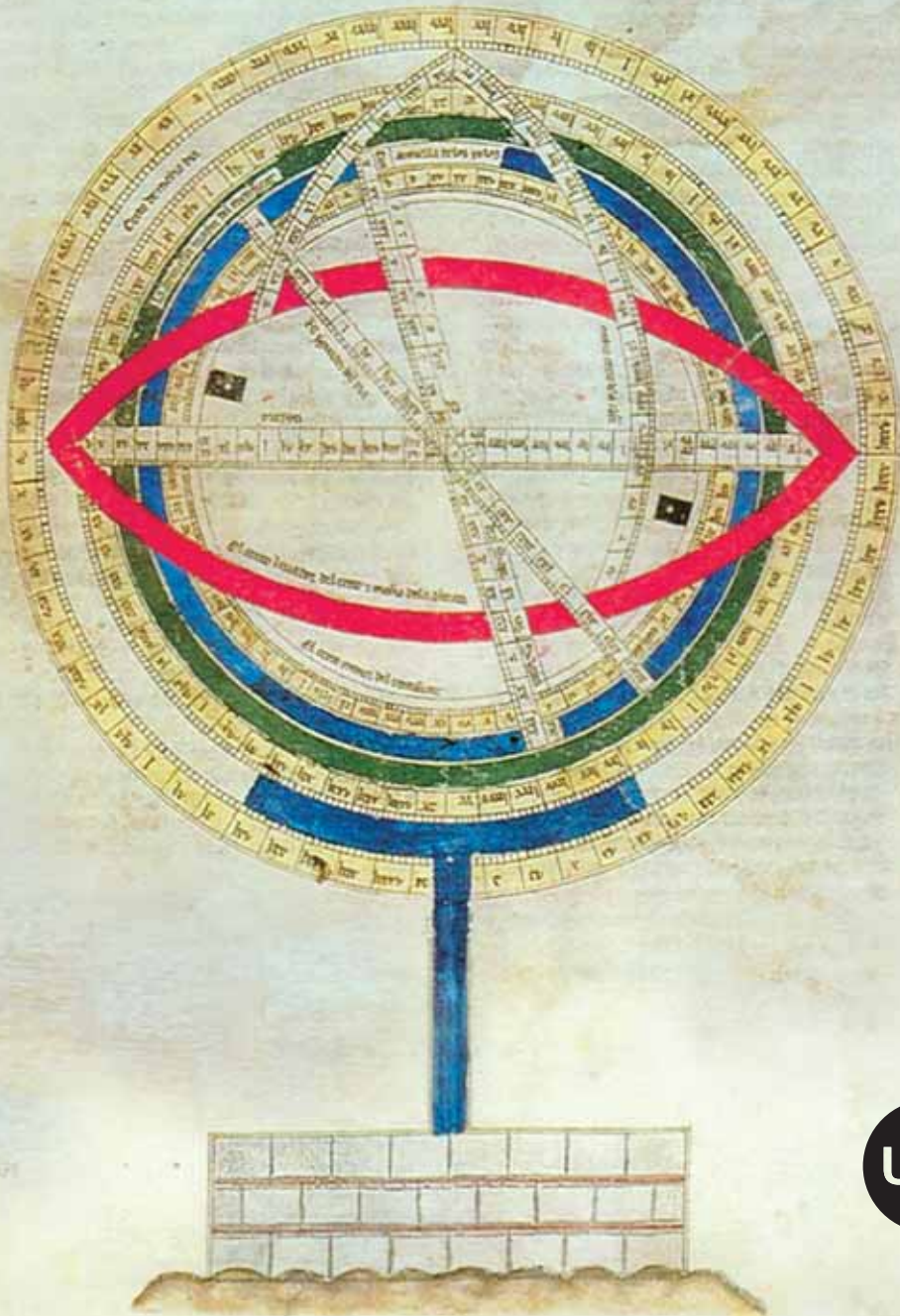


A SHARED LEGACY

Islamic Science East and West



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A SHARED LEGACY

Islamic Science East and West

Homage to professor
J. M. Millàs Vallicrosa

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Foreword

Julio Samsó

The 9th International Congress of History of Science took place in September 1959 in Barcelona and Madrid. At that time the organiser of the conference was my master Prof. Juan Vernet. The amount of work implied was so heavy that Vernet had a heart attack. This is why I decided that I would never become involved in the organisation of an international conference. This is also why my daughters in the spirit (Mercè Comes, Roser Puig, Emilia Calvo and Mònica Rius), with the very active help of the graduate students of our Department (Elia Romo, Glòria Sabaté and Marc Oliveras), were the ones responsible of *A Shared Legacy. Islamic Science East and West*, probably the most important international meeting on the history of medieval science held in Barcelona since 1959. The conference was also organised as an homage to Prof. J.M. Millàs Vallicrosa on the occasion of the 75th + 1 anniversary of the publication of his most important book: the *Assaig d'història de les idees físiques i matemàtiques a la Catalunya Medieval* (Barcelona, 1931).

Among the important absences in the congress I would like to mention those of E.S. Kennedy, Juan Vernet, David King, John North and Bernard Goldstein. David has, however, contributed to this volume with a brilliant state of the art of his life-time study of Islamic astronomical instruments. Other most important states of the art, presented by great masters, were those by Paul Kunitzsch (on translations and transmissions) and George Saliba, who succeeded in opening new ways to explain the process of the “obscure” transmission of the new planetary models, designed in and after Marāgha, to Copernicus and his contemporaries: to the possible Byzantine transmission suggested by Otto Neugebauer, we have to add now the importance of early European arabists like Guillaume Postel or the arrival to Italy in 1577 of the Jacobite patriarch Ighnāṭiyūs Nī‘matallāh. This has

become an important new hypothesis which should be explored in the future.

This has also been the conference of a most ambitious new project: that of ISMI (Islamic Scientific Manuscripts Initiative), a brilliant idea developed by Jamil and Sally Ragep. I believe the time of encyclopedic works written by individual authors (Suter, Brockelmann, Sarton, Sezgin, Rosenfeld) has reached an end and international cooperation is necessary for such enterprises. The problem is how many generations of scholars will be needed to finish a project like ISMI?. Will future generations find people like Jamil and Sally willing to push such a heavy vehicle? On a more limited level, I would like to remind here an analogous collective Spanish enterprise: that of the *Enciclopedia de al-Andalus*, of which three big volumes have already appeared and which is going to be the great reference work on Andalusī culture, which obviously includes the history of science.

The papers presented at the conference deal with a mixture of subjects, use different methodologies and different languages are involved (Arabic, Persian, but also Greek and Latin, among others). We have, however, found similar problems and common interests which prove the unity of the discipline in spite of its variety. During the conference, we all paid attention to other people's problems and did our best to try to contribute to their solution. Topics raised in the conference went from textual studies trying to recover truncated texts important for the transmission of Euclid's *Elements* to theoretical analysis of the criticisms to Ptolemaic astronomy in a 12th century Andalusī author. Medicine was also present including such uncommon subjects as the medicine of the soul. More unusual were papers dealing with Aristotelian meteorology or cartography, a discipline which knew a very important development in the Western Mediterranean in an atmosphere in which it is really difficult to establish limits between knowledge born in the Iberian Peninsula, the Balearic Islands, Italy and the Maghrib. This is a scientific discipline which crosses easily the borders of different cultures, probably due to the fact that language difficulties had little importance. Cartography is possibly the best example we can give of a shared legacy.

On the whole, something has attracted everybody's attention: a growing interest in the social aspects of the history of our disciplines. David King explained to me, about twenty-five years ago, how he had discovered that the study of *mīqāt* was the bulk of what could really be called an Islamic contribution to Astronomy and how this concern promoted the design of new instruments mainly applied to timekeeping. We have all complained of the lack of information about the lives of our scientists due to the fact

that the authors of biographical dictionaries did not consider them to have the same interest as those of experts in *fiqh* or transmitters of *ḥadīth*. The exception we always had in mind was that of physicians and it was clear that a history of the medical profession was more feasible than that of the practitioners of other scientific disciplines. It was a surprise for me to discover the amount of information on *muwaqqits* and *mu'adhdhins* available in the work of Shams al-Dīn al-Sakhāwī, something that we cannot find in Andalusī biographical sources. This, in spite of the fact that there was, in al-Andalus, a clear interest in astronomical instruments which always had an application to timekeeping. Technology is another kind of scientific discipline having a great social importance and was dealt with in our conference from very different points of view: theoretical studies on Mechanics, analysis of sources dealing with recreational machinery (*ʿilm al-ḥiyal*), or the gathering of information extant in literary sources about hydraulic machines, the development of industry in the pre-industrial age and other aspects of science. On the whole we all agreed that there were a series of centuries and cultures completely forgotten by standard eurocentric historical research.

