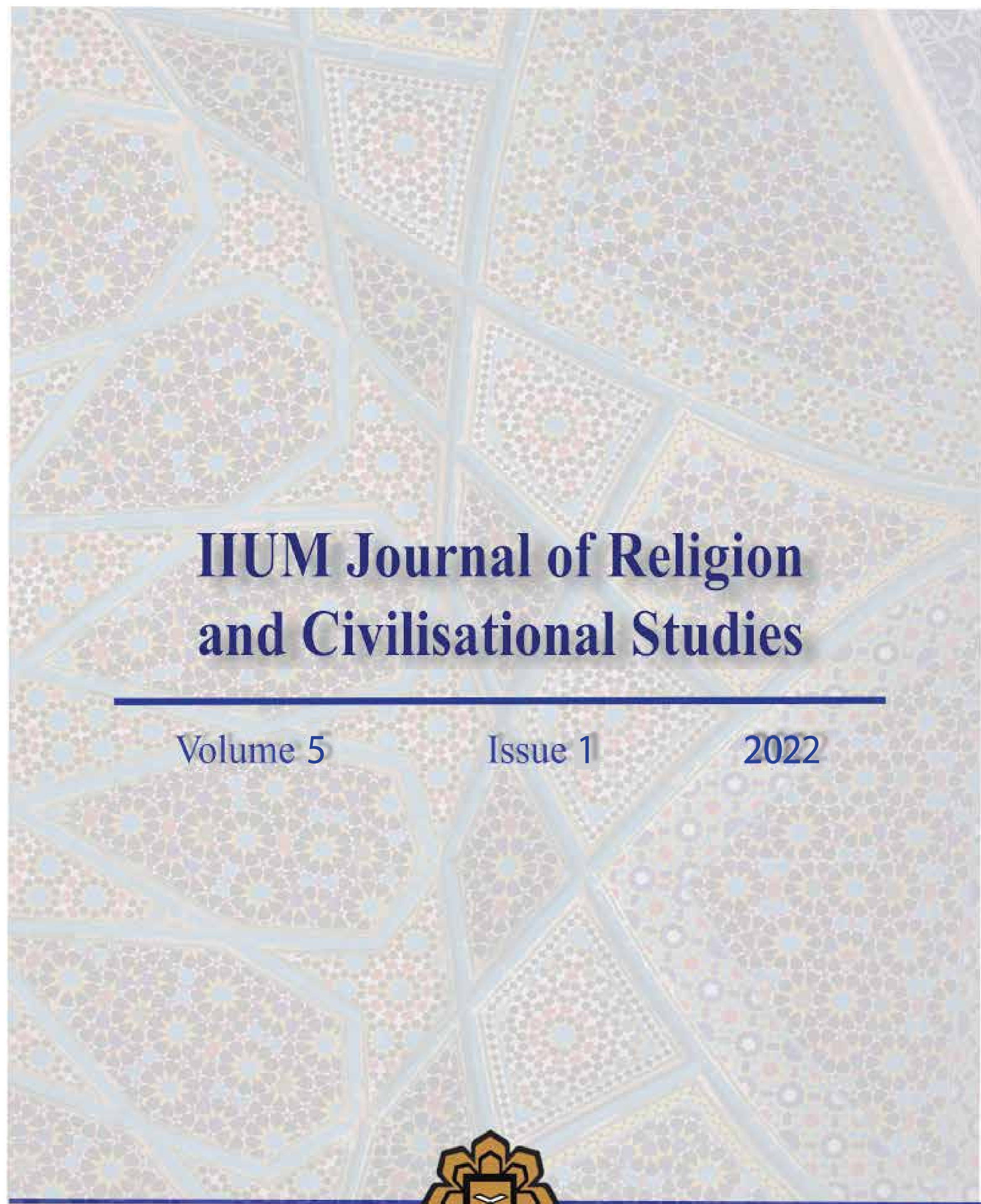

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CONTENTS

Editorial 1
Fauziah Fathil

Articles

Challenges Faced by Turkish Students Adjusting to Multicultural Environment in the International Islamic University Malaysia (IIUM) 5
Togan Nezihat Sena and Iyad Muhammed Eid

Measuring Time: An Islamic Contribution to Time Measurement Techniques 27
Syed Hasan Sardar

Colonial Civilisation: Consolation and Iron Fist within the Dutch Ethical Policy in Aceh 45
Nia Deliana and Arshad Islam

Christiaan Snouck Hurgronje on Makkah as a Centre of Pan-Islamism and Anticolonialism 66
Spahic Omer

