Foundation for Science Technology and Civilisation

Nutaf min al-Hiyal:

An Arabic Partial Version of Pseudo-Aristotle's *Mechanical Problems*

Author: Prof. Mohammed Abattouy

Chief Editor: Prof. Mohamed El-Gomati
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Release Date: June 2007
Publication ID: 706

FSTC Limited
27 Turner Street, Manchester, M4 1DY, United Kingdom
Web: http://www.fstc.co.uk Email: info@fstc.co.uk

NUTAF MIN AL-HIYAL:
AN ARABIC PARTIAL VERSION OF PSEUDO-ARISTOTLE'S *MECHANICAL PROBLEMS*

Prof. Mohammed Abattouy*

This article[1] investigates the Arabic tradition of the *Problemata Mechanica*, a Greek text of mechanics ascribed to Aristotle that has often been claimed to have been unknown in Arabic classical culture. Against this prevailed claim, it is shown that the Arabo-Muslim scholars had access to the text at least in the form of an abridged version entitled *Nutaf min al-hiyal* edited by al-Khāzinī (12th century) in *Kitāb mīzān al-hikma* (Book of the Balance of Wisdom). The article includes commentaries on the history of the text, the edition of the Arabic text, an English translation, and a short characterisation of the mechanical theory of the *Nutaf*.

The *Problemata Mechanica*, a Greek text of mechanical questions ascribed to Aristotle, is claimed in some recent publications to have been unknown in the Arabic traditions. To challenge this claim, it will be shown in the present article that the Arabo-Muslim scholars had access to the text at least in the form of an abridged version entitled *Nutaf min al-hiyal* included by al-Khāzinī (12th century) in his *Kitāb mīzān al-hikma* (Book of the balance of wisdom). This short version seems to have been epitomized by al-Isfizārī (11th-12th centuries), al-Khāzinī's immediate predecessor, who may have been responsible for the structuring of the *Nutaf* in the form of an epitome, or at least for its insertion among materials relevant to the practical description of the balance of wisdom. In order to reconstruct the Arabic tradition of the *Problemata Mechanica*, the text of *Nutaf min al-hiyal* is edited and translated into English. Furthermore, various kinds of materials are used to describe the historical and textual contexts in which the *Nutaf* fragment was inserted by al-Khāzinī in *Kitāb mīzān al-hikma*.

1. Historical and textual context

The *Problemata Mechanica* is a Greek treatise ascribed to Aristotle, but composed very probably by one of his later disciples. It deals with simple machines and many concrete phenomena on the basis of a constant procedure: the attempt to reduce them to the balance, and hence to the 'marvelous properties' of the circle.[2] It was long claimed that the Peripatetic *Mechanica* had not entered Arabic culture. It is possible now to affirm that this is not true, and that the scholars of the Islamic lands had access to it at least through a short text entitled *Nutaf min al-hiyal* (Elements/extracts of mechanics)[3] edited in the 5th Book of *Kitāb mīzān al-hikma*, al-Khāzinī's encyclopedia of ancient and medieval mechanics.[4]

* Mohammed Vth University, Rabat, Morocco. Member of FSTC, Manchester; representative of the Foundation in Morocco; Deputy Chief Editor of www.muslimheritage.com.

[1] Based on an earlier version published in Abattouy 2001a.

[2] Apparently completely unknown during the European Middle Ages, the text was printed in Venice in 1497 on the basis of a manuscript brought from Byzantium; it exerted then a considerable influence on the mechanical debates in the 16th century. For the history of the Greek text, the debate about its authorship, and its influence in the Renaissance, see Rose and Drake 1971, Aristotele 1982, p. 17 ff., De Gandt 1986, Micheli 1995, pp. 23-35, 133-152. A fresh account on the mechanical theory in the Peripatetic treatise is presented now in Damerow *et al.*, 2002 (published before in Berlin: Max Planck-Institut für Wissenschaftsgescichte, Preprint 145, 2000, 28 pp). The auhors of this article argue in favour of a possible connection between the ancient practical knowledge on balances and the mechanical theory exposed by al-Khāzinī.

[3] All the translations quoted in the article are mine, unless otherwise indicated. They are extracted from my edition and translation of a large corpus of Arabic mechanical writings due to be published in a near future: M. Abattouy, *The Arabic Science of Weights and the*

The text of the *Nutaf min al hiyal* represents indeed a significant partial Arabic version of the *Mechanical Problems*. Presented under a special title that indicates its character as an excerpt from a longer text, it is attributed directly to Aristotle; as we will see below, it begins by the sentence: "Aristotle said". It consists in a reliable abridged version of the preliminary two sections of the pseudo-Aristotelian text where the theoretical foundation of the treatise is disclosed. Thus it includes a methodically arranged compendium of the introduction giving a definition of mechanics and of Problem 1 on the reason of the accurateness in the larger balances to the detriment of smaller ones. As edited in *Kitāb mīzān al-hikma*, the *Nutaf* is preceded by a relatively long technical discussion on the balance equilibrium dealing with the different cases of incidence of the axis on the balance beam. In his analysis of this question, al-Khāzinī probably had in mind the Peripatetic Problem 2 which investigates the accidents that arise from the suspension of the balance beam from above or from below. Without our assuming the analysis of the balance equilibrium in *Kitāb mīzān al-hikma* to be closely connected to Pseudo-Aristotle's second mechanical question, it is hardly possible to understand why the *Nutaf* fragment was inserted precisely at the place it occupies in the middle of the first chapter of the fifth part of al-Khāzinī's large book.[5]

Transformation of Mechanics: 9th-12th Centuries, forthcoming.
[4] Al-Khāzinī 1940, pp. 98-100.
[5] As will be argued later on, this was done in order to provide a theoretical foundation for the discussion of the balance equilibrium problem. In the first and second books of *Kitāb mīzān al-hikma*, al-Khāzinī edited abridged versions of several mechanical texts of his Greek and Arab predecessors: al-Khāzinī 1940, pp. 15-45. In the order of their publication, these include a joint version of Abū Sahl al-Kūhī's and Ibn al-Haytham's works on centers of gravity, the texts of Euclid, Archimedes and Menelaus on heaviness and lightness, the work of Thābit ibn Qurra *Fī sifat al-wazn* (Properties of weight), a five-section text on the equal-armed balance, and a valuable version of al-Isfizārī's *Irshād* which contains a very important section on the construction and use of the steelyard. The style adopted by the author in his editorial enterprise of all these texts consists in the reproduction of more or less brief digests of the original works and in discarding large parts of the reasoning, mainly the geometrical proofs. Accordingly, this general procedure guided probably the edition of the *Nutaf* fragment, which might have been extracted from a longer Arabic text of the Pseudo-Aristotelian treatise, of which the existence is attested by other pieces of evidence: see below pp.6-9 and note 41.

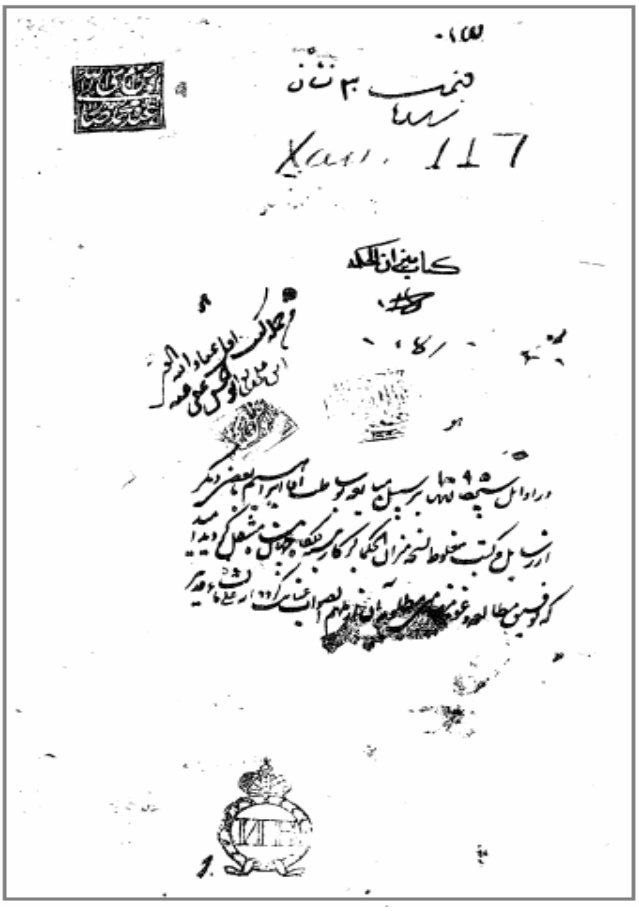

Figure 1. First page of *Kitāb mīzān al-hikma.* Saint Petersburg, Russian National Library, Khanikoff collection, MS 117.

