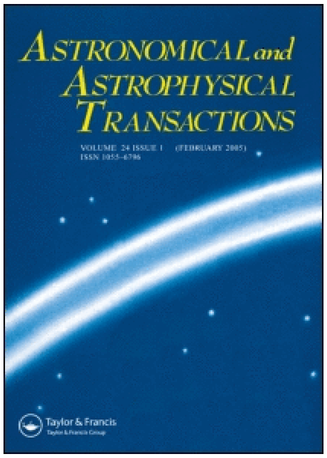

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The Antikythera mechanism: who was its creator and what was its use and purpose?

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We first give an account of the discovery of the Antikythera treasure, which was found by Symian sponge divers in November 1900. Among other finds was the Antikythera mechanism, which is the ancient mechanism of the highest level of sophistication among the mechanisms that have been found until now and is considered as the highest technology mechanism in antiquity. We have included in our account information from recent literature. We also give a description of this mechanism and its function, use and purpose. Finally, we present some scientific arguments in favour of our suggestion that the creator of the Antikythera mechanism was Posidonius of Rhodes.

Keywords: Antikythera mechanism; Posidonius of Rhodes

1. Introduction

Since its discovery in 1900 the Antikethyra mechanism has been studied in an attempt to answer the following questions.

(i) What is its structure and its function?
(ii) How and why was it used and what was its purpose?
(iii) Who made it and when?

For many years it was difficult to answer these questions. The advancement of modern technology and physics has helped towards this. Today there are three-dimensional X-ray tomographs with a resolving power of more than 0.001 mm. Thus, the Antikythera mechanism has been extensively studied over the years.

Derek de Solla Price [1–4], Professor of the History of Science at Yale University, was the first to examine the Antikythera mechanism and he produced significant results using modern techniques. However, there are still many mysteries regarding the precise structure

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and function, as well as the purpose, use and the creator of this device. The Antikythera mechanism was related, firstly, to the intellectual atmosphere of the time and place at which it was created, namely Rhodes, and, secondly, to its creator, namely Posidonius.

(i) *Rhodes.* The development of sciences and arts in ancient Rhodes started as early as the fourth century BC. Astronomy, mathematics, geometry, meteorology, geography and philosophy flourished in the ancient cities of the island. Rhodes had developed as an important astronomical centre of antiquity, especially during the second and first centuries BC, equivalent to that of Alexandria. Astronomical observations of several celestial phenomena were carried out and their detailed description as well as explanation were given. The astronomical inscription of Keskindos offers valuable information about the development of astronomy in ancient Rhodes [5]. The first meteorological observations ever were also carried out on the island and were used in order to produce the first known calendars, the so-called parapegmata.

Also the School of Art in Rhodes was considered among the most important of that era, particularly in the second and first centuries BC. A great number of statues and pieces of art decorated the city of Rhodes. Among the most well-known were the Kolossos of Rhodes, which was made to honour the god Sun and which was about 31 m tall, as well as Laokoon's complex and others.

Rhodes had developed as a significant centre of naval and military technology, had been able to resist the attack of the Macedonian Demetrius and had reached its peak after 304 BC and up until 168 BC. The finest ships in antiquity, carrying many scientific instruments and weapons, were built in the island's shipyards [6]. Rhodes at that time was the place where many war machines were developed, such as the 'polybolos'.

We studied [7] the coins in ancient Rhodes from 408 BC when the city was founded. At that time, the Sun's head without the rays was introduced as an emblem on the coins. We observed a gradual change in the rays depicted on Rhodian coins. For the first time we suggested that the change in the Sun's head as depicted on coins originated from the evolution of astronomical knowledge in ancient Rhodes. Astronomical knowledge influenced the artists and resulted in a change in the artist's perception of the Sun's head. Indeed, artists are influenced by the intellectual and cultural level of their age. The rays in the Sun's head symbolize its light and heat and generally the radiating energy, properties that man does not have. They also symbolize the 'life-giving source which penetrates the Earth and the heavens', as ancient Greeks used to say.

In conclusion, Rhodes' peak and eminence during antiquity was due mainly to the development of science, art, technology and navy.

(ii) *Posidonius.* In previous papers [5, 7–11] we studied thoroughly the work of Rhodian astronomers, mathematicians and geographers and showed how this work led not only to the development of science in ancient Rhodes but also to the creation of a fervent intellectual atmosphere. Among these was Posidonius of Rhodes [8].

Posidonius was in many ways an important personality, with rich and varied work. He was born in Apameia, a city of ancient Syria, in 135 BC and he died in Rhodes at about 51 or 50 BC [12, 13] at the age of 84. He was a great Stoic philosopher. He studied in Athens under the guidance of the Rhodian Stoic philosopher Panaetius, leader of the Stoic school of Athens, and succeeded him in that position after his death in 110 BC. In 90 BC or 97 BC he moved to Rhodes, where he founded a Stoic school at which he taught for the rest of his life. Posidonius was an eclectic Stoic, revising whatever doctrines of Stoicism did not satisfy his inquisitive nature. He was an accomplished orator, but also a natural scientist, interested in astronomy, mathematics, geography and meteorology. He used to check using different methods or to improve the results of the other scientists. Posidonius was also a qualified teacher and many students attended his lectures. Among these were not only Rhodians but also reputed Romans, such as Cicero and Gnaius Pompeius.