Viewpoints

The Intellectual and Cultural Impact of Islam on India during the Delhi Sultanate (1206-1526) 98
Arshad Islam

Book Review

Inglehart, R., *Religion's sudden decline: What's causing it, and what comes next?* 107
Makmor Tumin

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Measuring Time: An Islamic Contribution to Time Measurement Techniques

Syed Hasan Sardar[1]

Abstract: How does one calculate the nychthemeron? It is no secret that Muslims have gone to great lengths to find the answer to this question, even setting up institutions to study other civilisations' methods in order to introduce a first-of-its-kind understanding of the universe. This article explores the various Quranic motivations that inspired human creativity to find the hidden truths of the universe using math and science formula. The scientists took these indicators as guideposts to understand many untold or invisible realities of the universe, including time measurement. The Quran, for example, stresses the importance of time in many ways, including declaring Time as a sacred thing (103:1-3), mentioning the phases of day and night (4:103) and putting time into the obligation of daily prayers (17:78). Due to these motivations, Muslim scientists employed instruments such as the shadow measurement, astrolabe and water clock to determine time. Additionally, this article highlights Archimedes' pressure principle, the Persian method of releasing water and the Indian concept of division of time into days and nights to track how Muslim scientists eventually evolved these tools into the earliest model of the modern 24-hour clock. The primary sources for this study are *Kitāb al-Jabr wa-l-Muqābala (The Compendious Book on Calculation by Completion and Balancing)* by Muḥammad Ibn Mūsā al-Khwārizmī, *Kitāb al-Fihrist (The Catalogue)* by Ibn al-Nadīm and *Kitāb Mīzān al-Hikma (Book of the Balance of Wisdom)* by Abū-l-Fatḥ ʿAbd al-Raḥman al-Khāzinī.

Keywords: Water Clock, Time Measurement, Islam, Science and Astronomy.

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Introduction

Time is the world's greatest Mystery. Fundamental questions about time—how old is the world and what is the genesis of earthly life? How long can life on earth last? Will there be a resurrection, and how will it take place? How are earthly and heavenly times related—among others, have always encouraged human beings' curiosity to search for answers, which in turn has led us to develop and apply a number of scientific concepts to this effect. In this regard, human intelligence has prompted us to invent laws to measure and understand time as a frame of reference, including registering all that has happened in the past, in order to observe the present and pontificate on the future.

Although human beings are naturally inclined to delve into the unknown questions about time and its essence, these questions become more sophisticated when they are illuminated by divine text. The Quran upholds the essence and importance of time when it takes an oath concerning the Realness of Time as natural law, excluding those who practice righteous deeds while enjoining Truth and Patience from those who are lost (103:1-3). The righteous deeds are duties prescribed to humanity, and worship is the essence and spirit of such actions—this is the key purpose behind human beings and even the jinn's origin and development (51:56). The Almighty not only emphasised on the performance of worship through obligatory prayers, but also guided mankind to measure the year, months, weeks and days. Therefore, He has made it easy upon His believers to take careful account of time and to track the passing moments in order to perform the obligatory prayers (*ṣalāh*) at the right times (4:103). Furthermore, the Almighty specified the daily prayers times at dawn, at the decline of the sun from meridian and after sunset and night (17:78).

The dual edge curiosity (i.e., the natural and religious) ignited the minds of Muslim scientists to muse about the clued scientific suggestions of the Quran in order to develop the best technical and mechanical time measuring devices in history. This article highlights the chronicled development of this phenomenon in Muslim society, which has contributed to human advancement by fostering the exchange of thoughts and ideas, regardless of concerns about religion, culture and social structures.

First, the article proposes a theoretical Quranic framework for future scientific and technological research in time technology, before giving a brief account of how Muslim scientists successfully engaged with contemporary advanced technologies that resulted in the development of some of the most sophisticated time measuring devices in history, including the astrolabe and water clock.

This study shows how Ismāʿīl al-Jāzarī's water clock inspired the design and technique of modern clocks. The article finally discusses how religious extremism and orthodoxy have eroded this trend of scientific and intellectual development in the Muslim world.

