].

[This copy] was completed by the hand of he who is humble before God may He be exalted, Muḥammad b. Muḥammad Abī al-Fatḥ b. ʿIsa al-Ṣūfī al-Kutubī al-Falakī [the astronomer], al-Shāfiʿī, al-Miṣrī [the Egyptian], may God be benevolent to him and to the Muslims, except for the pictures of living creatures.[2] Nor have I used the symbolic letters which occur in the copies: I have returned to the intended meaning and changed them into the common Arabic letters, useful for all [purposes]. Dominion is God's.'

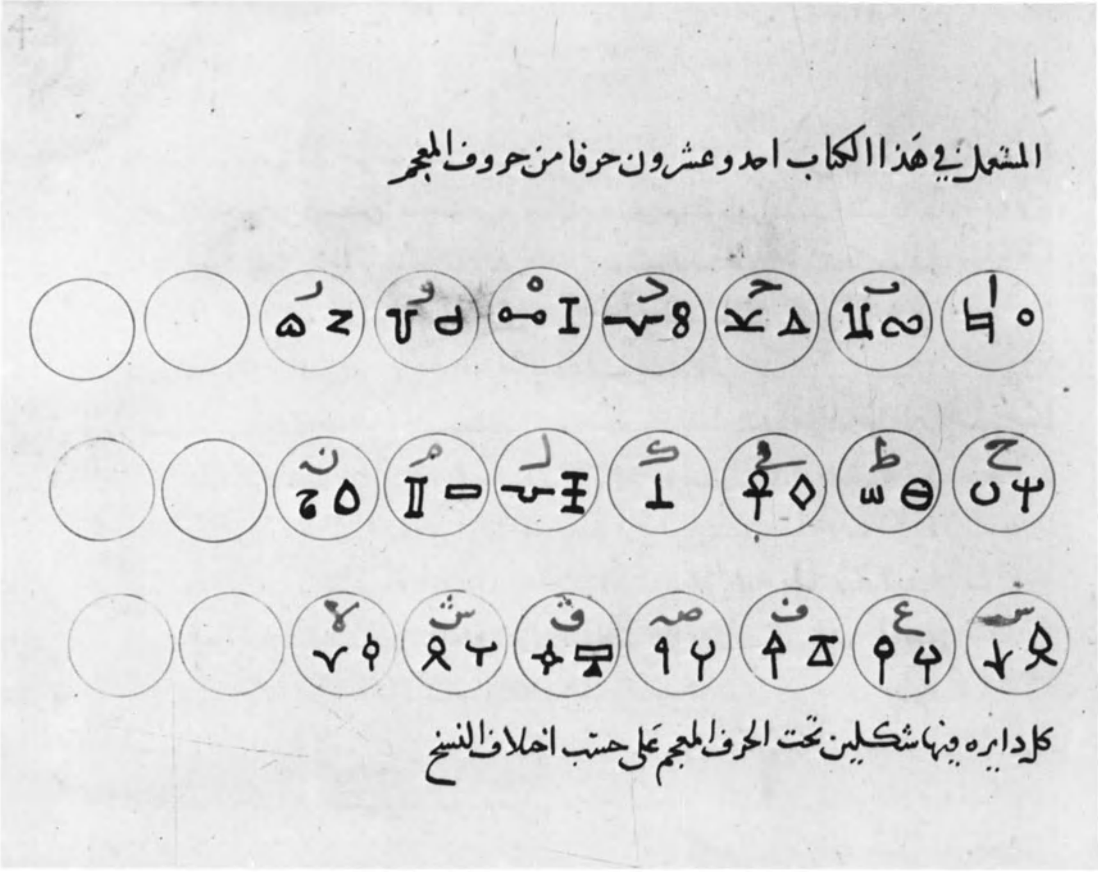


Fig. 174. Words above and below the circles read: 'Twenty-one letters of the alphabet are used in this book; in each circle there are two figures below the letter of the alphabet, according to different (ways) of transcription'.

[1] These dates are unusual. The use of the term 'Arabic' is rare, as is the expression of the date by '4.26' followed by the year, as in modern practice in the USA. This can only mean the 26th day of the 4th month, i.e. Rabīʿ II.

[2] *Khalā al-ṣuwar al-ḥayawāniya.* The scribe seems to be saying that he did not draw the representations of live creatures – the human and animal jack-figures. Presumably, on religious grounds, he delegated this to another – probably a Christian. Or perhaps he simply could not draw animals and people.

PLATES

Plate I – 1354 MS. *Main Illustration of the Castle Water-clock, Cat. I, Ch. 1. As Fig. 4.*
Courtesy, Museum of Fine Arts, Boston. Goloubew Collection.

ونصف ثم يثقب فى دايرارض النهر ٣٦٥ ثقبا بمثقب واحد وعمق واحد
متساوية البعد ثم يعتبر اى ثقب منها حاذى راس السرطان من فلك البروج
يعلم عليه علامة ظاهرة ثم يعد منه الى ل ثقبا على توالى البروج ويعلم عليه ايضا
علامة ويكتب بينهما برج السرطان و لذلك بمام البروج ويتخذ مسمار من
حديد فى احد طرفيه ثقب وليكن هذا المسمار ما ينزل فى كل واحد من
الاثقاب الى حد ثقب طرفه ضابطا مكانه هذا ما يحتاج اليه فى عمل الافلاك

Plate II – 1315 MS. *Zodiac from the Castle Water-clock, Cat. I, Ch. 1. As Fig. 33.*
Courtesy of the Smithsonian Institution, Freer Gallery of Art, Washington D.C.

Plate III – 1315 MS. *Main Illustration of the Water-clock of the Drummers, Cat. I, Ch. 2. As Fig. 34.*
Courtesy of the Smithsonian Institution, Freer Gallery of Art, Washington D.C.

اسفله بالقرب من ظهره ثقب مربع ليدخل فيه الفاضل من المحور
عن ارض الدكة وهو ايضا مربع ليتحرك المحور والكاتب معا
ولا يماس اسفل الكاتب ارض الدكة ويستر البكرات
الثلث من داخل المكبة بصفيحة فيها ثقبان يخرج فيهما الثقالة
والكرة ويلصق بحالها مع المكبة وهذه صورة المكبة وفيها
البكرات والكاتب على الدكة

الفصل السادس في

كيفيه عمل الفيال وعمل
ما يحرك يديه في باطن
صدر الفيل تتخذ من النحاس
كهيئة قميص مقص الذيل
والكمين قايم على ذيله ثم
تتخذ راس الفيال على حلقه
رووس اهل الهند كثير شعر
الراس واللحية وتوضع رقبته
في جنب القميص ويلصق من
داير الجيب ويعمل له يد يمنى
الى حد العضد وفيها فاس لطيف
خفيف ويثقب مرفقه عرضا وشقب كم القميص عند موضع
المرفق من الجهتين عرضا ويدخل العضد في الكم حتى يحادي
ثقب المرفق بهي الكم ويدخل فيهما محور ويلصق طرفاه في كم

Plate IV – 1315 MS. *Scribe from Elephant Water-clock, Cat. I, Ch. 4. As Fig. 51.*
Courtesy, L. A. Mayer Memorial for Islamic Art, Jerusalem, Israel.

Plate V – 1315 MS. *Mahout from the Elephant Water-clock, Cat. I, Ch. 4. As Fig. 52.*
Courtesy of the Metropolitan Museum of Art, Rogers Fund, 1955.

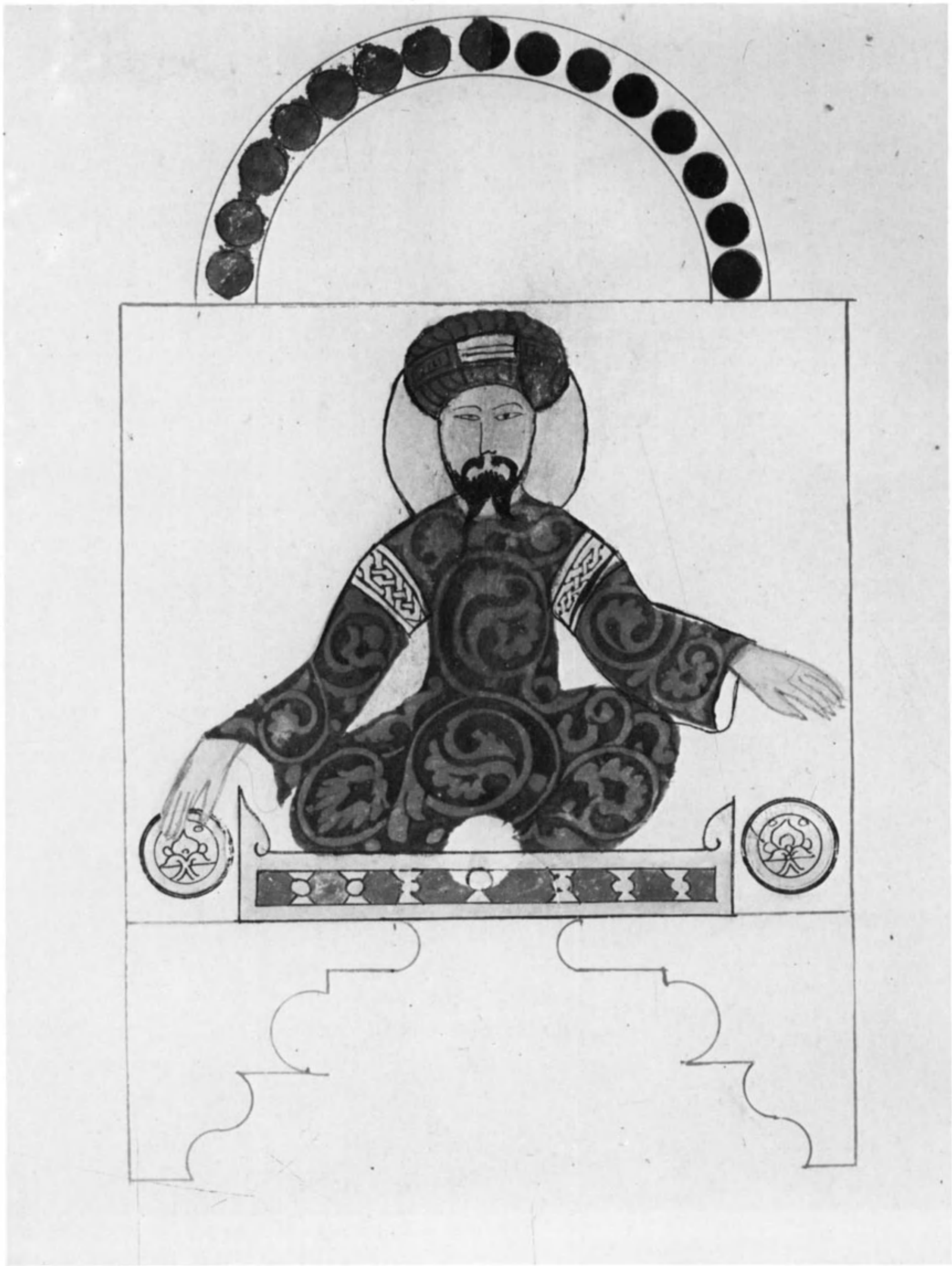


Plate VI – 1354 MS. *Man on Balcony from Elephant Water-clock, Cat. I, Ch. 4. As Fig. 59.*
Courtesy of the Smithsonian Institution, Freer Gallery of Art, Washington D.C.

Plate VII – 1354 MS. *Main Illustration of the Beaker Water-clock, Cat. I, Ch. 5. As Fig. 60. Courtesy, Museum of Fine Arts, Boston. Goloubew Collection.*

Plate VIII – 1315 MS. *Internal details of the Beaker Water-clock, Cat. I, Ch. 5. As Fig. 62. Courtesy, Mr. H. P. Kraus, New York.*

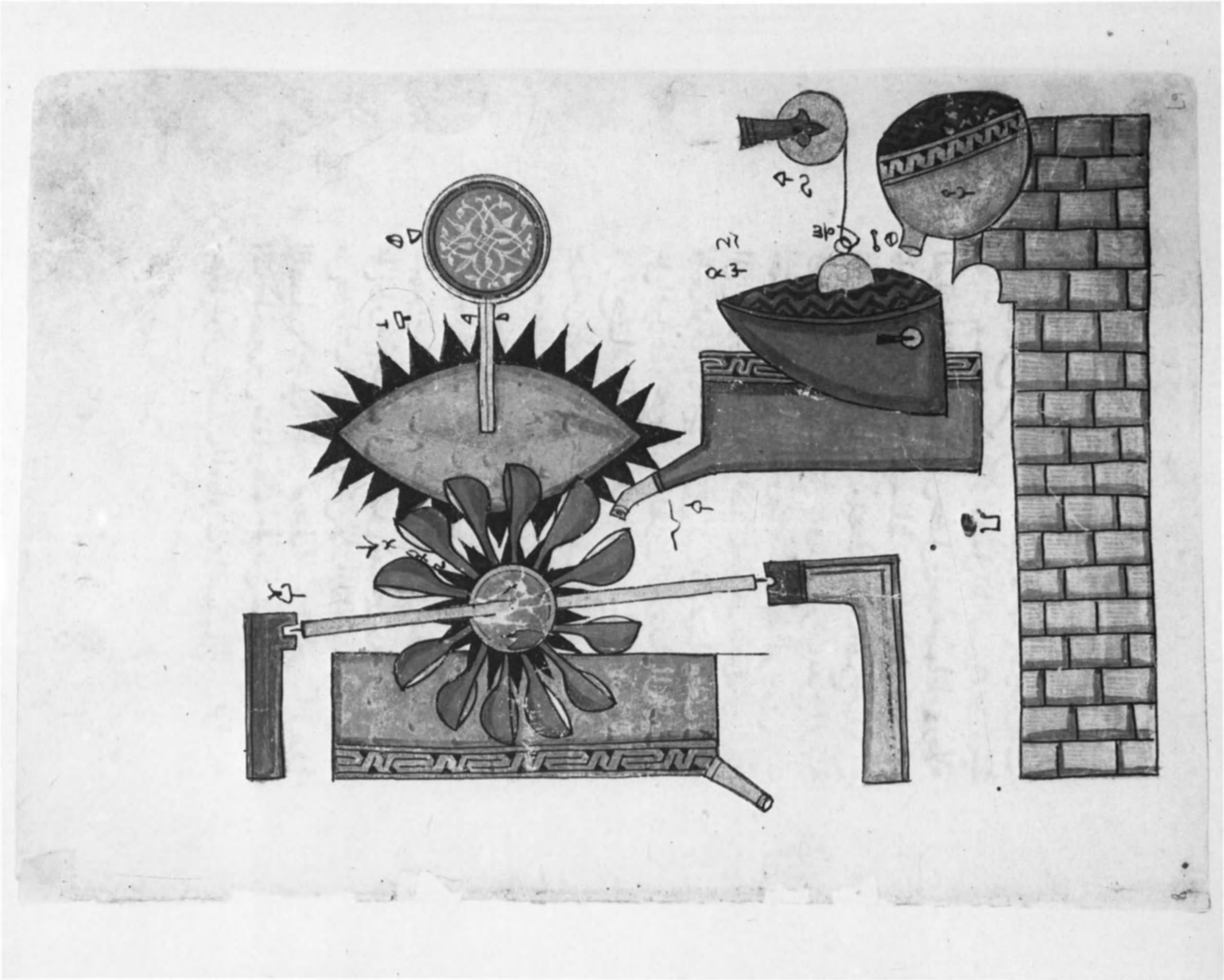


Plate IX – 1315 MS. *Details of Water Equipment of the Peacock Water-clock, Cat. I, Ch. 6. As Fig. 66.*
Courtesy, Mr. H. P. Kraus, New York.

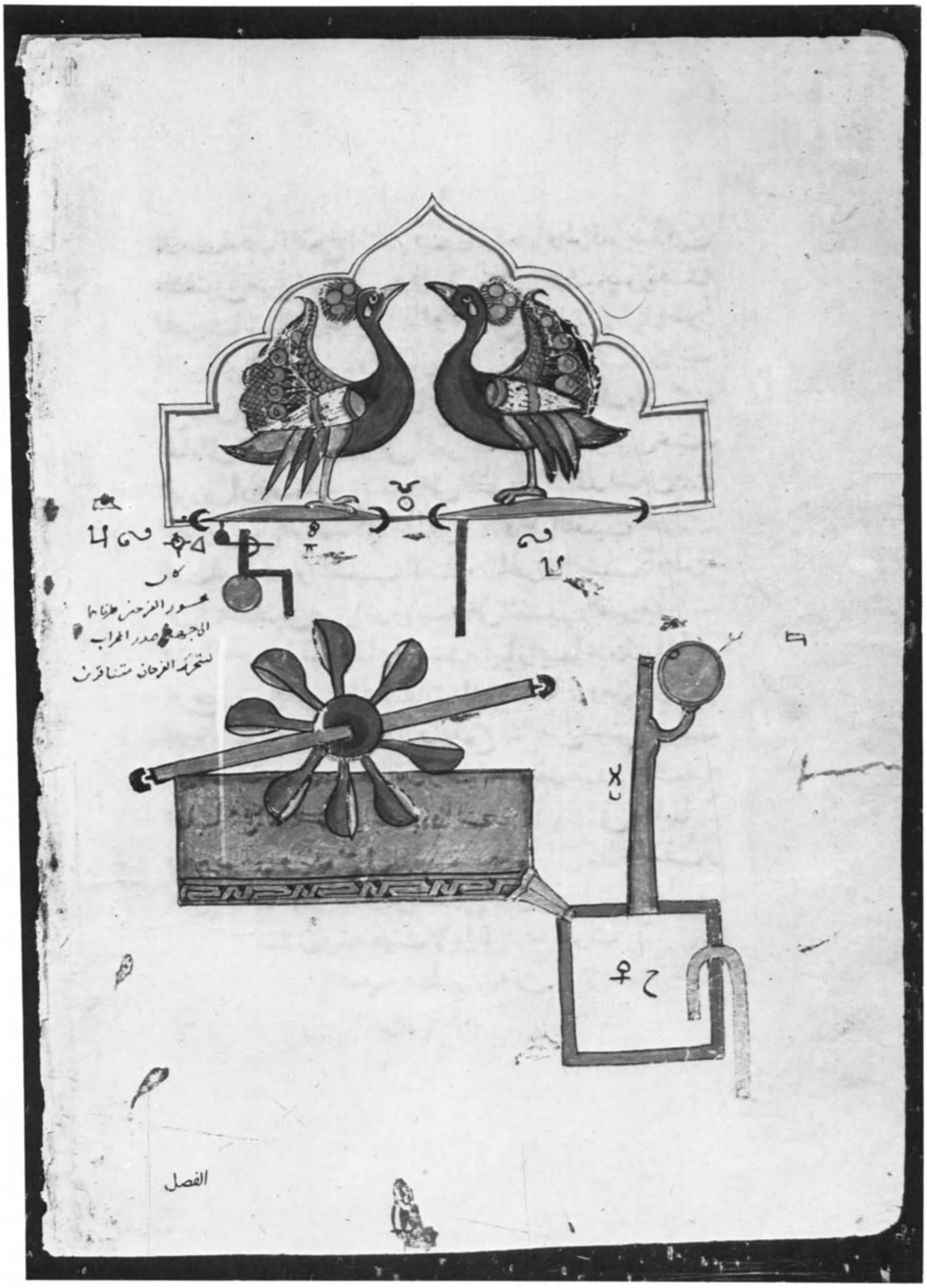


Plate X – 1315 MS. *Details of operation of chicks, Peacock Water-clock, Cat. I, Ch. 6. As Fig. 67. Courtesy of the Metropolitan Museum of Art, Rogers Fund, 1955.*

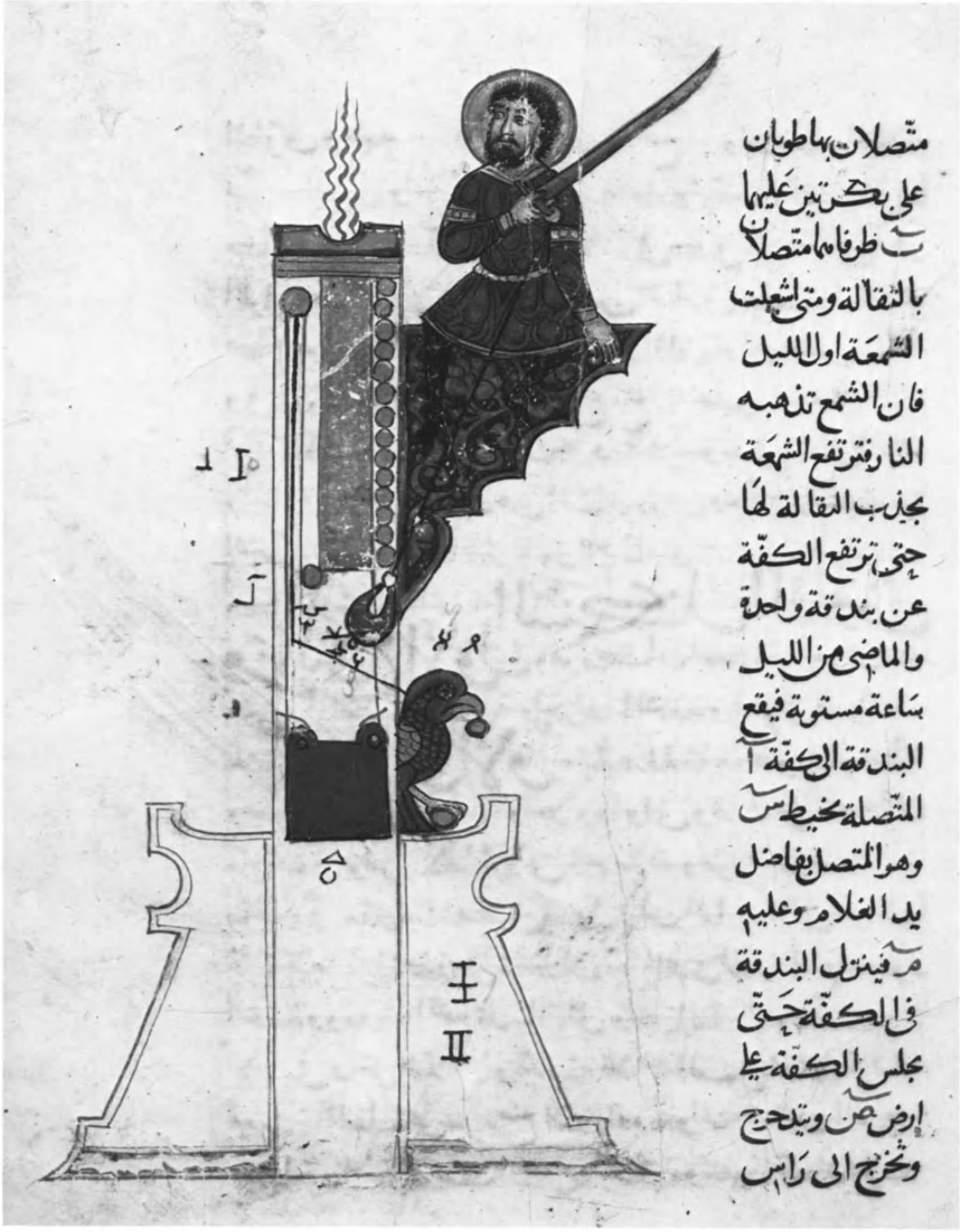


Plate XI – 1315 MS. *Main Illustration of the Swordsman Candle-clock, Cat. I, Ch. 7. As Fig. 74. Courtesy of the Smithsonian Institution, Freer Gallery of Art, Washington D.C.*

Plate XII – 1315 MS. Main Illustration of Wine Goblet, Cat. II, Ch. 1. As Fig. 80.
Courtesy of the Metropolitan Museum of Art, Rogers Fund, 1955.

Plate XIII – 1354 MS. *Main Illustration of the Castle Wine Dispenser, Cat. II, Ch. 3. As Fig. 82. Courtesy, Coll. Edwin Binney, 3rd. Boston.*

Plate XIV – 1315 MS. *Main Illustration of Boat, Cat. II, Ch. 4. As Fig. 87.*
Courtesy of the Smithsonian Institution, Freer Gallery of Art, Washington D.C.


وان شاء مورد صرف وان شاء اصفر صرف وان شاء احمر صرف
وان شاء نصب من كل لون من الاربعة ممزوجا نصفه شراب
ونصفه ماء وان شاء فثلث شراب وثلثان ماء وان شاء
خمس شراب واربعة اخماس ماء وبحسب اختياره وهذه صورة
ظاهر الباطية بالغطاء والبزال والكعب ٥

الفصل الثاني في كيفية عمل الباطية ٥
تتخذ من الشبه باطية كبيرة جالسة على كعب طوله شبر
ونصف وتتخذ للباطية غطاء كالقبة وعلى القبة كرة مقطعة

Plate XV – 1315 MS. *Main Illustration of the Dispenser for different liquids, Cat. II, Ch. 5. As Fig. 88.*
Courtesy of the Smithsonian Institution, Freer Gallery of Art, Washington D.C.

جنية مقلبه وعلى طرفه
ط وقد ارتفع كاس ك
الى ان صارت حافته
بين شفتي النديم
واندفع راسه الى ورايه
قليلا بالكاس ثم
ينصب الشراب من
طرف مقلب ط الى
قمع ج ويجتمع في حوض
ب ثم يجف حتى ر وفيه
من الشراب بقية
تخرج من المقلب فيرتفع
وتنحط اليد والكاس وعند مفارقة حافة الكاس شفة النديم
يعود راسه الى قدامه بسرعة ويخدم به مرارا ويستقر واما يده
اليسرى وعليها س فانها تنحط كلما ارتفع الشراب في حوض ب
ورفع العوامة وعليها ع والخيط المتصل بها وهو ملوى على بكرة
تحت كتف النديم وعليها ه ثم يلوى تحت بكرة اخرى
وعليها م وهي تحت طرف مرفق اليد ويرتفع الى فوق ويتصل
بثقب ص والنيلوفرة تنحط باليد وعليها ى حتى يكون اسفل
ساقها بماس فخذ النديم ولا يزال كذلك حتى يرتفع الشراب في
حوض ب الى ان يقارب جنية مقلب الحوض وعليه ن فحينئذ

Plate XVI – 1315 MS. *Details of internals of Slave, Cat. II, Ch. 6. As Fig. 97.*
Courtesy of the Metropolitan Museum of Art, Rogers Fund, 1955.

Plate XVII – 1315 MS. Main Illustration of Man with Goblet, Cat. II, Ch. 8. As Fig. 99.
Courtesy, Coll. Edwin Binney, 3rd. Boston.

Plate XVIII – 1315 MS. *Main Illustration of the two Shaykhs, Cat. II, Ch. 9. As Fig. 100. Courtesy of the Smithsonian Institution, Freer Gallery of Art, Washington D.C.*

Plate XIX – 1354 MS. *Otherwise as Plate XVIII.*
Courtesy, Museum of Fine Arts, Boston. Ross Collection.

Plate XX – 1315 MS. *Main Illustration of the Servant Girl, Cat. II, Ch. 10. As Fig. 102. Courtesy Mr. H. P. Kraus, New York.*


من سرّتها قضيب
ينفذ من ظهرها في خرق
مستطيل وطرفه معطوف
إلى أسفل وعليه ب
وهو مطروح على سفود
معارض عليه د وحوض
الكفة والكفة وعليها ه
وفيه أنبوب ينصب منه
الشراب إلى القدح وعليه و
وخزانة الشراب وفي أسفلها
ثقب عليه أنبوب يقطر
منه الشراب إلى الكفة وعليه
ر ومصب الشراب في
أعلى الخزانة وعليه ك
فمن الواضح الجلي أنه متى ملئت

Plate XXI – 1354 MS. *Otherwise as Plate XX.*
Courtesy of the Fogg Art Museum, Harvard University. Wetzel Bequest.

Plate XXII – 1315 MS. Main Illustration of Phlebotomy Measuring Device, Cat. III, Ch. 6. As Fig. 115. Courtesy of the Smithsonian Institution, Freer Gallery of Art, Washington D.C.

Plate XXIII – 1354 MS. *Otherwise as Plate XXII.*
Courtesy, Museum of Fine Arts, Boston. Ross Collection.

Plate XXIV – 1315 MS. *Main Illustration of the Peacock Hand-washing Device, Cat. III, Ch. 9. As Fig. 118. Courtesy, the Cleveland Museum of Art, J. H. Wade Fund.*

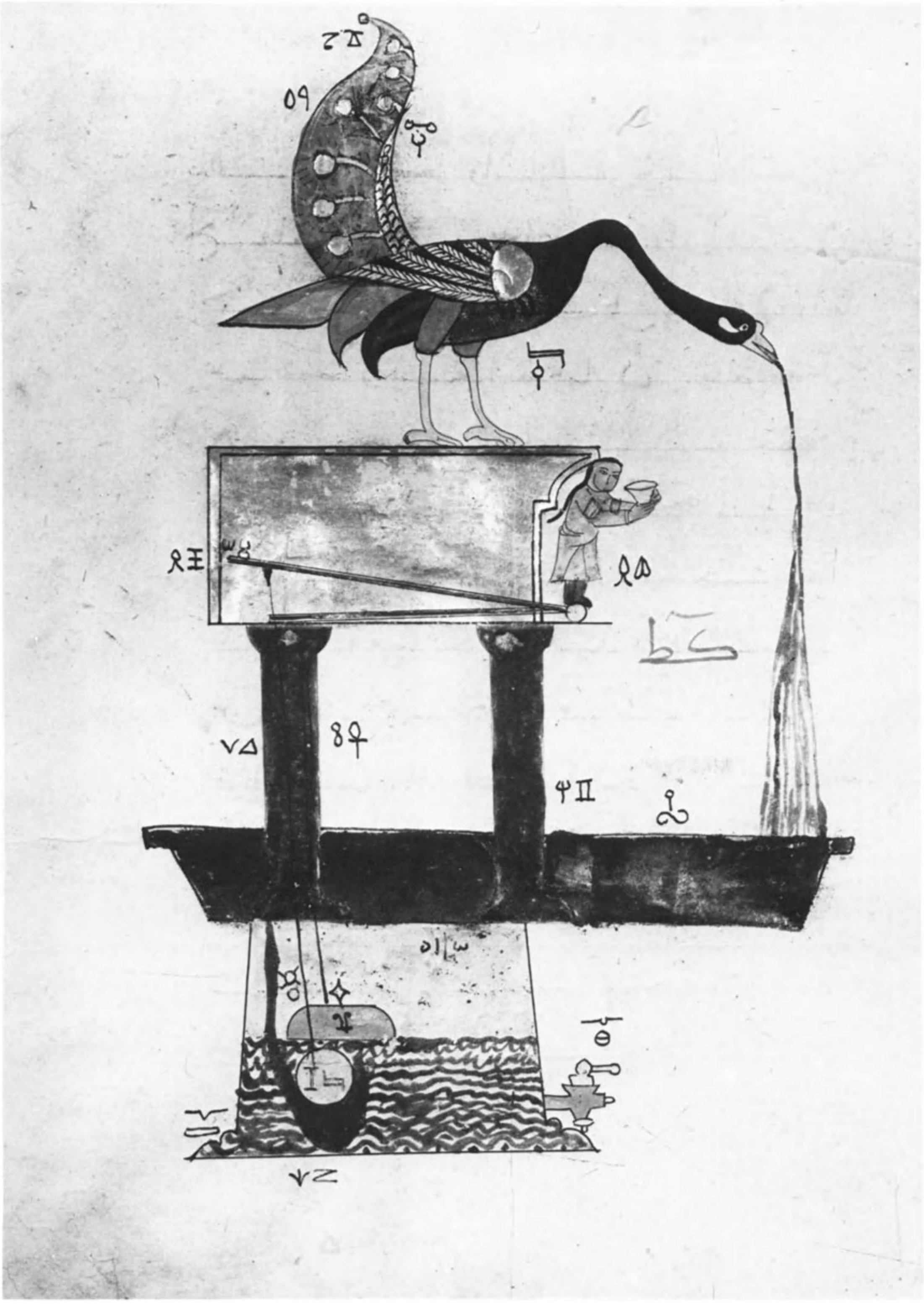


Plate XXV – 1354 MS. *Otherwise as Plate XXIV.*
Courtesy, Museum of Fine Arts, Boston. Goloubew Collection.

Plate XXVI – 1315 MS. Main Illustration of Servant with Pitcher and Basin, Cat. III, Ch. 10. As Fig. 119.
Courtesy of the Smithsonian Institution, Freer Gallery of Art, Washington D.C.

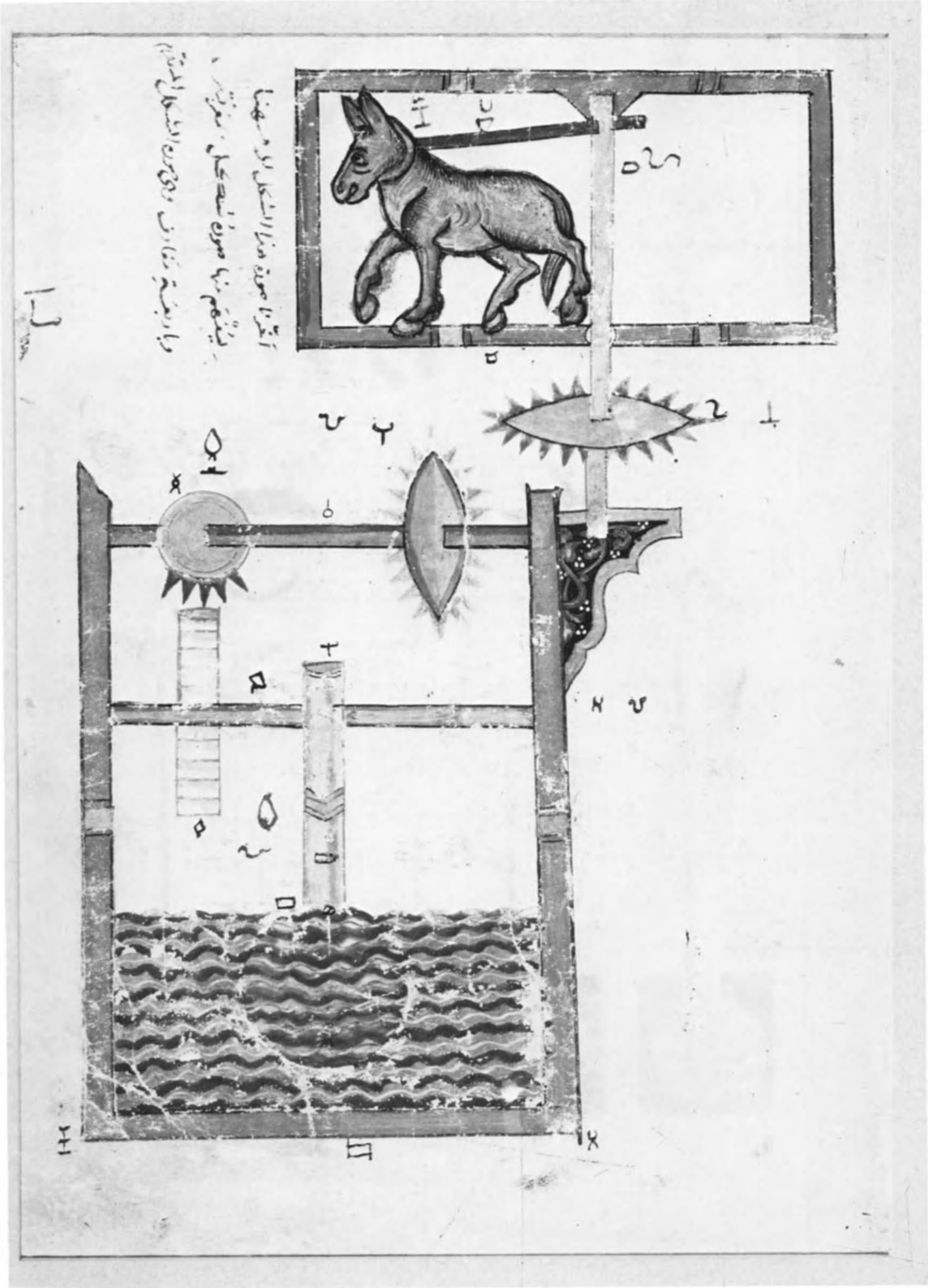


Plate XXVII – 1315 MS. *Main Illustration of Water-raising Device, Cat. V, Ch. 1. As Fig. 134.*
Courtesy of the Metropolitan Museum of Art, Rogers Fund, 1955.

