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Chapter 1

Ether and Atoms

Be not the first by whom the new are tried, Nor yet the last to leave the old aside.

Alexander Pope, An Essay on Criticism

1.1 The Most Famous Failed Experiment

It was July 1887. Everything was arranged in the basement of the dormitory building at Western Reserve University in Cleveland (Ohio) to carry out a physics experiment that, much later, would be consid- ered one of the most important ever. Two people entered the base- ment that warm July morning: Albert A. Michelson (1852–1931) and Edward W. Morley (1838–1923).

Five years earlier, Michelson had accepted an offer to be a professor of physics at Case School of Applied Science. The founders of Case had decided to hire a highly qualified expert in experimental science. He was the perfect choice to improve this industrial city's scientific culture. In the fall of 1886, a fire at Case destroyed the laboratory that Michelson had been setting up for 4 years. Morley, who was a Chemistry professor at the neighboring Western Reserve University, offered to install instruments that had been rescued from the fire in the basement of one of the university buildings. Morley was recognized as a skilled experimenter, and his contribution to setting up the experiment was crucial.

Albert Michelson made three large splashes in the waters of science from 1878 until his death. In two cases, his work confirmed what his colleagues had been expecting. In the third, definitely not, and it took many iterations by him and others before everyone was convinced of his correctness.

First, he measured the speed of light from his student days at the United States Naval Academy (Annapolis Maryland) right up to the time of his death, adding several significant figures to a number that had been known approximately since the work of the Danish astronomer Ole Rømer (1644–1710) in 1676.

Second, he turned the 100-inch Hooker telescope at Mt. Wilson Observatory into an astronomical interferometer, proving (with Francis G. Pease (1881–1938)) that giant stars really are BIG, hundreds of times the diameter of our own Sun.

Third was the Michelson–Morley experiment. This is the one that used what is now called a Michelson interferometer. Interferometers of this type are used in the Laser Interferometric Gravitational-Wave Observatory (LIGO), which started detecting bursts in 2015.

Michelson had built such an interferometer while he was at Potsdam (Germany) as a postgraduate in 1880. It was designed to detect the movement of the Earth through the luminiferous (this is a fancy word for light-bearing) medium called the ether, a substance whose theoretical existence had been postulated many centuries ago and which for the majority of physicists of the 19th century was absolutely necessary for the transmission of light, as air is for sound.

The results of the first Michelson experiment seem to demonstrate that light is not like other things that move as waves (sound or ripples on water) or as particles (trains or racehorses). For those, the speed you measure depends on how you and the source are moving, relative to each other or relative to some stationary background of water, air, or ground. But no matter who you are or what you are doing, if you measure the speed of light (in a vacuum or tenuous medium like air), you will always get the same answer, that c is about 300,000 km/sec that he had been measuring all along.

Michelson complained about the little attention his Potsdam experiment had received in the scientific community, but as a result of a letter received from Lord Rayleigh (1842–1919) encouraging him to repeat the test, he replied[1]: “Your letter has however once more fired my enthusiasm and it has decided my to begin to work at once”. What had everyone expected? Suppose you are a swimmer living near a river and swimming at a constant speed relative to water. Swimming a mile with the flow is the fastest, swimming a mile against the flow is the slowest, and swimming a mile straight across comes in between.

Most of Michelson’s contemporaries supposed that light moved in a medium called ether, in a way similar to the swimmer moving in water, or sound in air, only of course much faster.

If so, then if you set up an experiment in which you can compare how long it takes light to travel a mile parallel to Earth’s motion through the ether vs perpendicular (or against Earth’s travel), you should get different times, and a beam of light split in half, made to take the parallel and perpendicular paths, and then coming together should show the effect of the different times, by getting out of phase and producing an interference pattern.

The Michelson–Morley experiment was set up exactly in that way: swimmers in the river analogy were pulses of light in the interferometer (see Figure 1.1). The supposed ether wind played the role of the flow of water. But the result was, as Michelson wrote to Lord Rayleigh, “decidedly negative”: both half pulses always arrived at the same time, independent of their direction with respect to the supposed ether wind.

Albert Michelson won the Nobel Prize in Physics in 1907. He was the first American who won it. Nevertheless, the experiment showing no Earth’s drift through the postulated ether was not even mentioned in the citation for the prize. It was his measurement of the meter in terms of the wavelength of cadmium light that most impressed the Swedish Academy. That result was obtained also in collaboration with Morley and used the same interferometer.