Time Measurement: A Journey from Tradition to Modern Technique

Generally, in Islam, the determination of the stated time for obligatory prayers is strictly conditioned. Time inspection and calculation is simple in plain areas by shadow and accurate sun observation, but it is extremely difficult in regions where the weather shifts dynamically due to day and night imbalances, heavy rains and cloudiness, among others. As more territories came under Muslim rule, the issues with the calculation of time grew proportionately. The rapid expansion of Muslim rule, from its roots in the Arabian Peninsula to Spain in the West and India in the East by the 7th and 8th centuries respectively, broadened the meteorological and geographical challenges for Muslim scientists to find a solid solution to the *best* times for prayers. So, embracing new scientific astronomical methods to quench the thirst of their religious needs was among the first priorities of the Muslim authorities. Such early conquests on vast geographic territories of the world inspired people to accept Islam and develop scientific methods to meet the faith's fundamental requirements. Unlike the other religious rules, the Muslim rulers founded numerous scientific centres in Mesopotamia, Egypt, South East Asia and so on, with due regard to the respective multi-religious and pluralistic society they inhabited. Muslim scientists engaged in modern engineering, mathematics and astronomical computation for time measurement, drawing from Persian, Greek, Egyptian, Chinese and Indian methodologies that represent the pluralistic and inclusive nature of Muslims in scientific and scholastic development.

The Golden Age of Islamic scientific and mathematical sciences began with the letters about astronomy by Jābir Ibn Hayyān (d. 813 AD) during the rise of the Abbasid Caliphate in Baghdad. In this period (8th century CE), the Abbasid court in Baghdad became a lodge of tens of great mathematicians, astronomers, physicists and astrologers from both the East and West. In the realm of the Second Abbasid Caliph, an Indian astronomer visited Caliph Al-Manṣūr's court with some tables of planetary equations according to the mean observation motions related to both the solar and lunar eclipses and ascension of the sign (Brahmagupta & Bhaskara, 1817). The Caliph appointed his court astronomer, Muḥammad ibn Ibrāhīm al-Fazārī (d. 806 CE), to translate these tables into Arabic (*zīj*). Al-Fazārī is understood to be the first Muslim scientist to have worked on the methods and functioning of the astrolabe and astronomical tables. He was the author of the books *Kitāb al-Zīj ʿala sinī al-ʿArab (Tables of Arabic calendar)*, *Kitāb al-Miqyās al-Zawāl (The book on calculating the noon)*, *Kitāb al-ʿamal bi-l-usturlāb wa huwa zāt al-ḥalaq (The book on the use of the astrolabe and armillary sphere)* and *Kitāb al-usturlāb al-musattah (The book on the use of astrolabe)* (Ibn al-Nadīm, 1929).

This transformation of scientific methodology was explained by Colebrooke in the following words:

> …the system of astronomy, which was made known to the Arabs, and which is by them distinguished by the appellation in question, appears to have been that which is contained in the *Brahma-siddhánta*, and which is taught in BRAHMEGUPTA'S revision of it. (Brahmagupta & Bhaskara, 1817, p. ixv)

On the other hand, Ibn al-Nadīm (d. 995/998 CE) states that the book *Sind-Hind* was transformed by Yaʿqub ibn Ṭāriq with the title *Zīj maḥlūl fī al-Sindhind lī daraja daraja* (*The astronomical tables in Sindhind resolved for each degree*), which is supposed to be Brahmagupta Siddhanta's translation (Ibn al-Nadīm, 1929). As both astronomers belonged to Caliph al-Manṣūr's court, there is a possibility that a team of translators would have done this translation.

Baghdad's court also undertook a variety of other important projects, such as the Greco-Arabic translation movement, the establishment of

Bayt al-Hikma (The House of Wisdom) and establishing paper-making factories throughout Baghdad, which played a catalytic role in unfolding the science and scholastic skills of Oriental scholars. Such movements inspired the Arab scientists to translate ancient Greek philosophical works into Arabic and vice versa. With these accomplishments, a new milieu arose that bridged the gap between Oriental and Western sciences. The greatest milestone in the history of Indo-Islamic scientific transmission is Mohammad Ibn Musa al-Khwarizmi's tables, which merged the intrinsic essence of the Indian *Brahma-Siddhanta* and *Garita-Sara-Sangraha* (*Compendium of the essence of Mathematics*) of Mahaviracarya, *Zīj al-Shahriyār* (*The tables of Persian King*) of Persia and *Almagest*, which concerns Greek astronomy. Al-Khwarizmi, along with Brahmagupta Siddhanta, consulted with another founder of Indian astronomical assets. ʿAlī Mūsā Musharrafa and Muhammad Mursi Aḥmad (editors of al-Khwārizmī's *Kitāb al-Jabr wa-l-Muqābala*) explain:

> It appears Mahavira mathematical research was accessible to him during the Khwarizmi period. Mahavira had some formulas to solve second-degree equations, and it is worth remembering that he had attempted to substitute the negative equation with negative and its square, which is not consistent with current theory. (Al-Khwārizmī, 1937, p. 8)

By the time *zīj* (astronomical tables) literature was developed, Muslims also developed a specific science known as *'Ilm al-Mīqāt* (The science of time measurement) to observe ritual times. The Muwaqqit (an expert of time measurement) used this information to determine the prayer times by observing the breakdown of the day before sunrise for morning prayer, the shadow direction and lengths for the two prayers during the day, the shadow length after sunset for the evening prayer and the twilight for the late evening prayer.

