Foundation for Science Technology and Civilisation

The Arabic Transformation of Mechanics: The Birth of the Science of Weights

Author: Prof. Dr. Mohammed Abattouy
Chief Editor: Prof. Dr. Mohamed El-Gomati
Production:

Release Date: November 2006
Publication ID: 615

FSTC Limited
9 Conyngham Road, Victoria Park, Manchester, M14 5DX, United Kingdom
Web: http://www.fstc.co.uk Email: info@fstc.co.uk

THE ARABIC TRANSFORMATION OF MECHANICS: THE BIRTH OF THE SCIENCE OF WEIGHTS[1]

Mohammed Abattouy*

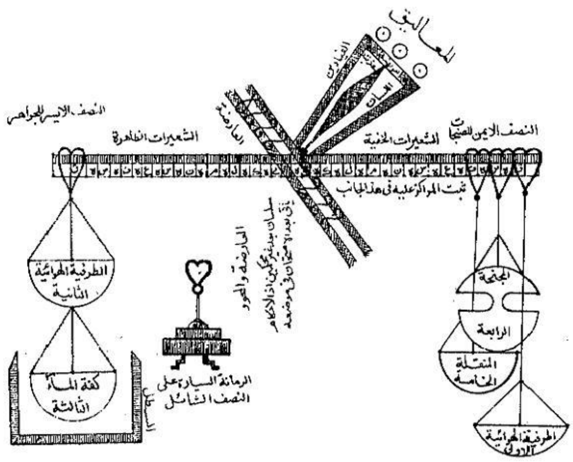
The following article focuses on three main concerns. The first is an overview of the textual tradition of a core part of Arabic mechanics, dealing with the science of weights. Secondly, the article will analyse the historical significance of the Arabic science of weights. Thus, the transformation brought about by this important segment of Arabic mechanics is interpreted as the reorganization of a core-part of ancient mechanics into an independent science of weights. On this basis, a strong claim is made in favor of the independent status of ›ilm al-athqŒl, which should no longer be confused with ›ilm al-úiyal, understood as a general descriptive discourse on different types of machines. The final section is devoted to a preliminary survey of the institutional setting of the control of weighing instruments in the Islamic medieval society through the office of the úisba. This study, covering the theoretical as well as the practical aspects of an important segment of Arabic classical science, i.e. mechanics, is part of a program of research which the author is developing, appealing for the renewal of the field of the history of Arabic classical sciences, by merging together historical research based on empirical investigation in the scientific texts, the epistemological reflexion on the concepts, categories and methods, and the sociological analysis of the contextual structures that shaped the practice of science in medieval Islam.[2]

1. The reconstruction of the corpus of the Arabic science of weights

The balance is an instrument of our current life, charged with history and science. In Islamic classical times, this familiar instrument was the object of an extensive scientific and technical debate of which dozens of treatises on different aspects of its theory, construction, and use are the precious remains. Different sorts of balances were the object of such an extensive enquiry, including the normal equal-armed balance (called in Arabic *m¥zŒn*, *‹ayyŒr*, and *shŒh¥n*), the steelyard (called *qaras‹´n*, *qaffŒn*, and *qabbŒn*) and sophisticated balances for weighing absolute and specific weights of substances.

1 An earlier version of this article was published in Abattouy 2002b. Several results exposed in this study were obtained under the sponsorship of the Max Planck Institute for the History of Science in Berlin (1996-2003). I am grateful to my colleagues at the MPIWG, especially to Professor Jürgen Renn, director of Department I at the MPIWG, for this long-lasting and fruitful collaboration. This article was also submitted to the Proceedings of the Manchester 1001 Inventions Day Conference.
* Mohammed Vth-Agdal University, Rabat, Faculty of Letters, Philosophy Department
2 For case studies, reflexions and references bringing evidence to this research program, see the three forthcoming volumes: Abattouy [In Press 2006a], [In Press 2006b], and [In Press 2006c].

Several drawings of balances are preserved in Arabic manuscripts, such as those of al-KhŒzin¥, al-ÎarÏr¥, and al-Qazw¥n¥. Further, some specimens of the ancient balances survived and are presently kept in museums. For illustration, we refer to two such Islamic steelyards from the 10th-12th centuries. The first, built in Iran, is preserved in the National Museum in Kuwait (LNS 65M). It is made of steel, and bears marks on its beam. Its dimensions (height: 11.5 cm, length: 15.6 cm) show that it was used for weighing small quantities.[3] The second is kept in the Science Museum in London (accession number Inv. 1935-457). This balance came to the Science Museum in 1935 from University College in London, together with a large selection of archaeological material consisting of ancient weights and measures collected from the Near East by the British archaeologist Flinders Petrie. A scale of silver is inlaid along its 2.37m long, wrought-iron beam. It bears two suspending elements and corresponding calibrations: one ranging from 0 to 900 *ra‹l*-s (1 *ra‹l* is approximately 1 pound); the other ranging from 900 to 1820 *ra‹l*-s.[4]



Al-mizan al-jami' (the universal balance) of al-Khazini, as depicted in Al-Khazini, Kitab mizan al -hikma, Hyderabad, 1359 (1940), p. 103.

Figure 1. *Al-Mizan al-jami' (the universal balance of) al-KhŒzin¥, as depicted in al-KhŒzin¥, KitŒb m¥zŒn al-úikma, Hyderabad, 1940, p. 103.*

The interest in balance in Islamic scientific learning was culturally nurtured by its role as a symbol of good morals and justice. The Qur‹Œn and the ÎadÏth appealed extensively to a strict observance of fair and accurate weighing practices with balance. Considered the tongue of justice and a direct gift of God, balance was made a pillar of right society and a tool of good governance. These principles were recorded explicitly in several treatises on balance, such as the introduction to *KitŒb m¥zŒn al-úikma* by al-KhŒzin¥, where balance is qualified as "the tongue of justice and the article of mediation." Furthermore, it was counted as a fundamental factor of

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3 See al-êabŒú 1989, p. 32.
4 The images of these balances can be seen at http://www.mpiwg-berlin.mpg.de/en/forschung/projects/theoreticalMechanics/project_image_Fig.11.jpg/showImagen and in Abattouy 2002b, p. 110.

justice, on the same level with "the glorious Book of God," and "the guided leaders and established savants."[5]

The emergence of Arabic mechanics is an early achievement in the scientific tradition of Islam. Actually, already in the mid-9th century, and in close connection with the translation of Greek texts into Arabic, treatises on different aspects of the mechanical arts were composed in Arabic, but with a marked focus on balances and weights. These writings, composed by scientists as well as by mechanicians and skilful artisans, gave birth to a scientific tradition with theoretical and practical aspects, debating mathematical and physical problems, and involving questions relevant to both the construction of instruments and the social context of their use. Some of these Arabic treatises were translated into Latin in the 12th century and influenced the European science of weights.

The corpus of the Arabic science of weights covers the entire temporal extent of scientific activity in medieval Islam and beyond, until the 19th century. The reasons for such an abundance of literature on the problems of weighing can be explained only by contextual factors. In fact, the development of the science of weights as an autonomous branch of science was triggered by the eminent importance of balances for commercial purposes. In a vast empire with lively commerce between culturally and economically fairly autonomous regions, more and more sophisticated balances were, in the absence of standardization, key instruments governing the exchange of currencies and goods, such as precious metals and stones. It is therefore no surprise that Muslim scholars produced numerous treatises specifically dealing with balances and weights, explaining their theory, construction and use. This literature culminated in the compilation by ›Abd ar-Raúmɑn al-Khɑzin¥, around 1120, of *Kitɑb m¥zɑn al-úikma*, an encyclopedia of mechanics dedicated to the description of an ideal balance conceived as a universal tool of a science at the service of commerce, the so-called 'balance of wisdom.' This was capable of measuring absolute and specific weights of solids and liquids, calculating exchange rates of currencies, and determining time.

A complete reconstruction of the Arabic tradition of weights is currently being undertaken by the author. This project began in the context of a long-term cooperation with the Max Planck Institute for the History of Science in Berlin. The work on the establishment of the Arabic corpus of the science of weights started in Fall 1996 by the systematic reconstruction of the entire codicological tradition of the corpus of texts dealing –on theoretical and practical levels– with balances and weights. By now almost two-thirds of the entire corpus has been edited and translated into English; this part, including texts dating from the 9th through the 12th centuries, is being prepared for publication with the appropriate commentaries.

5 Al-Khɑzin¥ 1940, pp. 3-4.

***Figure* 2.** *An Ottoman scales, in G. Kurkman, Anadoluda Agirlik ve Olculeri. Istanbul 2003.*

The preliminary analysis of the texts investigated so far established the importance of the Arabic tradition for the development of the body of mechanical knowledge. The Arabic treatises turned out to be much richer in content than those known from the ancient tradition. In particular, they contain foundations of deductive systems of mechanics different from those inferred from extant Greek texts, as well as new propositions and theorems. On the other hand, the Arabic treatises also represent knowledge about practical aspects of the construction and use of balances and other machines missing in ancient treatises.