The Michelson–Morley experiment is correctly described by Albert Einstein’s special theory of relativity and might even have partly inspired it (though years after, he said that wasn’t quite sure he had heard, before 1905, of that first 1887 result). In any case, there is no doubt that 1887 was an important year for the advancement of science. At the end of the very same year, Arthur Conan Doyle (1859–1930) published his first novel on Sherlock Holmes entitled *A Study in Scarlet.* In one of the insightful dialogs held with Dr. Watson, the famous detective says, “One’s ideas must be as broad as Nature if they are to interpret Nature”. Clearly, the Michelson–Morley experiment opened the door to broad ideas in science.

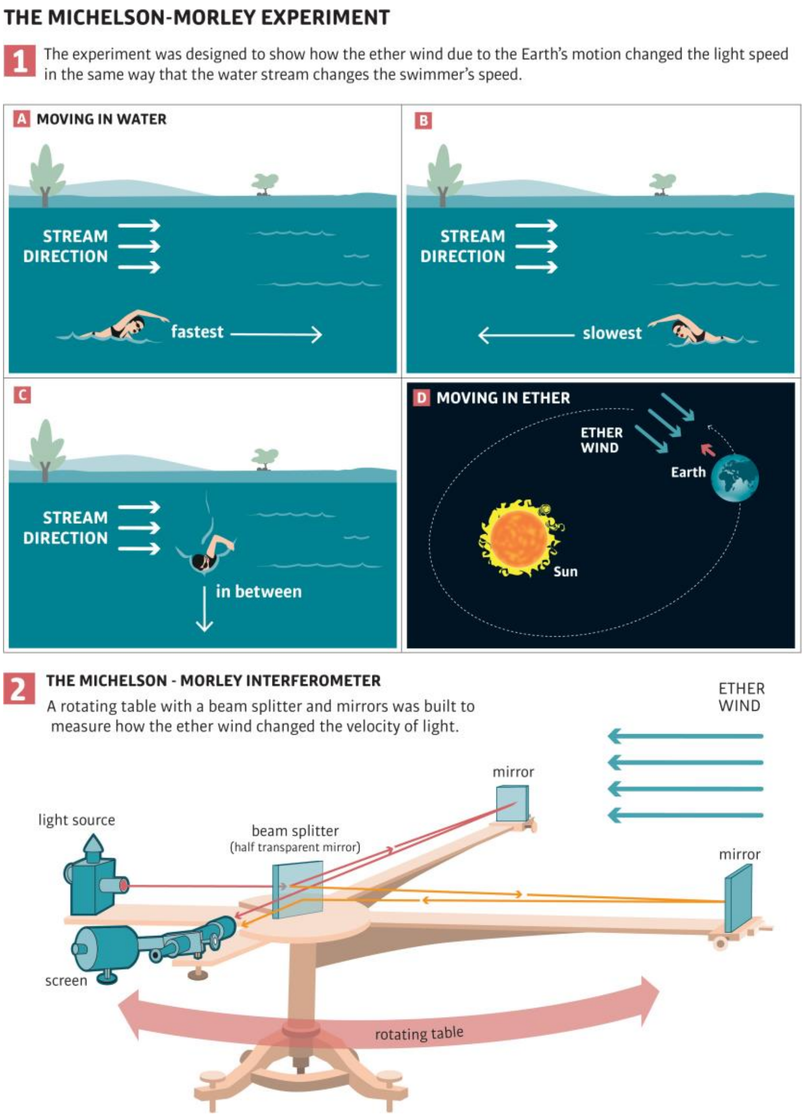

Figure 1.1 The analogy of the Michelson–Morley experiment with a swimmer in a river (top). Modern diagram of the experiment (bottom). Credit: Infographic sketched by the authors and elaborated

by Javier P´erez Belmonte.

Over the years, lots of other physicists carried out similar experiments, and some even won prizes for NOT confirming Michelson and Morley. Not needing ether was not quite the same as not allowing for it. The experiments conducted by Thomas Young (1773–1829), which indicated that light took the form of a wave, revived the notion of "luminiferous ether", described by Agnes M. Clerke (1842–1907) in 1902 as "the ethereal vehicle of the vibrations of light", just as sound required a medium, air, for its propagation. She ignored the experiment conducted by Michelson and Morley some years earlier that called into question the existence of ether. It seems clear that Clerke along with many other scientists of that time knew the negative results of the Michelson–Morley test to detect the ether drift.

