Antikythera mechanism


The Antikythera mechanism (main fragment)

The **Antikythera mechanism** (/ˌæntɪkɪˈθɪərə/ ***ANT**-i-ki-**THEER**-ə* or /ˌæntɪˈkɪθərə/ ***ANT**-i-**KITH**-ə-rə*) is an ancient analog computer[1][2] designed to calculate astronomical positions. It was recovered in 1900–1901 from the Antikythera wreck,[3] but its significance and complexity were not understood until a century later. Jacques-Yves Cousteau visited the wreck in 1978,[4] but found no additional remains of the Antikythera mechanism. The construction has been dated to the early 1st century BC. Technological artifacts approaching its complexity and workmanship did not appear again until the 14th century A.D., when mechanical astronomical clocks began to be built in Western Europe.[5]

Professor Michael Edmunds of Cardiff University, who led the most recent study of the mechanism, said: "This device is just extraordinary, the only thing of its kind. The design is beautiful, the astronomy is exactly right. The way the mechanics are designed just makes your jaw drop. Whoever has done this has done it extremely carefully ... in terms of historic and scarcity value, I have to regard this mechanism as being more valuable than the Mona Lisa."[6][7]

The Antikythera mechanism is displayed at the National Archaeological Museum of Athens, accompanied by a reconstruction made and donated to the museum by Derek de Solla Price. Other reconstructions are on display at the American Computer Museum in Bozeman, Montana, the Children's Museum of Manhattan in New York, in Kassel, Germany, and at the Musee des Arts et Metiers in Paris.

Origins

The mechanism is the oldest known complex scientific calculator. It contains many gears and is sometimes called the first known analog computer,[8] although the quality of its manufacture suggests that it may have had a number of undiscovered predecessors[9] during the Hellenistic Period. It appears to be constructed upon theories of astronomy and mathematics developed by Greek astronomers. It is estimated to have been made around 100 BC. In 1974, Yale University Professor Derek de Solla Price concluded from gear settings and inscriptions on the mechanism's faces that the mechanism was made about 87 BC and was lost only a few years later.[10]

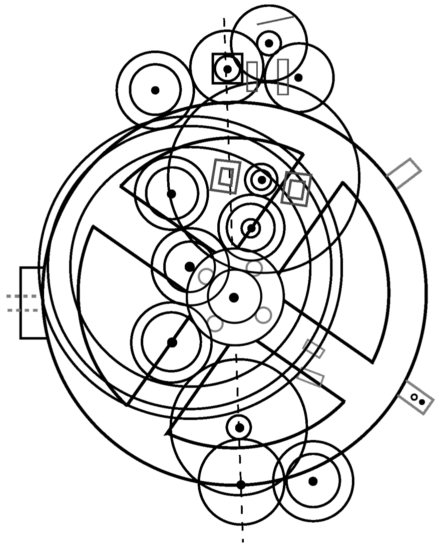
It is believed to be made of a low-tin bronze alloy (95% copper, 5% tin), but the device's advanced state of corrosion has made it impossible to perform an accurate compositional analysis.[11]

All of the mechanism's instructions are written in Koine Greek,[7] and the consensus among scholars is that the mechanism was made in the Greek-speaking world. One hypothesis is that the device was constructed at an academy founded by the Stoic philosopher Posidonius on the Greek island of Rhodes, which at the time was known as a center of astronomy and mechanical engineering; this hypothesis further suggests that the mechanism may have been designed by the astronomer Hipparchus, since it contains a lunar mechanism which uses Hipparchus's theory for the motion of the Moon. However, recent findings of The Antikythera Mechanism Research Project suggest that the concept for the mechanism originated in the colonies of Corinth, which might imply a connection with Archimedes.[12]