The existence of an Arabic version of the *Mechanical Problems* has been left unconsidered in recent historiographical debates. Surprisingly, however, the German scholar Thomas Ibel had identified the passage in *Kitāb mīzān al-hikma* as a partial Arabic version of the Peripatetic text, which he also translated into German.[6] Nonetheless, this brilliant achievement remained unnoticed, and none of the scholars who investigated the field of Arabic mechanics since then referred to it nor happened to identify the corresponding passage in al-Khāzinī's book when the latter was published in 1940. Rather, recent works relied heavily on the claimed non-transmission of the Peripatetic treatise to Arabic culture, and drew from this 'fact' general conclusions relevant to the reconstruction of its textual history and to the determination of its place in the history of mechanics.[7] In this regard, the passage preserved by al-Khāzinī provides a

[6] Ibel 1908, pp. 123-125.
[7] This is Micheli's attitude: Micheli 1995, pp. 94-95, 117-119. The same point of view seems to inspire some of W. R. Knorr's conclusions: Knorr 1982, p. 116. For Khalil Jaouiche and Mariam M. Rozhanskaya, it is unknown whether the *Mechanical Problems* was translated into Arabic, although Jaouiche had the intuition that Thābit ibn Qurra's proof of the law of the lever relied on the initial chapters of the Peripatetic treatise, and that Rozhanskaya identified the fragment edited by al-Khāzinī as an extract from Pseudo-Aristotle's *Mechanica*: see Jaouiche 1976, p. 28 ff., Rozhanskaya 1983, pp. 299-300, and Rozhanskaya 1996, p. 615.
In his informative *Aristoteles Arabus*, Francis E. Peters notes that the Aristotelian text appears in the Arabic *pinakes* deriving from a Greek catalogue of Aristotle's works by Ptolemy Chennus of Alexandria, known in the Arabic sources as Batlimūs al-Gharīb, Ptolemy the Foreign

decisive proof confirming the Graeco-Arabic transmission of the text and stands as an argument in favor of the possible existence of a complete Arabic version, longer than the short summary provided in the *Nutaf*.[8]

In its extant form, the *Nutaf* seems to have been compiled in the 'Khurasanian School' of mechanics. This informal group of scholars, led by al-Isfizārī and al-Khāzinī, maintained in the 11th-12th century Iran a lively debate on mechanical problems and brought the Arabic tradition of theoretical and practical works on the balance to a high level of sophistication.

Abū Hātim al-Muzaffar ibn Ismā'īl al-Isfizārī flourished in Khurāsān (north-east Persia) around 440 H/1048-510 H/1116, during the reign of the Saljuq dynasty over the Eastern part of the Islamic world.[9] He was a contemporary of the celebrated mathematician and poet 'Umar al-Khayyām (1048-1131). His work holds an eminent place in *Kitāb mīzān al-hikma*, the work of 'Abd al-al-Rahmān al-Khāzinī, his immediate successor. Al-Isfizārī's life and career may be reconstructed with the help of the meager information gleaned from short notices in a very few historical sources, such as the paragraph dedicated to him in al-Bayhaqī (d. 1170). According to the latter, al-Isfizārī exercised teaching, constructed an accurate balance and wrote treatises on mechanics, meteorology and mathematics.[10] The historian Ibn al-Athīr (1160-1233) mentions furthermore that al-Isfizārī was one of the scholars who carried on the program of astronomical observations in Isphahan from 1075 in the observatory founded and sponsored by Malikshāh.[11] But in spite of his multifaceted activities, al-Isfizārī's oeuvre remained largely unknown up to now. In the field of mechanics, where he contributed his most significant works, two important texts by him are extant. First, a two-part treatise on the steelyard, *Irshād dhawī al-'irfān ilā sinā'at al-qaffān* (Guiding the Learned Men in the Art of the Steelyard), undoubtedly al-Isfizārī's most important writing, which has never been studied. In this treatise on the theory and the practice of the unequal-armed balance, different textual traditions from Greek and Arabic sources are merged together for the elaboration of a unified mechanical theory.[12] Secondly, a collection of summaries – sometimes accompanied by comments – extracted from the mechanical works of Heron, Apollonius and Banū Mūsā.[13]

Another eminent member of the Khurasanian School of mechanics is 'Abd ar-Rahmān al-Khāzinī (fl. *ca.* 1115-1130). He worked in the court of the Sultan Sanjar, third son of Malik-Shāh (d. 485/1092), who after having been governor of Khurāsān, became the overall ruler of the Seljuk empire in 1118. It is to him that al-Khāzinī dedicated his astronomical work *al-Zīj al-mu'tabar al-sanjarī* and his encyclopedic work on the balance of wisdom, the famous *Kitāb mīzān al-hikma*, "the most important and comprehensive work on

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(late first and early second centuries). Further, he adds some secondary references to the Peripatetic *Mechanica* in Arabic historical sources (those quoted below in note 18), and indicates the explicit reference to the text that occurred in the *De arte venandi cum avibus* of Frederick II (13th century). But he considers fundamentally that the text was only 'possibly' used by al-Khāzinī and that "there is no distinct trace of a translation in either the Arabic or Arabic-Latin manuscript tradition": Peters 1968a, p. 61.

[8] The main features of the Graeco-Arabic transmission of mechanical texts are surveyed in Abattouy 1999, Abattouy 2001b, pp. 184-186, Abattouy 2002b, and Abattouy 2006.

[9] Al-Isfizārī's bio-bibliography is reconstructed in Abattouy 2000a.

[10] Al-Bayhaqī 1988, p. 125.

[11] Ibn al-Athīr 1378 H [1967], p. 121. On this point, see Sayılı 1960, pp. 162-163.

[12] The *Irshād* of al-Isfizārī is extant in a unicum copy preserved in Damascus (al-'Asad National Library MS 4460, al-Zāhiriyya Collection, folii 16a-24a) and in an abridged version reproduced by al-Khāzinī (1940, pp. 39-45). Its contents are surveyed and commented upon in Abattouy 2000a and Abattouy 2001b, pp. 226-238.

[13] This collection is preserved in two manuscript copies: MS 351 in the John Ryland's Library in Manchester and MS QO 620 H-G in the 'Uthmāniyya University Library in Hayderabad. Up till now, it has been mentioned only in the catalogues of Arabic manuscripts. It includes, in this order: a long reworked version of Banū Mūsā's *Kitāb al-hiyal* (Book of machines), a commentary on selected parts of the first two books of Heron's *Mechanics*, and a short text entitled *Kitāb fī al-bakara* (Book of the wheel) ascribed to Apollonius, probably an extract from the text on the screw ascribed to Apollonius of Perga by Proclus and Pappus. This text is to be published in M. Abattouy, "*Kitāb fī al-bakara*: An Arabic partial version of Apollonius' *On the Screw*", forthcoming on www.muslimheritage.com.

mechanics in the Middle Ages, from any cultural area".[14] Completed in 515 H (1121/1122), it covers a wide range of topics related to statics, hydrostatics and practical mechanics, besides reproducing abridged editions of several mechanical texts by or ascribed to Greek and Arabic authors. As such, al-Khāzinī's work is a real mine of information on mechanical knowledge up until the early 12th century.[15]

Before we proceed to the discussion of the *Nutaf min al-hiyal* and its textual context in al-Khāzinī's encyclopedic book, let us present first some historical data on the main cases of occurrence of the Peripatetic text in Arabic historical sources. The investigation of these classical sources confirms that *Problemata Mechanica* occurred indeed as a title of an Aristotelian work. The earliest reference of this kind is reported in the chronicle composed in 1053/54 by al-Mubashshir Ibn Fātik who mentioned among Aristotle's books "*Kitāb hiyal al-handasa*" (Book of geometrical mechanics).[16] Similar references are to be found also in the 13th-century bibliographical dictionaries of Ibn abī 'Usaybi'a and Ibn al-Qiftī. The former mentions among the works of Aristotle "*Kitāb fī 'l-masā'il al-hiyaliyya, maqālatān*" (Book on mechanical problems, in two chapters), whereas the latter quotes the very Greek title of the text: "his book called 'Mechanical Problems' (*masā'il hiyaliyya*) and entitled '*Mīkhānīqā problemātā*'."[17]

Furthermore, in *Kitāb al-Qādir* (Book of the powerful), a text ascribed to Jābir ibn Hayyān (721-815), the well known Arab alchemist and philosopher who flourished mostly in Kūfa (southern Iraq), familiar in the Latin world under the name of Geber, a short passage quotes in a peculiar way the Peripatetic *Mechanica*: "Aristotle said in the *Book of Mechanical Balances* (*kitāb al-mawāzīn al-mīkhanīqiyya*): "as for the 'how' of a thing it is a geometrical and mathematical matter, whereas the 'what' of a thing is a natural matter. How prestigious and honorable is this discourse for him who understands it".[18] The particular significance of this rather short reference to the *Mechanica Problemata* is that it might represent a very early occurrence of the Peripatetic text in the Arabic tradition. The archaic style in which the title of the Peripatetic text is mentioned indicates a paraphrase rather than a direct quotation. This is natural if it is supposed that the short passage in Jābir's *Kitāb* draws probably on *indirect* Greek sources.[19]

A second similar case comes from the other end of the Islamic medieval world. It seems indeed that Abū al-Walīd ibn Rushd (Averroes, d. 1198), the famous Andalusian philosopher, knew the *Mechanica Problemata* as he made a critical reference to its *quaestio* 24: why two connected concentric circles, one of which rolls along a straight line, during one revolution, cover equally long straight lines in spite of their different circumferences. Ibn Rushd had maintained that geometry cannot prove that this is the case. For this reason he was criticized by Cardano, who exclaimed in his *New Work on Proportions*: "Why did he not solve the

