Available online at www.elixirpublishers.com (Elixir International Journal)

Mechanical Engineering

Elixir Mech. Engg. 78 (2015) 29526-29534

ISSN: 2229-712X

Innovation of mechanical machinery in medieval centuries, part V: balances and Astrolabes

Galal A. Hassaan

Department of Mechanical Design & Production, Faculty of Engineering, Cairo University, Giza, Egypt.

ARTICLE INFO

Article history:

Received: 25 November 2014;

Received in revised form: 19 December 2014;

Accepted: 31 December 2014;

Keywords

Mechanical machinery in the medieval centuries,

Balances,

Astrolabes.

ABSTRACT

The Islamic civilization paid great attention to mechanical engineering during the medieval centuries. The mechanical engineers of the Islamic Empire gave outstanding attention to measurement instrumentation including balances and astrolabes. They used balances to adjust commercial activities in the society and for engineering purposes. They succeeded to use the balance in determining the specific weights of both solids and liquids, examining the purity of precious materials and examining the constituents of alloys. They developed the Greek astrolabe and discovered hundreds of applications required by their daily life. They also devised different type of astrolabes such as the planispheric, quadrant and spherical astrolabes. They wrote 100's of manuscripts explaining the design and use of the astrolabe where some of them still surviving up to now in a large number of libraries and museums around the world. The paper discusses the contribution of Islamic scientists to the development and application of balances and astrolabes.

Introduction

Great outstanding attention was given in the medieval Islamic history to engineering measurements including weight, specific gravity, time and dimensions. Therefore, they added new sophisticated features to known measurement instruments such as balances and astrolabes.

Mieli (1966) sees that the determination of specific weighs by Al-Biruni and Al-Khazini are some of the most outstanding results obtained by Muslims using experimental physics [1]. Abdul-Alim (1979) announced that the quadrant was invented by Al-Khwarismi (died 850 AC) and Europe started using the quadrant in 1462 [2]. King (1981) presented 33 samples of the Arabic and Persian texts about astrolabe with detailed definition of each manuscript [3]. Knorr (1982) announced that the medieval science of weights returns to the treatise on the balance 'Kitab al-Qurastun' by the 9th century mathematician-astronomer, Thabit ibn Qurra. His work retained a prominent place within work of Al-Khazini 'Mizan al-Hikma' (balance of wisdom) [4]. Al-Shakil (1989) pointed out that Al-Razi (died 932 AC) used a physical balance in determining the specific weight of liquids. Also, Abu al-Raihan Al-Biruni (died 1048 AC) used an apparatus for the specific weigh evaluation of metals including a balance to measure the weight of the displaced water [5]. Fernini (1998) said about Al-Khazini: astronomer , mathematician and physist received the best education in mathematics and philosophy. He became perfect in geometrical sciences and was an outstanding craftsman in the construction of scientific instruments [6]. Damerow et. al. (2000) referred to the book of Al-Khazini as it contained a detailed description of the procedure to construct his universal weighing instrument. He assembled all practical and theoretical knowledge on balances and weights to construct his balance of wisdom [7]. Newburry et. al. (2004) used synehrotron X-ray to perform non-destructive experiments on a group of 24 Islamic and European astrolabes dated between 1350 and 1720 in order to determine their composition. Their experiments showed that the Islamic astrolabes centered in Lahore displayed a much more advanced brass manufacturing technology then the European technology [8]. Ward (2004) analyzed the inscriptions of an astrolabe produced by Abdel-Karim in 1235 AC which is in display in the British Museum [9]. Zaimeche (2005) stated that Al-Khazini completed writing his book 'the balance of wisdom' in 1121 AC which remained one central piece of Muslim physics. His book studied the hydrostatics that lie behind it. He described the equipment necessary to obtain accurate specific gravity of metals, precious stones and alloys. He also determined the purity of various substances and detected fraud [10].

Abattouy (2006) referred to the book of Thabit ibn Qurra (died 901 AC) about Qarastun as the first Arabic text to deal with the theory of the unequal-armed balance in Islam. He mentioned also Thabit's book about the characteristics of weights where he stated the necessary conditions to achieve equilibrium in weighing with balances [11]. Farugi (2006) presented a discussion regarding the role that Muslim scholars played in the development of scientific thinking in the Middle Ages and played an important role in revitalizing a climate of learning and exploration in Europe leading to the renaissance in the 16th and 17th centuries [12]. Molayeri (2007) declared that Al-Zarqali (died 1100 AC) of Andalus constructed a universal astrolabe that can be used at any altitude [13]. Amin and Kurdi (2007) announced that Ibn Al-Shatir (died 1375 AC) constructed a number of astronomical instruments to adjust prayer times and perform astronomical measurements. Some of his works were stolen by the mathematician Copernicus (died 1543) who read some of the Astronomical treatises. Ibn Al-Shatir described in his treatise about the astrolabe the different parts of the astrolabe [14]. Borrelli (2008) strengthened the fact that the astrolabe was further developed in the Arabic-Islamic culture [15]. Hazmy, Zainurashis and Hussani (2009) declared that Yaqub Al-Kindi