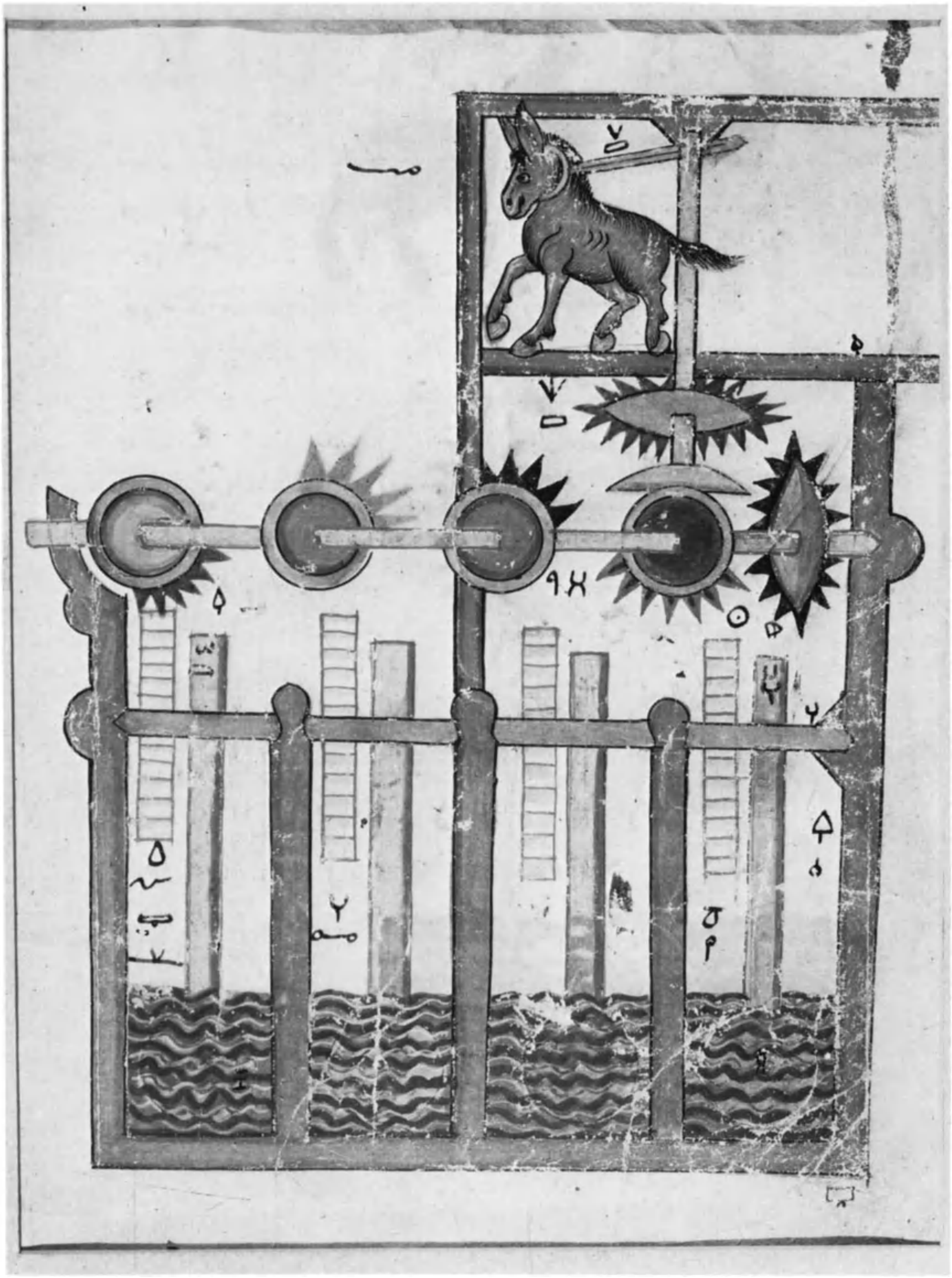


Plate XXVIII – 1315 MS. *Main Illustration of Water-raising Device, Cat. V, Ch. 2. As Fig. 135. Courtesy of the Metropolitan Museum of Art, Rogers Fund, 1955.*

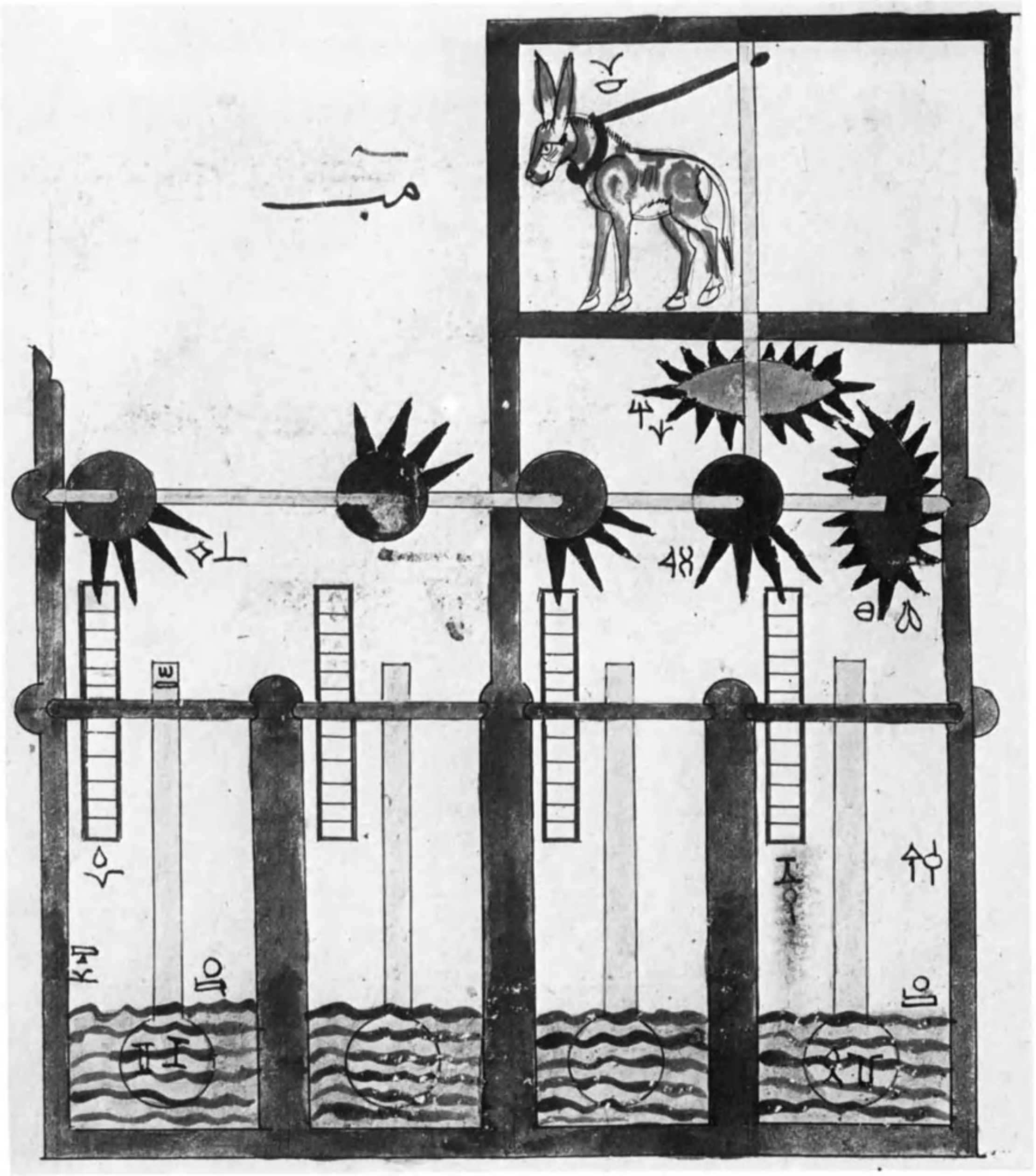


Plate XXIX – 1354 MS. *Otherwise as Plate XXVIII.*
Courtesy, Museum of Fine Arts, Boston. Harvey Wetzel Fund, Goloubew Collection.

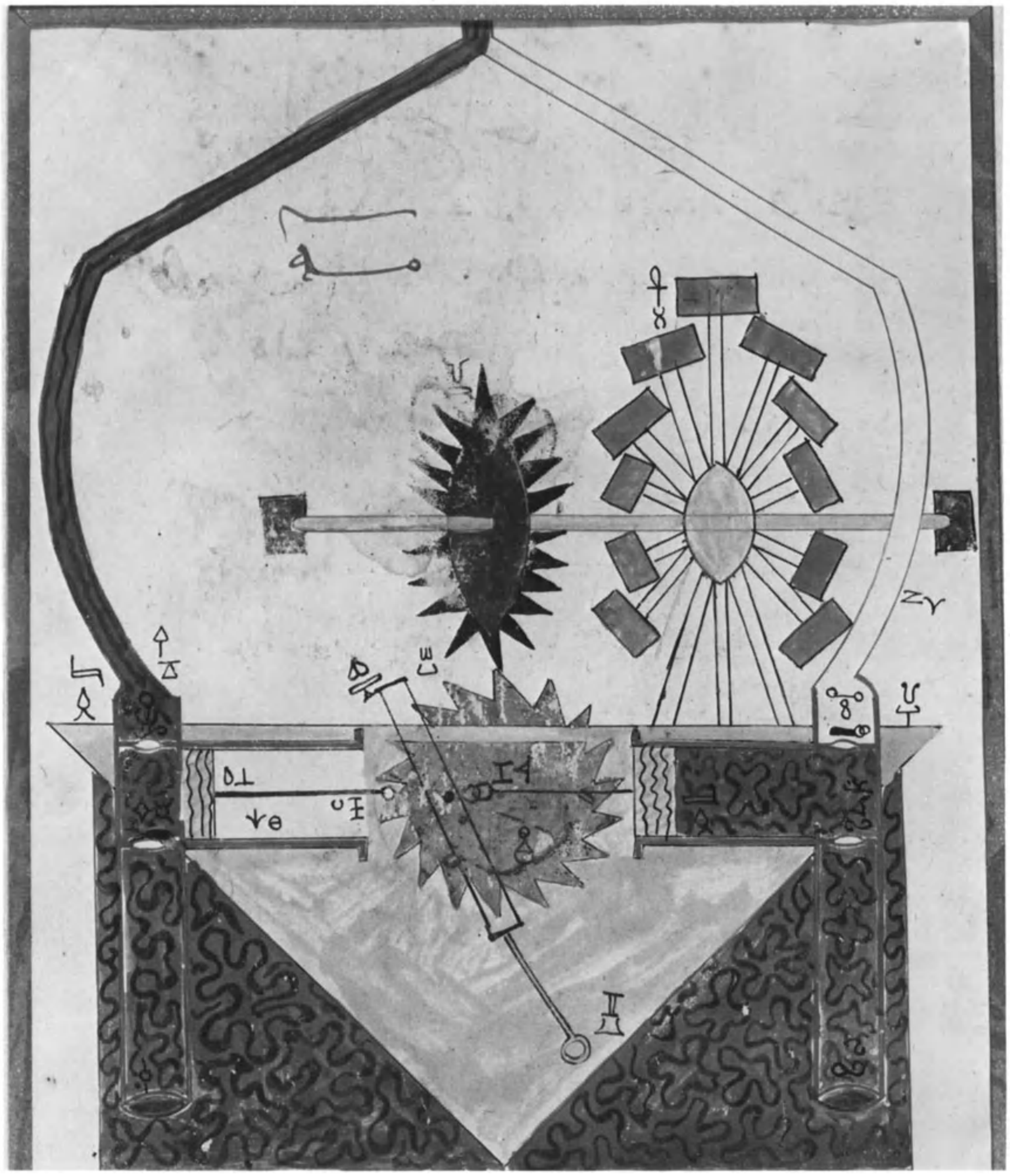


Plate XXX – 1354 MS. *Main Illustration of Pump, Cat. V, Ch. 5. As Fig. 141.*
Courtesy of the Fogg Art Museum, Harvard University. Bequest of Meta and Paul J. Sachs.

Plate XXXI – 1354 MS. *Main Illustration of Boat Clock, Cat. VI, Ch. 5. As Fig. 173. Courtesy Mr. H. P. Kraus, New York.*

Plate XXXII – Illustration of a device of unknown purpose, from the Graves 27 MS., *Folio 94 Recto.*

Part III

Notes

TRANSLITERATIONS

ع	ط	ص	ش	س	ز	د	ح	ج	ب	ا
x	ṭ	ṣ	sh	s	z	d	ḥ	j	b	a

لا	ى	و	ه	ن	م	ل	ك	ق	ف
p(la)	y	w	e	n	m	l	k	q	f

The 21 letters of the Arabic alphabet used by al-Jazarī, with the Roman equivalents used in the translation. Note that the consonantal points are usually omitted from the letters shown on the drawings.

ز	و	ه	د	ج	ب	ا
7	6	5	4	3	2	1
ن	م	ل	ك	ى	ط	ح
50	40	30	20	10	9	8

Numerical equivalents of Arabic letters, up to a value of 50. This system is known as abjad. For intermediate values the number is written, right to left, in tens and units. Thus 26 is written:

كو

Each chapter has one main drawing, and these are numbered in sequence from 1 to 50, in abjad. The letters are usually large and prominently displayed.

EXPLANATORY NOTES

Chapter 1 of Category I

GENERAL DESCRIPTION (FIGS. 1.1–1.6)

The clock consists of a house about 10 feet square by $11\frac{1}{2}$ feet high in which a screen of brass or wood, $7\frac{1}{2}$ feet high and $4\frac{1}{2}$ feet broad is installed. Doubtless the screen was pre-fabricated in the workshop. Apart from the spheres of the Zodiac, sun and moon, all the audible and visible means for recording the passage of the hours are located on this screen, while the machinery for operating them is contained inside the house.

The motive power for all the devices is supplied by the gravitational flow of water, this flow being constant during any given day or night. The driving mechanism is based upon a reservoir tank which is connected by a tap and conical valve to a float chamber, in which the head of water remains constant. The float chamber is in turn connected to a flow regulator. The purpose of the latter instrument is to vary the flow day by day, and from daytime to night time.

There are always twelve equal daylight hours and twelve equal hours of darkness, although the periods of day and night vary throughout the year. For instance, in the latitude of al-Jazarī's workplace (36°) on Midsummer's day, there are $14\frac{1}{2}$ hours each 60 minutes long during the day and $9\frac{1}{2}$ during the night. Therefore the same quantity of water must all flow out in the $14\frac{1}{2}$ daylight hours as flows and during the $9\frac{1}{2}$ hours of night, and similarly for the two divisions of the day at any time of the year. The drive for the various devices is supplied from two sources: the steady descent of the float in the reservoir and the steady stream of water from the outlet hole in the face of the flow regulator.

From the ring in the float strings are passed over small pulleys in the roof and thence to two large driving wheels mounted on shafts (or perhaps only one – see notes to Section 10). The upper of these two shafts turns the discs which represent the Zodiacal signs, the sun and the moon. The lower shaft turns a wheel which turns a disc, which uncovers, one by one, twelve glass roundels set in a semi-circular arc in the face of the screen. Every hour one disc is uncovered, allowing light to shine by night from lamps inside the house, until by daybreak all the twelve are unveiled. The lower shaft, by means of a string passing from the front disc over a small pulley, also draws a wooden vehicle (the 'cart') horizontally across the face of the screen. The cart carries a small gold crescent across the front of twelve small single-leaved doors, set in a horizontal line across the face of the screen. This crescent, which is connected to the cart through a slit in the screen, passes one door every hour. Above these doors is a second row of double-leaved doors. At each side of the screen, below the first row of doors, a brass falcon sits on a perch, in an alcove shaped like a prayer-niche (*miḥrāb*).

The cart carries a long vertical iron rod which, every hour, trips a mechanism above one of the upper doors. This mechanism activates several devices: the upper doors open, revealing the figure of a man; the lower doors turn on a horizontal axis through 180°, changing colour, since the rear surface is a different colour from the front; each of the falcons leans forward, raising its wings and lowering its tail, and a ball drops from its beak on to a cymbal contained in a brass vase in front of and below the falcon.

The stream of water falls on to a plate, shaped like a shallow pan, whence the water flows through a pipe into one of three divisions of a trough. At the sixth hour of the day a valve in this division is lifted by a string operated from the sixth of the upper doors (see above) and the water flows out into the base of the main trough, and thence through a pipe on to a water wheel. The shaft of this wheel carries iron pegs which operate the arms of the two drummers and cymbalist which are situated in front of the screen. The water from the wheel falls into a trough and is then conducted by a short pipe into an air vessel provided with a mechanical flute and a siphon. The end of the flute is set in the wall between the figures of two trumpeters, also situated in front of the screen. The air driven from the vessel operates the flute and the sound 'is believed to come' from the trumpeters. When the water reaches the elbow in the siphon, which is just below the lid, it drains out and runs into a storage cistern set in the floor.

Layout of Equipment (Figs. 1.1, 1.2, 1.3)

Some of the essential date for reconstructing the equipment layout were provided by al-Jazarī: – dimensions of reservoir and float chamber, diameter of flow regulator and driving wheels, width of screen. (As al-Jazarī says, the distance of descent of the float in the reservoir must be equal to the semi-circumference of the driving wheels and the distance travelled by the cart.) The capacity of the water vessels, but not their separate dimensions, were calculated from the amount of water which they must hold. Other dimensions, and the relative positions of the various pieces of equipment, were determined by using known dimensions and known datum points. The method was as follows: the air vessel was sized, knowing that it must contain a quarter of the daily flow from the reservoir. It had to be located near the screen, not far from the position of the trumpeters, and slightly above ground level to allow the siphon to evacuate the vessel on to the ground. The water wheel was located from two fixed datum points – its trough had to be above and close to the air vessel, and its axle must run close to the screen behind the drummers and the cymbalist. The divided trough had to be above the water-wheel, the centre-line of its outlet pipe in the same plane as the wheel, and high enough above the wheel for the impact of the water to turn it with adequate velocity. The dished plate had to be above the divided trough, its pipe able to discharge into any of the three divisions. The plate was then located beneath the outlet from the flow regulator, which automatically set the position for the float chamber and reservoir. (The process is not quite so simple as it sounds, since it is more difficult to locate the pieces in plan than in elevation, and care had to be taken to avoid moving parts and to allow room for supports, brackets etc.).

It will be noticed that al-Jazarī did not size his house at random – the entire height is needed to obtain the necessary fall of water through the system, and half the width and half the depth for fitting in the equipment. The rest of the space, apart from reasons of symmetry, was needed as working room for the operator.

For two relatively unimportant items, the sizes and locations cannot have been exactly as described and drawn in the manuscript. First, *miḥrābs* with the dimensions given (2 spans high by 1 span deep) cannot be fitted in at all between the semi-circle of roundels and the side of the screen. Perhaps some of this area was completed by decoration. Nor can the base of the *miḥrābs* be in line with the horizontal diameter of the semi-circle, as shown in Fig. 4, as they would then be too small to carry falcons of effective size. In Fig. 1.1 and 1.2 the semi-circle of roundels has therefore been lowered somewhat. Secondly, the 'spheres' cannot have their 'horizon' just above the top of the screen, again as shown on Fig. 4, because the timbers carrying the balls are also above this level, and they would then be visible, right across the face of the spheres. (The spheres cannot be nearer the wall than these timbers, as the lower semi-circle of their discs would foul the cart track and doors.) As shown in Figs. 1.1 and 1.2 the spheres must have been near the top of the house, with a semi-circular hole cut in the wall to allow them to be seen. No doubt the artist felt that the proportions were more aesthetically satisfying in his painting. The problems of arriving at a practical layout from al-Jazarī's description and drawings merited the foregoing discussion, particularly in this case, which is probably the most complex of his designs. For the remainder of this work the solution of these problems was achieved by a similar methodology, and it was not therefore considered necessary to include a similar discussion for each chapter, but only to indicate discrepancies and points of especial interest or difficulty.

Section 1

The introduction describes al-Jazarī's attempts, derived from the work of his predecessors, to design an instrument for regulating the outflow of water, by moving the position of the water outlet in a circular or semi-circular path. The passage is interesting, in that it reveals the dominance of attitudes of mind conditioned by astronomical ideas. All these instruments, including the one finally adopted by al-Jazarī, resemble astrolabes, and the assumption was made that there must be a direct mathematical correlation between the solar clockwork and the instrument measuring it.[1] In fact, as will be seen in the notes for Sections 3, 4 and 5, there is

[1] The equally divided circle embodies two errors: first that the flow varies directly with the static head; secondly, that the variation of daylight hours against the calendar follows a sine curve.

none. To obtain a working flow regulator, al-Jazarī had to resort to empirical methods, but he still retained the circular pattern, although a linear instrument would have been simpler to construct.

The second part of Section 1 is covered by the General Description at the beginning of these notes, and by the explanatory drawings. Al-Jazarī's description is clear and straightforward.

Sections 2–5 (Figs. 1.1, 1.2, 1.3, 1.4)

In these sections the basic water equipment, providing the motive power for the whole device, is explained. The text exemplifies admirably the main characteristics of al-Jazarī's descriptive abilities: on the one hand a careful description of the processes of manufacture, emphasising the really significant points, and a clear presentation of the functioning of the individual items, both singly and in relationship to one another; on the other hand, carelessness about the transmission of dimensions, and confusion in the presentation of mathematical data.

In Section 2 the manufacture of the reservoir vessel, with float and tap, and the float chamber with its float and valve plug are clearly described. Considerable care was taken to ensure that the reservoir had a uniform circular cross-section, by using a perfectly round wooden template, with a final check by pouring a measured quantity of water between a series of graduated divisions. The size of this vessel, however, is given as 6 spans high by $1\frac{1}{3}$ spans diameter in one passage, and 7 spans high by $1\frac{1}{4}$ spans diameter in another. Also, the hourly rate of flow is given as 5 *kayl* at the beginning of the section, thereafter as 10.

Al-Jazarī obviously took great care that the plug fitted properly into the valve-seating, so that the joint was watertight, while the plug was free to move.

Section 3 describes the fabrication of the flow regulator, which should be readily understood from al-Jazarī's text and illustrations, in conjunction with Fig. 1.4.

Section 4 gives the assembly of the three pieces of equipment – reservoir, float chamber, and flow regulator. The figure of 4 spans given for the height of the base of the reservoir above floor level is certainly too low. The height of the float chamber is $1\frac{1}{2}$ spans which is roughly correct (see below) and the lowest point of the water outlet is $4\frac{1}{2}$ fingers below the float chamber, and therefore 1.9 spans below the tap in the reservoir. If the tap is $\frac{1}{2}$ span above the base of this vessel the water outlet is therefore 1.3 spans below this point. This leaves only 2.6 spans, or about 26 inches from outlet point to ground level. In Section 8 the various mechanisms operated by the fall of water are described, and it will be seen that it would have been impossible to fit all of these into a distance of 26″. In Figures 1.1 and 1.2 the height of the bottom of the reservoir is shown at a little more than 6 spans – about 62.5 inches. By careful arrangement it might have been possible to reduce this a little, say to $5\frac{1}{2}$ spans, but no more.

The description otherwise requires little comment. What we have is a reservoir containing a set quantity of water which all flows out during the hours of daylight, and again in the hours of darkness, for any given day in the year. The float on top of the reservoir, which actuates all the mechanisms, directly or indirectly, thus always falls through the same distance on any day. On any given day the static head of water above the outlet is held constant by the float chamber: as water enters this chamber from the reservoir, the level rises and the plug in the float in the chamber stops the tap from the reservoir. When water runs to the outlet in the flow regulator, the level in the float-chamber falls, and the tap is opened. A closed loop is therefore in operation, and the level in the float chamber fluctuates only slightly. The method for varying the flow day by day is described below, under Section 5.

In Section 5 al-Jazarī describes the method he used for varying the flow from the water outlet from day to day in the year, and between daytime and nighttime on a given day. For example, at the summer solstice his day was $14\frac{1}{2}$ long, his night $9\frac{1}{2}$ hours, while at the equinox both day and night are 12 hours long. But for all these periods, and for intermediate days, the total outflow Q must be constant. He had prescribed Q, and first divided this by $14\frac{1}{2}$ to give the hourly flow for the daylight hours at summer solstice – the first point of Cancer. He then took a piece of onyx with a small hole drilled through it and set it over the water outlet which was vertically above the centre of the regulator's disc. He must have already have had an approximate idea of the bore and static head required, probably from experiments using a linear device. The flow was too small so he enlarged the hole with a copper wire and emery until the flow was correct. He had now fixed one of his two datum points. He then moved the outlet to the diametrically opposite position, for the night of the same day or the winter solstice, i.e. the first point of Capricorn, and checked the outflow – Q divided by $9\frac{1}{2}$. If the flow was too great he reduced the static head by moving the outlet nearer the centre a certain distance and by lowering the reservoir a like distance. In other words, if the required alteration was $2x$, he moved the outlet by x and the reservoir by x. In this way the head over the first point of Cancer was kept constant. If the flow was too small, these alterations were in the opposite direction. Al-Jazarī does not tell us how he moved the hole but probably, because of his previous experiments, the alterations were small. He may have made a long hole in the face of the regulator which was covered by a plate holding the onyx. This would be sealed around with wax while he was making his adjustments and finally soldered when his dimensions were fixed.

For the remaining positions of the Zodiacal signs he proceeded by trial-and-error on one side of the disc. He had already divided the face of the disc, with erasable signs, into the Zodiac signs and the degrees of a circle. This was done simply by taking 30° for each sign. The first point of each sign served as a starting point for his trials, and he then moved the outlet away from that point until the flow was correct for that day, and engraved a line along the face of the division marker. He thus marked out one side (the right-hand) into the correct divisions, then he was able to mark the left-hand side by making marks diametrically opposite those on the right. He divided each sign into 5-degree divisions in a similar manner, and finally sub-divided into single degrees.

The reader is strongly advised not to try to derive the actual angular dimensions from the passage in which al-Jazarī describes the trial-and-error division of the circle. Up to this point, the description of the fixing of the first points of Cancer and Capricorn is quite lucid, but it then becomes confused. No complete picture can be obtained for the division of the right-hand semi-perimeter, nor do the figures given for this side tally with those given for the left-hand side.

One can however supplement the description by mathematical considerations. Since the frictional losses are virtually constant for any position of the outlet, the flow is directly proportional to the square root of the static head. Al-Jazarī tells us that the distance from the outlet to the centre of the disc is $4\frac{1}{2}$ fingers, that there are $14\frac{1}{2}$ hours for the day of the summer solstice and $9\frac{1}{2}$ for its night. If the distance from the water surface in the float chamber to the centre of the regulator is h, then

$$\frac{h-4.5}{h+4.5}=\frac{9.5^2}{14.5^2}$$

Whence $h=11.35$ F

The height of the float chamber is given as

$1\frac{1}{2}$ spans or 18 fingers

Therefore the distance remaining $18-11.35=6.65$ F $=5.25$ inches.

This is the sum of the two sections of the float chamber which are not included in the static head, namely the distance below the outlet pipe and the distance above the float and value plug. This seems a reasonable result, and confirms al-Jazarī's dimensions for these equipment items.

It is also possible to derive the actual positions on the circle for the various divisions, for example: –

From al-Jazarī – hours for 1st point of Cancer 14 h. 30 m.
hours for 1st point of Gemini 14 h. 12 m.
hours for 1st point of Taurus 13 h. 12 m.
hours for 1st point of Aries 12 h.

Taking h as before, and knowing that the 1st point of Cancer is $4\frac{1}{2}$ F vertically above the centre, we have for the vertical distance (h_1) of the first point of Gemini, above the centre

$$\frac{11.35-4.5}{11.35-h_1}=\frac{14.2^2}{14.5^2}$$

Whence $h_1=4.21$ F.

This gives a position of the 1st point of Gemini about 20° from the first point of Cancer. By similar means we find that the sign of Taurus occupies 26°, the sign of Aries, 26°, and the first point of Aries is 18° above the horizontal. Similar methods could be followed to determine the remaining positions.

Section 6 (Figs. 1.1, 1.2, 1.3)

The operation of the parts described in this section is clear from al-Jazarī's text and illustrations, with cross-reference to the explanatory drawings. The falcons and their fittings and niches are not shown on the latter. It seems that al-Jazarī's is wrong in stating that the falcons lean forward until their beaks are two spans from the top of the *miḥrābs*, since the total height of the *miḥrābs* is given as two spans and even this distance, as mentioned above, is probably too great.

As will be seen from other parts of al-Jazarī's work, the operation of the arms of the jack musicians is typical. There is a fulcrum at the elbow, from which an extension piece passes through the screen, far enough to allow it to be struck downwards by the peg on the water-wheel axle. The hand therefore rises, and falls on to the instrument as soon as it is freed.

The channels that carry the balls from the vases into the interior of the house, and the place where they are collected, are not shown either in al-Jazarī's illustration or in the explanatory drawings. This is an unimportant detail – they could be located in any position provided they did not interfere with the working parts.

Section 7 (Figs. 1.1, 1.2, 1.3, 1.5)

Again there is little to add in general to al-Jazarī's description and the explanatory drawings. A point of interest is the careful tuning of the system to ensure smooth working: the wheel with the semi-circular iron rim is statically balanced; there is a counter-weight attached to the cart to ensure constant tension in the traction string; the float in the reservoir is weighted with sand so that it provides sufficient motive force.

As given here, the related distances are correct. The float falls $5\frac{1}{2}$ spans, the cart moves $5\frac{1}{2}$ spans and the circumference of the large pulley is $3\frac{1}{2}$ spans, and $(3.5/2)\times\pi$ is almost exactly $5\frac{1}{2}$.

Figs. 1.1, 1.2, and 1.5 show the operation of the cart, and the release mechanism for the doors and balls. Fig. 15 B is the reconstruction worked out by Wiedemann (pp. 78–80), and appears to be the most probable arrangement. A is the blade which rests in the slot in the timber holding the balls (shown in detail on Fig. 1.1), B the plate carrying the figure of a man, C a string from a ring in the top of B to a hole in the tail of the blade. DD are two strings from the upper door leaves to B, which hold the former closed when B is in the pre-release position. E is the timber carrying the hook F, and G is the iron pin from B resting in the hook F. KK are the upper hinges and LL the lower hinges of the upper doors. (In Fig. 1.5B these are shown diagrammatically, without the necessary cranked section.) JJ are the leaves of the upper door. M is the out-of-balance weight on its axle R, and N is the lower door, wedge-shaped, and its axles are PP. H is the iron rod attached to the back of the cart, which must have been cranked as shown to allow the upper doors to open and the lower doors to rotate. The upper doors must have been inclined as shown on the drawing to allow the plate B to enter and to give a forward motion upon release.

Both drawings give the pre-release position, with the plate B held by the pin G on the hook F; the distance between B and E must have been small, so that the timber prevented the plate from falling inwards. The weight M hangs over the top of door N, keeping the heavier end uppermost.

When the pin G is knocked from its hook by the rod H, the plate B falls – it is wider than the doors SS, but passes inside their hinges. Strings DD slacken and the doors JJ open under gravity. The bottom of plate B strikes the weight M and turns it, causing the door N to rotate (it probably oscillated before coming to rest). The plate B comes to rest on the weight, which then lies horizontally. Meanwhile the string C has tautened, jerking the blade from its slot and releasing the balls, which leave the lower timber and pass through the channel into the falcon's heads, out of their beaks, into the cymbals in their vases, and finally down to the floor of the house. In Fig. 1.2 the path of these channels is indicated – they must have been curved in this way to avoid the doors, cart, and cart track.

On the top of the sixth, ninth and twelfth plates (B) weights are placed (not shown) which fall off when the plate drops. Strings are attached to these weights and operate a mechanism which is described in Section 8.

Section 8 (Figs. 1.1, 1.2, 1.3)

This section describes the equipment which is directly operated by the flow of water from the regulator. The mechanisms are clearly, indeed exhaustively, described by al-Jazarī and require little additional explanation. If the explanatory drawings are referred to, however, it will be seen that the strings from the upper trough, which pass over pulleys to the plates above the sixth, ninth and twelfth doors (Fig. 1.5) have been omitted. This was done, as for all such omissions, to avoid confusing the drawings with too much detail. The plans and elevations (Figs. 1.1, 1.2, 1.3) show the working and interconnection of the various items as they were probably arranged. The arrangement is clear from the text and al-Jazarī's illustrations, apart from some confusion about the siting of the divided trough. At one point he says that the first division is near the cymbalist, and at another that it is to the right of the plate. Both statements cannot be correct, even if the trough were turned through 90°, which is in any case impossible, since the trough would then foul the large wooden pulley (not shown in Fig. 1.3). Furthermore, in Fig. 27 he has shown the sixth, ninth and twelfth doors in reverse order, as if he were viewing from the front of the house. The valves (e.g. in Fig. 1.3) have been shown in the middle of the troughs longitudinally, slightly off centre laterally. There is nothing rigid about this positioning. Al-Jazarī indicates that the holes were out-of-centre longitudinally in each trough, but draws them in the middle in Fig. 27. No doubt he had to experiment with the positioning of the valves to ensure that the pipe was moved to its correct discharges positions by the jerking of the strings. Twice al-Jazarī uses the phrase 'in one direction' when he refers to the water spilling over the sides of the divided troughs. Presumably he kept one of the sides slightly lower so that the water ran into the cistern without flooding the whole floor.

Section 9 (Figs. 1.1, 1.2, 1.6)

Legend for Fig. 1.6 (Note that Scrap Sections are enlarged, with clearances etc. exaggerated for maximum clarity).

a	perimeter of plate
c	circle shown in al-Jazarī Fig. 29
d	outer perimeter of outer band for Zodiac signs and degrees
e	outer perimeter of sun's sphere backing-ring
f	inner perimeter of sun's sphere backing-ring coincident with outer perimeter of moon's sphere backing-ring. (In practice there is a narrow gap – see Scrap Sections.)
g	outer perimeter of backing-ring for moon's phases
h	inner perimeter of backing-ring for moon's phases
j	inner perimeter of moon's sphere backing-ring
k	inner perimeter of inner band for Zodiac signs and five degree divisions
p	circle used for marking out Zodiac and degree bands
t	inner perimeter of Zodiac circle on front of plate
Z	Zodiac Sphere
S	Sun's Sphere
M	Moon's Sphere
D	Disc
L	Sun's Sphere backing-ring
N	Moon's Sphere backing-ring
R	Backing-ring for moon's phases
O_1	Main centre point
O_2	Upper centre point
bm	inscribed diameter

This device, although essentially simple in conception and operation, is somewhat complicated in its construction, and is by no means simple to describe or illustrate. A stage-by-stage description of al-Jazarī's method of construction, together with reference to Figs. 30, 31, 33, 1.1, 1.2, and 1.6, should help to clarify the obscurities.

He hammered out a copper sheet until it was in roughly circular shape, then cut from this a plate of 5 spans diameter. He then inscribed on the plate a second circle *t* of 4 spans diameter. The space between this circle and the edge of the plate was divided in the twelve Zodiacal signs, which were later embellished. Now, although this is not made clear, the plate was turned over, and the whole subsequent description applies to the reverse side only.

A diameter *bm* was inscribed on the reverse side between the first point of Cancer and the first point of Capricorn – i.e. transferred from the corresponding points on the front face. The centre point of this diameter is O_1 on Fig. 1.6A. He then made a second centre point O_2 on the diameter, 5 divisions towards *b*, assuming that *bm* is 60 divisions, so that O_1–O_2 is $\frac{1}{12}$th of *bm* (in Fig. 30 this eccentricity is drawn at less than $\frac{1}{12}$th, while Fig. 1.6A follows al-Jazarī's dimensions, and hence the appearance of the two drawings differs slightly.) On O_2 a circle was then drawn tangential to circle C at the top, and the plate was cut through along this circle, freeing the Zodiac sphere Z. Then a second circle was drawn and cut, its radius 4 F less than the previous circle, producing an annulus 4 F wide for the sun's sphere S. A second annulus 4 F wide was then cut from the remaining plate for the moon's sphere M. The copper backing-rings were now soldered to S and M: for S the backing-ring L overlapped both perimeters of the annulus by half a finger-nail (perhaps $\frac{1}{4}''$); for M, the backing-ring N lay inside the outer perimeter of the annulus by half a finger-nail and overlapped the inner perimeter by a like distance. When the two annuli were replaced between the disc D and the eccentric annulus Z, the inner perimeter of L and the outer perimeter of N were almost colinear ('almost' because there must have been a slight gap to allow for movement and fittings – see Scrap Sections). The outer perimeter of L then lay over the inner perimeter of Z, and the inner perimeter of N lay over the outer perimeter of D. The parts were now fitted together. The two backing-rings were provided with locating nails on their inner perimeters around which they could be rotated, and which ensured that there were small clearances between the main sections so that they did not bind together. Retaining lugs were also fitted to hold the assembly in one piece. A round hole was cut through S, into which was inserted a glass roundel backed with gold leaf, representing the sun, and a mark was inscribed on the outer perimeter of the annulus opposite the centre point of this roundel. A similar procedure was followed for the 'moon', but in this case the roundel was of clear white glass. (These are not shown in Fig. 1.6.) Obviously, holes must have been cut in the backing-rings behind these roundels.

A third backing-ring R was now laid on the moon's sphere backing-ring N, and this was also provided with locating nails and retaining lugs. Twenty-eight holes had been cut in this ring R. One of these was a full circle (say *x*) and one (say *y*), diametrically opposite *x*, was left blank. On either side of *x* the holes were almost circular, but had thin crescent-shaped blank pieces left inside the full circle, their convexities on the near side with respect to *x*. For each subsequent pair the crescent became larger, reaching a half-circle on the horizontal diameter, until the pair adjacent to *y* showed only thin open crescents, their convexities adjacent to *y*. On a given night one of these holes was set behind the glass roundel in the moon's sphere, to give the appropriate shape for that night. (These holes are not shown in Fig. 1.6 but the whole procedure is described in great detail in the text – see Fig. 31).

Four hand grips were provided for turning backing-ring R, and one each for L and N (see Fig. 1.6A and C). The assembly was completed by fitting six arc-shaped iron rods between the disc D and the Zodiac sphere Z. These are shown on Figs. 1.1, 1.2, and 32. To keep the drawings clear the lower half of the plate is omitted on Fig. 1.1, and only the top and bottom arcs are shown on Fig. 1.2.

Other circles were now inscribed on the reverse face of the plate: C was drawn on centre point O_1 near the edge of the plate (not mentioned in the text but shown on Fig. 30); *d* was drawn on centre-point O_2 outside the outer perimeter *e* of the sun's sphere backing-ring and tangential to C at the top; *k* was drawn on the disc, again on centre point O_2, inside the inner perimeter *j* of the moon's sphere backing-ring. In fact Jazarī says that two circles were drawn for each band. These must have been very close to the backing-ring perimeters *e* and *j*, and have not been shown in Fig. 1.6A. A small circle *p* was drawn on centre point O_1, divided into 360 degrees and used for marking out the signs of the Zodiac and degrees between circles *d* and *e*. These divisions were not quite equal because O_1 is eccentric with respect to O_2, the centrepoint of circles *d* and *e*. The Zodiac divisions, however, were co-linear with those on the front of the disc. The circle *p* was also used for marking the Zodiac signs and 5 degree divisions in band *j-k*, which were also unequal.

The assembly was now mounted on an iron axle and the plate checked for static balance, verticality, and true rotation. Six iron bracing rods (see Figs. 1.1, 1.2) were fixed between the back of the Zodiac disc and the centre of the axle.

After the front of the plate had been adorned, a wooden pulley was fitted to the other end of the axle. This had 360 holes drilled in the channel in its rim, and their position relative to the signs of the Zodiac on the sphere plate was determined and marked. A nail with a ring in its end was provided for inserting into these holes.

It has been necessary to describe the 'spheres' in some detail because of their somewhat intricate construction. In fact they serve little purpose other than that of adornment. It is true that the sun can be shown at different altitudes as the year goes by, and the moon can appear in its phases, in approximately the correct position on the celestial sphere. The variation in sun's altitude is merely indicative, however, and gives no real quantitative measure of the actual altitudes (minimum $30\frac{1}{2}$ degrees maximum $77\frac{1}{2}$ degrees for latitude 36°).

Section 10

This section describes first the erection of the spheres inside the house and the setting of spheres to a different starting point each day. The text is quite explicit. There is, however, one small discrepancy. Al-Jazarī says that the spheres were driven direct from the float in the reservoir by a string connected to the nail in the wooden pulley. At the end of this section, he says that he modified the arrangements and made two grooves in this pulley, and connected a fixed ring in the second groove by a string to the wooden pulley which drove the disc for uncovering the twelve glass roundels. The start point for the Zodiac sphere, however, is different each day, while the disc near the roundels must always start from the same position. What he probably did was to make two grooves in the lower pulley, and attach a taut string to the nail in the upper pulley, set to its correct position for the day.

