The Antikythera Mechanism: *still a mystery of Greek astronomy?*

Mike Edmunds and **Philip Morgan** take a fresh look at an ancient artefact.

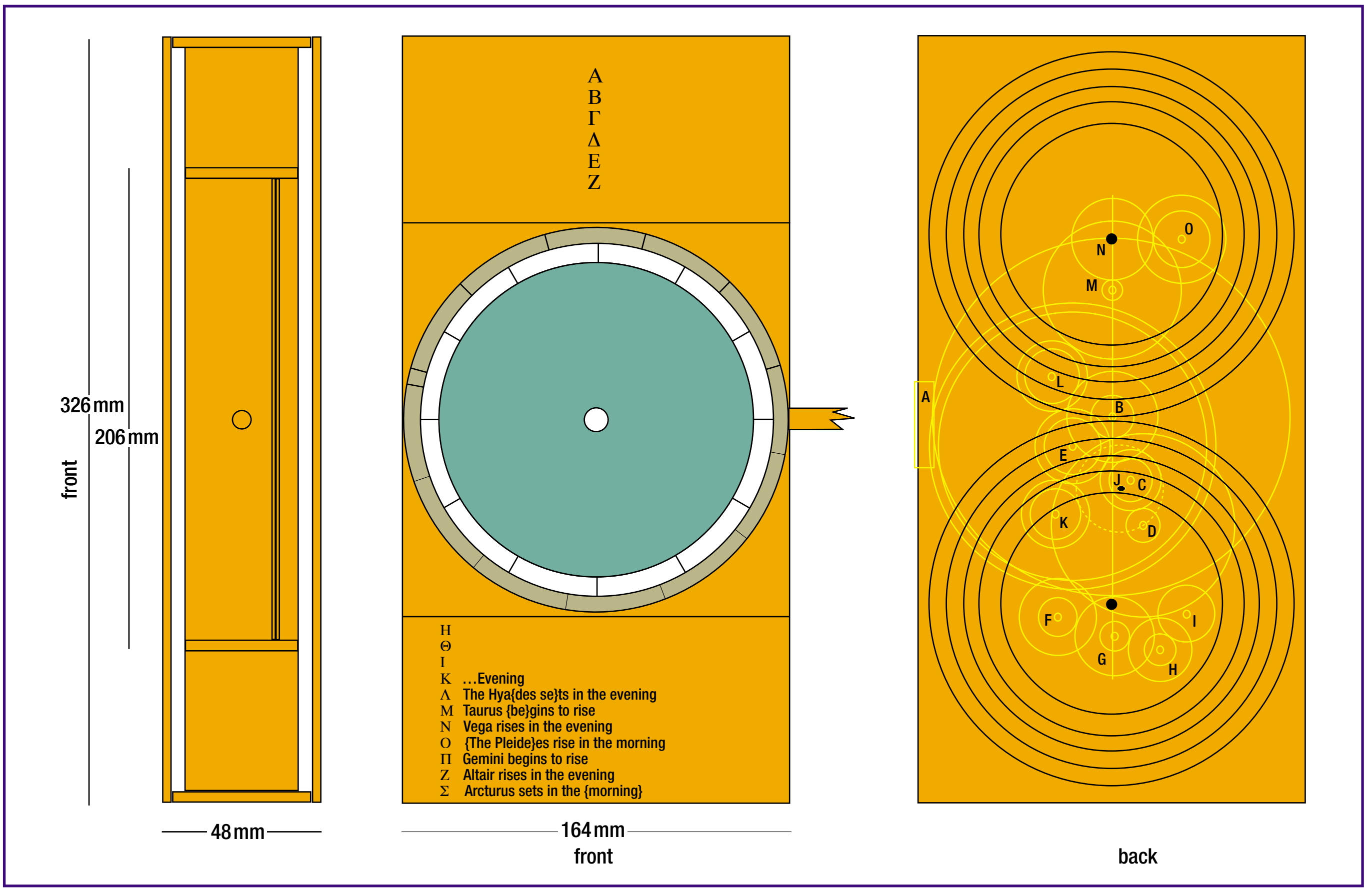
What may well be the most extraordinary surviving artefact from the ancient Greek world was discovered just one century ago. In 1900, sponge divers in the Mediterranean were forced away from their normal diving grounds by a storm. Off the coast of the island of Antikythera, they found a wreck which was to yield a priceless collection of Greek statues and other items. The yield from further dives during 1900–01 included an encrusted bronze lump, whose astronomical significance was only recognized some eight months after excavations had terminated, when it was found to have split apart. Containing some 30 gear wheels, and now known as the Antikythera Mechanism, this device is an order of magnitude more complicated than any surviving mechanism from the following millennium. There is no surviving precursor.

The Mechanism was extensively studied and heroically publicized by the late Derek de Solla Price in a book, *Gears from the Greeks* (de Solla Price 1975), and a *Scientific American* article "An Ancient Greek Computer" (de Solla Price 1959). But despite its profound implications, the Mechanism does not seem to have been given the prominence it deserves. Indeed, it has even been commented (Price 1995) that the Antikythera Mechanism has sunk twice – the second time after publication of de Solla Price's book! There are still many mysteries surrounding the device, in particular what was it for? And who made it? Just as fascinating are the implications for our view of the society in which it originated, and speculations on why nothing more advanced arose for a thousand years. In this article we summarize what is known about the Mechanism, try to place it in its historical context, and begin to re-interpret its function and purpose.

The ship, a Roman merchant ship of 300 tons, had sunk on a well-used trade route from the Eastern to the Western Mediterranean. The wreck (de Solla Price 1975, Illesley 2000) and its contents are consistent with a date for the wreck of 80–50 BC. Jacques Cousteau (1978) recovered Pergamese coins from about 86–67 BC, which with Ephesian coins of 70–60 BC (Yalouris 1990) reinforces a view that this had been a treasure ship on its way to Rome including booty from Pergamon (circa 84 BC, Cary 1970) after the First Mithradatic War. A reasonable date for the wreck is thus 85–60 BC. The ship itself is built from much older timber, 200±43 BC (de Solla Price 1975).

The Mechanism

We illustrate the structure and workings of the Mechanism with a series of new drawings, following de Solla Price's description and his theoretical reconstruction based on radiography of the remaining pieces. We start with the case, dials and inscriptions – although it is the com-



1: De Solla Price's reconstruction of the case (inscriptions incomplete).

A lump of bronze found in a shipwreck a century ago is a fragment of a complex device of gears and scales around 2000 years old. Its markings suggest it was used for astronomical and calendrical calculations. But uncertainty remains over its purpose: was it astronomical, astrological or educational? Here we summarize what is known about the Antikythera Mechanism and reconstruct its workings. We also examine its context in the Greek world of the first century BC and suggest that its purpose might be astrological more than astronomical. The existence of the Mechanism shows the sophistication of thought and manufacture available at this time. We speculate on the purpose of the device and demonstrate mechanisms that could enable such a device to give planetary positions, useful for astrology. It could also function as an accurate calendar, perhaps for civil holidays, or as an orrery.

plexity and sophistication of the internal gearing which astounds.