The first phase of the research on the Arabic science of weights focused on establishing the scope of its extant corpus. Surprisingly, this corpus turned out to be much larger than usually assumed in history of science. To date, more than thirty treatises dating from the 9th through the 19th centuries have been identified which deal with balances and weights in the narrow sense. The majority of these treatises have never before been edited or studied, and only exist in one or more manuscript copies. Some important manuscripts have been discovered or rediscovered even in the course of the research activities conducted by the author.

The textual constituents of the Arabic works on the problems of weights can be classified chronologically into three successive units. First, there is the set of Greek texts of mechanics extant in Arabic versions. Despite their Greek origin, these works can be regarded as an integral part of the Arabic mechanical tradition, at least because of the influence they exerted on the early works of Arabic mechanics. In the case of some of these texts, although they are attributed to Greek authors, their Greek originals are no more extant nor are they ascribed to their supposed Greek authors in antique sources. The second unit comprises founding texts composed originally in Arabic in the period from the 9th through the 12th centuries. This segment of writings laid the theoretical basis of the new science of weights, in close connection with the translations and editions of texts stemming from Greek origins. The third phase covers the 14th through the 19th centuries, and comprises mainly practical texts elaborating on the theoretical foundations laid in the earlier tradition. In the following, the texts belonging to these three phases will be described in brief, with a short characterization of some theoretical contents.

2. Arabic versions of Greek texts of mechanics

The corpus of Greek texts that were known to Muslim scholars through direct textual evidence and dealing with the problems of weighing and the theory of the balance are six in number:

1. First, *Nutaf min al-úiyal*, an Arabic partial epitome of Pseudo-Aristotle's *Mechanical Problems*: The *Problemata Mechanica*, apparently the oldest preserved text on mechanics, is a Greek treatise ascribed to Aristotle, but composed very probably by one of his later disciples. It has long been claimed that this text was not transmitted to Arabic culture. It is possible now to affirm that the scholars of Islamic lands had access to it at least through a partial epitome entitled *Nutaf min al-úiyal* (elements/extracts of mechanics) included by al-KhŒzin¥ in the fifth book of his *KitŒb m¥zŒn al-úikma*.[6]

2-3. Two texts ascribed to Euclid on balance (*MaqŒla f¥ 'l-m¥zŒn*) and on heaviness and lightness (*KitŒb fi 'l-thiql wa'l-khiffa*): Extant only in Arabic, the first one provides a geometrical treatment of balance and presents a sophisticated demonstration of the law of the lever. It is not recorded whether it was edited in Arabic, but there is enough evidence to conclude that this was probably the case. The second text survived in a version edited by ThŒbit ibn Qurra. It is an organized exposition –in 9 postulates and 6 theorems– of dynamical principles of the motion of bodies in filled media, developing a rough analysis of Aristotelian type of the concepts of place, size, kind and force and applying them to movements of bodies.[7]

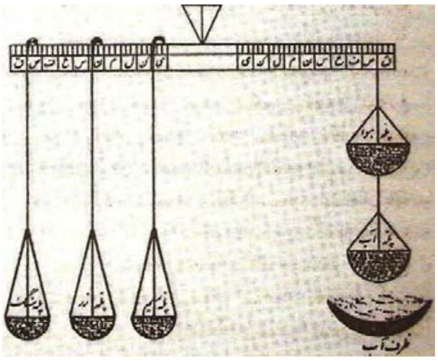

Figure 3. *The Balance of al-KhŒzin¥, in Seyyed Hossein Nasr, Islamic Science an Illustrated Study. Kent 1976.*

[6] Al-KhŒzin¥ 1940, pp. 99-100. The text of the Nutaf was edited and translated, with commentaries, in Abattouy 2001a.

[7] The contents of these two works are surveyed in Abattouy 2001b, p. 216ff. Their textual tradition is analyzed under the procedure of islŒú in Abattouy 2004c.

4. A partial Arabic version of Archimedes' *On Floating Bodies*: Contrary to the highly creative impact Archimedes had on Arabic mathematics, it seems that his main mechanical treatises such as *Equilibrium of planes* and *Quadrature of the parabola* were not translated into Arabic. However, some elements of his theory of centers of gravity were disclosed in the mechanical texts of Heron and Pappus, whereas the main ideas of his hydrostatics were transmitted in a *MaqŒla f¥ 'l-thiql wa'l-khiffa*, extant in Arabic in several manuscript copies. This short tract consists in a summarized digest of the treatise on the *Floating Bodies*, presenting mere statements of the postulates and propositions of Book I and the first proposition of Book II without proofs. [8]

5.6. Heron's and Pappus' *Mechanics*: Finally, the last two Greek texts to be connected with the Arabic tradition of the science of weights are the two huge treatises referred to as *Mechanics* of the Alexandrian scholars Heron (1st century) and Pappus (4th century). These texts are together major sources for the reconstruction of the history of ancient mechanical ideas. Given their composite character, only some of their chapters concern the foundations of theoretical mechanics as developed in the later Arabic tradition around the questions of weighing. Heron's *Mechanics* was translated into Arabic by Qus‹Œ ibn L´qŒ under the title *F¥ raf› al-ashyŒ‹ al-thaq¥la* (On lifting heavy loads).[9] After the loss of the Greek original text, it survived only in this Arabic version. Unlike Heron's *Mechanics*, Pappus' mechanical treatise was preserved in Greek *and* in Arabic. Its Arabic version is titled *Madkhal ilŒ ›ilm al-úiyal* (Introduction to the science of mechanics), by a translator who has not yet been identified, but there is enough evidence to affirm that this version saw the light in 10th-century Baghdad.[10]

3. Founding texts of the Arabic science of weights

In close connection with the translation and study of the above mentioned Greek sources, the Muslim scientists composed in the period from the 9th up to the 12th century a set of original texts that laid the foundation to the new science of weights. To mention just the main treatises, these texts are seven in number:

7. First, the *KitŒb f¥ 'l-qaras‹´n* by ThŒbit ibn Qurra (d. 901): Without contest the most important text of the Arabic mechanical tradition, it was apparently one of the first Arabic texts to deal with the theory of the unequal-armed balance in Islam and to systematize its treatment. As such, it established the theoretical foundation for the whole Arabic tradition.

KitŒb f¥ 'l-qaras‹´n presents a deductive theory of the steelyard based on dynamic assumptions. It is extant in four known copies, of which three contain complete texts with variant readings. Two of these, preserved in London (India Office MS 767-7) and Beirut (St.-Joseph Library, MS

8 A MS copy of this text was published in Zotenberg 1879 and translated into English in Clagett 1959, pp. 52-55.
9 Heron's *Mechanics* was edited and translated twice respectively by Carra de Vaux in 1893, with French translation, and by Schmidt and Nix in 1900, with German translation. These editions were reprinted recently: respectively Herons 1976 and Héron 1988.

223-11), were studied and published recently.[11] The third copy, formerly conserved in Berlin (Staatsbibliothek MS 559/9, ff. 218b-224a), was reported lost at the end of World War II. A colleague from Berlin, Paul Weinig and I happened to rediscover it in the Biblioteka Jagiellonska in Krakow (Poland) in October 1996. Recently Sonja Brentjes kindly attracted my attention to a partial fourth copy that exists in the archives of the Laurentiana Library in Florence (MS Or. 118, ff. 71r-72r). Never mentioned before, this valuable three-page text includes the introductory two sections of ThŒbit's treatise. This part of the text exposes the dynamic foundation of the treatise and an important passage that was, up to now, thought only to occur in Beirut MS copy (and thus known as Beirut scholium).[12]

8. *KitŒb f¥ §ifat al-wazn* by the same ThŒbit ibn Qurra: This five-section text on the balance is about the conditions necessary to achieve equilibrium in weighing with balances, primarily the equal-armed sort.[13] An important connection between this text and *KitŒb f¥ 'l-qaras‹´n* is provided by the occurrence, in the last section of *êifat al-wazn*, of the statement of a proposition identical with the postulate that opens *KitŒb f¥ 'l-qaras‹´n*.

9. *ZiyyŒda f¥ 'l-qaras‹´n* or An Addition on the theory of the *qaras‹´n*: A short anonymous text extant in a unicum copy preserved in Beirut. In this codex, the *ZiyyŒda* serves as an appendix to *KitŒb f¥ 'l-qaras‹´n.* The two texts are written in the same hand and display strong terminological affinities which include the basic vocabulary as well as the technical terms. ThŒbit ibn Qurra is mentioned twice in the *ZiyyŒda*. This and several other elements induce us to consider it as an appendix intended to amplify the analysis developed in ThŒbit's original work. The text of the *ZiyyŒda* is composed of five propositions. The first two are mere applications of the Proposition VI of *KitŒb f¥ 'l-qaras‹´n* while the last three establish a procedure for calculating the counterweight required to maintain equilibrium in a lever divided an evenly number of times.