Nevertheless, as the professor of History of Science Albert E. Moyer pointed out,[2] "Awareness of an experiment, however, differs from appreciation. Widespread appreciation of the test's significance come only after Michelson's Nobel Prize, when the physics community grasped the full implications of Albert Einstein's special theory of relativity". Ether is without a doubt the "postulated but unseen entity" that has most frequently appeared throughout discussions of the history of science, from Aristotle to the present day.

The story begins in the 5th century BCE when a group of philosophers put together and wrote about their view of how the world was built. At the time, and for over 2,000 years thereafter, the dominant view was that Earth, Air, Fire and Water were the basic indivisible elements of the world. All matter was made up of combinations of these four elements. The idea is attributed to Empedocles (c. 494–434 BCE), in the 5th century BCE and was later strongly supported by Aristotle (384–322 BCE) who added a fifth element: the Quintessence. Similar themes arose, some at even earlier times, in different parts of the world.[3]

For Aristotle and many of his predecessors and contemporaries, the main function of ether was to prevent voids, thought to be logically impossible, but also to make up the heavenly bodies. Anaxagoras had somewhat heftier ether, friction with which heated the hot stones that were the Sun, Moon, and stars, although it also carried them around the Earth.

For most natural philosophers of later times, action-at-a-distance was as much anathema as a void, so ether was needed to connect causes and effects — to transmit forces in somewhat more modern language.

Throughout the history of science, different thinkers, philosophers and scientists postulated the existence of different entities that played a role similar to the one played by the ether for centuries. Entities that, in spite of not being visible or detectable in their time, or perhaps ever, were nevertheless necessary to maintain the stability of the cosmos as the philosophers saw and understood it. They could be entities whose existence explained, or at least justified, the observations or experiments of the moment. Over the course of this book, we will identify some of these, from Antiquity to the present. Those are collectively called in the subtitle of this book "Dragons".

These were advocated on the maps of knowledge by scientists of all times. In many cases, the passage of time has revealed that these principles were wrong and that it was necessary to abandon the theories or beliefs on which they were based, as it happened with the ether. The experiment of Michelson–Morley erased this dragon from those maps of science forever (although at least two decades were necessary for a widespread recognition of the implications of the experiment). In other cases, the entities put forward were eventually discovered. Such findings were stellar moments in the history of science.

The fundamental questions are what picture of each particular aspect of nature was the proposer trying to explain, and would the suggested entity provide the required stability if it actually existed? The planet Neptune is probably the object that best illustrates the category of entities that were initially proposed to explain observations of the moment and then subsequently discovered. In Chapter 6, we will see how, in the 19th century, the astronomers Urban Le Verrier (1811–1877) and John Couch Adams (1819–1892) tried to explain the anomalies observed in the orbit of the planet Uranus by proposing gravitational pull produced by a planet beyond Uranus' orbit as the cause. This is how Neptune was discovered in 1846.

Throughout this book, we will also see other examples of objects (from stars to elementary particles) whose existence was conjectured at some point and which had not been observed when they were proposed but which were discovered later on. However, there are entities whose existence was postulated many years ago and are still needed to explain the cosmos as we understand it today but have not yet been detected. Readers' minds will surely have already turned to dark matter, which has been invoked by astronomers for 90 years to explain different cosmological observations. The nature of this possible dark matter remains a mystery, but few doubt its existence.[4]

A widespread early example of this kind was the need for there to be something to hold up the sky in order to make the room needed on Earth's surface for living creatures.

1.2 Separating the Heavens from Earth

In each era, the world has been seen in a particular way. Explanations of the structure and origin of the cosmos produce different civilizations' cosmology and cosmogony. The most ancient cultures had their own myths. Almost all ancient mythologies posited the existence of something or someone tasked with separating the heavens from Earth. Ancient mythologies and mythical thought obviously came about much earlier than scientific thought did. As Eudald Carbonell and Robert Sala explain in their book[5] *Encara no som Humans*, mythical thoughts must have appeared very long ago, even before our ice-age ancestors captured them in paintings on walls and ceilings of caves and in bone and stone carvings.

We may need to look back as far as the species *Homo heidelbergensis*, in the Middle Pleistocene, 300,000 years ago, to find the earliest "abstract thought about human existence and the construction of a primitive cosmos". For the Egyptians, Shu (air) kept Nut (the sky) above Geb (Earth). Nut and Geb were siblings and lovers. By separating them, their father, Shu, allowed life on Earth's surface to exist. Similar versions of this account exist in Chinese and Babylonian mythologies.