By now, Muslim scientists had made significant progress in calculating the best times for the defined daily prayers. In order to find the exact hour of all prayers, they had prepared the tables based on near-perfect measurement of the motion of the sun at its degree scale. However, this was not a universal solution because these tables were consistent with the particular latitudinal and longitudinal locations for which they were derived. Most of the tables were for Baghdad, Damascus, Cairo, Mecca and Medina, so the regions that did not fall into their orbit needed a resolution.

Finally, Baghdad's court scientists started designing and producing astronomical instruments rather than relying on computed astronomical tables based on solar, lunar and earth-axis algorithms. The most advanced instrument used by Muslim scientists was the astrolabe. The first Muslim astronomer, al-Fazārī (d. 796/806 CE) wrote about the use of the astrolabe, as earlier described. Later, al-Khwārizmī wrote a book on the use of the astrolabe (Ibn al-Nadīm, 1929). In his *Mafātiḥ al-ʿulūm* (*Keys of the sciences*), he separately describes a few astronomical instruments for time measurement and also provides manuals for their use.

A Revolution of Technical Devices

Astrolabe

In addition to a compass, the astrolabe also measures time and allows the user to identify stars and constellations. The primary specimen of the astrolabe is circular in shape, although spherical and triangle shapes are also found. Additionally, it was produced in different materials, including wood and metal, usually brass or iron. The earliest specimen of the astrolabe was found as far back as antiquity, but its most technical specimens and models originated in the Islamic Golden Age.

The earliest statements by al-Khwārizmī regarding the design, functions and usages of the astrolabe are found in *Mafātiḥ al-ʿulūm* (*Keys of the sciences*) from the Islamic Golden Age. In one sense, al-Khwārizmī explains the meaning of "Astrolabeon"—either it is a combination of "Astro", which means start, and "Labeon", which means woman; or "Lab", which means man, and "Astro", which means lines. As the nearest transmitters of the astrolabe's design were Arabs, it is likely that the latter meaning was influenced by them since *satir* in Arabic is the plural of *satr*, which means lines. As an alternative, al-Khwārizmī provides some other astronomical instruments to measure time, such as the bowl, watch box and horary clock (Ibn al-Nadīm, 1929).

Water Clock: A Step Closer to the Modern Clock

The water clock is one of the most ancient astronomical instruments in the world and has been used since antiquity. There were numerous fascinating models and designs of the water clock available until the 6th and 7th centuries. The Muslim scientists also utilised these various techniques of the water clock from the Greek, Persian, Chinese and Indian models. They took the main features of these models and produced the most sophisticated water clock devices of the period.

The mechanical and scientific details of the current models must be examined first.

Greek Model. The scientific exchanges between the Greek and Muslim scientists brought about a radical shift in water clock design, methodology and manufacturing. Early horological clocks are regarded as the ancestors of modern mechanical clocks, as both clocks are based on mechanical hydraulic and pneumatic means to produce transit and energy power. The oldest surviving model of a horary water clock is found in Egypt and its date of origin is estimated to be around 1380 BC. It has two water basins, one to regulate the clock's operation and the second to function as a reservoir (Hill, 2007). The Greek scientists borrowed Egyptian technology and built more mechanised water clocks to display all-hour time, in the way Archimedes (d. 212 BC) did. The later Roman kings burned the Greeks' scientific treatises and achievements, but some of them survived through Islamic intellectual renaissance due to translations. Ibn al-Nadīm explains that "although Romans burned Archimedes' treatises, some of them survived by translation: the Archimedes book on water clock functionality which releases balls is also one of them" (Ibn al-Nadīm, 1929, p. 386).