10. A short text on the balance by Muúammad ibn ›Abd-AllŒh b. Man§´r al-AhwŒz¥: Al-AhwŒz¥ is a well known mathematician of the 10th century; his text on the balance is extant in a unique copy preserved in Khuda Baksh Library in Patna (Codex 2928, folio 31) without title, save for the one provided by the curators of the library: *RisŒla f¥ 'l-mizŒn*.[14]

11. The treatises on centers of gravity of al-Q´h¥ and Ibn al-Haytham: These important contributions by two of the most important Muslim mathematicians of the 10th-11th centuries

[10] The Arabic text of Pappus' *Mechanics* was transcribed and translated into English in Jackson 1970.
[11] Respectively in Jaouiche 1976 and Knorr 1982.
[12] The mechanical theory of *KitŒb f¥ 'l-qaras‹´n* was studied in Jaouiche 1976, Abattouy 2000d and in Abattouy 2002a.
[13] This text was preserved thanks to its integration in *KitŒb m¥zŒn al-úikma*: al-KhŒzin¥ 1940, pp. 33-38. For translations, see the German version in Wiedemann 1970, vol. I, pp. 495-500 and a partial English version in Knorr 1982, pp. 206-208.
[14] On al-AhwŒz¥, see Sezgin 1974, p. 312.

survived only through their reproduction by al-KhŒzin¥ in a joint abridged version that opens the first book of his *KitŒb m¥zŒn al-úikma*.[15] The potential discovery of the complete versions of these texts will mean the recovery of fundamental sources.[16]

12. The statements on the law of the lever by the same al-Q´h¥ included in a discussion on the centers of gravity he had with Ab´ IsúŒq al-êŒb¥ around 990-91.[17]

13. The treatise of ¡lyŒ al-Ma‹rŒn on measures and weights: ¡lyŒ al-Ma‹rŒn was the Archbishop of Nisibin (north Mesopotamia, Nusaybin in present Turkey) in the first half of the 11th century. His *MaqŒla f¥ 'l-makŒyy¥l wa al-awzŒn* (Treatise of measures and weights) is essentially of practical interest, but it is based on the theory of the steelyard as elaborated in earlier Arabic works.

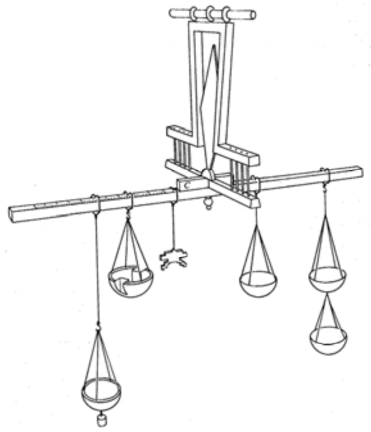

Figure 4. *Al-KhŒzin¥'s balance in Seyyed Hossein Nasr. Islamic Science an Illustrated Study. Kent 1976.*

14. *IrshŒd dhaw¥ al->irfŒn ilŒ §inŒ>at al-qaffŒn* (Guiding the Learned Men in the Art of the Steelyard) by al-IsfizŒr¥: A fundamental and long-neglected treatise, written by ab´ îŒtim al-Mu½affar b. IsmŒ>¥l al-IsfizŒr¥, a mathematician and mechanician who flourished in KhurasŒn (north-east Iran) around 1050-1110. In this original text on the theory and practice of the unequal-armed balance, different textual traditions from Greek and Arabic sources are compiled together for the elaboration of a unified mechanical theory. It is extant in a unique manuscript copy preserved in Damascus (al-‹Asad National Library, al-üŒhiriyya collection, MS 4460, folia

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15 Al-KhŒzin¥ 1940, pp. 15-20.

16 In his catalogue of Arabic manuscripts, Paul Sbath mentionned that there was a copy of Ibn al-Haytham's *MaqŒla f¥ 'l-qaras‹´n* in a private collection in Aleppo in Syria, which may be Ibn al-Haytham's treatise on centres of gravity: See Sbath 1938-1940, part 1, p. 86. For textual considerations on the treatise of al-Q´h¥, see Bancel 2001.

17 The correspondence was edited and translated into English in Berggren 1983.

16a-24a). In addition, an abridged version reproduced by al-KhŒzin¥ includes a section on the construction and use of the steelyard, which is omitted from the Damascus manuscript.[18]

15. *KitŒb m¥zŒn al-úikma* by al-KhŒzin¥: A special mention should be made of *KitŒb m¥zŒn al-úikma*, the encyclopedia of mechanics completed by AbderaúmŒn al-KhŒzin¥ in 1121-22, a real mine of information on all aspects of the theoretical and practical knowledge in the Islamic medieval area about balances. The book 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. This huge summa of mechanical thinking provides a comprehensive picture of the knowledge about weights and balances available in the Arabic scientific milieu up to the early 12th century. Therefore, it represents a major source for any investigation on ancient and medieval mechanics.[19]

The textual tradition of the Arabic science of weights between the 9th and the 12th centuries also contains additional sources that should be taken into account in any complete reconstruction of its corpus. These include the work of Muúammad Ibn ZakariyyŒ al-RŒz¥ (865-923) on the natural balance,[20] extracts from texts on weights by Qus‹Œ ibn L´qŒ and IsúŒq ibn Î unayn,[21] Ibn al-Haytham's largely expanded recension of Menelaus' (fl. Alexandria, 1st century) text on specific gravities,[22] and two writings on specific gravity and the hydrostatical balance by ›Umar al-KhayyŒm.[23]

4. Texts of the later period

The third and last phase of the Arabic writings on weights and balances is represented by a group of texts dating from the 14th to the 19th centuries and originating principally from Egypt and Syria. These two countries were unified during this long period under the rule of the Ayy´b¥d, Mamel´k, and Ottoman dynasties, respectively, and they constituted for centuries a common economic and cultural space. Consequently the *raison d'être* of this large amount of writings on the theoretical and practical problems of the balance and weights, was a direct outcome of the integration of economic and cultural activities in this vast area. The authors of these texts are mathematicians, mechanicians, and artisans. In the following some names and works are mentioned for illustration.

[18] Al-KhŒzin¥ 1940, pp. 39-45. Al-IsfizŒr¥'s biography and the contents of his *IrshŒd* are surveyed in Abattouy 2000b and Abattouy 2001b.
[19] On al-KhŒzin¥ and his work, see Hall 1981 and Abattouy 2000a.
[20] Reproduced in an abridged version by al-KhŒzin¥ 1940, pp. 83-86.
[21] These texts are preserved in Aya Sofya Library in Istanbul, Codex 3711.
[22] Obviously extant in a unique manuscript discovered in Lahore in 1979 by Anton Heinen: see Heinen 1983.
[23] Both edited in al-KhŒzin¥ 1940, pp. 87-92, 151-153. On KhayyŒm's mechanics, see Aghayani Chavoshi and Bancel 2000, and Abattouy [Forthcoming 2006a].

16. *MasŒ‹il f¥ 'l-mawŒz¥n* (Problems on balances) by Ya›¥sh b. IbrŒh¥m al-Umaw¥: This short tract is by a mathematician of Andalusian origin who lived in Damascus (fl. 1373), and is known as author of several arithmetical works.[24] His *MasŒ‹il* consists in a small collection of problems about weighing with hydrostatic and normal balances. The text is part of the codex DR 86 preserved in the Egyptian National Library in Cairo.

17. *RisŒla f¥ ›amal al-m¥zŒn al-‹ab¥›¥* by Taq¥ al-D¥n ibn Ma›r´f: The author is a well known mathematician, astronomer, and mechanician (born in Damascus in 1525-died in Istanbul in 1585). His short treatise on making the natural balance describes what was transmitted to Taq¥ al-D¥n of a previous writing on the balance that he ascribes to the mathematician GhiyyŒth al-D¥n al-KŒsh¥ (died in Samarkand in 1429). It is part of the collections of the municipal library of Alexandria.

18. *›Amal m¥zŒn li-sarf al-dhahab min ghayr §anj* (The construction of a balance for converting gold without standard weight) by Ab´ 'l-›AbbŒs Aúmad b. Ab¥ Bakr b. ›Al¥ ibn al-SarrŒj. The author, who was live around 714 H (1319-20) and 748 H (1347-8), was an important specialist in astronomical instrumentation in the Mamluk period.[25] His short text is the sixth item of the codex MR 30 conserved in the Egyptian National Library in Cairo.