It was discovered in a shipwreck off Point Glyphadia on the Greek island of Antikythera. The wreck had been found in October 1900 and divers had retrieved numerous artifacts, most of them works of art, which had been transferred to the National Museum of Archaeology for storage. On 17 May 1902, archaeologist Valerios Stais was examining the finds and noticed that one of the pieces of rock had a gear wheel embedded in it. Stais initially believed it was an astronomical clock, but most scholars considered the device an anachronism, too complex to have been constructed during the same period as the other pieces that had been discovered. Investigations into the object were soon dropped until English physicist Derek J. de Solla Price became interested in it in 1951.[13]

It is not known how it came to be on the cargo ship, but it has been suggested that it was being taken to Rome, together with other treasure looted from the island, to support a triumphal parade being staged by Julius Caesar.[14]

Function



Schematic of the artifact's mechanism

The device is remarkable for the level of miniaturization and the complexity of its parts, which is comparable to that of 19th-century clocks. It has more than 30 gears, although Michael Wright (see below) has suggested there may have been as many as 72 gears, with teeth formed through equilateral triangles. When a date was entered via a crank (now lost), the mechanism calculated the position of the Sun and Moon or other astronomical information, such as the locations of planets. Since the purpose was to position astronomical bodies with respect to the celestial sphere, in reference to the observer's position on the Earth, the device was based on the geocentric model.[15]

The mechanism has three main dials, one on the front, and two on the rear. The front dial has two concentric scales. The outer ring is marked off with the days of the 365-day Egyptian calendar, or the Sothic year, based on the Sothic cycle. Inside this, there is a second dial marked with the Greek signs of the Zodiac and divided into degrees. The calendar dial can be moved to compensate for the effect of the extra quarter day in the solar year by turning the scale backwards one day every four years. A $365\frac{1}{4}$-day year was used in the Callippic cycle about 330 BC and in the Decree of Canopus in 238 BC.

The front dial probably carried at least three hands, one showing the date, and two others showing the positions of the Sun and the Moon. The Moon indicator is adjusted to show the first anomaly of the Moon's orbit. It is reasonable to suppose the Sun indicator had a similar adjustment, but any gearing for this mechanism (if it existed) has been lost. The front dial also includes a second mechanism with a spherical model of the Moon that displays the lunar phase.


Front panel of a 2007 model

There is reference in the inscriptions for the planets Mars and Venus, and it would have certainly been within the capabilities of the maker of the mechanism to include gearing to show their positions. There is some speculation that the mechanism may have had indicators for all five of the planets known to the Greeks. None of the gearing for such planetary mechanisms survives, except for one gear otherwise unaccounted for.

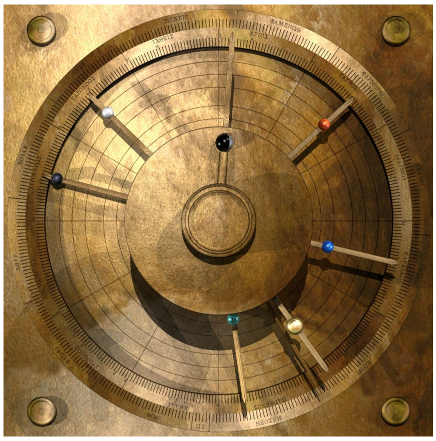
Finally, the front dial includes a parapegma, a precursor to the modern day almanac, which was used to mark the rising and setting of specific stars. Each star is thought to be identified by Greek characters which cross-reference details inscribed on the mechanism.

The upper back dial is in the form of a spiral, with 47 divisions per turn, displaying the 235 months of the 19-year Metonic cycle. This cycle is important in fixing calendars. In July 2008 experts from the Antikythera Mechanism Research Project discovered that one of the upper back dial's subsidiary dials, which was thought to display the 76-year Callippic cycle, in fact displayed the 4-year Olympiad cycle. The dial is divided into four sectors, each of which is inscribed with a year number and the name of two Panhellenic Games: the "crown" games of Isthmia, Olympia, Nemea, and Pythia; and two lesser games: Naa (held at Dodona) and another games which has not yet been deciphered.[16]

The lower back dial is also in the form of a spiral, with 223 divisions showing the saros; it also has a smaller subsidiary dial which displays the 54 year "triple saros" or exeligmos. (The saros, discovered by the Chaldeans, is a period of approximately 18 years 11 days 8 hours—the length of time between occurrences of a particular eclipse.)