The conference ended with a session in honour of Prof. Millàs-Vallicrosa, precisely the scholar whose scientific contributions became the starting point of the Barcelona school of history of Arabic science. Its members, together with the Commission on the History of Science and Technology in Islamic Societies and the Societat Catalana d'Història de la Ciència i de la Tècnica of the Institut d'Estudis Catalans were the organisers of this international meeting, which was the first to be held by the Commission independently from the symposia usually organised in the frame of the International Congresses of History of Science. I hope that this example will be followed in the future.

The Arabic Science of Weights (*ʿilm al-Athqāl*): Textual Tradition and Significance in the History of Mechanics^{*}

Mohammed Abattouy

The following article will be devoted to two main concerns:

1. The description of the textual tradition of the Arabic corpus of the science of weights (*ʿilm al-athqāl*), a tradition of scientific and technical treatises reconstituted from manuscripts, most of which were never published before. The components of this corpus, amounting to more than thirty texts, cover the whole range of scientific activity in Islamic lands from the 9th through the 19th centuries. This group of text is unified by a common theme: the spectrum of theoretical and practical problems related to the description, the functioning and the use of various types of balances, and especially of the steelyard, the balance with calibrated beam, unequal arms and moving weights.

2. The interpretation of the Arabic corpus of the science of weights as a transformation in the history of mechanics. Such a transformation was represented by the creation of an independent theoretical branch that evolved from ancient contributions and nourished physical debates until the advent of modern science on the problems of equilibrium and the properties of weighing operations. As a result, *ʿilm al-athqāl* should no

^{*} My work on Arabic mechanics began in the context of an interdisciplinary project on the history of mechanical thinking sponsored between 1996 and 2003 by the Max Planck Institute for the History of Science in Berlin. An earlier version of the present article was published in Abattouy 2002b. This version was reworked and published as Abattouy 2007b. Different aspects of the research on the Arabic science of weights by the author are exposed in his other publications: see the references below in the bibliography section; a large array of resources on Arabic mechanics are available in Abattouy 2007d, section 5, pp. 131-149.

more be confused with *ʿilm al-ḥiyāl*, understood as a general descriptive discourse on different types of machines.

Such an understanding of the historical significance of the Arabic science of weights brings about an important result, in the sense that this tradition was connected with the next important phase of the history of mechanics. Indeed, beyond cultural and linguistic boundaries, the Arabic science of weights afforded a foundation for the Latin *scientia de ponderibus* that emerged in medieval Europe from the 13th century.

1. The balance: instrument of the 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 *mīzān*, *ṭayyār*, and *shāhīn*), the steelyard (called *qarastūn*, *qaffān*, and *qabbān*) and sophisticated balances for weighing absolute and specific weights of substances.

Several drawings of balances are preserved in Arabic manuscripts, such as those of al-Khāzinī, al-Ḥarīrī, and al-Qazwīnī. Further, some specimens of the ancient balances survived and are presently kept in museums. For instance, the National Museum in Kuwait (item LNS 65 M) held an Islamic steelyard built in Iran between the 10th and the 12th centuries (fig. 1). It is an instrument made of inlaid engraved steel, with marks on its beam. Its dimensions (height: 11.5 cm, length: 15.6 cm) show that it was used for weighing small quantities.¹ Two significant steelyards are owned by the Petrie Museum (University College, London). One of them (accession number Inv. 1935-457) is a huge balance (fig. 2). 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 *raṭl*-s (1 *raṭl* is approximately 1 pound); the other ranging from 900 to 1820 *raṭl*-s.²

¹ This balance is described in al-Ṣabāḥ 1989, p. 32 and in Vaudour 1996, p. 88.

² It is described in Skinner 1967, p. 87 and in Knorr 1982, p. 118, plate 11.

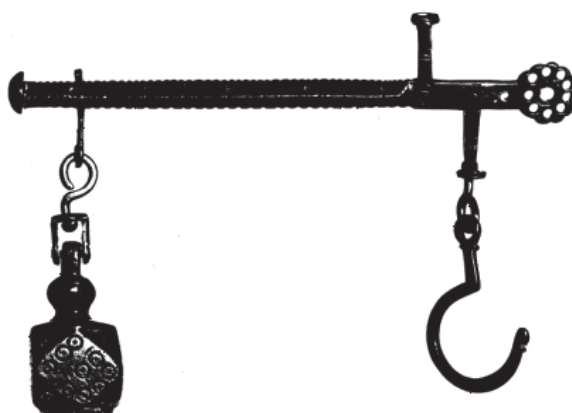


Fig. 1 Islamic steelyard from Iran
kept in the National Museum, Kuwait City.



Fig. 2 Islamic steelyard in Petrie Museum, London.

The interest in the balance in Islamic scientific learning was culturally nurtured by its role as a symbol of good morals and justice. The Qur'ān and the ḥadīth appealed extensively to a strict observance of fair and accurate weighing practices with the balance. Considered the tongue of justice and a direct gift of God, the balance was made a pillar of the right

society and a tool of good governance. These principles were recorded explicitly in several treatises on the balance, such as the introduction to *Kitāb mīzān al-ḥikma* by al-Khāzinī, where the balance is qualified as “the tongue of justice and the article of mediation.” Furthermore, it was counted as a fundamental factor of justice, on the same level with “the glorious Book of God,” and “the guided leaders and established savants.”³

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 *qarastūn* or *qabbān*, were also widely employed. As reported in a historical source,⁴ a site called *Qarastūn* 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 *fanādiq* (bazaars) of the old medina. One can infer from in this context that a similar public weighing site must have been present in all the markets of Islamic cities.

The *qarastūn* or steelyard with a sliding weight was largely used since Antiquity. It is mentioned in Greek sources by its ancient name, the *chariston*, and was employed extensively in Roman times.⁵ Composed of a lever or a beam (*‘amūd*) 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, *rummāna* 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.

³ Al-Khāzinī 1940, pp. 3-4.

⁴ Dozy 1927, vol. 2, p. 327.

⁵ On the ancient history of the steelyard, see Ibel 1908 and Damerow *et al.* 2002.



Fig. 3 Maghribi balance

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 variety of it is the Maghribi balance presented in fig. 3.⁶ Further, a typical example of such an instrument is the balance of Archimedes described by al-Khāzinī according to an account by Menelaus (fig. 4).⁷ 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

⁶ Described in Abattouy 2003a, pp. 105-109

⁷ Al-Khāzinī 1940, pp. 78-79.

arm. This is the main property of the *mīzān ṭabīʿī* (natural or physical balance) designed by Muḥammad ibn Zakariyyā al-Rāzī. In this model with equal arms and without counterpoise, one of the scale pans is movable and might behave as a counterweight.

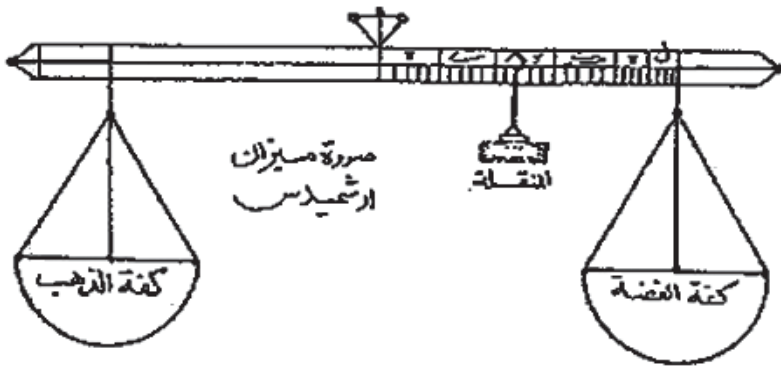


Fig. 4 The balance attributed to Archimedes

Nowadays, the steelyard balance is called in some Arab countries *al-mīzān al-qabbānī*; in Morocco it is designated as *mīzān al-qura*. Despite the introduction of modern balances more or less sophisticated, since 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 *ḥay taḥt al-rubʿ*, near the *Dār al-kutub*, not far from the Azhar Mosque, artisans build steelyards according to traditional methods. These balances are used massively throughout the country, for example in the weighing of cotton in the country side. In other Arab countries, the fabrication of these balance disappeared completely. For instance, in Morocco, it vanished since several decades, as a result of the introduction of modern balances and of the concurrence of the European industry of 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 balances and to supply certain of their equipments, as I could see by direct observation during my visits to their shops in Fez in the recent period.