Tele:

E-mail addresses: galalhassaan@ymail.com

(died 873 AC) wrote 16 treatises on astronomy, Al-Battani (died 929 AC) wrote a book about 'Al-Zij' with 57 chapters including known observations and the construction of astronomical instruments, Al-Farghani (died 860 AC) wrote a book about 'elements of astronomy' where he determined the earch diameter, found the greatest distances and the diameter of planets. Also, the mentioned the work of Omar Al- Khayyam (died 1123 AC) who led work on compiling astronomical tables of remarkable accuracy. He measured the length of the year as 365.24219858156 days compared with today value of 365.242190 [16]. Al-Rabbi (2010) stated that Mohammed ibn Abdullah (Nastulus) built the earliest surviving astrolabe in 927 AC. He pointed out that Al-Khazini generated the theory of center of gravity in his book 'the balance of wisdom' [17]. Capecchi (2011) praised the book 'Liber Karastonis' of Thabit ibn Qurra as one of the most important treatises in the science of weights [18].

Godoy (2011) on mechanics by Islamic authors were recovered during the 10th century AC. The contributions of medieval Islamic authors focused on more specialized topics than Greek authors gaining deeper knowledge about problems related to balances and weights. The statics of Al-Khazini included short summaries of the teachings of Thabit ibn Qurra, Al-Biruni and Al-Afizari [19]. Craig (2011) declared that a planisphercal astrolabe is a two-dimensional analog computer for solving problems related to celestial movements: time, seasons, and star positions. The back of the astrolabe is set to measure altitude of stars and planets including the sun. He explained how to build an astrolabe using Microsoft Power Point [20]. De Graaf 2011) provided formulas for the construction of an astrolabe similar to that of Hamed Al-Kujandi constructed in 984 AC [21]. Hayton (2012) pointed out the treatises on astrolabe by Massallah (died 815 AC), Al-Khwarizmi (died 825 AC), Ali ibn Isa (died 830), Al- Faragni (died 857 AC) and Al-Biruni (died 1048 AC). He summarized the use of astrolabe in telling time, religious observations, astrology and surveying [22]. Abdul-Rahman and Akhtar (2012) declared the importance of astrolabe in construction and its used in the application of spherical geometry to map one's location on earth relative to stars and sun on the celestial sphere. They summarized the uses of the astrolabe in the Islamic world as: solving problems of spherical astronomy, determining time of day or night for prayers, fixing the Qibla direction, solving the surveying problems (depth of wells, height, river width, longitudes of different planets) [23]. Saeed (2012) declared that Muslim scientists studied deeply the fundamental questions of science and technology, especially Ibn Sina (died 1036 AC) who made intensive studies on force, motion, light, heat, vacuum, etc. that paved the way for theoretical and applied mechanics. He pointed to Al-Khazini book 'the balance of wisdom' which was very remarkable [24]. Hall (2013) praised Abu Al-Rayhan Al-Biruni as one of the greatest scholars of the medieval Islamic era who was well versed in physics, mathematics and natural sciences [25]. Knox-Johnston (2013) explained how to use the astrolabe to measure the altitude of a chosen body, and how to use an astrolabe and quadrant to make star observations [26]. Sparvigna (2013) announced that Al-Biruni used the hydrostatic balance of Al-Khazini in measuring densities. In fact this is wrong because Al-Khazini died after 174 years from Al-Biruni death [27]. Akhtar (2013) acknowledged the book of Al-Khazini 'the balance of wisdom' and considered it a most remarkable medieval work on mechanics, hydrostatics and physics. He (i.e. Al-Khazini) studied the specific gravity of many liquids and solids. Besides he used the balance in leveling and measurement of time [28]. Cole (2014) strengthened the particular interest of the Islamic scholars in the structure of the cosmos and the accurate measure of time using the celestial globe, the armillary sphere and the astrolabe [29].

Balances

The mankind invented mechanical balanced since thousands of years. The purpose of this invention was to adjust the commercial activities between the people. Ancient Egyptians were superior in this aspects. This great attention to weighing balanced continued in the Islamic era because of religious and scientific reasons. Different types of balanced were designed in the medieval centuries by physical scholars such as Al-Razi , Al-Biruni and Al-Khazini .

Jabir Ibn Hayyan Balance

- Dr. Ali Al-Shakil in his book 'Chemistry in the Islamic Civilization' (in Arabic) announced that Jabir ibn Hayyan (died 776) explained the sensitive balance in his books in details [30].
- He used the balance in his laboratory experiments [31].
- Al-Shakil pointed out that this balance could weigh things as small as 0.06 gram [30].

AL-RAZI Balance

- Mohammed ibn Zakaria Al-Razi (died 932 AC) was one of the giant Islamic scientists worked in medicine, chemistry, astronomy, mathematics and philosophy [32]
- Fig.1 shows a line diagram for Al-Razi balance.