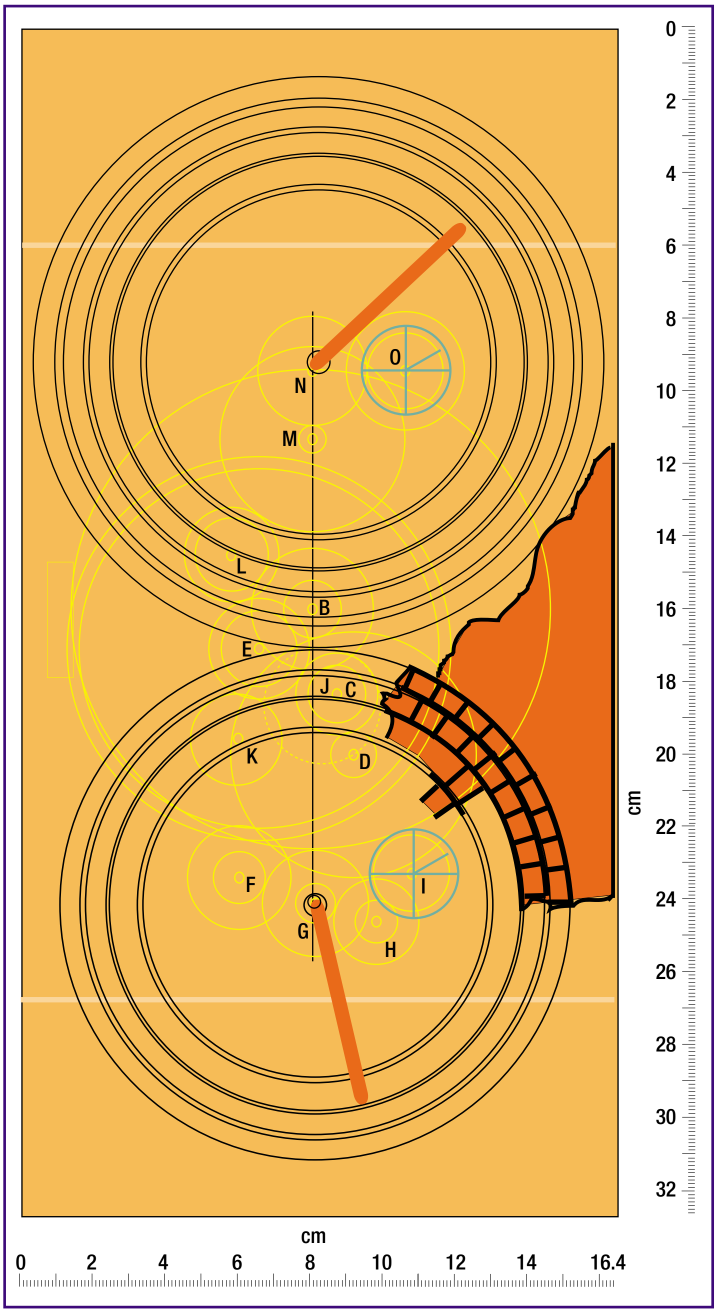
The fragments, as seen during de Solla Price's studies, consist principally of the decomposition products of the bronze mechanism, squeezed together under great pressure, corroded by the sea and covered with calcareous accretions. In some places the mechanism is hard and compact and in other areas the material is powder. It seems there is some "free metal" at the core. After the drying process had caused the case to shrivel, the calcified Mechanism broke into four main parts, but it is possible that some pieces of the Mechanism have been subsequently lost or dispersed.

The case

The Mechanism (figure 1) was encased in a wooden box with an approximate size of 326 × 164 × 48 mm (de Solla Price 1959, 1975). The box had one large metal dial on the front and a lower and upper dial on the back. Doors protected the dials and these, together with other surfaces, were covered with Greek text that described the operation of the object. All the wooden parts have essentially disintegrated.

The back plate (figure 2) has a pair of two concentric dials, which de Solla Price suspects have a diameter of only 2 mm less than the width of the case. Each of the dials has a series of rotatable annuli. The upper dial seems to consist of a central plate with a subsidiary dial and four rotatable annuli, and the lower dial has three rotatable annuli. The dials are much corroded and only partially deciphered, though de Solla Price gives the impression that they are heavily inscribed. He notes a continuous line of graduation running across all of the annuli on the upper dial. He also sees five even graduations in 38° around the outermost ring. This would yield 47 or 48 graduations around the entire ring.

The lower dial also has evidence of graduations around the outermost ring. Again he sees five divisions in an arc of 30° or 31°. This would give 58 or 59 divisions around the complete ring (59 days is the length of a double month).



2: The back dials.

The front face has a parapegma (star risings through the year) inscription and a dial containing two annuli. The diameter of the dial is, again, only about 2 mm less than the width of the case. The inner annuli is fixed and the outer rotatable. Between the two annuli is a series of small holes, about a degree apart, possibly to indicate the current day of the year. Both inner and outer annuli are graduated, the inner with marks every 30°. In one of these 30° segments (figure 3) can be seen the inscription ΧΥΛΑΙ (Chelai), the claws of the Scorpion, i.e. the early Greek zodiacal sign for Libra. This use of ΧΥΛΑΙ is interesting, because it follows Aratus (Kidd 1997, line 546) and Hipparchus (Goold 1997, page xxv), rather than Geminus who uses the later Ζυγός (Aujac 1975, Book 1, line 2), implying that Geminus's *Isagogue* was composed at a later date than the Mechanism. In the next segment two letters of {ΠΑΡΘΕ}ΝΟ{Υ} – Virgo – can be distinguished, thus indicating a cycle of the signs of the zodiac in a clockwise direction. Around this dial are letters of the alphabet, which apparently start and finish at the autumnal equinox and relate to the parapegma text beneath the dial.