The Egyptian astronomer Muúammad ibn Ab¥ al-Fatú al-ê´f¥ (d. 1543) composed several treatises on the theory and the practice of the steelyard balance which enjoyed wide diffusion. Al-ê´f¥ seems to be the last *original* representative of the classical Arabic tradition of works on balances and weights. With him, this tradition comes to an end, at the same time as pre-classical physics in Europe was undergoing a deep transformation that would finally integrate the science of weights into modern physics. Here are his main treatises, known in several extant copies preserved exclusively in Cairo and Damascus, attesting to their widespread use in Egypt and Syria over several centuries:

19. *RisŒla f¥ §inŒ›at al-qabbŒn* (Treatise in the art of the steelyard): a systematic description of the steelyard and its use in different situations, showing a clear acquaintance with steelyards. The text is explicitly written for the practitioners;

20. *IrshŒd al-wazzŒn li-ma›rifat al-awzŒn bi 'l-qabbŒn* (Guide to the weigher in the knowledge of the weights of the steelyard): similar to the previous text;

21. *RisŒla f¥ qismat al-qabbŒn* (Treatise on the division of the steelyard): contains arithmetical and geometrical problems on the calculation of the parts of the steelyard;

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[24] On al-Umaw¥, see Sa›¥dŒn 1981.

22. *RisŒla f¥ i§lŒú fasŒd al-qabbŒn* (Treatise on repairing the defectuosity of the steelyard): very detailed analysis of the different cases of deficiency of a steelyard and the solutions to repair these deficiencies. Other later texts include:

23. *Nukhbat al-zamŒn f¥ §inŒ›at al-qabbŒn*: a short text on the steelyard by ›UthmŒn b. ›AlŒ‹ al-D¥n al-Dimashq¥, known as Ibn al-Malik (fl. 1589);

24. *RisŒlat al-jawŒhir f¥ ›ilm al-qabbŒn* (Treatise of jewels in the science of the steelyard): a ten-chapter text written by Khièr al-Burlus¥ al-QabbŒn¥ (d. in 1672);

25. Two writings on the "science" (›*ilm*) and the "description" (*ta›r¥f*) of the steelyard by ›Abd al-Maj¥d al-SŒm´l¥ (18th century);

26. *Al-›Iqd al-tham¥n f¥mŒ yata›allaq bi-'l-mawŒz¥n* (The high priced necklace in what concerns the balances), a systematic treatise on the balance and weights, by î asan al-Jabart¥ (1698-1774);

27. Several short texts dealing with the principles and the construction of the steelyard by Muúammad al-Ghamr¥ (died before 1712);

28. *RisŒla f¥ 'l-qabbŒn* by Muúammad b. al-î usayn al-›A‹‹Œr (d. 1819), a Syrian author, is among the very last works written in Arabic in the style of the earlier mechanical tradition.[26] For some other texts, the authorship is not yet established firmly as they don't bear any name and they are catalogued until now as "anonymous texts". In this last category, we mention the following three tracts, which are very probably connected with the texts of the later period just mentioned above.

29. First, a huge summa titled *Al-qawŒn¥n f¥ §ifat al-qabbŒn wa 'l-mawŒz¥n* (The laws in the description of the steelyard and the balances) existing in Codex TR 279, ff. 1-62 in the Cairote DŒr al-kutub.

30. Then a short text, *BŒb f¥ ma›rifat ›amal al-qabbŒn* (Chapter in the knowledge of making the steelyard) (Cairo, DŒr al-kutub, MS K3831/1and MS RT 108/1).

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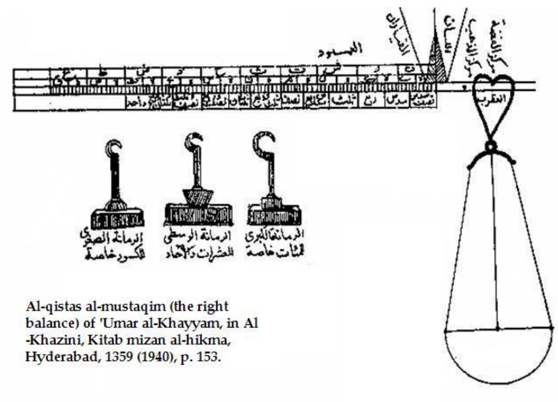
[25] See on Ibn al-SarrŒj King 1987 and Charette 2003.

[26] This treatise is a digest of earlier works composed of an introduction – devoted to the principle of the equilibrium of weights– and 2 chapters on 1. The construction of the steelyard, 2. The conversion of weights between countries. Chap. 1 deals in a didactic way with the elementary properties of the balances and a certain emphasis is made on the law of the lever. The text exists in 3 copies: Damascus, al-Asad Nat. Lib., üŒhir. coll., MS 4297; Aleppo, al-Aúmadiya Lib., al-Maktaba al-waqfiya, MS 1787; Rabat, National Library, MS D 1954.

31. An untitled tract, of which the beginning is:"*hŒdhihi risŒla f¥ ›ilm al-qabbŒn*" (Cairo, DŒr al-kutub, in the same codex K3831).

32. And finally two short tracts (*RisŒla mukhta§ara f¥ ›ilm al-qabbŒn* and *RisŒla f¥ ›ilm §inŒ›at al-qabbŒn*) preserved in Damascus (National Library, al-ÜŒhiriyya Collection, MS 4).[27]

The texts mentioned so far afford a precious testimony to the fact that scientific and technical works –sometimes with a high level of originality– continued to be composed in Arabic in the field of mechanics until the 19th century. This corresponds to similar information derived from recent research in other fields of Arabic sciences, such as astronomy and mathematics. The ongoing research into this later phase of science in the Arabic language will undoubtedly change our appreciation of the historical significance of Arabic science and of its place in the general history of science and culture.



Al-qistas al-mustaqim (the right balance) of 'Umar al-Khayyam, in Al -Khazini, Kitab mizan al-hikma, Hyderabad, 1359 (1940), p. 153.

Figure. 5. *Al-qistas al-mustaqim (the right balance of) 'Umar al-Khayyam, in al-KhŒzin¥. KitŒb m¥zŒn al-úikma, Hyderabad, 1940, p. 153.*

6. The status of the science of weights (*›ilm al-athqŒl*)

The availability of the major part of the Arabic texts on the problems of weights and balances makes it possible, for the first time, to address the question of the historical significance of this large corpus of mechanical works. The investigation of this question has already led to a far-reaching conclusion. It turns out that this corpus represents no less than the transformation of the ancient mechanics into a systematic science of weights and balances. As disclosed in the treatises of Pseudo-Aristotle, Philon, Heron, and Pappus, the Greek classical doctrine of mechanics was shaped as a collection of descriptions and riddles about machines, instruments,

[27] Among these anonymous texts, we should mention a "strange" text preserved in Paris (Bibliothèque Nationale, Fonds Arabe, MS 4946, ff. 79-82) under the title *Nukat al-qaras‹´n* (The secrets or the properties of the steelyard) and ascribed to ThŒbit ibn Qurra. Its contents are without any doubt related to the science of weights, and its main subject is very elementary and treats of some cases of weighing with the steelyard.

and common observation. In contradistinction, the new Arabic science of weights is focused on a relatively small range of subjects – mainly the theory of the balance and equilibrium and the practical issues of weighing with different instruments. On the conceptual level, it is built on a dynamic foundation and seeks to account for mechanical phenomena in terms of motion and force. As such, it restores a strong link between mechanics and natural philosophy. This new science of weight lasted in Arabic culture until the 19th century and constituted since the 12th century a basis for the Latin *scientia de ponderibus* that developed in Western Europe.

The emergence of the Arabic science of weights has been proclaimed by al-FŒrŒb¥ (ca. 870-950) in his *Iú§Œ‹ al-›ul´m*, where he produced an authoritative reflexion on the epistemological status of mechanics that set the stage for the question once and for all. In particular, he set up a demarcation line between the science of weights and the science of machines, and considered both as mathematical disciplines.