He wrote more than 20 philosophical books, dealing with such matters of physics as the refraction of light in the atmosphere, the influence of the Moon and the Sun on tides (he is considered the 'father' of tidal studies), the division of the Earth into zones, the diameters of the Sun and Moon and their distances from the Earth as well as the size of the Earth. In all his physical studies he produced innovative ideas and new experiments to test previous assumptions, never relying entirely on previous philosophers. Posidonius repeated Eratosthenes' experiment using an *astronomical* method to calculate the length of a meridian of the Earth (arriving at an underestimated value). This method was different from the *geometrical* method of Eratosthenes. He emulated Archimedes in creating his own planetarium. He travelled as far as Spain for his scientific observations and served as Rhodes' envoy in Rome. He was admired by the Roman orator Cicero, who visited him in Rhodes sometime between 79 BC and 77 BC. Gnaius Pompeius, the great Roman general, visited him in 67 BC, on his triumphant return from his campaign against Mithridates and bestowed upon him honours unheard of for non-Roman citizens. The Rhodians honoured him with high administrative posts and he was given the honorary title 'the Rhodian'.

In [8] we showed that the Antikythera mechanism was created by Posidonius of Rhodes. We studied the contribution of Posidonius of Rhodes to astronomy, geography, cartography, mathematics, mechanics and philosophy. We also discussed and explained the astronomical method used by Posidonius in order to estimate the length of the Earth's meridian.

This publication is based on previous work [8] and we have also included some recent information. We first give information about the discovery of the Antikythera treasure, which was found by Symian sponge divers in November 1900. Among other finds was the Antikythera mechanism. We give an overview of results on the Antikethyra mechanism, which is a specimen of a high-technology mechanism from antiquity and which has tremendous archaeological importance and interest. We also give a description of this mechanism and its function, use and purpose. Finally, we suggest that its creator was Posidonius of Rhodes as shown also in [8]. Our analysis is based on scientific arguments. The Antikythera mechanism has not been fully studied yet; it is likely that there exist other inscriptions and gears. The gears inside are not easily distinguishable.

2. The history of the discovery of the Antikythera mechanism

The start of marine archaeology in Greece occurred in November 1900, when seamen from the island of Symi made the first attempt to retrieve ancient treasures from the bottom of the sea. A few days before Easter Sunday of that year, Symian sponge divers, on returning to their island after many months of sponge diving off the shores of Tunisia, were forced by the rough weather to take refuge with their two boats on the northern shores (called Potamos) of Antikythera, a small island near and to the north of the island of Crete, and at a place called Pinakakia. When the storm ceased, some divers decided to dive for sponges. When one of these divers, Elias Stadiatis, reached a certain depth, he saw at the bottom of the sea the remains of an ancient ship, approximately 50 m long. The wreck contained treasure, including ancient jars (amphorae), gold jewellery, marble and bronze statues, ceramics and coins; they were unrecognizable because they were covered by seaweeds and marine organisms. The shipwreck had lain for about 2000 years at a depth of 59 m, on a large reef. When Stadiatis returned to his boat, *Euterpe*, whose captain was D. Kontos, he brought with him the large and

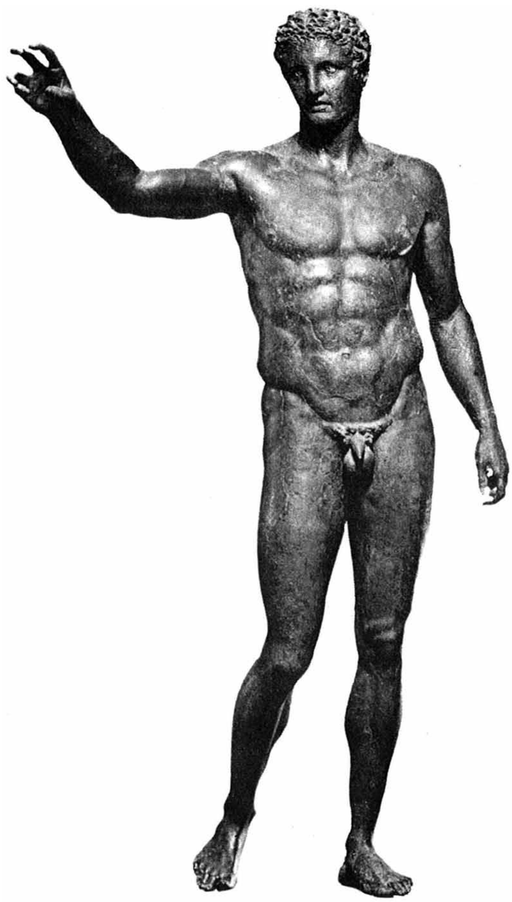

Figure 1. The statue of a young man from Antikythera (National Archaeological Museum, Athens).

well-preserved hand of a bronze statue, which was a part of the statue of a young man from Antikythera (figure 1).

Returning to their island, the seamen reported their finds to the Demogerontia (the Greek local authorities) of the then Turkish-occupied Symi. All agreed to inform the Symian Antonis Economou, then Professor of Archaeology at the University of Athens. With his assistance and intervention, they made a detailed briefing of their experience to the Minister of Education Spyridon Stais, who was also an archaeologist. The minister and the Greek government showed great interest and proceeded to make some immediate decisions. A special mission was scheduled, and in November 1900 the efforts to retrieve the ancient treasure began, again by the Symian sponge divers. The morphology of the sea bottom and the great depth made this endeavour very difficult and dangerous with the technology of the time. Two of the courageous divers lost their lives and two more were left paralysed by the bends (the so-called diver's disease). The effort continued through September 1901. The finds were numerous, important and of great historical and artistic value; nowadays they are at the National Archaeological Museum of Athens. For this reason, the finds became known as the *treasure of Antikythera*. Several researchers have concluded that the wreck was that of a Roman ship travelling from Rhodes to Italy (Rome) carrying ancient Greek treasures [1–4, 14–20]. The ship sank during a storm in the middle of the first century BC. Indeed, according to all datings performed on the various finds from the wreck, either using the radiocarbon method or archaeological methods, the year of the wreck was estimated to be between 80 and 50 BC. The estimation of the date for the wreck can also be justified by the following fact: the ship was carrying coins from Pergamon of about 85–65 BC, which were found by Jacques Cousteau [21], as well as coins from Ephesos of 70–60 BC [22].