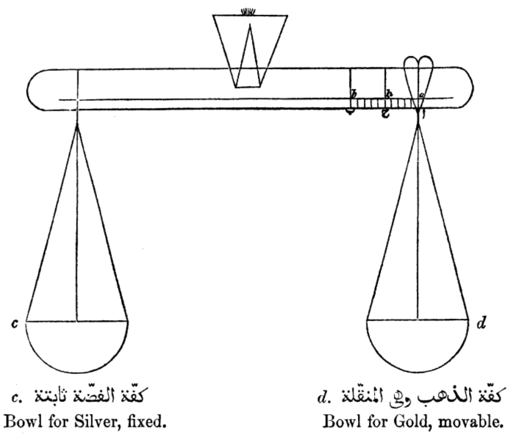

Fig.1 Al-Razi balance [31]

- Al-Razi introduced a needle called 'the tongue' and a movable suspended bowl on a specially designed scale for silver and gold.
- This balance was used by Al-Razi to examine the purity of silver and gold. It could designate the silver-gold alloy as: pure silver, pure gold, alloy of both.

AL-BIRUNI Balance

- Abu Al-Rayhan Al-Biruni (died 1048 AC) was the great scholar in Islam and one of the greatest international scientists who was pioneer in astronomy, mathematics, physics, history, geography, philosophy and literature [34,35].

Fig.2 shows the balance of A-Biruni.

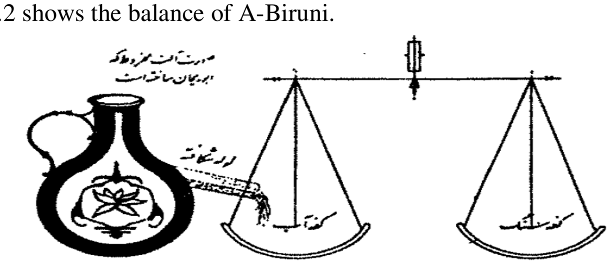

Fig.2 Balance of Al-Biruni [36].

- Al-Biruni used the apparatus shown in Fig.2 including an equal-arm balance to evaluate the specific gravity of some solids.
- The percentage error in the evaluated values by Al-Biruni compared with present days values was less than 1 %.

AL-KHAZINI balances

- Abdul-Rahman Al-Khazini (died 1155 AC) was a remarkable mathematician, astronomical scholar and physician [37].
- He wrote a number of books and articles, the most important of them is his book 'Mizan Al-Hikma' or 'The balance of wisdom' [38,39].
- This book was translated to English by Khanikoff in 1857 and published in both Arabic and English texts [40].

Balance of wisdom

- The balance of wisdom is shown in Fig.3 as a colored picture extracted from one of A-Kazini hand written manuscript [41].

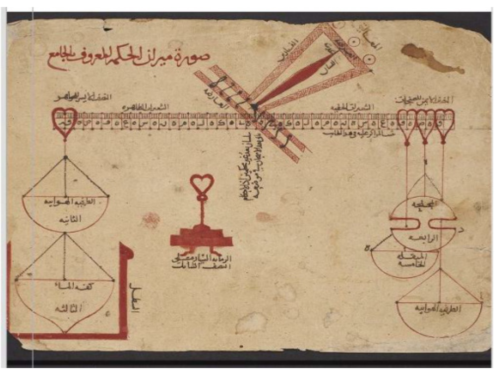

Fig.3 The balance of wisdom by Al-Khazini [41].

- This manuscript was written in 1270 AC and located in the Library of the University of Pennsylvania, USA.
- The balance consists of an equal halved beam, five bowls and movable weight.
- The beam is graduated by two different scales.
- It has a tongue to increase the measurement accuracy through locating the equilibrium position of the weight.
- Al-Khazini used cords replacing the revolute joint of the beam to reduce friction to minimum.
- A modern line diagram for Al-Khazini balance of wisdom was presented by Al-Shakil to illustrate the upper part of the balance [39]. It is shown in Fig.4.

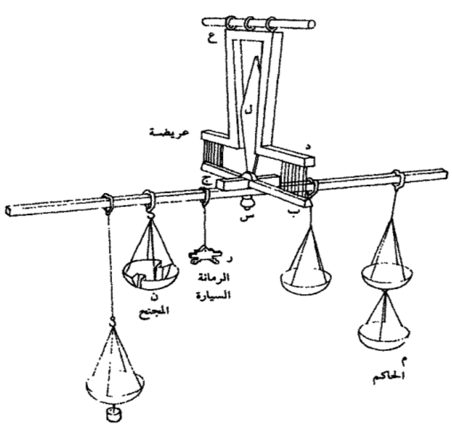

Fig.4 Modified drawing of the balance of wisdom [42].

- Applications of Al-Khazini 5 bowls balance [43]:

1. Accurate weighing.
2. Examining the purity of metals as gold and silver.
3. Knowing the constituents of alloys.
4. Knowing the material of the weighed solids.
5. Knowing the difference between the specific gravities of solids.
6. Knowing the weight of things without using weights but by moving the moving bowls.
7. Differentiating between precious and semi-precious materials.