Al-FŒrŒb¥ differentiated in his system between six principal sciences: those of language, logic, mathematics, nature (physics), metaphysics and politics. Mathematics is subdivided into seven disciplines: arithmetic, geometry, perspective, astronomy, music, the science of weights (›*ilm al-athqŒl*) and the science of devices or machines (›*ilm al-úiyal*). The last two are characterized as follows:

> *As for the science of weights, it deals with the matters of weights from two standpoints: either by examining weights as much as they are measured or are of use to measure, and this is the investigation of the matters of the doctrine of balances (‹um´r al-qawl f¥ 'l-mawŒz¥n), or by examining weights as much as they move or are of use to move, and this is the investigation of the principles of instruments (‹u§´l al-ŒlŒt) by which heavy things are lifted and carried from one place to another.*
>
> *As for the science of devices, it is the knowledge of the procedures by which one applies to natural bodies all that was proven to exist in the mathematical sciences… in statements and proofs unto the natural bodies, and [the act of] locating [all that], and establishing it in actuality. The sciences of devices are therefore those that supply the knowledge of the methods and the procedures by which one can contrive to find this applicability and to demonstrate it in actuality in the natural bodies that are perceptible to the senses.*[28]

Considering the two main branches of mechanics as genuine mathematical sciences, al-FŒrŒb¥ located their objects respectively in the study of weights and machines. Hence, ›*ilm al-athqŒl* is centered on the principles of the balances and of lifts, investigated with reference to measure and motion, whereas ›*ilm al-úiyal* is conceived of as the application of mathematical properties (lines, surfaces, volumes, and numbers) to natural bodies. As such, it includes various practical

[28] Al-FŒrŒb¥ 1949, pp. 88-89.

crafts: the overseeing of constructions, the measurement of bodies, the making of astronomical, musical, and optical instruments, as well as the fabrication of hydraulic mechanisms, mirrors, and tools like bows, arrows and different weapons.[29]

In this context, the main function of *›ilm al-úiyal* consists in bringing the geometrical properties from potentiality (*quwwa*) to actuality (*fi›l*) and to apply them to real bodies by means of special engines (*bi-'l-§an›a*).[30] Developing an Aristotelian thesis,[31] al-FŒrŒb¥ endows the science of machines with an eminent task, to actualize the mathematical properties in natural bodies. Such a function of actualization could not be extended to *›ilm al-athqŒl*. In fact, weight and motion, the two notions that delimit its field of investigation, can hardly be taken as geometric properties of natural bodies, limited by al-FŒrŒb¥ to spatial and numerical aspects, in accordance with the canonical Euclidean paradigm that banishes all the material properties of magnitudes from the realm of geometry.

The distinction of the science of weights from the different crafts of practical mechanics is a crucial result of al-FŒrŒb¥'s theory. The emphasis laid by the Second Master on *›ilm al-athqŒl* can not be stressed enough. It amounts to no less than a solemn announcement of the emergence of an independent science of weights. With roots in the long tradition of ancient mechanics, this new discipline came to light in the second half of the 9th century in the works of ThŒbit ibn Qurra and his colleagues.[32] It is this important scientific achievement that was recorded by al- FŒrŒb¥ while building his system of knowledge.

Al-FŒrŒb¥'s thesis had a long-lasting resonance in Arabic learning and was never seriously challenged. The fundamental singularity of the science of weights as an independent branch under the mathematical arts, distinct from the science of machines, became a feature of subsequent theories of science. For confirmation, a great number of instances, in different kinds of works and in various literary contexts, can be called upon. Some of these instances are presented in chronological order hereinafter.

In his *RisŒla f¥ aqsŒm al-›ul´m al-›aqliyya* (Epistle on the parts of rational sciences), Ibn S¥nŒ (980-1037) enumerated the mechanical arts, considered as 'secondary constituents' of geometry, as *›ilm al-úiyyal al-mutaúarrika* (the science of movable machines, i.e., automata),[33] the pulling of weights (*jarr al-athqŒl*), the science of weights and balances (*›ilm al-awzŒn wa al-mawŒz¥n*),

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[29] *î iyal* (sing. *ú¥la*) translated the Greek word *mechanê* which means both mechanical instrument and trick and is at the origin of the words machine and mechanics. On the affinities between *mechanê* and *ú¥la*, see Abattouy 2000c.

[30] In the Arabic partial version of Pseudo-Aristotle's Mechanical Problems, this very function of the úiyal is said to be carried out with artificial devices (úiyal §inŒ›iyya): see the edition of the Nutaf min al-úiyal in Abattouy 2001a, pp. 110, 113 and Aristotle 1952, 847a 25-30. The function of ›ilm al-úiyal as actualisation of potentalities is surveyed in Saliba 1985.

[31] Aristotle, *Metaphysics* XIII.3, 1078 a 14-16.

[32] The thesis of the birth of the Arabic science of weights was first formulated in Abattouy, Renn and Weinig 2001.

and the 'science of particular machines' (›*ilm al-ŒlŒt al-juz‹iyya*).[34] Ibn S¥nŒ establishes a clear distinction between the science of weights and balances, the craft of pulling heavy loads, and the art of devices. In addition, the latter is subdivided into the arts of automata and of particular machines. Likewise, the pulling of weights, included in the science of weights by al-FŒrŒb¥, is assigned as a specific branch of geometry. The main point, however, in Ibn S¥nŒ's schema is the emphasis laid on the science of *awzŒn* and *mawŒz¥n* in which weights and balances are combined. The reference to the *wazn* instead of the *thiql* could be interpreted as a privilege given to the statical standpoint. Indeed, the *wazn* is a constant quantity measurable in a balance, whereas the *thiql* is that quantity –called gravity or heaviness– which varies during the weighing process and depends on the position of the weighed object relatively to a particular point, the center of the world or the fulcrum of the balance.[35]

In his discussion on the divisions of sciences in *MaqŒ§id al-falŒsifa* (The Intentions of philosophers), al-GhazŒl¥ (1058-1111) subsumed the science of weights (›*ilm al-athqŒl*) as an independent branch under the mathematical arts and differentiates it from the study of ingenious devices (›*ilm al-úiyal*).[36] Ibn Rash¥q, a Moroccan mathematician of the late 13th century from Sebta, assumed a similar demarcation between weights and machines, and founded the latter on the former: the science of weights, of balances, and of catapults. (›*ilm al-athqŒl wa 'l-mawŒz¥n wa 'l-majŒn¥q*) deals with the downward motion of heavy bodies and constitutes the foundation of the science of machines (*wa-yatarattab ›alŒ ›ilm al-athqŒl ›ilm al-úiyal*).[37] In his biography of al-IsfizŒr¥, al-Bayhaq¥ did not confuse the two when he reported that al-IsfizŒr¥ "was mostly inclined to astronomy and to the science of weights and machines (›*ilm al-athqŒl wa al-úiyal*)."[38] This corresponds to what we know of his extant works in mechanics, the *IrshŒd* being clearly a book of *athqŒl*, whereas al-IsfizŒr¥'s work on *úiyal* is represented by a collection of compiled summaries (sometimes with comments) extracted from the mechanical works of Heron, Apollonius and Ban´ M´sŒ.[39] Later on, Taq¥ al-D¥n ibn Ma›r´f, the 16th-century mechanician,

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[33] That *al-ŒlŒt al-mutaúarrika* refers to automata is established in Abattouy 2000c, pp. 139-140.

[34] The other components of geometry are the sciences of measurement, of optics and mirrors, and of hydraulics: see Anawati 1977, p. 330 and Ibn S¥nŒ 1989, p. 112.

[35] The difference is well illustrated by the definition opening Pseudo-Euclid's *MaqŒla f¥ 'l-m¥zŒn*: "weight (*wazn*) is the measure of heaviness (*thiql*) and lightness (*khiffa*) of one thing compared to another by means of a balance": Paris, Bibliothèque Nationale, MS 2457, f. 22b.

[36] Al-GhazŒl¥ 1961, p. 139.

[37] Al-îusayn b. Ab¥ Bakr Ibn Rash¥q (d. 1292), *RisŒlat f¥ ta§n¥f al-›ul´m al-riyŒèiyya*, Rabat, al-Maktaba al-›Œmma, MS Q 416, p. 422. On Ibn Rash¥q, see Lamrabet 2002 and Abattouy 2003a, pp. 101-105.

[38] Al-Bayhaq¥ 1988, p. 125. Likewise, in the notice he devoted to the mathematician Ab´ Sahl al-Q´h¥, al-Bayhaq¥ states that he was "well-versed in the science[s?] of machines and weights and moving spheres" (*baraza f¥ ›ilm al-úiyal wa al-athqŒl wa al-ukar al-mutaúarrika*) (ibid., p. 88).

