nature

ARCHAEOLOGY

High tech from Ancient Greece

François Charette

The Antikythera Mechanism, salvaged 100 years ago from an ancient shipwreck, was long known to be some sort of mechanical calendar. But modern analysis is only now revealing just how sophisticated it was.

During renovation work in a northern Italian *palazzo*, an enigmatic artefact comes to light, dated to the late fifteenth century. After intensive analysis, it is identified as a complex steam engine — constructed 200 years before French inventor Denis Papin's pioneering experiments, and 300 years before the Industrial Revolution. Our view of the technical achievements of the Renaissance is completely changed. The reverberations are felt far beyond just scholarly circles.

True, this hasn't happened. But a century-old archaeological find is continuing to force a comparable rethink of the technology of classical antiquity. In this issue, Freeth *et al.* (page 587)[1] present the most up-to-date analysis of this artefact, the Antikythera Mechanism.

In 1900, a team of Greek sponge-divers working off the islet of Antikythera, midway between the Peloponnese and Crete, discovered an antique shipwreck 42 metres below the surface of the Mediterranean Sea. Among the many objects they recovered from the wreck, which has been dated to around 65 BC, were several bronze fragments. At first overlooked, these were later associated with some sort of astronomical machinery. But the realization that this was the earliest-known device involving an arrangement of gear-wheels came only slowly. In fact, staggeringly, the Antikythera Mechanism is the most sophisticated such object yet found from the ancient and medieval periods.

From the late 1950s to the early 1970s, the late historian of science and technology Derek De Solla Price studied the badly corroded and fragmented mechanism extensively, especially once γ-radiography techniques had become available. This work culminated in a lengthy essay, *Gears from the Greeks*[2]. In it, Price proposed that the mechanism had been an astronomical calendar with display dials on the front and back indicating the positions of the Sun and the Moon. This gearing, comprising some 30 wheels, was, according to Price, a clever mechanical simulation of a basic period relation that linked the length of the solar year with the phases of the Moon. This relation is the Metonic cycle, which says that in 19 solar years there are 235 lunations (the time from new Moon to new Moon, also known as a synodic month) and 254 sidereal months (the time the Moon takes to reach the same location with respect to the fixed stars).

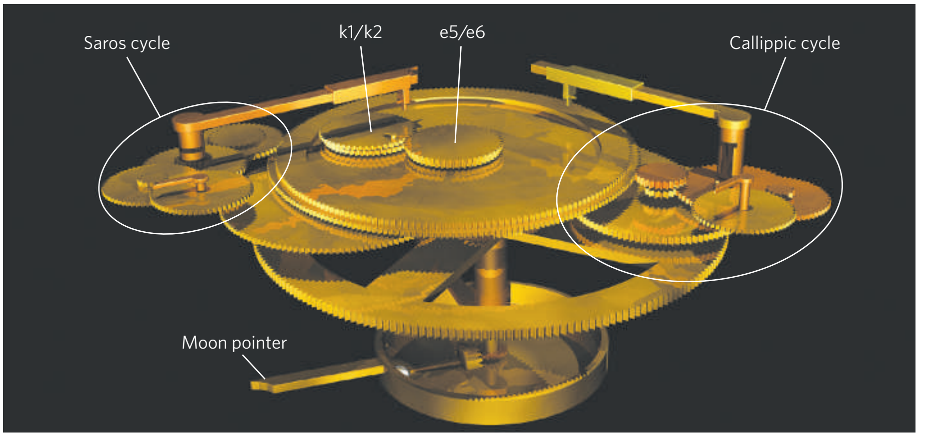

Figure 1 | Wheels within wheels. The rear side of Freeth and colleagues' reconstruction[1] of the Antikythera Mechanism, viewed sideways on. The left gear and pointer system simulated the Saros cycle for predicting lunar and solar eclipses; the right gears and pointers were for the Callippic cycle that synchronizes synodic months and solar years. At the centre, mounted on the large gear-wheel, were two pairs of identical gear-wheels, e5/e6 at the centre and k1/k2 at the left (see also Fig. 5 on page 590). The pair k1/k2 was provided with a pin-and-slot device that induced an irregular movement in the pointer at the front of the mechanism indicating the position of the Moon. This system simulated a model of the Moon's motion developed by Hipparchus of Rhodes in the second century BC.