The steelyard

- Al-Khazini designed a steelyard in his book of balance of wisdom.
- The line diagram of his steelyard is shown in Fig.5 [44].

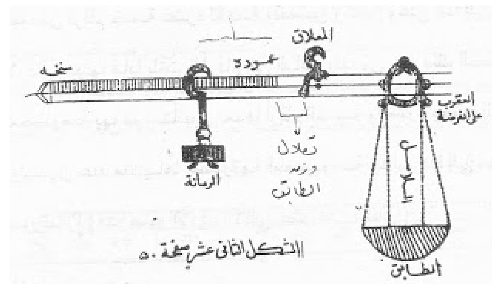

Fig.5 Steelyard of Al-Khazini [44].

- He used a graduated scale with a resolution of one mann (756 gram [45]).
- The scale was up to 200 mann (151.6 kg [45]).
- The weighing units could be changed by changing the value of the moving weight (rommana).

Omar AL-KHAYYAMI Balance

- Omar Ibn Ibrahim Al-Khayyami (died 1123 AC) was a pioneer mathematician , astronomer and metaphysician [46].
- His balance was described by AbdulRahman Al-Khazini in his book 'The Balance of Wisdom'.
- Fig.6 shows Al-Khayyami balance which is a sensitive one used for accurate weighing [47].

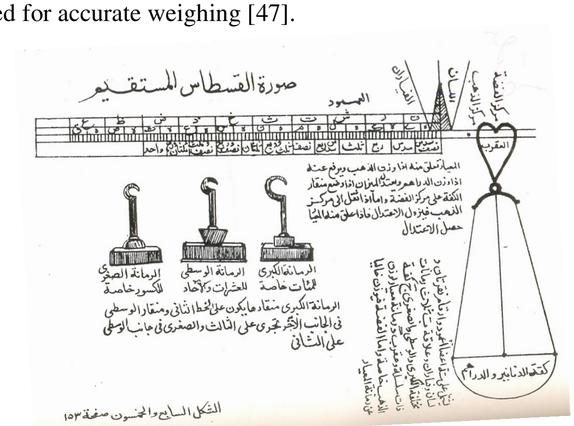

Fig. 6 Al-Khayyami sensitive balance [47].

- This balance (according to Al-Khazini) could weigh from one seed (0.05 gram [45]) to 1000 dinar (4.2 kg [45]).
- It had 4 scales, 3 moving weights and one bowl.
- It had a tongue and beam hanging cords.
- The biggest moving weight was for 100's dinars, the medium one was for 10's and 1's dinars and the smallest one was for fractions of a dinar.
- Its length was one cubit (0.494 m [48].

Steelyard balance from 9TH century

- Steelyard has non-equal arm elements.
- It was in use in the Islamic world before the days of Al_Khayyami and Al-Khazini.

- Fig.7 shows a typical surviving model of an Egyptian or Syrian steelyard [49].

Fig.7 Egyptian or Syrian steelyard [49].

- This steelyard is in display in the Benaki Museum, Athens, Greece.

Balance Weights

- In most balances weights are required to complete the weighing process.
- The balance designers used metal, glass or stone to manufacture their weights [50].
- Weights from 0.25 to 100 dinars were manufactured [50].
- Fig.8 shows an Islamic weight manufactured from Bronze dated 7th – 13th centuries [51].

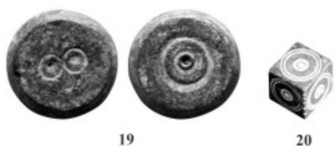

Fig.8 Bronze weights from 7th-10th AC Islamic centuries [51].

- The weight number 19 is for 20.5 gram.
- The weight number 20 is for 14.5 gram.
- Another weight manufactured from opaque glass during the 13th-15th centuries during the Fatimid period is shown in Fig.9 [52].

Fig.9 Fatimid glass weight in the Brooklyn Museum [52].

- Dimensions: Diameter: 20 mm , Thickness: 5 mm
- Location: Brooklyn Museum, USA.

Planispheric Astrolabes

A preliminary planispheric astrolabe was invented by the Greek astronomer Hipparchus in 150 BC [53]. The Muslim astronomers improved the Greek astrolabe by the addition of 100's of features to it such that the astronomer Abdul-Rahman Al-Sofi (died 986 AC) outlined over 1000 uses of the astrolabe [53].

NaSTuLUS Astrolabe

- Nastulus or Mohammed ibn Abdullah was particularly active between 890 and 930 AC [54].
- He was extremely innovative astronomer, mathematician and craftsman [54].
- Fig.10 shows one of Nastulus astrolabes which is the earliest surviving physical astrolabe located in the Kuwait National Museum [53].

Fig.10 Nastulus astrolabe in Kuwait National Museum[53]

- It consists of 8 parts: the mater (base plate), the rete (top web-like plate), 4 plates for different latitudes, the alidade (ruler) for making observations and reading off the scales and a pin acting as a revolute joint assembling all the parts [53].