[14] Hill 1993, p. 60.
[15] On al-Khāzinī's life and works, see Hall 1973 and Abattouy 2000b.
[16] See Ibn Fātik al-Amīrī 1958, p. 184. Originally from Damascus, this author lived in Egypt where he died around 489-90 H/ 1096. According to several sources (Ibn al-Qiftī, al-Safadī) he studied with the famous physicist Ibn al-Haytham and wrote his book in 445 H. Ibn Fātik's book exerted a remarkable influence on the Latin historiography in the late Middle Ages after it was translated into Spanish (*Los Bocados de Oro*) and into Latin and other European languages. It might have been one of the earliest sources in which Latin scholars knew about the existence of a work on mechanics ascribed to Aristotle. On Ibn Fātik, see Peters 1968b, pp. 126-128.
[17] See respectively Ibn abī 'Usaybi'a 1965, p. 104, and Ibn al-Qiftī 1903, p. 43. The *Kitāb al-hiyal* which Hajjī Khalīfa ascribes to Aristotle may be derived from these early sources: Hajjī Khalīfa 1835-58, vol. 5, p. 78, vol. 7, p. 851.
[18] *Kitāb al-qādir*, Paris, Bibliothèque Nationale, MS Arabe 5099, f. 66b, 8-10. Another copy of Jābir's *Kitāb al-qādir* is preserved in Teheran, Danishgāh Library, MS 491, ff. 141a-142a; see Sezgin 1971, pp. 101, 252.
[19] As it is well known, the *Corpus jabirianum* is a very complex set of texts, some of which were written in later times and were only falsely attributed to Jābir ibn Hayyān. Hence it is difficult to decide about the date in which this reference to the Pseudo-Aristotle's *Mechanica* was made, although the peculiar title under which this work is designated inclines to decide for an early one. In his *Jābir ibn Hayyān. Contribution à l'histoire des idées scienifiques dans l'Islam. Jābir et la science grecque*, Paul Kraus casts serious doubts on the authenticity of a large part of the Jābirian corpus but he does not say so when he quotes the passage of *Kitāb al-qādir* where the *Mechanical Problems* is mentioned: Kraus 1986, pp. 323-324. Kraus' thesis concerning the genuiness of the Jabirian corpus is challenged in Nomanul Haq 1994,

difficulty, which is exclusively mathematical and rests on evident principles?"[20] Hence according to Cardano the *Mechanical Problems* was known to Ibn Rushd and therefore was probably available in Muslim Spain, to where it was plausibly brought from the Islamic East. This is instructive as indication of the wide diffusion of the text throughout the Islamic world.[21]

Besides the references we find in classical Arabic culture to the Peripatetic *Mechanical Problems*, this text was accessible in the Islamic area, as mentioned above, at least through the partial version *Nutaf min al-hiyal* edited in the fifth part of al-Khāzinī's encyclopedic work on the balance of wisdom. The Book Five of *Kitāb mīzān al-hikma* is dedicated to the description and the trial of the balance of wisdom, a huge lever balance with equal arms having five scale-pans and a running counterweight. Its first chapter consists of a very minute description of the balance, probably according to written specifications by al-Isfizārī, whose name is mentioned three times in the chapter. The fragment *Nutaf* is introduced at the end of Section 4, following what might be considered the most important part of al-Isfizārī's description. The paternity of the latter is obviously valid for all the material enclosed in the limits of the chapter and naturally extends over the fragment extracted from the Peripatetic treatise. On this basis, al-Isfizārī might be considered logically as responsible for the adaptation of this partial Arabic digest and also for its insertion as a digression appended to the description of the parts of the balance. We owe to al-Khāzinī's predecessor indeed a whole body of recensions, reworkings and commentaries that comprise virtually all the corpus of theoretical mechanics to which he could have access, including Greek and Arabic works. Therefore, it would be quite natural that he would produce a digest of the *Mechanica Problemata*, one of the major ancient texts of mechanics.[22]

chap. 1.
[20] Geronimo Cardano 1570, Prop. 196, p. 222.
[21] According to Cardano, Ibn Rushd dealt with this problem of the wheels in his *Commentarium magnum*, to which he had access very probably in the edition of his commentaries on Aristotle's works: *Opera omnia Aristotelis Stagiritae… Averrois Cordubensis in ea opera omenes qui ad nos pervenere comentarii* (Venice: apud Cominum de Tridino, 1560); reprinted Venetiis, apud Junctas, 1562-1574 (recent edition in Frankfurt: Minerva, 1962). The Peripatetic problem of the concentric circles has been made famous after Galileo discussed it in the First Day of his *Discorsi* published in 1638. In his history of the question, I. E. Drabkin (1958) did not mention Ibn Rushd in connection with it.
[22] A supplementary confirmation of al-Isfizārī's direct knowledge of the Pseudo-Aristotelian text is provided by a passage of his *Irshād* where he says that the art of the steelyard "is composed of both geometrical and natural arts, combining the two categories 'why' and 'how'" (*Irshād*, f. 17a). As will be shown below, this is a characteristic thesis of the *Mechanical Problems*.

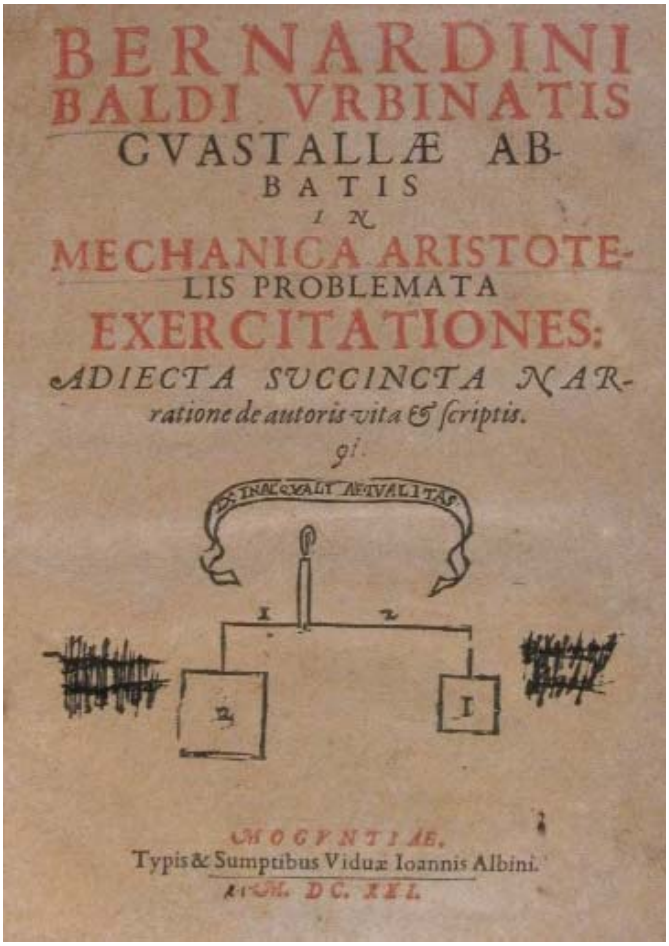

Figure 2. Page cover of Bernardino Baldi's, *Mechanica Aristotelis Problemata* (1621), a Latin commentary on the pseudo-Aristotelian *Questions of Mechanics.* Source: http://www.chlt.org/sandbox/lhl/Baldi/page.6.php

2. An ingenious solution to the balance equilibrium problem[23]

As said above, the *Nutaf* fragment is preceded in *Kitāb mīzān al-hikma* by a technical discussion on the balance equilibrium. Apparently, this discussion has no direct bearing on the contents of the *Nutaf* proper, but it might be easily shown that al-Khāzinī introduced it exactly there for a quite plausible reason: in order to provide a theoretical foundation for this practical discussion in which he was aware of having elaborated a solution going far beyond the Peripatetic version of this same problem.

The following brief look on the structure of al-Khāzinī's treatise will be helpful for the reconstruction of the textual context in which the *Nutaf* fragment appears. *Kitāb mīzān al-hikma* is divided into eight books or

[23] A summary of al-Khāzinī's improvemenent of this problem is exposed in detail in Abattouy 2000c, pp. 9-19, 29-33 and in Abattouy 2001b, sect. II.1.

maqālāt that the author organised in two principal parts (al-Khāzinī 1940, p. 92): Books I-IV set the theoretical foundations of the science of the balance in general, together with a summary description of the balances constructed by al-Khāzinī's predecessors, whereas Books V-VII are devoted to a minute description of the universal balance conceived by al-Isfizārī and built and explained in detail by al-Khāzinī.[24]

The corner stone of this second part is undoubtedly the Fifth Book which is dedicated to the description of different technical aspects of the balance of wisdom. Entitled "Mechanism, construction, explanation and trial (*fī al-san'a wa al-tarkīb wa al-ta'rīf wa al-imtihān*)" of the said balance, it occupies thus a crucial position in the structure of al-Khāzinī's text as it is dedicated to elaborate upon the previous theoretical and practical considerations for the description of the parts of the balance of wisdom and how they are articulated together. It is in this context that the appeal is made to the Pseudo-Aristotelian mechanical theory. Indeed, the discussion of the balance equilibrium problem occurs in Book V, chapter 1, sect. 4, and the *Nutaf* fragment is introduced at the end of this section, to which it is appended.

Four chapters compose Book Five of *Kitāb mīzān al-hikma*. The first, and most important for our concern, is made up of seven sections. It is entitled "On the construction (*san'a*) of the limbs of the balance of wisdom according to the figure (*hay'a*) indicated by the eminent master (*al-shaykh al-imām*) al-Isfizārī." The first three sections describe, respectively, the beam (*'amūd*), the needle or pointer (*lisān*) and the scissors-shaped forks (*fiyyārān*) between which the latter moves. The fourth section deals with "the universal and general science" of the axis, of the perforation of the beam for the fastening of the needle to it, and of the taking into account of the weight of the needle and of the scale-pans which are attached to the beam (*fī al-'ilm al-kullī al-mutlaq fī ahkām al-mihwar wa al-thaqb wa al-thiql*).[25] Thus it deals in theoretical and practical fashions with the different cases of incidence of the needle on the beam and with the accidental circumstances – due to the friction between the axis and the beam – which may obstruct the rotation of the latter.