The parapegma under the dial on the front of the Mechanism shows a traditional Greek calendar similar to that described by Geminus (see below). The last nine lines are preserved. Translations are from de Solla Price 1975, items in {brackets} are surmised:

{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

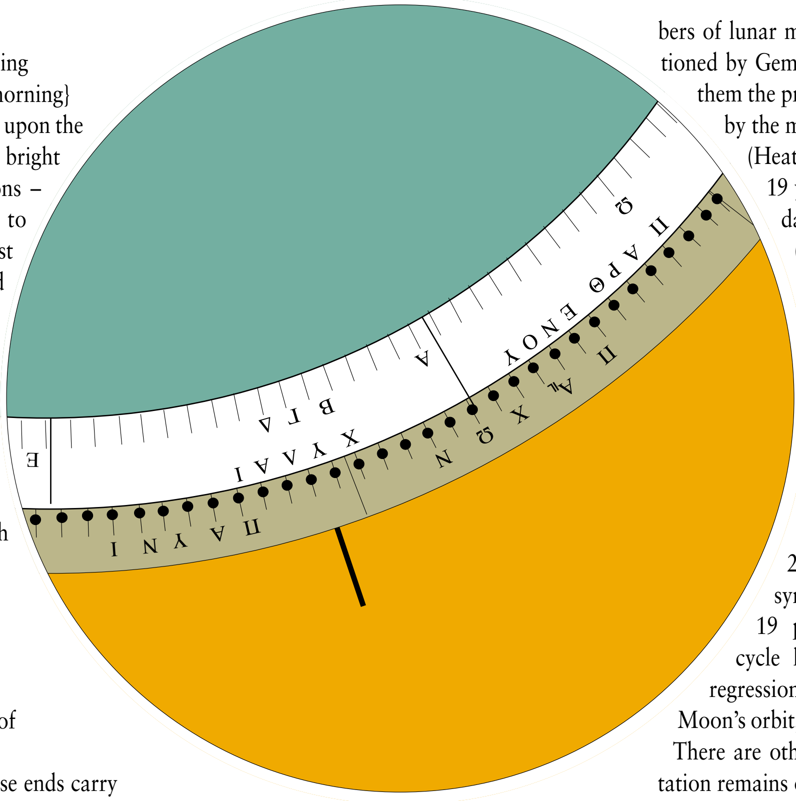
Π Gemini begins to rise
Ρ Altair rises in the evening
Σ Arcturus sets in the {morning}

This type of calendar is based upon the heliacal risings and settings of bright stars and zodiacal constellations – i.e. what is just beginning to appear at sunset, or is being lost in the dawn sky. They would also include seasonal indications such as weather and the solstices.

There is a large fragment of legible text on the back plate:

Line no.	Text
15	Protruding
16	carries of which one
17	and the other
18	{Venus}
20	the pointer
21	the Sun's rays
?	whence came out of
38	the first position
39	two pointers, whose ends carry
40	four, the one indicates
41	the 76 years, 19 years of the
42	2{23} coming together
43	so that the whole will be divided
44	Ecliptic
45	similar to those on the
46	Carries

The fact that just these tantalising clues survive might have prompted Sherlock Holmes to suspect a fake. But all other evidence overwhelmingly suggests the Mechanism is genuine. The text implies an explanation of the dial and pointer readings on the back dials. It shows that they were based upon the Metonic and Callipic cycles of 19 and 76 years (or 235 and 4 × 235 = 940 months), relating integer numbers of lunar months to solar years – as mentioned by Geminus: "The ancients had before them the problem of reckoning the months by the moon, but the years by the sun," (Heath 1913). The Metonic Cycle has 19 years of 365.25 days = 6939.75 days, 254 sidereal lunar months (27.3217 mean solar days) and 235 synodic lunar months (i.e. new Moon to new Moon, 29.5306 mean solar days). A full Moon on a certain date will occur on the same date 19 years later (Smart 1971). Although uncertain, de Solla Price believes that the number on line 42 is 223 rather than 235. This would refer to the 223 synodic months in which there are 19 possible eclipses. The eclipse cycle has to take into account the regression of the line of nodes of the Moon's orbit, giving an 18.6 year periodicity.



3: The front dial. The inner annulus shows the Zodiac, the outer annulus shows months.

There are other inscriptions whose interpretation remains obscure, but for which meaning should be sought within contemporary sources. These include "Towards the east (wind)"; "north west (wind)"; "west south west (wind)", which were noted by de Solla Price as reminiscent of the sculpture relief figures on the "Tower of the Winds" in Athens. This Horologion of Andronikos of Kyrrhes (Noble and de Solla Price 1968) dates from the second or first century BC, and once housed a water clock – but only the grooves and holes for the mechanism remain.

The gears

There are 30 known preserved gears in the mechanism. Each gear has been hand cut from a single sheet of bronze. The teeth have all been cut at an angle of 60° and are roughly the same size on all gears. De Solla Price speculates that the mechanism is "cranked" by a now lost handle that turned a contrate (as yet unidentified) gear that in turn rotated a Sun position dial and the main drive wheel. The mechanism then followed three known and one undetermined gear trains. One gear train ended through an inner shaft in the main drive wheel axis and turned a Moon position dial. Another train passes, via the differential turntable (see figure 5), to end up at a synodic month dial and then a lunar year dial. De Solla Price speculates that the third known train drives a four-year dial. The undetermined train is in the area of the Mechanism where the four-year dial is located. There is no known purpose for one gear on the differential turntable. The details of the known trains are outlined in the box "The gear trains according to de Solla Price".

The differential turntable is what, apart from the Mechanism's sheer complexity, sets it apart

The gear trains according to de Solla Price

Drive wheel to Moon position indicator

B2/C1 × C2/D1 × D2/B4 = 64/38 × 48/24 × 127/32 = 254 /19
i.e. 254 sidereal months in 19 tropical years.

Drive wheel to differential turntable

The relationship of sidereal months to sidereal years (254:19) and their difference is used to determine the synodic cycle of the Moon, i.e. 235 lunations in 19 years.
(B2/C1 × C2/D1 × D2/E2I [B4 idles] × E2ii/J) – (B3/E1 × E5/K2 × K1/J)
= (64/38 × 48/24 × 127/32 × 32/64) – (32/32 × 48/48 × 32/64) = (127/19) – ($\frac{1}{2}$)
for 19 turns (or in a period of 19 years) = 19 × 127/19 – 19/2 = 117.5
i.e. 117.5 turns of the differential turntable for 19 turns of the drive wheel. The output is half of the required value of 235 due to the constraints of the turntable, but is easily doubled to the correct value in the following train.

Differential output to synodic month

E3/F1 × F2/G2 = 192/48 × 30/60 = 2
i.e. just doubles the differential turntable output to 235 turns of the synodic month indicator for 19 turns of the drive wheel.
The lunar year follows on with G1/H1 × H2/I = 20/60 × 15/60 = $\frac{1}{12}$
i.e. one turn of the synodic month indicator results in $\frac{1}{12}$th of a turn of the lunar year indicator.