In his geographical book *Aḥsan al-taqāsīm fī maʿrifat al-aqālīm*, Muḥammad al-Muqaddasī, the Palestinian geographer of the 10th century,

reports that the most accurate balances were those fabricated at Ḥarrān in northern Mesopotamia. Kūfa, 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 Khurāsān. But others were better known for their fraudulent procedures. Various passages in the Qurʾān show that as early as the advent of Islam, false balances were in use in the markets. Later narratives report that some jewellers 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-Jawbarī (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.⁸

In order to reprimand these fraudulent tricks and deceitful behaviour, 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 *ḥisba*. This office was occupied by the *muḥtasib*, 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.⁹

2. The corpus of science of weights

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 mechanics 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

⁸ Al-Jawbarī 1979-80, vol. 2, p. 162.

⁹ A preliminary study of the interaction of the *ḥisba* institution with the science of weights may be found in Abattouy 2002b, pp. 124-126; 2004b; 2007b, pp. 72-75.

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-Raḥmān al-Khāzinī, around 1120, of *Kitāb mizān al-ḥikma*, an encyclopaedia 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 (fig. 5).

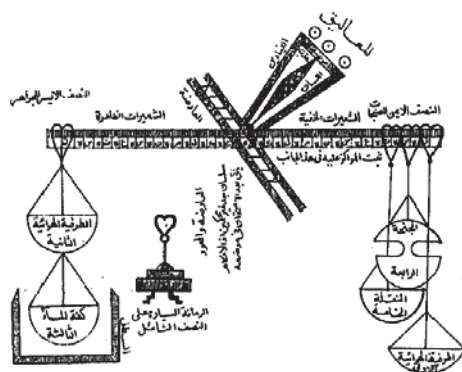


Fig. 5 Picture of the balance of wisdom (al-Khāzinī 1940, p. 103)

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 half of the 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.

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 was 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. Up to now 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 has never before been edited or studied, and only exists 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 a 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.

3. 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-ḥiyyal*, 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-ḥiyyal* (Elements / Extracts of Mechanics) included by al-Khāzinī in the fifth book of his *Kitāb mīzān al-ḥikma*.¹⁰

2-3. Two texts ascribed to Euclid on the balance (*Maqāla fī l-mīzān*) and on heaviness and lightness (*Kitāb fī l-thiql wa-l-khiffa*): Extant only in Arabic, the first one provides a geometrical treatment of the balance and presents a sophisticated demonstration of the law of the lever. It is not recorded if 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 Thābit 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.¹¹

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 *Maqāla fī l-thiql wa-l-khiffa*, extant in Arabic in several manuscript copies. This short tract

¹⁰ Al-Khāzinī 1940, pp. 99-100. The text of the *Nutaf* was edited and translated, with commentaries, in Abattouy 2001a.

¹¹ The contents of these two works are surveyed in Abattouy 2001b, p. 216 ff. On the textual tradition of *Maqāla fī l-mīzān*, see Abattouy 2004c and 2007a.

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.¹²

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 Qusṭā ibn Lūqā under the title *Fī raf' al-ashyā' al-thaqīla* (On Lifting Heavy Loads).¹³ After the loss of the Greek original text, it survived only in this Arabic version. On the contrary of Heron's *Mechanics*, Pappus mechanical treatise was preserved in Greek and in Arabic. Its Arabic version is titled *Madkhal ilā 'ilm al-ḥiyal* (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.¹⁴

4. 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 *Kitāb fī l-qarastūn* by Thābit 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.

Kitāb fī l-qarastūn 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

¹² A MS copy of this text was published in Zotenberg 1879 and translated into English in Clagett 1959, pp. 52-55.

¹³ 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.

¹⁴ The Arabic text of Pappus' *Mechanics* was transcribed and translated into English in Jackson 1970.

London (India Office MS 767-7) and Beirut (St. Joseph Library, MS 223-11), were studied and published recently.¹⁵ The third copy, formerly conserved in Berlin (Staatsbibliothek MS 559/9, ff. 218b-224a), was reported lost at the end of World War II. 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 over 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 Thābit's treatise. This part of the text exposes the dynamic foundation of the treatise and an important passage that was thought of up to now to occur only in Beirut MS copy (and thus known as Beirut scholium).¹⁶

8. *Kitāb fī ṣifat al-wazn* by the same Thābit 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.¹⁷ An important connection between this text and *Kitāb fī l-qarastūn* is provided by the occurrence, in the last section of *Ṣifat al-wazn*, of the statement of a proposition identical with the postulate that opens *Kitāb fī l-qarastūn*.

9. *Ziyyāda fī l-qarastūn* or An Addition on the theory of the *qarastūn*: A short anonymous text extant in a unicum copy preserved in Beirut. In this codex, the *Ziyyāda* serves as an appendix to *Kitāb fī l-qarastūn*. 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. Thābit ibn Qurra is mentioned twice in the *Ziyyāda*. This and several other elements induce us to consider it as an appendix intended to amplify the analysis developed in Thābit's original work. The text of the *Ziyyāda* is composed of five propositions. The first two are mere applications of the Proposition VI of *Kitāb fī l-qarastūn* 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 Muḥammad ibn 'Abd-Allāh b. Maṣṣūr al-Ahwāzī: al-Ahwāzī is a mathematician of the 10th century; his text is extant in a unique copy preserved in Khuda Baksh Library in Patna

¹⁵ Respectively in Jaouiche 1976 and Knorr 1982.

¹⁶ The mechanical theory of *Kitāb fī l-qarastūn* was studied in Jaouiche 1976, Abattouy 2000d, and Abattouy 2002a.

¹⁷ This text was preserved thanks to its integration in *Kitāb mizān al-ḥikma*: al-Khāzinī 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.

(Codex 2928, folio 31) without title, save for the one provided by the curators of the library: *Risāla fī l-mīzān*.¹⁸

11. The treatises on centers of gravity of al-Qūhī and Ibn al-Haytham: These important contributions by two most important Muslim mathematicians of the 10th-11th centuries survived only through their reproduction by al-Khāzinī in a joint abridged version that opens the first book of his *Kitāb mīzān al-ḥikma*.¹⁹ The potential discovery of the complete versions of these texts will mean the recovery of fundamental sources.²⁰

12. The statements on the law of the lever by the same al-Qūhī included in a discussion on the centers of gravity he had with Abū Ishāq al-Ṣābī around 990-91.²¹

13. The treatise of ʿĪlyā al-Maṭrān on measures and weights: ʿĪlyā al-Maṭrān was the Archbishop of Nisibin (north Mesopotamia) in the first half of the 11th century. His *Maqāla fī l-makāyyīl wa-l-awzān* (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.²²

14. *Irshād dhawī al-ʿirfān ilā ṣināʿat al-qaffān* (Guiding the Learned Men in the Art of the Steelyard) by al-Isfīzārī: A fundamental and long-neglected treatise, written by Abū Ḥātim al-Muṣaffār b. Ismāʿīl al-Isfīzārī, a mathematician and mechanician who flourished in Khurāsān (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-Ẓāhiriyya collection, MS 4460, folii 16a-24a). In addition, an abridged version reproduced by al-Khāzinī includes a section on the construction and use of the steelyard, which is omitted from the Damascus manuscript.²³

15. *Kitāb mīzān al-ḥikma* by al-Khāzinī: A special mention should be made of *Kitāb fī mīzān al-ḥikma*, the encyclopedia of mechanics completed by al-Khāzinī in 1121-22, a real mine of information on all aspects of the theoretical and practical knowledge in the Islamic medieval

¹⁸ On al-Ahwāzī, see Sezgin 1974, p. 312.