In July 2008, scientists reported new findings in the journal *Nature* showing that the mechanism tracked the Metonic calendar, predicted solar eclipses, and calculated the timing of the Ancient Olympic Games.[17] Inscriptions on the instrument closely match the names of the months on calendars from Illyria and Epirus in northwestern Greece and with the island of Corfu.[18][19]

Inscriptions

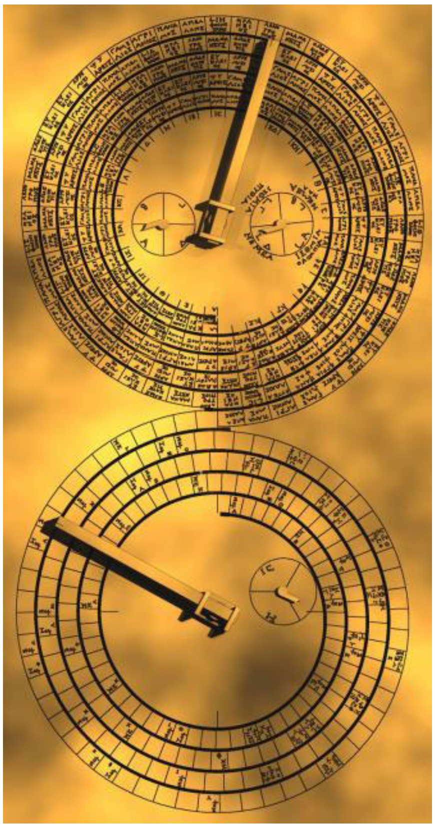

Computer-generated front panel

On the front of the Antikythera mechanism, there is one dial with two confirmed pointers, but, due to references on the inscriptions, there might have been as much as eight pointers, one for the day of the year and the rest representing the orbital positions for: Mercury, Venus, Sun, Mars, Jupiter, Saturn and the Moon. Although it has been confirmed that the pointer for the moon also rotates on its axis to show its phase along with its position, it is not clear whether the Sun position pointer would have been separated from a date pointer, or whether any planetary positions might have been displayed.[12]

The front dial is surrounded by two circular plates: the movable outer plate and the fixed inner plate. The following months are inscribed, in Greek letters, on the outer plate: Mecheir Phamenoth Pharmouthi Pachon Payni Epeiph Mesore Epagomene Thoth Phaophi Hathyr Choiak Tybi In addition, the following Zodiac signs appear on the inner plate: ΚΡΙΟΣ (Aries) ΤΑΥΡΟΣ (Taurus)

ΔΙΔΥΜΟΙ (Gemini) ΚΑΡΚΙΝΟΣ (Cancer) ΛΕΩΝ (Leo) ΠΑΡΘΕΝΟΣ (Virgo) ΖΥΓΟΣ (Libra) ΣΚΟΡΠΙΟΣ (Scorpio) ΤΟΞΟΤΗΣ (Sagittarius) ΑΙΓΟΚΕΡΩΣ (Capricorn) ΥΔΡΟΧΟΟΣ (Aquarius) ΙΧΘΕΙΣ (Pisces) Other inscriptions on the front dial are: {Κ} Evening {Λ} The Hya{des se}t in the evening Μ Taurus {be}gins to rise {Ν} Vega rises in the evening Θ {The Pleiad}es rise in the morning Ο The Hyades rise in the morning Π Gemini begins to rise Ρ Altair rises in the evening Σ Arcturus sets in the {morning}