The problem of the balance equilibrium in *Kitāb mīzān al-hikma* (Book 5, chapter 1, section 4) is formulated in statical terms and in a general way, producing thus an appropriate and suitable solution. Hence the equilibrium of the balance is said to include three cases to be considered, and all three depend on the position of the axis with respect to the centre of gravity of the beam. Therefore, the respective positions taken by the beam, whether it stays on the horizontal plane, comes back to it when inclined, or remains depressed to one side, correspond in turn to the coincidence of the axis with the centre of the balance, and to the cases when the former is situated above or below it.

The balance referred to by al-Khāzinī is composed of a system of heavy bodies (beam, needle and scale-pans) of which the conditions of equilibrium and stability are characterized on the basis of the theory of the centre of gravity developed earlier in Books I-II. The analysis starts by considering the case of a heavy cylindrical beam suspended in horizontal equilibrium. On disturbance of its equilibrium, the incidence of the axis on it takes three probable positions, depending on whether the axis of rotation passes through, above or below the centre of gravity of the beam. These positions are called respectively 'the axis of equilibrium' (*mihwar al-i'tidāl*), 'the axis of rotation' (*mihwar al-inqilāb*), and the 'axis of constraint' (*mihwar al-iltizām*),

[24] The Sixth Book is about the selection of appropriate counterpoises, the Seventh applies the balance of wisdom to exchange problems (conversion of gold and silver coins from and to *dirhams* and *dināars*), and the Eighth Book describes two varieties of a balance clock for the determination of time.
[25] The last three sections are devoted to the scale-pans, to the rings by which the balance is supported and to the bucket of water.

corresponding to the cases called in modern terminology: indifferent, unstable and stable equilibrium (al-Khāzinī 1940, pp. 96-98).

Instead of just describing what happens when the balance beam is supported from above or from below, as in the *Mechanical Problems*, our author endeavors to find a complete explanation of the problem. For this purpose, he invents a special terminology and analyses the problem on an abstract level. His procedure covers three cases, two of which correspond to those mentioned in the Peripatetic *Mechanica*.[26] Thus, when the axis is below the centre of the beam, the latter is said to remain inclined to one side; and when it is above the same centre it is constrained to return back to horizontal equilibrium. In the third case, wanting in Pseudo-Aristotle, when the axis coincides with the centre of gravity of the beam, the latter stays even. In the three cases, the Arabic text relies on a single principle: the change in the angle of incidence of the axis on the beam with respect to its centre of gravity. The beam is designed explicitly as being free from the needle or pointer and from any scale-pans or chains.

At the end of this theoretical discussion of the incidence of the axis on the balance beam, al-Khāzinī turns to the examination of the accidental circumstances caused by the friction between the axis and the beam and which obstruct the rotation of the latter. This practical question is surveyed rapidly as a conclusion for the balance equilibrium problem. Its location at this place points out that al-Khāzinī's investigation of the whole issue was aimed precisely at this practical end, namely the explanation of the way to fasten the needle to the beam. In this perspective, the needle and the crosspiece to which it is fixed represent the axis of rotation of the balance beam.

[26] The second mechanical problem debated in the Peripatetic *Mechanica* asks why is it that when the cord is attached to the upper surface of the beam of a balance, if one takes away the weight when the balance is depressed on one side, the beam rises again and returns to horizontal equilibrium, whereas if the beam is supported from below, when the weight is removed, it remains in the inclined position (Aristotle 1952, 850a 3-6). The answer of the author is that this happens because when the support is from above and that a weight is placed in a scale-pan, the larger portion of the beam is above the perpendicular represented by the chord. In this case, the greater part of the beam must incline until the line dividing the beam into two equal parts coincides with the perpendicular. In the other case, when the balance is supported from below, the greater part of the beam is the inclining part so that the beam remains in this position for this reason.

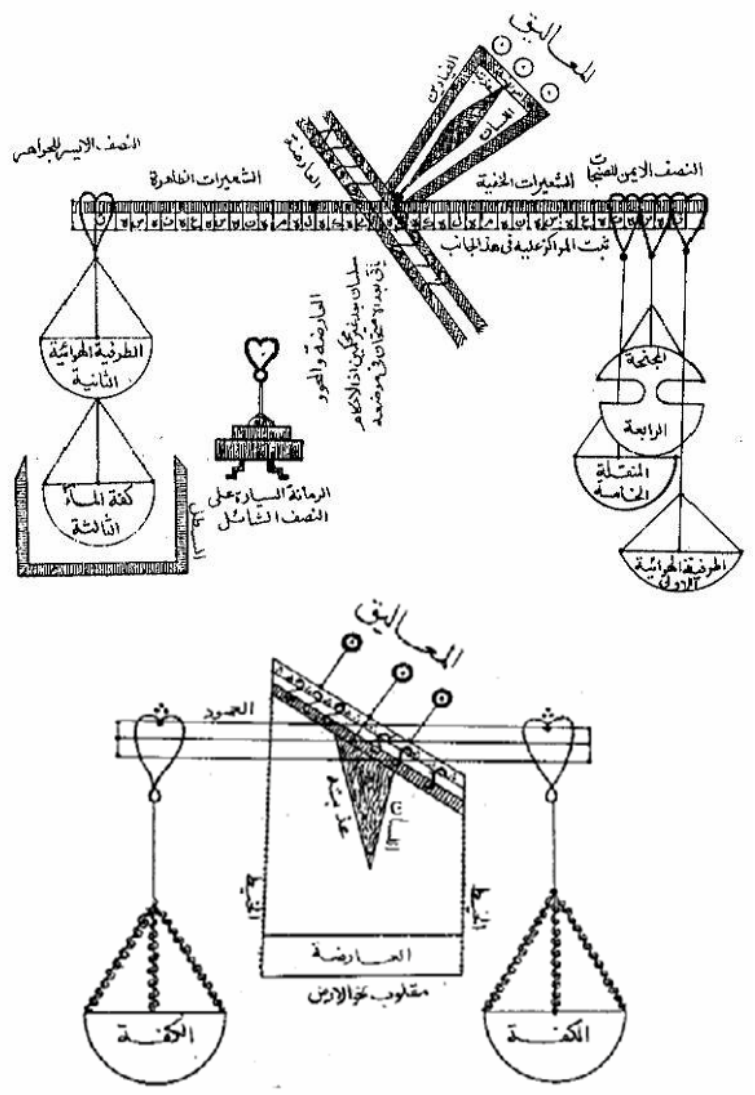

Figure 3. Two positions of the balance mentioned in *Kitāb mīzān al-hikma*: the normal situation in which the balance is suspended from above and the overturned balance. Source: al-Khāzinī 1940, pp. 103, 108.

In regard to the above-mentioned evidence, it turns out that al-Khāzinī's solution to the balance equilibrium problem is an improvement of the earlier Peripatetic argument elaborated in the course of the answer to the second *quaestio* of the *Mechanical Problems*. This connection is established for the first time. Further, it represents a brilliant instance of the improvement in Arabic mechanics of a technical problem stemming from Greek sources. As such, it embodies indeed a case of creative transformation of a product of transmission.

Moreover, the link between the balance equilibrium problem and the *Nutaf* in *Kitāb mīzān al-hikma* is incontestable, as the latter is physically *appended* to the former and as the passages corresponding to them in the Greek text come together (but in the inverse order). The interconnection between the two texts may

be worked out by supposing that al-Isfizārī and/or al-Khāzinī considered that, since they belong to the one and same mechanical theory in the Peripatetic *Mechanica*, then the properties of the balance equilibrium must be founded on the conception of mechanics provided by the two sections of the *Nutaf*. In this light, the solution elaborated for the balance equilibrium is referred to the same properties of mechanical devices (*hiyal sināʿiyya*) and of mechanical problems (*masāʾil hiyaliyya*) in general as defined in the first part of the *Nutaf* and thus circumscribed to the limits of the Peripatetic framework, rather than being reported to another theoretical horizon, that of Archimedes' statics. This second possibility was, however, not available as a result of the non-transmission of any of Archimedes' statical works to the Arabic science.[27]

3. Edition and translation of *Nutaf min al-hiyal*

In *Kitāb mīzān al-hikma* the text of the *Nutaf* follows immediately after the discussion on the balance equilibrium, probably with the aim to supply a theoretical framework for it. In the following section, *Nutaf min al-hiyal* will be edited and translated into English, then, in a last section, it will be commented upon briefly.

3.1. Edition of the Arabic text

Three known complete manuscript copies of *Kitāb mīzān al-hikma* are conserved:

- Al-Maktaba al-Muhammadiyy, al-Masjid al-Jāmiʿ in Mumbay (Bombay before), Codex 547.

- Saint Petersburg, Russian National Library, Khanikoff collection, MS 117.

- Andhra Pradesh Government Oriental Manuscripts Library and Research Institute in Hayderabad, Codex Riyādhī 125.[28]

The first copy was written at the beginning of Rābiʿ II 585 H / May 1189, some sixty-eight years only after the book was completed by its author (in 1121). Whence its extreme interest. Unfortunately, according to the present available information, it seems that this manuscript has been lost.[29] Thankfully enough, it was used in the edition of *Kitāb mīzān al-hikma* in 1940, where some of its most significant variant readings were cited.