3. Description and use of the device

Among the finds was an apparently formless metallic mass, a corroded mechanism made of bronze. Several parts of the Antikythera mechanism were found. Its various parts were cleaned and an attempt was made to assemble its parts, some of which had carved numerical inscriptions and astronomical labels. This Antikythera mechanism was characterized by the scientists of the era as an astrolabe. The four main rescued parts of the Antikythera mechanism were labelled by de Solla Price with the letters A, B, C and D. They are also kept at the National Archaeological Museum of Athens, placed in transparent Plexiglas. Figure 2 shows parts A, B, C and D, respectively.

This discovery, which is a specimen of high technology from antiquity and therefore has tremendous archaeological importance and interest, was studied by various scientists who formed different views. Some thought it was the *meteoroscope* of the astronomer Claudius Ptolemy, while others thought it was the mechanical *dromometron* of Heron of Alexandria (first century BC to the first century AD), since Heron, besides being a great mathematician, geodesist, physicist and astronomer, was also an engineer who studied gears. He is considered as the founder of the first technical university in history, in which both ‘theory’ and ‘practice’ courses were given. Svoronos (Svoronou) [14] supported the astrolabe view. However, according to Professor Albrecht Rehm [16], who studied the Antikythera mechanism: ‘. . . the Mechanism is an astronomical instrument that mechanically solved astronomical problems and bears gears as the modern clocks. It was a mechanism of the planets, a Planetarium, much like the Sphere of Archimedes and of Posidonius, therefore it should be called a *Sphere*, not an astrolabe.’ Rediades (Rediadou) [17] even claimed that it was the astrolabe described by Philoponos in AD 625 and he rejected the view of Rehm [16], stating that it was a nautical instrument. Rados (Radou) [18] formed the view that the Antikythera mechanism was too complicated to be an astrolabe. Moreover, Theophanides (Theophanidi) [19, 20], in a notable attempt to research and understand the Antikythera mechanism, agreed with Rediades that it was a nautical astrolabe. Other opinions have also been proposed such as that of Erich von Daniken who suggested that the Antikythera mechanism was created by some extra-terrestrial form of life which had visited the Earth in the past, but this suggestion is not valid [8].

However, the most complete study was made by de Solla Price [1–4]. In 1951, de Solla Price began a systematic and detailed study of the Antikythera mechanism, which would continue for 23 years, using also the help of physics. In 1959, after 8 years of study, de Solla Price published his own first conclusion that the fragments represented some form of intricate clockwork. From 1971, assisted by Dr Karakalos of the Nuclear Research Center “Demokritos” (now called the National Center for Scientific Research “Demokritos”), he used X-rays and gamma rays in order to radiograph and explore the interior of the corroded parts of the Antikythera mechanism. His study was finished in 1974 and published in 1975, containing more than 70 pages. It fully describes and analyses the Antikythera mechanism and its operation, and it is considered the most important source of information.

In general, the conclusion drawn by de Solla Price is that it is a complex astronomical instrument with many compounds and of high precision; hence it is very impressive. Originally

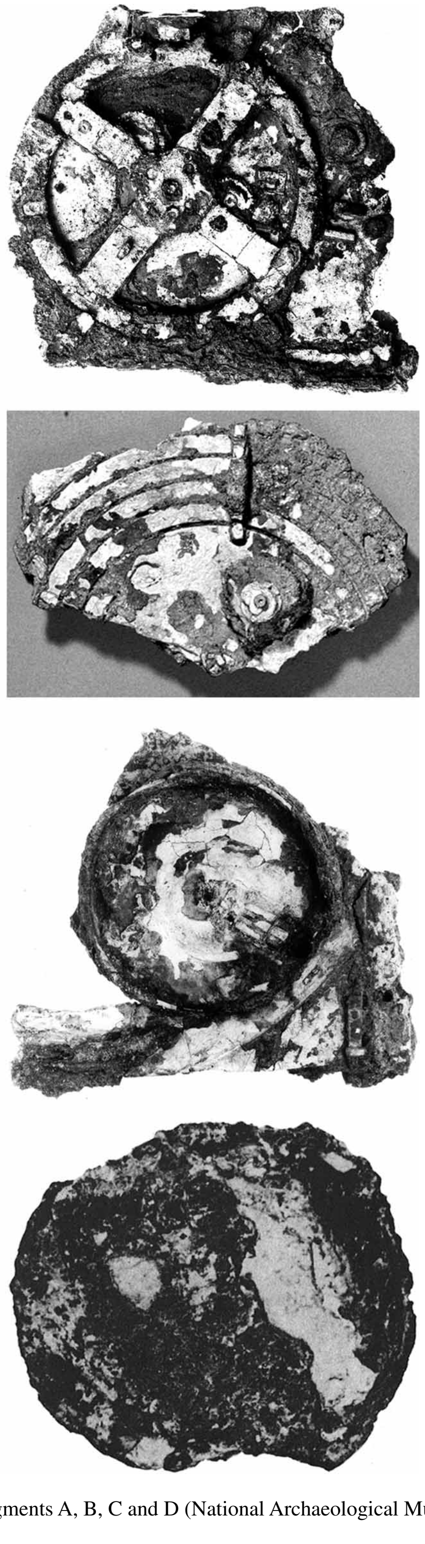

Figure 2. Photographs of the fragments A, B, C and D (National Archaeological Museum, Athens).