Drive wheel to four-year dial

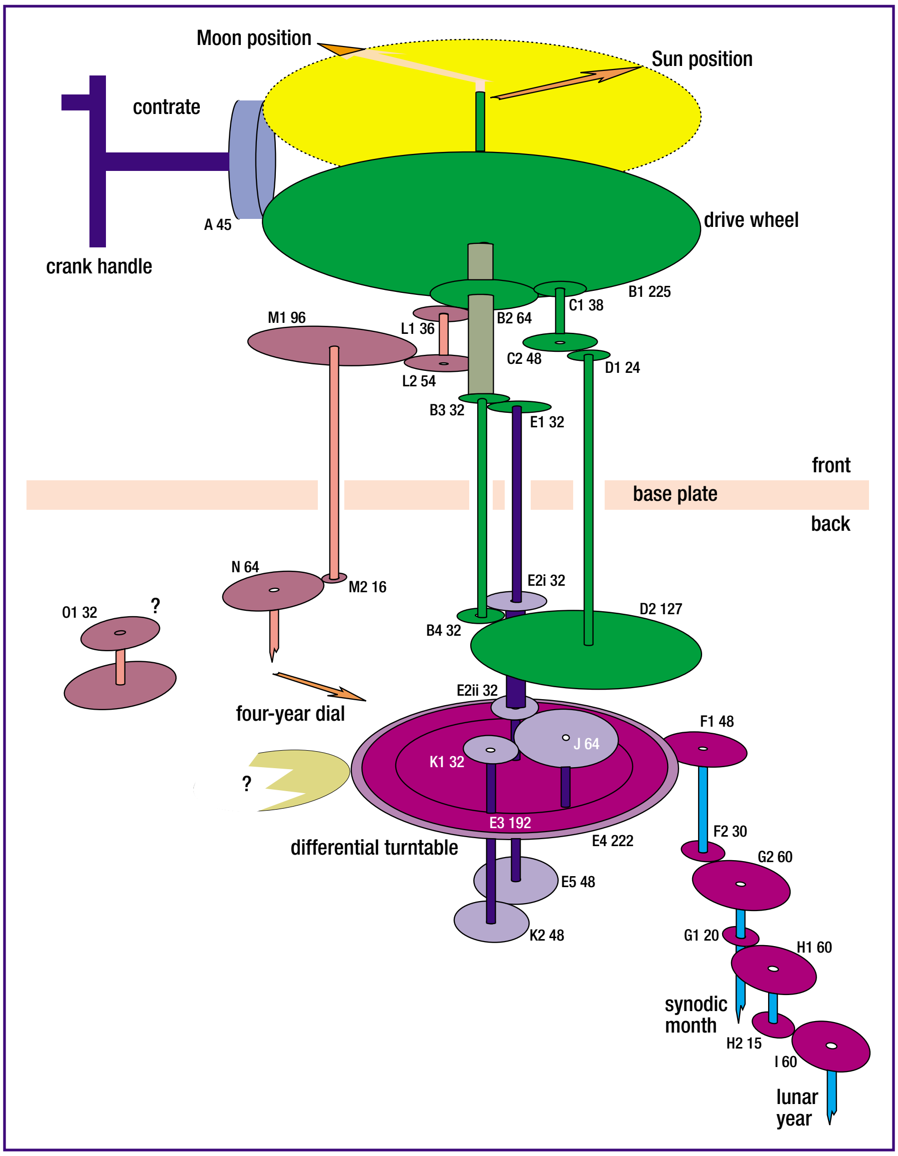
B2/L1 × L2/M1 × M2/N = 64/36 × 54/96 × 16/64 = $\frac{1}{4}$
i.e. one turn of the drive wheel results in $\frac{1}{4}$ turn of the N axle.

from all other gearing up to the 16th century. The modern differential is more familiar as the device that allows the inner wheel of a car to travel slower than the outer when turning a corner, but with power maintained to both wheels. The "drive" turns two wheels at different speeds. This process can be reversed so that two "drives" turning at different speeds can then give one output, the sum of the two inputs. The two "drives" in this case come from the Sun and Moon gear trains. One train rotates anticlockwise with the speed of the Moon while the other turns clockwise with the speed of the Sun. From its design, the differential turntable will then have an output of half of the algebraic sum of the two inputs i.e. (254 – 19)/2. That is 235/2, which can easily be doubled to give the synodic revolutions of the Moon in the 19-year Metonic cycle – i.e. it would be able to predict the Moon's phases, but it is not clear where (and whether) such an indication was given on the dials.

Bromley (1986) suggested that the Mechanism would not work in de Solla Price's reconstructed form, principally because of friction in the high-gearing-up chains. He offers some alternative reconstructions and drives. But John Gleave (2000) has actually made four physical reconstructions in de Solla Price's form, and although somewhat uneven they *do* rotate despite correct use of simple triangular gear teeth. An interesting discussion of the Mechanism and some surprisingly deep mathematical aspects of the gear ratios are given by Zeeman (1998).

Manufacture: place and technical capability

The identification of Rhodes as the likely source is circumstantial, but very attractive. As a suitably placed strong trading port it is certainly possible that the soon-to-be-wrecked ship would call in on its journey (circa 85–60 BC) to Rome, perhaps taking on extra cargo or even starting its journey there. The real clincher is a reference in the works of the Roman statesman, author and scholar Marcus Tullius Cicero. Cicero – who had already written a poetic version of Aratus's Phaenomena (see below) visited Rhodes in 78 BC (see the Introduction in Walsh 1998). He wrote later (in around 45–44 BC, Walsh 1998 Book 2 line 88): "Our friend Posidonius has recently fashioned an orrery, each time it revolves it makes the Sun, Moon and planets reproduce the movements which they make over a day and a night in the heavens." Although this does not necessarily imply that he saw an "Antikythera" mechanism, the reference (certainly noted by de Solla Price) does imply the existence in Rhodes – at the right time – of a tradition where astronomical mechanisms were made. Apart from some travel abroad,



4: All the gears according to the reconstruction of de Solla Price.

Posidonius, whose major astronomical works are lost, was in Rhodes (see Introduction in Kidd 1999) during the period from around 100 BC until his death in 51 BC. He continued the proud tradition of Hipparchus (who worked there from 160 to 127 BC), a tradition that would pass on to Geminus (see below). A glance at a street plan (Gabrielsen 1997) of ancient Rhodes – which looks like downtown Manhattan – and the naval commerce of Rhodes, reinforce the feeling that this was a state where technological innovation might well have occurred. A stone found at Keskinto on the same island is inscribed with planetary positions, and (unreliably) datable to 100 BC. The great scholar Otto Neugebauer (1975) has interpreted this as evidence of knowledge of epicyclic theory of planetary motions. This idea was certainly known to Geminus in Rhodes by around 55 BC; Heath (1913) translates him as: "Why do the Sun, Moon and planets appear to move irregularly? Because, whether we suppose that their circles are eccentric or that they move on epicycles…"