AL-KHUJANDI Astrolabe [55]

- Al-Khujandi was a famous Persian astronomer-mathematician.
- He designed and constructed his astrolabe in 984 AC.
- The surviving astrolabe of Al-Khujandi is located in the Museum for Islamic Art, Doha, Qatar.
- It is shown in Fig.11.

Fig.11 Al-Khujandi astrolabe in Doha [55]

AL-SABBAN Astrolabe [29]

- Mohammed Ibn Said Al-Sabban an Andalusian astronomer built his astrolabe at 1081 AC.
- Material: brass.
- Diameter: 138 mm.
- Location: The Museum of the History of Science, Oxford, UK.
- Design: Fig.12.

Fig.12 Astrolabe of Mohammed Al-Sabban [29]

AL-SAHLI Astrolabe [56]

- Ibrahim ibn Said Al-Sahli was an Andalusian astronomer.
- He built this astrolabe in 1067 AC.
- Material: Sand cast brass with engraved decorations.
- Dimensions: 242 mm diameter and 19 mm maximum thickness.
- Production place: Toledo, Andalus.
- Location: Museo Arqueologico Nacronal, Medrid, Spain.
- Design: Fig.13.
- There is another astrolabe of Al-Sahli in the Landesmuseum Kassel, Germany, produced in 1086 AC [57].

Fig.13 Astrolabe of Ibrahim Al-Sahli [56].

AL-NAQQASH Astrolabe [57,58]

- Fig.14 shows an astrolabe made by the astronomer Ahmed ibn Mohammed Al-Naqqash.

Fig.13 Astrolabe of Ahmed Al-Naqqash [57].

- It was produced in 1079 AC in Saragossa (Mediterranean island).
- Material: Brass.
- Diameter: 115 mm.
- It was designed to serve about 36 cities in three continents.
- Location: Germanischer Nationalmuseum, Nuremberg, WI353.

BADR IBN ABDULLAH Astrolabe [55]

- Produced by the astronomer Badr ibn Abdullah in 1130 AC.
- Location: Adler Planetarium , No. 2557.
- Some researchers see that this astrolabe was derived from Al-Khujandi astrolabe.

Fig.14 Astrolabe of Badr ibn Abdullah [55].

ABDUL-KARIM AL-MISRI ASTROLABE [59,60]

- Made by the astronomer Abdel-Karim Al-Misri in 1227 AC in Egypt.
- From the Ayyubid period, time of the Sultan Abul-Fath Musa (great Salahuddin nephio).
- Material: Brass.
- Dimensions: 278 mm diameter.
- It included a set of lunar mansions on its back reflecting the Arabic names of the mansions and their order.
- Location: In the British Museum, UK, No.37148.
- Design: Fig.15.

Fig.15 Astrolabe of Abdul-Karim Al- Misri [60].

- A zoomed section of Abdel-Karim astrolabe is shown in Fig.16 [59].

Fig.16 A zoomed section of Abdul-Karim astrolabe [59].

- The zoomed section shows details of the astrolabe surface.
- As specialist in mechanical engineering, one can say that it reflects the innovation and sophistication of the works that made some scientists consider this work as an analog computer.
- One can count about 10 circular accurate scales.
- The too many divisions make it awkward to perform on a piece of paper not on a brass sheet where it is manufactured.

Andalusian Astrolabe [61]

- This is an Andalusian astrolabe manufactured on 1260 AC.
- Location: The Ashmolean Museum, Oxford, UK.
- Design: Fig.17.

Fig.17 Andalusian astrolabe [61].

AL-SARRAJ ASTROLABE [62,63]

- This astrolabe was produced in Damascus, Syria about 1230 AC.
- It was made by Al-Sarraj Al-muezzin.
- It was mainly designed for the 'muezzin' who calls Muslims to prayer.
- Material: brass.
- Dimensions: 116 mm diameter.

- Location: National Maritime Museum, London, UK.
- Design: Fig.18.

Fig.18 Al-Sarraj astrolabe [62].

Quadrants

- An astrolabe quadrant is used to enable the measurement of altitude, latitude and longitude, besides the time of day and night [64].
- The quadrant was invented by the astronomer and mathematician Mohammed ibn Ahmed Al-Khwarizmi (died 846 AC) in Baghdad [65].
- There are a lot of Islamic quadrants surviving till now in a number of the museums all over the world.

Quadrant Of Mohammed Ibn Mahmoud [66]

- Made in the 10^{th} century AC by Mohammed ibn Mahmoud in Nishapur, Iran.
- Material: brass.
- Dimensions: Height: 73 mm, Width: 70 mm
- Location: The Metropolitan Museum of Art, USA.
- Number: 36.20.54
- Design: Fig.19

Fig.19 Quadrant of Mohammed ibn Mahmoud [66].

