Science of Mechanics in the Ottoman Classical Period (14–18th Century)

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Abstract. This study discusses the role of mechanics in the Ottoman classical period spanning the 14th and 18th centuries. Firstly, it is asserted that the science of mechanics in the Islamic world was based on the works of the Ancient Greeks, and then Muslim scholars contributed further on this field. Secondly, it is emphasised that Ottoman science inherited the classical Islamic scientific tradition and demonstrating the mathematical nature of mechanics through the encyclopaedic work of Tashkopruluzāde, a prominent Ottoman scholar from the 16th century. Additionally, Tashkopruluzāde's definition of mechanical disciplines is analysed to understand Ottoman perspectives on sciences. Thirdly, the study explains how mathematics and physics were taught in the Ottoman classical/scholastic education system, introducing some books on these subjects. Moreover, the practical knowledge of mechanics applied by Ottoman architects and engineers is reviewed. Finally, the works on mechanics written by the Ottomans are discussed, illustrating the subjects studied up to the modern period. In conclusion, it is stated that the Ottomans developed the Islamic mechanical tradition and sustained it until the 18th century. They established new Western-style schools and included modern Newtonian mechanics into their education system in the 19th century.

Keywords: Ottoman science · Mechanics in Ottomans · Ottoman education · Tashkopruluzāde · Classification of sciences in Ottomans

1 Introduction

In the Islamic world, physics and mechanics were acquired through the works of ancient Greek scholars such as Aristotle, Euclid, Archimedes, Philo, Hero, and Pappus. Building upon these inspirational foundations, Muslim scholars like al-Kindī, Ibn Sīnā (Avicenna), Ibn Bajjah (Avempace), al-Isfizārī, al-Khāzīnī, Banū Mūsā, Ibn al-Haytham, al-Murādī, al-Jazarī, and Taqi al-Dīn produced significant works in various branches of physics and mechanics. These works encompassed a wide range of topics, including light and optics, centres of gravity, lifting and transporting heavy objects, specific weights, equilibrium and statics, dynamics, water engineering, hydrostatics, mechanics, automata, and more.

In the tradition of Islamic scientific thought, the physical sciences can be categorized into four main branches: natural philosophy, optics, the science of weights, and mechanics/fine technology. The most significant contributions to natural philosophy come from

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peripatetic philosophers such as al-Kindī (801–873), Ibn Sīnā (Avicenna, 980–1037), al-Bīrūnī (973–1048), Ibn Bajjah (Avempace, 1095–1138), and Abu'l-Barakāt al-Baghdādī (1076–1166). These scholars' works are rooted in Aristotle's *Metaphysics*, *Physics*, *On the Heavens*, *Meteorology*, and *Animals*. The scope of natural philosophy generally covers topics such as matter, substance, motion, propelled objects, and the movements of celestial bodies. On the other hand, theologian scholars (*mutakallimūn*) in the Islamic tradition, drawing from classical atomism, have also addressed issues of matter, substance, motion, and causality in their works. Philosophical and theological books from 13th-century philosophers like Athīr al-Dīn al-Abharī (d. 1265) with his *Hidāyat al-hikma* and Najm al-Dīn al-Kātibī's (d. 1277) *Hikmat al-'ayn*, as well as 14th-century theologians like Sa'ād al-Dīn al-Taftazānī's (d. 1390) *al-Maqāsid fi 'ilm al-kalām* and Adud al-Dīn al-Ijī's (d. 1355) *al-Mawāqif fi 'ilm al-kalām*, are among the most widely studied philosophy and theology books in madrasas (Islamic colleges). In these works, the physics (*tabī'iyyāt*) topics lay the foundations for Islamic and Ottoman scholastic physics education [1].

One of the fundamental topics in natural philosophy is motion or dynamics. In the Islamic world, the concept of dynamics evolved in response to the criticisms of John Philoponus (490–570), regarding Aristotle's theories of motion. Following Philoponus, Ibn Sīnā introduced the term "inclination" (Ar. *Mayl*; Lat. *Inclinatio*) to shed light about projectile motion, where Aristotle's explanations fell short. This theory would later form the basis for the emerging *impetus theory* [2]. In the 12th century, Ibn Bajjah criticized Aristotle's theory of projectile motion, and his views later discussed by Thomas Aquinas and John Scotus and were recognized in the Western world as *Avempacean Dynamics*, which influenced Galileo [3]. Scholars such as Ibn al-Haytham, al-Baghdādī, and Fakhr al-Dīn al-Rāzī (1150–1209) continued their works on dynamics, introducing early perspectives on mass and gravity [4].

Optics stands out as one of the fields where Muslims made significant contributions. In the 9th century, Kindī, drawing on Euclid, wrote a treatise on optics, translated into Latin as *Liber Jacob Alkindi de causis diversitatum aspectus* or shortly *De Aspectus* by Gerard of Cremona (1114–1187). Scholars like Hunayn ibn Ishaq (810–873) and Abu Bakr al-Rāzī (865–925) delved into the anatomy of the eye and the process of vision. Philosophers such as al-Nayrīzī (d. 922), Ibn Sīnā, and Bīrūnī contributed works on light and optics. However, undoubtedly the most prominent figure in optics is Ibn al-Haytham (965–1040). His work, *Kitāb al-Manāzir* (Book of Optics), translated into Latin as *Opticae Thesaurus Alhazeni* by Gerard of Cremona in the 12th century, opened the door to experimentation in science. Ibn al-Haytham's famous *camera obscura* experiment influenced early writers like Roger Bacon (1220–1292), establishing him as a key figure in pre-Newtonian optics [5]. In the 13th century, Qutb al-Dīn al-Shirāzī (1236–1311) first discussed Ibn al-Haytham's optical ideas in his work *Nihāyat al-idrāq fī dirāyat al-aflāq*. His student Kamāl al-Dīn al-Fārisī (1267–1319) in his *Tanqīh al-manāzir* (Review of Optics), replicated Ibn al-Haytham's experiments and criticized his views. In the 16th century, Taqi al-Dīn Muhammad ibn Ma'rūf (1526–1585) in Istanbul discussed and developed the works of Ibn al-Haytham and al-Fārisī in his optical book *Navru* *hadīḳati'l-absār wa nūru ḥakīkati'l-anzār* [6]. It is known that Jacobus Golius (1596–1667), a Dutch orientalist and mathematics professor at Leiden University, collected manuscripts in Aleppo and Istanbul, including Taqi al-Dīn's studies on optics [7].