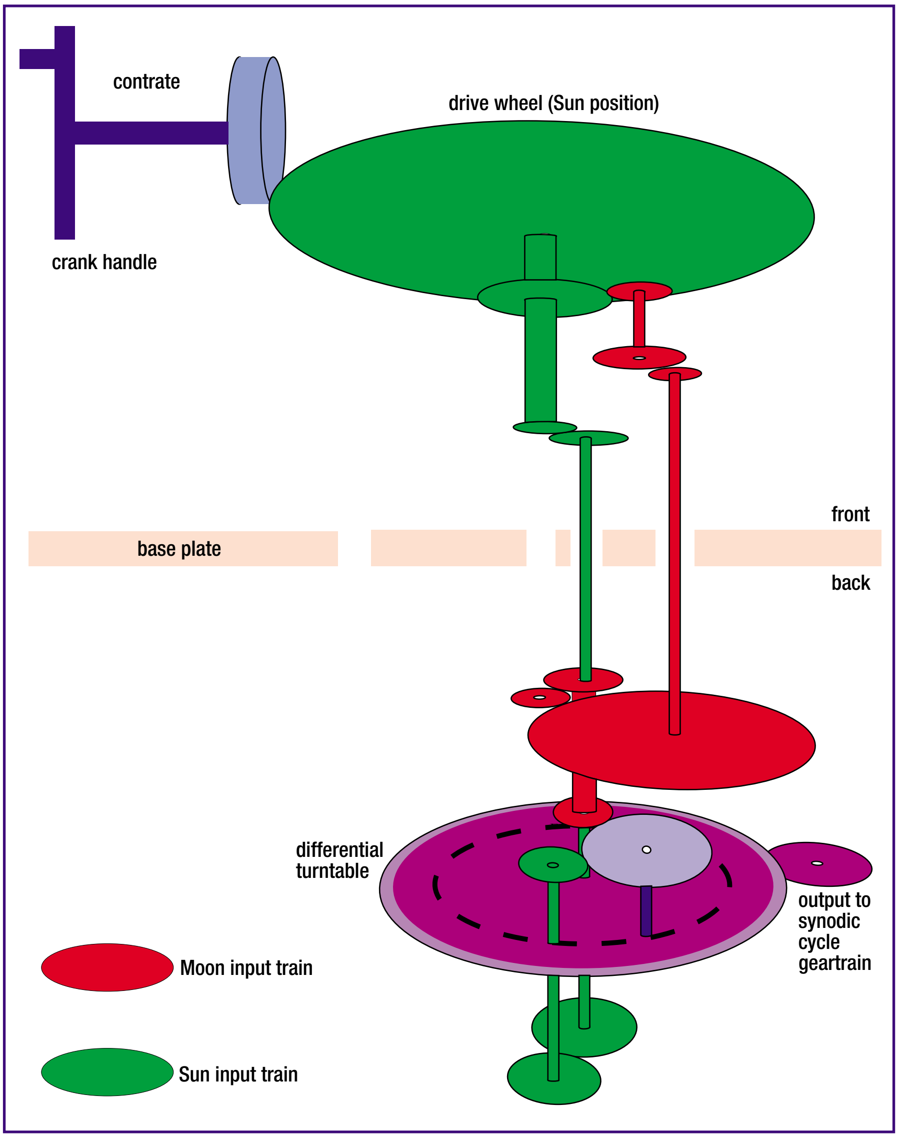
So who actually made the Mechanism? A very close collaboration between a craftsman and a philosopher/astronomer seems the most likely. Philosophers of the time were unlikely to have the necessary skills, or even feel it appropriate, to undertake mechanical work. The mechanic would be unlikely to be aware of the subtleties of the astronomy.

Towards new interpretations

One approach to the device is to ask what functions it *could* have had. Guided by Cicero's orrery description, an obvious need would be for planetary positions. De Solla Price mentions in his *Scientific American* article that on the back of the Mechanism "terms are used which refer to stations and retrogradations of the planets". It should be emphasized, though, that despite several claims (e.g. Lattin 1969, Dyson 2000) there is – as yet – no *prima facie* evidence for planetary prediction. We speculate here by showing that suitable simple mechanisms can be designed. A simple geometric explanation for apparent motion of

Table 1: Speculative planetary mechanisms

	Mercury	Venus	Mars	Jupiter	Saturn
Earth year/sidereal year of planet	n/a	n/a	0.53168	0.08430	0.03395
teeth on 01	n/a	n/a	33	15	11
teeth on N	n/a	n/a	62	70	66
teeth on N1	n/a	n/a	48	24	13
teeth on 02	n/a	n/a	48	61	64
01/N × N1/02	n/a	n/a	0.53225	0.08430	0.03385
error as 1 part in n	n/a	n/a	920	11800	366
teeth wheel L	63	25	35	118	298
teeth fixed wheel M	20	40	40	11	11
ratio d	0.25	0.19	0.2	0.35	0.5



5: The differential turntable.

the planets through the Zodiac was put forward by Apollonius of Perga (about 261 to 205 BC), and predates the Antikythera Mechanism. He proposed that a planet travelled along a circle (the epicycle) whose centre travelled along a circular path (the deferent) around the Earth. The size of the epicycles of Mercury and Venus could be estimated from their maximum elongation from the Sun. This theory was a natural sequel to Heraclides' (385–315 BC) proposition that Venus and Mercury describe circles about the Sun. Apollonius's model was not exact, but it is a model that would lend itself to a mechanical representation. Indeed, though Greek planetary theory was complex at the time of our interest it is clear that "if you were a Greek steeped in Aristotelian physics and Euclidean geometry, you could not understand what was going on unless you thought in terms of deferents and epicycles", (Pannekoek 1989).

We can propose a mechanism that replicates the longitude of Venus, for example, using just three gears (figure 6). The planetary mechanism would be driven from either the Sun position wheel or the existing M wheel. Wheel D revolves once in an Earth year (as Venus travels "with the Sun"), forcing wheel L to revolve and turn because it is constrained by the "fixed wheel". A bar pivoting at the centre of the fixed wheel is free to move on a peg a distance d from the centre of L, and sinusoidally oscillates about the centre of L as that wheel moves about D (the epicycle moving on the deferent). The sizes of these wheels can be determined by using a simple spreadsheet model and comparing the results with published data (Evans 1998). The sizes of wheels L and the fixed wheel give the number of greatest elongations east of the Sun, for the inferior planets, (or prograde stationary points, for the superior planets) and the distance d (percentage of size of L) determines the amplitude of the oscillation about the Sun (or the magnitude of retrograde motion). The size of wheel D is determined by the interaxle distance between L and the fixed wheel.

The positions of the superior planets would require a scaling factor. This factor describes the amount that the planet travels in one revolution of the year wheel, M, or 360°. For Mars 1.00004/1.88089 = 0.5317, i.e. it will travel just over half way around the zodiac in one Earth year. This scaling mechanism would require a further four wheels (figure 7). The sizes of these wheels are constrained by the need to return the output back to the axle of the input and by the physical size of the mechanism.