For the Babylonians, Enlil separated Anu (Earth) from Ea (the waters of the heavens and the oceans). Babylonian astronomy was highly developed. It seems that they were able to predict lunar eclipses, planetary conjunctions and other astronomical events, and these things demonstrate an in-depth knowledge of the heavens, the stars and their movements. Nevertheless, it must be said that this cosmology remained in the mythological terrain described above, and the empirical knowledge that they gained regarding what was happening or was going to happen in the celestial sphere did not lead to a more rational approach to the cosmos.

According to the Chinese, the deity Panku aided by a turtle and a set of mythical creatures (a phoenix, a dragon and a qilin) created a separation between Earth and the sky of about 43,000 km, at a rate of 3 meters per day for 18,000 years, as described by Helge Kragh in his *Conceptions of the Cosmos*. The turtle must have done most of the work, since the other three are mythical beasts (though the qilin must not be confused with the unicorn).

The Book of Genesis in Judeo-Christian scripture contains no similar entity. Here, the Creator himself puts each thing in its place — including heaven and Earth — at the first attempt. However, a pro- cess of separation like that in the Eastern mythologies does appear in Genesis[6]1:4–9

> *God saw that the light was good,*
> *and he separated the light from the darkness. . . And God said, "Let there be a vault between the waters to separate water from water. . . "*
> *And God said, "Let the water under the sky be gathered to one place, and let dry ground appear". And it was so.*

The roughly contemporary account in the Theogony of Hesiod (8th century BCE, Greek) puts the in-principle unobservable deep abyss of the Tartaros as far below the (flat) Earth as heaven is above. How far is that? How far can a brass anvil fall in nine days and nights to arrive on the 10th? A little further than the distance to the Moon if Hesiod had been a Newtonian. One suspects, however, that he had probably never dropped an anvil more than 20 or 30 feet, yielding a speed of a couple of meters per second, or a total distance of a few thousand kilometers. We post-Galileans can also remark that it would all come out the same if the anvil had been made of iron rather than brass.

There is an aspect of Greek mythology that we have learned since childhood, which explains how the constellations arose from the relationship between different gods and also between the gods and humans. What is relevant in the context under consideration here is the role of Atlas, who was condemned by Zeus to "hold up the pillars of the heavens", as in the Farnese Atlas statue, though other more recent versions often show him holding up a spherical Earth, hanging on at places that Greeks rarely visited (but you should see in Figure 1.2 where Shu touches Nut!).

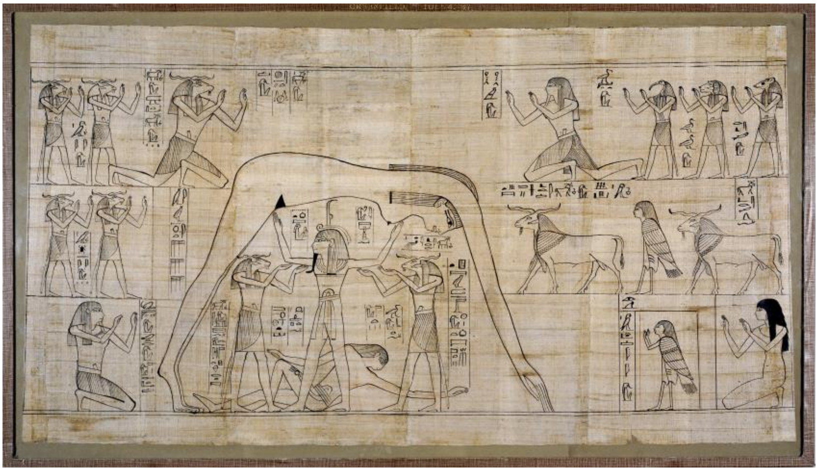

Figure 1.2 Details of the Greenfield Papyrus, Book of the Dead of Nestaneb- tasheru (sheet 87). The Egyptian god Shu (the air), holding Nut (the starry sky)apart from Geb (the Earth) allowing the life to exit.

Myths came slowly to be abandoned, and more rational explanations for the cosmos began to be sought. However, it should be pointed out that this abandonment was gradual. Often, imagined entities were proposed, that were not strictly speaking mythical in the sense that they were not gods, goddesses or composite creatures. In many cases, knowledge subsequently gained revealed that these things did not exist. Nevertheless, they were perceived as necessary at the time when they were put forward in order to maintain the consistency of what was being posited.