The Islamic world, spanning a vast geography, encompassed many major cities with vibrant trade. Consequently, issues of measurement and weight were extensively examined by scholars, leading to significant studies on balances and weights [8]. The *Maqāla fi'l-mīzān* (Treatise on the Balance) and the *Kitāb fī al-thiql wa'l-hiffa* (Book on Heaviness and Lightness), attributed to Euclid, laid the theoretical foundations of the science of weights in the Islamic world. While the Greek origins of these works are lost, they have reached us through Arabic translations. In the 9th century, Thābit ibn Qurrā's (821–901) *Kitāb al-Qarastūn* (Book of the Steelyard), following the Archimedean tradition, focused on equilibrium and levers. Translated into Latin as *Liber Karastonis*, it laid the groundwork for the science of weights (*scientia de ponderibus*) in medieval Europe [9]. Al-Fārābī (872–951) defined the science of weights (*'ilm al-athqāl*) in his philosophical work *Ihsā' al-'ulūm* (Enumeration of the Sciences) and classified it as a mathematical science. According to Fārābī, the science of weights examines two main aspects: the measurement of weights and the principles of tools needed to carry or lift heavy objects. In this work, Fārābī defined the science of weights or statics, outlined its scope, and endowed it with a mathematical character [10].

Following the translation period, some of the most important works on the science of weights were composed after the 10th century. Scholars such as Bīrūnī, Omar Khayyam (1048–1131), al-Isfizārī (early 12th century), and al-Khāzinī (12th century) wrote significant treatises on statics and hydrostatics. Abū Hātim Muzaffar al-Isfizārī, in his work *Irshād dhawī al-irfān ilā sınā'at al-qaffān* (Guiding the Learned Men in the Art of the Steelyard), attempted to establish a unified theory of balance by incorporating both Greek and Arabic sources. His student, Abd al-Rahman al-Khāzinī, based his encyclopaedic work *Kitāb mīzān al-hikma* (Book on the Balance of Wisdom) on Archimedes' studies on hydrostatics. He developed methods for accurately measuring the specific weights of substances and designed a precise balance named *al-mīzān al-hikma* (the balance of wisdom). The fifth book of this study contains a partial translation of the pseudo-Aristotelian *Mechanical Problems*, entitled *Nutaf min al-hiyal* (Elements of Mechanics) [11].

Islamic scientific and technical tradition exhibits a vast diversity in automata and various mechanisms. The development of political and economic life from Andalus to Central Asia facilitated the advancement of practical mechanics in both civilian and military domains. Muslim engineers, who developed various technologies from lifting heavy loads to timekeeping, scientific instruments to water-lifting machines, authored books describing their works and translated texts from other cultures [12]. Islamic scholars translated works on mechanics from Greek into Arabic, always acknowledging and respecting the names of Greek pioneers. The *Mechanica* of Hero of Alexandria, whose original Greek version is lost, was translated into Arabic by Qustā ibn Lūqā (820–912) as *Kitāb fi al-raf' al-ashyā al-thaqīla* (Book on the Lifting of Heavy Objects) [13]. The *Pneumatica* of the Philo of Byzantium was likely translated by Qustā ibn Lūqā, as *Kitāb* *fi al-ālāt al-rūhāniyya wa al-mihānik al-ma'* (Book on Pneumatic and Hydraulic Instruments) [14]. Among these books, there are several others related to water clocks and musical automata, some of them attributed to Archimedes.

In addition to translations, Muslim engineers authored numerous significant works on applied mechanics. In the 9th century, Muhammad, Ahmad, and Hasan, generally known as the Banū Mūsā, wrote the *Kitāb al-hiyal* (Book of Mechanics), following the tradition of Philo. The book covers a wide range of devices such as automata, various mechanisms, fountains, magical vessels, gas lamps, bellows, water pumps, and water clocks. The Banū Mūsā brothers, distinguished prominent mathematicians and astronomers of their time, are believed to be the first engineers to design a feedback-controlled automatic control system [15]. In the 11th century, Ibn Khalaf al-Murādī from Andalus included various mechanical devices, ranging from war tools to astronomical clocks, automata to water wheels, in his work *Kitāb al-asrār fi nata'ij al-afkār* (Book of Secrets in the Results of Ideas). The automatic mechanisms described in the book represent the pinnacle of precision and craftsmanship of the time [16]. The most significant mechanical book in the Islamic world was written by Abu'l-'Izz ibn Ismā'īl ibn al-Razzāz al-Jazarī in the 13th century. Working as a palace engineer in the service of the Artuqid dynasty, Jazarī presented his work, *al-Jāmi' bayn al-'ilm wa al-'amal al-nāfi' fi sinā'at al-ḥiyal* (Compendium of the Art of Mechanics Between Knowledge and Useful Work), to Artuqid Sultan Nasīr al-Dīn Mahmūd bin Kara Arslan in 1205 after 25 years of service. Jazarī refers to both ancient Greek authors and the Banū Mūsā in his work, indicating his integration of both traditions. The book introduces various mechanisms such as water clocks, water pumps, mills, scales, robotic automata serving drinks, and musical instruments. Jazarī describes and employs many new mechanisms, including the camshaft, crankshaft, and metal casting, in his devices [17].

The Ottoman Empire, established in the early 14th century, adhered to the traditions of Islamic physics and mechanics. Ottoman scholars who possessed copies of many of the significant works mentioned above in their libraries, translated important works into Turkish and wrote new books to meet their practical needs. Starting from the late 18th century, as the Ottomans embraced the establishment of modern Western-style educational institutions, they departed from the classical Islamic scientific tradition, introducing Newtonian mechanics in the newly formed modern schools. In the following section, we will delve into the physics and mechanics of the Ottoman classical period between the 14th and 18th centuries. First, we will examine the place of mechanics in the Ottoman classification of sciences literature. Next, we will discuss how physics and mechanics were integrated into the Ottoman madrasa education system. Finally, we will introduce works in the Ottoman scientific literature related to statics, hydrostatics, motion, mechanisms, and ballistics.