De Solla Price, because of a great degree of uncertainty in tooth counts, conjectures tooth counts for O1, N, and O2 as 32, 64 and 48, but with no meshing of N and O1. He determined, as has Economou (2000), that the gear train ends at N and shows a four-year indicator. However, actual values of 33 and 62 for O1 and N are well within likely error of the tooth counts. This would achieve a 1:920 accuracy for a Mars scaling, given the existing O2 wheel with 48 teeth and another 48 toothed wheel, N1, to take the motion back to the N axle centre. The full gearing to describe the longitude of Mars is shown in figure 8.

The data for the other planets is summarized in table 1, where we can see good fits for Mars and Jupiter but obvious problems for Saturn gearing due to the physical constraints of the mechanism. In the table, "error" represents the accuracy of the planetary scaling factor, as explained above for Mars.

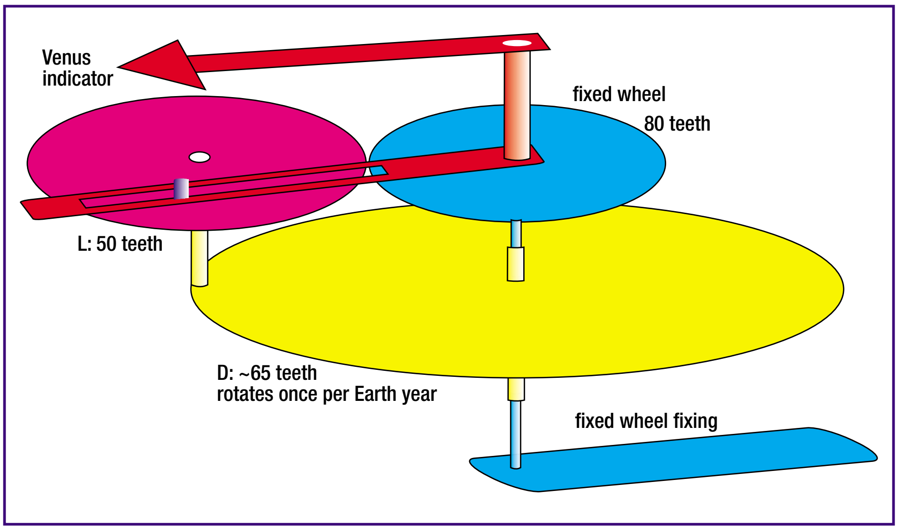
If this gearing were used then where is it? There is room for a single planet gearing in front of the differential turntable, but no more. John Gleave's model of the mechanism does turn, but would it turn with more than one extra set of planetary gears? Did the stiffness of turning lead to the removal of planetary gearing? We suggest that it would be possible to incorporate Mars (front dial) and Venus (back dial) into the Antikythera Mechanism without much difficulty (figure 9). We were interested to discover subsequently that very similar planetary mechanisms appear in the Giovanni de Dondi "Astrarium" clock completed in AD 1375 (Baillie, Lloyd and Ward 1974).

But to incorporate the other known planets – Mercury, Jupiter and Saturn – without some kind of interchange mechanism or cartridge would be difficult. Perhaps the position of each planet in turn would be predicted, and recorded on the mechanism by the rotating annuli. Inspection of the actual mechanism for any evidence of planetary trains could be fruitful, but we must admit that lack of prediction of *all* known planets may well vitiate an astrological interpretation (see below). It could be that a completely separate mechanism was necessary for planets, or that the loss of some planets was tolerated (with Sun and Moon regarded as the dominant "planetary" influences) – nevertheless, such a view cannot be maintained without other evidence.

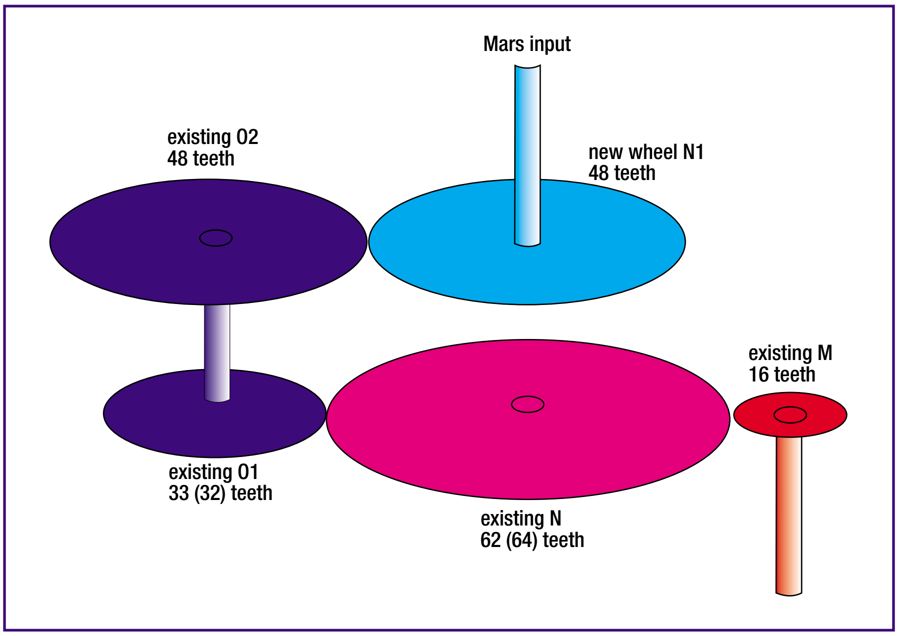
The context

A sequence of three books survives from the ancient world to provide an interesting background. All three are essentially "introductions to astronomy", outlining the constellations and the calendrical importance of phases: first or last visibility in the morning or evening sky. All include some weather lore. A delightful example comes from Aratus (Kidd 1997): "But if he [Sun] plunges cloudless into the western water, and the clouds standing near him are red while he is setting and after he is gone, there is no need for you to be afraid of rain tomorrow ... Nor, when reddish clouds appear here and there, when the sun delays his appearance before dawn, do the fields go unwatered on that day" – a clear precursor of "red sky at night, shepherds' delight; red sky at morning, shepherds' warning". All three books mention the irregular motion of the planets, but without extensive systematic explanation. But there is one crucial change in emphasis between them that we will shortly point out.