[39] In the incipit of this collection, al-IsfizŒr¥ writes: "We collected in this book what has reached us of the books on various devices (*anwŒ› al- úiyal*) composed by the ancients and by those who came after them, like the book of Philon the constructor of machines (*sŒúib al-úiyal*), the book of Heron the mechanician (*¡run al-majŒn¥q¥*) on the machines (*úiyal*) by which heavy loads are lifted by a small force... We start by presenting the drawings of the machines (*§uwwar al-úiyal*) conceived by the brothers Muúammad, Aúmad and al-îasan, Ban´ M´sŒ ibn ShŒkir." Manchester, John Ryland Library, Codex 351, f. 94b; Hayderabad, Andra Pradesh Library, Asafiyya Collection,

followed the same pattern. Accounting for the books he read in his scientific curriculum, he mentioned, in addition to texts of mathematics, "books of accurate machines (*kutub al-úiyal al-daq¥qa*), treatises of the science of the steelyard and of the balance (*rasŒ‹il ›ilm al-qaras‹´n wa al-m¥zŒn*), and of the pulling of weights (*jar al-athqŒl*)."[40]

Sometimes *›ilm al-athqŒl* is referred to as *›ilm marŒkiz al-athqŒl*, one of its branches which enjoyed a great reputation. A good instance of this is the following quotation we find in the correspondence between al-Q´h¥ and al-êŒb¥. In a letter to al-Q´h¥, al-êŒb¥ says:

> *We did not obtain a complete book on this science, I mean centers of gravity (marŒkiz al-athqŒl), nor was there done any satisfactory work by one of the ancients or one of the moderns. In my opinion it is in the rank of a singular science which merits to have a book of basic principles (al-§inŒ›a al-mufrada allat¥ yuútŒj an yu›mal lahŒ kitŒb u§´l).*[41]

A century later, al-IsfizŒr¥ qualified the centers of gravity as "the most elevated and honourable of the parts of the mathematical sciences" and defined it as:

> *the knowledge of the weights of loads of different quantities by the [determination of the] difference of their distances from their counterweights.*[42]

Al-KhŒzin¥ specifies further the definition of his predecessor when he explains that the study of the steelyard is founded upon the science of the centers of gravity (*wa ›alayhi mabnŒ al-qaffŒn*).[43] Therefore, it is obvious that the expression *marŒkiz al-athqŒl* is intended to account for the statical aspect of *›ilm al-athqŒl*, by the study of forces as they are related to weights, such as in the case of levers and scales. This same thesis is assumed by other Islamic scholars.[44]
In contrast, the tradition of *úiyal* delimits the contours of a distinct discipline, centered on the investigation of the methods of applicability of mathematical knowledge to natural bodies. As represented in several Greek and Arabic mechanical texts, written by Heron, Pappus, Philon, Ban´ M´sŒ and al-Jazar¥, the tradition of *úiyal* is focused on the description of machines and the explanation of their functions. Book I of Heron's treatise contains principles of theoretical mechanics, but the rest, more than three quarters of the whole, is predominantly about different

Codex QO 620, p. 1.
[40] In his *KitŒb at-‹uruq al-saniyya f¥ al-ŒlŒt al-r´úŒniyya* (The Sublim methods in spiritual machines): al-îasan 1976, p. 24.
[41] Berggren 1983, pp. 48, 120.
[42] *IrshŒd dhaw¥ al-›irfŒn ilŒ §inŒ›at al-qaffŒn*, al-‹Asad National Library in Damascus, al-ÜŒhiriyya collection, MS 4460, f. 16b.
[43] Al-KhŒzin¥ 1940, p. 5.
[44] For instance, Ibn al-AkfŒn¥ (fourteenth century) asserts that *›ilm marŒkiz al-athqŒl* shows "how to balance great weights by small ones, with the intermediary of the distance, such as in the steelyard (*qaras‹´n*)": Ibn al-AkfŒn¥ 1989, p. 409. The same idea is in al-TahŒnaw¥ 1980, vol. 1, p. 47.

kinds of devices. The same applies to the treatise of Pappus. As for Philon of Byzantium (fl. 230), his *Pneumatics* is mainly a catalogue of machines worked by air pression. [45]

An important constituent of the Greek traditional doctrine of mechanics –as it is disclosed in the texts by Pseudo-Aristotle, Heron and Pappus– is represented by the theory of the simple machines (the windlass, the lever, the pulley, the wedge, and the screw). Those simple machines were dealt with in Arabic science by several scholars such as the Pseudo-Ibn S¥nŒ,[46] al-IsfizŒr¥,[47] and SinŒn ibn ThŒbit[48] under the name of *úiyal*. Besides this trend on the basic simple machines and their combinations, the science of *úiyal* also included a description of other categories of machines necessary in daily life and useful for civil engineering. The most well known works describing this kind of engines are the texts of machines by Ban´ M´sŒ and al-Jazar¥. *KitŒb al-úiyal* by the Ban´ M´sŒ comprises a large variety of devices, the vast majority of which consist of trick vessels for dispending liquids. The book of al-Jazar¥ *al-JŒmi› bayna'l-›ilm wa 'l-›amal f¥ §inŒ›at al-úiyal* (*The Compendium of theory and practice in the art of mechanics*) enlarges this same feature in an unprecedented way. The author incorporates in it the results of 25 years of research and practice on various mechanical devices (automata, musical machines, clocks, fountains, vessels, water-raising machines, etc.) [49]

The conception of *úiyal* as the practical component of mechanics is additionally corroborated by the contents of a chapter of the *MafŒt¥ú al-›ul´m* by Muúammad b. Y´suf al-KhwŒrizm¥ (10th century). Chapter 8 of Book II of this lexicographic encyclopedia is dedicated to "*§inŒ›at al-úiyal, tusammŒ bi al-y´nŒniyya manjan¥q´n*" (the art of mechanics, called in Greek *manjan¥q´n*). Besides a short mention of machines for the traction of weights, the *úiyal* described are essentially of two types: automata (*ŒlŒt al-úarakŒt*) and hydraulic devices (*úiyal úarakŒt al-mŒ›*).[50] The author devotes great attention to the first two kinds; this might be taken as evidence to the preeminence of these machines in the domain of *úiyal* in his time. Significantly, al-KhwŒrizm¥ – like Ibn S¥nŒ – classifies the weight-pulling machines in the field of *úiyal* in contrast to their arrangement among that of *athqŒl* by al-FŒrŒb¥, which should be considered an

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[45] Philon's *Pneumatics* was translated into Arabic under the title *KitŒb F¥l´n f¥ al-úiyal al-r´úŒniyya wa mŒjan¥q al-mŒ›* (The Book of Philon on spiritual machines and the hydraulic machines). The Arabic text was edited and translated into French in Carra de Vaux: see Philon 1902.

[46] A Persian mechanical text called *Mi›yŒr al-›uq´l dur fan jar athqŒl* is attributed to Ibn S¥nŒ. The treatise, in two sections, is devoted to the five simple machines. It presents the first successful and complete attempt to classify simple machines and their combinations: Ibn S¥nŒ 1331 H [1952]. For a short commentary, see Rozhanskaya 1996, pp. 633-34.

[47] Al-IsfizŒr¥ is the author of a collection of summaries and commentaries extracted from the mechanical works of Heron, Apollonius, and Ban´ M´sŒ. He dealt with simple machines in his commentary on Book II of Heron's *Mechanics*: see Abattouy 2000b, pp. 147-48.

[48] SinŒn (d. 942), the son of ThŒbit ibn Qurra, is presumably the author of a fragment on the five simple machines preserved in Berlin, Staatsbibliothek, MS Orient fol. 3306.

[49] For the two works of Ban´ M´sŒ and al-Jazar¥, see respectively Hill 1974 and Hill 1979 for English translations and al-Îasan 1979 and al-Îasan 1981 for the Arabic texts.

[50] Al-KhwŒrizm¥ 1968, pp. 246-247.

evolution, as it narrows and refines the domain of weights, articulating the ideal model of the study of balances and measures.

The analysis of the overall significance of the Arabic medieval science of weights shows that this tradition does not represent a mere continuation of the traditional doctrine of mechanics as inherited from the Greeks. Rather, it means the emergence of a new science of weights recognized very early on in Arabic learning as a specific branch of mechanics, and embodied in a large scientific and technical corpus. Comprehensive attempts at collecting and systematizing (as well as updating with original contributions) the mainly fragmentary and unorganized Greco-Roman mechanical literature that had been translated into Arabic were highly successful in producing a coherent and orderly mechanical system. In this light, a redefinition of Arabic mechanics becomes necessary, initially by questioning its status as a unified field of knowledge. Such a redefinition may be worked out briefly by setting a sharp distinction between *›ilm al-athqŒl* and *›ilm al-úiyal*. The latter corresponds to the traditional descriptive doctrine of machines, whereas the core structure of the *›ilm al-athqŒl* is a genuine theory of mechanics articulated around the balance-lever model and its theoretical and practical elaborations. Uniting the theoretical treatment of the balance with concrete practical information about its construction and use, and adopting an integrative treatment of physics and mechanics, overcoming their original separation in Antiquity, the new science of weights distinguishes itself by turning mechanics from being originally a marginal part of geometry into an independent science of weights.