it was placed inside a wooden case bearing calibrated discs. The Antikythera mechanism itself consisted of a complex arrangement of about 30 gears. One of these transmitted the rotational motion to smaller gears, which rotated with various angular velocities. The user rotated the first gear with the help of an axle protruding from two opposite sides of the case. Around the disc of the large gear is a ring with mathematical subdivisions, on which are written the months of the year in the calendar of its construction era, while on other discs are marked the annual motion of the Sun through the Zodiac, the motion of the Moon, and the annual motions of the planets, the brightest stars and the constellations. In other parts of the Antikythera mechanism were carved indices of the rise and set times of the main celestial bodies. Also on the Antikythera mechanism there was a parapegma, as well as astronomical inscriptions in Greek, mainly on the exterior and interior sides of the wooden case. Although the gears seemed to be connected with each other in a rather complex way, this instrument was made with notable precision. However, the most impressive discovery was that of a differential gear (such as those used on the axles of the cars to harmonize two different angular velocities), which was present in order to compensate for the difference between the direct (eastward) motion of the Sun in the sidereal (fixed) system around the fixed centre of the World (Earth) and that (the direct motion) of the Moon and hence to allow calculation of the lunar phases. The function (purpose) of the differential gear was to subtract the direct rotation of the Sun from the direct rotations of the Moon to produce both the synodic month (29.53 days) and the cycle of the Moon's phases. (The synodic month is the interval of time (period) between two identical successive phases (or the period of the cycle of lunar phases), and the sidereal month (27.32 days) is the period of the Moon's revolution (or rotation) about the Earth with respect to the stars). Thus, the Antikythera mechanism could demonstrate both the motions of the Sun and the Moon and the lunar phases simultaneously.

Thus there is no doubt that, as de Solla Price himself has argued, the ancient Greeks were using this device in order to compute the position and phase of the Moon, the positions of

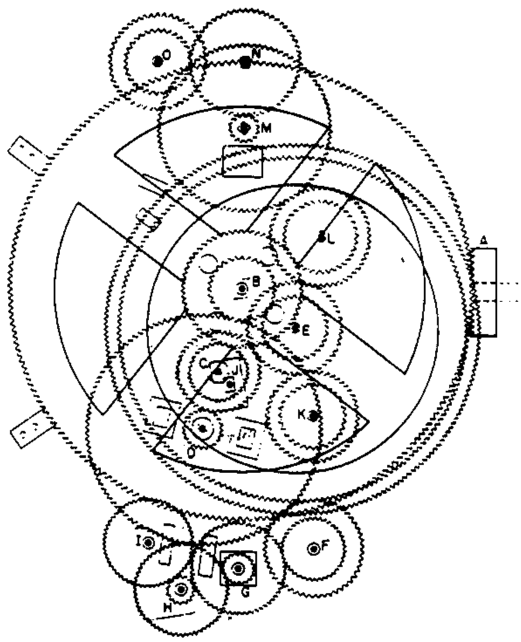

Figure 3. A reconstruction of the arrangement of the gears in the Antikythera mechanism.

the Sun and of the five planets known to the ancients relative to the Zodiac and the positions of the rising, set and annual motion of the celestial bodies. In other words, it was used as a planetarium.

de Solla Price tried to reconstruct the system of the 30 gears of the Antikythera mechanism (figure 3). He even tried to reproduce the Antikythera mechanism itself, based on his scientific corollaries, and he actually built its replica; this replica can be seen in the National Archaeological Museum of Athens (figure 4). Of course, we must also mention the statement by the Scientific Department of the National Archaeological Museum, according to which de Solla Price's reconstruction has not been unanimously accepted, since the Antikythera mechanism is still under study and analysis by specialists in order to understand its detailed structure and its exact use. Also there have been four physical reconstructions of de Solla Price's form implemented by Gleave [23], who found that the gears rotate although there are some abnormalities in the rotation.

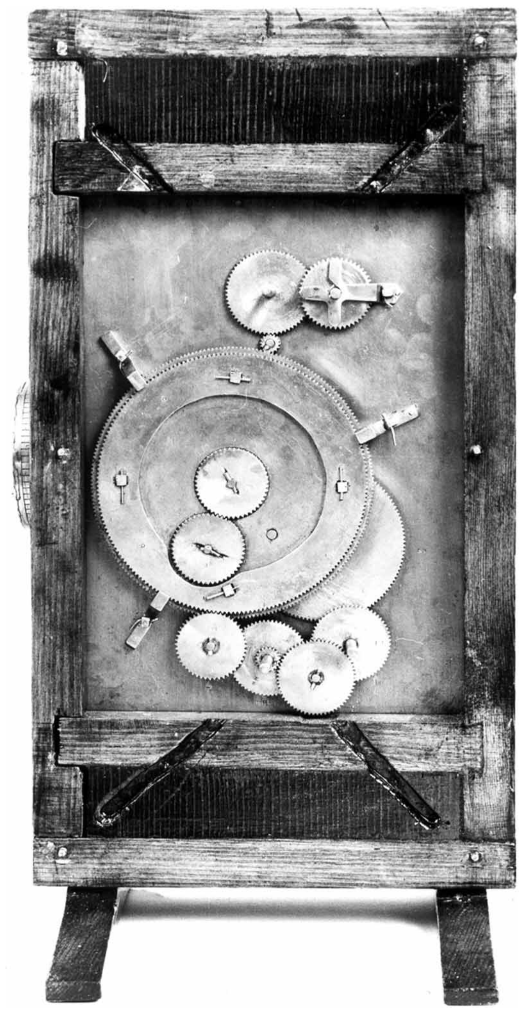

Figure 4. A photograph of the reproduction of the Antikythera mechanism according to de Solla Price (National Archaeological Museum, Athens).