The MS conserved now in Saint Petersburg seems to be very close to the lost Bombay copy, from which it most probably stems. It was discovered in Iran in the 19th century by the Russian consul in Tabriz, Nicholas Khanikoff, who used it for a partial publication and translation of al-Khāzinī's work.[30] A xerox copy of this same MS was later collated with the two afore-mentioned Indian copies for the publication of the Arabic text by the 'Uthmāniyya University in Hyderabad in 1940.[31]

[27] The fate of Archimedes' mechanics in the Arabic tradition is discussed in Abattouy 2002, pp. 184-185.
[28] Few years ago, Sam Fogg, a London firm of medieval, Islamic and Indian art, exhibited on its website (www.samfogg.com) some pages of a manusscript copy of al-Khazini's *Kitāb mīzān al-hikma* including very beautiful illustrations of the drawings included in the book. This manuscript was for sale, and at present (May 2007), it is no more displayed on the website.
[29] This is the official information I got from al-Maktaba al-Muhammadiyya in Mumbay. Fortunately, photographs of this manuscript seems to be conserved in the library of the Institute for the History of Arabic Sciences in Aleppo (Catalogue of the photographed manuscripts, n° 79), as announced in a recent issue of the *Newsletter* of the Institute.
[30] Khanikoff 1860.
[31] Al-Khāzinī 1940, p. 169; see also pp. 165-66, where the colophons of the two Indian copies are quoted in full. As it is extant, MS

The Codex Riyādhi 125 contains a very faulty text, infested with flagrant errors and with blanks. Its shortcomings are so numerous and multifaceted that it is simply impossible to rely on it for the establishement of a consistent and intelligible text. The few instances of variant readings derived from it and given below in the critical apparatus show that such a severe judgment is amply justified.

The followinng edited text of *Nutaf min al-hiyal* is based on the two manuscripts still extant (Codex Riyadhi 125, p. 82-line 10 – p. 84-line 5 and Khanikoff MS 117, folio 66b-line 8 – folio 67b-line 2), in addition to the variant readings supplied by the Hayderabed edition (al-Khāzin¥ 1940, p. 98 line 15 – p. 100 line 14). For ease of reading, the punctuation has been modernized and some formatting of the paragraphs introduced.[32]

Figure 4. *Kitāb mīzān al-hikma*, MS Khanikoff 117, f. 66b. Source: the Russian National Library, Saint Petersburg, Khanikoff Collection.

Khanikoff coll. 117 has no colophon and few lines of the last eighth book are missing (MS 117, f. 107b). A fourth and apparently independent partial copy of *Kitāb mīzān al-hikma* was discovered in Jerusalem in the 1940s. It was transcribed and published by Fu'ād Jamī'ān in Cairo in 1947. I did not yet consult this edition. According to Hall 1973 (p. 349), it contains an incomplete text and gives the name of the author as "al-Khāzin", a form encountered very often but which has the disadvantage of confusing al-Khāzinī with the 10th-century astronomer and mathematician, Abū Ja'far al-Khāzin, author of *Zīj al-safā'ih* (Table of Planes).
Finally, fragments from *Kitāb mīzān al-hikma* are inserted in MS 223 conserved in Beirut, Bibliothdhque Saint Joseph. These consist in nine pages without numbers put at the end of the volume and reproducing the last lines of Book II and almost the whole Book III of *Kitāb mīzān al-hikma* devoted to the edition of al-Bīrūnī's *Risāla fī al-nisab allatī bayna al-filizāt wa al-jawāhir fī 'l-hajm* (Treatise on the ratios existing between metals and jewels in volume). Another copy of al-Biruni's *Risāla* – written in a different handwriting – is included in this same Beirut MS 223, pp. 20-55. In his description of the contents of this codex, Louis Cheikho did not mention the existence of any partial copy of *Kitāb mīzān al-hikma*: Cheikho 1973, pp. 287-289.

[32] The variant readings that exist between the manuscript copies are documented in the original publication of this text in Abattouy 2001a, pp. 110-113.

[Some elements/extracts of mechanics]

[نتف من الحيل]

Some elements/extracts of mechanics, Aristotle said (*sic*), which people find marvelous [and which occur] either in accordance with nature but of which one does not know the cause, or contrarily to nature, and these are produced by art for the benefit of mankind, because nature follows always the same direction whereas the needs of humans differ widely. And in every difficult action which happens contrary to nature mechanical artifices are needed, and for this reason the lesser [things] overcome the greater [things].

نتف من الحيل - قال أرسطو طاليس- يتعجب الناس منها إما فى الأشياء التى تعرض طبعا فمما لا يُعلم علته وإما فى الأشياء المخالفة للطبع فمما يعمل بالصناعة لمنفــعة الناس، لأن الطبيعة تلزم أبدا جهة واحدة وأما منافع الناس فإنها تختلف إختلافا كثيرا. وكل عمل عسر مخالف للطبع يحتاج فيه الى حيل صناعية، ولذلك صارت الأصاغر تقوى على الأكابر.

The mechanical problems are common to both the mathematical and the natural sciences, for the 'how' in them belongs to the mathematical sciences, whereas the 'what' belongs to the natural sciences, as in the action of the lever: if its weight is increased it moves the heavy object [more] rapidly. The circle is the cause of all this, and the like.

فالمسائل الحيلية مشتركة للعلوم الرياضية والطبيعية معا، وذلك أن الكيف فيها هو من العلوم الرياضية وأما ماذا فمن العلوم الطبيعية. كعمل البيرم إذا زاد ثقله حرك الشيء الثقيل سريعا والدائرة علة هذا وما أشبهه.

The most marvellous is that in which contrary things are combined, and in the circle are combined motion and rest. In its circumference sinking and rising exist, and between them the tangency, just as the equal exists between the greater and the smaller and the straight between the concave and the convex.

والأعجب ما اجتمع فيه الأشياء المتضادة، وفي الدائرة تجتمع حركة وسكون، وفي إحاطتها انخفاض وارتفاع وبينهما التماس، كما بين الأعظم والأصغر بينهما المساوي، وبين الأخمص والمحدودب المستقيم.

And in one and the same movement of the circle there exists contrariety between forward and backward, upward and downward. A [straight] line draws it by motion on one side and by rest on the other, ending where it started and proceeding to what it has left. The motions of the points assumed on it differ in speed, the one closer to the end at rest being slower. Therefore, the circle is undeniably the first and the origin of any and every marvel.

وفى حركتها الواحدة تضاد من أمام وخلف وفوق وتحت، والخط يرسمها بالحركة من جانب والسكون من جانب وينتهي حيث إبتدأ وينتقل الى ما منه إنتقل. وإن حركات النقط التي تفرض عليه مختلفة السرعة، فالأقرب الى الطرف الساكن منه أبطأ. وغير منكر أن تكون هي أول الأعجوبات ومبدأها.

The things that occur in the balances occur only because of the circle and are referred to it,

والأشياء التي تعرض في الموازين إنما تعرض لها بسبب الدائرة وتنسب إليها، وأما

whereas those which occur in the lever are referred to the balance. And since a single circle can move with two different motions, it is possible to produce circles that move with a single motion from which many motions come about. This is the origin of many contrary and marvellous motions. Only one of them is obvious but its cause is hidden.

التي تعرض في البيرم فإنها تنسب الى الميزان. ولأن الدائرة الواحدة قد تتحرك حركتين مختلفتين، ويمكن أن تُعمل دوائر تتحرك حركة واحدة منها حركات كثيرة، وهذا أصل لحركات كثيرة متضادة عجيبة فالظاهر منها حركة واحدة وتخفى علتها.

Problem

مسئلة

It is also asked why the large balances are more accurate and of more precision than the small balances. The principle of the answer regarding this reason is to ask why, in the case of a line which departs from the centre of a circle and is long, and therefore the distance of its end from the centre is a greater distance, the motion of its end is faster when both ends are moved by the same force. The faster of two mobiles is the one that travels over a greater distance in the same time, whereas the farther from the centre travels over a greater distance along its circumference and the nearer a smaller distance.

كما يقال لم صارت الموازين الكبار أحدّ وأكثر استقصاء من الموازين الصغار. ومبدء الجواب عن هذه العلة أن يطلب لم صار الخط الذي يخرج من مركز الدائرة وكان طويلا، فكان لذلك بعد نهايته من المركز بعدا أعظم، كانت حركة نهايتـه أسرع إذا تحركا جميعا بقوة واحدة. والأسرع هو الذي من المتحركين يقطع مسافة أعظم في زمان واحد، والأبعد من المركز يقطع مسافة أعظم من مداره والأقرب مسافة أصغر.

It is infered from this reasoning that the fulcrum of the balance is a centre, since it is fixed and that the two sides of the beam which are on either side of the fulcrum stand for the lines departing from the centre. If the beam is longer, the motion of its end, as it is caused by the same weight, will be stronger than the motion it would have if it was shorter. [Hence] when some weights are put in small balances, they do not produce inclination towards their side, because of their smallness and of the shortness of the beam. But if they are put in a large balance, an evident inclination results, because of the length of the needle and of the beam.

ويتبين من هذه العلة أن علاقة الميزان تكون مركزا لأنها ثابتة وجهتي العمود عن جنبتي العلاقة تقومان مقام خطوط خارجة عن المركز. وإذا كان العمود أطول تحركت نهايته بالثقل الواحد حركة أشد من الحركة التي يتحركها إذا كان أقصر. وبعض الأثقال إذا وضع في الموازين الصغار فلم يحدث عنه ميل الى جهته لصغره وقصر عمود الميزان، وإن وضع في ميزان كبير كان منه ميل بيِّـن لطول اللسان والعمود.