¹⁹ Al-Khāzinī 1940, pp. 15-20.

²⁰ In his catalogue of Arabic manuscripts, Paul Sbath mentioned that there was a copy of Ibn al-Haytham's *Maqāla fī l-qarastūn* in a private collection in Aleppo in Syria. This *Maqāla* may be Ibn al-Haytham's treatise on centers of gravity: See Sbath 1938-1940, part 1, p. 86. For textual considerations on the treatise of al-Qūhī, see Bancel 2001.

²¹ The correspondence was edited and translated into English in Berggren 1983.

²² On ʿĪlyā al-Maṭrān, see Abattouy 2005a.

²³ Al-Khāzinī 1940, pp. 39-45. Al-Isfīzārī's biography and the contents of his *Irshād* are surveyed in Abattouy 2000b and Abattouy 2001b.

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.²⁴

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 Muḥammad Ibn Zakariyyā al-Rāzī (865-923) on the natural balance,²⁵ extracts from texts on weights by Qusṭā ibn Lūqā and Ishāq ibn Ḥunayn,²⁶ Ibn al-Haytham's largely expanded recension of Menelaus' (fl. Alexandria, 1st century) text on specific gravities,²⁷ and two writings on specific gravity and the hydrostatical balance by 'Umar al-Khayyām.²⁸

5. 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 century and originating principally from Egypt and Syria. These two countries were unified during this long period by the Ayyubid, Mameluk, and Ottoman dynasties, respectively, and they constituted for centuries a unified economic and cultural space. Whence the *raison d'être* of this large amount of writings on the theoretical and practical problems of the balance and weights, since it 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.

16. *Masā'il fī l-mawāzīn* (Problems on Balances) by Ya'īsh b. Ibrāhīm al-Umawī: 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.²⁹ His *Masā'il* consists in a small collection of

²⁴ On al-Khāzinī and his work, see Hall 1981, Abattouy 2000a, and Abattouy 2007c.

²⁵ Reproduced in an abridged version by al-Khāzinī 1940, pp. 83-86.

²⁶ These texts are preserved in Aya Sofya Library in Istanbul, Codex 3711.

²⁷ Obviously extant in a unique manuscript discovered in Lahore in 1979 by Anton Heinen: see Heinen 1983.

²⁸ Both edited in al-Khāzinī 1940, pp. 87-92, 151-153. On al-Khayyām's mechanics, see Aghayani Chavoshi and Bancel 2000, and Abattouy 2005b.

²⁹ On al-Umawī, see Sa'īdān 1981.

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. *Risāla fī ʿamal al-mīzān al-ṭabīʿī* by Taqī al-Dīn ibn Maʿrūf: The author is a well known mathematician, astronomer, and mechanic (born in Damascus in 1525, died in Istanbul in 1585). His short treatise on making the natural balance describes what was transmitted to Taqī al-Dīn of a previous writing on the balance that he ascribes to the mathematician Ghiyyāth al-Dīn al-Kāshī (died in Samarkand in 1429). It is part of the collections of the municipal library of Alexandria.

18. *ʿAmal mīzān li-ṣarf al-dhahab min ghayr ṣanj* (The Construction of a Balance to Convert Gold without Standard Weight) by Abū l-ʿAbbās Aḥmad b. Abī Bakr b. ʿAlī ibn al-Sarrāj. The author, who was alive around 714 H (1319-20) and 748 H (1347-8), was the most important specialist of astronomical instrumentation in the Mamluk period.³⁰ His short text is the sixth item of the codex MR 30 conserved in the Egyptian National Library in Cairo.

The Egyptian astronomer Muḥammad ibn Abī l-Faṭḥ al-Šūfī (d. 1543) composed several treatises on the theory and the practice of the steelyard balance which enjoyed a wide diffusion. Al-Šūfī seems to be the last representative of the classical Arabic tradition of works on balances and weights. With him, this tradition arrives at an end, in the same time when pre-classical physics in Europe was operating a deep transformation that will finally integrate the science of weights in 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 the centuries:

19. *Risāla fī ṣināʿat al-qabbān* (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. *Irshād al-wazzān li-maʿrifat al-awzān bi-l-qabbān* (Guide to the Weigher in the Knowledge of the Weights of the Steelyard): similar to the previous text;

21. *Risāla fī qismat al-qabbān* (Treatise on the Division of the Steelyard): contains arithmetical and geometrical problems on the calculation of the parts of the steelyard;

³⁰ See on Ibn al-Sarrāj King 1987 and Charette 2003.

22. *Risāla fī iṣlāḥ fasād al-qabbān* (Treatise on Repairing the Defectuousness 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-zamān fī ṣināʿat al-qabbān*: a short text on the steelyard by ʿUthmān b. ʿAlāʾ al-Dīn al-Dimashqī, known as Ibn al-Malik (fl. 1589);

24. *Risālat al-jawāhir fī ʿilm al-qabbān* (Treatise of Jewels in the Science of the Steelyard): a ten-chapter text written by Khidr al-Burlusī al-Qabbānī (d. in 1672).

25. Two writings on the “science” (*ʿilm*) and the “description” (*taʾrīf*) of the steelyard by ʿAbd al-Majīd al-Sāmūlī (18th century);

26. *Al-ʿIqd al-thamīn fī mā yataʿallaq bi-l-mawāzīn* (The High Priced Necklace in What Concerns the Balances), a systematic treatise on the balance and weights, by Ḥasan al-Jabartī (1698-1774);

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

28. *Risāla fī l-qabbān* by Muḥammad b. al-Ḥusayn al-ʿAṭṭār (d. 1819), a Syrian author, is among the very last works written in Arabic in the style of the earlier mechanical tradition.³¹

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-qawānīn fī ṣifat al-qabbān wa-l-mawāzīn* (The Laws in the Description of the Steelyard and the Balances) existing in Codex TR 279, ff. 1-62 in the Cairote Dār al-kutub.

30. Then a short text, *Bāb fī maʾrifat ʿamal al-qabbān* (Chapter in the Knowledge of Making the Steelyard) (Cairo, Dār al-kutub, MS K3831/1, and MS RT 108/1).

³¹ 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 the construction of the steelyard, and the conversion of weights between countries. Chapter 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 National Library, Zāhiriyya collection, MS 4297; Aleppo, al-Aḥmadiyya Lib., al-Maktaba al-waqfiyya, MS 1787; Rabat, National Library, MS D 1954.

31. An untitled tract which the beginning is: “*hādhihi risāla fī ʿilm al-qabbān*” (Cairo, Dār al-kutub, in the same MS K3831).

32. And finally two short tracts (*Risāla mukhtaṣara fī ʿilm al-qabbān* and *Risāla fī ʿilm ṣināʿat al-qabbān*) preserved in Damascus (National Library, al-Ẓāhiriyya Collection, MS 4).³²

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 will undoubtedly change our appreciation of the historical significance of Arabic science and of its place in the general history of science and culture.

6. The status of the science of weights (*ʿilm al-athqāl*)

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, 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.

³² 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-qarastūn* (The secrets or the properties of the steelyard) which is ascribed to Thābit 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.

The emergence of the Arabic science of weights has been proclaimed by al-Fārābī (ca. 870-950) in his *Ihṣā' al-'ulūm*, 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-Fārābī differentiated in his system between six principal sciences: those of language, logic, mathematics, nature, metaphysics and politics. The mathematics are subdivided into seven disciplines: arithmetics, geometry, perspective, astronomy, music, the science of weights (*'ilm al-athqāl*) and the science of devices or machines (*'ilm al-ḥiyyal*). 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 (*umūr al-qawl fī l-mawāzīn*), 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 (*uṣūl al-ālāt*) 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.”³³

Considering the two main branches of mechanics as genuine mathematical sciences, al-Fārābī located their objects respectively in the study of weights and machines. Hence, *'ilm al-athqāl* is centered on the principles of the balances and of lifts, investigated with reference to measure and motion, whereas *'ilm al-ḥiyyal* is conceived of as the application to natural bodies of mathematical properties (lines, surfaces, volumes, and numbers). As such, it includes various practical 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.³⁴

³³ Al-Fārābī 1949, pp. 88-89.