QUADRANT of Morocco [64]

- Made in Morocco during the year 1038 AC..
- Material: Wood and parchment. .
- Dimensions: Radius: 123 mm
- Location: Dar Batha Museum of Arts and Traditions, Morocco.
- Number: 38.11-2
- Design: Fig.20

Fig.20 Morocco Quadrant [64].

QUADRANT OF MOHAMMED IBN AHMED AL-MIZZI [67]

- Made in Damascus, Syria by Mohammed ibn Ahmed Al-Mizzi on 1333 AC.
- He was the 'Muwaqqit' (official time keeper) of the Great Umayyat Mosque in Damascus.
- It was designed for the latitude of Damascus (31^{o} 30').
- Location: The British Museum, UK.
- Number: 1888.1201.276
- Design: Fig.21

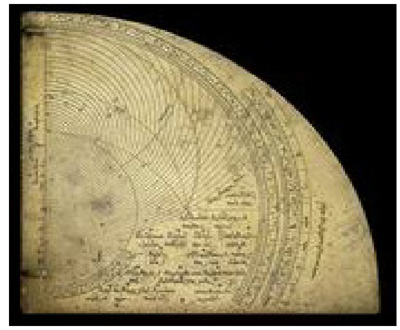

Fig.21 Quadrant of Mohammed ibn Ahmed Al-Mizzi [67].

- A zoomed photo for Al-Mizzi quadrant is shown in Fig.22 [68].

Fig.21 Zoomed photo of Al-Mizzi quadrant[68].

- It depicts the name of the manufacturer and five measurement scales.
- The scales are engraved on the brass sheet with an outstanding accuracy.

QUADRANT OF SHAMS AL-DIN AL-HALABI [69,70]

- Made in Aleppo, Syria during the year 1559 AC..
- The front of the quadrant has standard scales for a fixed latitude of 35^{o} 50'.
- Material: Brass. .
- Dimensions: Radius: 157 mm
- Location: Sold in a sale in London on 1 May 2001 by about 25000 $.
- Design: Fig.22.

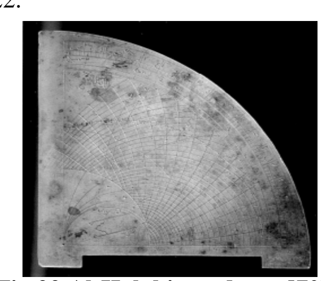

Fig.22 Al-Halabi quadrant [70].

Spherical Astrolabes [71,72]

- The Muslim astronomers used spherical astrolabes to make astronomical calculations [71].

- It is much complex than the planispheric astrolabe because it is a 3D mechanical instrument.
- There is a complete model of the spherical astrolabe surviving till now.
- It is manufactured by Musa in 1480 AC.
- Material: Brass.
- Location: The Museum of the History of Science, Oxford, UK.
- Design: Fig.23.

Fig.22 Spherical astrolabe of Musa [71].

- Inscriptions, hour lines, meridians and circles of altitude are in silver.
- The rotating star map is made of brass laminated with silver on the ecliptic and equatorial circles.
- The large ecliptic circle bears the names of the signs of the Zodiac.
- The rete (star map) is attached to the globe with pointers for 19 fixed stars.
- The use of the spherical astrolabe was explained in details by Al-Fadl ibn Hatim Al_Nairizi (died 902 AC) in an Arabic treatise survived in Al-Escorial Monastery [73].

Conclusion

- The Muslim mechanical scientists and engineers contributed in building the scientific and technological bases of the modern civilization.
- They invented very important instrumentation such as balances and astrolabes.
- They designed different types of balances such as the sensitive balances, five bowls balances and steelyards.
- They used balances for accurate weighing with accuracy of 0.05 gram.
- They succeeded to use the balance to find the specific weight of solids and liquids with error less than 1 %.
- They could differentiate between precious and semi-precious materials using the balance.
- They mastered designing and manufacturing planispheric, spherical and quadrant astrolabes using different materials.
- They invented about 1000 application for the astrolabe.
- One the important applications of the astrolabe was fixing the direction of Mecca and the prayer times during the day 24 hours.

References

[1] A. Mieli, “La Science Arabe et son role dans l'evolution mondiale”, Leiden, J. Brill.

[2] Abdul-Alim, "Navigation and sea sciences" (in Arabic), Knowledge World, 1979.

[3] D. King, "The origin of the astrolabe according to the medieval Islamic sources", Journal for the History of Arabic Science, Vol.5, 1981, pp.43-83.

[4] W. Knorr, "Ancient sources of the medieval tradition of mechanics", Supplemento agli Annali dell' Istituto e Museo di Storia della Science Anno, 1982.

[5] A. Al-Shakil, "Chemistry in the Islamic Civilization" (in Arabic), Dar Al-Shrook, 1989.

[6] I. Fernini, "A bibliography of scholars in medieval Islam", The Cultural Foundation, Abu Dhabi, 1998.

[7] P. Damerow, J. Renn, S. Rieger and P. Weinig, "Mechanical knowledge Pompeian balaces", Max-Planck-Institute for the History of Science, Preprint 145, 2000.