4. The mechanical theory in the *Nutaf*: a short characterisation

The text of the Arabic partial epitome of the *Mechanical Problems* is inserted right after the afore-mentioned technical discussion on the balance equilibrium, probably with the aim to supply a theoretical

framework for it. It is introduced under what seems to be a title: *Nutaf min al-hiyal* (Elements/Extracts of mechanics). That this group of words was intended as a title for the ensuing paragraph is suggested by the fact that the original Greek title *Problemata Mechanica* would have been correctly rendered by the expression *masā'il hiyaliyya*, which exists in Arabic historical literature as we saw before. Moreover, the term *nutaf* evokes the notion of selection from a longer text and thus corresponds to the Arabic epitome as a partial version.[33] As for the other term, *hiyal*, it refers obviously to mechanical devices, and may even be a hint at the Aristotelian *Mechanica*.[34]

After this title, follows immediately the reference to Aristotle: "*Qāla Aristūtālīs*" (Aristotle said).[35] As shown in the figure below reproducing the beginning of the *Nutaf* fragment in MS Khanikoff Coll. 117 (*Kitāb mīzān al-hikma*, St. Petersburg, Khanikoff Coll. MS 117, f. 66b), the bold line above the phrase "*nutaf min al-hiyal*" identifies it as a heading for the ensuing section. Further, in the Hyderabad copy of *Kitāb mīzān al-hikma* (MS Riyādhi 125, p. 82) these three words are written in a colored ink.

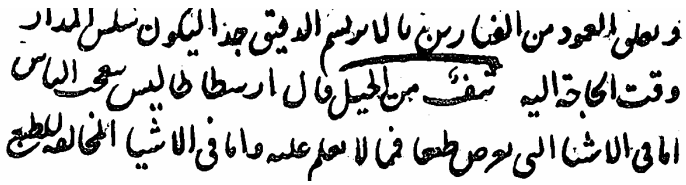

Figure 5. Title of *Nutaf min al-hiyal*.

From the very beginning, the text of the *Nutaf* is deliberately placed under the authority of Aristotle to whom the authorship of the text is ascribed. Hence, the fragment is clearly affiliated to the sole author to whom it was ever attributed until the 19th century. As a result, the contents of the short fragment are viewed as part of a recognized and coherent theory from which it is expected to derive legitimacy and prestige.

First, mechanics is defined as the art of using devices for performing difficult actions, like raising heavy weights by small forces. The Arabic text skips the quotation of the poet Antiphon given in the introduction of the *Mechanical Problems*, and manifestly intended to illustrate the intermediary status of mechanics between nature and art: "We by skill (σ□ϖμγ) gain mastery over things in which we are conquered by nature."[36] However, the spirit of this quotation is clearly reflected in the first sentences of the *Nutaf*, where mechanics is defined in terms of machines produced by art for the benefit of men. Opposing the constancy of nature and the inconstancy of human needs, the text proclaims the necessity of devices: what is against nature is produced by art and skill (*bi-'l-sinā'a*), with the intermediary of artificial devices (*hiyal sinā'iyya*). Now, these may give rise to paradoxical effects so that small forces overcome great weights (*wa li-dhālika*

[33] That al-Khāzinī intended the term *nutaf* in this sense is confirmed by his usage of it with the same signification in a more explicit context. The title of Book III-chap. 1 of *Kitāb mīzān al-hikma* reads indeed: "The ratios between the metals and jewels, and these are extracts (*nutaf*) from the book on the ratios between metals and jewels in volume [by al-Bīrūnī]": al-Khāzinī 1940, p. 55.
[34] The correspondence *hiyal*-mechanics is studied in Abattouy 2000d.
[35] This reference to Aristotle does not occur in one manuscript of *Kitāb mīzān al-hikma*, as it is indicated by the editors of the Arabic text of al-Khāzinī (1940, p. 99, footnote 2).
[36] Aristotle 1952, *Mechanica*, 847a 20-21. The opposition art/nature is a classical Aristotelian thesis which is well documented: see for a summary and bibliographic references Whitney 1990, pp. 34-36, and G. Micheli 1995, pp. 23-35.

sārat al-asāghir taqwā 'alā al-akābir). This theme corresponds to a major specialty of ancient and medieval mechanics, namely the one concerned with different means of moving great weights with little force. As formulated in the *Mechanical Problems*, in its Greek as well as in its Arabic versions, such a thesis could afford a theoretical leitmotiv for the numerous writings devoted to this question.[37] In the Arabic tradition, the problem of moving weights was conceived of as a particular branch of mechanics known as the science of weights. This classification emerged first in Abū Nasr al-Fārābī's (*ca.* 870-950) *Ihsā' al-'ulūm* (The Enumeration of sciences). Considering mechanics as a mathematical science, the Second Master (after Aristotle) distinguished the science of weights (*'ilm al-athqāl*) from the mechanics proper (*'ilm al-hiyal*). Hence *'ilm al-athqāl* refers to the weights whether as they are measured or used for measuring (the practice of the balance), or as they are moved or used to move (the principle of the machines for raising and displacing heavy loads). *En revanche*, *'ilm al-hiyal* encompasses the procedures by which all what is proved in mathematical sciences is applied to natural bodies and actualised in them.[38] Al-Fārābī's position had far-reaching consequences in the history of mechanics, as it afforded an adequate epistemological and philosophical background for the Arabic transformation of the ancient tradition of mechanics, which gave rise to a new science of balances and weights. This science constituted the basis of the Latin *scientia de ponderibus* that developed in Europe since the 12th century, after the translation of a significant part of the Arabic corpus of mechanics and of al- Fārābī's *Ihsā'*.[39]

The intermediary status of mechanics as a mixed science, namely that its object is physical whereas its method applies mathematics, is emphasized in the *Nutaf*. Being so, the mechanical problems have an intermediary epistemological status, in so far as they are common to the mathematical and the natural sciences. Their methods of resolution are mathematical whereas the application of their results is relevant to the field of physics. In other words, the study of the properties of machines requires mathematics as a tool of analysis and physics to account for the practical explanation. The typical example in this respect is the lever, whose weight moves the heavy load rapidly while the geometrical properties of the circle provide the reason of its action. In general, the circle is the reason of all what happens in mechanical instruments, because of its distinctive features. Therefore the properties of the balance are explainable by the circle whereas those of the lever are referred to the balance.

The phrase about the action of the lever (*'amal al-bayram*) contains the substance of Problem 3 in *Mechanical Problems*. Its occurrence here, followed by the principle of the close correspondence between the lever and the circle, may account in part for the absence of this question from the Arabic *Nutaf*.[40] In the third problem of the *Problemata*, this question is formulated differently: "Why is it that small forces can

[37] For instance, Heron's *Mechanics* was translated into Arabic under the title *Fī raf' al-ashyā' al-thaqīla* (On lifting heavy objects); this title was coined – already in Greek – with reference to the *Barulcos*, a machine for raising heavy weights and described in the first chapter of the treatise: see Héron d'Alexandrie, 1988. Concerning the importance of raising weights in ancient mechanics, Pappus wrote: "They say that the crafts needed more than any others in human affairs, and which are related to the field of mechanics... are [firstly] what is called in Greek the craft of *manjānā*, this being what the ancients also used to call the craft of mechanics. For the masters of this craft raise great weights aloft by means of their devices, contrary to the weight's natural motion, with very little power" (quoted in Jackson 1970, p. A3. Accordingly, the description of machines for raising heavy weights occupied a central part in Arabic works of mechanics, such as in al-Jazarī's machines book, especially the fifth category: see Hill1974,.

[38] Al-Fārābī, 1949), pp. 43, 88-89. The echoes of al-Fārābī's distinction extend over all Arabic culture, from *Mafātīh al-'ulūm* by Abū 'Abdallāh b. Yūsuf al-Khwārizmī (10th century) (al-Khwārizmī 1968, pp. 246-247), until the *Kashshāf istilāhāt al-funūn* composed in the 18th century by Muhammad b. 'Alī al-Tahānawī (al-Tahānawī 1980, vol. 1, p. 47).

[39] For a first glance on this seminal thesis, see M. Abattouy, Jürgen Renn and Paul Weinig 2001.

[40] The *Nutaf* fragment does not make any mention of the law of the lever. However, Thābit ibn Qurra constructed in *Kitāb fī 'l-qarastūn* his proof of this same theorem along the model indicated in a sketchy 'proof' contained in the Greek text of the *Mechanical Problems*. This could stand as an argument that he had presumably access to a longer text than the abridged one reproduced by al-Khāzinī. For a survey on the methodological and theoretical affinities between Thābit ibn Qurra's proof of the law of the lever and the rough justification of this proposition in the third *quaestio* of the *Mechanical Problems*, see Abattouy 2001b, sect. III.

move great weights by means of a lever?" The crucial importance of this question for theoretical mechanics in ancient and medieval times is well-known. In the original Greek text, the question is followed by a clause which seems – as it is rendered in the current English translations of the *Mechanical Problems* – to turn it into a rather foolish direction: "Why is it that small forces can move great weights by means of a lever, although the weight of the lever is added?" The formulation of the phrase in the Arabic text of the *Nutaf* – which corresponds to a similar phrase in the introductory chapter of the *Mechanical Problems* – does not to reproduce this riddle in full. It is limited to illustrate the case by the action of the lever. The mechanical problems are common to mathematics and physics as it is illustrated by the action of the lever, the increase of its weights – *i.e.* of its strength and power – adds to its capacity to move heavy objects rapidly (*idhā zāda thiqluhu harraka al-shay' al-thaqīl sarī'an*). The reason of this "peculiar property" is the circle because of the special features which are then listed.