³⁴ *Ḥiyyal* (sing. *ḥīla*) 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 semantic affinities between *mechanê* and *ḥīla*, see Abattouy 2000c.

In this context, the main function of *ʿilm al-ḥiyyal* consists in bringing the geometrical properties from potentiality (*quwwa*) to actuality (*fiʿl*) and to apply them to real bodies by means of special engines (*bi-l-ṣanʿa*).³⁵ Developing an Aristotelian thesis,³⁶ al-Fārābī 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 *ʿilm al-athqāl*. 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-Fārābī 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-Fārābī's theory. The emphasis laid by the Second Master on *ʿilm al-athqāl* can not be stressed enough. It means no less than a solemn announcement of the emergence of an independent science of weights. With roots in the long tradition of the ancient mechanics, this new discipline came to light in the second half of the 9th century in the works of Thābit ibn Qurra and his colleagues in Arabic science.³⁷ It is this important scientific achievement that was recorded by al-Fārābī while building his system of knowledge.

Al-Fārābī's thesis had a long-lasting resonance in Arabic learning and was never challenged seriously. 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. Hereinafter, some of these instances are presented in chronological order.

In his *Risāla fī aqṣām al-ʿulūm al-ʿaqliyya* (Epistle on the Parts of Rational Sciences), Ibn Sīnā (980-1037) enumerated the mechanical arts, considered as 'secondary constituents' of geometry, as *ʿilm al-ḥiyyal al-mutaḥarrika* (the science of movable machines, i.e., automata),³⁸ the pulling of weights (*jarr al-athqāl*), the science of weights and balances (*ʿilm al-awzān wa al-mawāzīn*), and the 'science of particular machines'

³⁵ In the Arabic partial version of Pseudo-Aristotle's *Mechanical Problems*, this very function of the *ḥiyyal* is said to be carried out with artificial devices (*ḥiyyal ṣināʿiyya*): see the edition of the *Nuṭaf min al-ḥiyyal* in Abattouy 2001a, pp. 110, 113 and Aristotle 1952, 847a 25-30. The function of *ʿilm al-ḥiyyal* as actualization of potentialities is surveyed in Saliba 1985.

³⁶ *Metaphysics* XIII.3, 1078 a 14-16.

³⁷ The thesis of the birth of the Arabic science of weights was first formulated in Abattouy, Renn and Weinig 2001.

³⁸ That *al-ālāt al-mutaḥarrika* refers to automata is established in Abattouy 2000c, pp. 139-140.

(*‘ilm al-ālāt al-juz’iyya*).³⁹ Ibn Sīnā 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-Fārābī, is assigned as a specific branch of geometry. The main point, however, in Ibn Sīnā’s schema is the emphasis laid on the science of *awzān* and *mawāzīn* in which weights and balances are combined. The reference to the *wazn* instead of the *thiqal* could be interpreted as a privilege given to the statical standpoint. Indeed, the *wazn* is a constant quantity measurable in a balance, whereas the *thiqal* 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.⁴⁰

In his discussion on the divisions of sciences in *Maqāṣid al-falāsifa* (The Intentions of philosophers), al-Ghazālī (1058-1111) subsumed the science of weights (*‘ilm al-athqāl*) as an independent branch under the mathematical arts and differentiates it from the study of ingenious devices (*‘ilm al-ḥiyyal*).⁴¹ Ibn Rashīq, a Moroccan mathematician of the late 13th century, 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-athqāl wa-l-mawāzīn wa-l-majānīq*) deals with the downward motion of heavy bodies and constitutes the foundation of the science of machines (*wa-yatarattab ‘alā ‘ilm al-athqāl ‘ilm al-ḥiyyal*).⁴² In his biography of al-Isfizārī, al-Bayhaqī did not confuse the two when he reported that al-Isfizārī “was mostly inclined to astronomy and to the science of weights and machines (*‘ilm al-athqāl wa-l-ḥiyyal*).”⁴³ This corresponds to what we know of his extant works in mechanics, the *Irshād* being clearly a book of *athqāl*, whereas al-Isfizārī’s work on *ḥiyyal* is represented by a collection of compiled summaries (sometimes with comments) extracted from the mechanical works of Heron, Apollonius

³⁹ The other components of geometry are the sciences of measurement, of optics and mirrors, and of hydraulics: see Anawati 1977, p. 330 and Ibn Sīnā 1989, p. 112.

⁴⁰ The difference is well illustrated by the definition opening Pseudo-Euclid’s *Maqāla fī l-mīzān*: “weight (*wazn*) is the measure of heaviness (*thiqal*) and lightness (*khiffa*) of one thing compared to another by means of a balance”: Paris, Bibliothèque Nationale, MS 2457, f. 22b.

⁴¹ Al-Ghazālī 1961, p. 139.

⁴² Al-Ḥusayn b. Abī Bakr Ibn Rashīq (d. 1292), *Risālat fī taṣnīf al-‘ulūm al-riyāḍiyya*, Rabat, al-Maktaba al-‘Āmma, MS Q 416, p. 422. On Ibn Rashīq, see Lamrabet 2002 and Abattouy 2003a, pp. 101-105.

⁴³ Al-Bayhaqī 1988, p. 125. Likewise, in the notice he devoted to the mathematician Abū Sahl al-Qūhī, al-Bayhaqī states that he was “well-versed in the science[s?] of machines and weights and moving spheres” (*baraza fī ‘ilm al-ḥiyyal wa-l-athqāl wa-l-ukar al-mutaḥarrika*) (ibid., p. 88).

and Banū Mūsā.⁴⁴ Later on, Taqī al-Dīn ibn Maʿrūf, the 16th-century mechanician, 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-ḥiyyal al-daqīqa*), treatises of the science of the steelyard and of the balance (*rasāʾil ʿilm al-qarastūn wa-l-mīzān*), and of the pulling of weights (*wa-jarr al-athqāl*).”⁴⁵

Sometimes *ʿilm al-athqāl* is referred to as *ʿilm marākiz al-athqāl*, one of its branches which enjoyed great reputation. A good instance of this is the following quotation extracted from the correspondence between al-Qūhī and al-Ṣābī. In a letter to al-Qūhī, al-Ṣābī says:

“We did not obtain a complete book on this science, I mean centers of gravity (*marākiz al-athqāl*), 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-ṣināʾa al-mufrada allatī yuḥtāj an yuʿmal lahā kitāb uṣūl*).”⁴⁶

A century later, al-Isfīzārī qualified the centers of gravity as “the most elevated and honorable 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” (*Irshād*, f. 16b).

Al-Khāzinī 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-ʿalayhi mabnā l-qaffān*).⁴⁷ Therefore, it is obvious that the expression *marākiz al-athqāl* is intended to account for the statical aspect of *ʿilm al-athqāl*, 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.⁴⁸

In contrast, the tradition of *ḥiyyal* delimits the contours of a distinct discipline, centered on the investigation of the methods of applicability of

⁴⁴ In the incipit of this collection, al-Isfīzārī writes: “We collected in this book what has reached us of the books on various devices (*anwāʾ al-ḥiyyal*) composed by the ancients and by those who came after them, like the book of Philon the constructor of machines (*sāhib al-ḥiyyal*), the book of Heron the mechanician (*Ḥirun al-majānīqī*) on the machines (*ḥiyyal*) by which heavy loads are lifted by a small force... We start by presenting the drawings of the machines (*suwwar al-ḥiyyal*) conceived by the brothers Muḥammad, Aḥmad and al-Ḥasan, Banū Mūsā ibn Shākir.” Manchester, John Ryland Library, Codex 351, f. 94b; Hayderabad, Andra Pradesh Library, Asafiyya Collection, Codex QO 620, p. 1. I thank Sonja Brentjes who afforded me kindly a xerox copy of Hayderabad manuscript.

⁴⁵ In his *Kitāb at-turuq al-saniyya fi l-ālāt al-rūḥāniyya* (The sublime methods in spiritual machines): al-Ḥasan 1976, p. 24.

⁴⁶ Berggren 1983, pp. 48, 120.

⁴⁷ Al-Khāzinī 1940, p. 5.