Included in this category of entities that were "postulated but not seen" were crystalline spheres, rotating transparent spheres made of ether carrying planets and stars, which were introduced in Greek astronomy to explain the movements of the celestial bodies and were used until the late 17th century (see Chapter 5).

1.3 Replacing Myths by Rational Thought

British evolutionary biologist Richard Dawkins (b. 1941) has said that science and literature are the human activities that justify the application of the specific name *Homo sapiens* to our species.[7] Theprecise moment in history when humans began to nurture these activities depends on the definitions that we attach to the words “literature” and “science”. Some authors consider the birth of science to have taken place in the 16th century with the Copernican Revolution and the subsequent development of scientific method.

However, in our opinion (and that of many others), this is too restrictive a view of science. We have to go much further back in time to find the origins of scientific thought. In his book *The Forgotten Revolution*, Italian physicist Lucio Russo (b. 1944) puts the date for its birth at 323 BCE. This is the beginning of the Hellenistic period according to the terminology introduced by German historian Johann Droysen (1808–1884). The year 323 BCE was when Alexander the Great (356–323 BCE) died. It was the era of Archimedes of Syracuse (ca. 287–212 BCE), Euclid of Alexandria (fl. 300 BCE), Herophilos of Chalcedon (ca. 335–280 BCE), Eratosthenes of Cyrene (ca. 276–195 BCE), Aristarchus of Samos (310–230 BCE), Apollonius of Perga (ca. 240–190 BCE) and Hipparchus of Nicaea (ca. 190–120 BCE), among others.

The most creative scientific activity occurred in the 3rd and 2nd centuries BCE, and a decline then began, following the conquest of Alexandrian lands by the Roman Empire, which ended in 30 CE with the annexation of Cleopatra’s Egypt and the Romans’ complete domination of the entire Mediterranean Basin. Formally speaking, this marked the end of the Hellenistic period, though there was still an impetus for scientific activity for some centuries in the former Alexandrian kingdoms under the *Pax Romana*. Greek culture and language were not ousted by the Roman Empire, and a clear division between the Latin West and the Greek East persisted. The technology and the economic activity of the Eastern part of the empire continued, allowing the continuity of scientific development, though without the initial strength and splendor. Alexandria would continue to be the nerve center of this activity.

This was the era of Ptolemy (ca. 100–170 CE), Heron of Alexandria (ca. 10–70 CE), Galen of Pergamon (129–216 CE) and Diophantus of Alexandria (ca. 200–284 CE). The end of this period is usually set at the date when Hypatia of Alexandria (ca. 360–415 CE) was killed at the hands of Christian fanatics in 415 CE, a moment immortalized in Alejandro Amenábar's film *Agora*, in which Hypatia is played brilliantly by Rachel Weisz.

Russo believes that one of the key factors in the birth of scientific thought through the expansion of the Alexandrian Empire was the meeting of civilizations produced by that expansion, because the Greek hegemon, led by Alexander the Great, invaded Egypt and Mesopotamia, and thereby discovered civilizations with technology and economies that were superior to those of the conquerors themselves. To be sure, classical Greek culture had reached very high levels in aspects such as philosophy, theater, literature and politics (in the form of the birth of some aspects of democracy), but in technological terms, it was behind its eastern neighbors. As Russo states:

The Greeks who moved to the new kingdoms that arose from Alexander's conquests had to administer and control those more advanced economies and technologies with which they were not familiar; their one crucial advantage and guide consisted in the sophisticated methods of rational analysis developed by the Greek cultural tradition during the preceding centuries. It is in this situation that science is born.

Technological development has always been linked to scientific advances. As Cambridge University cosmologist Malcolm S. Longair[8] argues, "Many of the pioneers of the technology of astronomy deserve their rightful places in the pantheon of the founders of modern cosmology". The impact that Galileo Galilei's *Sidereus Nuncius*, published in March 1609, had on 17th century scientific thought is a direct consequence of the astronomical observations that the Italian thinker undertook using a telescope. The Hellenistic era's forgotten scientific revolution was also accompanied by spectacular technological development.

Unfortunately, few physical vestiges of those advances remain, but there is one, and its perfection must lead us to conclude that the level of sophistication in technology reached in the Hellenistic period was impressive and was not surpassed until many centuries later. This instrument is the Antikythera mechanism. Here is the story of its discovery and interpretation.