After the work of de Solla Price, others wrote about the Antikythera mechanism. Among those articles, the most important are those by Bromley, who studied the Antikythera mechanism [24–26]. Bromley had found a different reconstruction which avoids some of the problems appearing in the reconstruction by de Solla Price. In 1989, he collaborated with Wright and Magou to apply the technique of linear tomography to acquire more precise images of the Antikythera mechanism's inner gears [27]. Their work was interrupted by Bromley's death, but Wright continued on his own, publishing his results and demonstrating his own reconstruction of the Antikythera mechanism in 2002 [28] and 2003 [29].

After analysing the new X-ray images obtained in 1989, Wright *et al.* [27] concluded that some of the assumptions of de Solla Price were wrong. The number of teeth in certain gears did not seem to correspond to de Solla Price's astronomically significant ratios, while some of his speculations were considered unwarranted. Wright *et al.* also disputed the inclusion of a differential gear, which instead, according to them, seemed to be an epicyclical mechanism. Regarding the above, de Solla Price wrote: 'It is unlikely that the rotational plate [he means the differential gear] would serve as an epicyclical mechanism for the demonstration of the planetary motions. There is not enough space in the box (containing the Mechanism) for such an additional mechanism which would reproduce planetary motions using epicyclical gears . . . .'

In other words, Wright [28, 29] found evidence that the Antikythera mechanism was able to reproduce the motions of the Sun and the Moon accurately, using the epicyclical model devised by Hipparchus and the motions of Mercury and Venus using an epicyclical model devised by Apollonius of Perga. We note that these models were introduced by Heraclides of Pontus [10, 30].

In particular, Wright noticed a fixed boss at the centre of the Antikythera mechanism's main wheel, which he considered as suggestive of a fixed central gear around which other moving gears would rotate. However, the idea that the device modelled only the motions of Sun, Moon, Mercury and Venus does not make much sense. Therefore, Wright suggested an expanded model, including extra layers of gears that have been lost, in which such epicyclical mechanisms formed a planetarium of all the known planets in the first century BC, including Mars, Jupiter and Saturn. In this way, the device may have been able to predict the positions of the known celestial bodies for any given date with a satisfying degree of accuracy, using bronze pointers on a circular dial with the constellations of the zodiac moving round its edge.

The remnants of the Antikythera mechanism's wooden case, however, leave limited space for extra gears. If all planets are not included, that strengthens the case for an astrological interpretation of the Antikythera mechanism's function [31], as only the more 'important' planets would be required for the drafting of horoscopes. Edmunds and Morgan [31] postulated that there is room for two extra planetary sets of gearing: one for Mars behind the front dial, and one for Venus behind the back dial. The fact that Mercury was not included in the Antikythera mechanism raises some doubts on the validity of that proposition. Namely, Mercury's orbit can be modelled similarly to that of Venus, resulting in a small increase in the size of the wooden case of the Antikythera mechanism.

Zeeman [32] provided a mathematical discussion of several aspects of the mechanics, and in particular of the gear ratios.

We consider more likely the assumption of the differential gear for the following reasons.

(i) The use of the differential gear is the easiest and shortest way to achieve the resonance of different rotations.

(ii) The use of the differential gear does not require much space, while the epicyclical mechanism does, because it includes the *deferent* as well as the *epicycle* for each celestial body.

(iii) The system with the epicyclical mechanism is much more complicated and difficult to use in the small volume of the Antikythera mechanism, even if we suppose that it included only some of the planets and not all of them. If we accept that the Antikythera mechanism was constructed by Posidonius, then according to Cicero (see II, XXXIV, of [33]) the Antikythera mechanism represented the motions of the five planets, the Sun and the Moon.

(iv) Posidonius introduced new aspects in science and discovered new methods for dealing with the various scientific problems. He is the most likely candidate for the discovery of the differential gear in order to synchronize the different rotations instead of the epicycles.

The texts, inscriptions and the writing style of the letters, the astronomical content of the Antikythera mechanism (i.e. the terminology and the calendar carved on it) and the alloy of metals used for its construction reveal that it was constructed during the first century BC. Also, the radiocarbon dating of pieces of the wooden case by de Solla Price gave an era around 80 BC, the year during which the Antikythera mechanism had been adjusted for the last time. The year of the construction of the instrument was determined to be around 87 BC [4].

In summary, among the many and interesting aspects that were discovered is that the Antikythera mechanism is the most ancient known example and is the forerunner of a differential mechanism and of astronomical–calendrical computational devices. Subsequently, it constitutes the most important evidence of the high level of engineering and technology during the Hellenistic era. Concerning the Antikythera mechanism's use, we consider it to be an astronomical or astrological calculating instrument, an orrery or planetarium, which was moreover used as a calendrical computer [8].