2 The Science of Mechanics in the Ottomans

To understand the roles and relationships of sciences in classical Ottoman thought, one can refer to Tashkopruluzāde Ahmed Çelebi (1495–1561) [18]. As a member of the Tashkoprulu scholar family, Ahmed Çelebi is recognized as one of the prominent Ottoman thinkers of the 16th century, serving as a theologian, jurist, and encyclopedist

[19]. His most famous work is the biographical study titled *al-Shaka'ik al-nu'māniyya fi 'ulāma al-dawlat al-'Uthmāniyya*, providing insights into the lives of Ottoman scholars until his time. Regarding the classification of sciences, his work *Miftāh al-sa'āda wa misbāh al-siyāda fi mavzu'āt al-'ulūm* follows the tradition of classical scholars, particularly influenced by figures like Fārābī, Ibn Sīnā, and Ibn al-Akfānī (d. 1348). This classification has left a lasting impact on subsequent scholars, including Kātib Çelebi (Hājjī Khalīfa, 1609–1657) and Sachaklizāde (d. 1732). In this context, we will first examine Tashkopruluzāde's classification of physical and mathematical sciences (Fig. 1).

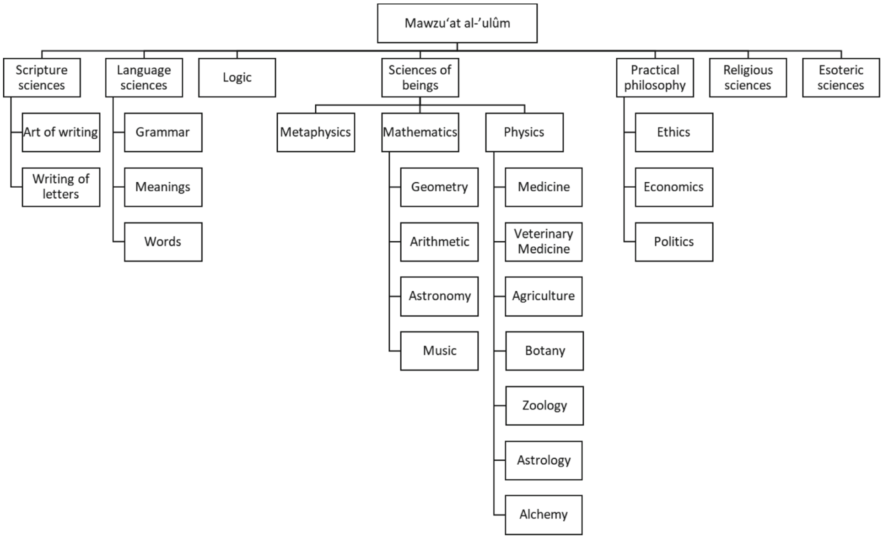

Fig. 1. General view of Tashkopruluzāde's classification of sciences

Tashkopruluzāde categorizes sciences into seven main classes: literary sciences, linguistic sciences, logic, sciences concerning beings, practical philosophy, religious sciences, and esoteric sciences. Within the classification related to the study of beings, three branches emerge: metaphysics, mathematics, and physics. This division is fundamentally based on Aristotle's classification of sciences, as outlined in the *Prior Analytics* [20]. According to this framework, metaphysics deals with entities that are not present in nature and cannot be demonstrated when pointed to. Metaphysical entities are objects that are unchanging and stable in terms of existence. Mathematics, on the other hand, focuses on the study of objects that do not exist in nature but can be indicated when discussed. The subject of mathematics is to examine objects that are abstract and can only exist in the mind. The branches of mathematics include geometry, astronomy, arithmetic, and music. Physics, the third category, encompasses the study of objects that exist both in nature and can be indicated when pointed to. Physics examines the changes in natural objects. The sub-branches of this science include medicine, veterinary medicine, agriculture, botany, zoology, astrology, and alchemy (Fig. 2).

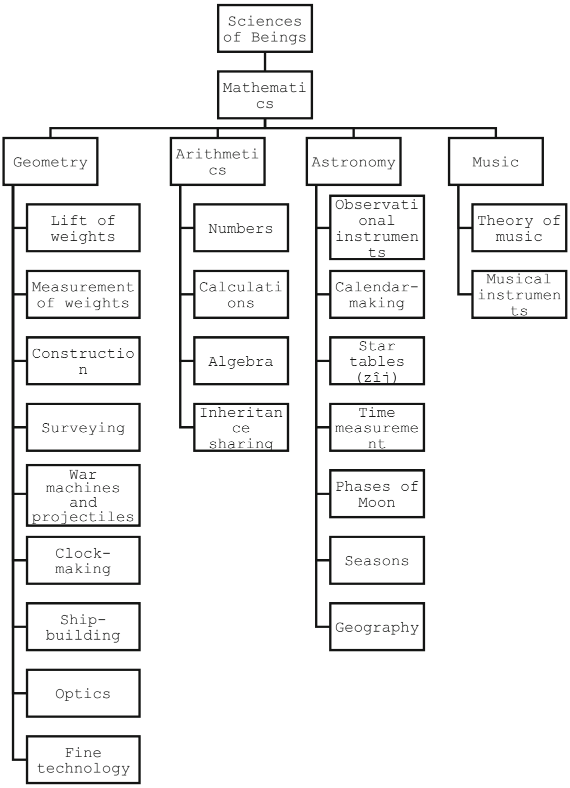

Fig. 2. Mathematical sciences on Tashkopruluzāde's classification

The science of physics, despite being a "mathematical" science in the contemporary context, was a branch of philosophy in ancient/scholastic thought. After the Scientific Revolution, this distinction disappeared, and physics converged with mathematics. This is the main distinction between scholastic and modern science. In scholastic thought, mathematical sciences provided "precise and unchanging" results, while physics dealt with the changes in entities, including motion. Medicine, one of the sub-branches of scholastic physics, focused on the changes in the human body, i.e., health and disease. The transformations of plants and animals were the subjects of botany and zoology. Alchemy studied the changes in substances, and astrology explored the effects of celestial bodies on humans. The goal of these sciences was to investigate the effects of changes in living and non-living objects. On the other hand, topics such as mechanics, optics, and engineering fall under the scope of the "geometry", which was subjected to to mathematical sciences in scholastic thought, although they are the branches of physics in today's understanding. According to Tashkopruluzāde, geometry is concerned with measurements and proportions. The subject of geometry includes the dimensions of lines, surfaces, and solid objects, as well as the ratios between dimensions. Since the principles of mechanical and optical sciences are based on the measurements and proportions of geometric shapes, they are referred to as "geometric sciences". This tradition persists in modern Turkish, where the word "mühendis" (engineer), meaning a person engaged in engineering, has Arabic origins, translating to "geometrician."