1.4 Analog Computers from the Distant Past

There was once an old boat that undertook a voyage, probably from the Greek coast towards Italy, with a hold filled with sculptures, ceramics and other riches of Hellenistic culture. But it was also transporting another item: a precision instrument that has turned out to be one of antiquity's most surprising objects. This item was a bronze analog astronomical calculator that was built in the 1st or 2nd century BCE. It could even have been built at the end of the 3rd century BCE. The date is uncertain. It showcases the level of technological sophistication and astronomical knowledge of its designers and makers.

The ship sank near the small island of Antikythera, between the Peloponnese peninsula and the island of Crete. Its crew members perished, and the hull plus all its cargo ended up at the bottom of the Mediterranean Sea. And there it remained hidden for centuries. In 1900 at Easter, the Greek Elias Stadiatis donned a diving suit and descended about 45 meters in that precise place. He was looking for sea sponges but came across the remains of the old shipwreck. Stadiatis was traveling aboard a sponge fishing boat captained by Dimitrios Kondos. The captain reported the finding to the Greek authorities, and work to rescue the cargo began very soon afterward. The items retrieved were transferred to the National Museum of Archaeology in Athens.

Among such a wealth of eye-catching treasures, a rather corroded piece of bronze and wood initially went unnoticed until, on 17 May 1902, the Greek archaeologist Spyridon Stais noticed that there were cogwheels inside the contraption. Although its gears seemed surprising, it was not until much later, in the 1970s, that the Antikythera mechanism's extraordinary structure was revealed through the use of X-ray techniques. Earlier, the German philologist, Albert Rehm (1871–1949), in the period 1905–1906, was the first to understand that it was an astronomical calculating machine. British science historian Derek de Solla Price, Greek nuclear physicist Charalambos

Karakalos and his wife, Emily, conducted the first detailed study of it. Price published their findings in 1974 in a lengthy article entitled: *Gears from the Greeks: The Antikythera Mechanism — A Calendar Computer from ca. 80 B.C.*

A study of this curious object by Tony Freeth (University College London) and an interdisciplinary team appeared[10] in *Scientific Reports* in March, 2021. It carried the striking title: *A Model of the Cosmos in the ancient Greek Antikythera Mechanism.* In this work, the authors put forward a coherent story to explain the mechanism's different uses. They analyze the inscriptions that appear on both the wooden covers and the bronze pieces, and they also study the function of the different gears that make up the mechanism. They conclude that this planetarium, the oldest in the world, perfectly combines all the knowledge of Babylonian astronomy with the mathematical and astronomical expertise of ancient Greece.

Thirty gears from this piece of engineering have been partially preserved. Study and modeling work has led to the discovery that it could be used to predict astronomical phenomena, such as the phases of the Moon or the positions of the Sun and planets. It was at the same time a calculator, capable of predicting the dates of eclipses or the dates on which the different panhellenic games (the Olympic, Pythian, Nemean and Isthmian games) were to be held (see Figure 1.3).

The Antikythera mechanism is so sophisticated that it surely could not have been a one-off. It is very likely that other similar instruments had previously been built and allowed the necessary technology for the piece to be developed. Beyond the makers' understanding of the movement of the stars and the different cycles that were used in ancient times, their technical knowledge of gears, fric- tion and strength of the materials used is surprising. Some have tried to link this instrument to similar pieces that are referred to in Roman texts. For example, in *De re Publica I*, Cicero (103–46 BCE) refers to a mechanical planetarium, probably an orrery, built by Archimedes.

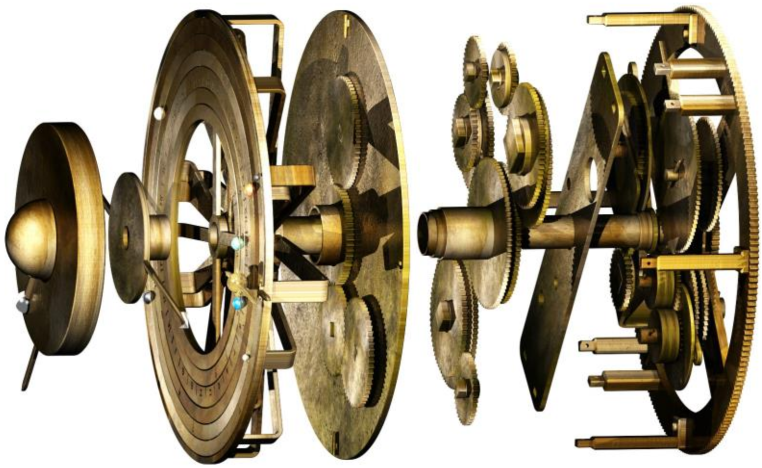

Figure 1.3 Reconstruction of the Antikythera mechanism: Exploded model of Cosmos gearing. Credit: © 2020, Tony Freeth, Images First Ltd.