On the back of the mechanism, there are five dials: the Metonic, the Olympiad, the Callippic, the Saros and the Exeligmos. The Metonic Dial is the main upper dial. It is a 19-year calendar with a total of 235 months. Each month is written over two or three lines within one of the 235 cells circumscribed by two of the six turnings of a spiral. The Corinthian months are: 1. ΦΟΙΝΙΚΑΙΟΣ 2. ΚΡΑΝΕΙΟΣ 3. ΛΑΝΟΤΡΟΠΙΟΣ 4. ΜΑΧΑΝΕΥΣ 5. ΔΩΔΕΚΑΤΕΥΣ 6. ΕΥΚΛΕΙΟΣ 7. ΑΡΤΕΜΙΣΙΟΣ 8. ΨΥΔΡΕΥΣ 9. ΓΑΜΕΙΛΙΟΣ 10. ΑΓΡΙΑΝΙΟΣ 11. ΠΑΝΑΜΟΣ 12. ΑΠΕΛΛΑΙΟΣ


Computer-generated back panel

The Olympiad Dial is the right secondary upper dial. It is a four-year dial, representing the cycle of the Panhellenic Games. The labels on each one of the four divisions are: 1. LA (Year 1) 2. LB (Year 2) 3. LΓ (Year 3) 4. LΔ (Year 4) In addition, outside and above of each of these four division are the following inscriptions: 1. ΙΣΘΜΙΑ, ΟΛΥΜΠΙΑ (corresponding to year 1) 2. ΝΕΜΕΑ, ΝΑΑ (corresponding to year 2) 3. ΙΣΘΜΙΑ, ΠΥΘΙΑ (corresponding to year 3) 4. ΝΕΜΕΑ, undeciphered text (corresponding to year 4)

The Callippic Dial is the left secondary upper dial, which follows a 76-year cycle, quadrupling the Methonic dial.

The Saros Dial is the main lower dial. It is an 18-year calendar with a total of 223 lunar months. Each month is represented by one of the 223 cells circumscribed by two of the five turnings of a spiral. This dial predicts eclipses and the predictions are shown in the relevant months as glyphs, which indicate lunar and solar eclipses and their predicted times of day. There are 51 glyphs, specifying 38 lunar and 27 solar eclipses. The glyph times are still incomplete. Beneath each glyph is an index letter. Some of the index letters are: Σ = ΣΕΛΗΝΗ (Moon) Η = ΗΛΙΟΣ (Sun) Η\Μ = ΗΜΕΡΑΣ (of the day) ω\ρ = ωρα (hour) Ν\Υ = ΝΥΚΤΟΣ (of the night) Moreover, the divisions on the inside of the dial at the cardinal points indicate the start of a new Full Moon Cycle.

The Exeligmos Dial is the secondary lower dial. It is a 54-year triple Saros dial. The labels on each one of the three divisions are: 1. Blank, which represents the number zero. 2. Η (number 8) 3. Ις (number 16) So the dial pointer indicates how many hours must be added to the glyph times of the Saros Dial in order to get the exact eclipse times.

The Front Door also has inscriptions.

The Back Door appears to be the "Instruction Manual". On one of its fragments, it is written "76 years, 19 years" representing the Callippic and Metonic cycles. It is also written "223" for the Saros cycle. On another one of its fragments, it is written "on the spiral subdivisions 235" for the Metonic Dial.[12][20]

Speculation about the mechanism's purpose

Derek J. de Solla Price suggested that the mechanism might have been on public display, possibly in a museum or public hall in Rhodes. The island was known for its displays of mechanical engineering, particularly automata, which apparently were a speciality of the Rhodians. Pindar, one of the nine lyric poets of ancient Greece, said this of Rhodes in his seventh Olympic Ode:

> The animated figures stand
>
> Adorning every public street
>
> And seem to breathe in stone, or
>
> Move their marble feet.

Arguments against the device having been on public display include the following:

1. The device is rather small, indicating that the designer was aiming for compactness and, as a result, the size of the front and back dials is unsuitable for public display. A simple comparison with the size of the Tower of the Winds in Athens would suggest that the Antikythera mechanism manufacturer designed the device for mobility rather than public display in a fixed location.
2. The mechanism had door plates that contained at least 2,000 characters, forming what members of the Antikythera mechanism research project often refer to as an instruction manual. The attachment of this manual to the mechanism itself implies ease of transport and personal use.
3. The existence of this "instruction manual" implies that the device was constructed by a scientist and mechanic for use by a non-expert traveler (the text has much information associated with well known Mediterranean geographical locations).