Tashkopruluzāde introduces the sciences related to mechanics as follows:

Weight-Lifting: The science that enables the lifting of heavy objects with a small force. This topic has been elaborated with proofs by Hero of Alexandria.

Center of Gravity: Used to find the center of gravity of objects. If the center of gravity of objects is accurately determined, heavy objects can be easily carried.

Measurement and Weight: Through this science, it is possible to determine how the weights of materials to be used in construction will be measured and which tools will be used for measurement.

Construction/Architecture: This science involves the construction, reinforcement, and aesthetics of buildings. Constructing sturdy castles, beautiful mansions, robust bridges, building dams on rivers, digging canals, excavating wells, and lifting water from low places to high places are within the scope of this science.

Clock-making: Discusses how instruments that measure time are made. It is useful for knowing the prayer times, understanding when stars and other celestial bodies appear and disappear.

Science of Instruments Based on the Absence of Void: Tashkopruluzāde primarily defines this branch of science based on the effects of void (vacuum), particularly through "magic vessels". The interior of these vessels is divided into sections to create different levels of liquid pressure; overflow occurs when the filled liquid exceeds a certain level due to the disturbance in liquid balance. Tashkopruluzāde emphasizes that the internal structures of such vessels are related to engineering, i.e., the science of geometry. Otherwise, it should be considered a branch of "physics" due to the change of liquid pressure, since it involves a "change" in the physical condition. The author notes that there are books by Banā Mūsā, Philo, and Jazarī on this subject [21].

Tashkopruluzāde's classification demonstrates that the Ottomans followed the classical Islamic scientific tradition. Disciplines within the field of mechanics, such as statics, equilibrium, center of gravity, and lifting heavy loads, adhere to the precise principles of geometry. Therefore, the science of mechanics is considered a mathematical/geometric science. This approach was not only accepted by classical scholars (*'ulamā*) who came after Tashkopruluzāde but was also embraced by Western-style modern engineering schools established at the end of the 18th century teaching Newtonian sciences, which has the name *Hendesehāne*, "School of Geometry."

Within this traditional framework, how did the Ottomans acquire knowledge of mechanics and physics? In the following section, we will discuss education in mathematics, physics, and mechanics within the Ottoman classical education system, the *madrasas*.

3 Mathematics and Physics Education in the Ottoman Classical Period

In the classical Ottoman education system, children would attend primary schools or children's schools (*sıbyan mektepleri*) before going to madrasas. In these primary schools, children, typically around the age of 7–8, would learn to read the Qur'an, practice Arabic calligraphy (hat), and acquire fundamental religious knowledge. Around the ages of 12–15, they would additionally study Arabic grammar, logic, and arithmetic at a level useful for daily life. During the reign of Mehmed II (1451–1481), madrasa regulations stipulated that after mastering Arabic grammar, students were required to take courses in astronomy, geometry, and rhetoric to attain "maturity". Arithmetic was taught alongside other sciences like geometry and astronomy. In the documents establishing a madrasa during the reign of Ahmed III (1703–1730), it was specified that an arithmetic teacher was needed to handle inheritance cases and ensure the proper distribution of shares according to Islamic law. Moreover, 18th century scholars, such as Sachaklizāde (d. 1732), emphasized the importance of studying arithmetic before legal topics like *'ilm al-farā'iz*, which dealt with inheritance laws [22].

Giambattista Toderini (1728–1799), a Venetian cleric, book collector and man of letters, provides insights into Ottoman education in his work *Letteratura Turchesca* (Turkish Literature) written during his stay in Istanbul from 1781 to 1786. According to Toderini, education begins with four fundamental sciences: verb conjugation, sentence structure, logic, and research on proofs. Following these, rhetoric, interpretation of the Qur'an (*tafsīr*), sayings of the Prophet (*hadith*), Islamic law (*fiqh*), inheritance distribution (*'ilm al-farā'iz*), theology (*kalām*), mathematics, and geometry are taught in madrasas [23].

In mathematics, the most widely used books are those of Ali Qushji (1403–1474) and Bahâ al-Dīn al-Āmilī (1547–1621), along with their commentaries. In geometry, Shams al-Dīn al-Samarqandī's (1250–1310) *Ashkāl al-ta'sīs* and Nasīr al-Dīn al-Tūsī's *Tahrīr al-usūl fî 'ilm al-handasa* have been widely used. In astronomy, the book *al-Mulahhas fi al-hay'a* by al-Jaghmīnī (d. 1221) and its commentaries were studied for a long time. However, the list of studied books is not limited to these, and there is a vast literature of Turkish, Arabic, and Persian books on these subjects [24].

In Ottoman madrasas, lessons were taught by reciting books written on the respective subjects. For each topic, there were designated beginner, intermediate, and advanced level books. As students progressed, they would read more advanced-level books. According to the anonymous *Kawākib-i Sab'ā*, written in 1739 at the request of the French embassy to introduce the Ottoman education system, four books were used for arithmetic lessons, covering from the beginner level to the upper-intermediate. Madrasas had a break for students on Tuesdays and Fridays. On these days, students engaged in practical arithmetic exercises such as finger counting and mental calculations, as well as measurement exercises in geometry. Additionally, they practiced using astrolabes and quadrants for astronomy and engaged in practical activities like lifting weights in mechanics. However, our knowledge about how these practices were carried out is limited [25].