To be sure, the sage of Syracuse combined theoretical knowledge with a technological dimension to build different scientific instruments. According to Russo, Cicero relied on a now-lost text by Sulpicius Gallus in which the latter recounts having seen a planetarium in operation at the home of Consul Marcus Marcellus, the grandson of General Marcellus, who sacked Syracuse. In any case, with the sinking of the Antikythera mechanism in the shipwreck and its 2,000-year stay on the bottom of the Mediterranean Sea, this technology was lost. Centuries would pass before similar instruments were developed.

Similar instruments are mentioned in the literature in the centuries after the Antikythera Mechanism, though no physical instruments have been found. We find similar but much less sophisticated gears in a treatise on the astrolabe from the late 10th century written by Arabic mathematician al-Biruni (973– 1048), in which he describes a lunisolar calendar. It was not until the analog clocks of the 14th century that examples of technology comparable to that of the Antikythera mechanism came along.

As in other aspects of science and knowledge, the advances in technology of the Hellenistic revolution were also lost. The reinvention of sci- ence became essential, as researcher Francois Charette eloquently expresses in his article[11] "High tech from ancient Greece", published in the journal *Nature* in 2006: "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".

1.5 Atoms and the Infinite

Why did Hellenistic culture and the nurturing of scientific thought disappear? Mainly because of the Roman invasion of different parts of the old Alexandrian Empire and the subsequent wars: the siege of Syracuse and the killing of Archimedes in 212 BCE, the destruction of Corinth and Carthage in 146 BCE, the defeat of Athens in 86 BCE, the pillage of Rhodes in 43 BCE and the final annexation of all of Egypt in 30 BCE. Libraries were broken up, and many Greek citizens who inhabited these lands and worked in their cultural centers were sent to Rome as slaves, tutors, copyists and scribes. The authority of Aristotle's philosophy, which prevailed from the 1st century CE, was another element that contributed to forgetting the Hellenistic thinkers, as did the subsequent adoption of Aristotelian thought by Christianity, especially by the Scholastics, represented by Thomas Aquinas (ca. 1224–1274).

The school of Plato and Aristotle was not the only school of thought in classical Greece. At least two other schools coexisted: the atomists and the stoics. The atomist school of philosophers envis- aged an entire universe composed of invisible and indivisible small particles ("atoms") moving around in space (the void) out of which everything we see was built. In their view, the four elements of those ancient times, Earth, Air, Fire and Water, were themselves made from different organizations of atoms moving in the void.

The idea of something more fundamental than the four elements is attributed to the 5th century BCE philosophers Leucippus and his pupil, Democritus (ca. 460–370 BCE). We have relatively little information about them. Not only were they sidelined by their opponents but also many of their manuscripts have been lost, destroyed or locked up in libraries that have since disappeared. Those who supported their view were known as “the atomists”.

These atomists also supported the notion of a “void” in which the atoms moved freely. Nowadays we refer to this void as the “vacuum”. Aristotle declined to think that such a concept should ever be seriously discussed. He took the not-unreasonable view that it is impossible to talk about “nothing”. The concept of empty space has, of course, persisted into modern science as the vacuum, and even Aristotle’s ether resembles modern-day “quintessence”, whatever that might turn out to be.

The ideas of these leading classical figures on the constituents of matter and the introduction of the word “atom” were of fundamental importance to the atomist school. They spoke rationally about entities that they obviously could not observe, “dragons”, but which were necessary for preserving their understanding of the cosmos. Almost 25 centuries later, atoms were introduced in modern physics, in a context of experimental and theoretical knowledge that was utterly different. To be sure, modern atoms have nothing in common, except for the name, with the classical version, but we must recognize that the modern concept is, at least, deeply rooted in the line of thought that began in classical Greece.