Price's heroic analysis and reconstruction, and his claim that the mechanism "requires us to completely rethink our attitudes toward ancient Greek technology"[3], and perhaps even our understanding of Hellenistic and Graeco-Roman civilization, did not meet with the enthusiasm, or even generate the widespread recognition, that it perhaps deserved. Since the late 1980s, various criticisms have been levelled at the reconstruction, and a number of alternative proposals have been made. Price, it seems, was a little too quick to adopt tooth numbers and arrangements that satisfied his preconceived idea of the nature and function of the mechanism.

Great advances in deciphering the Antikythera Mechanism have been made in recent years by Michael Wright, who has relied on digitized X-rays and linear tomography to achieve better imaging of the mechanism and some remarkable insights into its functions[4]. Freeth and colleagues' paper[1] now details the investigations of a multidisciplinary team from Britain, Greece and the United States that reanalysed the Antikythera Mechanism using the best available technology — three-dimensional X-ray computer tomography and high-resolution surface imaging.

Compared with Price's readings, twice as many textual data are now legible from the Greek inscriptions on the mechanism. Analysis of the now much clearer lettering indicates a construction date of 150–100 BC, slightly earlier than had been assumed. Freeth and colleagues clarify the function of the front and back dials of the mechanism: on the front were graduations for the zodiac and the solar calendar, and pointers for the Sun and Moon with an indication of the lunar phase. The back dials indicated time in terms of two astronomical cycles. Each dial involved a pointer with an ingenious spiral design (Fig. 1). One dial is for the Callippic cycle. This cycle is a later attempt to improve the Metonic cycle's prediction of the relation between lunar months and solar

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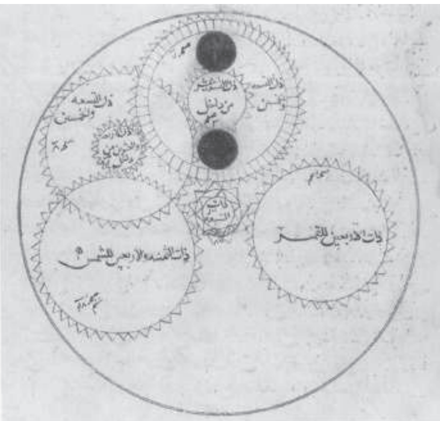

Figure 2 | Islamic descendant. An eight-geared lunisolar calendar illustrated in al-Biruni's treatise on the astrolabe, written in AD 996. The design is much simpler than that of the Antikythera Mechanism, but is very probably descended from it.

years, and holds that 940 lunations occur in 76 years (four Metonic cycles) less one day. A second dial is for the Saros cycle of 223 lunations (roughly 18 years), which was used to predict the occurrence of solar and lunar eclipses.

Freeth and colleagues' reconstruction[1] involves 37 gear-wheels, of which seven are hypothetical; Price found 29 gears and proposed a further two[2]. In the face of fragmentary material evidence, such guesswork is inevitable. But the new model is highly seductive, and convincing in all of its details. It ought to force us, definitively, to abandon Price's reconstruction, which is still frequently reproduced in general and scholarly books.

Among the most important of the authors' conclusions[1] is that a highly ingenious pin-and-slot device connecting two superimposed gear-wheels, one slightly off-centre, induced a quasi-sinusoidal variation in the movement of the Moon in the mechanism (Fig. 1). They show this to be a mechanical realization of a geometrical model of the first lunar anomaly — an initial approximation of the irregular nature of the Moon's motion — that had been developed by the astronomer Hipparchus of Rhodes in the second century BC. The authors speculate that Hipparchus might even have been involved in the initial design of the mechanism; there is circumstantial evidence that the ship that carried the Antikythera Mechanism set sail from Rhodes, based principally on the Rhodian origins of artefacts such as amphorae and coins found on it[2]. Newly deciphered inscriptions that relate to the planetary movements make it plausible that the mechanism originally also had gearings to predict the motions of the planets.