The Archimedian concept played the central role in the production of water clocks by Muslim astronomers and scientists. Archimedes' techniques are understood to have spread to Persia before Islam arrived. Ibn al-Nadīm describes several more 8th century scientists who continued the upgrade of Archimedes' clepsydra. He provides descriptions of Banū Mūsā—who were three famous Persian brothers named Muḥammad (d. 873), Aḥmad (d. 9th century) and al-Ḥasan (d. 9th century)—whose father was Mūsā Ibn Shākir. They travelled to Byzantine and returned with a number of great manuscripts, which they preserved for years. They were masters in mechanical engineering, algebra, movements, poetry and astronomy. They translated a treatise called *Qarastun*, a book that discusses Archimedes' theory of balance (Ibn al-Nadīm, 1929). Another scholar that Ibn Nadim credited with furthering the Archimedes treatise was Qurra Ibn Qamita al-Harrānī.[2] Ibn al-Nadīm claimed that Thābit ibn Qurra plagiarised his work. As he says "I saw his success on *Dubayqi* (A kind of cloth known in Damascus Syria) he had a book about making an instrument that releases the balls on Archimedes' account" (Ibn al-Nadīm, 1929, p. 411).

Persian Model. While the Islamic kingdom reached Egypt and even some parts of Europe, the Persian model served as the prototype for the Islamic water clock. The Persians used different types of water clocks for various purposes, as al-Khwarizmi reported. Al-Khwārizmī describes one of the Persian water clocks used for agricultural needs in the following words:

> Finkal (Pangan/Fanjan) is equal to 10 Bast [Bast is a measuring scale for People of Marv whose length and width is equal to shaieera (barley)] and it has a hole at the bottom to release the water. (Al-Khwārizmī, 1989, p. 79)

In agricultural tools, al-Khwārizmī considered Pangan/Fanjan to be superior to the clock, which implies that the people of Marv used water clocks for irrigation.

Furthermore, al-Khwārizmī describes the Saat al Moavveja/Dabba process or water clock in the following words:

> Water movements are only attracted by themselves by placing an empty plate or something similar with a hole at the bottom above the water, and strings are attached to it, just as the scales are attached to the palm of the scale. These movements may be equal to arts of different shapes, some of which are gentler than others and refer to what I have mentioned. And it may be another race, and it is making a machine from zero to a hollow, which has no outlet at all, and it is placed in a bucket or the like, and then poured into the bucket gentle water. As the water increases, the water floats that instrument and rises what is attached to it from the

---

[2] He lived before Thabit ibn Qurra (died 901).

> bodies, then movements will occur to that as well, and this hollow deity is called the bear. (Al-Khwārizmī, 1989, p. 219)

However, the primary usage of the water clock was attributed to measuring the water distribution for farming and other cultivation needs. Other usages, such as calculating the nychthemeron and finding the duration of the night and day across the year, were also recorded by Persian sources. Furthermore, most of the Persian sources show that, similar to the common usage of the water clock, copper was a dominant material used to manufacture water clocks among Persians.

Despite the uses and material, the Persian mechanism for dividing the nychthemeron into units and sub-units was also different from the Greek and Indian modules. The Persians defined the *tāq* as their main horary unit, in which the duration changes as per the duration of their sub-units called *bang*. The minimum duration of a *bang* is five minutes, while the maximum duration is 10 minutes. If a water clock was manufactured as per mechanism of five minutes Bang, then a single *tāq* would have 144 Bang, and the total would be 720 minutes or 12 hours in today's standard. On the contrary, if a water clock design was based on 10 minutes *bang*, then its single tāq would include 72 *bang*, which totals 720 minutes or 12 hours in today's standard (Ezadkhwasti et al., 1396).

Those who used to run a water clock were known as *mīrāb*. A *mīrāb*, or operator of a water clock, used to control the entire operation, including emptying a sunk bowl and repeating the process from start. Moreover, a *mīrāb* was also responsible for keeping track of all the passing units. For maintaining the record, he used to toss a tiny stone after each bowl was sunk (Saadatmand et al., 1395).

Indian model. While Islamic knowledge was supplemented with Persian and Greek techniques, there were also other influences. The initial transmission of the Indian treatise called *Brahmagupta Siddhanta* (*Brahmagupta's treatise*) to the Baghdad court—a part of the assimilation of the principle of zero and Indian astronomical tables—transformed into a thorough study of time measuring instruments used by Indian scientists. The 26th chapter of *Brahmagupta Siddhanta*, titled *Yantradhaya* ("Chapter on instruments"), discusses 17 types of time measurement instruments:

1. Dhanuyantra- Bow instrument
2. Turyagolaka yantra- Quadrant (one-fourth sphere)
3. Cakra Yantra- Wheel or circle
4. Yasti Yantra- A pole or staff instrument
5. Sanku Yantra- Gnomon
6. Ghatika Yantra- A clock or pot instrument (main)
7. Kapala Yantra- Bowl or potsherd instrument (main)
8. Karttari Yantra- Scissor or knife-cutter
9. Pitha Yantra- Pedestal or seat instrument
10. Salila Yantra- Water leveller
11. Brahma or Sana Yantra-For drawing circles/compass
12. Avalamba Sutra-Threads with plumbs (plumb lines)
13. Karna or Chaya-Karna- A set of squares for diagonals
14. Chaya or Sanku-Chaya- Sundial
15. Dinardha Yantra-Midday measure instrument
16. Arka Yantra-Sun instrument
17. Aksa or Palansa Yantra- Small degree measuring arc instrument (Brahmagupta, 1966, pp. 333-334)

The water clock had been in use in India since ancient times. Among the post-*Aryabhatta* treatises, *Surya Siddhanta* (Sun Treatise) offers the most detailed description of its use:

> At the equator, the length of the day is always 30 Ghatikas and the length of the night is also same, and in the days', length increases as we move further away from the equator, and vice versa is true for the northern hemisphere. (Shahstri, 1861, p. 82)

Surya Siddhanta describes that the function of the water clock is to determine the exact hour; this is called *Kapala Yantra* (Shahstri, 1861). It is manufactured through a copper vessel with the shape of a water jar tapering downwards with a small hole at the bottom. The clock floats on a clean water reservoir and sinks exactly 60 times in a day and night. (Brahmagupta, 1966)

Varahamihira details a similar mechanism in his 6th century work titled *Panca Siddhantika* (*The Five Astronomical Canons*). He describes a water clock similar to that which is detailed in *Surya Siddhanta* (*Sun Treatise*) in terms of manufacturing and functionality—that a water clock is made by placing a copper vessel on a spherical pot with a tiny hole pierced at its centre. The vessel's hole is calibrated for it to sink 60 times during the day and night. This period is described as being equivalent to reciting a 60-syllable-long verse for 60 times. Vahamihira calls a sinking bowl's time measuring unit as Nadi: a Nadi has 24 minutes described as the time taken to draw 180 breaths, according to Varahamihira (1993).

Abū Rayḥān Muḥammad ibn Aḥmad al-Bīrūnī (d. 1048), on the other hand, describes remarkable details of the materials, sizes and uses of contemporary water clocks. He quotes from Uppala Kashmiri's *Srudhava* that a day is divided into 60 Ghati (Units), determined by a wooden clock. He describes the Indian water clock mechanism as follows:

> If you bore in a piece of wood a cylindrical hole of twelve fingers diameter and six gingers height it contains three mana (a mana is about 40 kilograms) water. If you bore in the bottom of this hole another hole as large as six plaited hairs of the hair of a young woman and not of an old one nor of a child, then three mana of water will flow out through this hole in one Ghati (Unit). Each Ghati is divided into sixty sub-units called Cashaka/Cakhaka or Vighatika. (al-Bīrūnī, 1958, 282)[3]

This is equivalent to today's timing module: a day of 24 hours, with each hour divided into 60 minutes and each minute further divided into 60 seconds, with the total seconds count adding up to 86,400.

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[3] Sub-unit equal to 24 seconds. https://www.wisdomlib.org/definition/vighatika

Al-Bīrūnī's description of a day has 60 Ghati (Units). 1 Ghati has 60 Vighatika (sub-unit), with each Vighatika equivalent to 24 seconds. Therefore, each day in both formulations has 86,400 seconds.

The Indian astronomers used a particular kind of water clock made from various materials, including bronze, gold and wood. According to further research by al-Bīrūnī, it is obvious that Indians used announcement tricks to pass each unit of the hour. Biruni writes:

> In some parts of their country, they have clepsydra regulated according to the Ghatis by which the times of the eight watches are determined. After a watch which lasts seven and a half Ghati has elapsed, they beat the drum and below a winding shell called "Sankha" (Conch), in Persian "Sapeed Mohreh" (White Conch). I have seen this in the town of "Purshur". (al-Bīrūnī, 1958, p. 285)