Different schools of thought during the Hellenistic era, holding opposing positions about the finiteness of the cosmos, coexisted with one another. The stoics for example, a school founded by Zeno of Citium (333–262 BCE) in Athens, argued, in contrast to the atomists, that there was a single, finite universe, although, they affirmed the existence of a non-physical infinite void surrounding the physical finite cosmos. This idea would be taken up by Johannes Kepler in the 17th century, and different astronomers supported it even in the 20th century — for instance, the North American Harlow Shapley (1885–1972), who was the director of the Harvard College Observatory for nearly 40 years.

Modern cosmology does not have a definitive answer to whether the universe is finite or infinite, though we can state that it is very large compared to the part we can observe. Whether or not it is infinite depends on values of some cosmological parameters which have yet to be determined with accuracy.

Another example given by Russo in *The Forgotten Revolution* is that of the famous paradoxes of Zeno of Elea (ca. 490–430 BCE), and especially the paradox of Achilles and the tortoise.[12] We can clearly see in it the difference between the concepts introduced in the philosophical field in classical Greece. Later, in the Hellenistic period, these concepts would be addressed in a scientific way. These paradoxes involve ideas such as the continuity of physical magnitudes (for instance, time and space), though these were not part of his mathematical modeling. But they were in Euclid's, 150 years later, in the fifth book of his *Elements*. We must recognize, however, that Zeno's arguments are, at least, the forerunners of the basic ideas that underpin modern infinitesimal calculus developed in 1666 by Isaac Newton (1642–1727) and Gottfried Leibniz (1646–1716).

In short, although the birth of science can be placed at the beginning of the Hellenistic period, the contribution to rational thinking made by pre- and post-Socratic philosophers was essential in displacing cosmogonies based on ancient mythologies as the only way to explain the world. The transition would be smooth rather than abrupt, such that the particular elements of scientific thought grew with classical Greece's most impressive sequence of masters and disciples: Socrates, Plato and Aristotle. Appearing in Aristotle's natural philosophy, for example, are many of the elements needed to describe physical phenomena, such as the forces to explain movement.[13] But Aristotle works in a speculative manner, without making use of a scientific method, even a nascent one, as Archimedes would, decades later, to explain the same phenomena. We note that Aristotle was the teacher of Alexander the Great, with whom the Hellenistic period began.

To Aristotle, the four elements — Earth, Air, Fire and Water — were fundamental; everything in the sublunary region[14] was made from these four elements. To the atomists, there was a more fundamental indivisible building block, the "atom".

The atomist view was adopted in the 3rd century BCE by Epicurus of Samos who incorporated it within his ethical hedonistic philosophy in order to provide his views with a solid philosophical basis. He felt that life should be lived for the present and not to satisfy the whims of the gods or for the dream of an afterlife. For Epicurus, a good life was one that was free from pain.[15] He rejected the classical idea that our lives were controlled by the whims of self-serving and often disruptive gods: he was an atheist. Epicurus promoted the view that we should live our lives to the full because there was no afterlife. This one life was all we had.

Epicurus endowed the atoms with the additional property of weight and argued that their motion cannot be simple straight lines but rather that they should have a small random component of motion that enables them to interact. In the 3rd century BCE, randomness was a revolutionary concept. The atomists however believed everything was in motion and moreover that there was a randomness in those motions, leading to an indeterministic world. If there were no such random component, the laws of motion would be deterministic, and everything would depend on the starting conditions. Those would pre-determine human actions and there would be no free will.

However, the atomists' view did not go down well with the dominant Aristotelians. Epicurus and his followers were marginalized except in the popular writings of the day. It is, however, by Aristotle that we are told that Epicurus had endowed the atoms with hooks so that they could combine together to build other things. Despite this, the Epicurean view of life became quite popular in later Roman times, when Titus Lucretius Carus, "Lucretius" for short, wrote an epic 7500 line[16] poem in the 1st century BCE: *De Rerum Natura* presenting his version of Epicurus' philosophy.

The poem is largely a detailed summary of the works of Epicurus with the addition of Lucretius' own reflections, written in six parts, beginning with a description of matter and space in the first part and the movement and shapes of atoms in the second. It goes on to use atomism as a basis for building and justifying the system of ethics and life advocated by Epicurus. Bertrand Russell, one of the great philosophers of the 20th century, remarked that Lucretius' poem is our main source about the ideas of Epicurus and the atomists. Curiously, the poem was thought not to have been preserved after the decline of the Roman Empire, until a manuscript that contained it was discovered in 1417 in a European monastery. The existence and survival of this poem is the central part of our story[17] in the next chapter.