Is this the last word on the Antikythera Mechanism? Certainly not, but it does provide a new standard, and a wealth of fresh data, for future research. In the meantime, although stunned at the ingenuity of the ancients, we will still be tempted to continue speculation about the specific functions fulfilled by the mechanism. Beyond that, there is the more substantive question of the place and scope of such advanced technology in the ancient Eastern Mediterranean world, and of its eventual fate. It was a long time before gearing mechanisms of this sophistication re-emerged, at least on the current archaeological record. Certain elements of the mechanism are encountered, albeit in much simpler design, in fifth-century Byzantium, and again in medieval Islam[2,5]. The celebrated Persian scholar al-Biruni described, shortly before AD 1,000, a mechanical lunisolar calendar that was usually inserted within an astrolabe with displays on the back, and that approximated the Metonic cycle by means of eight gear-wheels (Fig. 2)[6]. An astrolabe from thirteenth-century Iran containing such a device is in the Museum of the History of Science at the University of Oxford, UK.

Al-Biruni mentioned two alternative gearing arrangements for such a mechanical calendar commonly used by contemporary craftsmen. An anonymous Arabic treatise has recently surfaced that precisely describes one of them, based on a purely lunar calendar. The mechanism is attributable to Nastulus, an instrument-maker and astronomer active in Baghdad around AD 900. This tradition probably derives from ancient technology that was either an antecedent form or a later simplification of the Antikythera Mechanism. But it is equally obvious that much of the mind-boggling technological sophistication available in some parts of the Hellenistic and Graeco-Roman world was simply not transmitted further. The gear-wheel had, in this case, to be reinvented. The Antikythera Mechanism is a useful reminder that history seldom follows simple, linear paths. ■

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STEM-CELL BIOLOGY

A move in the right direction

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Stem-cell therapy is valued for its potential to restore damaged or degenerating tissues. Stem cells are now regularly used to renew blood, and it looks as if the next success could be in treating dystrophic muscle.

The potential of stem-cell technologies to revolutionize medical care is causing great excitement among biologists and the general public. Recent studies on embryonic and adult stem cells, coupled with advances in our understanding of how they can be coaxed into forming particular cell types and tissues, have improved the prospects for addressing a host of untreatable diseases. Bone-marrow transplants to renew blood stem cells are now routine, but significant technological hurdles must still be overcome before the power of stem cells can be harnessed to regenerate solid organs such as muscle. On page 574 of this issue, Giulio Cossu and colleagues (Sampaolesi *et al.*)[1] describe evidence from an animal model that a fairly straightforward infusion of stem cells into the bloodstream might one day be able to treat muscular dystrophy*.

Cossu and colleagues focused on Duchenne muscular dystrophy, one of the most common and devastating inherited disorders, which is caused by mutations in the gene that encodes the dystrophin protein. A treatment for this condition has long been sought[2], and a flurry of breakthroughs has led to current or planned clinical trials of at least five different treatment strategies[3]. Prominent among these are stem-cell transplantation and gene therapy, two approaches that can also be combined by manipulating an individual's own (autologous) stem cells to 'correct' the genetic defect before transplantation. Cossu and colleagues studied an animal model of Duchenne muscular dystrophy — the dystrophic GRMD dog — that closely mimics the human disease, in particular showing extensive muscle wasting and early death (unlike mouse models of the disease). They transplanted either donor stem cells or corrected autologous stem cells into the dogs and observed dramatic improvements in the animals' muscles.

A key factor in this work was the previous identification by the Cossu lab of a novel type of adult stem cell, termed a mesoangioblast, which can be harvested from small blood vessels[4]. Like all stem cells, mesoangioblasts can divide to make more of themselves, but they are also 'preprogrammed' to develop into muscle cells. Although a variety of stem-cell types can become muscle cells when injected into the

*This article and the paper concerned[1] were published online on 15 November 2006.