Toderini notes that the Ottomans were highly proficient in practical arithmetic, being able to perform rapid calculations with very large numbers. He mentions that Ottoman accountants could accurately calculate and record the empire's enormous income without errors. He even suggests that Europeans could gain a lot by translating and studying several Arabic and Turkish books on this subject. However, Toderini remarks that the Ottomans lagged Arab masters in algebra. Nevertheless, he encountered knowledgeable Turkish youth who studied algebra from European books, likely students from modern engineering schools. Toderini observes that the Turks possessed practical knowledge in geometry but were content with using basic concepts. Some scholars however, delved deeper, researching the works of Greek geometers such as Archimedes, Theodosius, Menelaus, and Apollonius, available in numerous Arabic translations in libraries. According to Toderini, the Turks had a strong interest in astronomy, leading them to adeptly use geometry, especially in fields like navigation, calendar making, sundial construction, and map drawing. Students at the Imperial Naval Engineering School enthusiastically learned geometry. Toderini also notes a shift in Ottoman attitudes, mentioning that in the past there was a proud indifference to European ideas, but lately, this stance had been abandoned. He personally encountered two Turkish intellectuals from the upper class who could read and write in Italian, and one Turkish youth asked him for modern logarithm and trigonometry tables.

In Ottoman madrasas, there was no distinct course specifically dedicated to physics. Instead, topics related to physics were covered within the sections on natural philosophy in classical philosophy and theology books. The teachings typically followed the Aristotelian/scholastic natural philosophy tradition. Some of the most commonly studied books in madrasas include Ibn Sīnā's *al-Ishārāt wa al-tanbīhāt*, al Abharī's *Hidāyat al-hikma*, Kātibī's *Hikmat al-'ayn* from the philosophical tradition, and also *kalām* books as mentioned before. These works cover topics such as matter, substance, motion, time, space, and the movements of celestial bodies, as well as phenomena like light and sound.

Toderini states that the Ottomans learned physics after mastering grammar, logic, rhetoric, *tafsīr*, *hadith*, *fiqh*, and mathematics. According to Toderini, one should learn physics and logic before delving into Islamic theology (*kalām*). Toderini states that physics in the Ottomans was largely the same as the physics taught in Europe before the conquest of Constantinople (1453) and that Arabic translations of Aristotle's works were in circulation in Europe during this period. Toderini also asserts that Muslim science surpassed European's during those times. Despite the flawed translations from Arabic to Latin, complete and accurate copies of Ibn Sīnā's works are found in Istanbul libraries. After the conquest of Istanbul, scholars fleeing from Byzantium to Italy brought Greek philosophical works and taught them to Europeans in their original language. Turks translated important works on optics and mechanics into Turkish, including a translation of Jazarī's famous work during the reign of Murad III (r. 1574–1595). Toderini also mentions that, besides optics and mechanics, there are manuscripts in Ottoman libraries on botany, zoology, and minerals. He notes the printing of a work on magnetism and compasses in Turkish printing houses. The specific work referred to is *Füyūẓāt-ı Mıknatısiyye* (Virtues of Magnetism), printed by Ibrāhim Müteferrika (1674–1745), the founder of the first Turkish printing house. One of the interesting pieces of information provided by Toderini is the interest shown by Grand Vizier Koca Rāgıb Pasha (1698–1763) in

Voltaire's *Éléments de la philosophie de Newton*. Recognized for his intellectual personality and the establishment of a library, Rāgıb Pasha wanted this work to be translated into Turkish. However, such a translation has not reached us today [26].

In the classical Ottoman madrasas of the time, the subject of mechanics was not taught as a separate course. However, we know that students engaged in practical exercises in mechanics during their free time, along with arithmetic and geometry. Madrasas, which trained administrators, jurists, and religious scholars for the empire, focused on practical applications of arithmetic for inheritance cases, geometry for land disputes, and the teaching of astronomy for determining prayer times, determining the direction of the Qibla, and navigation. On the other hand, the vibrant social life and enormous military power of the Empire necessitated many applications of architecture and engineering. Mills were the mostly used machines in daily life. Until the mid-19th century in the Ottoman Empire, there were three types of mills: windmills in windy regions, watermills in areas with abundant rivers, and animal-powered mills mostly in cities. In Istanbul, animal-driven mills were commonly used. The renowned traveller Evliya Çelebi (1611–1681) reported the existence of horizontal water mills in the Balkans and many places in Anatolia, especially used for flour production. Windmills were used in high and windy regions of the Aegean and Mediterranean [27].

In various applications such as the construction of castles and houses, shipbuilding, bridge repair, and machine tools, machines like levers, cranes, pulleys, and gear systems were highly used. Cranes were intensively used in tasks such as lifting and transporting heavy loads in Ottoman military facilities like Imperial Shipyard (*Tersāne*), artillery factories (*Tophāne*), and gunpowder factories (*Baruthāne*). Cranes used for lifting loads in ports were called "machuna", a term likely derived from the Italian word "macchina". Large cranes were used in monumental structures like the Sultanahmet Mosque and the Süleymaniye Mosque, built by the most prominent Ottoman architect-engineer, Mimar Sīnān (d. 1588). Mimar Sīnān, the chief architect and engineer of the Ottoman Empire, is also known for his monumental water transportation systems built for Istanbul. In addition to the ancient Roman-Byzantine water system, the colossal water system he constructed for the growing settlements of Istanbul included kilometers of pipelines, galleries, aqueducts, city reservoirs, and fountains [28]. Recognized as the most distinguished among engineers, Mimar Sīnān's achievements in architecture and engineering led the Ottomans to refer to him as the "elite of engineers" (*'ayn-ı 'ayân-ı mühendisîn*) [29]. Ottoman architects, belonging to a military class, acquired theoretical knowledge of mathematics and geometry from books and practical skills from their masters. The extensive boundaries of the empire and frequent military campaigns allowed architects to learn from various geographical experiences, combining theoretical knowledge with practical applications.

4 Literature on Mechanics

The Ottomans had collected many mechanical books translated or written from the classical period of Islamic civilization in their libraries. Among these were translations of works by Greek scholars such as Hero, Philo, Pappus, Apollonius, Archimedes, as well as books by Muslim mathematicians like the Banū Mūsā brothers, Jazarī, Ibn al-Haytham, Omar Khayyam, and many others [30]. Additionally, Ottoman scholars wrote various works based on their own needs and interests. In the classical period of the Ottoman Empire, works on mechanics can be divided into three main groups: hydrostatics, scales, and books on machines and fine technology. As mentioned earlier, the topic of motion was addressed not by mathematicians but by philosophers and theologians, resulting in the creation of numerous treatises on this subject.