The remainder of the section is concerned with the duties of the servant at daybreak and at nightfall, and in effect describes once more the operation of the complete system. As al-Jazarī had already mentioned in Section 8, several functions are omitted at night. The musicians perform only twice – at midnight and daybreak (although al-Jazarī says that it was three times in Section 1) and the balls do not fall from the falcon's beaks on to the cymbals.

The duties of the servant must have taken some time. He may have done all he could before daybreak, and the remainder as quickly as possible. A more leisurely method would have been to have set everything for, say, half-an-hour after daybreak (or nightfall), pour the amount corresponding to half-an-hour's flow into the first division of the trough, and the balance of the day's supply into the reservoir. He would then open the tap on the half-hour and the clock would then be synchronised with the solar time 30 minutes after daybreak.

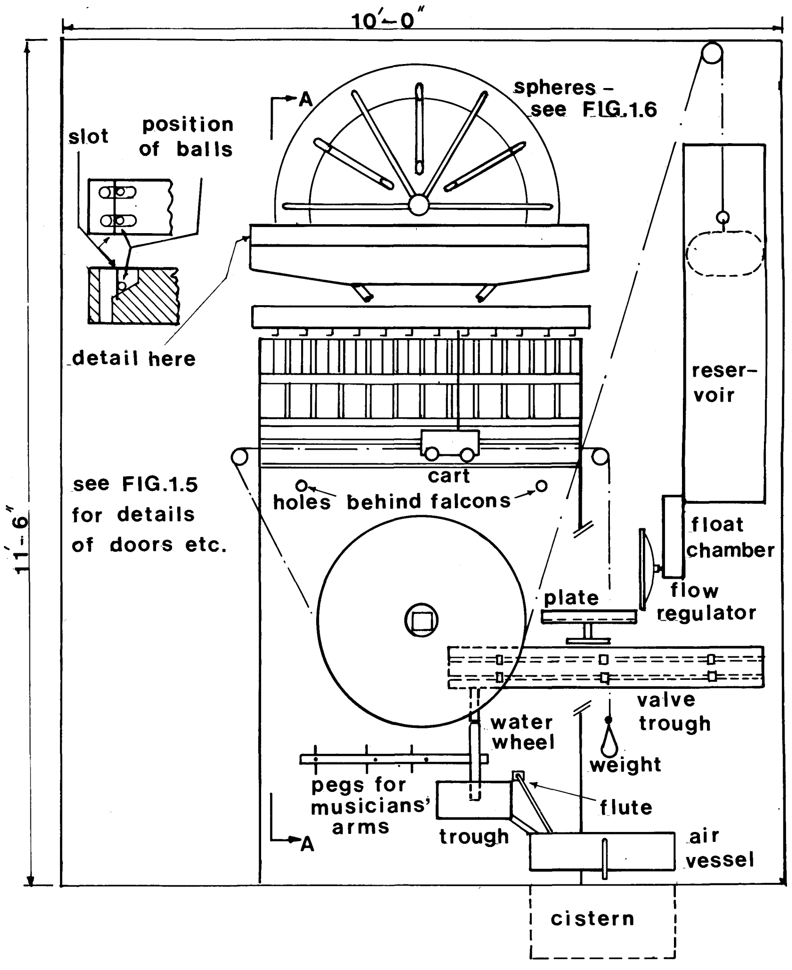


Fig. 1.1. Elevation from rear of house.

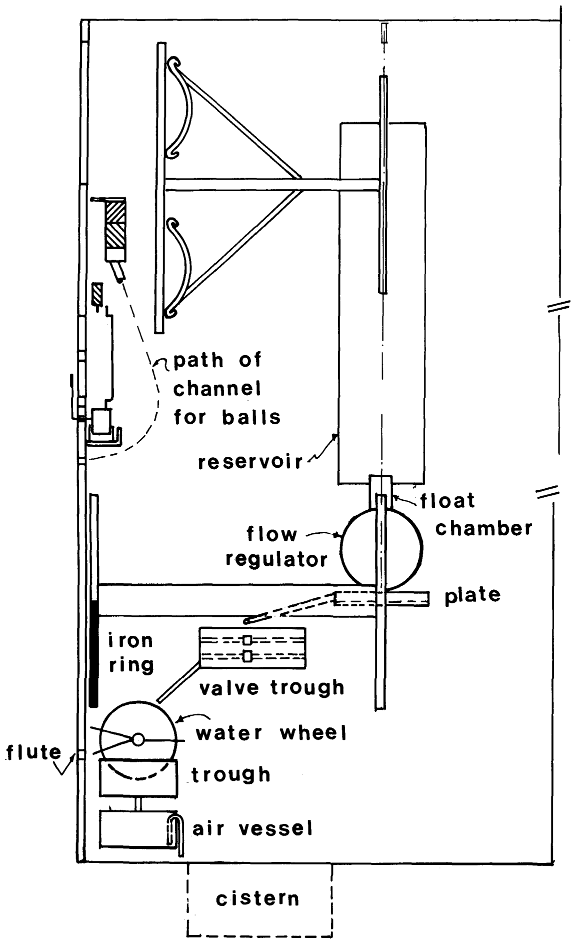


Fig. 1.2. View in direction AA on Fig. 1.1.

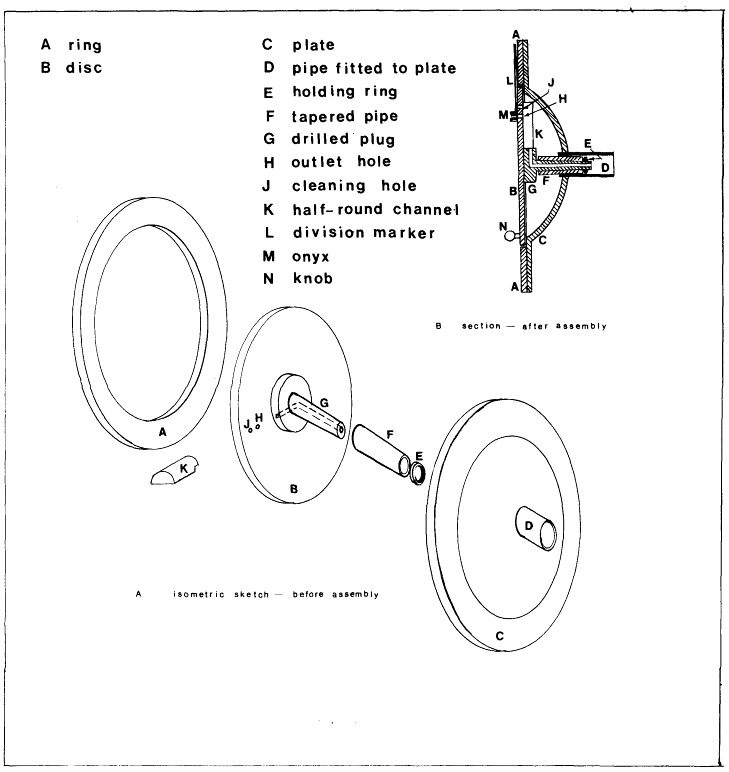


Fig. 1.4. Flow regulator.

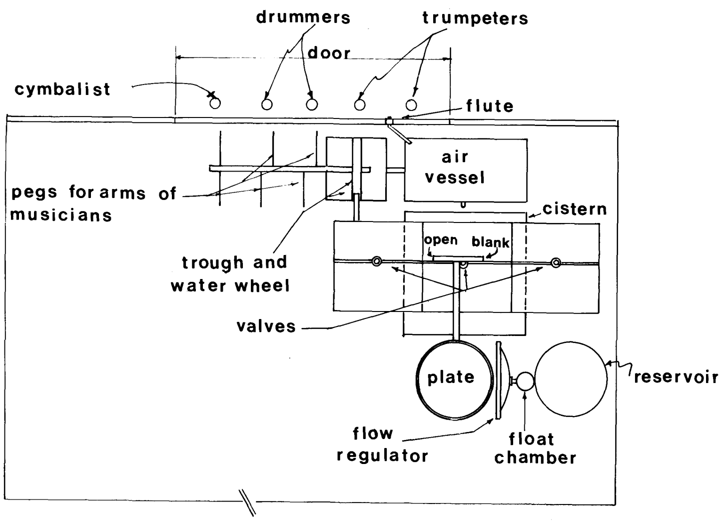


Fig. 1.3. Part plan (water equipment only).

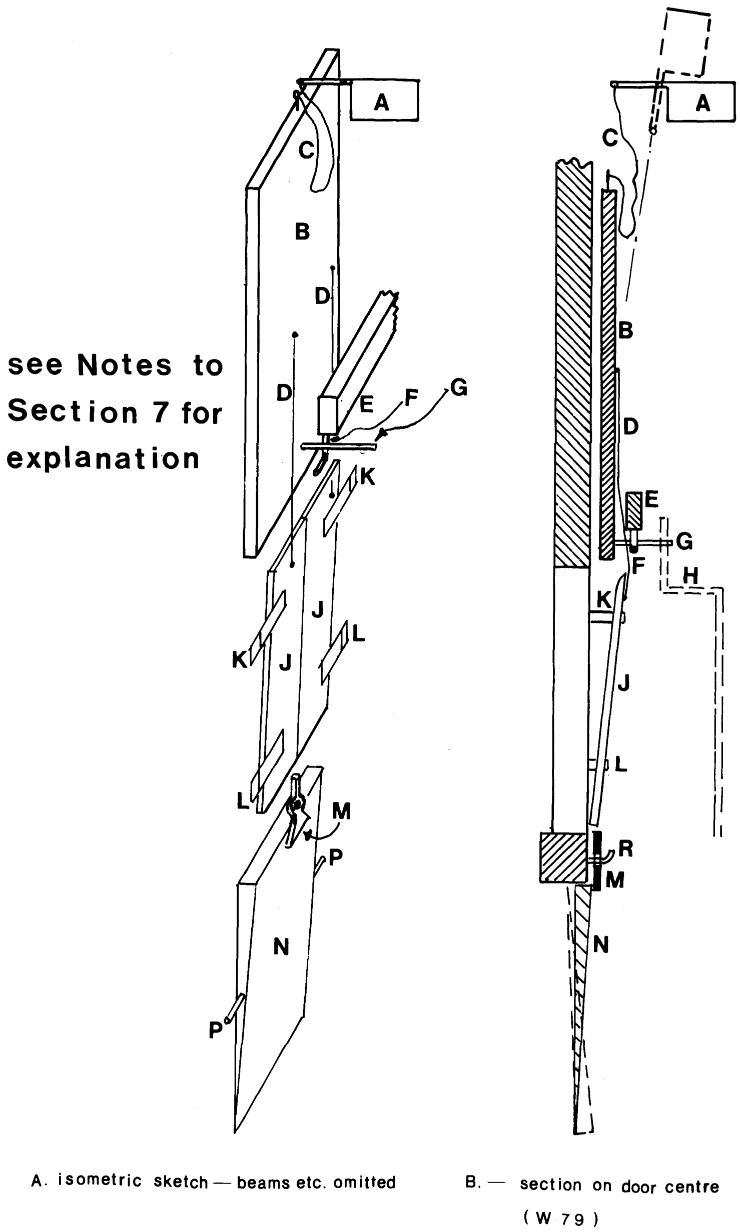


Fig. 1.5. Operation of doors.

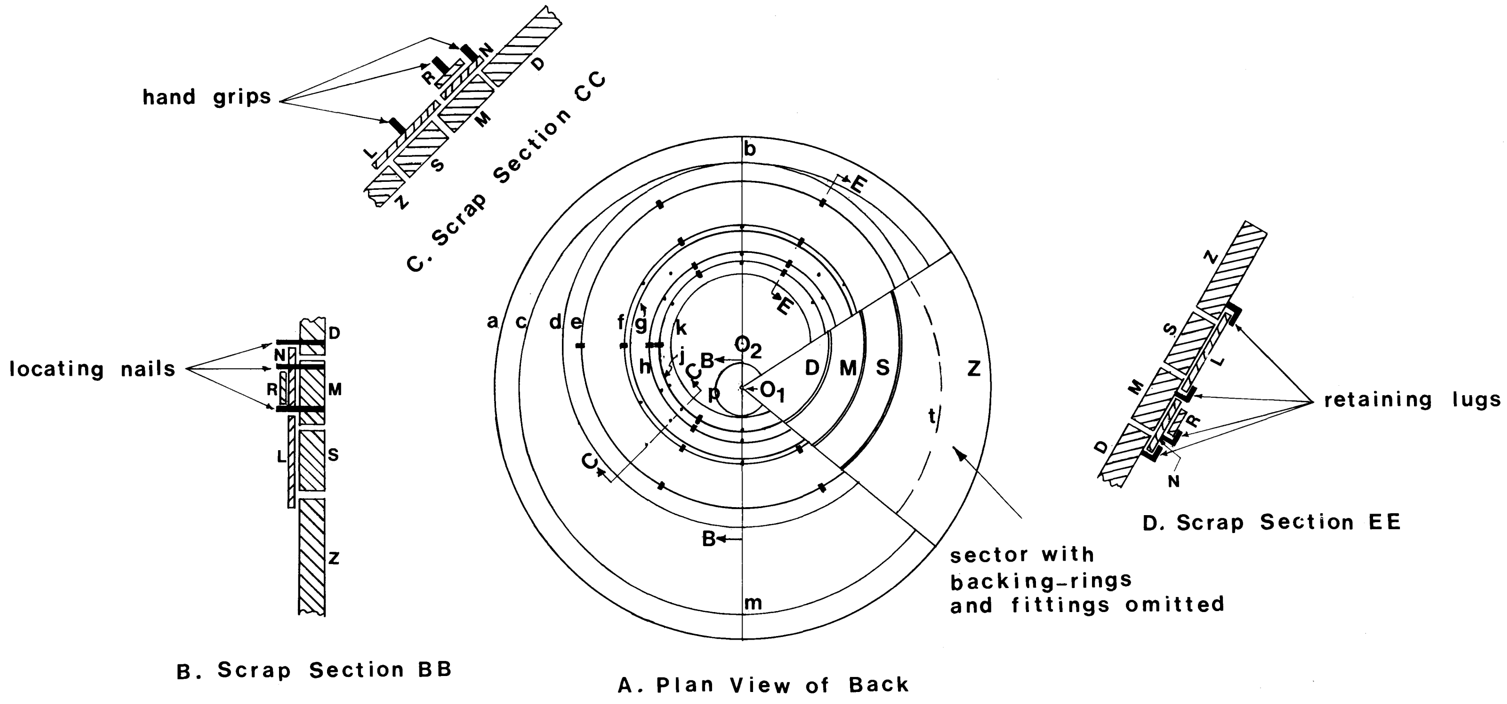


Fig. 1.6. Detail of spheres.

Chapter 2 of Category I

GENERAL DESCRIPTION (FIG. 2.1)

This clock is basically a simplified version of the one described in Chapter 1, with fewer, less complicated, mechanical devices for indicating the hours. No difficulty should be found in understanding its operation from the text, and from al-Jazarī's drawings. Fig. 2.1 has been supplied to give a general idea of the layout of the driving mechanisms, and to illustrate one or two points which are made below.

Layout of Equipment

The display area was the height of three men (say 16′6″) and would have been about 4′7″ wide, as in the first clock, if the fall of water in the reservoir was the same. The face was recessed from a point about 5′6″ above ground level, to just below the level of the cart-track. The musicians stood on a platform which was the floor of the recess; the falcon in his niche was also in the wall of the *Īwān*, being thus set back from the front wall of the clock. This facilitated the passage of the ball into its head, because the channel from the ball magazine would not have had to be curved to avoid the cart track, as was the case in the first clock.

The suggested layout of the water equipment and jack activation is shown in Fig. 2.1. The drive from the reservoir to the end of the cart-track cannot have been transmitted through two pulleys only, as Jazarī states. Pulleys A and B must have been installed so that the line of pull was always parallel to the diameters of the pulleys.

Section 2

The basic water equipment – reservoir, float chamber and flow regulator – is as described in Chapter 1.

The most interesting feature of this clock is the use of the tipping-bucket, which discharges at the end of each solar hour. As will be seen in later chapters of his work, this device is frequently used by al-Jazarī but this bucket differs significantly in design and performance from those described later. Instead of having a bucket which tipped automatically when filled with a given quantity of water, he provided it with a lead counterweight, and the overbalancing moment was applied by the impact of a ball falling into the cup at the end of the bucket. As al-Jazarī tells us, the bucket was designed to hold slightly more than the quantity of water flowing out in one hour of the first point of Cancer. (Doubtless it was made slightly longer to allow for the additional height required for the axle.) It is clear from a later section (Section 5, p. 46) that he meant one *constant* hour, since he says 'this is the least quantity of water of all the hours in the year.' Again, in Section 5 (p. 46) he says that 'if the hours have lengthened after some days,' the extra water is discharged from the overflow pipe at the back of the bucket. He was of course in error in this last statement since the solar hours are longest at the first point of Cancer. In fact, however, the length of solar hour is irrelevant as the following example demonstrates.

Capacity of reservoir	6900 cubic inches
Length of daytime at first point of Cancer	$14\frac{1}{2}$ constant hours
Flow in one constant hour $= \dfrac{6900}{14\frac{1}{2}} =$	475 cubic inches

– which was the effective capacity of the bucket.

Now in one solar hour, the flow is constant for any day in the year, i.e.

$$\frac{6900}{12} = 575 \text{ cubic inches}$$

Since the bucket tips at the end of a solar hour, the overspill will always be the same,

$$575 - 475 = 100 \text{ cubic inches}$$

Now a neater method of release would have been to have designed the bucket to tip when its contents reached the exact outflow for one solar hour, and this type of bucket was used by al-Jazarī in other devices.

Section 3

This describes clearly the mechanisms for the movement of the man on the battlements, the screening of the roundels, and the release of the balls. No tensioning device is mentioned for the roll of leather which may therefore have tended to sag.

Section 4

The construction of the jack musicians is typical of al-Jazarī's methods.

Section 5

When al-Jazarī refers to his water-wheel as being strongly made, and able to withstand the weight of water falling on it, he can only have been speaking relatively. There was only about $2\frac{1}{2}$ gallons of water at each hourly discharge, issuing from a pipe, and the fall must have been considerable to turn a wheel of 2 sp. (20 inches) diameter.

At the end of the chapter, al-Jazarī says that the reservoir for this clock may be small, although earlier he has given the dimensions that he used for the large clock in Chapter 1. There seems to be some discrepancy here since if the vessel were shorter, the width of the clock would be less. And if it were narrower, the quantity of water at each hourly discharge would be less. Yet the length of each 'ruler' activating a drummer is given as $1\frac{1}{2}$ spans, which presupposes a greater width than for the first clock. Probably the original design was for the same width as the first clock – $5\frac{1}{2}$ sp. or 55″ – and later models were made to a smaller scale. The length of 'ruler' may be an error, or one may have served for two musicians, although this is contradicted by the text.

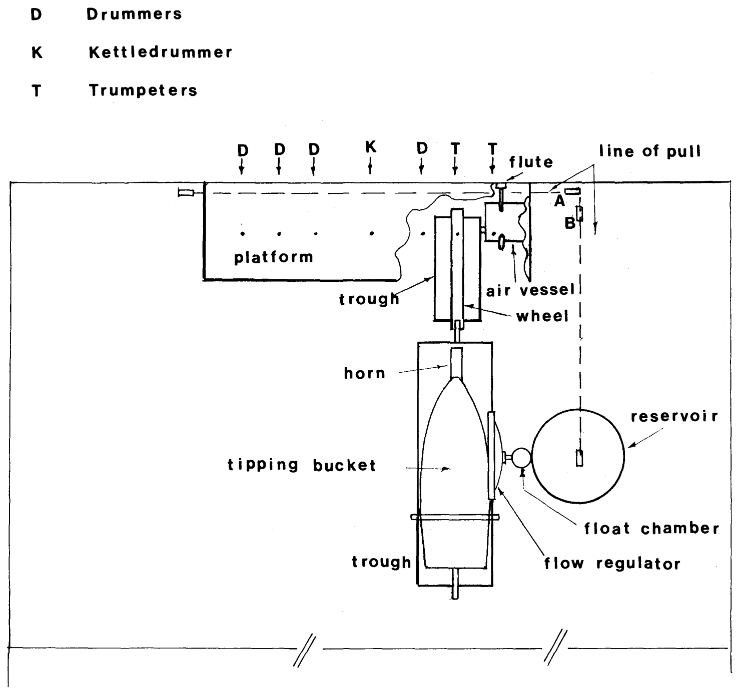


Fig. 2.1. Part plan.

Chapter 3 of Category I

The clock described in Chapter 4, the elephant water-clock, includes all the devices described here for the boat water-clock, and many additional features. For an understanding of this clock, therefore, reference may be made to the notes and drawings for Chapter 4.

The following notes apply specifically to al-Jazarī's drawings and text for Chapter 3.

Fig. 45. This drawing of the float shows the details of the fixtures on both upper and lower sides.

Fig. 46. The ring with its attached chains is in reality vertically below the plane of the drawing. The weight on the first blade is not mentioned in the text, but is shown on the drawing.

Chapter 4 of Category I

GENERAL DESCRIPTION (FIG. 4.1)

A	Trough for collecting balls
B	Cymbal
C	Spoon which activates mahout
D	Weight
E	Float
F	Whistle
G	Dais
H	Dome
J	Skirt
K	Platform for scribe
L	Chain from float to hook at end of wire R
M	Chains (2) to staples in serpents' backs
N	Balance
P	Trough
Q	Pulley (interpolated by author)
R	Wire from moving channel to chain L
S	Hinge
T	Moving channel
U	First channel (magazine for balls)
V	Axle from trough's wheel, through cupola, to bird on top of cupola
W	Ring for blacking-out holes
Z	Holes for falcons' heads

The body of the elephant is about 11″ in diameter and probably about 4 feet long. Four pillars, each about 2′6″ long are fixed to the corners of a square plate soldered to the back of the elephant. The feet of the castle are supported on these pillars. The castle is a box made up of brass plates – it is about 1′3″ tall and 1′0″ square and is surmounted by an ornamental bird. The total height of the structure, including the elephant's legs was probably about 6′0″.

A trough is formed from the belly of the elephant by erecting two vertical plates between belly and breast and between belly and rump. This trough is tinned to make it watertight. The dais which is fitted to the back of the elephant has a large octagonal opening in it, into which is fitted the octagonal skirt of the dome shaped cover, which has a cylindrical section at the top. The cover of this cylindrical section forms a platform for the scribe, and is engraved with the arc of a circle divided into $7\frac{1}{2}$ divisions. Inside the cylindrical section is a large pulley mounted on a vertical axle; the lower end of this axle rests on a bearing on a cross-beam and the upper end passes through the platform. The top of it is square in section and enters a square hole in the underside of the scribe, so that the scribe turns with the axle. On either side of the large pulley is a small pulley turning in a channel fixed to the side of the cylindrical section.

There are transoms across the centres of the pillars which support two serpents, whose tails are in the form of large rings. These serpents are so balanced that their normal position is with the heads raised to the front of the castle.

The heart of the mechanism is the sinking float, or *Ṭarjahār*, which is on the water in the trough in the elephant's belly. Essentially this consists of a hemisphere with a hole in the underside of such a calibre that the float fills with water and sinks in exactly half-an-hour when weighted by a solid ball. The float is connected by a hinged chain to the side of the trough. Two chains are connected to its underside, near the centre-point, and each passes through an aperture in the domed cover, through a hole in the platform, and is made fast to a staple in the back of one of the serpents. A ring in the top of the float is connected to a hook in the end of a wire which leads to the ball release mechanism inside the castle. In this clock the float is provided with a raised deck into which air is forced when the float sinks, and the air operates a mechanical whistle connected to the top of the deck. The ring first mentioned is fixed to this deck. (In the boat clock the deck and the whistle are omitted, and the ring is in the centre of a rod fitted across an upper diameter of the float. Also the float is timed to sink in one hour, not half-an-hour as with the elephant clock.)

The ball inside the float has an axle through it which is bent above the ball into a semi-circle. The ball is prevented from coming out of the float by a lug soldered to the rim of the float. A string is attached by its centre to a staple in the large pulley. One end of this passes round the large pulley, over a small pulley and a weight is tied to the loose end. The other end of the string is also passed round the large pulley, over the second small pulley, and its end tied to the axle of the ball in the float.

The essential functions are as follows: at the beginning of a half-hour period the float is on the surface of the water, chains L and M are slack, and the scribe's pen is at the beginning of the arc. The float slowly sinks, turning the scribe, whose pen indicates the passage of time. When the float submerges chain L operates the ball-release mechanism and a ball passes through the apparatus (described below) and falls into the mouth of one of the serpents. This provides a turning moment and the head slowly sinks, and the float is raised by chain M. The purpose of chain M and the hinged chain is to tilt the float and empty all the water it contains back into the trough. When the serpent's head reaches the limit of its travel, the ball is released and the serpent returns to its original position, while the float settles evenly on the surface of the water.

Layout of Equipment (Fig. 4.1A, B, C)

It was no easy matter to reconstruct the General Layout from al-Jazarī's instructions. As he himself says (Section 13, p. 68) it was not possible to work rigidly to design dimensions because it was essential to ensure that all parts were properly balanced and weighted, and that they were all interconnected in working order in the confined space allowed. He suggests the use of models, and trial-and-error methods, and this would undoubtedly be the only way of reconstructing this device. It is a much less positive device than the clocks described in Chapters 1 and 2, which were operated by a constant static head of water. In particular the float, the serpents and the balance could only have been constructed as working parts by practical experiment, which again was suggested by al-Jazarī in the passage just mentioned. For this reason the layouts as drawn in Fig. 4.1 should be taken as partly diagrammatic, and explanatory, showing the interrelationships of the working-parts, and giving an approximate idea of the proportions.

Apart from supports and bearings, which are seldom shown in these drawings, the following parts were omitted from Fig. 4.1: falcons' heads, channels from balance to falcons' heads, vaned wheel in trough, man on balcony, balcony, scribe, elephant's rear quarters and legs, mahout (his position is above the spoon C), spiral continuation of channel U. The pillars are foreshortened.

On some minor points al-Jazarī's instructions have been modified. The ring tied to the end of chain L has been moved to the edge of the float to obtain a more direct line to the pulley between the serpents. (Note that the foreshortening of the pillars distorts the line of chain L – in fact it would rise vertically to the pulley as shown.) The left-hand wall of the trough has been brought some distance inside the edge of the dome, since the length of the hinged chain is given in Section 4 as one finger's length only, or about 2″.

Inside the castle there was some difficulty in positioning the moving channel. It must drop a ball into the trough and its end must therefore be vertically above a point inside the perimeter of the trough. In this case the wire R would foul the rim of the trough and the pulley Q has therefore been interpolated to move this wire to one side. The wheel W has been shown with its centre slightly below the top of the castle – otherwise the axle would have passed through the cupola, which is contrary to the text; moreover, the cupola was removable (Section 11). The holes Z for the falcons' heads are shown at the bottom of the castle. They are shown near the top in Fig. 48, but near the bottom in Fig. 53, which agrees with the text in Section 8. They must have been near the bottom since the ball had to fall through the other devices before reaching them.

It must again be stressed that it was impossible to draw the layout of this clock as a working drawing, from the data given. Nevertheless, Fig. 4.1 gives a clear representation of the mechanisms, and their interrelationships.

Chapter 4, Sections 4, 5 and 13 (Fig. 4.4)
Also Chapter 3, Sections 3 and 4

The hinged chain, the two light chains on the underside of the float, and the inlet holes, are not shown in Fig. 4.4. They are shown in Figs. 45 and 50, and clearly described in the text.

In Section 4, al-Jazarī is in error in stating that the two chains are connected to a single ring, since each chain was connected to the back of one of the two serpents. He gives the correct construction in Section 13. The size of the ball is calculated from the weight given in Chapter 4, Section 5 – 30 *dirhams* or about 3 ounces. Taking the density of bronze as 550 lbs per cubic foot, this gives a ball diameter of about 1.1 inches. For the boat clock the diameter was about 0.92 inches.

The float of the boat clock was simpler than the one for the elephant clock: it had no flute, and the ring C was in the centre of a rod soldered diametrically between opposite sides. There was also a lug to prevent the ball from coming out.

In Fig. 4.4 the aperture D is just large enough to allow the ball A and its axle to be inserted. The bracket B, one of the brackets supporting the deck, has been extended to serve the same purpose as the lug in Chapter 3, i.e. to prevent the ball from coming out of the float. Ring C, as mentioned above, has been located off-centre, to obtain a more direct pull over the pulley on the serpents' axle.

In the elephant clock the time interval is half an hour, and there are $7\frac{1}{2}$ divisions; in the boat flock the interval is one hour and there are 15 divisions. Each division therefore marked 4 minutes. Presumably the figure of 15 divisions of the hour was selected because the earth turns through 15 degrees in one hour.

Chapter 4, Section 8
Also Chapter 3, Section 2

The castle was formed of 4 rectangular plates, soldered together to form a box. Neither the roof nor the floor of the castle are mentioned directly in the instructions for manufacture but are referred to elsewhere in the text. The chiselled arches were formed partly in the plates themselves and partly by separate brass feet, but in neither chapter is the description of this detail made absolutely clear (see Chapter 3, Section 2, p. 53, and Chapter 4, Section 8, p. 63). Note that in the boat clock the torso of the falcon tilts, while in the elephant clock the torsos are fixed rigidly.

Chapter 4, Section 9 (Fig. 4.2)

Fig. 4.2 shows the operation of the two channels. The moving channel is shown with a ball about to drop from its open end. When it is released it settles back, with the closed end slightly lower than the open end, so that the ball which then runs in from the first channel remains at the closed end until the next pull. The end of the first channel farthest from the moving channel is in fact turned around spirally inside the castle and up into the cupola to form a magazine for 29 balls.

Chapter 4, Section 10 (Fig. 4.3)

The Balance is shown in Fig. 4.3. The two main channels are at right angles to each other, but the upper channel is tilted down slightly from the horizontal towards the open end, and the lower channel is hence slightly off vertical. A ball falls in the upper channel at a point above the axle, the Balance tilts and the ball drops out. The lead ball in the pipe soldered to the axle keeps the Balance in its new position until the movement is reversed upon release of the next ball.

The mechanism for tilting the man on the balcony is also shown as a separate detail. When the Balance rotates clockwise, the man rotates anti-clockwise, and vice versa.

Chapter 4, Section 11

In Fig. 58, from the Oxford MS, the projections on the wheel are shown as pins. In the Leyden and Dublin MSS they are shown triangular.

Chapter 4, Section 13

From al-Jazarī's remarks, on page 68 it is clear that the fashioning of the serpents' heads is to be done with considerable care, so that they were properly balanced, in relation to the weight of the ball and the weight of the float.

Chapter 4, Section 15

For the sinking-float design of clock the servant did not have the same problems in re-setting the mechanism as he had with the constant flow types. On the night of the first of Cancer, for instance, only 19 balls were required and he could load these at any time after $9\frac{1}{2}$ hours of daylight had passed, when 19 balls would have been discharged from the magazine.

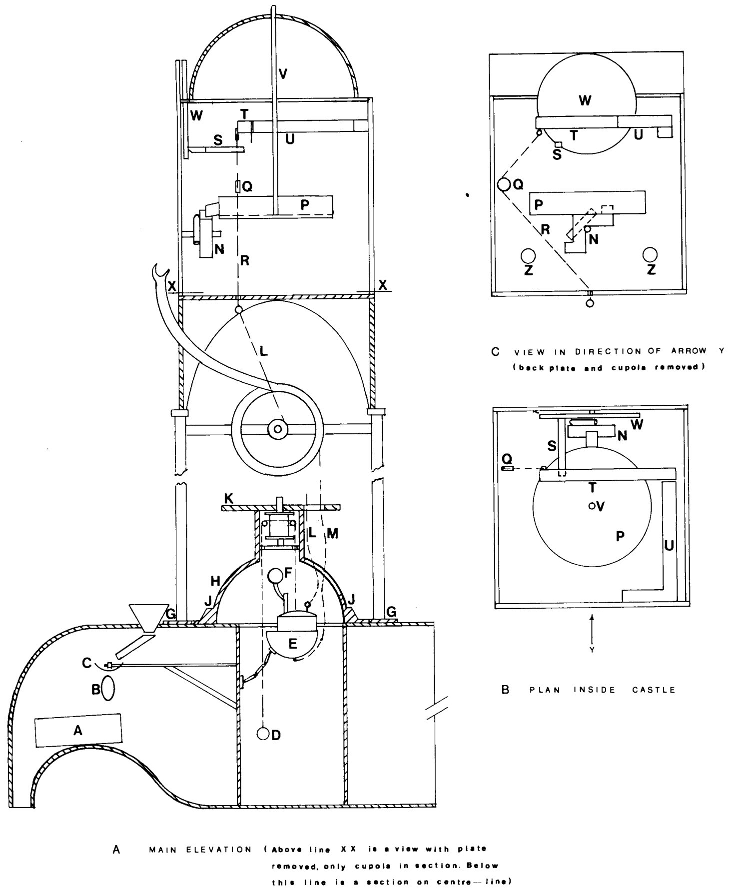


Fig. 4.1. General layout.

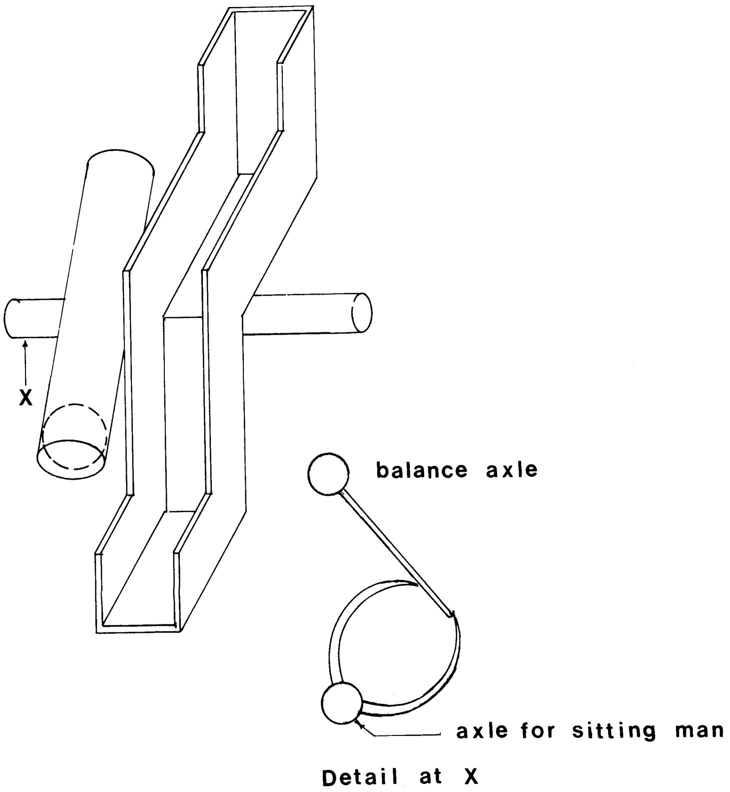


Fig. 4.3. Balance.

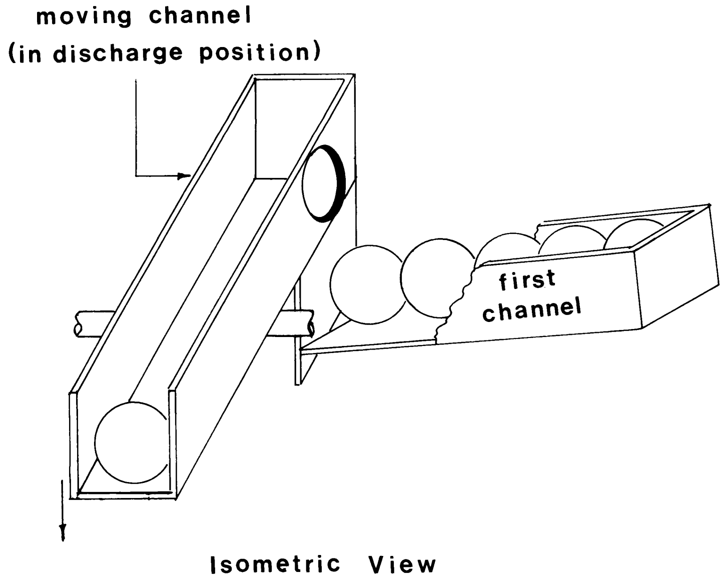


Fig. 4.2. Channels for balls.

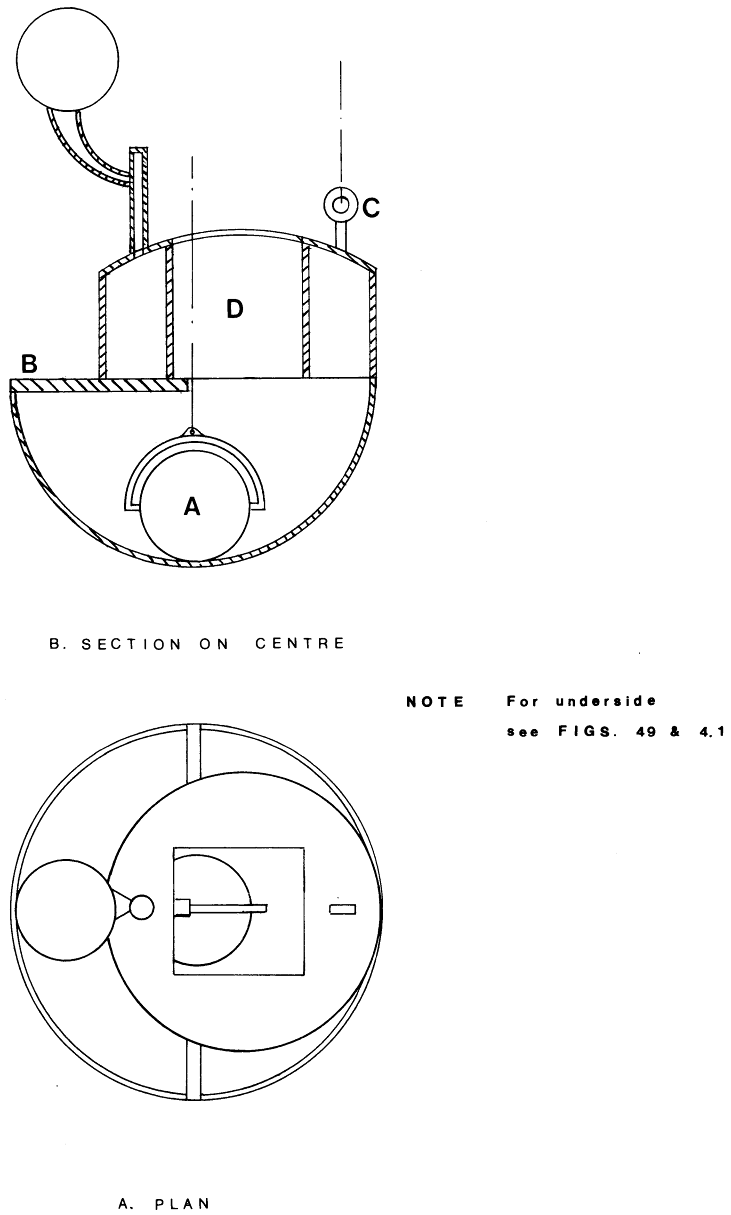


Fig. 4.4. Float.