⁴⁸ For instance, Ibn al-Akfānī (fourteenth century) asserts that *ʿilm marākiz al-athqāl* shows “how to balance great weights by small ones, with the intermediary of the distance, such as in the steelyard (*qarastūn*)”: Ibn al-Akfānī 1989, p. 409. The same idea is in al-Tahānawī 1980, vol. 1, p. 47.

mathematical knowledge to natural bodies. As represented in several Greek and Arabic mechanical texts, written by Heron, Pappus, Philon, Banū Mūsā and al-Jazarī, the tradition of *ḥiyyal* 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 kinds of devices. The same applies to the treatise of Pappus. As for Philon of Byzantium (fl. 230), his *Pneumatics* is just a catalogue of machines worked by air pressure.⁴⁹

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 Ibn Sīnā,⁵⁰ al-Isfīzārī,⁵¹ and Sinān ibn Thābit⁵² under the name of *ḥiyyal*. Besides this trend on the basic simple machines and their combinations, the science of *ḥiyyal* 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 Banū Mūsā and al-Jazarī. *Kitāb al-ḥiyyal* by the Banū Mūsā comprises a large variety of devices, the vast majority of which consist of trick vessels for dispensing liquids. The book of al-Jazarī *al-Jāmiʿ fī ṣināʿat al-ḥiyyal* 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.).⁵³

The conception of *ḥiyyal* as the practical component of mechanics is additionally corroborated by the contents of a chapter of the *Maḥāṣin al-ʿulūm* by Muḥammad b. Yūsuf al-Khwārizmī (10th century). Chapter 8 of Book II of this lexicographic encyclopedia is dedicated to “*ṣināʿat al-ḥiyyal, tusammā bi-l-yūnāniyya manjanīqūn*” (The Art of Machines,

⁴⁹ Philon's *Pneumatics* was translated into Arabic under the title *Kitāb Fīlūn fī l-ḥiyyal al-rūḥāniyya wa-mājanīq al-māʾ* (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.

⁵⁰ A Persian text called *Mī'yār al-ʿuqūl dur fan jar athqāl* is attributed to Ibn Sīnā. 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: Rozhanskaya 1996, pp. 633-34.

⁵¹ Al-Isfīzārī is the author of a collection of summaries and commentaries extracted from the mechanical works of Heron, Apollonius, and Banū Mūsā. He dealt with simple machines in his commentary on Book II of Heron's *Mechanics*: see supra, n. 45, and Abattouy 2000b, pp. 147-48.

⁵² Sinān (d. 942), the son of Thābit ibn Qurra, is presumably the author of a fragment on the five simple machines preserved in Berlin, Staatsbibliothek, MS Orient fol. 3306.

⁵³ For the two works of Banū Mūsā and al-Jazarī, see respectively Hill 1974 and Hill 1979 for English translations, and al-Ḥasan 1979 and al-Ḥasan 1981 for the Arabic texts.

Called in Greek *Manjanīqūn*). Besides a short mention of machines for the traction of weights, the *ḥiyyal* described are essentially of two types: automata (*ālāt al-ḥarakāt*) and hydraulic devices (*ḥiyyal ḥarakāt al-māʾ*).⁵⁴ 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 *ḥiyyal* in his time. Significantly, al-Khwārizmī –like Ibn Sīnā– classifies the weight-pulling machines in the field of *ḥiyyal* in contrast to their arrangement among that of *athqāl* by al-Fārābī.

The analysis of the overall significance of the Arabic medieval science of weights showed 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 *ʿilm al-athqāl* and *ʿilm al-ḥiyyal*. The latter corresponds to the traditional descriptive doctrine of machines, whereas the core structure of the *ʿilm al-athqāl* is determined by 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 took 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

⁵⁴ Al-Khwārizmī 1968, pp. 246-247.

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 Thābit ibn Qurra and al-Isfizārī 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-Qūhī 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-Khāzinī pushed forward this idea and drew from it a spectacular consequence 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.⁵⁵

7. For an intercultural history of mechanics

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, *Kitāb fī l-qarashūn* by Thābit ibn Qurra and *Ihṣā' al-'ulūm* by al-Fārābī.

⁵⁵ 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 in science is developed in Abattouy 2004a.

Indeed, the very expression *scientia de ponderibus* was derived from the Latin translation of al-Fārābī's *Iḥṣā' al-ʿulūm*. Versions of this text were produced both by Gerard of Cremona and Dominicus Gundissalinus. The latter made an adapted version of the *Iḥṣā'* in his *De scientiis* 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-Fārābī's characterization of the sciences of weights and devices, called respectively *scientia de ponderibus* and *scientia de ingeniis*.⁵⁶ 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.⁵⁷ 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 reflection on their epistemological status. It must be added also that Gundissalinus seems to ignore all their developments in the Arabic science either, including Thābit 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 the light on a considerable underdevelopment in several sciences. This concerns particularly the different branches of mechanics.⁵⁸

As said before, *Liber karastonis* is the Latin translation by Gerard of Cremona of *Kitāb fī l-qarastūn*. The general structure of both Arabic and Latin versions is the same, and the enunciations of the theorems are identical. Yet the proofs might show greater or lesser discrepancies. None of the Arabic extant copies of Thābit's *Kitāb* 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

⁵⁶ Gundissalinus 1903, *De Div. Phil.*, pp. 121-24 and Gundissalinus 1932, *De Scientiis*, pp. 108-112.

⁵⁷ 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.

⁵⁸ This was noted by Hugonnard-Roche 1984, p. 48. Other Arabic works on the classification of the sciences translated into Latin might have been a source for the distinction of the science of weights and its qualification as the theoretical basis of mechanics. For instance, al-Ghazālī's *Maqāsid al-falāsifa*, translated as *Summa theoriae philosophiae* by Gundissalinus and Johannes Hispanus in Toledo, and Ibn Sīnā's *Risāla fī aqsām al-ʿulūm*, translated by Andrea Alpago: *In Avicennē philosophi praeclarissimi ac medicorum principis, Compendium de anima, De mahad..., Aphorismi de anima, De diffinitionibus et quæsitis, De divisione scientiarum*, Venice, 1546, fols 139v-145v.

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.⁵⁹ In addition, at least one version of Thābit'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 codexes. It is precisely a digest of the logical structure of *Liber de karastonis*, in the shape of statements of all the theorems.⁶⁰

8. References and bibliography

- ABATTOUY, M. (1999) "The Arabic Tradition of Mechanics: Textual and Historical Characterization." *Majallat kulliyat al-ādāb wa-l-ūlūm al-insāniyya bi-Fās*, vol. 12.1 (1999): pp. 75-109.
- 2000a. "La Tradition arabe de la balance: Thābit ibn Qurra et al-Khāzinī." In *Quelques aspects de l'évolution des idées scientifiques. Antiquité et moyen âge*. Rabat: The Faculty of Letters Press, pp. 49-91.
- 2000b. "Al-Muṣaffar al-Isfīzārī 'ālim mina l-qarnayn 5-6 H/11-12, mu'allif *Irshād dhawī al-irfān ilā šinā'at al-qaffān* (Al-Muṣaffar al-Isfīzārī a scholar from the 5th-6th century H/11th-12th CE, author of *Guiding the learned men in the art of the steelyard*)." In *Ibidem* (*Quelques aspects de l'évolution des idées scientifiques*), pp. 135-175.
- 2000c. "Mechané vs. ḥiyāl: Essai d'analyse sémantique et conceptuelle." In *Imagination and Science*. Rabat: The Faculty of Letters Press, pp. 127-151.
- 2000d. "Sur quelques démonstrations grecques et arabes de la loi du levier: transmission et transformation." In *Āliyyāt al-istidlāl fī l-ilm*. Rabat: The Faculty of Letters Press, pp. 7-43.
- 2001a. "Nūtaf min al-ḥiyāl: A Partial Arabic Version of Pseudo-Aristotle's *Mechanica Problemata*." *Early Science and Medicine* (Leiden) vol. 6: pp. 96-122. Revised version published (June 2007) online at: <http://muslimheritage.com/topics/default.cfm?ArticleID=706> and http://www.muslimheritage.com/uploads/Nutaf_Min_Al-Hiyal.pdf.
- 2001b. "Greek Mechanics in Arabic Context: Thābit ibn Qurra, al-Isfīzārī and the Arabic Traditions of Aristotelian and Euclidean Mechanics." *Science in Context* (Cambridge University Press) vol. 14: pp. 179-247.