The central mechanical problem is said to be the lever, the instrument for lifting heavy weights with small forces. However, the cause of such a peculiar phenomenon is not the law of the lever but the circle which is presented as the source of all other marvels, including those of the balance. The singular properties of the circle are presented first in rhetorical terms, as the combination of the contraries one in the other (the mobile and the immobile, the concave and the convex, motion and rest, forward and backward motions). Then a more rational reason is given, emphasizing the dynamic features of the circle: the more a point is further from the centre the quicker it is moved by the same force. The focus on the properties of the circle denotes that the epitomist of the Arabic text was aware that the problem at stake has the character of a theoretical principle.

After this general and introductory part, the *Nutaf* fragment proceeds to the statement of a specific question corresponding to Problem 1 in the Peripatetic *Mechanica*. This question is presented under the heading of *mas'ala* (question or problem): "It is also asked why the large balances are more accurate (*ahadd*) and of more precision (*akthar istiqsā'*) than the small balances." This fact is accounted for on the basis of the same theoretical principle mentioned before: a point farther from the centre moves quickly than a closer one, even if both are animated by the same force. In the present case, the beam of the balance is considered as a line of which the centre is the fulcrum. In this context, it is thought that the rotation of a longer beam produces a motion faster than that of a shorter one, and thus a balance having a long beam should be of more precision. Therefore, the reason of accurateness in a large balance in comparison with a smaller one is reported to the length of the beam, and, consequently, to the alleged sensitiveness generated by the swiftness of the circular motion of its end, with regard to the short beam, even if they are both moved by the same force.

In this analysis, the original problem about the accurateness in the balances is reformulated in terms of the difference of velocities according to the distance from the centre. But this problem itself is not accepted as a mere geometrical fact. It receives a dynamical explanation: the same force generates different effects. In the original Greek text, the difference of velocities according to the distance from the centre is said to be the result of the composite character of circular motion, which is treated in length as a compound motion.[41] The long geometrical argument embodying this reasoning is skipped in the Arabic *Nutaf*, which emphasises instead the status of the motion of the balance beam. In particular, in the Arabic epitome, the fulcrum is considered as a centre and the focus is laid on the motions of the unequal arms describing different distances with different speeds, the end of the longer arm being moved with quicker motion, *i.e.* travels

[41] This issue is surveyed in De Gandt, 1982, pp. 120-124.

over a greater distance in the same time. Such an allusion to the centre and to the rotation of lines departing from it is an evident indication on the model of the circle which inspired the whole reasoning. The law of the lever in the third problem of the Peripatetic *Mechanica* will be justified exactly in terms of the circular motions of the lever arms. But the *Nutaf* fragment ends exactly after the discussion of the former mechanical problem.

Another noteworthy element in this final paragraph of the *Nutaf* text is related to the use of the term *mayl* (inclination), which translates the Greek ροπή. This term is used here in a restricted sense for the downward inclination of heavy objects, and only in the context of the balance. This concept introduced the supplementary precision that while the *mayl* – as an internal downward tendency – is not perceptible in small balances, it is made evident when the same loads are put in great balances. However, the term remains essentially Aristotelian, in that ροπή is exclusively connected in the *Mechanical Problems* to ὄγκος (weight) and denotes an internal force of motion.[42] This corresponds precisely to one of the main significations of *mayl* in the Arabic natural philosophy, such as in Ibn Sīnā's *mayl tabʿī* (natural inclination).[43]

At the end of this discussion, the *Nutaf* text specifies the needle of the beam as a part of the balance. This specification does not appear in the Greek text, but, in turn, the Arabic version passes over other practical details that occur at the end of the discussion of Problem 1 in the *Mechanical Problems*, where Pseudo-Aristotle describes how the merchants of purple arrange their balances so that they realise a greater benefit in their commercial transactions.

On the other hand, in answering the *masʿala* formulated above concerning the reason of accurateness in certain balances, the Arabic text of the *Nutaf*, as well as the rest of *Kitāb mīzān al-hikma*, remains silent about the correctness of the answer furnished by the Peripatetic author, to whom no criticism is addressed on this issue. [44] As masters of the art of weighing, al-Khāzinī and al-Isfizārī, the probable co-authors of the *Nutaf*, evidently knew that the Peripatetic thesis was not correct in spite of the cleverness of the geometrical argument sustaining it, *i.e.* the farther point from the centre moves more freely.[45]

On the other hand, in the Greek as well as in the Arabic versions of the *Mechanical Problems*, we are not told if what is meant by precision and accuracy regards small weights or large ones. Actually on the practical level it is exactly the contrary that happens: the small balances are more sensitive to little variations of weight than larger ones, as the weighers know well. This is why small balances are used for the determination of quantities of precious substances – such as gold and silver. For instance, the jewellers do not use huge balances but tiny ones and they never lost a penny. This is how the Peripatetic *Mechanica* is structured: an incoherent patchwork of problems and answers some of which go against common sense. This fundamental character of the text is conserved in the Arabic epitome presented by the *Nutaf* fragment

[42] See for example Aristotle 1952, *Mechanica*, 850 a 8-16, 851 b 26, 858 a 22. This was noted by G. Micheli 1995, p. 64n.
[43] For a summarized view on the Arabic tradition of ροπή, see Lettinck 1994, p. 666 ff.
[44] In the Renaissance, several mechanicians contested that huge balances are more accurate than smaller ones, such as Tartaglia in the seventh book of his *Quesiti*. Seeking a similar criticism in the Arabic texts of mechanics, I checked more than two-dozens of Arabic texts on the balance dating from the 9th through the 16th century. This checking yielded a negative result, in that no trace of the pseudo-Aristotelian thesis was found. The result supplied by this survey – still to be confirmed by further research – could stand as an argument that such a 'reproachful silence' is meaningful enough to be worth all possible criticism.
[45] Al-Khāzinī must not have been indifferent to the argument of Pseudo-Aristotle defending the accurateness of large balances as his balance was a huge lever balance of which the beam – made of iron or brass – was 2 meters long and of which the cross-section was a square with sides of about 6-8 cm. For a description of this "universal balance" (*al-mīzān al-jāmiʿ*), see al-Khāzinī 1940, pp. 93-108, Wiedemann 1913-36, and Hill 1993, pp. 68-69.

Nutaf min al-hiyal is composed in a style strongly characterized by a remarkable conciseness, which makes it brief but comprehensive. The variety of arguments displayed in the extant Greek text is absent from the *Nutaf*. Skipping all the geometry that sustains the original reasoning in the Peripatetic text, the analysis developed in the former is very dense and presents a rather reliable compendium of the corresponding parts of the latter. In this respect, the degree of agreement between the two texts is striking. The Arabic text does not contain any material absent from its Greek homologue and the main ideas of the latter are maintained and expressed in a straightforward style, without any diggressions. A close comparison of the two texts yields a significant result: almost all the material extant in the Greek text but missing from the *Nutaf* – be it large pieces of text and geometrical reasoning or simple sentences and words – look like comments and additions appended to specific parts of an original short and concentrated text. If this is how this additional material was produced, it might have been introduced progressively as a collection of scholia and marginal additions, in the frame of the long historical process of copying and editing that shaped the Greek text, since it was written in the antiquity until it was edited in pre-modern times.

Bibliography

Abattouy, Mohammed 1999. "The Arabic Tradition of Mechanics: Textual and Historical Characterisation. I. Greek Sources and Works of Practical Mechanics." *Majallat kulliyyat al-ādāb wa al-'ulūm al-insāniyya bi-Fās* (Journal of the Faculty of Letters and Humanities in Fez), vol. 12.1: pp. 75-109;

Abattouy, M. 2000a. "Al-Muzaffar al-Isfizārī 'ālim min al-qarn 5-6 H/ 11-12 M, mu'allif *Irshād dhawī al-'irfan ilā sinā'at al-qaffān*" [al-Isfizārī a scholar from the 5th-6th H/11th-12th, author of *Guiding the Learned Men in the Art of the Steelyard*]". *Quelques aspects de l'évolution des idées scientifiques. Antiquité et moyen âge*. Rabat: Publications of the Faculty of Letters, pp. 135-175 (Arabic section).

Abattouy, M. 2000b. "La tradition arabe de la balance: Thābit ibn Qurra et al-Khāzinī". In *Quelques aspects de l'évolution des idées scientifiques* (ibidem), pp. 49-91 (French section).

Abattouy, M. 2000c, *Nutaf min al-hiyal: An Arabic Partial Version of Pseudo-Aristotle's Problemata Mechanica. Arabic Text, English Translation and Commentaries*. Berlin: Max Planck Institute for the History of Science, 2000, Preprint 153.

Abattouy, M. 2000d. "*Mechané vs. hiyal*: Essai d'analyse sémantique et conceptuelle." In *Imagination and Science*. Rabat: Publications of the Faculty of Letters, pp. 127-151.

Abattouy, M. 2001a. "*Nutaf min al-hiyal*: An Arabic Partial Version of Pseudo-Aristotle's *Problemata mechanica*". *Early Science and Medicine* (Brill), vol. 6 (2001): pp. 96-122.

Abattouy, M. 2001b. "Greek Mechanics in Arabic Context: Thābit ibn Qurra, al-Isfizārī and the Arabic Traditions of Aristotelian and Euclidean Mechanics." *Science in Context* (Cambridge University Press), vol. 14: pp. 179-247.