[8] B. Newbury, et. al., "Synchrotron application in archaeometallurgy: analysis of high zink brass astrolabes", International Center for Diffraction Data, Advances in x-ray Analysis, Vol.47, 2004, pp.30-35.

[9] R. Sward, "The inscriptions of the astrolabe by Abdel-Karim in the British Museum", Muqarnas, Vol.21, 2004. pp.345-357.

[10] S. Zaimeche, "Merv", Foundation for Science Technology and Civilization, Publication ID:4077, March 2005.

[11] M. Abattouy, "The Islamic science of weights and balances", ibid, Publication ID:616, November, 2006.

[12] Y. Faruqi, "Contributions of Islamic Scholars to the scientific enterprise", International Education Journal, Vol.7, No.4, 2006, pp.391-399.

[13] M. Molayer, "The Persian astronomical connections and the European Renaissance", Academia Europaea 19th Annual Conference, 2-5 September 2007, Toledo, Spain.

[14] M. Amin and A. Kurdi, "Explanation and editing of Ibn Al-Shatir treatise on astrolabe" (in Arabic), Department of Physics and Astronomy, Faculty of Science, King Saud University, SA, November 2007.

[15] A. Borelli, "Aspects of the astrolabe", Franz Steiner Verlag Publication, 2008.

[16] W. Hazmy, Z. Zainurashid and R. Hussaini, "Biography Muslim scholars and scientists", Islamic Medical Association of Malaysia, 2009.

[17] R. Al-Rabbi, "Muslims, scientific contributions: lost in oblivion", http://www.muslimlinkpaper.com/editors-desk/11-opinion/2224-muslims-scientific-contributions-lost-in-oblivion.html (July 2010).

[18] D. Capecchi , "Weight as active or passive principle in the Latin and Arabic scientia de ponderibus", Organon, Vol.43, 2011, pp.49-78.

[19] L. Godoy, "Structural stability concepts in medieval and renaissance mechanics", Laten American Journal of Solids and Structures, Vol.8, 2001, pp.83-105.

[20] . Craig, "How to construct an astrolabe using your PC", Astronomy Report, 21st Century Science and Technology, Winter 2011-2012, pp.38-54.

[21] W. de Graaf, "The astrolabe", www.astro.ru.nl/fverbunt/iac2011/astrolabe.pdf (2011).

[22] D. Hayton, "An introduction to the astrolabe", Darlin Hayton, 2012.

[23] Abdul-Rahman and M. Akhtar, "Heart pleasing and praiseworthy buildings: reviewing Mughol architecture in the light of primary sources", Pakistan Journal of Engineering and Applied Science, January 2012, pp.103-113.

[24] K. Saeed, "Islamic technology: an appraisal on the reciprocal exchange between the east and the west", International Journal of Humanities and Social Science, Vol.2, No.3, February 2012, pp.106-112.

[25] H. Hall, "Books mentioned in the fiction of Louis L'Amour", https://repository.tamu.edu/bitstream/handle/1969.1/147615/BooksinLAmour-2-2013.pdf?sequence=1 (February 2013).