Chapter 5 of Category I

GENERAL DESCRIPTION (FIG. 5.1)

The construction and operation of this clock are essentially simple, but there are some technical difficulties about the design.

Fig. 5.1 follows al-Jazarī's instructions fairly closely for dimensions, and for the shape of the main parts. The design of the base follows the text rather than Figs. 60 and 62, where its top is shown flat. The text gives it as convex upwards with a flat section at the top which fits into the circular extension of the beaker.

The text gives the diameter of the 'seat' as one small span less than diameter of the top of the beaker. This leaves no room to instal the balcony inside the outer limits of the beaker and this balcony has therefore been shown overhanging the beaker's rim. It is shown in hollow box section rather than solid – the purpose of the ring on top of this balcony was probably to provide an adequate thickness of metal for engraving. Fig. 62 suggests this design, but the balcony should be shown completely circular, since the scribe turns a complete circle in the longest day.

Inside the central seat a large pulley and two small pulleys are installed. The diameter of the large pulley is fixed (see below, Section 2) and the diameter of the 'seat' is given. There is thus a large gap between the large pulley and the sides of the seat. It is probable, therefore, that the small pulleys were fixed to the roof of the seat, rather than to its sides, as stated in the text. The pulleys are otherwise similar in construction and operation to those described in Chapters 3 and 4. As in the previous chapters the upper part of the axle of the large pulley projects through the lid – its end is square in section, and enters a square hole underneath the scribe. The other end rests in a bearing on a cross-beam fitted between the sides of the 'seat'. An oblate float is made, through which a pipe is inserted to form a square, watertight hole offset from the centre of the float. The float is slipped on to the 'ruler', a square-section copper rod, which is then fitted vertically in the centre of the beaker between its floor and the cross-beam carrying the large pulley.

A light chain is attached to a staple in the groove of the large pulley, wound around it, passed over a small pulley, and a weight is attached to its free end. A second, similar chain is fitted in like manner, but its free end is attached to a ring in a staple, fitted to the float on the opposite side to the hanging weight. The beaker is filled with water which slowly discharges through the onyx, and the float sinks, rotating the large pulley and the scribe. The tip of the scribe's pen moves over the divisions on the ring, marking the passage of the constant hours in intervals of four minutes.

Section 1

The ring is divided into $217\frac{1}{2}$ divisions, in total. This represents $14\frac{1}{2}$ main divisions for the hours, each main division being divided into 15 sections, to record a time interval of 4 minutes – $14\frac{1}{2} \times 15 = 217\frac{1}{2}$.

One can only speculate as to the method of construction of the beaker and the ruler actually used by al-Jazarī. It would be exceedingly difficult to make a vessel by empirical methods, so that the water level fell by equal distances in equal time intervals.

A vessel of the shape shown, a frustum of a cone with straight sides, would give nothing approaching this condition. The sides should not be straight, but should follow the relationship $r = C \times \sqrt[4]{h}$ where r is the radius of the vessel for a static head h, and C is a constant which depends upon the size of the outlet hole and the height of the vessel. Given this configuration, the water level would always fall equal distances in equal time intervals, irrespective of the waterlevel at the start of the operation. Al-Jazarī tells us that he obtained the correct conditions for the bottom and top sections of the vessel, but this would have been of little use unless the whole vessel were correctly shaped. He may, of course, have merely ensured that the effective quantity of water flowed out in $14\frac{1}{2}$ hours, and then calibrated the graduated ring with a timing device as he describes in Section 3. This would have been satisfactory for recording the constant hours and their minor divisions, provided the beaker was always full at the outset, or that the water level when the pen was on a given division at the starting time corresponded to the water level used for calibrating that division. In this case, however, the fall in static head would have been unequal for equal time intervals; and the graduated ruler would have served no useful purpose. In the addendum to this chapter, however, the adaptation of the clock for recording the solar hours is described, which would have presented a formidable problem, since each band would have required separate calibration. The most likely explanation seems to be that the first model, for solar hours only, was made by calibrating the ring by marking the divisions as each time interval elapsed, using a vessel which discharged its contents in $14\frac{1}{2}$ hours, but without a constant relationship between the rates of change of time and static head. The development of a vessel embodying this relationship came later.

Section 2

The relationship of the diameter of the large pulley to the graduated length of the ruler is $4\frac{2}{3}:14\frac{1}{2}$. Thus the pulley turns a full circle, as does the scribe's pen, on the longest day of the year. $\pi \times 4\frac{2}{3} = 14.64$, so the ratio is not quite exact.

Section 3

The reason for using a plumb-line to make a mark on the cover, and presumably also on the seat and the balcony, was probably to provide a firm base-line, in case the brass ring was moved, or removed for cleaning.

Addition to the text (Fig. 5.2)

Fig. 5.2 has been provided as an aid to understanding the text. Here 18 bands are shown, each band for 10 days in a year of 360 days. Each band is divided into 12 equal divisions for the solar hours, but on Fig. 5.2 only the largest and smallest arcs have been completely divided – for the others only the 3-hourly divisions are shown. In al-Jazarī's design the outer band was marked with the $14\frac{1}{2}$ constant hours, in addition to the solar hours, but these are also omitted on Fig. 5.2.

The principle is as follows: only the outer band, for the longest days in the year, is a full circle, and it represents $14\frac{1}{2}$ hours for the daytime of the 1st point of Cancer. The smallest arc represents the hours of the 1st point of Capricorn, or $9\frac{1}{2}$ hours from sunrise to sunset. The length of the arc is therefore $(9\frac{1}{2}/14\frac{1}{2}) \times 360 = 236°$.

The constant increment in the length of the remaining 17 arcs therefore $(360-236)/17 = 7°18'$ approximately.

The numbering in the spaces on Fig. 5.2 elucidates al-Jazarī's meaning in the final sentence. If one starts numbering at the longest day there will only be one number on the shortest band, and vice versa if one begins at the shortest day. For the night of a given day one observed the band which differed by 180° from the band used during the day.

Clearly, Fig. 5.2 represents the design assumptions made in the text, i.e. that the rate of change of time with respect to static head was always constant. If this were not so, then it would have been necessary to calibrate each band separately (a most tedious task) and the divisions would then have been unequal.

It is not without significance that the addition of the solar hours came later. If we accept that it was al-Jazarī himself who made this addition, then several years must have elapsed between the original design and the modification. One would like to feel that the amendment *was* al-Jazarī's own. From internal evidence he seems to have been a most conscientious craftsman, and a great problem solver, and this problem must have worried him. It is possible that he achieved the solution by using full size models in wax or some other easily shaped material, and arrived at the correct profile by trial-and-error, making small alterations until the desired result was achieved. No doubt the master made the alterations himself and then left the tedious task of checking the fall in water level against time to an apprentice.

Technical Note

If the area of cross-section is A, when head = h, with an orifice area = a, and a coefficient of discharge = C_d, then:

$$\frac{dh}{dt} = -\frac{C_d\sqrt{2gh}}{A}$$

For dh/dt to be constant, A must be proportional to the square root of h, and the radius to the fourth root of h.

From my calculation, however, it appears that the condition changes from turbulent to laminar at some point in the descent. At that point the coefficient of discharge will change suddenly, and will continue to change until the vessel is empty. It is by no means easy, therefore, to arrive at a theoretical profile for the beaker.

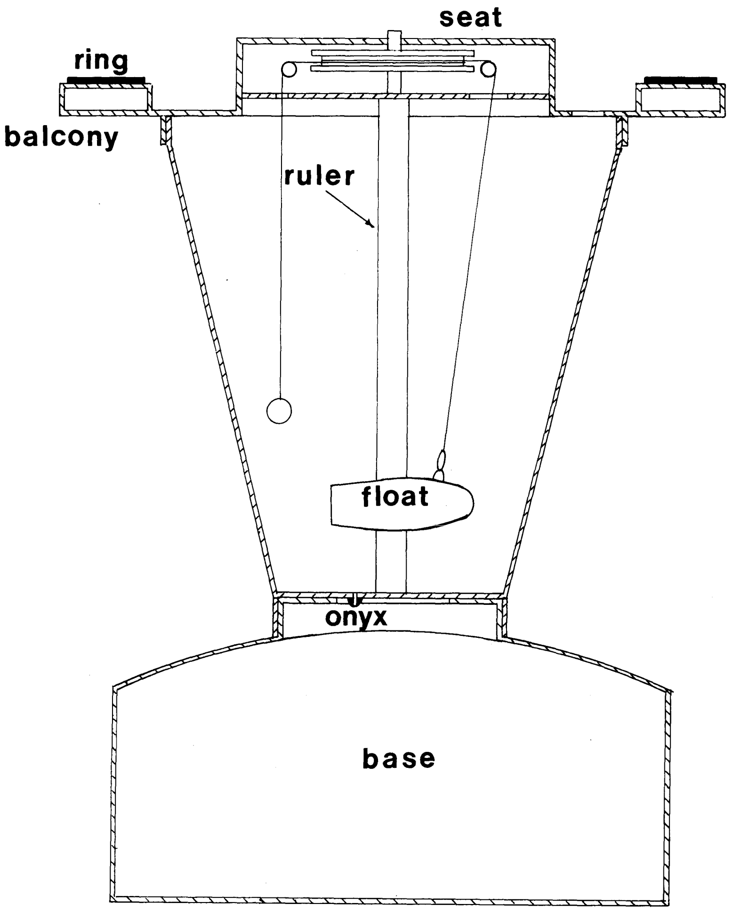


Fig. 5.1. Section on centre.

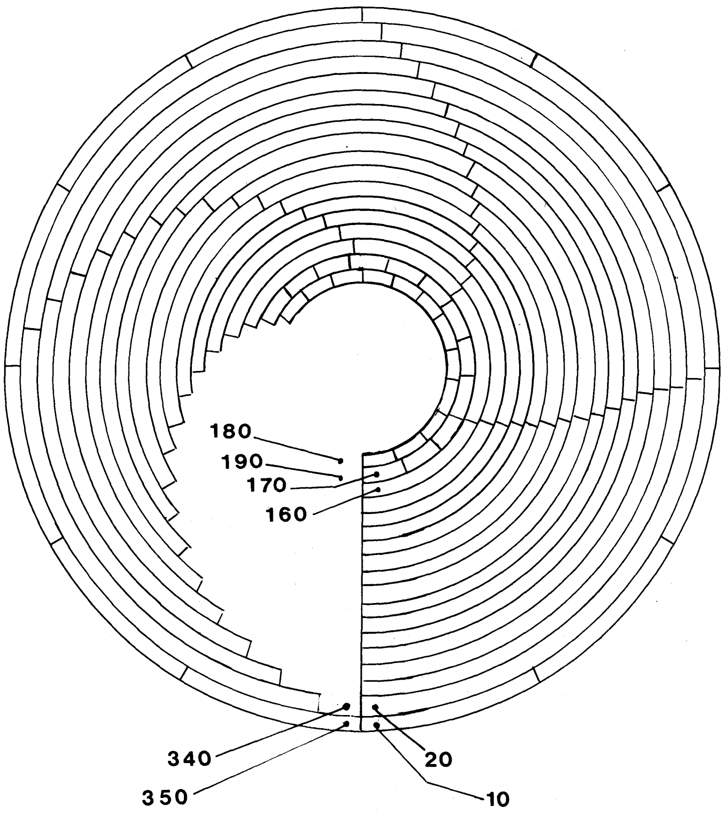


Fig. 5.2. Division of disc for solar hours.

Chapter 6 of Category I

GENERAL DESCRIPTION (FIG. 6.1)

The clock was set in a wall by the side of an ornamental pool, with fountain. There were also side walls and a rear wall, as in Chapters 1 and 2, to screen the mechanisms from onlookers.

The apparatus is one of the most pleasing of al-Jazarī's clocks from the point of view of technical design, with a fairly straightforward transfer of power from the water supply to the timing devices. Obviously a constant supply of water was laid on to the reservoir vessel A, probably from the ornamental pool. The inflow from this supply was approximately equal to the outflow from the onyx mouthpiece, but an overflow hole was included to ensure that a constant head was maintained. From the onyx water fell into the tipping-bucket B, which tipped every half hour, discharging its constant into the trough W, whence it ran out over the scoops of the water-wheel L. There was a toothed wheel M on the same axle as the water-wheel, which turned the horizontal toothed wheel N, and the ball O for the male peacock. In rotating, the scoops also operated the arms PP. The right-hand arm (Fig. 6.1) operated the young peacock's axle directly, while the left-hand arm was cranked and had a fulcrum near the top. The axles YY therefore turned in different directions, and both chicks tilted their heads towards the centre of the *miḥrāb*. Water from the scoops fell into the trough U, and passed into the air-vessel V, expelling the air and operating the whistle X, which was set in the floor of the male-peacock's *miḥrāb*. When the water neared the top of the air-vessel it was discharged through the siphon, and presumably returned to the pool.

Two other mechanisms were operated directly from the tipping-bucket. In the bucket was a float C which was connected by a string, passing over two small pulleys to the large pulley Q, upon which was the ball carrying the peahen. On the other side of the pulley Q was another small pulley over which the string passed to the weight Z. As the float rose the weight descended, rotating pulley Q. When the bucket tipped the float returned to the bottom of the bucket and the pulley Q rotated back to its original position.

The tip of the bucket carried a one-way hinge E, which could flex about its upper surface, but was inflexible on its underside. The hinge was set between the teeth of a ratchet-wheel G. When the bucket tipped the hinge flexed and came away from the ratchet-wheel. When the bucket rose again the hinge entered the next pair of teeth and turned the wheel G $\frac{1}{29}$th of a revolution. (There were 29 teeth on the wheel.) The wheel was thus turned a complete revolution in $14\frac{1}{2}$ hours, corresponding to the longest daylight period in this latitude. By the side of wheel G, on the same axle, was a pulley wheel F, which was connected by a string to pulley wheel R. This was on the same axle as the wheel S, which had a ring cut away from one semi-circumference. The end of this axle was in the disc T, which was set in the wall of the house. Only the lower half of disc T was visible, and this semi-circle had a ring of 15 glass roundels on its perimeter. Wheel F was half the diameter of wheel R, and the latter, together with wheel S, therefore turned through 180° while wheels F and G turned through 360°. Wheel G was provided with a pawl H, which prevented rotation in the reverse direction to that prescribed for the operation.

Layout of Equipment

It proved impossible to give a clear picture of the equipment by conventional plan and elevations, because so much of it is along a narrow band parallel to the wall. An isometric view was therefore shown (Fig. 6.1) which gives a reasonably clear diagrammatic view of the way the mechanisms functioned and of their interconnections. From al-Jazarī's dimensions it appears that the total height of the clock, from ground level to the top of wall was about 14′0″. No attempt has been made in the diagram to make the dimensional ratios between the various parts follow exactly those given by al-Jazarī, although none of them are greatly out of proportion. The rigging, however, follows al-Jazarī's directions. Wheel N turns towards the left, along the inside of the wall and hence towards the right from the direction of an outside viewer. This is the direction given for the peacock. Wheel Q turns in the opposite sense, as does the peahen, also in accordance with the text. From outside the roundels are covered and uncovered from the right, as stipulated in the text. It seems that with the inverted semi-circle the sun was to be imagined as beneath the horizon, moving from west to east with the observer facing south. On the other hand, it is assumed that Fig. 67 was drawn from inside the house, so that the operating arms for the chicks are as in Fig. 6.1. In any case this is unimportant, as the chicks both nod towards the centre of the *miḥrāb*.

Section 6

Wheels R and S performed a half revolution every $14\frac{1}{2}$ hours. At daybreak the nail was set in the hole in wheel R so that all the roundels were uncovered by wheel S. i.e. the larger semi-circle was on top, with the diameter between the two semi-circles horizontal. At nightfall wheel S was turned through 180°, and was in the position shown in Fig. 6.1. On the longest day $14\frac{1}{2}$ roundels were uncovered by daybreak. This is because constant hours were being recorded. For all other days and nights, therefore, some of the roundels would be unaltered – e.g. by nightfall on the first day of Capricorn only $9\frac{1}{2}$ roundels would have been covered.

Al-Jazarī says that the clock could be adapted to the solar hours, using the basic water equipment described in Chapters 1 and 2, together with the tipping-bucket. In this case it would have been necessary to alter disc T to carry only 12 roundels, and wheel G would have required only 24 teeth. The tipping-bucket would have been unchanged since the amount flowing in a solar hour from the flow regulator would have been the same as the amount flowing in a constant hour under a constant static head.

It is interesting that the disc carrying the roundels was made from laminated timber, to minimise warping.

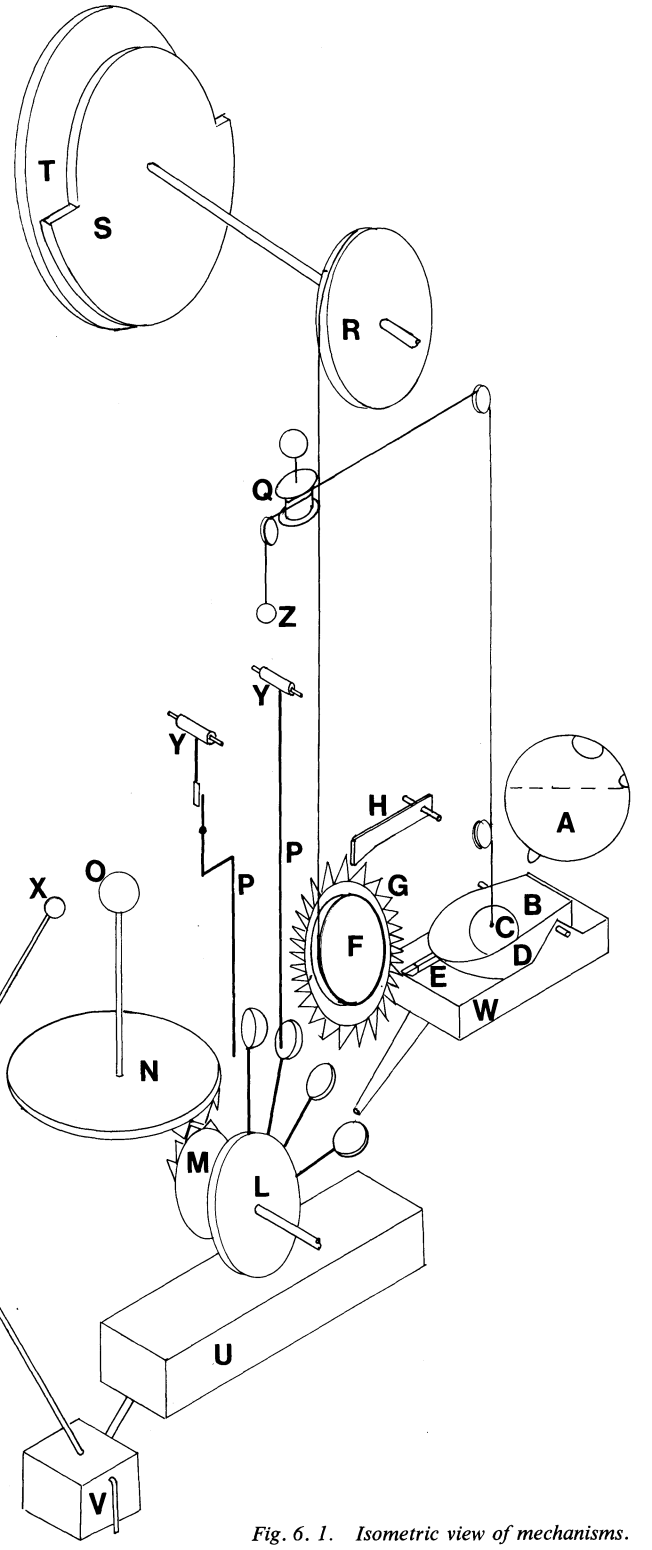


Fig. 6. 1. Isometric view of mechanisms.

Chapter 7 of Category I

GENERAL DESCRIPTION (FIG. 7.1)

This clock consists of a brass sheath or tube about 40″ long (taking the longer of the two dimensions given by al-Jazarī), set in a pedestal 15″ tall. The candle itself is also about 15″ long, and is encased in a second sheath which has its edges turned out to form a groove. When the second sheath is inserted in the first this groove forms a closed passage between the two sheaths – which are soldered together along the edges of the groove. The candle is divided into 14 sections, each giving an hour's burning time and it has a further length at the bottom equal to two of these sections. A channel is made as long as the 14 sections, and is divided into this number of chambers by vertical partitions. Fourteen balls are loaded into this channel, one to each chamber, and it is then lowered into the gap between the two sheaths, open side towards the candle and suspended from a hook inside the first sheath.

There is a flat dish fitted to the bottom of the candle. Two flat rods are soldered to the ends of this dish, and these hang down vertically below the dish, and have holes in their lower ends. Vertically above these holes are two small pulleys fitted to the sides of the inner sheath near its top. Strings pass from the holes, over these pulleys and down to a lead weight to which they are attached.

The main assembly is completed by a bronze cap which fits over the top of the outer sheath, where it is held in place by a bayonet fitting. The top of the candle is hard against this cap and its wick emerges from a hole in the centre of the cap. The bottom of the candle, in its dish, is at the same level as the bottom of the inner sheath, and the bottom of the lowest ball chamber.

When the candle burns and becomes shorter it rises in the second sheath. This is because an upward pull is transferred from the descending weight by means of the strings passing over the pulleys and down to the ends of the strips. When the lower end of the candle, with the dish on it, has passed the first chamber a ball falls from that chamber and a constant hour has elapsed – and so on until all fourteen balls have dropped from their chambers.

In falling the ball drops first into the pouch and its weight operates the arm of the slave as described clearly enough in the text. The ball then drops out of the pouch into the sloping channel across the diameter of the second sheath, runs from the channel into the falcon's head, and then drops into the pedestal of the candle-holder. The time is told by counting the number of balls which have been discharged.

Assembly of the Clock

Again it was felt that an isometric diagram was the simplest way of demonstrating the mechanisms since in this model so much would be concealed in a conventional elevation. Most of the first sheath and part of the second have been cut away to give a clearer view. The candle has been shown thicker in relation to its length than it actually was. (Fig. 8.1 shows the true proportions.) The length of the candle is given as $1\frac{1}{2}$ sp. or about 1.25 feet, and its weight as 160 *dirhams* or about 0.95 lbs. Taking the specific weight of the wax as 0.96, the diameter of the candle in inches is given by:

$$d:\ 12\sqrt{\frac{4\times 0.95}{\pi\times 62.4\times 0.96\times 1.25}}$$

Whence d is about $1\frac{1}{2}''$.

(Note that Wiedemann's calculation – p. 151, note 4 – is incorrect, since he erroneously read the length of the candle as half a span.)

The length of the candle is 1.25′, of the candle-holder 1.25′ and of the sheath 3.33′. Therefore there is about 0.83′ or 10 inches between the bottom of the candle and the top of the candle-holder, when the candle is about to be lit. Into this space must be fitted the sloping channel and the suspended pouch.

The length of the candle to be burned is $1.25 \times (14/16) =$ or about 1.10 feet.

The two strips attached to the bottom of the dish must therefore be more than 1.10 feet, since they must remain below the second sheath when 14 divisions of the candle have burned away. Similarly the weight must travel 1.10 feet in order to raise the candle by that amount. In Fig. 7.1 the weight and the two strips are shown at the mouth of the candle-holder, with the strips slightly lower than the weight. In Fig. 74, from the Oxford MS., sufficient travel has not been allowed for the weight, whereas on the pictures from the Istanbul 1315 and Dublin MSS, the weight has sufficient room.

In Fig. 74 the balls are shown too high – the top two divisions of the candle are not used.

Section 1

Al-Jazarī's care over the design and specification of this device shows true craftsmanship. The length and weight of the candle are prescribed as is the weight of the wick. The length burned in an hour is carefully ascertained. The cap is checked on a mandrel to ensure that it is perfectly flat, and it is held firmly in place with a bayonet fitting. Despite some obscurity in the text there is no doubt that this type of fitting was being described.

The candle-holder itself is not very clearly described but its main features can be deduced, particularly if reference is made to Chapters 8, 9 and 10, where the pedestal is hollow. It was made of brass and was probably cast, since a pedestal of plate brass would hardly have been stable enough to carry the superstructure. The word *qaṣʿa* is used for the pedestal, this word having the general sense of 'bowl', and when al-Jazarī says that the balls fell into the *qaṣʿa* he must mean the hollow area which surrounded the candle. In the later chapters, however, he refers to the inside of the *qaṣʿa*. so the word must apply to the whole pedestal or plinth, which is the main part of the candle-holder. The *barbakh*, he says, was pierced at its lower end to allow the sheath to pass through and it was soldered to the candle-holder. It seems, therefore, that the candle-holder, or rather the *qaṣʿa*, was made with a cylindrical hole in its centre, reaching partway down the pedestal, and closed at its lower end. The *barbakh* was probably a short hollow cylinder, also closed at one end, which was inserted into the hole in the pedestal. Presumably this was so that candles of different diameters could be used in the same holder, by using different *barbakhs*, all with the same external diameter, but which differing internal diameters.

Section 3

The operation of the slave's hand is perhaps a little ambiguous in al-Jazarī's description. The string from the pouch passed over the pulley and down to the extension from the slave's elbow. Forearm and extension turned about an axle in the sleeve which was set at an angle. When the extension was pulled up, the sword arm came slantwise down across the body. The slave is shown too low in Fig. 73.

The pouch like the pouch of a *manjanīq:* almost certainly the reference is to the machine operated by men pulling on a shaft, which rested on a fulcrum on top of a wooden tower. On the other side of the fulcrum, at the end of the arm, was a short sling carrying the missile pouch. The pouch shown here was of the type used in this engine, the type used in the counterweight engines being longer and heavier. In any case, the counterweight trebuchet was not in general use at the end of the 12th century. As al-Jazarī suggests, the rigging of this device must have caused considerable trouble. It can have been no easy matter to achieve a correct balance between the different variables of position, balance, weight and velocity.

N.B. The best general work on siege engines in Islam is: Huuri, K., *Für Geschichte des Mittelalterlichen Geschützwesens aus Orientalischen Quellen*, Helsinki 1941.

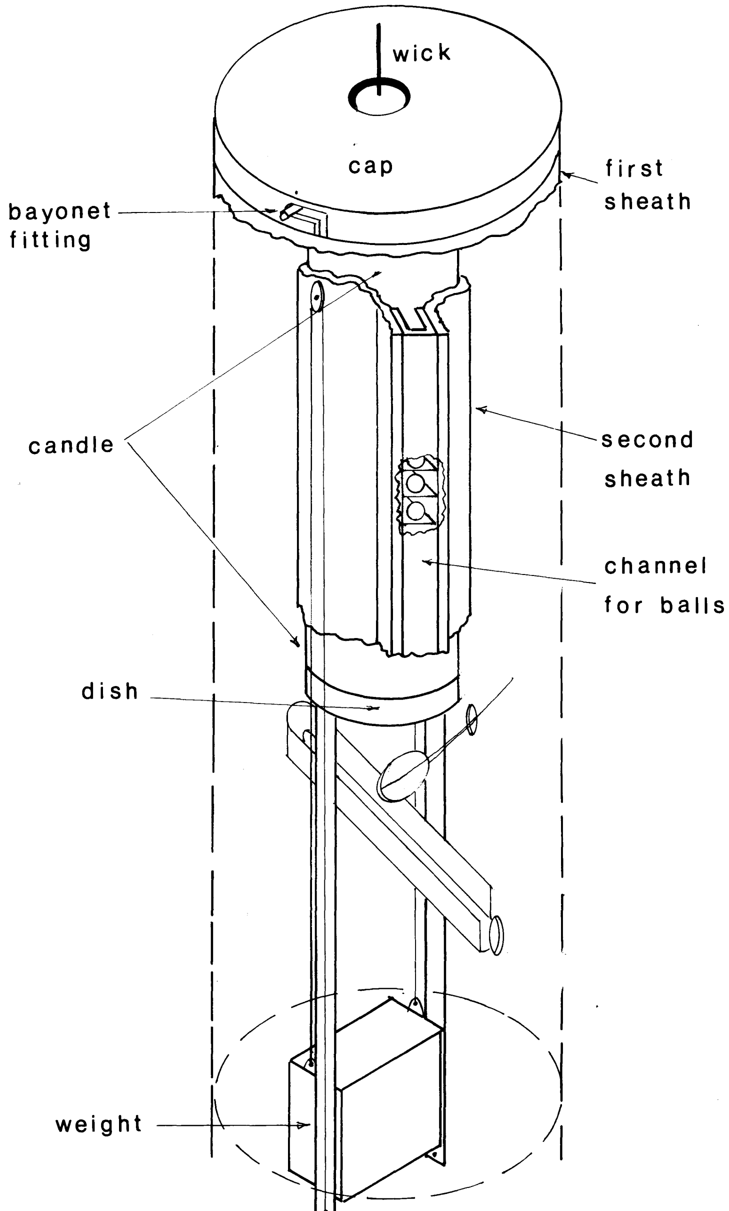


Fig. 7.1. Isometric.

Chapter 8 of Category I

GENERAL DESCRIPTION AND ASSEMBLY (FIG. 8.1)

Fig. 8.1 gives an elevation of the clock on its centre-line. It was possible to give a clear picture of the mechanism by a conventional view, because it is a simpler design than that of Chapter 7. In this pattern there is no second sheath – the candle is supported on a disc which is on the end of an iron rod. The side of the disc is connected directly to the top of the channel carrying the balls, which is divided into chambers as before, with their open ends facing the side of the sheath. The balls' channel runs in a guide channel, soldered to the side of the sheath. It is closed at the bottom to retain the balls' channel. When the candle rises the balls' channel is lifted, and the balls drop out, one after another, as they pass the hole in the sheath which connects to the hole in the falcon's head.

The rigging for this clock is also different from that of the first candle-clock. The weight has a wide channel in it, through which pass the rod and the back of the guide channel. The strings from the top of the weight pass over pulleys fixed to the wall of the sheath below the lowest level of the bottom of the candle. The strings pass through the groove in the weight and the ends are tied to a hole in the lower end of the rod.

A ring in the bottom of the weight is connected through a slit in the sheath to a pulley system in the hollow interior of the pedestal, on the opposite side to the falcon. The main pulley should have its circumference equal to the total travel of the candle, and is thus shown too small in Fig. 75. The axle of the large pulley turns a scribe, whose pen marks the hours at intervals of 4 minutes. This is a very similar system to those described in Chapters 3, 4 and 5.

Section 1

Wiedemann (p. 156, Note 1) suggests that the Yūnus mentioned may be Ibn Yūnus, the astronomer, who died in 399/1009.

One can appreciate that a simple cross-piece at the top of the candle would have allowed the wax to flow over the working parts, bringing the mechanism to a standstill. Al-Jazarī's cap overcame this disadvantage: presumably the wax collected in the hollow at the top and was removed regularly.

He gives the number of balls as 15 in this section, 14 in Section 2. The latter is correct, since the fifteenth would never reach the hole.

Section 2

The position of the mechanisms at the commencement of the operation is shown correctly in Fig. 8.1, in accordance with al-Jazarī's directions. In Fig. 75 the balls above the falcon's head would have been discharged. The upper part of the channel, obviously, was empty before the operation began.

It is not absolutely clear why the design used for Chapter 7 would not have worked for this model, as stated by al-Jazarī at the end of Section 2. The previous design, however, required a wider sheath, and probably this would not have left sufficient space for the pulley system.

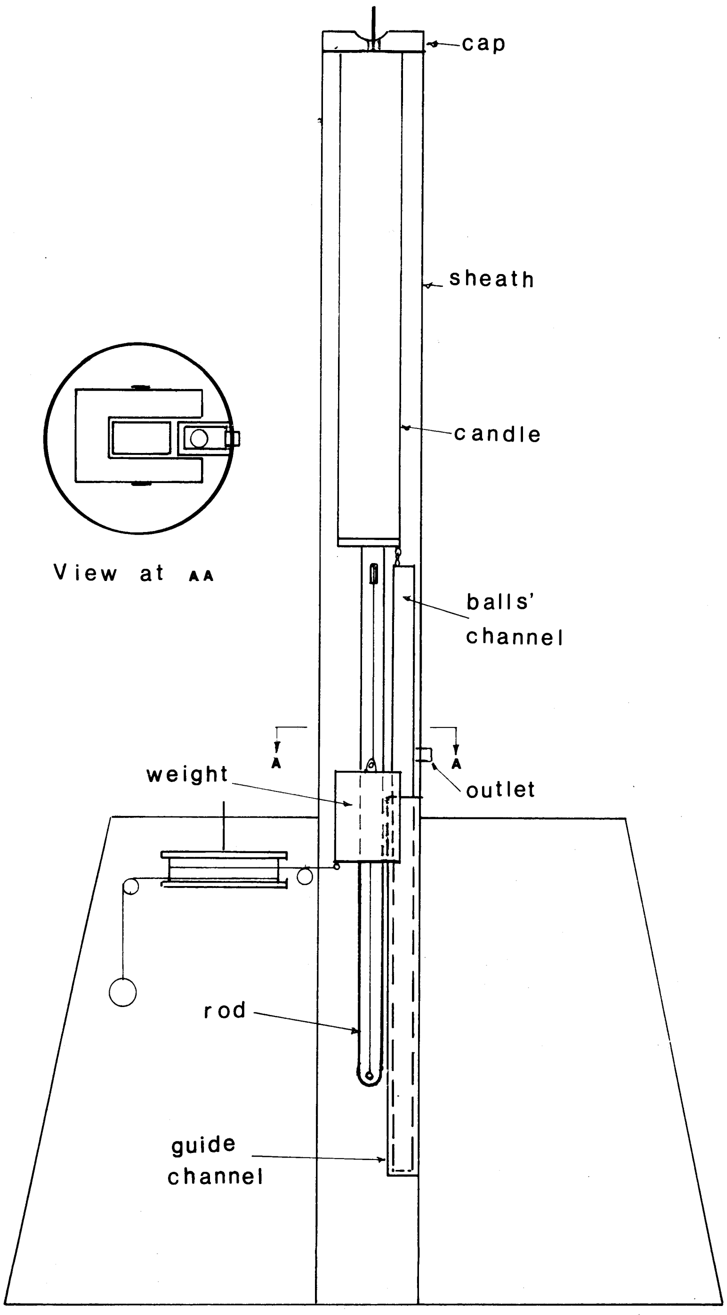


Fig. 8.1. View on centre.

Chapter 9 of Category I

It was not felt necessary to include explanatory drawings or detailed notes for this clock, which is very similar to the previous one. The main mechanism and the ball release are exactly the same, but the time recorder is on a straight line instead of a circle, and the rigging is therefore different. The 218 points in the side of the sheath represents the hours and their divisions, i.e.

$14\frac{1}{2}$ hours each with 15 divisions
$=217\frac{1}{2}$ divisions, or 218 points.

Chapter 10 of Category I

GENERAL DESCRIPTION (FIG. 10.1)

Again, the main mechanism and the ball release are exactly similar to those described in Chapter 8.

Section 2

The text says that the staple is on the door and the hook on the plate, but Fig. 77 shows the reverse. The latter was probably the actual arrangement.

Fig. 10.1A shows the arrangement of the door opening mechanism. (The ring cannot have been the same width as the inside of the candleholder as space must be allowed for the plates and their connections.) The figure is shown on the plate in relief, so that it passed through the aperture and pushed the door leaves apart. It then projected through slightly, holding the leaves open. This seems the most probable arrangement.

Fig. 10.1B shows the modified method for holding and releasing the balls, as mentioned by al-Jazarī at the end of the chapter. Instead of two channels – one fixed and one moving – there was a single channel, soldered to the side of the sheath with its open side outwards. There was a slit along its back through which the 'poker' passed. The end was fixed to the main rod, the other end was disc shaped and supported the balls. As the rod rose the balls arrived one after another at the outlet hole.

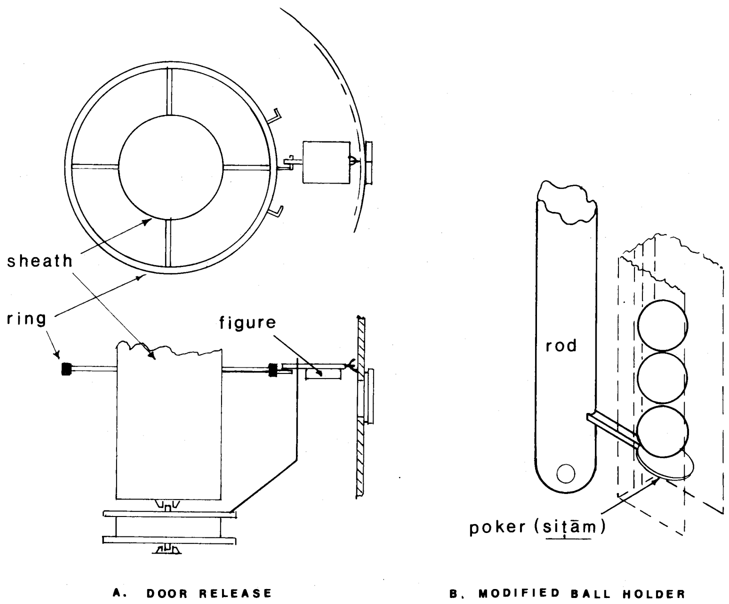


Fig. 10.1. Details.

Chapter 1 and 2 of Category II

The design and functioning of these devices is clear from the text and from Figs. 80 and 81.

In Fig. 80, the hole in the second cover through which the wine flowed is not clearly marked. It lay above the outside edge of the water-wheel, so that this was turned as the wine flowed over it. The purpose of the small protuberance in the centre of the second cover was to prevent the wine from running down the axle.

In Fig. 81 a pipe is shown covering the valve and valve rod, although this is not mentioned in the text. In any case, some kind of control would have been necessary, so that the valve could be replaced in its seating – either a pipe, or something to limit the travel of the rod.

The steward was apparently required to do a little play acting when setting down the second goblet, making a mock complaint about its weight to cover the action of lifting the valve rod.