Abattouy, M. 2002a. "The Aristotelian Foundations of Arabic Mechanics: From the Ninth to the Twelfth Century." In *The Dynamics of Aristotelian Natural Philosphy from Antiquity to the Seventeenth Century*. Edited by C. Leijenhorst, C. Lüthy and H. Thijssen. Leiden: Brill, pp. 109-140.

Abattouy, M. 2002b. "The Arabic Science of weights: A Report on an Ongoing Research Project." *BRIIFS. The Bulletin of the Royal Institute for Inter-Faith Studies* (Amman), vol. 4 (2002), n° 1: pp. 109-30.

Abattouy 2006. "The Arabic Transformation of Mechanics: The Birth of the Science of Weights". Publié en décembre 2006 sur le portail "Muslimheritage.com" de la *Foundation for Science, Technology and Civilisation (Manchester)*. URL:

http://muslimheritage.com/topics/default.cfm?ArticleID=615 -
http://muslimheritage.com/topics/default.cfm?ArticleID=616

Abattouy, M., Jürgen Renn, Paul Weinig 2001. "Transmission as Transformation: The Translation Movements in the Medieval East and West in a Comparative Perspective". *Science in Context* vol. 14 (2001): pp. 1-12.

Aristotle 1952. *Mechanica*.Translated by E. S. Forster. In *The Works of Aristotle*, vol. 6: *Opuscula*. Oxford: Clarendon Press.

Aristotele 1982. *MHXANIKA. Tradizione manoscritta, testo critico, scolii*, a cura di Maria E. Bottecchia. Padua: Editore Atenore.

Bayhaqī, al-, Zahīr al-Dīn 1988. *Tārīkh hukamā' al-islām*. Edited by M. Kurd 'Alī. Damascus: Matbū'āt mujamma' al-lugha al-'arabiyya (reprint of 1946 first edition).

Cardano, Geronimo 1570. *Hieronymi Cardani Opus novum de propositionibus numerorum, motuum, ponderum, sonorum, aliarumque rerum mensurandarum... in V. libros digestum*, Basileae: Henricpetri.

Cheikho, Louis 1973. "Catalogue raisonné des manuscrits de la Bibliothèque Orientale de l'Université Saint Joseph de Beyrouth". *Mélanges de l'Université Saint Joseph*, reprinted by Kraus Reprint, Nendeln / Liechtenstein (reprint of L. Cheikho, *Catalogue raisonné des manuscrits de la Bibliothèque Orientale de l'Université Saint Joseph de Beyrouth*. Beirut, 2 vols., 1921, 1929).

Damerow, P, Renn, J, Rieger, S, and Weinig, P. 2002. "Mechanical Knowledge and Pompeian Balances." In: *Homo faber: Nature, Technology, and Science at the Time of Pompeii*. Edité par Jürgen Ren et Giuseppe Castagnetti. Roma: L'"Erma" di Bretschneider, pp. 93-108.

De Gandt, François 1982. "Force et science des machines." In J. Barnes *et al. Science and Speculation. Studies in Hellenistic Theory and Practice*. (Cambridge/Paris: Cambridge University Press / Editions de la Maison des Sciences de l'Homme, 1982), pp. 96-127.

De Gandt, F. 1986. "Les *Mécaniques* attribuées à Aristote et le renouveau de la science des machines au XVI^{ème} siècle." *Etudes Philosophiques* (Paris), n° 3: pp. 391-405.

Drabkin, I. E. 1958. "Aristotle's Wheel: Notes on the History of a Paradox", *Osiris* vol. 9 (1958): pp. 162-198.

Fārābī, al-, 1949. *Ihsā' al-'ulūm*. Edited by 'Uthmān Amīn. Cairo: Dār al-fikr al-'arabī, 2nd edition.

Hall, Robert A. 1973. "Al-Khāzinī", in *Dictionary of Scientific Biography.* Edited by Charles Gillispie (New York: Scribner, 1973), vol. 7: pp. 335-51.

Héron d'Alexandrie 1988. *Les Mécaniques ou l'élévateur des corps lourds*. Texte arabe de Qustā ibn Lūqā établi et traduit par B. Carra de Vaux. Paris: Les Belles Lettres..

Hill, Donald R. 1974. *The Book of Knowledge of Ingenious Mechanical Devices. An annotated translation of al-Jazarī's Treatise*. Dordrecht: D. Reidel.

Hill, D. R. 1993. *Islamic Science and Engineering*. Edinburgh: Edinburgh University Press.

Ibel, Thomas 1908. *Die Wage im Altertum und Mittelalter*. Inaugural-Dissertation zur Erlangung der Doktorwürde der Friedrich-Alexanders-Universität Erlangen (Tag der mündlichen Prüfung: 2. November 1906). Erlangen: K. B. Hof- u. Univ.-Buchdruckerei von Junge & Sohn.

Ibn abī 'Usaybi'a, Muwaffaq al-Dīn 1965. *'Uyūn al-anbā' fī tabaqāt al-atibbā'*. Edited by Nizār Ridhā. Beirut: Dār Maktabat al-hayāt.

Ibn al-Athīr, 'Alī 1378 H [1967]. *Al-Kāmil fī 'l-tārikh*. 9 vols. Beirut: Dār al-kātib al-'arabī, 2nd edition.

Ibn al-Qiftī, Jamāl al-Dīn 1903. *Tārīkh al-hukamā'*. Edited by Julius Lippert. Leipzig: Dieterich'sche Verlagsbuchhandlung..

Ibn Fātik al-Amīrī, Abū al-Wafā al-Mubashshir 1958. *Mukhtār al-hikam wa mahāsin al-kalim*. Edited by 'A. Badawī (Madrid: Matba'at al-ma'had al-misrī li-'l-dirāsāt al-islāmiyya.

Jaouiche, Khalil 1974. *Le Livre du qarastūn de Thābit ibn Qurra. Etude sur l'origine de la notion de travail et du calcul du moment statique d'une barre homogène*. Leiden: Brill.

Khanikoff, Nicholas 1860. "Analysis and Extracts of *Kitâb Mizan al-Hikma*, an Arabic Work on the Water-balance." *Journal of the American Oriental Society* vol. 6: pp. 1-128.

Khalīfa, Hajjī 1835-58. *Kashf al-zunūn*. Edited by G. Flügel, 7 vols., Leipzig.

Khāzinī, al, Abdurrahmaan 1359 H [1940]. *Kitāb mīzān al-hikma*. Hayderabad: Dā'irat al-ma'ārif al-'uthmāniyya.

Khwārizmī, al-, Abū 'Abdallāh b. Yūsuf 1968. *Liber Mafatih al-Ouloum.* Edited by G. Van Vloten. Leiden: Brill, 2nd edition (1st edition 1895).

Knorr, Wilbur R. 1982. *Ancient Sources of the Medieval Tradition of Mechanics: Greek, Arabic and Latin Studies of the Balance*. Firenze: Istituto e Museo di Storia della Scienza.

Kraus, Paul 1986. *Jābir ibn Hayyān. Contribution à l'histoire des idées scienifiques dans l'Islam. Jābir et la science grecque*. Paris: Les Belles Lettres. (Reprint of the second of two volumes published in the *Mémoires de l'Institut d'Egypte*, Cairo, 1942-43).

Lettinck, Paul 1994. *Aristotle's Physics and its Reception in the Arabic World*, Leiden: Brill.

Micheli, Gianni 1995. *Le origini del concetto di macchina*. Firenze: Olschki.

Nomanul Haq, Syed 1994. *Names, Natures and Things. The Alchemist Jābir ibn Hayyān and his Kitāb al-ahjār (Book of stones)*. Dordrecht: Kluwer.

Peters, Francis E. 1968a. *Aristoteles Arabus. The Oriental Translations and Commentaries on the Aristotelian Corpus*. Leiden: Brill.

Peters, F. E. 1968b. *Aristotle and the Arabs: The Aristotelian Tradition in Islam*. New York/London: New York University Press/University of London Press.

Rozhanskaya, Mariam 1983. *Al-Khazini, Kniga vesov midrosti* [The Book of the Balance of Wisdom] (in *Naucnoye nasledstvo* [Scientific Heritage]), Moskva: Akademija Nauk SSSR vol. 6: pp. 15-140, 276-308

Rozhanskaya, M. 1996. "Statics," in *Encyclopaedia of the History of Arabic Science*. Edited by R. Rashed, London: Routledge, vol. 3, pp. 614-642.

Sayılı, Aydin 1960. *The Observatory in Islam* (New York: Arno Press, 1981, reprint of the first edition, Ankara: Türk Tarih Kurumu Basimevi, Publications of the Turkish Historical Society.

Sezgin, Fuat 1971. *Geschichte des Arabischen Schriftums*. Band IV: *Alchimie-Chemie, Botanik-Agrikultur. Bis ca. 430 H.*. Leiden: Brill.

Tahānawī, al-, Muhammad b. 'Alī 1980. *A Dictionary of the Technical Terms Used in the Sciences of the Musalmans*. 2 vols. Osnabrück: Biblio Verlag. (Reprint of the 1st edition in Calcutta: W. N. Lee's Press, 1862).

Whitney, Elspeth 1990. *Paradise Restored. The Mechanical Arts from Antiquity Through the Thirteenth Century*. Philadelphia: Transactions of the American Philosophical Society.

Wiedemann, Eilhard 1913-36. "Al-Karastūn", and "al-Mīzān." In *First Encyclopaedia of Islam*. Leiden: Brill (reprinted 1993), respectively vol. 4: pp. 757-760 and vol. 5: pp. 530-539.