4. The creator of the Antikythera mechanism

We are now faced with the questions: who did the Antikythera mechanism belong to, who constructed it and what was its exact purpose? According to de Solla Price: '. . . the Mechanism was probably constructed by some engineer related to the School of Posidonius in Rhodes. This machine was found on a ship that was travelling from Rhodes to Rome and was wrecked about the same era Cicero visited the School of Posidonius, around 78 BC. The structure of the Mechanism seems to follow the technological tradition started by Archimedes for orrery construction. This tradition continued at the School of Rhodes (Posidonius), it was transmitted to the Islamic world and finally bloomed during the Medieval Ages with the construction of large astronomical clocks. The most impressive part of the Mechanism is the differential gear, which accepts two different angular velocities . . . .' Later, concerning one of the inscriptions on the instrument, he wrote: 'The shape and the astronomical content are very similar to those of the traditional Greek Calendar, especially the one cited in the appendix of the book by the Rhodian astronomer Geminus (Gemini) [34] *Introduction to the Phenomena* written circa 77 BC, i.e. the same period as the Antikythera shipwreck.'(See also [35]).

In another point, de Solla Price noted: 'The differential gear may have appeared for the first time in the Antikythera mechanism in an attempt to represent the motions of the Sun and the Moon in combination with the latter's phases. . . . It must certainly be recorded as one of the most important and essential inventions in engineering of all times, and its inventor, whether he is Archimedes or some unknown but ingenious engineer from the School of Posidonius, deserves the highest honor.' Finally, he concluded: '. . . most probably this machine was constructed by some anonymous engineer from Rhodes and not by Archimedes; nevertheless, we should credit the latter not only with the invention of complex gear systems along with their application in astronomical clockworks, but also the next great step inherent in the invention of the differential gear. . . . But even then we have others who could claim the invention of the Antikythera mechanism, like Andronicus the Kyrrestes, who built the Tower of Winds and one of the most complex astronomical sundials (located in the island of Tinos), Posidonius, whose relative works are cited by Cicero, Geminus of Rhodes, whose theory of lunisolar cycles and Calendar (Parapegma) that can be found in his book *Introduction to the Phenomena* are texts that fit well with the inscriptions on the Mechanism, and possibly several others from the same period . . . .'

Lazos [36] wrote: 'Therefore we can conclude that the device of Antikythera or (as it is more and more called) the computer of Antikythera constitutes a pioneering mechanism, a truly revolutionary invention in the field of engineering for its era (circa 80 BC), whose inventor is essentially unknown to us. We give as a probable name that of Archimedes, but this is not certain, since we have only relative evidence . . . .'

We should additionally note that Theophanides (Theophanidi) [19, 20] made a serious attempt to understand and explain the Antikythera mechanism; however, with the meagre means that he had at his disposal back then, he could not approach the truth to the extent that we now have, especially after the work of de Solla Price. According to his conclusion: 'it was an astrolabe invented by Hipparchus, built in order to be used for navigation; that is, it was to be found on ships, used by the captain and not by an astronomer.' Of course, Hipparchus lived in the second century BC, while the Antikythera mechanism was built during the first century BC.

Before expressing our opinion, we should note that among the few sources regarding planetaria in antiquity, the most important testimonies are to be found in the works by Cicero (106–43 BC): *De Natura Deorum* [33], *De Republica* [37] and *Tusculanarum Disputationes* [38]. From these we deduce that the construction of orreries began with the *Krikote Sphaera* (ringed sphere) of the great mathematician and astronomer Eudoxus of Knidos (408–355 BC), on the surface of which there were the constellations and the brightest stars (see I, XIV, of [37] and I, XXX, of [38]), and the celestial circles were represented by rings (krikoi). (According to Cicero, it seems that Thales of Miletus had built an early simple version of a solid celestial sphere, without voids in its interior). This statement by Cicero should be taken seriously because, firstly, Cicero was one of the reliable authors who had seen the planetarium of Archimedes (287–212 BC) as well as the planetarium built by Posidonius in Rhodes, secondly, Eudoxus had a great and well-known scientific ability and all necessary conditions for the construction of a planetarium and, thirdly, with his ringed sphere, Eudoxus could present and explain his theory of the *homocentric spheres* for the motions of the celestial bodies. In this way, not only could his theory be comprehended, but also the ringed sphere could be used as a teaching aid in the schools for the understanding of astronomical knowledge and ideas in general. Moreover, Loria [39] wrote, noting the tremendous ability of Eudoxus in mathematics and astronomy: 'We have to stress the deep familiarity of the inventor [of the concentric spheres theory] with the spherical geometry, a special branch named by the ancients *Sphairiki* (Spherical), but also with the art of conceiving mechanisms suitable for presenting a satisfactory paradigm of the motion of the stars, another branch created by the ancients and known as *Sphairopoiia*.' (Σφαιροποϊία is sphere making).

In the same book, Cicero (see also Claudius Claudianus [40]) stated that Archimedes was constructing spheres much more sophisticated than the usual ringed spheres made by Eudoxus of Knidos. He moreover described the planetarium that he himself saw in 78 BC in Rhodes, built by Posidonius and apparently used by the latter for studying the irregular motions of the five planets, the Sun and the Moon. As he himself confessed, this planetarium was more sophisticated than the device of Archimedes that he had seen in Marcellus' house or the common spheres with the rings used for teaching astronomy. Cicero explicitly stressed the distinction between the early type of ringed sphere made by Eudoxus and improved with the construction of planetaria by Archimedes and Posidonius, and the planetaria of the latter, which, as we mentioned earlier, were reproducing the motions of the celestial bodies.