On the methodological level, the new science of weights was marked by a close combination of experimentation with mathematization. The Aristotelian qualitative procedures were enriched with quantitative ones, and mathematics was massively introduced in the study of mechanical problems. As a result, mechanics became more quantitative and the results of measures and experiments were given more and more weight in mechanical knowledge. Certainly, the fundamental concepts of Aristotelian physics continued to lie in the background, but the scholars were able to cross their boundaries and to accomplish remarkable discoveries in physical ideas. For instance, the generalization of the theory of centers of gravity to three-dimensional objects, the introduction of a dynamic approach in the study of problems of statics and hydrostatics, the improvement of the procedures and methods for the determination of specific weights and of weighing instruments, the development of the theory of heaviness and the establishment of a theory of the ponderable lever. Further, the treatment of the law of equilibrium by ThŒbit ibn Qurra and al-IsfizŒr¥ opened the horizon of a unified theory of motion in which the dichotomies of natural-violent, upward-downward motions vanish, exactly as they disappear in the concomitant motions of the two arms of a balance lever. In this physical system, indeed, the weight of the body might be considered the cause of the downward as well as of the upward motion, overcoming the Aristotelian balking at making weight a cause of motion. For their parts, al-Q´h¥ and Ibn al-Haytham had the priority in formulating the hypothesis that the heaviness of bodies vary with their distance from a specific point, the center of the earth. Moreover, they contributed to unify the two notions of heaviness, with respect to the center of the universe and with respect to the axis of suspension of a lever. In his recension of the works of his predecessors, al-KhŒzin¥ pushed forward this idea and drew from it a spectacular conclusion regarding the variation of gravity with the distance from the centre of the world. All this work represented strong antecedents to the concept of positional weight (*gravitas secundum situm*) formulated by Jordanus in the 13th century.[51]

The historians of mechanics, from Pierre Duhem until Marshal Clagett, assumed that the foundation of the science of weights must be credited to the school of Jordanus in Europe in the 13th century. Now it appears that this science emerged much earlier in Islamic science, in the 9th century. Moreover, the first steps of the Latin *scientia de ponderibus* should be considered as a direct result of the Arabic-Latin transmission, and especially as a consequence of the translation of two major Arabic texts in which the new science and its name are disclosed, *KitŒb f¥ 'l-qaras‹´n* by ThŒbit ibn Qurra and *Iú§Œ‹ al-›ul´m* by al-FŒrŒb¥.

Indeed, the very expression *scientia de ponderibus* was derived from the Latin translation of al-FŒrŒb¥'s *Iú§Œ‹ al-›ul´m*. Versions of this text were produced both by Gerard of Cremona and Dominicus Gundissalinus. The latter made an adapted version of the *Iú§Œ‹* in his *De scientis* and used it as a framework for his own *De divisione philosophiae*, which later became a guide to the relationships between the sciences for European universities in the 13th century. In the two texts, Gundissalinus reproduced –sometimes verbatim– al-FŒrŒb¥'s characterization of the sciences of weights and devices, called respectively *scientia de ponderibus* and *sciencia de ingeniis*.[52] The reason for this close agreement is easy to find: he could not rely on any scientific activity in this field in his times in Latin.[53] Among all the sciences to which Gundissalinus dedicated a section, the sciences of weights, of devices, and of optics were obviously less known in the Latin west in the 12th century. Even the antique Latin tradition represented by Boece and Isidore of Sevilla could not furnish any useful data for a sustained reflexion on their epistemological status. It must be added also that Gundissalinus seems to ignore all their developments in the Arabic science either, including ThŒbit ibn Qurra's book on the theory of the balance and Ibn al-Haytham's achievements in optics. Hence, the effort of theorization deployed by Gundissalinus, by showing the state of the sciences in the late 12th century in Western Europe, throws light on a considerable underdevelopment in several sciences. This concerns particularly the different branches of mechanics.[54]

[51] It is evident that all these issues need to be treated and instantiated separately and thoroughly, as they document the theoretical components of the new science of weight: see for a first analysis Abattouy 2001b and Abattouy 2002a. The interpretation of the Arabic science of weights as a progress of science is developed in Abattouy 2004a.
[52] Gundissalinus 1903, *De Div. Phil.*, pp. 121-24 and Gundissalinus 1932, *De Scientiis*, pp. 108-112.
[53] It is to be noted that Hughes de Saint Victor who, in his *Didascalicon de studio legendi* , provided the most complete Latin classification of the sciences before the introduction of Arabic learning, just overlooked the two mechanical arts. On the *Didascalicon* see Taylor 1991.
[54] This was noted by Hugonnard-Roche 1984, p. 48. Other Arabic works on the classification of the sciences translated into Latin might

As said before, *Liber karastonis* is the Latin translation by Gerard of Cremona of *KitŒb f¥ 'l-qaras‹´n*. The general structure is the same in both Arabic and Latin versions, and the enunciations of the theorems are identical. Yet the proofs might show greater or lesser discrepancies. None of the Arabic extant copies of ThŒbit's *KitŒb* seem to be the direct model for Gerard's translation. The Latin version was repeatedly copied and distributed in the Latin West until the 17th century, as it is documented by several dozens of extant manuscript copies. This high number of copies instructs on the wide diffusion of the text. Further, the treatise was embedded into the corpus of the science of weights which was understood to be part of the mathematical arts or quadrivium, together with other works on the same topic, in particular the writings of Jordanus Nemorarius in the science of weights.[55] In addition, at least one version of ThŒbit's work was known in Latin learning as a writing of *scientia de ponderibus*. This version is the *Excerptum de libro Thebit de ponderibus*, a Latin text which appears frequently in the codices. It is precisely a digest of the logical structure of *Liber de karastonis*, in the shape of statements of all the theorems.[56]

7. Mechanics in the service of society

This final section will be dedicated to a preliminary overview on the institutional setting of the usage of the balance in medieval Islamic societies. The focus will be laid on a brief description of the role the *úisba* office played in the control of the fabrication and usage of weighing instruments.

The balance most widely used in the Islamic lands of medieval times was the equal-armed platform scale, made mostly in copper. There were tiny balances for gold and jewels, average ones for retail traders, and huge balances for the merchants of grains, wood, wool, etc. In general, the balances had beams and weights made of steel or iron. Steelyards, called *qaras‹´n* or *qabbŒn*, were also widely employed. As reported in a historical source, [57] a site called *Qaras‹´n* existed in the ancient medina in Fez until the early 20th century, probably because of a huge public balance set up there. Public balances are still located today in the *fanŒdiq* (bazaars) of the old medina. One can infer in this context that a similar public weighing site must have been present in all the markets of Islamic cities.

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have been a source for the distinction of the science of weights and its qualification as the theoretical basis of mechanics. For instance, al-GhazŒl¥'s MaqŒ§id al-falŒsifa, translated as Summa theoricae philosophiae by Gundissalinus and Johannes Hispanus in Toledo, and Ibn S¥nŒ's RisŒla f¥ aqsŒm al->ul´m, translated by Andrea Alpago: In Avicennæ philosophi præclarissimi ac medicorum principis, Compendium de anima, De mahad..., Aphorismi de anima, De diffinitionibus et quæsitis, De divisione scientiarum, Venice, 1546, fols 139v-145v.

[55] The Liber karastonis is edited with English translation in Moody and Clagett 1952, pp. 88-117. For more details on its codicological tradition, see Buchner 1922 and Brown 1967.

[56] Brown, 1967, pp. 24-30 and Knorr, 1982, pp. 42-46, 173-80.

[57] Dozy 1927, vol. 2, p. 327.

The *qaras‹´n* or steelyard with a sliding weight was widely used since Antiquity. It is mentioned in Greek sources by its ancient name, the *charistion*, and was employed extensively in Roman times.[58] Composed of a lever or a beam (*›am´d*) suspended by a handle that divides it into two unequal arms, the center of gravity of the instrument is located under the fulcrum. In general the shorter arm bears a basin or a scale-pan in which the object to be weighed is set, or suspended from a hook. The cursor-weight, *rummŒna* in Arabic, moves along the longer arm in order to achieve equilibrium. This arm, which has generally a quadrangular cross section, bears two different scales which are engraved along the two opposite sides. Due to the fact that the steelyard can be suspended by two hooks, there are two independent graduations. According to the choice made, there will be different relations between the lengths of the longer and smaller arms of the lever, corresponding to the different scales. On the beam or near the fulcrum, the number of units or fractions corresponding to the capacity of the balance was engraved as was the official stamp of the authorities. The advantage of the steelyard is that it provides an acceptable precision in weighing and allows heavy loads to be supported by small counterweights. In addition, it can be carried around easily.

Another kind of balance is a combination of the ordinary balance and of the steelyard in the form of an equal-armed balance with mobile weight. A typical example of this instrument is the balance of Archimedes described by al-KhŒzin¥ according to an account by Menelaus.[59] In addition to its two equal arms to which two fixed scale pans are suspended, this balance had on one of the arms a cursor weight which could be hang up on different points of a small scale graduated in two series of divisions. Presented as a hydrostatical balance for the determination of specific gravities, it could also serve for ordinary weighing. A variety of the Archimedes' balance consists in moving the scale pan on a part of the arm. This is the main property of the *m¥zŒn ‹ab¥›¥* (natural or physical balance) designed by Muúammad ibn ZakariyyŒ al-RŒz¥. In this model with equal arms and without counterpoise, one of the scale pans is movable and might behave as a counterweight.