Chapter 3 of Category II

GENERAL DESCRIPTION (FIGS. 13.1 AND 13.2)

Basically this device consists of a dais with short feet with columns on its corners which support the two 'castles'. These castles are brass boxes, the lower one containing the working parts and the upper one serving as the wine reservoir. Although al-Jazarī says that a copper tank is placed in the upper castle to contain the wine, it is possible that he made the shell of the castle serve this purpose. The machinery operates various jacks: a man who emerges from a door in the upper castle, a dancer in a niche in the side of the lower castle, four female musicians on a balcony in the lower castle, a slave-girl on the dais who dispenses drinks, and a horse and rider on a dome at the top of the structure. All of these except the first perform at intervals of about twenty minutes. The man emerges from the door only when the wine is nearly exhausted, after some seven hours of revelry.

The reservoir tank has a pipe passing through it from bottom to top. Sliding on this pipe is a float which operates the mechanism for the man behind the door. Through the centre of the pipe is an axle which connects the horse to a driving axle at the top of the lower castle. The wine drips through from the reservoir into a tipping-bucket at the top of the lower castle. The bucket tips after about twenty minutes, although this period will of course lengthen as the static head in the reservoir diminishes. From the bucket's trough the wine flows over the scoops of a water-wheel which has a small toothed wheel in its axle, which engages with a much larger, horizontal wheel. It is the axle of the latter which is connected to the rider's axle, which rotates slowly, the gear ratio being about 1:8.

From the trough of the water-wheel, the wine flows over the scoops of a second water-wheel. This also has a toothed-wheel on its axle which transmits rotation to a second axle by engaging with another wheel. This latter is not toothed, but consists of two discs with a gap between them. In the gap, connecting the perimeters of the two discs, are spacer bars, and the cog-wheel's teeth enter the spaces between the bars and thus turn the wheel and the axle. The axle carries the usual kind of lever arms for operating the jack musicians, together with three similar arms which turn the dancer. From the trough of the second scoop-wheel the wine runs into the usual kind of air vessel for operating the mechanical flute. It is then discharged through a siphon into the bore of one of the columns, runs through a channel fixed to the underside of the platform, through a pipe into the hollow body of the slave-girl, and into the specially constructed bottle. This tilts and the wine is poured into a goblet and handed to the reveller towards whom the rider's lance is pointing.

One wonders whether this was the sole means of serving drinks throughout the carousal. Nearly a litre of wine was produced at each dispensing but since the selection of the recipient was quite random, some of the revellers could have become completely drunk, while others remained sober – and disgruntled.

Layout of Equipment

The diagrams – Figs. 13.1 and 13.2 – show the flow of liquid through the system and the activation of the mechanisms. One cannot, however, be fully confident about the positioning of the various pieces of equipment, since al-Jazarī's directions are more ambiguous than usual in this case. Detailed points will be dealt with in the notes for the different sections. By way of example the most important ambiguity can be mentioned, which is the positioning of the tipping-bucket and the two water-wheels. The tipping-bucket and the lower water-wheel are said to be in the left-hand side of the castle, which is consistent with the position given for the outlet from the reservoir, and with the natural position for the flute's air vessel. But the upper water-wheel is said to be at the right-hand side of the castle, which would seem unnecessarily to complicate the pattern of flow – left to right, then back to the left. In the diagrams the upper water-wheel has therefore been shown with its surface parallel to the rear wall of the castle. Its position relative to the centre is of course determined by the large toothed wheel.

Section 2

The feed-pipe from its connection to the channel under the dais through to the outlet may be considered as a single rigid pipe. It passes through the slave-girl's hollow body, through the slit in the lower part of the bottle, through a slit in the upper part of the partition and discharges through its crooked end into the upper part. Its fulcrum is on the underside of the partition. As the wine flows into the upper part this becomes heavier, the bottle tilts, and discharge commences. The wine therefore never rises as high as the slit in the partition, and cannot flow back into the bottom of the bottle.

Section 3

The main drawing, Fig. 82, shows ideal proportions, which do not correspond to the dimensions given in the text. These are followed in Figs. 13.1 and 13.2. Also the section of the lower castle with the dancer in it could not have been made narrower, as shown in Fig. 82, as this would not have allowed room for the machinery.

Section 4

The wine reservoir fills the upper castle, except for a rectangular re-entrant to allow for the kiosk, and extends into the dome. It is not clear why this should be, since this capacity is several times the stipulated quantity of wine for the entire session, even allowing for the fact that it could never be more than half full because of the limitation due to the travel of the float.

The description of the man's movements does not tally with the movements which would be produced by the mechanism shown. Certainly he would open the doors eventually, but only gradually, not with a sudden forward lunge, and there is no provision for tilting him back and closing the doors. To achieve this he may have been provided with a counterweight, and strings connecting him to the door leaves.

The outlet from the upper castle to the lower is shown in the detail to the left of Fig. 13.1. This kind of connection was necessary so that the sections could be assembled and dismantled. For the same reason a joint is provided in the main axle connecting the rider to his wheel.

As mentioned above (Layout of Equipment) the directions for sizing and locating the various appliances are below al-Jazarī's usual standard, but they supply sufficient information to permit a reconstruction of power transmission and liquid flow.

One sympathises with al-Jazarī's warning about leaving the base-plate detachable so that the moving parts are accessible for repairs. Even nowadays it is not unknown for plants to be designed without sufficient thought for their maintenance. One must, however, cast some doubt on the period of 30 years before repairs were necessary. Many of the moving parts, particularly the bearings and the teeth of the cog-wheels, would have worn out long before this.

Throughout this work the woodwind instruments have been called 'flutes'. Neither of the Arabic words used by al-Jazarī, *zamr* or *nāy*, are flutes like those used in a modern orchestra. For further information on Arabic music, including bibliography, see Wiedemann II, 580/LXVI, 7.

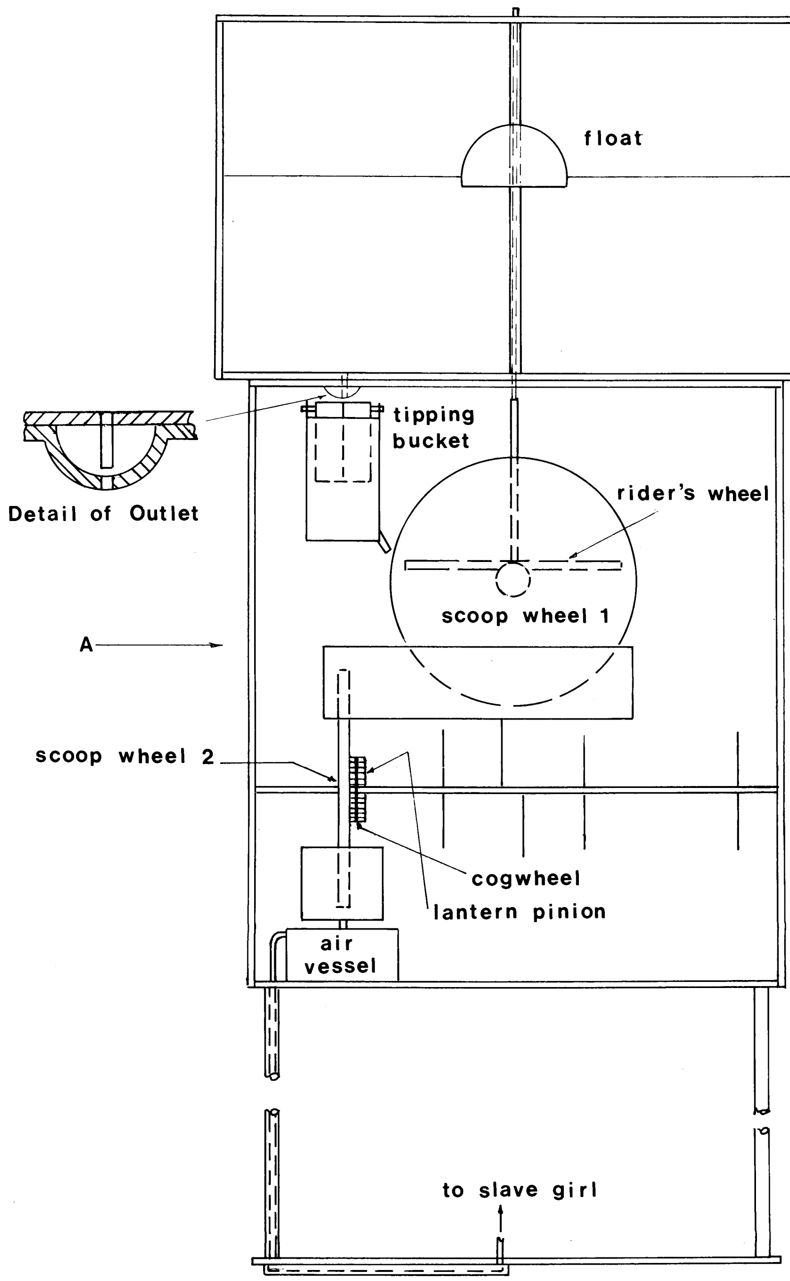


Fig. 13.1. View from rear inside.

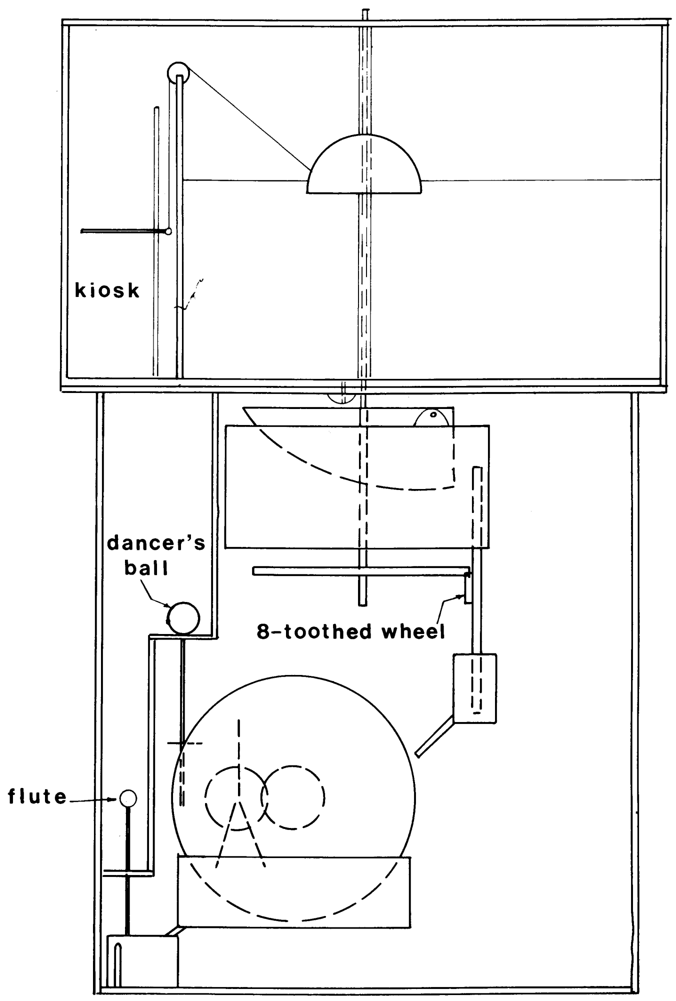


Fig. 13.2. View in direction A, *Fig. 13.1.*

Chapter 4 of Category II

It is not necessary to comment in detail on this device, nor to provide additional drawings, since the mechanisms and their layout are simple and have all been encountered in earlier chapters.

The treatment is perfunctory, both in the text and in the drawings. The figures of the two oarsmen, the chamberlain and the weapon bearer, mentioned in the text, are missing from all the drawings which are available, including those from the Oxford MS and the Istanbul 1315 MS.

No method is described for imparting movement to the sailors, which indeed could only have been done while the water was being discharged, not throughout the entire session. As in the previous chapter, the interval between successive discharges would lengthen as the static head in the reservoir fell.

Chapter 5 of Category II

GENERAL DESCRIPTION (FIG. 15.1)

This is basically a simple device, and the general principles of operation should be clear from the drawings in the text, and from Fig. 15.1. There are, however, some obscurities in al-Jazarī's description, particularly as regards the construction of the chamber. Some of the confusion arises from the failure properly to distinguish between various parts of the vessel, especially between the dome and the neck. Further ambiguity is caused by what appears to be a passage interpolated, perhaps from an earlier draft (See footnote 1) in which the fitting of the cover plates is anticipated. This makes it appear as though a second set of covers were fitted to the plates, whereas of course there was only one.

The sequence of fabrication appears to have been as follows:

(1) A hemispherical shell was made for the lower part of the pitcher, and a circular section was cut out from its underside. A large hole was cut in its side, near the bottom of the remaining piece, to receive the valve body.

(2) A disc was soldered into the shell, above the valve hole, to form the actual floor of the pitcher. Note that this could not have been inserted through the hole in the bottom because its diameter was necessarily greater than that of the hole.

(3) The shell for the dome and neck was made.

(4) A complete plate was made with the same profile as the pitcher from false bottom to neck. Three half plates were then made, with one side vertical, the other side with the same profile as the first.

(5) These plates were erected on the false bottom of the lower section. The complete plate was soldered to the sides and to the false bottom along a diameter, dividing the shell into two halves. The three half plates were then erected in the chamber on the opposite side to the valve

hole, at 45° to one another, forming four chambers, each one an eighth of the total capacity of the vessel. The half plates were then soldered to the false bottom, to the sides of the vessel and to the complete plate.

(6) The dome and neck were then slipped over the projecting parts of the plates, the lower perimeter of the dome adjoining the upper perimeter of the hemisphere. This joint was then soldered, as were the joints between the edges of the plates and the sides of the dome. A few inches of the neck projected over the top of the plates.

(7) Cover plates were then made for the five chambers, with the inlet pipes and ball valves fitted to them. The plates were then fitted to the tops of the chambers and soldered to the neck of the dome and to the top edges of the vertical partitions.

(8) The lower half-ball, with the inlet hole in its centre, was soldered to the neck of the dome.

(9) The valve, in the shape of a cow's body, was cast, complete with inlet chamber, valve seat and outlet channel. A plug was also cast and ground to a turning fit with the valve seat.

(10) A vertical row of six holes was drilled in the inlet side of the valve seat. A matrix was drawn on the plug through which holes were drilled horizontally through the plug, in a line inclined at 45°. As the plug turned in the seat, each of these holes lined up with a corresponding hole in the valve seat.

(11) A disc was soldered to the top of the valve seat, with a circular hole in its centre to receive the plug. The figure of a man was soldered to the top of the plug. His arm was outstretched, and when the plug was inserted in the seat his index finger pointed to the annulus of the disc.

(12) The holes were lined up in succession and the position of the index finger on the disc was marked for each alignment. By each mark the name of the appropriate liquid was written – one for each of the wines and two for water.

(13) The valve was soldered to the hole in the pitcher, below the level of the false bottom.

(14) Marks had already been made on the false bottom, marking the position of each chamber. Holes were made into the chambers, one for each of the wine chambers, two for the water chamber. These holes were connected by pipes to the corresponding holes in the valve seat, both ends of each pipe being soldered.

(15) The piece cut away from the bottom of the hemisphere (see (1) above) was replaced and soldered. The pitcher was placed on the pedestal, which covered the joint just made.

(16) The vessel was suitably decorated, and was then ready for use.

Al-Jazarī does not mention any small outlet holes for air in any of the chambers. These would have been necessary, both for the operation of the siphon and for the straight inlet pipes.

In Fig. 88 the neck is much too narrow and in Fig. 89 the lengths of the plates do not match the length of the pitcher, although the upper profiles are correct.

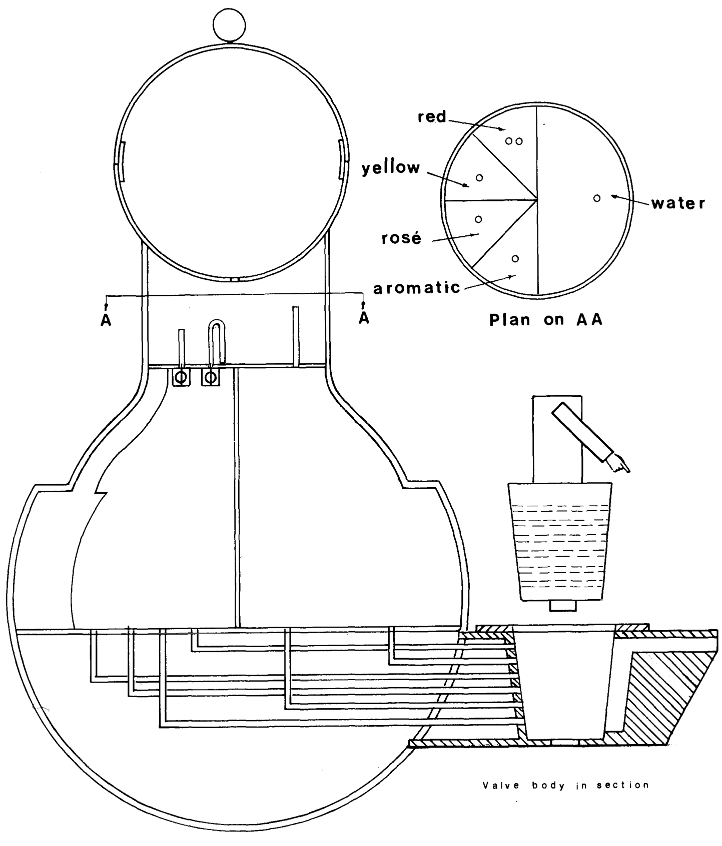


Fig. 15.1. Elevation (half of shell removed).

a single unit and tilt together about the axle through the hole in the rod at the end of the pipe. There was perhaps also a slight downward movement of the pipe which may have deflected as the load on its end increased.

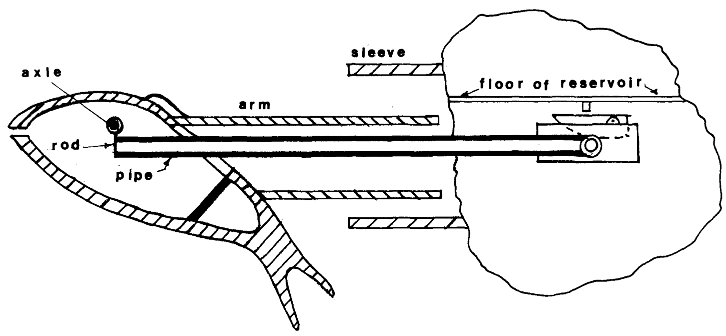


Fig. 17.1.

Chapter 6 of Category II

This simple device is adequately explained in text and illustrations. It should be noted that Fig. 97 does not depict the arms correctly: from the positions shown the right arm could not rise so that the goblet touches the lips, nor could the left arm sink so that the water-lily's stalk touches the thigh. Both would be prevented from completing their travel by the sleeves.

Chapter 7 of Category II

GENERAL DESCRIPTION (FIG. 17.1)

This is quite a simple device but the description of the construction and mechanism of the fish and the left arm in Section 3 is not altogether clear. Fig. 17.1 has therefore been provided to clarify this description. It is a section in the centre of the arm with the right-hand side cut away to show the inside of the figure. The forearm, hand and fish are virtually

Chapter 8 of Category II

This figure may be said to combine the functions of the figures in Chapters 6 and 7. In the former the supply was manual and the discharge automatic, in the latter the supply was automatic and the extraction manual. In the present figure both supply and discharge are automatic. Hence there is both a reservoir and a sump. The sump, formed from the man's belly, is not described in detail.

In the main drawing on Fig. 99 the bottle is obviously shown incorrectly; it must point downwards to allow the wine to flow under gravity. Two detailed drawings of the right arm are shown. The lower drawing apparently was added to correct the upper one, which is in fact a left arm.

Chapter 9 of Category II

In Fig. 100 the balanced channel should of course be shown with the fulcrum at its centre. The two struts *ṣṣ* should be at right angles to the plane of the drawing, not across the partition as shown.

The meaning of the passage, towards the end of Section 2, is simply that the first 20 *dirhams* discharge did not provide a head of water high enough to drive the water through to the outlet. After the discharge there was water in the pillar and water in the pipe leading through the man's arm. The static heads of these two columns of water were equal when the rising pipe was filled up to the man's elbow. A second discharge was necessary to provide a large enough head of water in the pillar to drive water out of the riser.

Chapter 10 of Category II

In Fig. 102 the iron bar is incorrectly shown – it runs horizontally along the back of the cupboard, a short distance away from it.

Chapter 1 of Category III

GENERAL DESCRIPTION (FIGS. 21.1 AND 21.2)

The two drawings Figs. 21.1 and 21.2 were provided, not because of any intrinsic complexity in the device itself, nor because of obscurities in the text, but simply because the main drawing does not give a very clear idea of the construction of the pitcher [Fig. 103]. The legend on Figs. 21.1 and 21.2 is as follows:

A	Upper cover
B	Lower cover with inlet holes and air outlet holes
C	Deflector, with groove along its centre
D	Deflector's axle
E	Cross piece
F	Lug from float
GG	The two funnels
HH	The funnels' spouts
J	Hollow handle
K	Pipe from cold chamber into handle. (Another pipe runs from the hot chamber but this is, of course, not shown because it is behind the plane of the section.)
LL	Closing plates for bottom of chambers
M	Single closing plate at bottom of pitcher
N	Strainer at end of pitcher's spout
P	Float
R	Walnut
S	Indicator rod from walnut
TT	Dividing plates
V	Plate dividing the spout into two outlet channels

The two drawings, Figs. 21.1 and 21.2 should be examined at the same time to obtain the clearest understanding. The gap between the plates TT has been exaggerated in the interests of clarity. To give rigidity they were joined together at the level of the line joining the spout to the lower end of the handle. This join is omitted in Figs. 21.1 and 21.2. It is not clear from the text whether there was a second such join near the top, or whether it was sufficient to bend the top edges of the plates down at right angles and then solder along the join.

Cover A, although shown in Fig. 104, is not mentioned in the text. It was of course necessary, to ensure that the vessel was airtight.

The long narrow spouts on the funnels were doubtless provided so that when the pitcher was tilted during pouring the back pressure was kept to a minimum. Similarly the outlet was provided with a kind of strainer to minimise the sucking-in of air through the pitcher's spout.

It is not clear why the servant was allowed to subject selected members of the company to a kind of ordeal by water, apparently threatening to pour very hot or very cold water on to their hands, or withholding washing water from them. It is another example of the considerable latitude that seems to have been allowed to this type of servant.

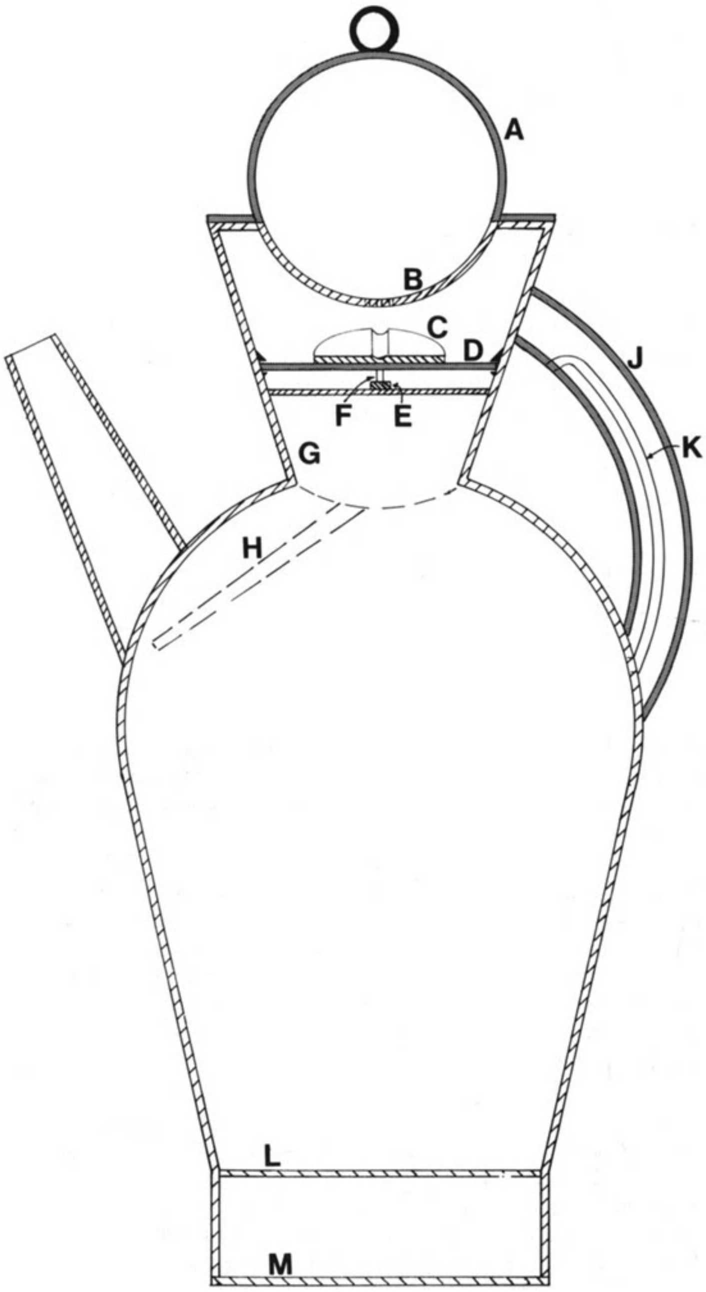


Fig. 21.1. Section between plates.

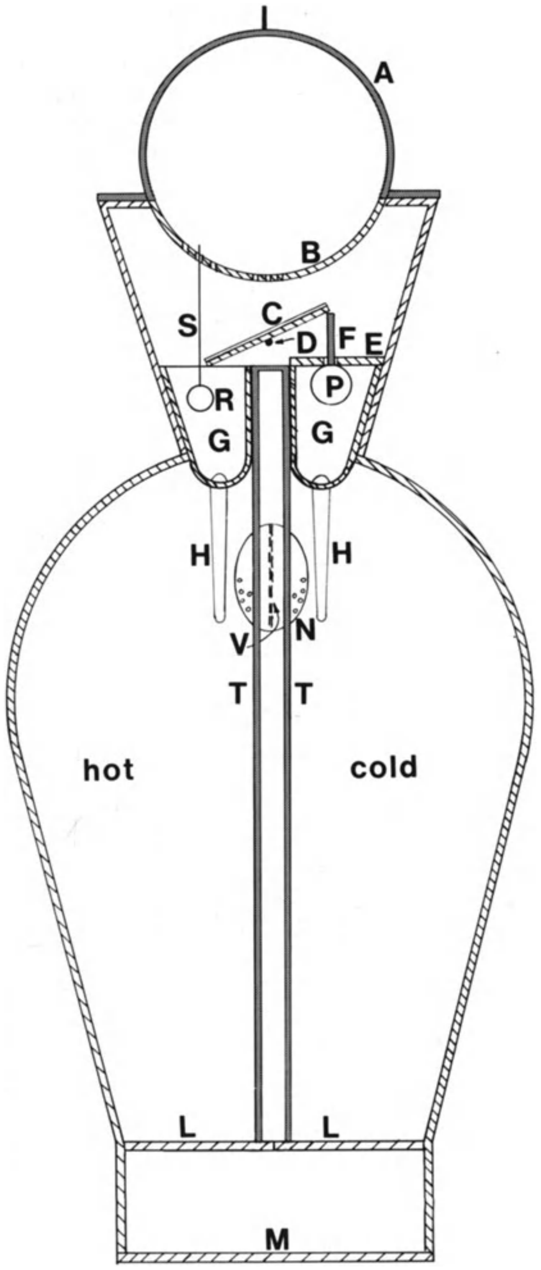


Fig. 21.2. Section across plates.

Chapter 2 of Category III

GENERAL DESCRIPTION (FIG. 22.1)

Legend to Fig. 22.1A and B.

A	Knob on top of upper cover.	L	Lower crossbar.
B	Valve rod.	M	Float
C	Upper cover.	N	Slot for retaining pin.
D	Valve plug.	P	Retaining pin.
E	Valve seat	R	'Duck's neck' siphon.
F	Hole through valve plug.	S	Plate dividing pitcher into two chambers.
G	Tipping-bucket.	T	Inlet hole in upper cover
H	Siphon in cover unit.	V	Inlet hole in lower cover.
K	Upper crossbar.	W	Ring and staple.

In this drawing the cover unit is shown about to be lowered into the neck of the pitcher; when fully inserted the bottom of the unit is just above crossbar K. The valve is shown open, although it would normally be closed until the unit was inserted – this has been done to show a section through the oblique hole. When the valve was closed, the ring and staple were directly above the handle, and in this position holes T and V coincided, and hence water could be poured into the upper chamber of the cover units.

The crossbar K is located so that the siphon R will discharge when the water reaches its upper edge. Hence water is poured into the pitcher until the float touches its lower edge. All that is required thereafter to set the siphon in motion is for the water level to rise above the upper edge of crossbar K. This water was provided from the cover unit by repeated fillings and dischargings of the tipping-bucket until the water reached the bend of siphon H. (Note that in Fig. 106 the bend in the 'duck's neck' siphon is much too low.)

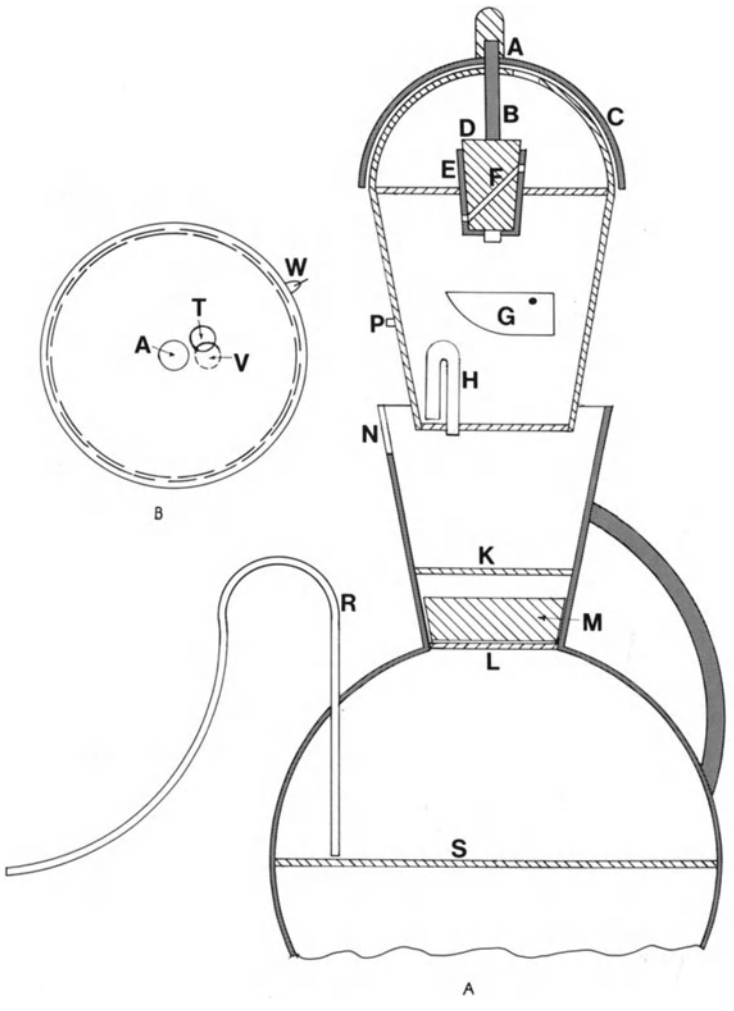


Fig. 22.1. A – *Section on centre.* B – *Plan on cover.*

Al-Jazarī suggests two simpler methods of setting siphon R in motion, both of which would have worked satisfactorily.

In the introduction and in Section 1 al-Jazarī mentions a bird which whistles on top of the cover unit after the pitcher is set down by the servant, but no description of any device for producing this sound is described in the text.

Chapter 3 of Category III

This device may be considered as an adaptation of the pitcher described in Chapter 2, together with some movements typical to al-Jazarī's jack figures. The reservoir, valve, and valve rod in the slave's body, are similar in design and function to equipment in the pitcher's cover unit, if this were adapted in accordance with al-Jazarī's second suggested modification. The pitcher is constructed in a similar manner to the pitcher in the previous chapter, with the addition of the narrow pipe for the whistle.

The reservoir, simply a small tank inside the slave's body, is not shown in Fig. 111. The catchpot (*ḥuqq*) was a cylinder with one end open. It was slipped over the end of the valve which protruded from the reservoir and the rim at the open end was soldered to the underside of the reservoir.

The indicator rod on top of the float is also omitted from Fig. 111. It was similar to the rod from the 'walnut' in Chapter 1. It had two small discs on its upper end to limit its travel. The upper one bore against the underside of the inlet funnel, and the lower one was restrained by some sort of projection in the slave's head.

Chapter 4 of Category III

This is simply the pitcher of Chapter 2 reconstructed in the shape of a peacock. As described it embodies the second modification suggested by al-Jazarī at the end of that chapter. The modification suggested here at the end of the chapter, is the first modification proposed by al-Jazarī in Chapter 2.

Chapter 5 of Category III

GENERAL DESCRIPTION (FIG. 25.1)

Although this device is simple enough, it was found necessary to make a drawing (Fig. 25.1) in order to obtain a clearer picture of the design. The width of the pedestal has to be taken as 4 fingerlengths, as if 4 fingerbreadths were taken there would be no room for the equipment.

The key dimensions are the diameters of the receiver and the large pulley. The former is given as 'that which can be encircled by thumb and middle finger with a gap one finger's breadth left between the two'. Say 2.25″ for the outside diameter, 2.1″ for the bore. Then 120 *dirhams* = .725 lbs approximately, and the specific gravity of milk is 1.05. This gives a maximum height of fluid of 5.3″, and hence a diameter of pulley of $5.3/\pi$ or 1.7″.

Taking these dimensions, and allowing for the positioning of the small pulley, and for the free movement of the float, the layout must be approximately as shown in Fig. 25.1. This point has been emphasised because of some discrepancy in the text, since al-Jazarī says that the aperture in the centre of the basin is one finger wide and that the string from the float passes through this aperture. This was, however, impossible. Fig. 113 contradicts the text, and shows very much the same arrangement as arrived at in Fig. 25.1. The miniature from the Istanbul 1354 MS, depicting the very similar device described in Chapter 6, shows a similar arrangement.

The moistening of the surface of the basin with a little water, before blood was poured into it, probably served a double purpose. One was to raise the float above the floor of the receiver, so that it started its travel as soon as the blood flowed into the receiver. The second was to reduce the surface tension between the viscous blood and the surface of the basin, so that the blood flowed freely into the outlet.

One cannot but feel that the patient must have felt some apprehension at having the extraction of his blood measured by this device, and the similar ones described in the following chapters. Friction in the pulleys, or any slack in the system, would tend to decrease the amount indicated as against the actual flow. Why not simply use a graduated cylinder?

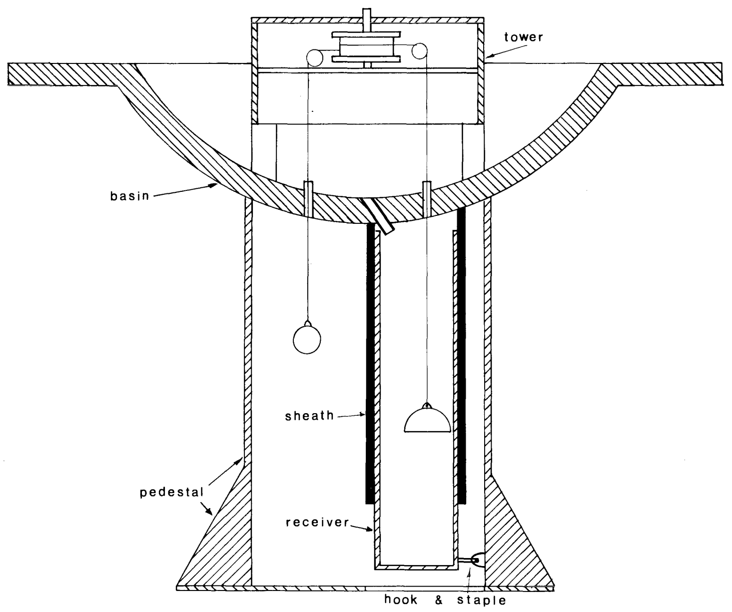


Fig. 25.1. Selection on centre.

Chapter 6 of Category III

This is very similar to the vessel described in Chapter 5, with the addition of the rising, graduated bar. The pulley system is not connected directly to the float, but to a hole in the graduated bar. The transfer of blood from the basin to the receiver is more clearly described here than it was in the previous section. Since the receiver is off-centre, a sloping channel is fitted beneath the central hole and passes through a hole in the side of the sheath into the receiver.

The drawings from the Istanbul MSS (Pls. XXII and XXIII) are better executed than the drawing from the Oxford MS [Fig. 115] where the rod is shown bent.

Fig. 27.1 shows the layout of a basin similar to this one: if the two forts were omitted from Fig. 27.1 it would then be almost identical to the device described here.

Chapter 7 of Category III

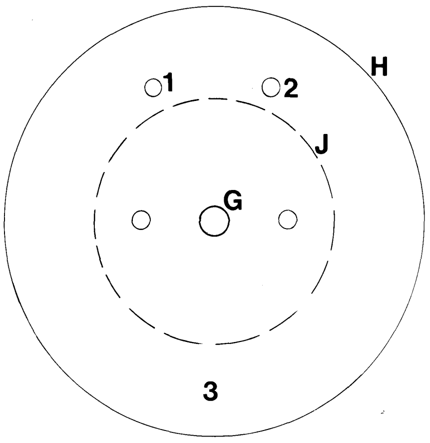
GENERAL DESCRIPTION (FIG. 27.1)

For additional clarification Fig. 27.1 (A, B, C) has been included. The legend is as follows:

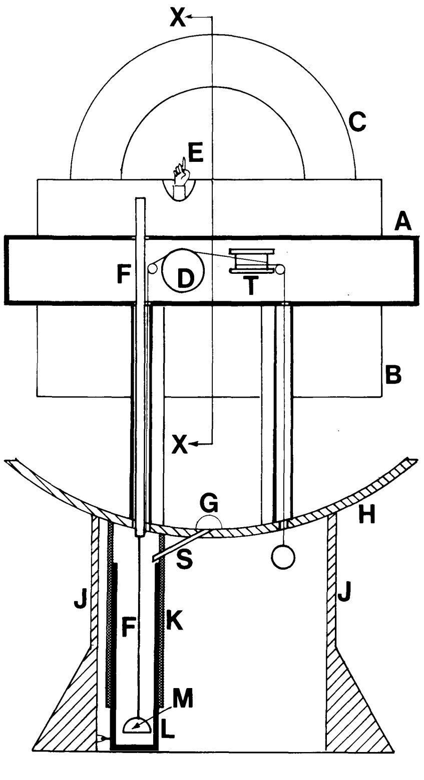
A	Platform	G	Dome over central hole
B	Lower fort	H	Basin
C	Upper fort	J	Pedestal
D	Pulley for 'hand' wheel	K	Sheath
E	Hands (shown as lines only on Fig. 27.1C.)	L	Receiver
		M	Float
F	Graduated bar, hammered into the shape of a board in its upper half, remaining as a rod in its lower half.	N	Weight
		P	Axle for wheels D and R
		R	'Hand' wheel
		S	Deflecting channel
		T	Pulley for rotating scribe.