The device is unlikely to have been intended for navigation use because:

1. Some data, such as eclipse predictions, are unnecessary for navigation.
2. Damp, salt-laden marine environments would quickly corrode the gears, rendering it useless.

Similar devices in ancient literature

Cicero's *De re publica*, a 1st century BC philosophical dialogue, mentions two machines that some modern authors consider as some kind of planetarium or orrery, predicting the movements of the Sun, the Moon, and the five planets known at that time. They were both built by Archimedes and brought to Rome by the Roman general Marcus Claudius Marcellus after the death of Archimedes at the siege of Syracuse in 212 BC. Marcellus had great respect for Archimedes and one of these machines was the only item he kept from the siege (the second was offered to the temple of Virtus). The device was kept as a family heirloom, and Cicero has Philus (one of the participants in a conversation that Cicero imagined had taken place in a villa belonging to Scipio Aemilianus in the year 129 BC) saying that Gaius Sulpicius Gallus (consul with Marcellus' nephew in 166 BC, and credited by Pliny the Elder as the first Roman to have written a book explaining solar and lunar eclipses) gave both a "learned explanation" and a working demonstration of the device.

> I had often heard this celestial globe or sphere mentioned on account of the great fame of Archimedes. Its appearance, however, did not seem to me particularly striking. There is another, more elegant in form, and more generally known, moulded by the same Archimedes, and deposited by the same Marcellus, in the Temple of Virtue at Rome. But as soon as Gallus had begun to explain, by his sublime science, the composition of this machine, I felt that the Sicilian geometrician must have possessed a genius superior to any thing we usually conceive to belong to our nature. Gallus assured us, that the solid and compact globe, was a very ancient invention, and that the first model of it had been presented by Thales of Miletus. That afterwards Eudoxus of Cnidus, a disciple of Plato, had traced on its surface the stars that appear in the sky, and that many years subsequent, borrowing from Eudoxus this beautiful design and representation, Aratus had illustrated them in

> his verses, not by any science of astronomy, but the ornament of poetic description. He added, that the figure of the sphere, which displayed the motions of the Sun and Moon, and the five planets, or wandering stars, could not be represented by the primitive solid globe. And that in this, the invention of Archimedes was admirable, because he had calculated how a single revolution should maintain unequal and diversified progressions in dissimilar motions.
>
> When Gallus moved this globe it showed the relationship of the Moon with the Sun, and there were exactly the same number of turns on the bronze device as the number of days in the real globe of the sky. Thus it showed the same eclipse of the Sun as in the globe [of the sky], as well as showing the Moon entering the area of the Earth's shadow when the Sun is in line ... [missing text]
>
> [i.e. It showed both solar and lunar eclipses.][21]

Pappus of Alexandria stated that Archimedes had written a now lost manuscript on the construction of these devices entitled *On Sphere-Making*.[22][23] The surviving texts from the Library of Alexandria describe many of his creations, some even containing simple drawings. One such device is his odometer, the exact model later used by the Romans to place their mile markers (described by Vitruvius, Heron of Alexandria and in the time of Emperor Commodus).[24] The drawings in the text appeared functional, but attempts to build them as pictured had failed. When the gears pictured, which had square teeth, were replaced with gears of the type in the Antikythera mechanism, which were angled, the device was perfectly functional.[25] Whether this is an example of a device created by Archimedes and described by texts lost in the burning of the Library of Alexandria, or if it is a device based on his discoveries, or if it has anything to do with him at all, is debatable.

If Cicero's account is correct, then this technology existed as early as the 3rd century BC. Archimedes' device is also mentioned by later Roman era writers such as Lactantius (*Divinarum Institutionum Libri VII*), Claudian (*In sphaeram Archimedes*), and Proclus (*Commentary on the first book of Euclid's Elements of Geometry*) in the 4th and 5th centuries.