The first work written on mechanics is *Badāyi‘ al-‘amal fi san‘āyi‘ al-hiyal* (Fine Works in the Art of Mechanics) by Alā' al-Dīn al-Kirmānī, who came from Iran to Anatolia during the reign of Mehmed II. The work consists of four sections: the first section covers clocks, the second section discusses an automatic device that plays continuous music, the third section focuses on a device for drawing water from wells, and the fourth section deals with observation and measurement tools such as sundials, hourglasses, and quadrants, as well as a solar calendar. This book is probably a partial translation of Jazarī's work. It is also known that during the reign of Mehmed II, Ali Qushji wrote a book titled *Tazkīra fi ‘ilm al-hiyal* (Epistle on Mechanics). Although this work has not survived to the present day, we become aware of it through a reference provided by Taqi al-Dīn in the introduction to his own mechanical book. In the introduction, Taqi al-Dīn refers to Ali Qushji when discussing a figure that moves according to the state of time, indicating that Ali Qushji's work was related to mechanical clocks and moving automata.

The first work on hydrostatics and specific gravity is a translation titled *Risāla al-Aflātūniyya* (Treatise of Plato), written by Muslih al-Dīn ibn Sīnān during the reign of Bayezid II. The original work was authored by a Byzantine scholar at the order of Mehmed II and presented to his son Bayezid II after the Mehmed's death. The identity of the Byzantine scholar is unknown. E. Wiedemann published this short work in German in 1906 [31], and A. Adıvar provided a Turkish summary of the content based on this publication [32]. The treatise begins with the expression "A commentary on the words of Plato by a Byzantine scholar." In the work, the method of determining the amount of each metal in a cup made of two different metals, lead and silver, without altering the structure of the cup is explained. The problem of finding the weight of each metal in an object made of different metals is based on Archimedes and was a problem tackled by scholars in the Islamic world, including al-Khāzīnī, Bīrūnī, and Omar Khayyam. According to Wiedemann, the work follows the method of Bīrūnī in addressing the problem, or it is a study benefiting from his works [33]. Although the reason why the translator attributed the work to Plato is unknown, Adıvar suggests that in Eastern culture, attributing significant and complex problems to Plato described with the "divine" attribute, was a customary practice.

In the 16th century and beyond, there is an increase in the number of books on scales, especially in major cities of the Empire such as Istanbul and Egypt. This development is undoubtedly related to the flourishing commercial life in these major cities. Sufficient research has not been conducted on these works, and here we will content ourselves with providing the names of some significant works. Muhammad ibn Abū al-Fath al-Sūfī (b. 1543), one of Egypt's most important mathematicians and astronomers in the 16th century, wrote numerous works on scales and clockmaking. Al-Sūfī, who was also a maker of astronomical instruments, was a mentor to Taqi al-Dīn. During the same period in Istanbul, Abd al-Macid al-Sāmūlī and Aşrafzāde Ali Çelebi had books on scales and weight measurement. Some of these works were written for alchemists and include discussions on how to precisely measure the weights of small amounts of minerals [34].

The most important work on mechanics written in the Ottoman Empire is *al-Turuk al-saniyya fi al-ālāt al-rūhāniyya* (The Elegant Methods of Spiritual Machines), authored by Taqi al-Dīn ibn Ma'rūf, a pioneering mathematician-astronomer of the 16th century and the founder of the Istanbul Observatory. Written in 1551, this work follows the tradition of Jazarī but introduces many new and different mechanisms. This work, the latest and most advanced mechanical book in the Islamic world, presents various machines, including animal-drawn and gear-driven water pumps, a six-cylinder water pump, a gear winch system capable of lifting a 1500 kg load with a force of 1.5 kg, and a pulley system with 16 wheels. The most significant machine in the book is a time-regulated cooking device operated by a clock mechanism. Taqi al-Dīn mentions that some mechanics built automatic rotating cooking machines using steam power, while others used weights. He, along with his brother, created a fixed machine with four iron legs to achieve this. The machine consists of gear wheels connected to a winding mechanism, allowing automatic operation with a rotating arm for time adjustment. Taqi al-Dīn claims to have built this machine in 1546. During this period, mechanical clocks had become widespread in Europe, and the German inventor Peter Henlein (1485–1542) had invented the first portable clocks. Taqi al-Dīn's cooking machine holds significant importance in the history of technology as the first device to use a regulated clock mechanism for practical utility [35].

Taqi al-Dīn's interest in clocks seems extended beyond mere curiosity. His work titled *al-Kawākib al-durriyya fi wadh' al-bankāmāt al-dawriyya* (The Brightest Stars in the Construction of Mechanical Clocks), written in 1563, stands as one of the earliest and most significant works on the construction of mechanical clocks in both Europe and the Islamic world. This work delves into various types of clocks, including pocket watches, table clocks, wall clocks, and astronomical observation clocks. Notably, the distinctive feature of this work is its portrayal of the clock as an astronomical observation tool, capable of indicating minutes and seconds [36].

In the late 16th century, the renowned mechanical work of Jazarī was translated into Turkish by an unknown translator under the title *Tarcuma-i Hiyal* (Translation of Mechanics). Presented to Murad III (r. 1575–1595), this work is significant for the emergence of Turkish as a language for scientific discourse. The translator explicitly states the intention to "dress the work in Turkish attire and make it known." Therefore, the translation of the work into Turkish reflects the curiosity of Ottoman engineers in the field of mechanical science. The content of the work includes water clocks, automatic beverage dispensers, deceptive containers, fountains, water lifting machines, and various measuring instruments [37].

The unsuccessful Siege of Vienna in 1683 had a significant impact on the Ottoman Empire. Recognizing the inadequacy of existing military institutions and tactics due to consecutive defeats, Ottoman bureaucrats began closely monitoring new military developments applied in Europe. Starting from the reign of Ahmed III (r. 1703–1730), there was a translation effort of military-related works from European authors into Turkish.