N.B. the numbers 1, 2, 3 on Fig. A are used in the notes for Chapter 9.

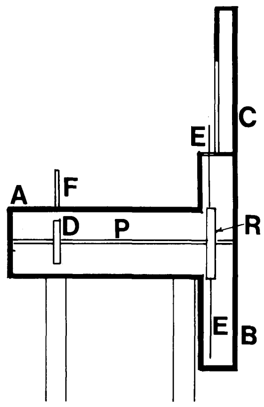
Fig. 27.1 B is drawn at the ten *dirham* juncture, although naturally one does not know whether the hand is indicating 'ten' correctly. The pedestal J has been shown somewhat wider than the one in Chapter 5,



A. OUTLINE PLAN OF BASIN FLOOR



B. SECTION ON CENTRE



C. SECTION ON X-X

Fig. 27.1.

shown in Fig. 25.1. This would have been necessary to obtain adequate spacing for the columns, and to ensure stability. Al-Jazarī does not revise this dimension in his text but indicates the change in his drawings – compare Figs. 113 and 115.

In Fig. 116 the lower fort is of course incorrectly positioned. It must be as shown in Fig. 27.1 B and C, so that the hands are concealed when they are at the lower part of their travel. The figure in fort C was evidently in bas-relief, since there is no room for a full figure. There was a gap, however, between his body and the beard, hand and forearm. The right hand passed through this gap.

There is a slight error in the text, concerning pulley D, which is said to be of the same diameter as pulley T. It must in fact have been somewhat larger, otherwise the first hand, indicating 'ten', would have re-appeared when 120 *dirhams* had been collected.

Chapter 8 of Category III

This again is very similar to the basins described in Chapters 6 and 7, except that a twelve-sided castle rests on six pillars and the two scribes are on top of this castle. The board, and the axle for the rotating scribe therefore go through this castle.

The mechanism for releasing the figures and opening the doors is exactly similar to that used for the candle-clock described in Chapter 10 of Category I, which is illustrated in Fig. 10.1A.

In Fig. 117 the detail for the ring carrying the hands is incorrect. The hands are not fixed radially but are around the perimeter at right angles to the surface of the ring.

Chapter 9 of Category III

This device can be understood easily when it is realised that it includes features from earlier chapters. Thus the basin on its pedestal, and the positioning of the columns, are similar to the layouts described in Chapters 6 and 7, and illustrated in Fig. 27.1. Referring to part A of this drawing, the slave carrying the jar is above column 1, and the other slave over column 2, the peacock's head is vertically over the position marked '3'. Both these columns are open from the floor of the castle through to the pedestal, and there is an aperture at the foot of column 1, at floor level, which allows the water in the basin to flow into the column. In the pedestal, below column 1 is a float with a rod on its top, which lifts the lever arm attached to the first slave, and tilts him forward. This float is in a small chamber and has its upwards travel stopped by a projection at the top of the chamber. The other float, which operates the second slave, is free to rise to the top of the pedestal, but has a short rod so that the slave is not tilted until the pedestal is nearly full. It is interesting that al-Jazarī, as usual, describes the sequence of operations for fitting the equipment into the pedestal. He does not merely describe the device in its completed form. Thus the base plate for the pedestal is cut into two halves; the float's chamber is soldered onto one half in its correct position; the float with the rod on it is placed in the chamber, the lug which restrains its travel is fixed to the chamber; the base plate is then offered up, the rod being inserted in the column, and the base plate is soldered to the pedestal. Then the other float is placed inside the pedestal with its rod up the column, and the other half of the base plate is soldered to the pedestal. Finally the joint between the two halves is soldered, as the pedestal becomes a watertight container.

The peacock itself is similar to the one described in Chapter IV except that there is a simple cone valve in the plate instead of a cylindrical valve.

Chapter 10 of Category III

This is very similar to the device described in Chapter 3, with the addition of the half basin on the side, and the re-location of the reservoir and the float to positions outside the slave's body. Also the level-indicator rod is omitted: it is not necessary, since the water in the tank is visible.

The valve is somewhat different in this device since it is on the same axis as the downpipe. A hole is drilled horizontally through the valve seat as far as he axis of the plug, and a hole is drilled along the axis of the plug from its underside, to meet the first hole. The valve is operated in the usual way by a rod fixed to the top of the plug.

Chapter 1 of Category IV

GENERAL DESCRIPTION (FIG. 31.1)

The fountains described in the following chapters all worked on the same basic principles. A house for the machinery was built at some distance from the pool in which the fountain was installed. It must have been accessible to the water supply – a stream or another pool – from which water was tapped to provide an adequate flow for operating the fountain. The house must also have been sufficiently high above the pool to provide satisfactory jets of water from the fountain.

These fountains all alternated, i.e. they changed shape at regular intervals. The device described in Chapter 1 was typical and operated as follows (see Fig. 31.1): inside the house were two adjacent tanks, and across the top of these was a pipe, oscillating on a central axis, and hence working like the arm of a balance (as usual the bearings for the axle are shown in the wrong plane in Fig. 121 – they should be vertical to the plane of the drawing). In the centre of this pipe was a funnel, into which the supply channel discharged. The pipe was tilted towards one of the two tanks. Most of the water ran into the tank from the end of the main pipe, but some of it was bled off through a small pipe, which had an onyx mouthpiece, into a tipping-bucket. This filled in one hour, and when it tilted to discharge its contents, a projection on its rear end lifted the main pipe and tilted it over, so that it discharged into the other tank, where the operation was repeated. The pipe then swung back into the first tank, and so on, at hourly intervals.

One pipe was led from the underside of each tank, the narrower of the two being inserted into the side of the wider one. The double pipe was then laid into the pool, and was brought up vertically in the centre of the pool. In this case the wider pipe was soldered inside a brass sphere with six holes in the upper part of the shell. These threw arcs of water in curved jets over the pool. The narrower pipe passed through this sphere and protruded a short distance above the top – it was soldered to the sphere. This produced a single, vertical jet of water.

The projections on the back of the tipping-buckets are mentioned in the text but are not shown on Fig. 121. They are, however, shown in drawings in later chapters, e.g. Figs. 129, 131 and 133, and they have been included on Fig. 31.1.

Fig. 31.1 is purely diagrammatic, to give a clear picture of the mechanism. Naturally, it was not possible to draw the various pieces in proportion, because the dimensions would have depended upon the flow, the static head of the supply and the delivery as well as the height of jet required.

For all these fountains it would have been necessary to site the house so that the static head above the pool was adequate. This presupposes the use of land surveying techniques.

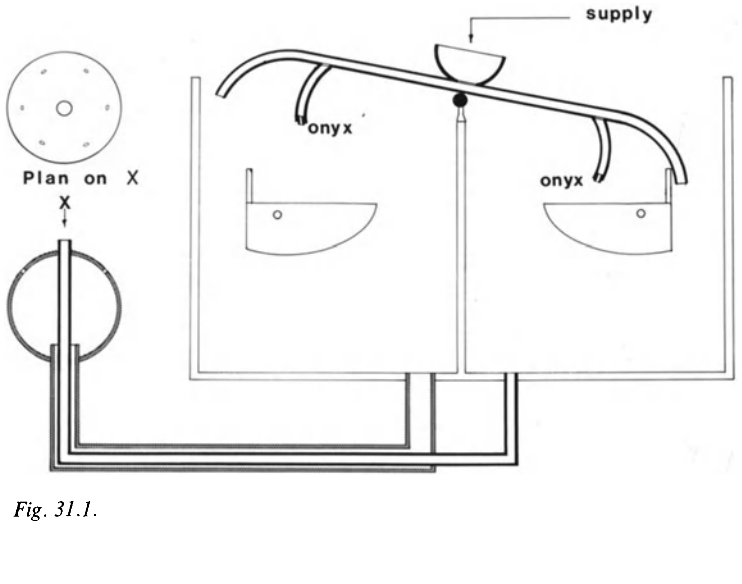


Fig. 31.1.

Chapter 2 of Category IV

This is merely an elaboration on the fountain described in Chapter 1. The arrangement for alternating the discharge, now into one tank, now into the other, is exactly the same as in Chapter 1. The arrangement of the delivery pipes shown in Fig. 31.1 is duplicated, and the second pair of pipes leads to a second fountain. When fountain *s* is producing a single jet, fountain *n* is throwing out water in arcs – and vice versa.

Chapter 3 of Category IV

This fountain differs from those described in Chapters 1 and 2 in that the water did not flow directly from the tank into which the pipe was dis charging. A tank was first filled, and the water was released when the valve was opened, and only flowed into the fountain until that tank was empty. Hence there was a shorter interval between changeovers – only quarter of an hour. Presumably the design was at least partially dictated by the profile of the ground: this design would be suitable for a fairly slow delivery rate and a moderate altitude of house above pool; the other designs were appropriate for a higher delivery rate and higher altitude.

The machinery inside the house is not difficult to understand from al-Jazarī's text and drawing. The floats must have been restrained from lateral movement by cylindrical wire cages, or something of the sort, which allowed the water to flow freely.

The instrument for producing the 'lily-of-the-valley' is not clearly described, nor does the sphere shown in Fig. 123 tally with the description given in the text. A *burniya* is, however, shown in Fig. 129 illustrating Chapter 6, where it was used to produce a 'tent'. The arrangement was perhaps as follows: the wide pipe *l* had a vessel shaped like the 'citron' of Chapter 5 soldered to its end; the narrow pipe *x* passed through pipe *l* and through this vessel, terminating slightly above the hole in the top of the vessel – this hole had a greater diameter than the pipe. Then a copper section, shaped like the top of an urn, was soldered to the top of pipe *x*, so that the 'citron' together with this extension then resembled the vase or urn, called a *burniya*. The 'citron' filled from pipe *l*, the water impinged on the extension piece, and sprayed out in the shape of a lily-of-the-valley. Pipe *x* must have been continued above the extension, and bent over, so that it emitted an arc.

Chapter 4 of Category IV

This bears the same relationship to the fountain of Chapter 3 as does the fountain of Chapter 2 to that of Chapter 1. The pipes were duplicated and two fountains alternated continuously. The addendum describes the addition of two further pipes so that one fountain displayed two forms while the other was displaying one, then vice versa.

Chapter 5 of Category IV

GENERAL DESCRIPTION (FIG. 35.1)

The text does not pose any special difficulties but since al-Jazarī's drawing [Fig. 126] is not very clear in certain details Fig. 35.1 has been added. This has been provided mainly to show the operation of the two valves with the central plug, with the outlets and also the fountain-head. It may also be of service however, in illustrating the construction of the tank, tower and channel. The channel was covered over, as shown. The purpose of the long pipe on the left was to ensure that the water level was contained within the system.

The fountain-head should be clearly understood from Fig. 35.1. As shown the 'tree' was produced by a fitting similar to the 'rose' that is fitted to watering-cans and garden hoses, except that there was also a single larger hole in the centre to provide a wider vertical jet.

The weight marked 'A' is shown on al-Jazarī's drawing but not mentioned in the text. Perhaps it had to be added later when it was found that the system did not alternate properly without an additional counterweight.

Note that some of the letters are missing from Fig. 126.

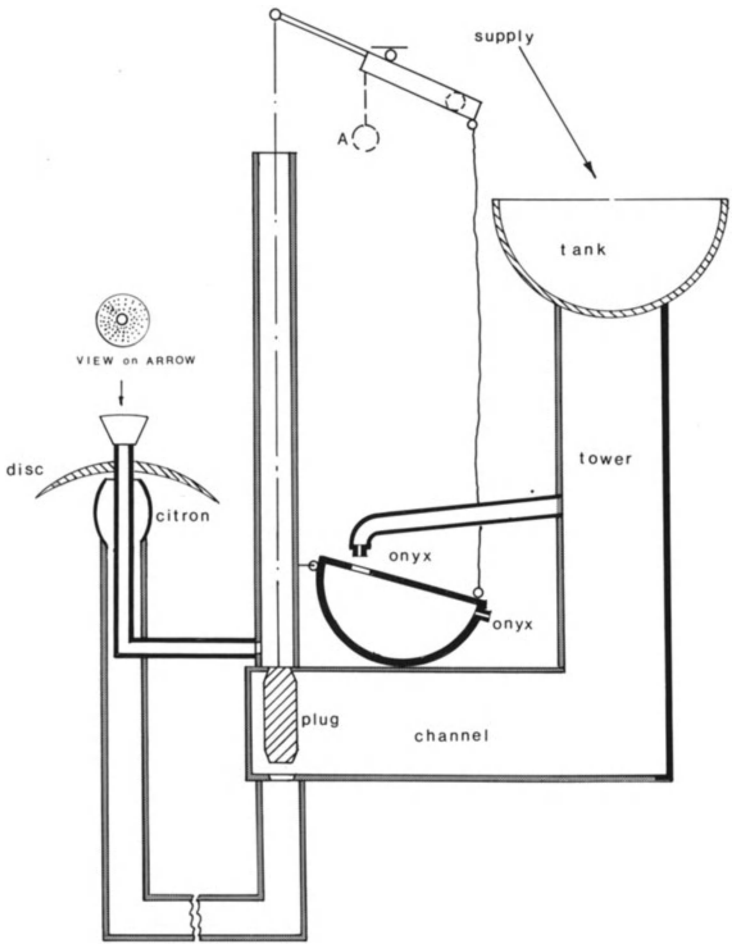


Fig. 35.1. Section.

Chapter 6 of Category IV

This is a very similar device to the one described in Chapter 5, except that the balanced pipe is tilted by the tipping-buckets, instead of by the tilting bowl.

Parts of Section 2 and Section 3 are missing from the Oxford MS, but fortunately these are included in both Leiden MSS. The translation of this passage was made from the Or. 656 MS, since this is a copy of the Oxford MS, while the Or. 117 MS was used as a control. The beginning and end of the lacuna have been indicated in the text by the letters 'a' and 'b' respectively.

Fig. 128 is also omitted from the Oxford Graves 27 MS, so the illustration shown here has been reproduced from the equivalent drawing in the Oxford Fraser 186 MS.

There is, however, another illustration in a similar position in the Oxford Graves 27 MS, which is reproduced as Plate XXXII. No description of this is given in the text; the caption to the left of the stanchion merely states: 'this device (*shakl*) is not included in the fifty devices'.

Chapters 7–10 of Category IV

Mention is made of early authors who dealt with automic flutes in Part 1, p. 9, p. 12.

Apart from one or two minor difficulties, none of these four devices presents much difficulty.

Chapter 7 (Fig. 130)

The detail at the top of the tank is incorrectly shown – it is more accurate, although still imperfect, in the drawing in the Dublin MS. The tanks were completely closed at the top with concave plates, semicircular in section. Near the outside of the wall of each tank there was a depression in the cover with a hole in it. The chain passed through this hole. On the other side of the cover was a narrow hole with a pipe on it, which carried the flute's jar. This jar did not touch the sphere, as erroneously shown in Fig. 130. Presumably there was a guide on the valve plug to ensure that it dropped into the seat.

Chapter 8

One of the clearest drawings [Fig. 131] in the whole work.

Chapter 9

Again a clear drawing.

Chapter 10

Basically the upper tanks are continuations of the lower ones, connected by a hole, so each siphon must rise to the upper limit of its float's travel. The principle is very similar to that used in the fountains described in Chapters 3 and 4.

Chapter 1 of Category V

The shape of the 'ladle' is shown in Fig. 44.1. It is a scoop, with the stem formed into a channel through which the water runs into the outlet channel. The latter is not shown in al-Jazarī's drawing [Fig. 134], on which, incidentally, the animal has been drawn upside down.

The runged wheel y[1] is similar to the one described in Chapter 3 of Category II (see Fig. 13.1). If its diameter is the same as that of the partially toothed wheel s, then the latter must be toothed for slightly more than one third of its diameter to allow the teeth to engage fully and then to turn wheel y through slightly more than 90% since the ladle rises slightly above the horizontal.

Chapter 2 of Category V

Only two drives are described in the text: cogwheel k to runged wheel f to ladle s, and coghweel y to runged wheel n to ladle m. The description of the movement tallies with the presence of two drives, since there is said to be a quarter revolution between the release of the first ladle and the lifting of the second. The drawing [Fig. 135] therefore shows al-Jazarī's third modification, i.e. with four drives; (indeed a space is indicated for a fifth). On Fig. 135 the runged wheels are drawn much too large. If indeed the cogwheels were toothed for exactly $\frac{1}{4}$ of their diameters, then the runged wheels would have to be slightly smaller than these. Judging by his remark at the end of this chapter, al-Jazarī obviously took pride in the fact that his modified versions were more efficient than the model described in Chapter 1, since idle time is progressively reduced as more drives are added.

Of greater importance, however, is his remark about the self-regulating properties of the machine with four drives, and the necessity for having the 'weight' exactly right. Interestingly, the word he uses for 'regulating' is *ḍābiṭ*, which in modern technical Arabic means 'governor' or 'regulator'. In effect he is saying that with four drives the out-of-balance forces were greatly reduced, provided the system was properly balanced (in the modern sense) before being put into use: It is therefore most unfortunate that he gives no information about the sizes of the various components, and the materials used in their manufacture – much less information than he gives, for instance, for some of his clocks. Nor does he give any details about the bearings, but of course, this omission is general. Were such information provided one could make a most interesting structural and dynamic analysis of the machine.

Chapter 3 of Category V

GENERAL DESCRIPTION (FIG. 43.1)

One can reconstruct the vertical dimensions as follows: the chamber is 8 sp. deep, and the scoop wheel's axle is on its centre-line. The vertical axle is 12 sp. long and thus 8 sp. of it is above the floor of the pool. The Sindī wheel is 4 sp. in diameter, so, assuming its axle coincides with the tip of the vertical axle, its top is 10 sp. above the floor of the pool. The actual lift of water will therefore be a little less than 10 sp., allowing for the clearance of the jars in the pool, and the outlet channel below the top of the Sindī wheel. This is, therefore, not a large plant, the total height of the timber work around the pool being 11 sp., or about 9 feet. The pool itself seems to have been about 6 feet square. Judging by the materials used in its construction – copper and marble – and the instructions given for adornment of the parts, its purpose would seem to have been at least partly decorative, not simply functional. Some other device was included in the installation, but we are given no description of this.

The functioning of the device can be readily understood from al-Jazarī's own illustration, given that the cog-wheels and the scoop-wheel are, as usual, drawn in semi-perspective. An overflow pipe is shown on the left of the pool, but is not mentioned in the text.

[1] More correctly, a 'lantern pinion'.

The construction of the Sindī wheel is shown in Fig. 43.1. The discharge was in the centre of the wheel, so only the rear rim was spoked; the front wheel being supported by the horizontal slats that connected it to the rear rim. The outlet channel could therefore be installed between the two rims, as shown. It must have been clamped securely to the scaffolding, since it is acting as a cantilever from the structure to the centre of the wheel. For the sake of clarity only two jars have been shown and their size is exaggerated. This makes it appear as though some of their contents would spill over the collecting channel but this is merely due to the distorting effect of this exaggeration. The word Sindī indicates that the provenance of this design of wheel was Sind, the semi-arid region in the north-west of the Indian sub-continent. This area had been for centuries within the Arab sphere of influence; indeed the first incursions are said to have occurred in the days of Umar I, in the 1st/7th century. (See Balādhurī, *Futūḥ*, p. 430 ff.)

This device is notable as being the first of only two of al-Jazarī's machines in which the water wheel is the prime mover. The second is described in Chapter 5 of this Category.

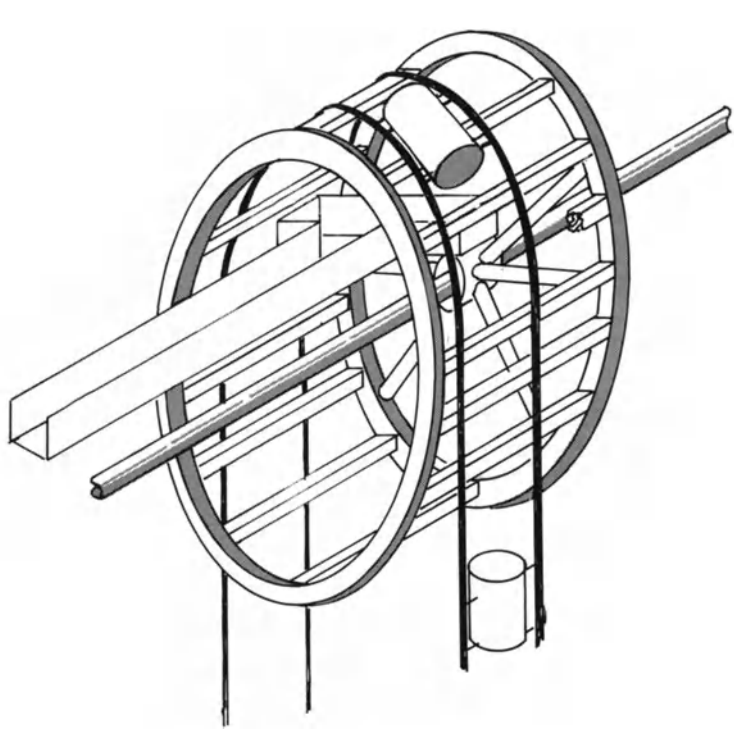


Fig. 43.1. Isometric of wheel.

Chapter 4 of Category V

GENERAL DESCRIPTION (FIG. 44.1)

This device is simple enough in conception but Fig. 137 is badly drawn, even allowing for the usual conventions employed by al-Jazarī. Fig. 44.1 shows the actual layout. It seems unlikely that lever-arm j was vertical when the ladle was at its lowest inclination since the lever-arm would then have been excessively long and the ladle would have risen well above the horizontal. The end of the crank did not therefore move symmetrically in the slot, but had a longer travel towards the scoop. In Fig. 44.1 the discharge position has been indicated with the dotted lines, and the outlet channel v, not shown by al-Jazarī, has been added.

This device has two features of great interest. One, of course, is the conversion of rotary motion to linear motion, by means of a crank operating in a slot. The second is the severity of the stress pattern imposed on the system. Fig. 44.1 is drawn to the dimensions given in the text, except that the end of the ladle projects further from the top of the well than the 2 sp. stipulated by al-Jazarī (the gear wheels have been shown conventionally, with only the pitch circles of the teeth drawn). As the ladle approaches the horizontal something like 30 feet of ladle – a load of water and wet timber – is opposed by a couple exerted by dowel b

and axle ṣ. There is therefore a high bending stress in the crank. Similarly the torque transmitted from the animal, through the capstan and the two cogwheels was considerable. Great care would have been necessary, therefore, in the manufacture and fixing of the various components, particularly the two cogwheels and their bearings. In a modern assembly the bearing blocks would be held firm by anchor bolts cast into a concrete foundation. One wonders, in fact, whether the fittings were strong enough, and rigid enough, to endure this heavy duty for very long. There was probably a good deal of play in the bearings to add to the problems posed by shear, bending and torsional stress, and one therefore imagines that breakdowns must have been frequent.

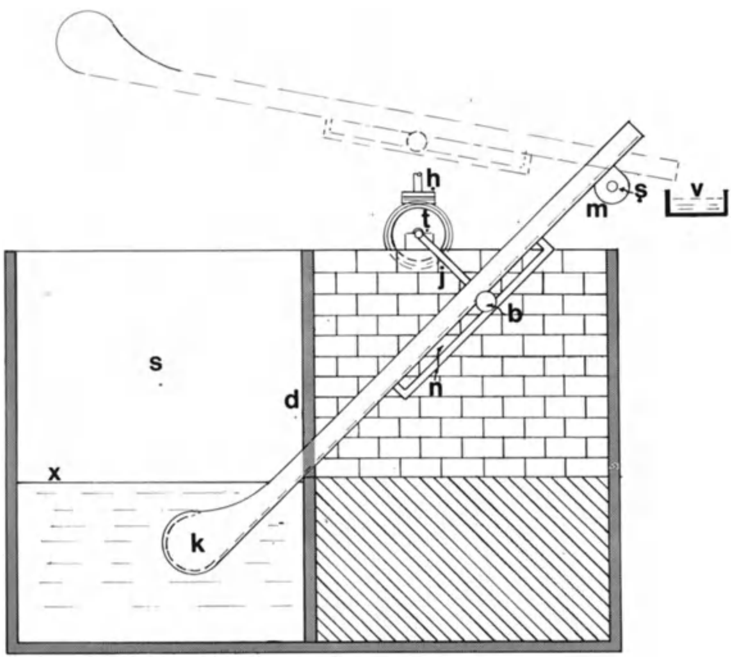


Fig. 44.1. Section.

Chapter 5 of Category V

This Chapter is really quite straightforward, but some confusion may arise if al-Jazarī's sequence of thought is not understood. He is considering the disc with the eccentric peg as the activator of the pump, and first of all he describes two ways of rotating this disc. In the first version the disc is horizontal and is connected directly to a horizontal water-wheel by a vertical shaft. In the second version the disc is vertical and has teeth on its perimeter; these teeth mesh with the teeth of another vertical wheel that is driven by a vertical water-wheel on the other end of its horizontal axle. (It is unfortunate that the illustrations depicting this second type of drive – Fig. 139 in this book – are almost incomprehensible in all the available manuscripts.)

Then he ignores the source of power for the time being and concentrates upon the pumping machinery. He describes the construction of the box and its equipment with the box lying flat, probably because it was most convenient to build it in this position. The toothed disc is flush with the end of its axle, and the axle runs in a bearing on one of the triangular faces of the box, and in a ring bearing (presumably supported by a bracket) close behind the disc. Since the width of the box was 2 sp. the axle was only about 9 inches long, and could be supported quite rigidly in this way.

It should be noted that by describing the disc as toothed al-Jazarī is anticipating its use with the second type of drive, since no teeth are necessary if it is driven by the horizontal water-wheel. And indeed he concludes by describing the assembly of the complete machine, *but only the second version*, powered by the vertical water-wheel. The box is therefore lifted into a vertical position.

Fig. 141 gives a good general idea of the assembly. The only errors are that the left-hand piston-rod is shown disconnected from the rocker-arm, and that a disc with teeth is shown on the paddle-wheel.[1]

This machine embodies four noteworthy concepts: a paddle-wheel used as a prime mover; rotational motion converted to reciprocating motion; the use of two horizontally opposed cylinders, producing a double-action effect; the use of true suction pipes rather than a drowned suction. It is also interesting that al-Jazarī says that his cylinders and their associated equipment are similar to, but larger than, the ejectors used for hurling naphtha in warfare. This is one of the few direct references we have to the construction of the so-called 'Byzantine siphon'.

[1] The first error occurs also in the drawings from the 1354 Istanbul MS and the Leiden Or. 656 MS. The second error occurs only in the Oxford MS and in the Leiden Or. 656 MS. The drawings in the Dublin MS and in the Leiden Or. 117 MS show a completely correct assembly.

Chapter 1 of Category VI[1]

GENERAL DESCRIPTION (FIG. 46.1)

This massive door was composed of two leaves in cast brass, each about 15 feet high and 5 feet broad. The brass sections were nailed to heavy wooden door-leaves, nails being cast into the brass sections for attaching them to the wood. These timber leaves are not, however, directly mentioned by al-Jazarī. This chapter is, of course, mainly of interest in that it supplies important information about the development of casting techniques in the late 12th century A.D. in Western Islam.

The centre of each door leaf was composed of a lattice-work pattern, and this was bounded by brass plates *a* which carried Kufic inscriptions and leaf motif decorations. In Fig. 142 the only decoration shown is a lateral inscription across the top of the lattice-work. This reads 'the dominion is God's, the One, the Conqueror' (*al-mulku li-llahi al-wāḥidi al-qāhiri*). Outside this inscribed plate was a border *b* made up of a number of brass plates placed end to end. The plates were decorated with copper leaves cast into the brass, and with chiselled brass leaves. Above the transverse part of this border was a brass plate *d* and this was crossed by a transom *e* which carried a row of ornamental nails *f*. The top and bottom rails and the doorpost styles consisted of strips of cast brass *c*. The closing-style *g* of each leaf was a handsome column, its central section was a half round pipe, decorated with silver inlay and with painted leaves, its ends were rectangular in section, their faces decorated with leaves in bas-relief – brass leaves balanced by copper leaves. Other decorative details, and descriptions of the manufacturing methods are given in the text.

Apart from questions of details, which are dealt with below, there are omissions form the description which makes it a little difficult to understand at first reading. There appears to be no mention of the manufacture of the inserted plate *a*, nor are any fixing nails mentioned for the border *b*. Plate *d* was presumably held in place by transom *e*, which was furnished with nails.

Section 1

Most of this section is covered by the general description given above. It is to be noted that the round moulding on the centre of the lattice-work bars, and the small pipes at the side of the central section of the closing-style are mentioned here, but are not referred to when the manufacture of these components is described.

In the closing paragraph of this section al-Jazarī seems to be calling attention to the difficulties inherent in making a working drawing for a design of this nature. And indeed these difficulties are formidable without the advantage of modern engineering drawing techniques.

Section 2

The general pattern of this lattice-work is shown in Fig. 46.1. The geometry of the design is such that it can be fitted together easily in recurrent patterns, being based up 90°, 45°, and 30° angles, and their complements. When the main shapes had been cast, the various filler pieces were made, i.e. the domes with their bases [Fig. 144], and the three other shapes [Fig. 145]. These were provided with a rim, half the width of the bottom of the bars which formed the stars and the quadrilaterals. The bars rested on these rims, so that when the bars were nailed to the woodwork the whole assembly was held in place. This is shown on the left-hand drawing on Fig. 46.1, in which only the nails have been omitted. (The base for the dome must have been cast integrally with the dome and its plinth, as implied in the text.) There is some difficulty in interpreting al-Jazarī's instructions about setting the nails, since he says that the nail is pushed into the sand so that the top of the nail almost touches the sand (p. 192 line 33). This can only refer to the lateral placing of the nails, since it would hardly have done to have buried the decorative nails in the molten brass. Some clarification comes from the caption written by the side of the drawing of the nail [Fig. 143a], which reads 'thickness of the bar and its side, with one nail in it'. The rectangular section of the bottom of this drawing therefore represents the bar, the upper part is the decorative head of the nail, and the lower part is its spike, which is drawn too wide and too short.

Section 3

Border plates *b*: from the description given, there are two possible interpretations of the method used. First, the pattern for the copper leaves may have been cut right through the base strip (the word *kharrama* can mean a full perforation, or merely a chiselled engraving). The wooden pattern, somewhat thicker than the brass plate was laid in the sand, and an impression was taken. The brass plate was then laid front face downwards in the sand and the copper poured on to its back. The copper ran through, filling the pattern, and then forming a layer on the back up to the thickness of the wooden pattern. The copper layer on the back would thus be integral with the copper in the cut out design, and would act as a retainer. Alternatively, the pattern would have been engraved in the brass plate, which was laid face uppermost in the impression made by the wooden pattern. The copper would then be poured on to the face of the brass up to the top of the impression. Afterwards the surplus copper could have been filed off the unengraved part of the brass, leaving only an inlay of copper in the excised part.

The second method seems unduly wasteful. Why not merely form a small tray around the engraved section and pour the copper on to that? There seems little point in covering the entire strip, only to have to remove most of the copper afterwards. The first method seems to have been the one that was most likely to have been used, particularly as it would have ensured that the copper inlay did not fall away after the door had been in use for some time,

Closing styles *g*: the description of the manufacture of the central section is a sketchy, but accurate account of the *cire-perdu* process. The pattern is first made in wax, and inside of it is packed with clay (plaster in modern practice). Then nails, which al-Jazarī mentions here, are pushed from the outside through the wax into the core. These nails are left protruding outside the wax. Then a clay 'investment' is built up outside the wax. The investment has wax sticks in it which lead up to the pouring hole. The wax is then burnt out in an oven – in modern practice this 'firing-out' can take as long as 24 hours at temperatures up to 600 °C. The firing-out serves the additional purpose of baking the core and investment to the required hardness. The molten metal is poured into the pouring

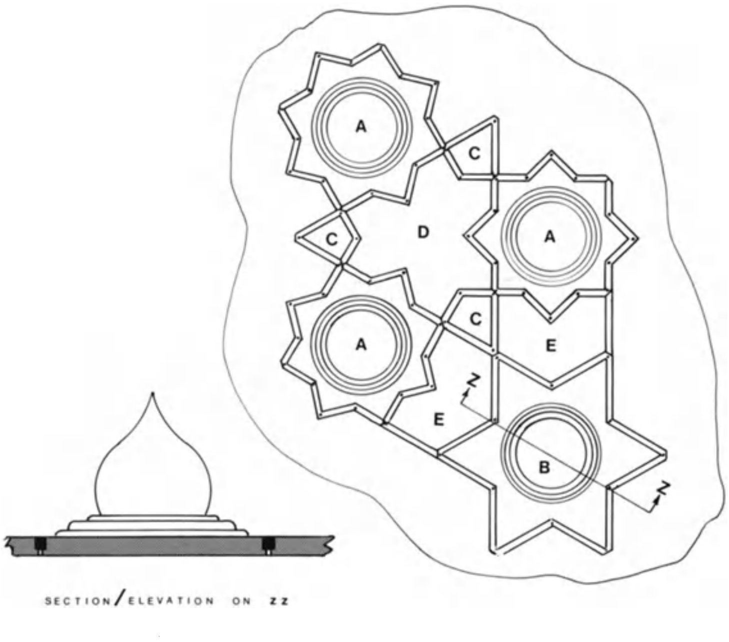


Fig. 46.1. Part of latticework.

[1] The letters shown in square parentheses are not in the text. They have been added as an aid to understanding and are shown on the equivalent line drawing, E.142.

hole, runs down the ducts in the investment left by the firing-out of the wax sticks, and then runs up into the mould. When the mass has cooled the clay is broken away and the surplus metal is filed away.

For the leaf patterns on the ends of the styles al-Jazarī first made a bas-relief pattern in brass. Then he matched this pattern with a symmetrical pattern in wax. He placed the plate face down in the mould, and obtained an impression of the complete design. The plate was then taken out of the mould and the wax was removed, by cutting where possible, by burning in the inaccessible parts. The plate was then placed in the mould and the molten copper poured in through a channel cut into the sand. The copper would then fill only the places left by the wax, since the rest of the impression was occupied by the brass. When the plate was removed the finishing touches of the leaves were made with the appropriate tools.

In modern practice sand is placed on top of the pattern to hold it firmly in place and to keep the molten metal homogeneous, i.e. free from blow-holes and inclusions. Pouring ducts are left in the sand on one side of the pattern, with similar ducts on the other sides as escape holes for the gases.

There seems every reason to believe that these casting techniques were well-developed in al-Jazarī's milieu. His references to foundry-masters and to foundry apparatus, as well as his descriptions of the techniques, all point to the existence of a well-established industry.

Chapter 2 of Category VI

This simple instrument, as first described, is merely a vertical straight edge mounted on the centre-point of a graduated ruler. This is then adapted as a protractor by setting the alidade to various measured angles, drilling the semicircle on the ruler of the various positions, and marking the angles by the holes. The use of the instrument for the surface of a sphere is mentioned but not described: presumably both the ruler and the alidade had to be curved to suit the curvature of the sphere.

Angles are specified as quintuple (*mukhammas*), sextuple (*musaddas*) etc. The acute sextuple angle, for instance, is 180/6 or 30°, while the obtuse sextuple angle is $180° - 30 = 150°$.

Chapter 3 of Category VI

Before one considers this somewhat complicated locking device in any detail, attention must be given to a few anomalies in al-Jazarī's drawings and text. The disc shown in Fig. 154 should have a second circle, indicating the hole for the cylinder, as in Fig. 156. This latter erroneously shows a bird's head instead of the projecting knob specified in the text. The disc-and-cylinder assembly shown in Fig. 155 should in fact be larger than the similar assembly shown in Fig. 157. The disc illustrated in Fig. 160 should be the same size as the disc in Fig. 161, and there is a radial tooth omitted from the inner circle (the drawing is shown correctly in the Dublin MS). In Fig. 163 the rod of the 'earring' is too short. On Fig. 166 the left-hand of the two pegs marked *k* should be on the other side of tooth *m*. Footnote 4 calls attention to al-Jazarī's method of describing what one sees on his plan view of the underside of the plate. He tells us that we see only one circle for discs 1, 2, 3 and 4 because there are concentric and have equal diameters. He then says that we see disc 5 and the end of the almond's rod with the cotter through it, and also the end of the earring's rod with the cotter through it. In fact the cotters are not shown, but they are indicated by single lines in the equivalent drawing in the Dublin MS.

GENERAL DESCRIPTION (FIGS. 48.1 AND 48.2)

This device consists of 4 circular combination locks in the lid of a chest. The setting part of each lock passes through a horizontal plate which is on the underside of the lid. The three discs which are the opening and closing operators are held to the barrel of the lock, below the lid, by a fourth, smaller, disc retained by a cotter through the central rod of the lock. (Although al-Jazarī makes no mention of this, the plate was probably given additional support by small brackets attached to the walls of the chest). The three large discs each had a triangular notch in its outer perimeter: when all the notches on all four locks were aligned the lid of the chest could be opened.

The plate was cut through the centre by a zig-zag line, and on the centre point of this cut there was a hole. There was a key-knob (the 'earring') on the centre-point of the chest's lid and the shank of this key went through a hole in the lid and through the hole in the plate. The end of the shank was rectangular and passed through a rectangular hole in a small disc located on the underside of the plate; the disc was held against the plate by a cotter through the end of the shank. This disc had four triangular cams on its perimeter, which bore against four pegs, two fixed to the left-hand side of the cut in the plate, two to its right (see Fig. 166, bearing in mind, as mentioned above, that the left-hand peg *k* is incorrectly located.) On the underside of the plate, were four vertical lugs ('almonds'). The operative part of each lug was triangular in cross-section, and the apex of each triangle almost touched the perimeters of the three large discs. When the triangular notches in the discs were in line, on each of the four locks, the lugs could enter the notches, and the locking device could be opened. This was done by turning the 'earring' anti-clockwise: two of the cams on the small disc then bore against left-hand peg *l* and right-hand peg *k*, forcing the plate apart. Similarly, a clockwise turn closed the plate. The obliquity of the cut served to allow the pegs to be set wider apart laterally than would have been the case with a straight cut, hence increasing the leverage. For additional leverage, however, a draw-bar was provided at either end of the chest's lid. When the plate had been closed, the notches on all four locks were moved out of alignment, to re-lock the chest.