Cicero also said that another such device was built 'recently' by his friend Posidonius, "... each one of the revolutions of which brings about the same movement in the Sun and Moon and five wandering stars [planets] as is brought about each day and night in the heavens..."[26]

It is unlikely that any one of these machines was the Antikythera mechanism found in the shipwreck since both the devices fabricated by Archimedes and mentioned by Cicero were located in Rome at least 30 years later than the estimated date of the shipwreck, and the third device was almost certainly in the hands of Posidonius by that date. The scientists who have reconstructed the Antikythera mechanism also agree that it was too sophisticated to have been a unique device.

This evidence that the Antikythera mechanism was not unique adds support to the idea that there was an ancient Greek tradition of complex mechanical technology that was later, at least in part, transmitted to the Byzantine and Islamic worlds, where mechanical devices which were complex, albeit simpler than the Antikythera mechanism, were built during the Middle Ages.[27] Fragments of a geared calendar attached to a sundial, from the 5th or 6th century Byzantine Empire, have been found; the calendar may have been used to assist in telling time.[28] In the Islamic world, Banū Mūsā's *Kitab al-Hiyal*, or *Book of Ingenious Devices*, was commissioned by the Caliph of Baghdad in the early 9th century AD. This text described over a hundred mechanical devices, some of which may date back to ancient Greek texts preserved in monasteries. A geared calendar similar to the Byzantine device was described by the scientist al-Biruni around 1000, and a surviving 13th-century astrolabe also contains a similar clockwork device.[28] It is possible that this medieval technology may have been transmitted to Europe and contributed to the development of mechanical clocks there.[5]

Investigations and reconstructions

The Antikythera mechanism is one of the world's oldest known geared devices. It has puzzled and intrigued historians of science and technology since its discovery. A number of individuals and groups have been instrumental in advancing the knowledge and understanding of the mechanism including: pioneering German Philologist Albert Rehm; Derek J. de Solla Price (with Charalampos Karakalos and his wife Emily); Allan George Bromley (with Frank Percival, Michael Wright and Bernard Gardner); Michael Wright and The Antikythera Mechanism Research Project.

Reconstruction of the Antikythera mechanism in the National Archaeological Museum, Athens (made by Robert J. Deroski, based on Derek J. de Solla Price model)

Derek J. de Solla Price

Following decades of work cleaning the device, in 1951 British science historian Derek J. de Solla Price undertook systematic investigation of the mechanism.

Price published several papers on "Clockwork before the Clock".[29][30] and "On the Origin of Clockwork",[31] before the first major publication in June 1959 on the mechanism: "An Ancient Greek Computer".[32] This was the lead article in *Scientific American* and appears to have been initially published at the prompting of Arthur C. Clarke, according to the book *Arthur C. Clarke's Mysterious World* (see end of chapter 3). In "An Ancient Greek Computer" Price advanced the theory that the Antikythera mechanism was a device for calculating the motions of stars and planets, which would make the device the first known analog computer. Until that time, the Antikythera mechanism's function was largely unknown, though it had been correctly identified as an astronomical device, perhaps being an astrolabe.

In 1971, Price, by then the first Avalon Professor of the History of Science at Yale University, teamed up with Charalampos Karakalos, professor of nuclear physics at the Greek National Centre of Scientific Research "DEMOKRITOS". Karakalos took both gamma- and X-ray radiographs of the mechanism, which revealed critical information about the device's interior configuration.

In 1974, Price published "Gears from the Greeks: the Antikythera mechanism – a calendar computer from ca. 80 BC",[33] where he presented a model of how the mechanism could have functioned.

Price's model, as presented in his "Gears from the Greeks", was the first theoretical attempt at reconstructing the device based on its inner structure revealed by the radiographs. According to that model, the front dial shows the annual progress of the Sun and Moon through the zodiac against the Egyptian calendar. The upper rear dial displays a four-year period and has associated dials showing the Metonic cycle of 235 synodic months, which approximately equals 19 solar years. The lower rear dial plots the cycle of a single synodic month, with a secondary dial showing the lunar year of 12 synodic months.