We shall quote the translation of some relative passages from Cicero's works. In his book *De Republica* (see I, XIV, of [37]) he meticulously described the sphere, i.e. the planetarium constructed by Archimedes, which was in the house of Marcus Marcellus. This device had been brought to Rome from Syracuse by the grandfather of the latter, the general Marcellus, after he had conquered the city in 212 BC. This planetarium was easily used by a colleague of Marcus Marcellus in Hypateia, called Sulpicius Gallus, who wrote several astronomical books. As Cicero reported: '. . . this Sphere was worthy of great admiration, because Archimedes thought of a novel way to represent the different motions of the celestial bodies, that is to describe with the aid of the planetarium the motions of the Sun, the Moon and of the five planets [known at the time], using one single mechanism to rotate the Sphere.' Cicero was amazed, as he himself related, 'when Gallus operated the Archimedian planetarium, explaining at the same time the various motions of the celestial bodies'. He then went on to say: '. . . the wonderful characteristic of Archimedes' invention was precisely the method he used in order to combine upon one sphere and to reproduce all the different motions of the celestial bodies, and this led me to the conclusion that the famous Sicilian was gifted with far greater ingenuity than one could imagine for any other person.' He continued: 'When Gallus rotates the Sphere, one can observe the Moon replacing the Sun at the terrestrial horizon in the way it truly happens in the sky. Also, the Moon on the bronze shell of the Sphere is behind the Sun by as many rotations as exactly the number of days the Moon is really staying behind the Sun in the sky. Moreover, the Sun disappears from the sky and the Moon enters gradually in the shadow of the Earth when the Sun was on the opposite side, exactly as it happens in reality when solar and lunar eclipses occur.' (See I, XIV of [37] and I, XXX of [38]).

However, despite the experience that Cicero had already had with the Archimedian planetarium, when he saw the planetarium of Posidonius in Rhodes, where he had travelled between 79 and 77 BC, his impression and admiration were still greater. This fact indicates that his teacher's planetarium was something rare, something he was seeing for the first time in his life and which required a higher technology and deep knowledge of engineering (*Sphairopoiia*), astronomy and geography. In his book *De Natura Deorum* (see II, XXXIV, of [33]) he wrote: 'If someone transferred to Scythia or to Britain the celestial Sphere (Planetarium) recently constructed by the well-known to all of us Posidonius, on which the Sun, the Moon and the five planets move with each rotation exactly as they move in the sky every day and night [every 24 h], who would not believe in these . . . countries that this Sphere had been perfectly constructed by God?'

According to our opinion, a number of scientific and historical facts, which we present below, suggest that Posidonius was the creator of the Antikythera mechanism, which he constructed with the help of some engineer–technician of Rhodes.

(i) The ship carrying the instrument was going from Rhodes to Italy (Rome), with a stop at Piraeus.
(ii) The various scientific datings of the shipwreck lead to the conclusion that it occurred between 80 and 50 BC, i.e. the period during which Posidonius lived in Rhodes.
(iii) Cicero, who saw for the first time the planetarium of Posidonius when visiting Rhodes between 79 and 77 BC, stated that '[the planetarium] was recently constructed by the well-known to all of us Posidonius' matches well both with the dating of the shipwreck (between 80 and 50 BC) and the date of construction of the Antikythera mechanism (around 87 BC) according to de Solla Price.
(iv) The planetarium of Posidonius made an impression on Cicero in comparison with his previous experience with the planetarium of Archimedes operated by Gallus. From the

comparison between the two mechanisms, Cicero deduced their difference. We postulate that the novelty that Cicero observed in the planetarium of Posidonius is the differential gear, which could reproduce more faithfully than the Archimedian planetarium the different motions of the five planets, the Sun and the Moon.

(v) In the introduction, we briefly outlined the development of astronomy, mathematics, meteorology and geography in ancient Rhodes. We also stated that ancient Rhodes had a long tradition in science and was one of the most important astronomical centres in antiquity, especially during the second and first centuries BC. The cultural and artistic activity of Rhodes reached its culmination mainly during the second and first centuries BC, namely during the period that the astronomers Hipparchus, Posidonius and Geminus lived there. The Rhodian School of Art was considered one of the most important of that period and became famous throughout the then known world [8].

Since 408 BC (the year that the city of Rhodes was built) the united Rhodian state had adopted a new system of coining and used golden, silver and copper coins. The main figure on these coins was the ray-crowned head of Helios, the Sun god and patron of the city, while the back side was decorated with the characteristic flower of Rhodes, the rose, and the inscription RHODION. The ray-crowned head of Helios underwent an evolution with time, appearing different in different periods. We believe that this evolution is a result of the evolution of astronomical knowledge and ideas [7]. This evolution culminated during the period of the great Rhodian astronomers Hipparchus and Posidonius, an era when the Rhodian minting also reached its highest point.

Engineering was highly developed in Rhodes. Philon of Byzantium (260–180 BC), who lived and worked in Rhodes and Alexandria, was one of the most famous engineers and physicists of antiquity. His work was broad and important and contributed to the development and evolution of engineering technology. He wrote many treatises on all branches of engineering that had numerous applications and which included many novel ideas [41].

We should also note that Hipparchus not only improved certain previous astronomical instruments but also invented more complicated and accurate ones, with the aid of advanced technology developed during that period in Rhodes and Alexandria.