On the centre-line of the plate's edge, at one side, were two hook-like lugs. The end of a latch, hinged to the outside of the chest, passed through a hole in the vertical edge of the lid and, when the two halves of the plate were apart, it came between these two lugs. There was a hole in the end of the latch. When the two halves of the plate were brought together the lugs entered this hole, and the lock was thus closed.

One combination lock, and the latch mechanism, are described in detail below.

The combination lock (Fig. 48.1)

Fig. 48.1 shows a section through the lock (A–from Wiedemann and Hauser, p. 238, Fig. 29a), and drawings of the various components (B–J) as manufactured, but before assembly. The legend is as follows:

Unit B (elevation) a_3 – almond 3
r – rod

Note: The retaining lug (q in Fig. 165) has been omitted. This would have had to be very short to pass through the hole in cylinder z, and the holes in discs 3, 4, 5. The hole in disc 6 would have required enlarging to allow it to pass through.

Unit C (elevation) a_2 – almond 2
k – knob, for turning unit
d_2 – disc 2
c_2 – cylinder 2
m – nicks

N.B. Here and on unit D the nicks are merely indicated conventionally. They may have been shaped to give a more positive fit with the tooth, or they may have been set radially.

Unit D (elevation) a_1 – almond 1
b – bird's head, for turning unit
d_1 – disc 1
c_1 – cylinder 1
p – nicks

Unit E (plan) d_4 – disc 4
f – tooth
y – notch

Unit F (plan) d_3 – disc 3
e – tooth
x – notch

Unit G (plan) d_5 – disc 5
z – notch

(The 16 small holes are also shown)

Unit H (plan) d_6 – disc 6
i – nail

Unit J (elevation) g – cotter (*faras*)

The same nomenclature is repeated in section A, which shows the lock assembled in the lid and in the plate. On this drawing n is marked on the triangular lug fixed to the plate.

The method of assembly can be followed from Fig. 48.1, read as a whole. Unit D was placed in the hole in the lid and was held flush with the lid by a_1 and b. Unit C was then dropped into unit D, and unit B into unit C. At this juncture a_1 was set to the required letter on the lid's circle, a_2 to the required letter on the circle of disc 1, and a_3 to the required letter on the circle of disc 2. Then unit F was slipped on the end of cylinder 1, with its notch x opposite lug n, its tooth e entering one of nicks p. Unit E was slipped over the end of cylinder 2, with its notch y opposite lug n, its tooth f entering one of nicks m. Unit G was slipped on to the end of rod r, its notch z opposite lug n. With the units held in position, unit H was slipped on to the end of rod r, its nail entering one of the 16 holes on disc 5, and the cotter was pushed home. This was the 'open' position, and a record was made of the three letters – on the lid, on disc 1, and on disc 2 – which made up the opening combination for this lock. The procedure could, of course, have been followed in reverse, assembling the lock at random, bringing the notches d, y, z into line opposite lug n, and then recording the letters indicated by the three almonds.

A similar procedure was followed for the other three locks. Any of the locks, or all of them, could be dismantled and reset to different combinations whenever desired. The locks were closed by turning a_1, a_2, and a_3 at random.

N.B. For reasons of clarity Fig. 48.1, section A, shows a special case, with all the almonds in line when notches x, y, z are also in line. A full elevation of the almonds can therefore be illustrated. Each almond could, of course, be on any one of sixteen angular settings.

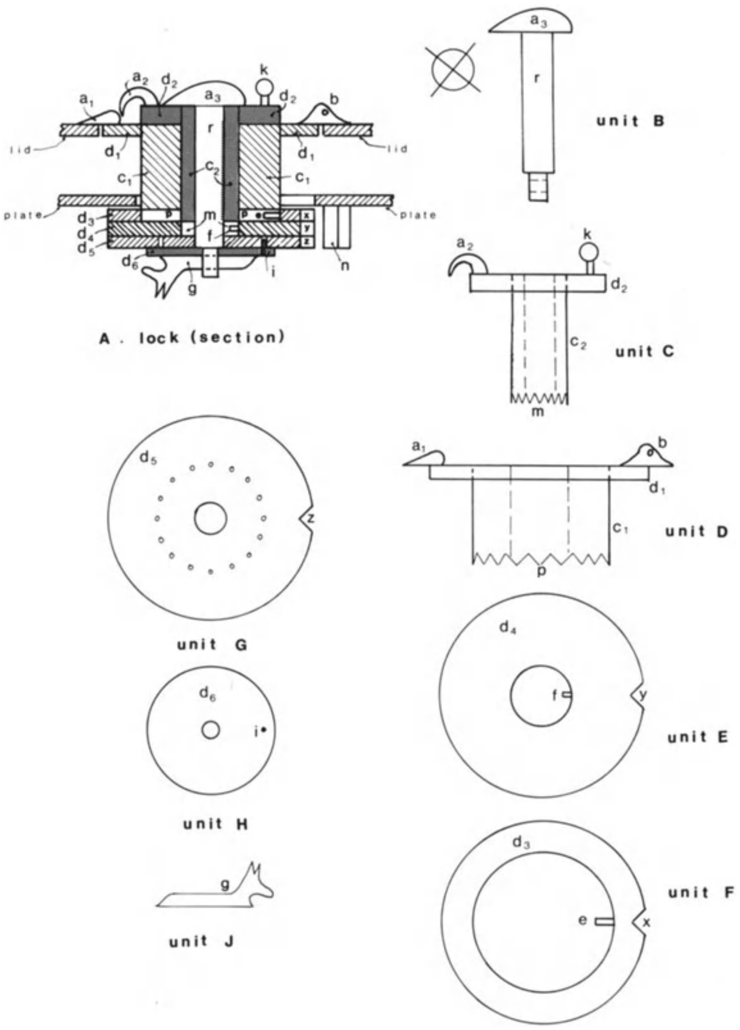


Fig. 48.1. Lock details.

The Latch (Fig. 48.2)

The latch is shown in Fig. 48.2: on the left is a section through the side of the chest, immediately to the side of the latch, to the right is a section on line xx (from Wiedemann and Hauser p. 240, Fig. 30a).

The legend is as follows:

a – lid	f – hole through lid
b – wall of chest	g – one half of plate
c – latch	m, m – hook-like lugs on plate
d – arm of latch	s – head of latch
e – vertical edge of lid	

The drawing is self-explanatory. It is a weakness of this design that the hinge of the latch is on the outside of the chest. It would therefore have been simple to force the chest open by inserting a crowbar between the latch and the chest, and levering forcefully. It would have been better to have fixed the hinge inside the chest, and to have brought the arm out through a slot in the wall of the chest.

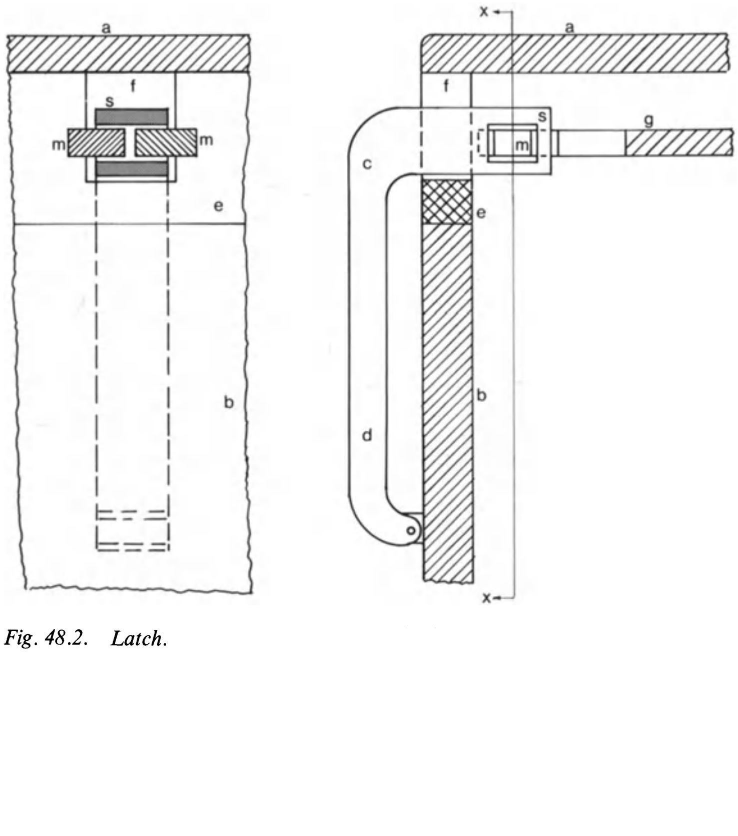


Fig. 48.2. Latch.

Chapter 4 of Category VI

GENERAL DESCRIPTION (FIG. 49.1)

This chapter does not appear to present any special difficulties, and the mechanism is well described in the text. The arrangement of the bolts is shown in Fig. 49.1A. The short bolts were undoubtedly fabricated as shown in this drawing, since the total thickness of short and long bolts is given as 4 F. In other words, the short bolts were not toothed along the recess, but along one of the narrow sides of this recess. One can only speculate as to the purpose of the thicker portions left at the end of these bolts. Indeed, if Fig. 172 is drawn correctly there would appear to have been similar sections on the end of the long bolts, although these are not mentioned in the text. (In Fig. 172 these sections are shown turned through 90°). Doubtless they had something to do with the method used for holding the ends of the bolts secure, and perhaps also for limiting their travel.

The legend on Fig. 49.1 is as follows:

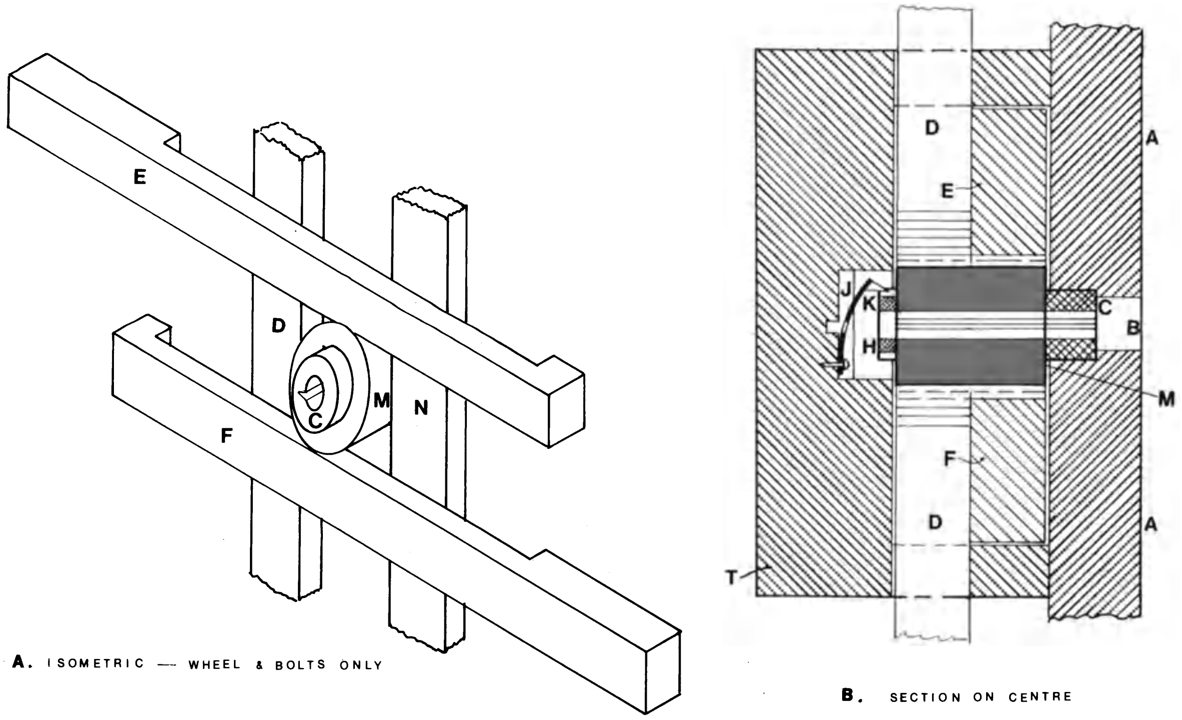
e, f – short bolts	c – cylinder on end of main cog-wheel
d, n – long bolts	b – entry hole for key
k – spring and pawl	j – slot for receiving spring when it is pushed back by the key
h – small cog-wheel for restraining movement	t – tray (*qafīr*)
a – door	
m – main cog-wheel	

As stated in Footnote 1, the thickness of the tray must have been 4 fingerlengths. The thickness of two bolts together is 4 F, and there must have been a reasonable thickness of timber left in the tray after cutting.

One or two comments on al-Jazarī's drawings are necessary. In Fig. 167 the length of the recess is too long in relation to the length of the bolt. In Fig. 170 the short bolts *ṣ*, *x* should be shown on top of the long bolts *q*, *m* at all four intersections. (This error does not occur in the equivalent drawing on the Dublin MS.) In Fig. 172 the cog-wheel is drawn square; this drawing and Fig. 170 are drawn with the long bolts running laterally.

Chapter 5 of Category VI

This is basically a sinking-float, or *ṭarjahār*, with the sailor acting as an air-vessel, so that when the boat submerges the air is driven through the pipe into the mechanical pipe. The small holes in the sailor's cap were presumably to allow the air to escape while the boat was slowly sinking. They would, however, be too small to prevent most of the air rushing into the pipe during the final rapid submersion of the boat.



A. ISOMETRIC — WHEEL & BOLTS ONLY

B. SECTION ON CENTRE

Fig. 49.1.

GENERAL NOTES

Category I – Clocks

WATER CLOCKS

Various related words are used for clocks, and the meanings seem to be interchangeable. Thus in his introduction to Category I, al-Jazarī uses *binkām* pl. *banākīm* but adds that one also says *finkān* pl. *fanākīn*. The latter is the word most commonly used throughout his work. Occasionally *minkāb* occurs. In Riḍwān the term *sāʿa* occurs, and this word is also used in the Arabic version of Philon (Carra de Vaux (3), 77). In the title of the pseudo-Archimedes the word is *binkām*, but in the sound feminine plural *binkamāt*, not the broken plural used by al-Jazarī.

The first two clocks in al-Jazarī's work are clearly derived directly from the clock described in the pseudo-Archimedes,[1] and indeed this derivation is clearly indicated by al-Jazarī. The basic mechanism is very similar in both clocks but al-Jazarī's flow regulator was carefully calibrated whereas in the pseudo-Archimedes it is simply a semi-circle divided into twelve equal parts. Features common to both works include: balls dropping from a bird's mouth on to a cymbal; cone-valves and seats; air vessels; siphons; mechanical flutes; opening doors; jack figures, both human and animal. The transmissions to the signalling devices differed slightly – for instance in the 'Archimedes' clock the float in the reservoir operated a geared mechanism which in turn operated the ball release. There was, however, a 'sled' without wheels in the 'Archimedes' clock, which served the same purpose as al-Jazarī's 'Cart'. In the 'Archimedes' clock the water-outflow was used to operate a tipping-spoon (*mighrafa*) which, when it tilted, operated a mechanical device by means of a pulley system. The water then ran into an air-vessel where it displaced the air into mechanical whistles, and then it discharged through a jacketed siphon into a second air-vessel, displacing the air into an automatic flute. The intricately constructed astronomical spheres of the first of al-Jazarī's clocks do not appear in the 'Archimedes'.

The clock over the Bāb Jayrūn of the great mosque of Damascus[2] was built by Muḥammad b. ʿAlī b. Rustam al-Khurāsānī al-Saʿātī (the clockmaker) in the reign of Nūr al-Dīn Maḥmūd b. Zenkī (541/1146–568/1173). After the death of its constructor it fell into disrepair, and after several unsuccessful attempts had been made to repair it, the task was successfully undertaken by the son of its maker, Fakhr al-Dīn Riḍwān b. Muḥammad, whose work describing the clock was completed in 600/1203.[3] Again this clock is similar to the 'Archimedes' clock (which is mentioned by Riḍwān). The basic water machinery was similar, although in this case the flow regulator was based upon a full circle, divided into 12 equal parts. All the mechanisms were driven directly from the float in the reservoir and these included: two falcons which dropped balls on to cymbals; 12 large doors with upper and lower leaves which rotated through 180°; a semi-circle of glass roundels for the night and a Zodiac circle (simpler than al-Jazarī's). There was a 'sled' like the one in the 'Archimedes' clock. The water outflow, however, simply ran into a receiver, and was not used to operate jacks or mechanical flutes.

Greater attention has been given to the pseudo-Archimedes clock, than to Riḍwān's, since it is obviously the forerunner both of Riḍwān's clock and of al-Jazarī's first two. It is strange that al-Jazarī and Riḍwān seem to have been unacquainted with each other's work – neither mentions the other. Yet travel in al-Jazīra, and between al-Jazīra and Syria appears to have been easy enough at this period, as attested by Ibn Jubayr.[4] In the absence of further evidence, however, we must assume that al-Jazarī had not examined Riḍwān's clock, or read his work.

It was Drachmann's suggestion that the pseudo-Archimedes was the work of a Muslim inventor who put together details from several sources, one of them doubtless Philon, another probably Heron.[5] Vitruvius, particularly in his transmission of Ctesibios's clocks, may also have been used as a source. The suggestion is credible, although many of the devices in Philon and Heron's treatises on pneumatica have more affinity with the Banū Mūsà than with the pseudo-Archimedes. Certainly jack-figures, siphons, floats and air vessels occur in Heron and Philon, while Heron in his Mechanics has several examples of gears. (I tend to agree with Drachmann[6] that much of Heron's work on gears was purely theoretical.) In the Arabic MS of Philon there is a tipping-spoon, very similar to that described in the pseudo-Archimedes, and this is described, as 'similar to the operation of a clock'.[7]

Several related water-clocks are described by Vitruvius[8]. Two are attributed to Ctesibios, both operated by constant flow. In the first water discharges from an upper vessel (or from the mains) into a second vessel, which is provided with an overflow. From the bottom of this constant-head vessel the water runs through an orifice into a third vessel in which there is a float which rises at a uniform rate. The float has a vertical rod attached to its upper surface and this rod operates gears which in turn work the devices which indicate the hours-moving statues, turning obelisks, falling pebbles, and sounding trumpets. There is no mention of any scale of hours, nor of any device for varying the length of the hours. The orifice was formed from a hollow tube of gold, or from a pierced gem.

In the second clock Ctesebios attempted to vary the flow by using a cone valve which was made tighter or looser in its seat by means of wedges. This seems not to have worked, and the problem was solved by having the pointer – a jack-figure at the end of the float's rod – move over a different scale length for each day of the year.

The other two clocks described by Vitruvius were apparently not the inventions of Ctesibios. Neither is very clearly described but their construction has been carefully and convincingly reconstructed by Drachmann.[9] The main drive in both clocks is by constant flow of water into a receiver containing a float. In the third clock, a string attached to the rising float passes over a drum mounted on an axle. The other end of the string has a weight attached to it: the drum turns once every twenty four hours. There is a pleasing, but rather complicated, method of indicating the passage of the hours, and the travel of the sun through the sky in its appropriate Zodiacal sign.

For the fourth clock, only the flow regulator is described. In this the outlet orifice is moved around a complete circle during the year. It is thus one of the instruments that was tested and rejected by al-Jazarī. To summarise, we can say that there is little in the design of al-Jazarī's first and second clocks that is not found in the pseudo-Archimedes, and little in the pseudo-Archimedes that is not found in the Greek writers.

This is not the case for the next two clocks, Nos. 13 and 14, which are based upon the *ṭarjahār*, a float with an orifice on its underside which submerged in a known period of time. The vessel itself had long been used as a recorder of time intervals, not necessarily related to the regular passage of the hours. The word is more usually feminine, *ṭarjahāra*, for instance in the Apollonius MS.[10] Muqaddasī (p. 357) tells us that in Qūmis taxation assessment was based upon the quantity of irrigation water used, and this was measured by timing the period of flow into a given plot by means of a *ṭarjahāra*. A similar vessel is described by Heron (Woodcroft No. 63) as part of the control mechanism for a wine-dispensing vessel. In the Surya-Siddanta a sinking float is described (p. 408), which sank sixty times in a day and night and was an 'accurate hemispherical instrument'. Al-Jazarī himself several times makes mention of the use of the *ṭarjahār* for measuring time intervals, e.g. in VI, 5. There was therefore nothing new in the idea of a sinking float used as a timing device, rather like a simple clepsydra in reverse. I have, however, found no record, other than in al-Jazarī, of the use of a *ṭarjahār* as the driving mechanism of a monumental water-clock. At the beginning of I.4 al-Jazarī tells us that he made many clocks using the *ṭarjahār*, but makes no mention of any predecessors who built similar clocks. In the light of present knowledge the question as to the originator of this design must be left open – it may, of course, have been al-Jazarī himself.

[1] See W.H.8.
[2] W.H.1, 166–266.
[3] The first known description of the clock was given by Ibn Jubayr (1) p. 270f, who saw it on a visit to Damascus in 580/1184. The people called it *al-manjāna*.
[4] See Ibn Jubayr (1) 237ff.
[5] Drachmann (2), 40.
[6] Drachmann (1), 200f.
[7] Carra de Vaux (3), 77f.
[8] Vitruvius IX, 8, Paras 2–14. See also Drachmann (2), 19ff.
[9] Drachmann (2), 21 ff.
[10] Wiedemann II, 51f/XXXVI, 21f. (Fol. 18 in MS).

Some of the secondary mechanisms are of interest, particularly the hinged lever in No. 4 for activating the toothed wheel,[11] the 'balance' in No. 4, and the ball release devices in both clocks. The elephant clock is especially noteworthy for the ingenuity of its mechanisms and the manner in which they are interconnected in a restricted space. The idea of the serpents which appear to threaten the birds was probably derived from a similar design in the pseudo-Archimedes, although in the latter case there is no transfer of a ball from bird to serpent.

Of greater interest than the mechanisms is the concept, in both these clocks, of a 'closed-loop' system. One might speculate that there is here an echo of ideas about perpetual motion which were coming into currency at about this time.[12] There is no evidence, however, that al-Jazarī lent himself to such speculations – he probably knew too much about the effects of wear and corrosion.

The fifth clock, the Beaker, takes us back to the outflow clepsydra, a very ancient measuring device[13]. As indicated in the notes to this chapter, I think it is possible that al-Jazarī had solved the problem of finding empirically the correct profile for the vessel so that the rate of charge at static dead against time was always constant. This would have been a practical necessity for recording the passage of the solar hours.

Clock No. 6 is essentially a variant on Nos. 1 and 2, with some simplifications, since the clock was used only for recording constant hours. The supply vessel with an overflow hole recalls Ctesibios' clock. The hinged lever rotating a toothed wheel is similar to the device used in Clock No. 4, but this is the first mention of a ratchet wheel and pawl. These occurred in Greek[14] weaponry and were probably used in the arming mechanisms of Chinese crossbows by about 200 B.C.[15] We do not have any evidence of al-Jazarī's derivation of this mechanism, either from the East or from the West.

CANDLE-CLOCKS

Very little appears to be known about these devices. Al-Jazarī tells us, at the beginning of I.7, that he had seen no works on candle-clocks, and only one finished model. Again, at the beginning of I.8 he mentions a clock made by Yūnus al-Asṭurlābī, perhaps the famous astonomer Ibn Yūnus al-Ṣadafī (d. 399/1009)[16]. We also have two descriptions of later candle-clocks, one from Zarkhuri and one from Alfonso X of Castile.[17]

It would seem from al-Jazarī's remarks that he had some basis to build upon, and that he considerably improved on the earlier models. The success of his designs lay in the careful specification of the candle and wick (see I.7.1.) and in the design of the tightly fitting cap, combined with the steadily applied load to the bottom of the candle. The cap stopped the wax from running back into the mechanism and was so designed that the wax could be removed regularly, so that the candle burned with a steady flame. The bayonet-fitting which attached the cap to the sheath is a fitting of some antiquity, and was known in China in the 6th Century B.C.[18] Otherwise the various mechanisms, transmissions and signals in these four candle-clocks are typical of al-Jazarī's designs, and many have already been met with in the water-clocks.

Categories II and III
Vessels and Measuring Basins

Although al-Jazarī describes these devices at considerable length, the designs show little advance on those described by the Banū Mūsà. Indeed the latter are in several ways more sophisticated, they make frequent use of cone-valves, and of gears. They also make use of the jacketed siphon, which does not appear in al-Jazarī. The monumental wine dispenser described by al-Jazarī in II.3 is of some interest, but it is in effect a kind of clock, with most of the essential features of Clock No. 6. Also of interest is the dispenser of hot and cold water described in III.1, which must be one of the earliest examples of the use of double-walling, with an air space, for thermal insulation.

One would like to know more about a possible ancestry for the phlebotomy measuring devices described in Chapters III, 5–8. I have been unable to find references to any such vessels in primary or secondary sources.[19]

In general there may be much of interest in these chapters for those concerned with social history and with history of costume. There are some revealing insights into the attitudes of masters to their servants, particularly in Category II.

Category IV
Fountains and Perpetual Flutes

FOUNTAINS, IV, 1–6

Fountain *fawwāra* pl. *fawwārāt*. *Fawwārāt* are mentioned in *Mafātīḥ al-ʿUlūm* (p. 255). They 'are erected in tanks, baths etc., and water sprays out from them in different shapes'.

It is not quite correct of al-Jazarī to say that he has not followed the system of the Banū Mūsà, at the beginning of Category IV. The fountains in question are given in Hauser, Nos. 89–94, although Nos. 87, 90 and 91 are the designs to which al-Jazarī seems to be referring. Certainly al-Jazarī's designs, as he says, are superior, but he could have derived certain basic ideas from the Banū Mūsà. In particular the running of one delivery pipe inside the other, the running of two such double pipes, and various designs for the fountain-heads, are all to be found in their work, as also is the idea of a balanced delivery pipe with bleed-off orifice. Al-Jazarī's main criticism, however, is of their method of producing the alternations: he says the intervals were too short, and implies that the operation was erratic. These criticisms are valid, from his own point of view.

No. 89 consists of a pipe, balanced on a fulcrum over two tanks. In one phase the water discharges into a receiver fixed to end *b* of this pipe and runs into a tank *k* through a small orifice at the other end *g* of the pipe. It flows out of *k* through the inner delivery pipe to the fountain. Towards end *g* of the balanced pipe there are two small adjoining chambers, *e* and *f*, fitted to the underside of the pipe. Water from the pipe trickles into *e* and when this is full the pipe tilts, receiver *b* lifts away from the supply pipe, which then discharges directly into the second tank *u*. Water from *e* trickles into *f* and then runs into tank *k*. When *e* and *f* are empty the pipe tilts back, and the cycle starts again.

In No. 90 water runs into a horizontal tank *q*, *l* which has a discharge nozzle at one end. This tank is mounted on a vertical axle which carries a horizontal vaned wheel at its upper end. The discharge from the rotating tank can be into one of two adjoining large tanks, *g* and *b*, the inner delivery pipe leading from one and the outer pipe from the other – in the usual way. Say the discharge is into tank *g*: the wind turns the vaned wheel, tank *q*, *l* rotates and the water now flows into tank *b*. No. 91 is similar to No. 90, but has two double pipes instead of one.

In No. 92 the inlet water turns a horizontal vaned wheel. On its vertical axle is a screw which engages a vertical cog-wheel. This cog-wheel is on the end of the plug of a horizontal valve. As the plug turns the valve discharges now into one outlet, now into the other. Nos. 93 and 94 work on the same principle.

All of these fountains must have changed shape at short intervals, and the operation of Nos. 90 and 91, in particular, must have been most erratic. For a decorative feature such as a fountain this could,

[11] An analogous design occurs in a Chinese clock of the 2nd Century A.D., see Needham (2), 112.
[12] Needham (1) 538ff.
[13] Drachmann (2) 16; Von Bassermann, Jordan 337.
[14] Burstall, 91.
[15] Needham (1), 86f.
[16] W.H. (1) 156, Note 1.
[17] W.H. (1) 17f. Von-Bassermann Jordan 340.
[18] Needham (1), Fig. 376.

[19] Dr. Joseph Needham told me that he has met with nothing similar in the course of his investigations into Chinese technology. Dr. J. R. Crellin, of the Wellcome Trust, informed me by letter that he has not come across any calibrated collecting vessels from European countries before the 18th Century. As far as he knows, there has been no definitive study of blood-letting equipment.

however, have been part of its charm, and perhaps the Banū Mūsà showed, in this case, more artistic flair than al-Jazarī.

Again, we should like to have known whether al-Jazarī had access to any other information about fountains. Indeed we should like to have known, whenever he mentions his sources, whether he is being comprehensive or selective. The simple fountain must be an ancient invention,[20] but of these more complicated devices, nothing appears to have come to light of an earlier date than the Banū Mūsà. Referring specifically to fountains which change their shape, there are no references in Heron, Philon, or Vitruvius, nor do they appear to have been known in China.[21]

PERPETUAL FLUTES, IV, 7–10.

The importance of al-Jazarī's opening remarks to these four chapters has never been appreciated presumably because the Wiedemann translation[22] omits two key sentences. The first is al-Jazarī's comment that the alternations in the machine of Apollonius were too rapid. The second concerns the machine of unknown origin, of which al-Jazarī says that he had seen no written description, only a drawing. Here, in addition to some inaccuracies in the translation, the following sentence is omitted by Wiedemann: 'I say that even if the wheel caused a number of rods to fall in succession it would not be slow enough to display the changes of shape [adequately].' The design of these arms, and their exact purpose, cannot be ascertained from so brief a comment, but the import is quite clear: that al-Jazarī realised the necessity for an escapement, and had in mind some method for providing one.

Finally al-Jazarī refers to an article by Hibat Allah b. al-Ḥusayn, written in Baghdad in 517/1123–4. This machine seems to have been similar to those built by al-Jazarī himself, having the closest similarity to IV.9. Al-Jazarī's machines are, in turn, very similar to his own fountains, as far as the operating mechanisms are concerned.

The mechanical flutes themselves are of course used by al-Jazarī in many devices; the method of making the flute's 'jar' is, for instance, described in I.1.8. Mechanical musical instruments occur with some frequency in the works of earlier authors. The two organs of Heron (Nos. 76 and 77 in Woodcroft), and Vitruvius' organ (X.8.8) are well known. In Islamic works there is a fairly complicated instrument in the book of the Banū Mūsà (W.H.5, 169 ff.) which could play a melody through a series of pipes – it is a little surprising that al-Jazarī makes no mention of this machine. There are flutes and whistles in the pseudo-Archimedes, and there is the instrument described by Apollonius.[23] Al-Jazarī therefore had ample material to draw upon, not to mention the machine described by Hibat Allah, of which we have no record.

Category V – Water Lifting Devices

The swape or *shadūf* in its simplest form consists of a balanced beam with the bucket on one end and the counterweight on the other, and this is undoubtedly of considerable antiquity.[24] The flume-beam *shadūf*, where the beam is channel-shaped, is presumably a development of the simple swape, and this too has a long history, particularly in India.[25]

The *sāqiya*, or endless chain of pots, was also in use long before the time of al-Jazarī. A chain of pots driven by a water wheel was described by Philon about 210 B.C.,[26] and Vitruvius writing about 30 B.C., mentions the machine clearly.[27] In the Hellenistic age it spread rapidly all over the Near East. Nevertheless it is significant that al-Jazarī calls this machine 'the Sindī wheel', so perhaps it may first have originated in northwestern India.

For the first four of al-Jazarī's devices, therefore, the basic principles of the machines were of some antiquity by the 6th/12th century and their use must have been widely understood.

The application of segmental gears for raising a flume swape, as in al-Jazarī's devices Nos. V.1 and V.2, may have been his own invention. This appears to be the first application of segmental gears, at least with an appreciable applied torque. Similarly, the application of the crank for lifting the flumebeam, in V.4, is perhaps the earliest application of the crank in Islam and Byzantium, and may pre-date the application of the crank to machinery in Europe.[28] I find no reason for doubting that al-Jazarī devised and constructed these three machines, but I question whether they would have worked satisfactorily, without frequent breakdowns. In all of them there is a heavy, intermittent, torque at the axle of the beam, and this is transmitted to the machinery. It is very doubtful whether the anchorages, bearings, and cog-wheel teeth, in their contemporary state of development could have sustained this heavy torque for long.

The case of the machine described in V.3 is different. This was quite small, and was apparently built partly for ornament. The loads were light, and their application was steady, so there is no reason why this machine should not have seen long and satisfactory service.

Of these five machines, the pump described in V.5 is certainly the most interesting. It is described clearly enough in the text, with further elucidation in my notes. There is a minor error in the translation by Wiedemann and Hauser,[29] who introduced a second disc on the end of the axle of the second cog-wheel. They placed the offset peg, and the slot-rod on the face of this disc, instead of on the second cog-wheel, as clearly specified by al-Jazarī. For some reason, however, an incorrect design was developed by Professor Aubrey Burstall who even built a working model to this design.[30] In this reconstruction the lower cog-wheel is shown set upon a shaft which is in loose bearings at one end and free to rotate in an annular groove at the other, so that while the wheel turns upon its geometrical centre the shaft describes a conical path. The offset peg is omitted, and the shaft itself moves in the slot-rod.[31] In fairness to Burstall, he may have been misled by Coomaraswamy's description of this device,[32] since this description is by no means clear. Although it may seem that this is a relatively minor point, it is in fact of some importance that al-Jazarī's actual design is correctly transmitted. His pump can then be appreciated as a more direct ancestor of the steam-engine combination, than would appear from the faulty interpretation just described.

Force pumps occur in the Greek and Roman sources – in Philon,[33] Heron[34] and Vitruvius,[35] who describes a pump made by Ctesibius. The cylinders were vertical and stood in the water. Heron's 'fire engine' can be taken as a typical example of these machines: there were two vertical cylinders standing on a flat box submerged in the water and the connecting rods were attached to a horizontal rocker-beam. The inlet valves were simply pin-mounted plates fitted over holes in the base of the cylinders. A horizontal pipe connected the two cylinders and the delivery pipe was fitted vertically to the centre of this pipe. There were clack-valves on each cylinder over the exit of the horizontal pipe. The Roman plunger pumps discovered at Silchester, and similar bronze pumps found at Bolsena in Italy, each consist of a receiver, a rising delivery pipe, two pump barrels and connecting passages for a two-throw pump, with leather clack-valves.[36] These pumps were also submerged in water and although one could argue that there are short lengths of pipe leading to the receiver which act as suction-pipes, these are integral with the machine-block. The principle is not essentially different from that embodied in Heron's design.

We should probably look elsewhere for the direct ancestry of al-Jazarī's

[20] Vitruvius (VIII, 6) mentions the use of pipes to conduct water to fountains.
[21] Needham (1), 132f.
[22] W.H.5, 165f.
[23] Wiedemann II, 50f/XXXVI, 21f.
[24] W.H.6, 126. Needham (1), 331f.
[25] Ewbank, 88f. Needham (1), 334.
[26] Carra de Vaux (3), 209f.
[27] Vitruvius X, Ch. 4.
[28] See White, 110f and Notes, p. 170. White doubts whether al-Jazarī had grasped the meaning of the crank for converting reciprocating to rotary motion, because of what he felt to be the extraordinary complexity of al-Jazarī's pump (V. 5). But White was misled by Burstall's incorrect reconstruction of al-Jazarī's pump – see commentary below on this device.
[29] W.H.6, 145f.
[30] The design is reproduced in Needham (1), Plate 238 and in Needham (3), Fig. 15.
[31] Discussed in Needham (1), 381f, Needham (3), 43, White 170.
[32] Coomaraswamy (1), 17.
[33] Carra de Vaux (3), 172f, 174f.
[34] Woodcroft, No. 27.
[35] Vitruvius X, Ch. 7. A discussion of these machines is found in Drachmann (1), 155f.
[36] Burstall, 100f.

pump, when it is remembered that he tells us that it resembles the naphtha projectors – *al-zarāqāt*. The whole question of the origins and inter-cultural transference of box-bellows and flame-throwers has received considerable attention from modern writers, because of its relevance to the historical development of reciprocating machinery. The subject is a great interest but at the present time, as Needham says,[37] 'the progress of these inventions in east and west still presents unsolved problems', and it would not be of much additional value to summarise the evidence and arguments at this juncture, particularly since they have been admirably handled elsewhere.[38] It is preferable to examine some of the meagre evidence available from Islamic sources on naphtha-projectors, on the reasonable assumption that al-Jazarī recognised the derivation of his own machine.

In *mafātīḥ al-ʿulūm*, Muḥammad b. Aḥmad al-Khuwārizmī (late 4th/10th century) mentions the *bāb al-midfaʿ* and the *bāb al-mustaq* which, he says, were parts of naphtha-throwers and projectors (*al-naffāṭāt wa al-zarāqāt*).[39] *Bāb* is the usual word for valve in technical writings, and indeed we find *bāb al-midfaʿ* used for horizontal clack-valves in the 'Apollonius' treatise.[40] The whole question of the technical expressions used in military pyrotechnics is discussed by Ayalon (pp. 9–30), who developes the thesis that the employment of naphtha fell into disuse after the expulsion of the Crusaders, and that when terms such as *midfaʿ al-naft* reappear about 150 years later, they refer to cannon. *Midfaʿ* is the usual term for cannon in modern Arabic, (and here one recalls White's remark that the cannon is a one-cylinder internal combustion engine).[41] It does seem almost certain that the original *midfaʿ* was a cylinder in a naphtha projector and the *bāb al-midfaʿ* was the clack-valve that controlled the passage of the fluid through that cylinder. To provide a continuous jet a combination of two cylinders would have been required, as suggested by Hall and Needham.[42] Theoretically it would have been possible to have had vertical cylinders submerged in the naphtha, as in the Ctesibian force-pump, but it would have been much easier and safer to have had the pump unit separate from the fuel reservoir, and connected to it by suction pipes. The aiming of the projector would, for instance, have been facilitated by this arrangement. Frankly we do not know the definitive design of the Byzantine 'siphon', and al-Jazarī may have made important modifications to the weapon when he designed his pump. Perhaps it is significant that he uses the term *burj* and not *midfaʿ* for his cylinder, as if indicating a departure from the pattern of the naphtha projector.