Among these translations was the memoir *Commentarii Bellici* by Raimondo Montecuccoli (1609–1680), an influential 17th-century military commander [38]. During this period, Bayramoglu Ali Aga, an officer in the Bombardier Corps, wrote a unique work titled *Umm al-gazā* (Foundations of War). This work provides original insights into the creation of explosive cannons called *khumbara*, the manufacture of mortar cannons that launch them, the calculation of shooting distances, and the placement of *khumbara* cannons in castle sieges and defences. Bayramoglu Ali Aga, an experienced military engineer who participated in significant military campaigns such as the Siege of Belgrade and the Russian Campaign, describes the construction and usage of war machines such as six-barreled mortar cannons, wheeled mortar cannons, barrel bombs, flame-throwing rockets, and grappling hooks and wheeled ladders for crossing trenches. His work stands as one of the most important studies on Ottoman military technology in the 18th century [39].

In 1731, renowned French commander and military engineer Alexander Comte de Bonneval (1675–1747) entered to Ottoman service, upon converting to Islam, adopted the name "Ahmed Pasha" and reorganized the Bombardier Corps in Istanbul. Additionally, in 1733, he established an engineering school within the corps named *Hendesehāne* (School of Geometry) [40]. This school provided practical artillery training for bombardier soldiers, covering applied shooting techniques, alongside theoretical education in mathematics, geometry, trigonometry, and ballistics. Initially, the textbooks used in the school were based on works brought from France by Ahmed Pasha. However, later, translations and original works inspired by these texts were introduced into the curriculum. One such original work was authored by Mustafa ibn Ibrahim, a scribe in the Bombardier Corps, titled *Fann-i Khumbara wa Sanāyi'-i Âtaş-bāzī* (Artillery Science and Fireworks Industry). The book begins with the history of explosive weapons and goes on to cover topics such as cannon firing, distance measurement, characteristics of mortar cannons, manufacturing explosive cannons, angle measurement and geometry, properties of gunpowder, and techniques for digging trenches [41].

François Baron de Tott (1733–1793), a French officer and diplomat, played a leading role in establishing an artillery school and a naval engineering school in Istanbul [42]. As a result of the advice from European military experts and the efforts of Ottoman administrators, the Imperial Naval Engineering School was first founded in 1775, followed by the Imperial School of Army Engineering in 1795. Unlike the traditional madrasa system, these schools embraced a secular educational approach and implemented a Western-style curriculum. In the 19th century, mechanical courses continued to be taught, covering statics, dynamics, kinematics, machine engineering, steam engines, and thermodynamics, based on the modern principles of Newtonian physics.

5 Conclusion

The foundations of physics and mechanical sciences in the Islamic world were laid based on the works of ancient Greek scholars, and Muslim scholars made significant contributions by producing important works in these fields. The Islamic scientific tradition is divided into four main categories: physics, optics, weights, and machines. Optics, particularly advanced through the works of Ibn al-Haytham, witnessed significant developments, and important concepts in physics were developed with contributions from Ibn

Sīnā and other scholars. Additionally, detailed studies were conducted in the areas of measurement and weighing, leading to the design of balances and the development of precise measurement methods. In the realm of mechanics and fine technology, Muslim engineers pioneered various technologies, ranging from lifting heavy loads to automatons and water wheels. They authored books describing these technologies. During the Ottoman era, the Islamic scientific tradition was followed, and works covering physics and mechanics were translated into Turkish.

Tashkopruluzāde Ahmet Çelebi, one of the leading scholars of the 16th century, demonstrates the understanding of mathematics and physics in the classical Ottoman period through his classification of sciences. In his work, subjects like mechanics, optics, and engineering are considered as mathematical/geometric sciences closely associated with mathematics. While modern physics relies on a mathematical foundation, classical Ottoman thought viewed physics more as a science focused on the changes and effects of objects. This classification highlights the distinction that Ottoman classical thought made between mathematics and physics, reflecting a demarcation seen in modern physics characterized by the Scientific Revolution.

In Ottoman madrasas, physics, mathematics, and geometry were not typically taught as separate courses but were rather included in the curriculum of philosophy and theology texts. Students, especially those aspiring to become religious scholars or jurists, would learn these subjects for their practical utility. However, these lessons did not cover the topic of mechanics. Practical knowledge in physics and mathematics was particularly crucial for architects, engineers, and those working in the military field. Various machines, tools, and construction techniques used in both civilian and military contexts formed a significant part of engineering and mechanical applications during this period in the Ottoman Empire. While the teaching of these subjects wasn't formalized in madrasas, individuals acquired practical mechanical knowledge through hands-on experience and apprenticeships. Although mechanics wasn't directly taught in madrasas, scholars wrote important works on topics such as hydrostatics, scales, machines, clocks, and weapons. The Ottomans, preserving the Islamic scientific tradition until the 18th century, also embraced new scientific and technological knowledge emerging in Europe, contributing to the modernization of the empire.

References

1. Nasr, S. H.: Islamic Science: An Illustrated Study. World of Islam Festival Pub. Co. (1976)
2. Sayılı, A.: Ibn Sīnā and Buridan on the motion of the projectile. Ann. N. Y. Acad. Sci. **500**, 477–482 (1987)
3. Franco, A.B.: Avempace, projectile motion, and impetus theory. J. Hist. Ideas **64**(4), 521–546 (2003)
4. Pines, S.: Les Précurseurs Musulmans de la Théorie de L'Impetus. Studies in Arabic Versions of Greek Texts and in Medieval Science. E. J. Brill, Leiden (1986)
5. Sabra, A.I.: "Manāẓir, or ʿIlm al-Manāẓir." In: Encyclopaedia of Islam, 2nd edn. E. J. Brill. Leiden, vol. 6, pp. 376–377 (1991)
6. Fazlıoğlu, İ.: "İlm-i Menâzır (Osmanlılar'da)." In: İslam Ansiklopedisi. TDV. İstanbul, vol. 22, pp. 131–132 (2000)
7. Aydüz, S., Şen, H.: "Taqī al-Dīn ibn Maʿrūf". In: The Oxford Encyclopedia of Philosophy, Science, and Technology in Islam. Oxford University Press. Oxford (2014)