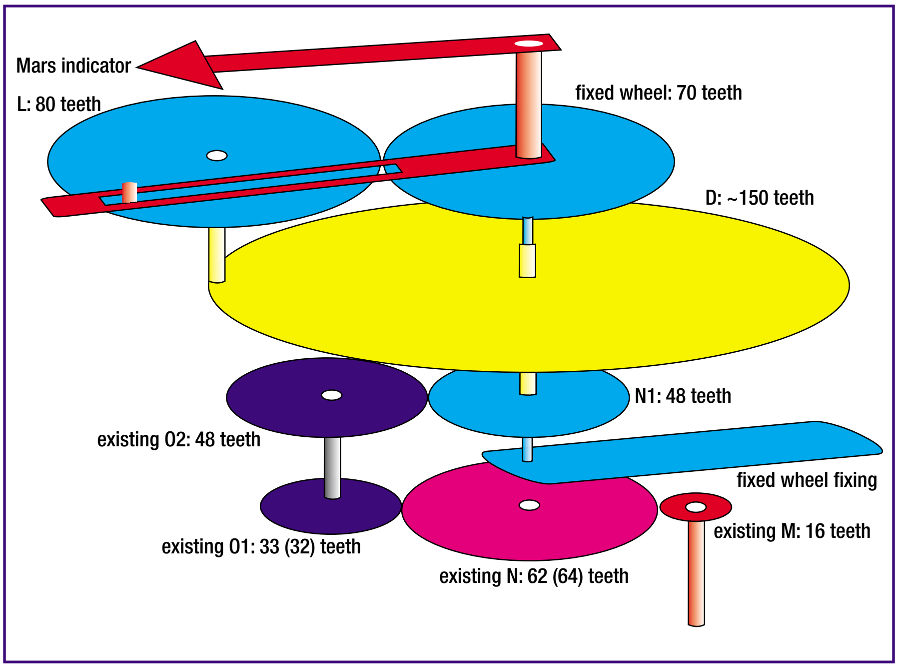
Aratus is believed to have written *Phaenomena* (Greek) shortly after 276 BC, Geminus probably wrote his Introduction to Phenomena the *Isagoge* (Greek) in Rhodes about 55 BC, and Marcus Manilius's *Astronomica* (Latin) dates over a period between circa AD 10–20. Good modern translations (Kidd 1997, Aujac 1975, Goold 1997 respectively) of these works have only become available over the last 25 years. The classic editions of Manilius by the poet A E Houseman (of *A Shropshire Lad* fame) should certainly not be ignored, if only on account of their introductions which



6: A speculative planetary mechanism.



7: A speculative planetary scaling mechanism.



8: A speculative full Mars mechanism.

include wonderful vituperative academic invective against his critics. The dates of the life of Geminus were placed rather later by Neugebauer (1975) on the basis of interpretation of calendrical evidence in the *Introduction to Phaenomena*, but the dating circa 80–10 BC by Geminus's modern editor Aujac (1975) seems more likely. The linking of inscription on the Antikythera Mechanism with the parapegma in Geminus is not necessarily a constraint, since Neugebauer points out that this text may date from two or so centuries earlier. The writing style on the Mechanism is, however, consistent with an 85–70 BC date.

The first century BC is a period over which Rome came to dominate the Mediterranean region. The sequence of these three books shows the continuity of astronomical ideas from the Greeks into Rome. But what is noticeable is the increasing content of astrology. Apart from some mention of extispacy (inspection of entrails for signs – a rather gory form of reading tea leaves) there is virtually no mention of astrological interpretation in Aratus. Geminus refers a little to it (perhaps rather reluctantly) at the beginning of Book 2 of his *Introduction*. Manilius's work is, however, essentially devoted to linking the "dances of the stars" with astrology. This explosion of belief in astrology may provide a context for the construction of the Antikythera Mechanism.

The purpose

Apart from its discovery on a ship, there appear to be no grounds – other than a passing reference to winds – for a navigational function for the Mechanism. As a purely calendrical device it may be over-engineered – tabular material would have been more convenient, and the design of the device must have rested on extensive knowledge of such material and/or its periodicities. Its fragility and complete lack of known successors or of known literature reference to use of such devices in the actual calculation implies that it was not an astronomical computer. Interpretation as an orrery, a mechanism for demonstration or educational purposes, perhaps quite a high status object, is certainly possible given Cicero's admiration for similar constructions.

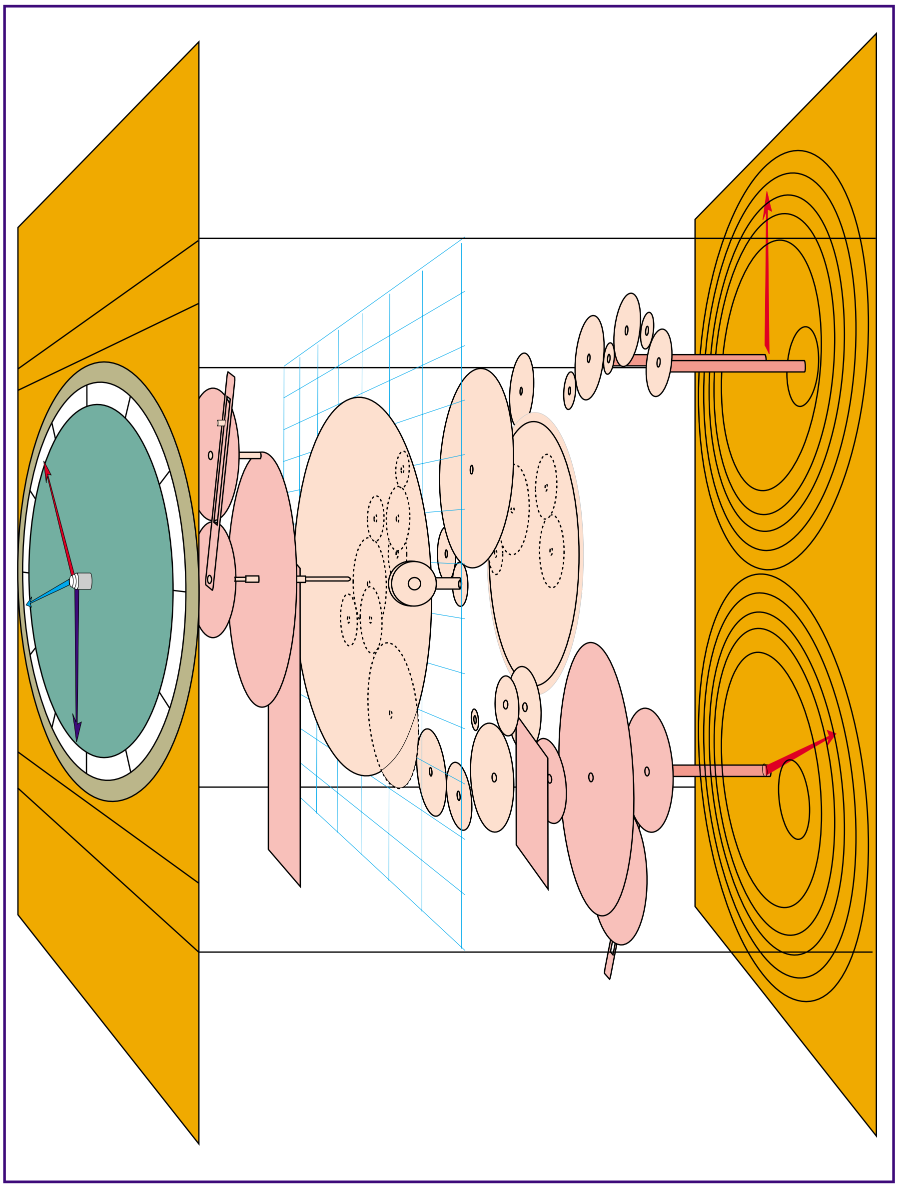
An astrological interpretation may be equally valid. Horoscopes are certainly known from this period – Neugebauer and van Hoesen (1959) astronomically date a horoscope for the coronation of Antiochus to 62 BC. With the changing attitude to astrology – "It is as if in Greece one discusses astrology, in Rome they believe it" (Introduction in Aujac 1975) – would it be surprising if a commercial opportunity arose for a device which could compute the horoscope? Literally, the horoscope means the zodiac sign rising on the horizon at the time of birth, and planetary positions in the zodiac, including the Moon, would have been needed. Lunar phases may also have been used – at least two examples of their use in astrological prediction are given in Barton (1994). The other aspects of the device would help sort out the correct date to use relative to the various civil calendars. It might have been worked in the following way: the mechanism would have been set up at the time of assembly to show the correct date and the current longitudes and phases of the heavenly bodies and their relative positions in their cycles. The mechanism could then be used in two modes.