Category VI – Miscellaneous

CHAPTER 1 – THE PALACE DOOR

It is almost certain that al-Jazarī's description of the casting of the important parts of the lattice-work refers to the use of closed mould boxes, with green sand as the casting medium. It is also clear from his comments that the practice was well-established in Mesopotamia at that time, and must have been introduced at an earlier date. We therefore have evidence that this technique was well known in the area not later than the middle of the 12th Century A.D. This is an extremely important point: the use of a sandy clay is ancient, but all moulds with a high clay content have to be heated to drive out all moisture before the molten-metal is poured in. Green sand moulds, used without drying, seem to have appeared first in Europe a little before 1500 A.D.[43] The first description, in Europe, of this technique is in Biringuccio's Pirotechnica, written in 1540 A.D.[44]

We know nothing certain about the point of origin of casting in green sand, although it seems certain that this is not to be located in Europe. There is valuable information, however, in a Chinese work – '*Hsi Chhing Tshung Hua*' by Yao Khuan, (Ch. 1 p. 48a), written some decades earlier than the period of al-Jazarī's activity in Diyār Bakr. (I am indebted to Dr. Joseph Needham for sending me this information, and for giving me permission to use it, pending publication of Vol. v, Part 6 of his '*Science and Civilisation in China*').

The passage runs as follows: 'The Illustrated Local History of Jen-ho in Lin-an prefecture [Hangchow] [says that] this place produces "bellows sand" (*tho-yo sha*). People along the shore four miles east of the city collect this sand and use it to make moulds for the casting of bronze [lit. copper and tin] People from other counties all come to collect it also. It is like the *hsing sha* sand which can be used for grinding jade'.

It is fairly certain that this passage refers to casting in green sand, but we do not know whether the mould-boxes were open or closed. We know that al-Jazarī used closed boxes, and that the technique was well understood in Mesopotamia not later than the middle of the 12th century A.D. On present information, therefore, the situation in the western Islamic cultural area in this period seems to have similar to the situation in China. We must hope that new information comes to light, so that the point of origin of the technique can be identified. For the present the question must remain open.

It seems highly probable that the fully developed method – casting in closed mould-boxes with green sand – passed into Europe from Islam. Again, we must wait for fresh information before we can determine how the transmission occurred.

CHAPTER 2 – THE PROTRACTOR

This is a very simple instrument and the text serves mainly to emphasise the rudimentary nature of al-Jazarī's mathematical knowledge, when compared with his engineering skills.

CHAPTERS 3 AND 4 – THE LOCKS

The history of locks in Asia remains to be written.[45] We do have some information about locks in Egyptian, Roman, Celtic and Scandinavian cultural areas, but these are mostly tumbler locks and padlocks.[46] Nothing resembling either of al-Jazarī's locks has, however, come to my attention. The combination lock described in Chapter 2 is of particular interest. These are not as ancient as tumbler locks or warded locks, but were well known in Europe by the early 17th century.[47] It is interesting to observe that the wheels in the Butterworth combination lock (about 1846 A.D.) are strikingly similar to the discs used by al-Jazarī.[48]

CHAPTER 5 – THE ALARM CLOCK

This is an elaborate version of the *ṭarjahār*, or sinking float, provided with a mechanical whistle.

Individual Components

The following notes describe some of the more important components used in al-Jazarī's devices, with some references to vocabulary and history.

WHEELS, AXLES, AND BEARINGS

Wheel – Dawlāb. This is the usual word, and occurs frequently in al-Jazarī, and also in Riḍwān, Archimedes, and other writers.

[37] Needham (1), 135.
[38] Needham (1), 135–155; Needham (3), *passim*; Burstall, 93–104; Reti, *passim*; Hall, 375–82.
[39] p. 254. Earlier, on p. 237 he says that the *mustaq* is a Chinese musical instrument.
[40] Wiedemann II, 53; 36.23. Fol. 20 in NY MS.
[41] White, 100.
[42] Hall, 376; Needham (1), 147.
[43] Smith, 23.
[44] Maryon, 475.
[45] Needham (1), 236f.
[46] Pitt-Rivers, *passim*.
[47] Hopkins, p. 36f.
[48] Hopkins, Photograph on p. 72.

Cog-wheel – Dawlāb dhū Dandānjāt, meaning simply 'a wheel with teeth'. *Dandānjāt* is a word of Persian origin.

Al-Jazarī has cog-wheels at right-angles (e.g. v.3, 2; v.4), a cog-wheel turning a lantern pinion parallel to it (e.g. II.3.4.), a rack and pinion (VI.4); a ratchet and pawl (I.6.6) – the pawl is called a *ṭāriḥ*. Only one example (v.5, 1) of parallel cog-wheels occurs, and there is no use made of worm-and-wheel gears.

All these types of gearing have a lengthy history, with apparently a parallel development in east and west. Chinese bronze gear wheels, dated from 300 B.C. to 300 A.D., including ratchet wheels, have been found in archaeological excavations.[49] It is noticeable that most of the gearing described in western and early Islamic works – Philon, Heron, the Banū Mūsà and al-Bīrūnī[50] – is for transfer of motion rather than power. Some of Heron's gear-trains are in power mechanisms but I concur with Drachmann that these were probably only theoretical, and were never actually made and used[51]. From antiquity and early medieval times perhaps the mill of Vitruvius was one of the few working examples of transmission of power through gear wheels.[52] In the west there was not much development of gears after the fall of the Roman empire and in the Middle Ages arrangements of gears remained simple and crude. Not until the 17th century were the correct shapes for gears developed by de la Hire and Roemer.[53]

Most of al-Jazarī's gears were for fairly light duties, and it is noticeable that for parallel meshing he normally used a cog-wheel and lantern pinion, rather than two cog-wheels. Doubt has already been cast upon the practicality of the devices described in v, 1., v, 2., and v, 4 because of the imposition of a heavy, intermittent torque, not only on the gears, but only on the bearings and anchorages.

WATER-WHEELS

The history of water-wheels, particularly as prime-movers, has received a good deal of attention from modern writers.[54] Again, rather than summarise the arguments about the development of the various types of wheel in east and west, it may be of more value to see what can be learned from the statements of al-Jazarī and his predecessors. Al-Jazarī uses three types of water-wheel: the scoop-wheel, *dawlāb dhū kaffāt* (e.g. I. 6, 3; II. 3, 4); the horizontal vaned-wheel, *dawlāb dhū rīshāt* (e.g. II. 1, 2; v. 5, 1); the vertical paddle-wheel, *dawlāb dhū ajniḥa,* (v. 5, 1). All of these wheels are used for taking energy from the water and transmitting it to other mechanisms, not as water raising devices. The only wheel used for the latter purpose is the *'Sindī'* wheel in v. 3.

Perhaps the most significant sentence occurs in al-Jazarī's description of his small horizontal water-wheel in II. 1, 2. He says: 'the vanes are separated so that they take the form of a *surn al-arḥā'*'. In *Mafātīḥ al-ʿUlūm* (p. 254) we have the following definition: '*surn al-raḥā* is the rotor (*dawwāra*), which is struck by the water and rotates, *barkār al-surn* are its paddles (*ajniḥa*) – it [i.e. *barkār*] is an arabicised Persian word'. Now *raḥā* pl. *arḥā'* is the Arabic word for 'mill'. The meaning in both al-Jazarī and in *Mafātīḥ al-ʿUlūm* seems to be that *surn* is the water-wheel. In the pseudo-Archimedes the word *surn* is used for an axle (Fol. 2, W.H. 8; 171), but this is certainly not the meaning in the other two works, particularly since al-Jazarī refers later to the axle of the water-wheel – *miḥwar al-surn*. There is a further reference to water-mills in the 'Apollonius' MS, (folio 23v in London MS); there are lacunae in the text, but it refers unequivocally to the Byzantine (*rūmī*) mill-wheel in contrast to the 'new' mill-wheel that is vertical on its axle. Finally, one may mention that the Banū Mūsà show horizontal vaned wheels in two of their fountains (Hauser Nos. 92 and 93).

It is not easy to derive, from the somewhat fragmentary evidence just presented a clear idea of the types of mill-wheels in use in al-Jazarī's time. The Byzantine mill, the one most familiar to al-Jazarī, seems to have a horizontal, vaned wheel. We do not know whether the paddle-wheel mentioned by al-Khuwārizmī was vertical or horizontal. If horizontal, it would then have been of the so-called Norse variety, which may have originated in the Middle-East, and which retained its popularity until the late Middle Ages.[55] The fact that al-Jazarī, in v. 5, 1, uses a vertical undershot paddle-wheel, seems to indicate that he had seen examples of this type of machine. One must, however, take account of the fact that he only uses the expression 'mill-wheel' for the horizontal, vaned, variety.[56]

The scoop-wheel, used by al-Jazarī for taking energy from water, was more commonly used in the reverse sense, i.e. for imparting motion to water, in a water-raising machine.[57] In the sense used by al-Jazarī it is, in effect, a primitive Pelton wheel, which depends for its effectiveness on a high head of water, since there is no utilisation of pressure energy. The water must be directed accurately into the scoops, which have to have a properly designed profile profile to obtain a maximum change in momentum of the jet. There is therefore no question that al-Jazarī's scoop-wheels, operating under a low fall of water, with scoops of random design, could have done anything more than the simple duty for which they intended, which was usually the operation of jack figures.[58] It is a reasonable assumption that al-Jazarī derived his scoop-wheels from the principle of the *noria*, a large wheel for lifting water with buckets or scoops fixed to its outer rim. This type of wheel had long been established in India and in the Middle East.[59] The large *norias* on the Orontes at Ḥamāt were built shortly after the time of al-Jazarī,[60] but the excellence of their design and construction presupposes a long history of development.

PULLEYS

It hardly seems necessary to point out that the single pulley is a very ancient device, which was known, for example, in Assyria in the 8th century B.C.;[61] examples of multiple pulley trains occur in Heron's Mechanics. Al-Jazarī uses the word *bakra*, which is also found, for example, in Qustā b. Lūqā's translation of Heron, and in the pseudo-Archimedes.

AXLES AND BEARINGS[62]

Bearings are of great antiquity, having been used for the potter's wheel as early as the fourth millenium B.C. in lower Mesopotamia. Metal-to-metal bearings were used by the Romans and Greeks – Heron mentions, in his Mechanics, an axle whose ends were sheathed in copper and ran in copper-covered bearings. Part of a bearing of about 40 A.D. was discovered under water in Lake Nemi, near Rome. It had bronze balls on trunnions. These supported a disc which may have carried a small statue.

In China the journals and bearings of vehicle axles were of bronze or iron in Chou and Han China just as they were in European antiquity. The mechanised armillary spheres of the 2nd to 8th centuries A.D. had metal bearings, as did the monumental clock of Su Sung in A.D. 1088. There is evidence for the existence of roller bearings in China in the 2nd century B.C.

Lubrication is equally ancient. Egyptian chariots had plain grease-packed bearings which were protected from sand by leather covers. An Egyptian wall painting of about 1800 B.C. shows 172 men transporting a colossus from a quarry on sledges, while one man is pouring oil or grease ahead of the base of the statue on which he rides.

In the West there was a retrogression in the Middle Ages and plain bearings of wood were chiefly used in machines. Iron bearings and jour-

[55] Forbes (1), 594.
[49] Needham (1), 85ff.
[50] Wiedemann (2).
[51] Drachmann (1), 200–203.
[52] Vitruvius x, Ch. 5.
[53] Davidson (1).
[54] e.g. White, 79ff; Forbes (1), 593ff; Needham (1), 366ff; Needham gives, in his bibliography, details of a number of works on this subject.

[56] Mills seem to have been common enough in Diyār Bakr at this time According to Ibn Jubayr (1), p. 243, the banks of the Khābūr at Raʾs al-ʿAyn were lined with mills.
[57] Needham (1), 337f.
[58] The large water-clock of Su-Sung described in Needham (2) was operated by a scoop-wheel as prime mover. This was a large wheel, and each scoop held about 12 lbs of water (p. 39). An essential part of the mechanism was the escapement, which allowed each scoop to fill completely before it was released. The escapement does not of course, appear in al-Jazarī's scoop-wheels.
[59] Coomaraswamy (2).
[60] Mieli 155. I have examined these myself.
[61] Burstall, 58.
[62] The data on earlier bearings are taken from Davidson (1) and Needham (1), 92–95.

nals came into use for tower clocks and other devices from the 14th century onwards.

It is difficult to assess the standard of craftsmanship attained by al-Jazarī in the manufacture and fitting of his axles and bearings, since he tells us so little about them. The bearings are shown as rudimentary components on the drawings, but then so are many other parts that we know from the text to have been made with great care and skill. It is quite likely that they were drawn conventionally, much as a modern designer will show pitch circles for the teeth of a cogwheel, for instance. Al-Jazarī's machines, particularly the large clocks and the monumental wine-dispenser (II. 3) could hardly have worked properly unless the bearings were carefully made. After all, he took great care to ensure that his wheels were running true, and in static balance (e.g. see I. 1.9), and this care would have been wasted if there was too much play or friction in the bearings.

Some further clues can be gathered by considering the terms which al-Jazarī uses for various kinds of bearings. For small axles the bearings are called *kharaza*. This word is also used for an orifice drilled through a piece of onyx, although the commoner word in this sense is *jazʿa*. Since orifices were calibrated carefully it is reasonable to assume that the bushes used as bearings were also made with accuracy. Bearings into which were inserted the lower ends of vertical axles are called *sukurruja*. Wooden axles had iron 'acorns' (*ballūṭa*) nailed to their ends, and these rotated in bearings called *mukḥula*. A *mukḥula* is properly a jar used for containing kohl, and later it came to denote a kind of cannon or mortar. In one passage (II. 3, 4) two parts of a shaft are joined by a push-fit connection, and the female part of this joint is also called a *mukḥula*. Finally, heavy duty bearings are called *rukn*, which simply means 'support'.

Al-Jazarī made his axles of wood, copper or iron depending on the duty, and the usual word for them is *miḥwar*, although he occasionally uses non-technical words such as *qaḍīb* (stick) or *saffūd* (rod). The term *miḥwar* is also used by the Banū Mūsà, 'Archimedes', and al-Khuwārizmī. Only Riḍwān uses the word *quṭb*.

What little information the other writers give us about axles and bearings indicates that they were less well constructed than those of al-Jazarī. Riḍwān brings the ends of his copper or wooden axles to a conical point and inserts part of this in a hole. 'Archimedes' has a similar arrangement. Neither uses a special word for their bearings. No one, including al-Jazarī, makes any mention of lubrication.

Davison tells us that plain wooden bearings were used in the West up to the 14th century. If this is the case, then al-Jazarī was considerably in advance of European technology in this respect, since all his bearings are metal-to-metal. He used different types of bearings for different duties and had a special term for each one. Because of the great care he took in constructing and tuning his machines it seems probable that his bearings were at least adequate, particularly when it is remembered that in most cases loads were light and running speeds slow. This does not apply to his three flume-beam water raising devices, but doubts have been expressed above about the practicality of these machines.

WATER EQUIPMENT

Pipes, channels, siphons

Heron and Philon made considerable use of pipes in their devices. Presumably these were made of copper – neither writer is very strong on constructional details. Vitruvius has a chapter (Book 8, Chapter 6) in which he discusses lead and earthenware pipes for water, giving accurate specifications for various duties.

In al-Jazarī, and all the other Islamic writers, the usual word for pipe is *anbūb*. Al-Jazarī, Riḍwān and al-Khuwārizmī also use the expression *barbakh*, which seems to have been a short pipe of relatively large diameter. Riḍwān tells us that pipes were made by bending sheet copper to a circular cross-section and soldering the edges together. Pipes were joined together by making the end of one wider than the end of the other, and pushing the two together. The wide end was called 'female', the narrow 'male', exactly as in modern technical parlance. Occasionally pipes were made of brass. Short lengths, particularly where accuracy was of importance, were cast in bronze. When pipes were to be bent they were first filled with lead, bent, and the lead then melted out (al-Jazarī I. 3.2).

Channels are referred to as *mīzāb* by all the writers. Al-Jazarī uses them frequently, both for transmission of liquids and for carrying balls.

Al-Jazarī himself uses only the simple siphon, for which he generally uses the term *maqallab* and, in one place, *al-saḥḥāra al-miṣrīya* (the Egyptian witch). Al-Khuwārizmī calls it simply *al-saḥḥāra* or *Sāriqa al-māʾ* – the (female) water-thief. The jacketed siphon is described above in the section on the Banū Mūsà. Al-Khuwārizmī calls this *al-saḥḥāra al-makhnūqa* – the strangled witch.

Valves and Taps

The clack-valves used by al-Jazarī in his pump are discussed above under 'Water-lifting devices'.

The apparently simple cone-valve does not appear to have been known to Heron or Philon. There is an interesting passage in Vitruvius, however, where he describes how Ctesibius attempted to control the flow of water from a vertical pipe.[63] The end of the pipe was conical and into this a conical plug was fitted and hel in position by wedges. Ctesibius tried to vary the flow by adjusting the wedges, but does not seem to have been very successful.

In the Apollonius treatise,[64] the drawing from the Paris manuscript (Fig. 2a) shows cone-valves but this contradicts the text which says quite clearly that the holes are square. The drawing from the London manuscript shows hinged clack-valves, but this is also incorrect, since the text says that the plugs are fitted to the seats to form an air-tight seal. No doubt in the former case the draughtsman was led astray by the fact that cone-valves were in widespread use in his day.

I have therefore found no earlier description of the true cone-valve – i.e. a valve which opens and closes automatically – than that in the clock of 'Archimedes'. As discussed earlier however, this is described and drawn merely as a rounded knob on top of the float, and the precise designation – *bāb maṭḥūn* or 'ground valve' – is not used. This designation is first found in the book of the Banū Mūsà, who used such components frequently. In *Mafātīḥ al-ʿUlum* (p. 253 f), al-Khuwarizmī gives an interesting description of this type of valve. 'The *bāb maṭḥūn* has a male and a female – the male enters the female; it opens and closes. When it is closed, it is tight-fitting (*muhandam*) and has no outlet. Most of them are cone-shaped. One says that one grinds (*inṭahana*) something into something [else] if it moves in it with no gap between them.'

Al-Jazarī's description of the fabrication of a *bāb maṭḥūn* is of great interest. It occurs towards the end of Section 2, of Chapter 1 of Category I, where he is referring to the plug on top of the float entering the vertical end of the tap: 'for the bent-down end a plug is prepared from cast bronze and is fitted (*handama*) to the inside of the bent-down [end] and ground (*ṭaḥana*) with emergy (*sunbādhaj*) on the lathe (*jahr*) in the usual way. This is done with the greatest precision since this is one of the most important and essential parts of the works. Every tap (*fathyūn*) *and bāb maṭḥūn* [is made] in this way. This is the picture of the plug – conical, with a wide base. If the plug is pushed into the bent-down end, and is not restrained by something, it will not be fixed, but free, because its base is wider than its head'. This is not essentially different from modern practice, in which valve and seating are ground together until the fit is perfect.

These quotations have been included since they demonstrate, for a simple device like the cone-valve, the high standard of workmanship attained by Muslim craftsmen. Although the first full description of the manufacturing process occurs in al-Jazarī, it is evident from al-Khuwārizmī's remarks that the technique was understood much earlier From the historical point of view all we can say with any certainty is that the technique was developed by the time of the Banū Mūsà about 235/850. One can only suggest tentatively that, if the Byzantine origin of the Apollonius treatise is accepted, and since in that treatise the square plugs are machined to fit their seats, this basic principle may have been taken up by the Muslim craftsmen from Byzantium, and developed into the true cone-valve.

Horizontal taps fitted to vessels, with vertical plugs, occur in the works of Philon and in the Banū Mūsà, and in some of these the plug has more then one drilling, so that the liquid can be drawn off from different points inside the vessel. There are precedents, therefore, for the complex tap described by al-Jazarī in Category II, Chapter 5, Section 3.

Al-Khuwārizmī writes (252f): 'a bathyūn is a tap (*buzāl*) made from a pipe, through which a hole is drilled. Another pipe is fitted vertically in

[63] Vitruvius Bk IX, Ch. 8. See Drachmann (2), 20, 34f.

[64] Wiedemann II, 51f/XXXVI, 21f and Figs. 2a and 2b.

the hole and rotates in it, to open and close [the tap].' This statement is helpful in supplying information on vocabulary, but misleading in its constructional details. The plug was a solid piece of metal, drilled with one or more holes (see Fig. 15.1). The generic term for valves and taps was derived from a Greek word, according to Wiedemann (I 205/VI 33) and occurs in various spellings: *fītūn* and *fathyūn* in al-Jazarī, *fathyūn* and *bathyūn* in the Banū Mūsa, *bathyūn* in Riḍwān. The *buzāl* was a horizontal tap fitted to the side of a vessel, and is used in this sense by the Banū Mūsà.

Al-Jazarī, precise as ever, seems to have reserved the term *fathyūn* for vertical valves, and *buzāl* for horizontal taps. His descriptions are correspondingly precise. Describing the tap made in the shape of a cow (II. 5.3) he tells that the *buzāl* is made from cast bronze in the shape of a cow. He continues: 'In the centre, between back and belly, a seat (*buthūr*) is made, and in this a plug (*dhakr* = 'male') is fitted (*handama*) and ground (*ṭahana*), in the normal manner for making taps (*buzāl*).' We thus have a unique word for the type of tap and for its seat. *Buthūr* does not occur in the other writers: its literal meaning is 'pimple' or 'pustule' and was probably derived from the outside appearance of the tap. The fitting process is similar to that used for cone-valves, with the same terminology. Presumably the method of casting was such that the plug was cast on the same pattern as the body of the tap, with an allowance for grinding.

I have not found examples of al-Jazarī's vertical valves, with oblique holes in the plugs (e.g. III, 2.2: III, 3.2) in the works of any other writers, earlier than or contemporary with al-Jazarī. His manufacturing instructions are similar to those for horizontal valves but the terminology is different. The plug is still called *dhakr*, the whole valve is called *fītūn* and the valve-body *tanūr*. *Tanūr* is usually an oven for baking bread, so again the similarity of shape may have suggested the transfer of the word to describe the valve-body.

VESSELS AND THEIR FITTINGS

The derivation of the tipping-bucket from the tipping-spoon of Archimedes has been discussed above (General Notes – Clocks). Al-Jazarī's own statement (I. 2.2) runs as follows: 'When I made this bucket, even though I did not know that I was the first to make it, I thereby rendered unnecessary many appliances of value in this craft.' This is somewhat obscure, since the spoon in the 'Archimedes' clock tipped at regular intervals, although it was not part of the main mechanism. Furthermore this tipping-spoon was similar to one described in Philon's Pneumatics, and Philon says that this 'was constructed like those of the clocks'.[65] Perhaps al-Jazarī meant that he perfected the design and operation of the bucket, to make it accurate enough, and large enough, to be used as part of the main mechanism. It is unnecessary to go into further details about the other vessels used by al-Jazarī. These are described adequately in the text and discussed, where appropriate, in notes at the ends of the chapters. Floats are used extensively by the Banū Mūsà, probably deriving from the works of Philon and Heron, where they occur frequently. The vocabulary for the principal vessels, and for floats, is given below.

Equipment	*al-Jazarī*	*Banū Mūsà*	*'Archimedes'*	*Riḍwān*
Reservoir	*Khizāna*	–	*Khizāna*	*Khizāna* also *Binkān*
Float Chamber	*Rubʿ*	–	*Rubʿ*	*Rubʿ*
Tank or Trough	*Ḥawḍ*	*Ḥawḍ*	–	–
Float	*ʿAwwāma Ṭafāfa*	*Dabba*	*ʿAwwāma Dabba*	*ʿAwwāma Ṭafāf*

Vessels and floats were made of beaten copper, bent to shape, with overlapping joints, which were then soldered. All parts which were to be in contact with water were tinned. Al-Jazarī uses the word *raṣṣaṣa* and Riḍwān *bayyaḍa* (to whiten) and both are insistent upon the need for tinning parts in contact with water.

Orifices from which a measured flow was required were made from onyx (*jazʿ*), and the orifice itself was called a *jazʿa*. This designation is used by al-Jazarī, Riḍwān and 'Archimedes', who all used this device. The use of a pierced gem is very old – Vitruvius mentions that Ctesibus used such orifices in his clocks (Book XI, Chapter 8).

MISCELLANEOUS PARTS AND FITTINGS; MATERIALS

Jackwork appears in the works of Ctesibius, Philon and Heron, and in Chinese and Byzantine machines.[66] The Muslim craftsmen were particularly fond of these human and animal figures, which occur in the works of 'Archimedes', the Banū Mūsà, Riḍwān and, of course, in al-Jazarī. Al-Jazarī made them from beaten copper, beaten brass, wood, or papier mâché. I have not come across any detailed instructions for the manufacture of these figures, apart from al-Jazarī's description (II. 7.2) of the manufacture of a copper 'man' (*shakhs*).

All the Islamic writers used similar fixings and connections, although, by the nature of their devices and the brevity of their descriptions, one learns little from the Banū Mūsà. Riḍwān and al-Jazarī are the most informative. All used soldering, a very ancient technique, probably well-known 5000 years ago in Ur.[67] Nails, cotters, lugs, male-female joints and push-fit connections were used extensively by al-Jazarī and by Riḍwān. Wire (*sharīṭ*) was usually made of copper, and chain (*silsila*) of copper or iron. Rope (*ḥabl*) was made of hemp or stranded silk. The material used for making string (*khayṭ*) is seldom specified, except when it was made of silk. Hinges (*namādhaj*) are mentioned by al-Khuwārizmī, and were used by all the Islamic writers.

An interesting word, used frequently by al-Jazarī, is *shaẓīya*. This could be translated as 'activator', since it seems to be used for any small component which activates another part of the mechanism. Cams, trip-lugs, push-rods, etc. could all be described by this word.

Most of the materials used by al-Jazarī are common to the other Islamic writers, with the exception of one or two mentioned below. The main materials are as follows: (references are all to al-Jazarī, except where otherwise stated):

Metals

Iron – *Ḥadīd*; lead – *raṣāṣ aswad* ('black lead'); tin – *raṣāṣ abyaḍ* ('white lead'), referred to occasionally as *raṣāṣ al-qalʿī* (II. 1, 2); gold – *dhahab*; silver – *fiḍḍa*; copper – *nuḥās*; brass – *shabah*; bronze – *ṣufr*.

The metal used by al-Jazarī for his cymbals he calls *Isfādhrūh*, and this word is not found in the other Islamic works on machines. According to al-Dimashqī the word is Persian,[68] and the metal it describes is similar to a metal of Chinese origin. The Chinese metal, however, is superior in colour, hardness and tone.[69] Interestingly, modern cymbals are made from a bronze consisting of copper alloyed with 15 to 20% of tin. The manufacture of cymbals was for years a monopoly of Turkish craftsmen.[70]

The mountains around Diyar Bakr have always been rich in metals. In 516/1122 a copper mine was discovered near Dhū al-Qarnayn. Iron was also plentiful. The Caliph al-Mustaḍī, in 570/1173 required a chain weighing 1500 *dīnārs* for a bridge over the Tigris. He had it brought from Hānī.[71]

Other materials

There is little of especial interest in al-Jazarī's use of non-metallic materials, most of which were common substances which had long been in everyday use. Wood occurs frequently, of course, in wheels, axles and structural work. The use of lamination to produce a wheel that would not warp is of interest (I.6.6). He used glass for his roundels and occasionally for a drinking goblet. Other materials used were cloth, leather, oil of Sandarac, paints, paper, and papier mâché. This last named was used for making jack figures when lightness was important, e.g. for the horse on top of the castle in II.3.3. It is described as *kāghadh maʿjūn* – paper made into a paste. The Persian word *kāghadh* is the usual word for 'paper' in medieval Arabic texts. Papier mâché does not occur in the other Islamic works.

66 Chapuis and Droz, Chapter 2; Needham (1) – Refer to index under 'Jackwork'.
67 Burstall, 37.
68 *Safīd rūy* = white bronze.
69 Quoted by Wiedemann, I, 120/V, 403.
70 Street and Alexander, 193.
71 Cahen 271. Dhū ak-Quarnayn and Hānī were in central Jazīra, north of Mayyāfāriqīn.

WEIGHTS AND MEASURES

There was a large number of weights and measures whose values fluctuated widely, depending upon the region, and even upon the choice of the individual craftsman. Riḍwān, for instance, used the span of his own hand and the thickness of his own finger for taking measurements. There is little point, therefore, in making a detailed survey of these expressions and their values. (A thorough examination of the subject was undertaken by H. Sauvaire, *Journal Asiatique*, VIII, Vols. 3, 4, 5, 7, 8, 1884–86). Only indicative values can be given – these are derived directly from Wiedemann and Hauser (W.H.1, p. 6f.).

Weights	1 *Dirham* = 3 gr; 1 *Mit͟hqāl* – 4.5 gr; 1 *Uqīya* (Syrian) = 150 gr; 1 *Raṭl* (Damascus) = 1850 gr; 1 *Mann* – about 1 kg.
Measures	1 *D͟hirāʿ* (cubit) = ½ Metre 1 *S͟hibr* (span) = ½ *D͟hirāʿ* = 25 cm.

The span is the distance between the tip of the thumb and the tip of the forefinger, when the hand is outspread. I have used the abbreviation sp.

The span consisted of 12 fingers, placed side by side (*Aṣbaʿ maḍmūm*). Each finger width was thus equivalent to 2 cm. I have used the abbreviation F. Sometimes the length of a finger (*aṣbaʿ maftūḥ*) was used and this was equal to about 4 cm.

Small dimensions are given by the width of a barleycorn (*shaʿīra*). Laid 'belly to back' there were six barleycorns to 1 F. The *shaʿīra* was therefore equal to about ⅓ cm.

The small span (*fitr*) was the distance between the tips of the thumb and index finger, when outspread. This is taken to be about 16 cm.

Al-Jazarī also uses the breadth of a fingernail (*ẓufr*) say about 1 cm. To indicate very small distances he uses the width of a nail-paring (*qulāma*).

CONCLUSION

We can legitimately discuss the contribution made by Leonardo da Vinci, James Watt and a host of others, known and anonymous, to the development of technology, but we cannot do so in al-Jazarī's case. We do not know what effect, if any, his work had upon later generations of engineers. The number of extant manuscripts, dating from the 13th through to the 19th century, are evidence of the interest taken in al-Jazarī's work throughout a large part of the Islamic world. But this interest was not seminal – no-one was moved to take up al-Jazarī's ideas and incorporate them in the development of 'useful' machines. The reason for this must lie in historical and sociological causes which cannot be identified and discussed here. One may remark in passing, however, that the scribes who copied out the two Leiden manuscripts considered that the description of the manufacture of the palace door was of no interest, and omitted this chapter from their copies. It seems likely that the patrons of medieval Islamic craftsmen were interested mainly in startling effects, ingeniously contrived, rather than in the mundane processes of manufacture – a preference not confined to that class in that cultural area.

We do not know whether any knowledge of al-Jazarī's work, or the works of his predecessors, ever passed over into Europe. Mayr says that the float valve device for water-level regulation dropped out of sight after al-Jazarī's time. It was reinvented in England in the 18th century as a means of feedback control, apparently without knowledge of its earlier career.[1] The continuous-recording gas calorimeter, perfected about forty years ago, not only evokes the memory of the Su Sung water-powered clock, but embodies components familiar to medieval Islamic craftsmen, including the use of the tipping-bucket.[2] Nevertheless, all that we can honestly do, when considering al-Jazarī's work, is to compare his achievement with the achievement of his predecessors, without assuming that he had any influence upon his successors.

It should be evident, from reading this translation and the accompanying notes that al-Jazarī, in one sense at least, was not primarily an innovator. Most of his machines and their components were derived from the works of earlier craftsmen – e.g. the Banū Mūsà and 'Archimedes' – with whose writings al-Jazarī was familiar. Indeed he obviously took pride in belonging to the established and continuing community of craftsmen, as attested by his remarks in his introduction, where he tells us that he uses technical terms and foreign expressions which are common currency in his craft. Similarly, when describing the casting of the palace door (VI.1), he refers to 'the masters of this craft'. He also makes due acknowledgement of the work of his predecessors (e.g. in the introductions to IV, 1, and IV, 7). Sometimes, as in the chapter on the combination lock (VI, 3) he refers to similar devices, made earlier, without mentioning the names of their makers – which, of course, he may not have known. Admittedly, when he makes mention of the work of his predecessors, he continues by explaining how he had improved upon it, but then he had every right to be proud of his superior craftsmanship.

I have said that al-Jazarī was not primarily an innovator, but this is not to imply that he made no innovations, nor that such as he made were without importance. His direct innovations may be listed as follows:

1. The perfection of the tipping-bucket.
2. The reciprocating pump (V.4).
3. The *ṭarjahār* clocks (I, 3 and 4).
4. The phlebotomy measuring basins (III. 6–9).

We should also include in his significant innovations his remarks that indicate that he had ideas about the application of an escapement to a water-wheel (IV.7).

These innovations, together with the use of components and techniques that were not known in Europe until much later, make al-Jazarī's book of the first importance, even though we do not know how much of his work was transmitted to the West. Nevertheless, I believe that the book has a value for us which goes beyond a mere consideration of the devices as working machines. It is one of the earliest manuals of engineering practice that has come down to us. No really satisfactory definition of the term 'engineer' has yet been produced, and this is a question which is still capable of generating a good deal of heat in engineering circles. Nowadays we are apt to think of engineering in terms of the application of mathematical processes to the solution of problems, together with a rigorous attitude towards cost control. Here I intend to define the time 'engineer', somewhat arbitrarily I admit, as follows: 'A mechanical engineer is a man who designs and constructs machines of some complexity, which when completed fulfil the function for which they were intended. He should pay due regard to previous practice, and make the best use of the tools and materials at his disposal.' Judged by this definition al-Jazarī was an engineer, and his book is an engineering document.

The interest of the book lies first in the careful description of the fabrication of individual parts, and the assembly of those parts to construct the complete machine. One could cite many examples, but perhaps the most notable passages are the construction of the reservoir (I.2), of the flow regulator (I.1, 3 and 5), and the instructions for balancing the elephant clock's mechanisms, first using a paper model (I.4, 13). Al-Jazarī is, furthermore, always careful to give the exact sequence of construction and assembly, ensuring that the craftsman's access is never blocked by work carried out previously. (See, for example, Chapters II.5, and III.6). A number of methods still in use today are clearly described by al-Jazarī; for example, the use of a plumb-line (I.5, 3), static balancing of a wheel (I.1, 9), the use of a mandrel to check parts for flatness (I.7.1), and of course the grinding in of valves, which was discussed earlier. He also distinguishes quite clearly between the three main types of fit used in modern engineering practice: the push-fit (I.6, 6), the sliding fit (I.8, 2) and the running fit (I.4, 9).

The presentation is usually very clear and follows a set pattern. First comes a general description of the machine and how it works; this is followed by a number of sections describing the manufacture of various parts of the machine, and each section includes a passage which repeats the description with reference to the relevant detailed drawing. Every so often (several times in the longer chapters, once only in the shorter ones), we are given a succinct description of the functioning of the device(s), described in earlier sections. These passages invariably begin with the words 'it is very clear that...', and indeed they usually are clear.

Al-Jazarī's work is not, of course, free from defects, among the most serious of which are his carelessness about dimensions and his inability to give a coherent record of mathematical or geometric processes. His description of the marking out of the face of the flow regulator is perhaps the worst example of the latter defect. A third defect is his use of the directions 'right' and 'left' without specifying the viewpoint. In general, however, these defects are not serious – I found little difficulty, for instance, in producing orthographic and isometric views from al-Jazarī's instructions, with some confidence in their general accuracy.

To our way of thinking al-Jazarī is unnecessarily longwinded, giving a succession of detailed instructions for a series of related processes, where a modern writer would merely say 'and so on'. The operation of the three cone-valves connected to the jack figures (I.1, 8) and the cutting of the ring for the moon's phases (I.1, 9) are two examples that come to mind. And the method of presentation also makes repetition inevitable, since a mechanism may be described once in the manufacturing instructions, again when the drawing is referred to, and again in the summary. In my view, however, I do not find that this repetition detracts from the work when it is considered as an explanatory document. The whole work, drawings and text, falls into a coherent pattern which comes to be seen as a most effective way of communicating the writer's designs.

It has been said that Arabic drawings, al-Jazarī's in particular, were bad,[3] and undeniably they are pretty crude. But although crude, and in a few cases misleading, they usually give a fair idea of the machine or component being described, particularly when read together with the text. Moreover, we should not judge these drawings against modern practice, but against the standards of other medieval draughtsmen. Booker points out that up to the 16th and 17th centuries T squares and drawing boards were not in general use, and many of the obvious drawing techniques in use today were quite inapplicable.[4] He further points out that multi-view orthographic drawings are easy to make and are a record but can be very difficult to interpret.[5] And in a comment of

[1] Mayr, 114.
[2] Needham (1), 537.
[3] Needham (3), 57.
[4] Booker, 38.
[5] Booker, 141.

especial interest Booker says: 'even when an all round genius, such as Leonardo da Vinci thought on paper about machines, he nearly always did so in terms of apparent view pictures, and not in terms of true plans and elevations.[6] Even nowadays, engineers have recourse to modelling and photography, both to improve the clarity of presentation and to improve the finished design.

That al-Jazarī was well aware of the problems involved in the preparation of explanatory drawings is shown by several remarks, particularly in a passage concerning the drawings for the palace door (VI.1, 1). He certainly used a technique that is indispensable for all engineering drawing – the use of general arrangement drawings in combination with detailed drawings of individual components and mechanisms.

To our eyes, the perspective drawings in the works of engineers such as Ramelli are greatly superior to those of al-Jazarī but it is frequently very difficult to understand the construction and functioning of one of Ramelli's machines from the drawing of it. In the end, one can only reiterate that, taking text and drawings together, al-Jazarī's method serves its purpose, since most of his machines could be reconstructed from the data which he gives.

Al-Jazarī, then, gives us the full engineering content of his work. For a given machine he tells us its appearance, purpose and functioning; he describes, step by step, the manufacture of its component parts, setting-out, assembly and fitting, joints and connections, and testing. In doing so he tells us a good deal about himself. He was a master craftsman, fully conversant with all branches of his trade, consciously proud of his membership of the technical fraternity. More rarely, he was a master craftsman who could write, and who has left us an engineering document of the first importance.

[6] Booker, 47.

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INDEX

The listing in this index is alphabetic, but prefixes to Arabic names are ignored for this purpose. These include the definite article *al-*, *ibn* (son), *banū* (sons) and *abū* (father).

The references are comprehensive for names of places and persons, with the exception of al-Jazarī himself, for whom the references have been limited to the significant passages. For the remainder of the subject matter the index is selective – it would have been of little assistance to the reader, for example, to include every mention of common fittings and materials. Furthermore, the index concentrates largely on Part II of the book, references being made to the Notes only when these emphasize points of particular interest or importance. This applies especially to the Notes for individual chapters, which are designed to be read in conjunction with those chapters.