8. Rozhanskaya, M., Levinova, I.S.: “Statics”. In: Encyclopedia of the History of Arabic Science. Routledge. London & New York, vol. 2. pp. 274–298 (1996)
9. Clagett, M.: The Science of Mechanics in the Middle Ages. The University of Wisconsin Press, Madison (1961)
10. Al-Farabi.: “Enumeration of the Sciences”. In: The Political Writings: Selected Aphorisms and Other Texts. Translated by Charles E. Butterworth. Cornell University Press, Ithaca and London, pp. 69–84 (2001)
11. Abattouy, M.: Greek mechanics in arabic context: thabit ibn Qurra, al-Isfizari and the Arabic traditions of Aristotelian and Euclidean mechanics. Sci. Context **14**, 179–247 (2001)
12. Al-Hassan, A.Y., Hill, D.R.: Islamic Technology: An Illustrated History. Cambridge University Press, Cambridge (1986)
13. Carra de Vaux, B.: (trans. & ed.): Les mécaniques ou L’élévateur de Héron d’Alexandrie. Imprimerie Nationale. Paris (1894)
14. Carra de Vaux, B.: (trans. & ed.): Le livre des appareils pneumatiques et des machines hydrauliques par Philon de Byzance. Imprimerie Nationale. Paris (1902)
15. Banū Mūsā: The Book of Ingenious Devices. Ed. & Trans. Donald Routledge Hill, Hijara Council, Islamabad (1989)
16. Al-Murādī: The Book of Secrets in the Results of Ideas: Incredible Machines from 1000 Years Ago. Kitāb al-Asrār fī Natāyij al-Afkār. Leonardo3. Milano (2008)
17. Al-Jazari: The Book of Knowledge of Ingenious Mechanical Devices. Ed. & Trans. Donald Routledge Hill. Hijara Council, Islamabad (1988)
18. Inalcik, H.: The Ottoman Empire: The Classical Age 1300–1600. Orpheus Publishing Inc., New York (1989)
19. Fleming, B.: Ṭas̲h̲köprüzāde.In: Encyclopaedia of Islam, 2nd edn. E. J. Brill. Leiden, vol. 10, pp. 351–352 (2000)
20. Aristotle: Categories, On Interpretation, Prior Analytics, vol. 1. Trans. H. P. Cooke. Loeb Classical Library No. 325. William Heinemann Ltd., London (1962)
21. Taşköprülüzāde: Mevzû‘âtü’l-Ulûm. Üçdal Neşriyat, İstanbul (2011)
22. İzgi, C.: Osmanlı Medreselerinde İlim: Riyâzî ve Tabiî İlimler. KüreYayınları, İstanbul (2019)
23. Toderini G.: De la littérature des Turcs. Trans. Antoine de Cournand. Paris (1789)
24. İhsanoğlu, E., Şeşen R., İzgi, C. (eds.): History of Mathematical Literature During the Ottoman Period. 2 Volume. IRCICA. İstanbul, (1999)
25. İhsanoğlu, E. (ed.): Kevâkib-i Seb’a. Turkish Academy of Sciences, Ankara (2023)
26. Bolchovitinov, E.A.: Réflexions sur L’Etat Critique Actuel de la Puissance Ot-tomane (1774). https://gdz.sub.uni-goettingen.de/id/PPN399615652
27. Evliya Çelebi: Narrative of Travels in Europe, Asia, and Africa, in the Seventeenth Century. Trans. by Joseph von Hammer-Purgstall. Oriental Translation Fund, London, vol. 2 (1834)
28. Çeçen, K.: Sīnān’s Water supply system in Istanbul. İSKİ, İstanbul, (1996)
29. Mülayim, S.: “Mimari”. In: İslam Ansiklopedisi. TDV. İstanbul, vol. 30, pp. 94–95 (2020)
30. Necipoğlu, G., Kafadar, C., Fleischer, C.H.: Treasures of Knowledge an Inventory of the Ottoman Palace Library (1502/3–1503/4). Kon-inklijke Brill NV, Leiden, vol. 2 (2019)
31. Wiedemann, E.: Beiträge zur Geschichte der Naturwissenschaften VIII: Über Bestimmung der spezifischen Gewichte. Sitzungsberichte der Physikalisch-Medizinischen Sozietät zu Erlangen **38**, 173–180 (1906)
32. Adıvar, A.A.: La Science chez les Turc Ottomans. Paris (1939)
33. Wiedemann, E.: Al-Mîzân. In: Encyclopedia of Islam. 199. E. J. Brill, Leiden (1993)
34. İhsanoğlu, E., Şeşen, R. Bekâr M.S., Gündüz, G., Bulut, V.: History of the literature of natural and applied sciences during the ottoman period, Istanbul, vol. 2. IRCICA (2006)
35. Al-Hassan, A.Y.: Taqi Al-Din wa-‘l-handasah al-mikanikiyah al-‘arabiyah (Taqi Al-Din and the Arabic mechanical engineering) with “Kitab al-turuq al-saniyah fi al-alat al-ruhaniyah”

from the sixteenth century. Aleppo, (1976). Al-so in Turkish see, Taqi al-Dīn er-Râsıd: Et-Turuku's-Seniyye fi'l Âlâti'r-Rûhâniyye (Olağanüstü Aletlerin Yapımında Şahane Yöntemler. Eds. Atilla Bir, Mustafa Kaçar, and Adem Akın. Turkish Academy of Sciences, Ankara (2022)
36. Tekeli, S.: The clocks in Ottoman Empire in 16th century and Taqi al Din's the brightest stars for the construction of the mechanical clocks. 2nd edn. Minis-try of Culture, Ankara (2002)
37. Fazlıoğlu, İ., Koç, M. (eds.) Tercüme-i Hiyel. Türkiye Yazma Eserler Kurumu, İstanbul (2014)
38. Montecuccoli, R.: Funūn al-Harb. İstanbul University Rare Books Library, TY6850
39. Bayramoğlu Ali Ağa: Ümmü'l-Gazâ. Türkiye Yazma Eserler Kurumu, İstanbul (2013)
40. Memoirs of the Bashaw count Bonneval, from his birth to his death. London (1750)
41. Mustafa bin İbrahim: Fenn-i Humbara ve Sanayi'-i Âteş-bâzî. Türkiye Yazma Eserler Kurumu, İstanbul (2015)
42. Baron de Tott, F.: Mémoires du Baron de Tott sur les turcs et les tartares, Amsterdam (1785)