Nowadays, the steelyard balance is called in some Arab countries *al-m¥zŒn al-qabbŒn¥*; in Morocco it is designated as *m¥zŒn al-qura*. Despite more or less sophisticated modern balances being introduced a long time ago (in the first half of the 19th century), the steelyards continue to be utilized in Arab and Islamic countries. They serve in popular markets and are widely used in some activities, such as in the slaughterhouses and in the shops of butchers. In Egypt, the industry of traditional steelyards is still active. Egyptian colleagues informed me that in the old city of Cairo, in an area called *î ay taút al-rub›*, near the *DŒr al-kutub*, not far from the Azhar Mosque, artisans build steelyards according to traditional methods. These balances are used

[58] On the ancient history of the steelyard, see Ibel 1908 and Damerow *et al.* 2002.
[59] Al-KhŒzin¥ 1940, pp. 78-79.

massively throughout the country, for example in the weighing of cotton in the country side. In other Arab countries, the fabrication of these balances disappeared completely. For instance, in Morocco, it vanished several decades ago, as a result of the introduction of modern balances and of the concurrence of the European industry manufacturing these same instruments. Therefore, the steelyards used in the country are imported from Southern Italy and Spain. But local artisans are able to repair the imported engines and to supply certain equipment for them, as I could see by direct observation during my visits to their shops in Fez in 1999 and 2000.

In his geographical book *Aúsan al-taqŒs¥m f¥ ma›rifat al-aqŒl¥m*, Muúammad al-Muqaddas¥, the Palestinian geographer of the 10th century, reports that the most accurate balances were those fabricated at î arrŒn in northern Mesopotamia. K´fa, in southern Iraq, was also famous for the accuracy of its balances. Other regions were celebrated for the honesty of the weighing practices of their merchants, such as KhurŒsŒn. But others were better known for their fraudulent procedures. Various passages in the Qur‹Œn show that as early as the advent of Islam, false balances were in use in the markets. Later narratives report that some jewelers and goldsmiths, in order to fraudulently weigh their wares, blow gently on the scale-pan of their balance, stick a small piece of wax under it, or merely use false weights. Al-Jawbar¥ (fl. 1216-22) described two such arrangements. In the one the beam of the balance consisted of a hollow reed containing quicksilver, which was closed at both ends. By a slight inclination of the beam, the quicksilver could be made to flow as desired to the side with weights or with goods and thus make one or the other appear heavier. In the other case, the tongue of the balance was of iron and the merchant had a ring with a magnetic stone; by bringing the ring close to the balance, it moves down to the right or left.[60]

In order to reprimand these fraudulent tricks and deceitful behavior, and to implement the instructions of Islam about the strict observance of the just weighing, the Islamic society invented a specific institutional setting, represented by the office of *úisba*. This office was occupied by the *muútasib*, an officer regularly appointed to take charge of the harmonization between the commands of Islam and the social practice, especially concerning the control of markets. As such, one of his main duties was to observe that correct scales and weights were used in commercial transactions.

The office of *úisba* was established towards the 2nd century of Hijra as a consequence of the development of large cities and after that the various schools of *fiqh* (jurisprudence) assumed form. With the establishment of the new office, certain text-books began to include chapters dealing with the theory of its functions and their practical application, and in the course of time independent manuals intended to assist the *muútasib* in the performance of his duties were

[60] Al-Jawbar¥ 1979-80, vol. 2, p. 162. Similar fraudulent practices are described in detail in the books of *úisba*: for references to the *úisba* literature relevant to the balances and weights knowledge, see Abattouy [Forthcoming 2006b].

written. Among these text-books, the best known are *NihŒyat al-rutba f¥ ‹alab al-úisba* by ›Abd-al-Rahman al-Shayzar¥ (d. 589/1193), and *Ma›Œlim al-qurbŒ f¥ aúkŒm al-úisba*, by ëiyyŒ‹ al-D¥n al-Qurash¥, known as Ibn al-Ukhuwwa (d. 729/1329). The manuals for the guidance of the *muútasib* are an important source for the reconstruction of the social structures within which the making and the use of the balances and weights were organized and regulated in medieval Islam.

The *muútasib* was in charge of the morality, integrity, and quality of the various trades, but his main duty, the basic and permanent one, was to watch over and to supervise the balances and weights. In his *NihŒyat al-rutba f¥ ‹alab al-úisba* (The utmost authority in the pursuit of *úisba*), the earliest extant book of its kind to appear in the Islamic East, al-Shayzar¥ defines as follows the duties of the *muútasib* in this domain:

> *The most accurate scale is that in which the two sides are equal, the pans are balanced and the hole for the attachment on either side of the centre of the beam is one third of the thickness of the attachment. The hole should be one third of the way under the peg of the attachment, and two thirds above it. This allows for the inclination of the scales by taking the tongue of the balance out of the beam of the attachment, and the pan will descend with the slightest weight (…). The peg might be square, triangular or round. The best is the triangular one because it inclines with more sensitivity than the others.*
>
> *The* muútasib *must order those who use scales to wipe and clean them hourly of any oil or dirt, as a drop of oil may congeal on them and affect the weights. The merchant must settle the scales before he begins to weigh and should place the merchandise on them gently, not dropping it into the pan from his raised hand, nor moving the edge of the pan with his thumb, as all of this is fraudulent…*
>
> *The merchant should acquire* ra‹l-s *and* awqiyya-s *made of iron and test their accuracy against the standard weights. He must not use stone ones, as these chips when they knock against each other and thus become inaccurate. If stone weights have to be used because iron ones are unavailable, then the* muútasib *must order the merchant to bind them with leather and he must stamp them after testing their accuracy. He should re-examine them now and again in case the merchant has replaced them with wooden weights which look the same.*[61]

In the 13th-century Fatimid Cairo, the fabrication as well as the control of the balances and weights was undertaken within a specific institution, the *DŒr al-›iyyŒr*, itself under the supervision of the *muútasib*. In his *al-MawŒ›i½ wa 'l-‹i›tibŒr f¥ dhikr el-khi‹a‹ wal-ŒthŒr*, al-Maqr¥z¥ (1364-1442) provides a valuable report about this institution and shows in a new light the duties of the *muútasib* in the regulation of balances and weights:

61 Al-Shayzar¥ 1999, pp. 43-44. The same instructions are in Ibn al-Ukhuwwa 1938, pp. 80 ff. and in other manuals of úisba: see ZiyyŒda 1962 and Izzi Dien 1997.

> *The* muútasib *inspects the* DŒr al->iyyŒr*… The standard measures were in a place known as the* DŒr al->iyyŒr *in which the accuracy of all the parts of scales and all the weights were checked. He used to pay the costs of this* DŒr*, and whatever was needed of copper, steel, wood, glass and other apparatus, and the wages of the workmen, overseers and such like, from the government administration. The* muútasib *and his deputies would go there to check in his presence the accuracy of what was produced in it. If it was correct, he endorsed it, and if not then he ordered that it should be re-made until it was correct. In this* DŒr *were specimens with which he corrected the standard measure; for the weights, scales and measures would not be sold except from this* DŒr*. All the merchants would go to this* DŒr *upon the* muútasib*'s summoning them, bringing their scales, weights and measures to be tested every so often. If a deficiency was found then the [scale, etc.] was destroyed and its owner was taken to the* DŒr *and compelled to purchase a replacement from that which was accurately manufactured there, and to pay its price. Then he is forgiven. (…) This* DŒr *still remains in all of the Fatimid states. When* SalŒú al-D¥n *took over the government he confirmed this* DŒr *… and it still remains.*[62]

According to this report, the *DŒr al->iyyŒr* was in fact the factory where legal balances and weights were fabricated and tested under the control of the *muútasib* and his collaborators. It also comprised the office in which the standard weights were kept. The merchants had to test their usual weights against these legal weights. In the light of this report, it becomes clear therefore why the authors of the Ayyubid, Mamluk and Ottoman Egypt and Syria were so prolific in the composition of technical treatises on the construction of balances, especially of the steelyard type, and on their reparation and testing. There was a strong social demand on them.

The *DŒr al->iyyŒr*, the *úisba* office and similar other institutions provided the Islamic society with the institutional setting for the control of the balances, weights, and measures. These institutions must have been connected in one way or another to the scientific and technical activities shaped by the scientists involved in what we called the science of weights. Indeed, the scientific discoveries and the technical improvements must have provided the controllers of scales and weights with the knowledge and expertise to accomplish their task. In fact, it is easy to demonstrate that the large amount of texts on different sorts of balance written in Arabic between the 9th and the 19th centuries were not intended to remain solely in the circle of scientists. At least a substantial part of them was surely addressed to practitioners and artisans, and to the state officials overseeing the markets. This is another instance of the connection between science and society in medieval Islam which deserves closer investigation.[63]

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[62] Quoted in Buckley 1992, p. 86.

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