The Final Water Clock Model by Muslim Scientists

The Muslim individual who advanced the water clock mechanism was Abū Abdallah Muḥammad ibn Ḥasan ibn Akhi Hishām al-Shatawī (Ibn al-Nadīm placed him in the category of unknown scientists and astronomers). He wrote treatises and manuals on several topics, such as making oblique sundials, making drum-shaped sundials and also determining Azimuth's elevation and the ball release technique (al-Bīrūnī, 1958). The last one was in the nature of a clepsydra, in which water releases the balls that push a lever to make it function. The aforementioned initial attempts to modernise the water clock design based on Persian and Greek technologies planted the seeds of inspiration in the smartest medieval scientists of the Islamic Golden Age, such as Abū al-Fatḥ ʿAbd al-Raḥman al-Khāzinī (d. 12th century), Ismāʿīl al-Jazarī (d. 1206) and Riḍwān al Sāʿātī (d. 1230). After obtaining the designs and techniques from different regions, the scientists at the Baghdad court based their designs by combining the best aspects of the available knowledge. This included Archimedes' pressure or balance principle, the Persian water releasing techniques as well as the Indian concept of division of time into day and night. From these emerged the designs of three large water clocks, including the one discussed in detail below.

Al-Khāzinī discusses the function of the water clock in Chapter 8 of his legendary book titled *Kitāb mīzān al-ḥikma* (*Book of the balance of wisdom*). He called the clock Finjan and defined two types of water clocks: a small one and a large one. The small water clock operated only to measure an hour, while the large one was used to measure 24 hours (including 60 minutes per hour) (al-Khāzinī, n.d.). Al-Khāzinī placed conditions on the water temperature and its purity, as the water weight varies with changes in temperature and density.

In al-Khāzinī's *Kitāb mīzān al-ḥikma*, the water clock is briefly described in the following words:

> The balance-clock consisted of a long lever suspended similarly to the balance-level. To one of its arms was attached a reservoir of water, which by means of a small hole perforated on the bottom of it, emptied itself in twenty-four hours. This reservoir, being filled with water, was poised by weights attached to the other arm of the lever, and, in proportion as the water flowed from it, the arm bearing it was lifted the weights on the other arm slid down, and by their distance from the centre of suspension indicated the time which had elapsed. (Khanikoff, 1857, p. 105)

Al-Sāʿātī developed the next most advanced water clock concept in 1203 AD. In his treatise titled *Kitāb ʿamal al-sāʿāt wa-l-ʿamal bihā* (*Book on the construction of clocks and their use*), he provides the full description of his water clock. This clock used to project the time on a panel made from a timber board that was 4.23 meters long and 2.78 meters high. There was a row of 12 gates at the centre of the board and two falcons on both sides of the row. At the passing of each hour, a door opened and a falcon bent down, as if prostrating to God, and released the ball. On the upper side of the doors, there was a wheel with 12 holes. Each hole was a symbol of 12 signs and hours of the zodiac. One hole was completely illuminated during the darkness of night to indicate the passing of an hour (Hill, 2007). One of this clock's most innovative features was that it used a pulley to gear the doors open. This clock is known as Jayrun Water Clock because it was built at the gate of the Great Mosque of Damascus, known as Jayrun.

However, the most sophisticated water clock was designed by another Muslim scientist named Ismāʿīl al-Jazarī. In his work titled *Kitāb fī maʿrifat al-ḥiyāl al-handasiyya* (*The book of knowledge of ingenious mechanical devices*), the headings of Chapter 4 present the overall layout of his elephant water clock, as follows:

1. Elephant water clock appearance outside.
2. Inside working water clock mechanism.
3. Elephant and dais.
4. Inside Elephant Machinery.
5. Completed the platform above the dome above the dais floor, the scribe above the platform and the movement thereof.
6. Building of mahout and hand moving equipment.
7. Two pairs of pillars, each pair having a cross-beam.
8. Building of a castle on which is a cupola and two falcons' heads.
9. Building a path in which balls pass and come to a stop, one after the other appears, now to the head of the right-hand falcon, now to the left falcon.
10. Creation of the balls from which they fall, going through a channel and dropping to the right and to the bottom.
11. Construction of the ring, half white and half black, covering the sections: construction of its movement; construction of the wheel on which the bird rotates on the dome of the castle: completion of the balls path.
12. Balcony and the man sitting thereon.
13. Two snakes on an axle with the ends in two holes.
14. A whistling instrument in the likeness of a bird's voice at the top of the cupola.
15. On the two vases on the Elephant's shoulders, the hanging cymbal and the water-clock planning. (Al-Jazārī, 1974, pp. 58-69)

Al-Jazarī's clock was the epitome of multicultural technological inventions depicting Chinese dragons, an Egyptian falcon, Greek constellations, an Indian elephant and a Muslim time-teller. His clock was the most sophisticated and profound advancement of the water clock. As of the 13th century, the Muslim scientists' water clock and time measurement technology was far superior to their counterparts in India. Indian scientists focused more on the astrological uses of water clocks, whereas Muslim scientists also worked on more advanced uses of measuring mechanical time, beyond merely for agricultural and astrological needs.