The above remarks indicate that at the time of Posidonius there was the necessary background, tools, methods and, in particular, people that could help in the construction of a complex device, which could reproduce the different motions of the celestial bodies.

(vi) The inventor of such an astronomical mechanism would possess a deep knowledge of astronomy, geography and mathematics (especially spherical geometry) as well as engineering (*Sphairopoiia*) and the contemporary technology in general. He would have studied, among others, the works by Archimedes, especially the book *On Sphairopoiia*, and, of course, he would have a complete understanding of the operation of the Archimedian planetarium, so that with his own ingenuity he would conceive the idea of the differential gear. We suggest that this person was Posidonius, who was considered by Strabo as having the broadest mind after Aristotle because of his knowledge of many and diverse topics, together with his innate tendency for research and innovative thought.

Indeed, as we have already mentioned, Posidonius modified certain theories of the earlier Stoic philosophers and formed his own philosophical system. He also discovered new methods for dealing with various scientific problems from different scientific aspects. On the one hand, this aimed at a better teaching of his students and, on the other hand, it was an attempt to check by different methods or to improve the results of the other scientists such as Eratosthenes, Aristarchus of Samos, Dikaiarchus, Polybius, Pytheas and Hipparchus. Therefore, the concept of the construction of a novel planetarium by Posidonius was motivated by the teaching of his students. We think that it was also motivated by a better understanding of the astronomical phenomena and, in particular, the more faithful representation of the motions of the five planets, the Sun and the Moon, with the use of the differential gear. As de Solla Price [4] stated, the Antikythera mechanism was being used because it had already been fixed twice by the time of the shipwreck.

(vii) Regarding the conjecture by de Solla Price that probably the creator of the Antikythera mechanism was the Rhodian Stoic philosopher, mathematician and astronomer Geminus, based on the fact that the inscriptions on the device are in accordance with the theory of lunisolar cycles and the calendar (parapegma) described in his book *Introduction to the Phenomena*, we make the following remarks: Geminus, a student of Posidonius, tried to popularize some of the writings of his teacher for educational purposes and wrote among others a classic work on mathematics, as well as the astronomical *Introduction to the Phenomena* and a summary of the major opus of the Meteorologica of Posidonius *(On Meteorological Phenomena)*. The latter work of Geminus has been lost, but we can retrieve relative information from Simplicius [42] (see also [43]). Thus Geminus cited in his writings the theories developed by his teacher and apparently the calendar appearing in his book was taken from that compiled by Posidonius, which was used during that period. Manitius [34] even showed in his edition of the *Introduction to the Phenomena* that this calendar annexed by Geminus in his book predated the rest of the text (which was written around 70 BC) by almost a century [7, 43]. Without disregarding the considerable scientific merit of Geminus, we would like to mention that Geminus is not considered as important as his famous teacher. Therefore, the argument of de Solla Price in fact favours Posidonius, and not Geminus.

5. Conclusions

Based on the arguments presented here we conclude:

(i) The Antikythera mechanism has about 30–32 gears. The precise determination of the number of gears, as well as the number and the precise geometrical shape and dimensions of the teeth, has not yet been accomplished. The Antikythera mechanism has not yet been fully studied; there probably exist more inscriptions and gears. The gears inside are not easily distinguishable. The diameters of only some of the gears can be estimated directly and these diameters vary between 9 and 132 mm. In order to estimate the circumferences and the centres of the remaining gears it could be useful to apply curvature theory, similarly to that used in [44]. Also about 793 letters were found.

(ii) We think that Posidonius is the inventor of the Antikythera mechanism, which probably had a differential gear. The actual construction is probably the work of some engineer–technician of the Rhodes school under the guidance of Posidonius.

(iii) Regarding the Antikythera mechanism's purpose we note the following: Posidonius conceived the idea of constructing a more advanced planetarium than that made by Archimedes and was motivated not only by educational purposes but also by his own improved understanding of astronomical phenomena and in particular by the more faithful representation of the motions of the five planets, the Sun, the Moon and the rise and set of some stars and constellations, with the aid of the differential gear.

(iv) As far as the Antikythera mechanism's use is concerned, we consider it to be an astronomical or astrological calculator, an orrery or a planetarium, which was also probably used as a calendrical computer.

This device could also have had other applications and could have been used as a navigation instrument. This conjecture is based on the fact that since Eratosthenes' era the Earth was divided into parallels and meridians and the main parallel and main meridian crossed at Rhodes. Furthermore, Hipparchus of Rhodes described the celestial phenomena for various areas of geographical latitude and constructed tables of the astronomical data per 1° of latitude or per 700 stades [44]. The navigation at that time was mainly based on observations of the positions of the stars. In addition, the ancient calendars were very useful and important for Rhodian sailors, who were away from the island for long periods of time.

(v) It is very likely that the Antikythera treasure was bought by Romans or was donated to Rome by Rhodes. This argument is supported by the following facts. During that time, Rhodes was not occupied by the Romans and it was an independent island (Rhodes was occupied by Rome in 42 BC while Athens was occupied by Romans in 142 BC) and wanted to have good relationships with Rome. If we combine this with the fact that many eminent Romans such as Cicero, Gnaius Pompeius and others visited their teacher Posidonius, we may conclude that they favoured in the purchase and donation of pieces of art and of scientific instruments for Romans.

(vi) We should mention that, according to information retrieved from ancient writers, Rhodes and Syracuse were the two ancient cities where sophisticated planetaria were used for educational and scientific purposes. Probably, the questions of what its precise structure and function were and also what its purpose and use were cannot be answered easily.

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