[26] R. Krox-Johnston, "Practical assessment of the accuracy of the astrolabe", The Mariner's Mirror, Vol.99, No.1, 2013 , pp.67-71.
[27] A. Sparavigna, "The science of Al-Biruni", International Journal of Science, Vol.12, 2013, pp.52-63.
[28] W. Aktar, "The evolution of physics and technology: A saga with ancient middle east scientists", www.shamskm.com (2013).
[29] T. Cole, "Astrolabe of Mohammed ibn Said Al-Sabban", JAMA, Vol.311, No.19, 2014, pp.1946-1947.
[30] A. Al-Shakil, p.131.
[31] C. Khanikoff, "Analysis and extracts of book of balance of wisdom by Al-Khazini", American Oriental Society, California, 1857, p.87.
[32] A. Al-Shakil, p.55.
[33] C. Khanikoff, p.87.
[34] A. Muntasir, "History of science" (in Arabic), Dar Al-Maarif, 1980, p.153.
[35] A. Sparavigna, p.1.
[36] A. Al-Shakil, p.81.
[37] F. Sezgin, "Mathematical geography and cartography in Islam", Frankfortam Main 2011, p.297.
[38] A. Al-Khazini, "The book of balance of wisdom" (in Arabic), Ottoman Encyclopedia, Hyderabad Deccan , 1940.
[39] M. Megahid, "Balance of wisdom and the scientific research procedure of Al-Khazini", General Egyptian Authority for Book, 2005.
[40] C. Khanikoff, "Analysis and extracts of book of balance of wisdom by Al-Khazini", American Oriental Society, California, 1857.
[41] A. Al-Khazini, "Kitab Mizan Al-Hikma", Library of the University of Pennsylvania, USA, MS No. LJS386.
[42] Al-Shakil, p.133.
[43] M. Mazzawi, "Arabic balances science: Al-Khazini as an example" (in Arabic), Modern Dialoque, Vol.2314, June 2008.
[44] A. Al-Khazini, pp.46-53.
[45] M. Al-Baba (editor), "Al-Kalanci medicines" (in Arabic), University of Aleppo, Syria, 1983.
[46] R. Green, "Omar Khayyam: much more than a poet", Montgomery College Student Journal of Science and Mathematics, September 2002.
[47] A. Al-Khazini, pp.151-153.
[48] A. Al-Hassan (editor), "The book of ingenious devices by Banu Musa", University of Aleppo, Syria, 1981, p.438.
[49] J. Buttner, "Ancient balances of the nexus of innovation and knowledge", Max Planck Institute for the History of Science, October 2013.
[50] www.acadernla.edu/2216522/weights
[51] E. Analdolu, "Anatolia antique", Institut Francais D'Etudes Analtolieniermes Geages-Dumezil, De Boccard, 2013, p.176.
[52] ------,"Collections: Arts of the Islamic world – Fatimid weight", http://www.brooklynmuseum.org/opencollection/objects/121425/Fatimid_Weight
[53] E. Winterburn, "Using an astrolabe", Foundation for Science, Technology and Civilization, August 2005.
[54] G. Khangi, "Qibla and its assignment in Jurisprudence, astronomy Jurisprudence and engineering", The 3rd Islamic Astronomical Conference , Amman, Jordon, 20-21 October, 2003.
[55] -------, "The Al-Khujandi astrolabe and some later derivatives", http://islamicartandscience.blogspot.com/2011/09/al-khujandi-astrolabe-and-some-later.html (September 2011).
[56] R. Covington, "Rediscovering Arabic science", www.muslimheritage.com/article/rediscovering-arabic-science (2007)
[57] https://www.pinterest.com/pin/236579786648766806/
[58] http://dla.library.upenn.edu/dla/fisher/record.html?id=FISHER_v064755&fq=period_facet%3A%2211th%20Century%22%20AND%20worktype_facet%3A%22Industrial%20Design%22&
[59] Carlesdorce, "The British Museum", (2013) http://themathematicaltourist.wordpress.com/tag/astrolabe/page/2/
[60] --------, "Astrolabe with lunar mansions by Abdel-Karim", http://www.mhs.ox.ac.uk/astrolabe/catalogue/browseReport/Astrolabe_ID=149.html
[61] Carlesdorce, "The Ashmolean Museum in Oxford", http://themathematicaltourist.wordpress.com/tag/astrolabe/page/2/ (2013)
[62] E. Winterburn, "Astronomical instruments through time", http://www.bbc.co.uk/history/ancient/cultures/astronomical_instruments_01.shtml (2011)
[63] ------, "Astronomical and navigational instruments", http://collections.rmg.co.uk/collections/objects/10710.html
[64] ------, "Astrolabe quadrant", http://www.qantara-med.org/qantara4/public/show_document.php?do_id=273&lang=en
[65] ------, "Astronomi in medieval Islam", https://nauticajonkepa.wordpress.com/2008/11/02/astronomy-in-medieval-islam/ (2008).
[66] --------, "Horary quadrant", http://www.metmuseum.org/collection/the-collection-online/search/449085
[67] --------, "Astrolabic quadrant made by Mohammed ibn Ahmed Al-Mizzi", http://www.britishmuseum.org/explore/highlights/highlight_objects/me/a/astrolabic_quadrant.aspx
[68] British Museum, "Arabic astrolabes, clocks sundials", http://traveltoeat.com/arabian-astrolabes-clocks-and-sundials-british-museum/
[69] -------, "An important group of scientific instruments from the Islamic world", in "Arts of the Islamic world", London, April 2005, p.58.
[70] -------, "A rare Ottoman Syrian brass quadrant", http://www.christies.com/lotfinder/LotDetailsPrintable.aspx?intObjectID=2034572
[71] ------, "Spherical astrolabe by Musa", http://www.artfund.org/supporting-museums/art-weve-helped-buy/artwork/3600/spherical-astrolabe
[72] ------, "Islam Part 4: Islam's gifts to the world", http://www2.mcdaniel.edu/german/islamindach/islkamindach_PDF/Islam_Part_4.pdf
[73] Al-Fadl ibn Hatim Al-Nairizi, "The work with spherical astrolabe" (Arabic Manuscript), Escorial Monastery, No.961.

Biography

Galal Ali Hassaan:

- Emeritus Professor, Faculty of Engineering, Cairo University, Giza, EGYPT.
- Has got his Ph.D. from Bradford University, UK in 1979 under the supervision of the great professor John Parnaby.
- Served in Cairo University, Bahrain University, Al_Ain University, British University at Cairo, Institute of Aviation Engineering & Technology at Giza, Al_Fayyoum University and Sues Canal University.
- Research in Automatic Control, Mechanical Vibrations, Mechanism Synthesis and History of Mechanical Engineering.
- Published 10's of research papers in International Journals and Conferences.
- Published books on Experimental Systems Control and Evolution of Mechanical Engineering.