⁵⁹ 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.

⁶⁰ Brown, 1967, pp. 24-30 and Knorr, 1982, pp. 42-46, 173-80.

- 2002a. “The Aristotelian Foundations of Arabic Mechanics (Ninth-Twelfth centuries).” In *The Dynamics of Aristotelian Natural Philosophy from Antiquity to the Seventeenth Century*. Edited by C. Lüthy, C. Leijenhorst and H. Thijssen. Leiden: Brill, pp. 109-140.
- 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: pp. 109-130.
- 2003a. “‘Ulūm al-mīkānikā fī l-gharb al-islāmī al-waṣīt: dirāsa awwaliyya” (The mechanical sciences in the medieval Islamic west: a preliminary study). In *La Pensée Scientifique au Maghreb: le Haut Moyen Age*. Rabat: The Faculty of Letters Press, pp. 91-121 (republished in *Etudes d'Histoire des Sciences Arabes*. Textes réunis et présentés par Mohammed Abattouy. Casablanca: Publications de la Fondation du Roi Abdulaziz pour les Sciences Humaines et les Etudes Islamiques, 2007, pp. 65-100 – Arabic section).
- 2004a. “Min ‘ilm al-ḥiyyal ilā ‘ilm al-athqāl: wilāda thāniyya li-l-mīkānikā” (From the science of machines to the science of weights: a new birth of mechanics). In *Maḥmūd al-taqaddum fī l-‘ilm* (The concept of progress in science). Rabat: The Faculty of Letters Press, pp. 89-109.
- 2004b. “Science des poids et ḥisba: Prolégomènes à l’étude des structures sociales de la mécanique arabe médiévale.” In *Les éléments paradigmatiques, thématiques et stylistiques dans la pensée scientifique*. Rabat: The Faculty of Letters Press, pp. 119-130.
- 2004c. “Iṣlāḥ comme un mode éditorial d’appropriation: la tradition arabe de *Maqāla fī l-mīzān* un traité sur la théorie du levier attribué à Euclide.” *Majallat kullīyyat al-ādāb wa-l-‘ulūm al-insāniyya bi-Fās* (Fès) vol. 13: pp. 153-193.
- 2005a. Entries “al-Ahwazī”, “Ilyā al-Matran” and “al-Isfizari” in *Mawsū‘at a’lām al-‘ulamā’ wa-l-udabā’ al-muslimīn*. Published by the ALECSO (Arab League Educational, Cultural and Scientific Organization) (Tunis). Beirut: Dār al-Jayl.
- 2005b. “*Al-Qisṭās al-mustaqīm*: la balance droite de Omar Khayyām.” *Farhang. Quarterly Journal of Humanities and Cultural Studies* (Tehran) (Issue Topic: Commemoration of Ḥayyām 3) vol.18, nḲ 53-54: pp.155-166.
- 2006. “The Arabic Transformation of Mechanics: The Birth of the Science of Weights”. Published online at: <http://muslimheritage.com/topics/default.cfm?ArticleID=615> and http://www.muslimheritage.com/uploads/The_Birth_of_Science_Weights_Roman.pdf.
- 2007a. “La tradition arabe de *Maqāla fī l-mīzān* un traité sur la théorie du levier attribué à Euclide”. In: *Ayené-ye Miras (Miror of*

Heritage). *Quarterly Journal of Book Review, Bibliography and Text Information* (Téhéran) New series vol. 4, issue 4 (N^o 35) Winter 2007, pp. 67-104.

— 2007b. “The Arabic Tradition of *ʿilm al-athqāl* (Science of Weights): Texts and Context”. In *Etudes d'Histoire des Sciences Arabes*. Textes réunis et présentés par Mohammed Abattouy. Casablanca: Publications de la Fondation du Roi Abdulaziz pour les Sciences Humaines et les Etudes Islamiques, 2007, pp. 43-82.

— 2007c. “Al-Muṣaffar al-Isfizārī” and “ʿAbd al-Raḥmān al-Khāzinī.” In: *The Biographical Encyclopedia of Astronomers*. Editor in Chief Thomas Hockey. Heidelberg/Berlin: Springer Verlag.

— [2007d]. *L'Histoire des sciences arabes classiques: une bibliographie sélective commentée*. Casablanca: Publications de la Fondation du Roi Abdulaziz pour les Sciences Humaines et les Études Islamiques.

— [Forthcoming (1)]. *L'édition du corpus arabe de ʿilm al-athqāl (science des poids): Leçons d'une histoire épistémologique des sciences*. Proceedings of the International Colloque *Édition et étude du corpus textuel arabe: situation présente et perspectives d'avenir* (Casablanca, 15-17 février 2007).

ABATTOUY, M., J. RENN and P. WEINIG (2001) “Transmission as Transformation: The Translation Movements in the Medieval East and West in a Comparative Perspective.” *Science in Context*, vol. 14: pp. 1-12.

AGHAYANI CHAVOSHI, J. and F. BANCEL (2000) “Omar Khayyām et l'Hydrostatique.” *Farhang. Quarterly Journal of Humanities and Cultural Studies* (Tehran) vol. 12 : pp. 33-49.

ANAWATI, G. C. (1977) “Les divisions des sciences intellectuelles d'Avicenne.” *Mélanges de l'Institut Dominicain d'Études Orientales du Caire* vol. 13: pp. 323-335.

ARISTOTLE (1952) *Mechanica*. Greek text with English translation by E. S. Forster. In *The Works of Aristotle*, vol. 6: *Opuscula*. Oxford: Clarendon Press.

BANCEL, F. (2001) “Les centres de gravité d'Abū Sahl al-Qūhī.” *Arabic Science and Philosophy* vol. 11: pp. 45-78.

BAYHAQĪ, al-, ʿAlī ibn Zayd (1988) *Tārīkh ḥukamāʾ al-islām*. Edited by M. Kurd ʿAlī. Damascus: Maṭbūʿāt mujammaʿ al-lughā al-ʿarabiyya. Reprint of the 1st edition (1946).

BERGGREN, L. J. (1983) “The Correspondence of Abū Sahl al-Kūhī and Abū Ishāq al-Ṣābī. A Translation with Commentaries.” *Journal for the History of Arabic Science* vol. 7: pp. 39-124.

- BROWN, J. E. (1967) *The Scientia de Ponderibus in the Later Middle Ages*. Ph. D. Dissertation. Madison: The Wisconsin University Press.
- BUCHNER, F. (1922) "Die Schrift über den Qarastûn von Thabit b. Qurra." *Sitzungsberichte der Physikalisch-Medizinischen Sozietät zu Erlangen*: pp. 141-188.
- CHARETTE, F. (2003) *Mathematical Instrumentation in Fourteenth-Century Egypt and Syria. The Illustrated Treatise of Najm al-Dîn al-Miṣrî*. Leiden: Brill.
- CLAGETT, M. (1959) *The Science of Mechanics in the Middle Ages*. Madison: University of Wisconsin Press.
- DAMEROW, P., J. RENN, S. RIEGER and P. WEINIG (2002) "Mechanical Knowledge and Pompeian Balances." *Homo Faber: Studies on Nature, Technology, and Science at the Time of Pompeii*. Edited by Jürgen Renn and Giuseppe Castagnetti. Roma: L'Erma, pp. 93-108.
- DOZY, R. 1927. *Supplément aux dictionnaires arabes*. Leiden: E. J. Brill, 2 vols.
- FĀRĀBĪ, al-, Abū Naṣr Muḥammad (1949) *Iḥṣā' al-'ulūm*. Edited by 'Uthmān Amīn. Cairo: Dār al-fikr al-'arabī, 2nd edition.
- GHAZĀLĪ, al-, al-Imām Abū Ḥāmid (1961) *Maqāṣid al-falāsifa*. Edited by Sulaymān Dunyā. Miṣr [Cairo]: Dār al-ma'ārif.
- GUNDISSALINUS, Dominicus (1903) *De Divisione Philosophiae*. Herausgeben und philosophiegeschichtlich untersucht... von Dr. Ludwig Baur. *Beiträge zur Geschichte der Philosophie des Mittelalters*, 4.2-3. Munster: Druck und Verlag der Aschendorffschen Buchhandlung.
- [GUNDISSALINUS, D.] Domingo Gundisalvo 1932. *De Scientiis*. Texto latino establecido por el P. Manuel Alonso Alonso. Madrid-Granada: Imprensa y Editorial Maestre.
- HALL, R. A. 1981. "Al-Khāzinī." *Dictionary of Scientific Biography*. 16 vols. Edited by Charles Gillispie. New York: Scribners, vol. VII: pp. 335-351.
- ḤASAN, al-, A. Y. (1976) *Taqī al-Dīn wa-l-handasa al-mikānīkiyya al-'arabiyya. Ma'a Kitāb al-ṭuruq al-saniyya fī l-ālāt al-rūḥāniyya min al-qarn as-sādis 'ashar*. Aleppo: Institute for the History of Arabic Science.
- 1979. *Ibn al-Razzāz al-Jazarī: Al-Jāmi' bayna l-'ilm wa-l-'amal al-nāfi' fī ṣinā'at al-ḥiyyal*. Aleppo: Institute for the History of Arabic Science.
- 1981. *Banū Mūsā: Kitāb al-ḥiyyal*. Aleppo: Institute for the History of Arabic Science.
- HERON VON ALEXANDRIA (1976) *Heronis Alexandrini Opera quae supersunt*. 5 vols.; vol. 2: *Mechanica et catoprica*. Edited by L. Nix and