One of the remarkable proposals made by Price was that the mechanism employed differential gears, which enabled the mechanism to add or subtract angular velocities. The differential was used to compute the synodic lunar cycle by subtracting the effects of the Sun's movement from those of the sidereal lunar movement.

Allan George Bromley

A variant on Price's reconstruction was built by Australian computer scientist Allan George Bromley of the University of Sydney and Sydney clockmaker Frank Percival. Bromley went on to make new, more accurate X-ray images in collaboration with Michael Wright.

Michael Wright

Michael Wright, formerly Curator of Mechanical Engineering at The London Science Museum and now of Imperial College, London, made a completely new study of the original fragments together with Allan George Bromley. They used a technique called linear X-ray tomography which was suggested by retired consultant radiologist, Alan Partridge. For this, Wright designed and made an apparatus for linear tomography, allowing the generation of sectional 2D radiographic images.[34] Early results of this survey were presented in 1997, which showed that Price's reconstruction was fundamentally flawed.[35]

Further study of the new imagery allowed Wright to advance a number of proposals. Firstly he developed the idea, suggested by Price in "Gears from the Greeks", that the mechanism could have served as a planetarium. Wright's planetarium not only modelled the motion of the Sun and Moon, but also the Inferior Planets (Mercury and Venus), and the Superior Planets (Mars, Jupiter and Saturn).[36][37]

Wright proposed that the Sun and Moon could have moved in accordance with the theories of Hipparchus and the five known planets moved according to the simple epicyclic theory suggested by the theorem of Apollonius. In order to prove that this was possible using the level of technology apparent in the mechanism, Wright produced a working model of such a planetarium.[38][39]

Wright also increased upon Price's gear count of 27 to 31[37] including 1 in Fragment C that was eventually identified as part of a Moon phase display.[40] He suggested that this is a mechanism that shows the phase of the Moon by means of a rotating semi-silvered ball, realized by the differential rotation of the sidereal cycle of the Moon and the Sun's yearly cycle. This precedes previously known mechanisms of this sort by a millennium and a half.

More accurate tooth counts were also obtained,[41] allowing a new gearing scheme to be advanced.[42] This more accurate information allowed Wright to confirm Price's perceptive suggestion that the upper back dial displays the Metonic cycle with 235 lunar months divisions over a five-turn scale. In addition to this Wright proposed the remarkable idea that the main back dials are in the form of spirals, with the upper back dial out as a five-turn spiral containing 47 divisions in each turn. It therefore presented a visual display of the 235 months of the Metonic cycle (19 years ≈ 235 Synodic Months). Wright also observed that fragmentary inscriptions suggested that the pointer on the subsidiary dial showed a count of four cycles of the 19-year period, equal to the 76-year Callippic cycle.[43]

Based on more tentative observations, Wright also came to the conclusion that the lower back dial counted Draconic Months and could perhaps have been used for eclipse prediction.[44]

All these findings have been incorporated into Wright's working model,[43] demonstrating that a single mechanism with all these functions could be built, and would work.

Despite the improved imagery provided by the linear tomography Wright could not reconcile all the known gears into a single coherent mechanism, and this led him to advance the theory that the mechanism had been altered, with some astronomical functions removed and others added.[43]

Finally, as an outcome of his considerable research,[34][43][45][46][47][48][49] Wright also conclusively demonstrated that Price's suggestion of the existence of a differential gearing arrangement was incorrect.[40][43]

In 2006 Wright completed what he believed to be an almost exact replica of the mechanism.[50]

Michael Wright's research on the mechanism is continuing in parallel with the efforts of the Antikythera Mechanism Research Project (AMRP). Recently Wright slightly modified his model of the mechanism to incorporate the latest findings of the AMRP regarding the function of the pin and slot engaged gears that simulate the anomaly in the Moon's angular velocity. On 6 March 2007 he presented his model in the National Hellenic Research Foundation in

Athens.