Al-Jazarī's elephant water clock, in spite of being a complete symbol of religious pluralism and intercultural scientific transmission, was a fascinating version of various techniques of ancient water clocks as well. The most vibrant technical feature of al-Jazarī's elephant clock is that he applied the best tricks to protect the water flow from invisible force or pressure. He used a conical plug and installed it in the main reservoir for transferring the water to the adjacent float chamber. Additionally, he placed all of the equipment inside the elephant's stomach in order to protect the water clock from outside air pressure and to help get flawless time results. He divided the day and night into 24 hours, which were dynamic in describing day and night. Unlike the Persians, al-Jazarī equipped his water clock as per the dynamic time telling techniques of India, whereby he described that the longest day of Jazīra (the latitude of his water clock) was 14.5 hours long, while the night length was 9.5 hours (Al-Jazārī, 1974).

Although engineering was al-Jazarī's fundamental and basic qualification, he was a master of craft skills as well. He explained the complete engineering details of the design and diagram of cylinder and other copper and wooden equipment (Al-Jazārī, 1974).

While the Indian and Persian scientists were motivated by different occupational and regional requirements to build water clocks, the Muslim scientists were largely motivated by religious necessities. Nevertheless, the general issues of common Muslims remained intractable since al-Jazarī's system was not accessible to ordinary people who needed to find the exact moments of specified times for mandatory prayers. This problem demanded an administrative solution, as the prototypes al-Khāzinī, al-Sāʿātī and al-Jazarī were difficult to replicate and generalise.

The growth of Muslim rule led to the development of astronomical knowledge, accompanied by vibrant incentives for Muslim scientists to improve the established techniques from Greece, Egypt, Persia, China and India so as to update time measuring instruments for more accurate and consistent measurements, irrespective of geographical coordinates. The astronomical tables and the astrolabe were previously either only concise with a specific location or intended for a particular party, rather than the public interest. Therefore, Baghdad's Muslim scientists were constantly engaged in the modification and development of scientific instruments until the death of Caliph Al-Ma'mūn (d. 833 AD), which led to the fall of the Abbasid Empire. Thereafter, the authority of the Abbasid caliphs slipped to other Central and West Asian rulers.

In the Golden Age of Muslim expansionism, foundations were laid for a pluralistic society. This had a knock-off effect on scientific syncretism and exchange, which enabled Muslim scientists to rapidly advance solutions to several problems in the social and religious realms.

Surprisingly, while most Muslim scholars and *ʿulamā'* of the Middle Ages were quite mutable and tendentious in practising natural science and engineering alongside accomplishing jurisprudential responsibilities, Muslims today have abandoned learning modern and natural sciences by the same orthodox religious authorities.

This progress was put to halt, and even reversed in due course, due to two key reasons:

- The reactionary prejudice of Muslim scholars and religious leaders weakened this impetus internally.
- The Abbasid empire was unable to successfully repel repeated foreign attacks and invasions on Muslim kingdoms, which became the principle external cause of its decline.

Thereafter, there were limited attempts at revivalism by the Muslim rulers in India in the 12th and 13th centuries CE, but these never reached the towering successes of the Golden Age of Islamic science and technology development. Consequently, the scientific developments until the 8th century CE of the Muslim caliphate remain ineffable in the history of Muslim rule.

Conclusion

There are several questions hotly debated in society related to Islam, science and religious diversity that are answered in this study. Throughout the article, a critical focus is placed on the importance of time in Islam and the time measurement achievements of Muslim scientists, ranging from shadow measurement, astrolabes and water clocks. Additionally, it debunks the many fabricated claims about Islam being an anti-scientific or anti-intellectual religion. Thus, this multidimensional study of Islamic scientific achievements about time measurement illuminates how the early Muslim scientists with a simple and first-hand understanding of the Quran, together with other scientists and scholars of various religious beliefs, embarked on highly advanced scientific activities and created a multicultural scientific society that laid the foundation for many modern inventions in the Islamic Golden Age. It also accounts for the causes of breaking this scientific wave from many different perspectives, encompassing religious and cultural aspects. Accordingly, the study reveals that the Quran upholds intellectual development and progress, and encourages science without provocation of religious extremism. In contrast, it indicates that if Muslims are afflicted by religious extremism and social and cultural separatism, it will lead to an intellectual and scientific decline in the Islamic world as it has happened in the past.

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