W. Schmidt. Stuttgart: B. G. Teubner. Reprint of the 1st edit. Leipzig: 1899-1914.

— (1988) Héron d'Alexandrie. *Les Mécaniques ou l'élèveur des corps lourds*. Texte arabe de Qusṭā ibn Lūqā établi et traduit par B. Carra de Vaux, Introduction de D. R. Hill et commentaires par A. G. Drachmann. Paris: Les Belles Lettres

HEINEN, A. (1983) "At the Roots of the Medieval Science of Weights: A Report on an Edition Project." *The Journal of Sophia Asian Studies* (Tokyo) vol. 1: pp. 44-55.

HILL, D. R. (1974) *The Book of Knowledge of Ingenious Mechanical Devices. An Annotated Translation of al-Jazarī's Treatise*. Dordrecht: Reidel.

— 1979. *The Book of Ingenious Devices. An Annotated Translation of the Treatise of Banū Mūsā*. Dordrecht: Reidel.

HUGONNARD-ROCHE, H. (1984) "La classification des sciences de Gundissalinus et l'influence d'Avicenne." *Études sur Avicenne*. Dirigées par J. Jolivet et R. Rashed. Paris: Les Belles Lettres, pp. 41-75.

IBEL, Th. (1908) *Die Wage im Altertum und Mittelalter*. Erlangen: Junge (Erlangen Univ., Diss., 1906).

IBN AL-AKFĀNĪ, Shams al-Dīn (1989) *Kitāb Irshād al-qāṣid ilā asnā al-maqāṣid*. Edited by Junuarius Justus Withkam. Leiden: Ter Lugt Pers.

IBN SĪNĀ, al-Shaykh al-Ra'īs Abī 'Alī (1989) *Tis 'Rasā'il fī l-ḥikma wa-l-ṭabī'īyyāt*. Cairo: Dār al-'arab li-l-Bustānī, 2nd edition.

IBN AL-UṬUWWA, M. (1938) *The Ma'ālim al-qurba fī aḥkām al-ḥisba*. Edited, with abstract of contents, glossary and indices by Reuben Levy. Cambridge: Cambridge University Press/London: Luzac & Co.

JACKSON, D. E. P. (1970) *The Arabic Version of the Mathematical Collection of Pappus Alexandrinus Book VIII*. Ph. D. Dissertation. University of Cambridge.

JAOUICHE, Kh. (1976) *Le Livre du qarastūn de Thābit ibn Qurra. Étude sur l'origine de la notion de travail et du calcul du moment statique d'une barre homogène*. Leiden: Brill.

JAWBARĪ, al-, 'Abd al-Raḥmān (1979-80) *Le voile arraché. L'autre visage de l'Islam*. Traduction intégrale sur les manuscrits originaux par René Khawam 2 vols. Paris: Phébus.

KHĀZINĪ, al-, 'Abd al-Raḥmān (1940 [1359 H]) *Kitāb mizān al-ḥikma*. Hayderabad: Dā'irat al-ma'ārif al-'uthmāniyya.

KHWĀRIZMĪ, al-, Abū 'Abdallāh b. Yūsuf (1968) *Liber Maḡatih al-Ouloum*. Edited by G. Van Vloten, Leiden: E. J. Brill, 2nd edition.

- KING, D. A. (1987) "The Astronomical Instruments of Ibn al-Sarrāj: A Brief Survey." In D. A. King, *Islamic Astronomical Instruments*. London: Variorum, B IX.
- KNORR, W. 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.
- LAMRABET, D. (2002) "Ibn Rashīq (XIII^{ème} siècle) et la classification des sciences mathématiques." In *Science et pensée scientifique en Occident musulman au moyen-âge*. Rabat: Publications de la Faculté des Lettres, pp. 43-56.
- LANE, E. W. (1984) *Arabic-English Lexicon*. 2 vols. Cambridge: The Islamic Texts Society.
- MOODY, E. and M. CLAGETT (1952) *The Medieval Science of Weights (Scientia de Ponderibus). Treatises ascribed to Euclid, Archimedes, Thabit ibn Qurra, Jordanus and Blasius of Parma*. Madison: The University of Wisconsin Press.
- PHILON DE BYZANCE (1902) *Le livre des appareils pneumatiques et des machines hydrauliques*. Paris: C. Klincksieck.
- ROZHANSKAYA, M. M. (1996) "Statics." In *Encyclopaedia of the History of Arabic Science*. 3 vols. Edited by R. Rashed. London: Routledge, vol. III, pp. 614-642.
- ṢABĀḤ, al-, H. al-Sālim (supervision) (1989) *Al-ʿulūm ʿinda l-ʿArab wa-l-Muslimīn. Collection of Dār al-Āthār al-Islāmiyya*. Kuwait: Dār al-Āthār al-Islāmiyya.
- SAʿĪDĀN, A. S. (1981) "Al-Umawī." *Dictionary of Scientific Biography*. Vol. 13/14, pp. 539-540.
- SALIBA, G. (1985) "The Function of Mechanical Devices in Medieval Islamic Society." *Science and Technology in Medieval Society*. Edited by Pamela Long. *Annals of the New York Academy of Sciences*, vol. 441: pp. 141-151.
- SBATH, P. (1938-1940) *Al-Fihris: Catalogue des Manuscrits Arabes*. 3 parts plus Supplement. Cairo.
- SEZGIN, F. (1974) *Geschichte des Arabischen Schriftums*. Vol. V: *Mathematik*. Leiden: E. J. Brill.
- SKINNER, F. G. (1967) *Weights and Measures: Their Ancient Origins and Their Development in Great Britain Up to AD 1855*. London: Her Majesty's Stationary Office.
- TAHĀNAWĪ, al-, M. (1988 [1862]). *Kashshāf iṣṭilāḥāt al-funūn. A Dictionary of the Technical Terms Used in the Sciences of the Muslims*. 2 vols. Edited by M. Wajīh et al., Calcutta: W. N. Lees' Press. Reprinted Osnabrück: Biblio Verlag.

TAYLOR, J. (1991) *The Didascalicon of Hugh de saint Victor. A Medieval Guide to Arts*. New York: Columbia University Press.

VAUDOUR, C. (1996) (sous l'autorité de). *A l'ombre d'Avicenne: la médecine au temps des califes*. Catalogue de l'exposition (18 novembre 1996-2 mars 1997) tenue à l'Institut du Monde arabe, Paris: Institut du Monde arabe.

WIEDEMANN, E. (1970) *Aufsätze zur Arabischen Wissenschaftsgeschichte*, 2 vols. Hildesheim / New York: G. Olms.

ZOTENBERG, H. (1879) "Traduction arabe du *Traité des corps flottants* d'Archimède", *Journal asiatique*, vol. 7: pp. 509-515.