The Antikythera Mechanism Research Project

The Antikythera mechanism is now being studied by the Antikythera Mechanism Research Project,[51] a joint program between Cardiff University (M. Edmunds, T. Freeth), the National and Kapodistrian University of Athens (X. Moussas, Y. Bitsakis), the Aristotle University of Thessaloniki (J.H. Seiradakis), the National Archaeological Museum of Athens, X-Tek Systems UK[52] and Hewlett-Packard USA, funded by the Leverhulme Trust and supported by the Cultural Foundation of the National Bank of Greece.[53]

The mechanism's fragility precluded its removal from the museum, so the Hewlett-Packard research team[54] and X-Tek Systems had to bring their devices to Greece. HP built a 3-D surface imaging device, known as the "PTM Dome", that surrounds the object under examination. X-Tek Systems developed a 12-ton 450 kV microfocus computerised tomographer especially for the Antikythera Mechanism.

It was announced in Athens in October 2005 that new pieces of the Antikythera mechanism had been found. There are now 82 fragments. Most of the new pieces had been stabilized but were awaiting conservation.

In May 2006, it was announced that the imaging system had allowed much more of the Greek inscription to be viewed and translated, from about 1,000 characters that were visible previously, to over 2,160 characters, representing about 95% of the extant text. The team's findings shed new light on the function and purpose of the Antikythera mechanism. The first results were announced at an international conference in Athens in November and December 2006.[51]

Nature papers 2006 and 2008

In November 2006, the science journal *Nature* published a new reconstruction of the mechanism by the Antikythera Mechanism Research Project, based on the high-resolution X-ray tomography described above.[55] This work doubled the amount of readable text, corrected prior transcriptions, and provided a new translation. The inscriptions led to a dating of the mechanism to around 150 to 100 BC. It is evident that they contain a manual with an astronomical, mechanical and geographical section.

The new discoveries confirm that the mechanism is an astronomical analog calculator or orrery used to predict the positions of celestial bodies. This work proposes that the mechanism possessed 37 gears, of which 30 survive, and was used for prediction of the position of the Sun and the Moon. Based on the inscriptions, which mention the stationary points of the planets, the authors speculate that planetary motions may also have been indicated.

On the front face were graduations for the solar scale and the zodiac together with pointers that indicated the position of the Sun, the Moon, the lunar phase, and possibly the planetary motions.

On the back, two spiral scales (made of half-circles with two centers) with sliding pointers indicated the state of two further important astronomical cycles: the Saros cycle, the period of approximately 18 years separating the return of the Sun, Moon and Earth to the same relative positions and the more accurate exeligmos cycle of 54 years and one day (essential in eclipse prediction, see Eclipse cycle). It also contains another spiral scale for the Metonic cycle (19 years, equal to 235 lunar months) and the Callippic cycle with a period of 1016 lunar orbits in approximately 76 years.

The Moon mechanism, using an ingenious train of gears, two of them linked with a slightly offset axis and pin in a slot, shows the position and phase of the Moon during the month. The velocity of the Moon varies according to the theory of Hipparchus, and to a good approximation follows Kepler's second law for the angular velocity, being faster near the perigee and slower at the apogee.

In July 2008, a paper providing further details about the mechanism was published in *Nature*.[12] In this paper it is demonstrated that the mechanism also contained a dial divided into four parts, and demonstrated a four-year cycle through four segments of one year each, which is thought to be a means of describing which of the games (such as the ancient Olympics) that took place in two and four-year cycles were to take place in any given year.

The names of the months have been read; they are the months attested for the colonies of Corinth (and therefore also traditionally assumed for Corinth, Kerkyra, Epidamnos, and Syracuse, which have left less direct evidence). The investigators suggest that the device might well be of Syracusan design and so descend from the work of Archimedes; alternatively it could have been ordered by and customized for any of these markets and was being shipped.

Nature published another study in November 2010,[56] which suggests that the mechanism may be based on computation methods used in Babylonian astronomy, not ancient Greek astronomy, implying that Babylonian astronomy inspired the Greek counterpart – including the mechanical constructs.

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External links

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