In the first mode, it is used as a simple calendar that could be advanced each day using the peg holes on the front dial. The positions and phases of the Sun and Moon could then be predicted. Alternatively, in this mode the current date could be determined by winding the mechanism forward or backward until the mechanism reflects the current state of the sky, and the date could then be read from the agricultural calendar on the front dial.

In the second mode it could be used to determine the positions of the planets. The Mechanism and the planet's cartridges would have been set up to coincide at the time of assembly. To find the longitude of a planet at some date in the past or future the Mechanism would be cranked to the date at the time of assembly and the cartridge inserted. The mechanism would then be cranked either forward or backward to a required date and the position of the planet recorded by moving one of the slip rings on the dial. The other planets would be determined by repeating the process. This is pure speculation, but can be tested by looking for traces of the necessary machinery.

A possible test of actual astrological use might be the future discovery of evidence of prediction by the machine of the fate or Lot of Fortune position. As described in Manilius (Goold 1997), this involves simple calculation from the horoscopic, Sun and Moon positions.

The environment of Rhodes certainly does



9: A speculative reconstruction including Mars and Venus prediction.

not discourage the idea of an astrological function. Although the tradition of Hipparchus may seem firmly astronomical, it must be remembered that Posidonius – probably the most brilliant mind behind the Rhodes school in the relevant period circa 100–51 BC – was a Stoic philosopher, with inevitably a holistic view of the universe. As summarized by Cumont (1912): "Posidonius defined man as the beholder and expounder of heaven," and "In the declining days of antiquity, the common creed of all pagans came to be a scientific pantheism, in which the infinite power of the divinity that pervaded the universe was revealed by all the elements of Nature." On such a linked and predestined view, the foretelling of events by stellar and planetary positions would certainly not seem – and did not seem in the increasingly dominant Roman mind – unreasonable. Indeed, a continuing tradition can be seen in the fact that Tiberius, who was to become Emperor AD 14–37, retired himself to Rhodes for seven years from about 6 BC to "give himself up to astronomical studies" (Buchan 1937) – and this must also be interpreted as "astrological" given his later employment of astrologers, and even use of astrological symbolism on his coins. It is our much later understanding of the limits of causal links and physical influence which have rendered the astrological aspects of the history of astronomy rather an embarrassment – parts of Ptolomy's writings are still studiously ignored (Barton 1994). It is, though, rather sobering that the subsequent two millennia of scientific advance have not led to the complete abandonment of astrology. A report in *Physics World* for June 2000 on a survey by M De Robertis and P Delaney suggests that in a sample of 1600 Canadian undergraduates, 53% believed in astrology, a figure that is 6% higher than 10 years ago.

The new suggestion by Economou (2000) that the Mechanism was a computing aid for moveable public holidays fixed by the position of the Sun is a refreshing alternative. It avoids the need for the device to show planetary positions (although the mention of Venus and planetary retrogradations in the inscriptions is then perhaps surprising, unless the reading is in error). The four-year dial might be connected with the holding of the Olympiad. For whom might such a mechanism have been made? Is there any literary reference to actual use of mechanical computing in this way?

Posidonius was the father of tidal studies (Cartwright 1999, Kidd 1999), realizing the importance of both seasonal and lunar influences. It may, therefore, be worthwhile to look for some tidal prediction in the Antikythera Mechanism. In fuelling a belief in astrology, a demonstrable link between celestial phenomena (the positions of the Moon and Sun in the sky) and occurrences on Earth (the tides) must surely have been influential.

The lack of any further Greco-Roman technological advance remains unexplained. Perhaps it is simply that no evidence has survived – metal was precious and would have been recycled. A sundial/calendar mechanism containing eight gears is known from the fifth century AD (Field and Wright 1996), but nothing as complicated as the Antikythera Mechanism would emerge until the mediaeval and Chinese clocks in the next millennium. The lack of need for useful mechanical devices in a society with plenty of cheap or slave labour has been suggested (e.g. Brumbaugh 1966) as the reason that Greek technology did not advance, but does not explain why a luxury or pure science device should not be developed further. If planets were considered a vital inclusion, it may be that refinement of planetary theory was just too difficult to translate easily into a more advanced geocentric mechanical device.

Future work

Renewed interest in the Antikythera Mechanism is welcome. A fine computer graphic animation by Roumeliotis (2000) of de Solla Price's gear trains can be viewed on the Web. State-of-the-art X-ray tomography would be valuable to add to our knowledge of gear ratios, axle and support holes, inscriptions and any differential wear from actual use. Non-invasive metallurgical study might establish whether the raw materials were characteristic of those used in Rhodes. A wider appreciation of the advanced state of technology in Rhodes might lead to collateral evidence from other sources – illustrations on pottery (unlikely at this date) or elsewhere, obscure literary references, or even recognition of previously ignored artefacts. Other reconstructions of the Mechanism can be attempted, the functions of the subsidiary dials must be found. All inscriptions should be scrutinized more carefully. Proof of *no* planetary computation on the device would fairly conclusively demonstrate a calendrical, rather than an astrological, use. Careful reading of contemporary Greek and Roman sources is needed for any evidence of mechanical computation in an astronomical, astrological or calendrical context. A long shot in understanding the Greek tradition in astronomical mechanisms is that transcriptions of palimpsests (Kleiner 2000) might bring to light a copy of Archimedes' rumoured lost third century BC work on the construction of planetaria.

Whatever its true function is found to be, the Antikythera Mechanism remains a remarkable testament to a fascinating transitional era in the development of human thought and cosmology. It will be the archetypal Greek Tragedy if its importance remains unrecognized or ignored. ●

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