# *A History of* SCIENCE *in* SOCIETY

## FROM PHILOSOPHY TO UTILITY

3rd EDITION

ANDREW EDE AND
LESLEY B. CORMACK

A History of Science in Society

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## From Philosophy to Utility

**Third Edition**

Andrew Ede and Lesley B. Cormack

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To Graham and Quin, who have grown up with this book—and who put up with two authors working in the house at the same time. We would also like to thank those people who helped make this book possible: our editor and publisher; friends and colleagues who read early drafts and gave advice; reviewers and users who have offered helpful criticism and forced us to defend our position; and all the amazing historians of science on whose shoulders (or toes) we stand.

# INTRODUCTION

Science has transformed human history. It has changed how we see the universe, how we interact with nature and each other, and how we live our lives. It may, in the future, even change what it means to be human. The history of such a powerful force deserves a full and multifaceted examination. Yet a history of science is unlike a history of monarchs, generals, steam engines, or wars because science isn't a person, an object, or an event. It is an idea, the idea that humans can understand the physical world.

This is a history of what happens when a legion of thinkers, at different times and from different backgrounds, turned their minds and hands to the investigation of nature. In the process, they transformed the world.

The history of science is such a vast subject that no single book about it can really be comprehensive, and so the story we tell examines science from a particular point of view. Some histories of science have focused on the intellectual development of ideas, while others have traced the course of particular subjects such as astronomy or physics. In this book, we have chosen to look at science from two related perspectives that we believe offer a window onto the historical processes that shaped the study of nature. First, we have examined the link between the philosophical pursuit of knowledge and the desire of both the researchers and their supporters to make that knowledge useful. There has always been a tension between the intellectual aspects of science and the application of scientific knowledge. The ancient Greek philosophers struggled with this problem, and it is still being debated today. The call in every age by philosophers and scientists for more support for "research for its own sake" is indicative of the tension between the search for knowledge and the pressure to apply that knowledge. What counts as useful knowledge differed from patron to patron and society to society, so that the Grand Duke Cosimo de' Medici and the United States Department of Energy looked for quite different "products" to be created by their clients, but both traded support for the potential of utility.

The tension between intellectual pursuits and demands for some kind of product not only was felt by many natural philosophers and scientists but has also led to controversy among historians of science. Where does science end and technology begin? they have asked. Perhaps the most famous articulation of this is the "scholar and craftsman debate." Historians of science have tried to understand the relationship between those people primarily interested in the utility of knowledge (the craftsmen) and those interested in the intellectual understanding of the world (the scholars). Some historians have denied the connection, but we feel it is integral to the pursuit of natural knowledge. The geographers of the early modern period provide a good example of the necessity of this interconnection. They brought the skills of the navigator together with the abstract knowledge of the mathematician. Translating the spherical Earth onto flat maps was an intellectual challenge, while tramping to the four corners of the globe to take measurements was an extreme physical challenge. Getting theory and practice right could mean the difference between profit or loss, or even life and death.

Our second aim has been to trace the history of science by its social place. Science does not exist in disembodied minds, but is part of living, breathing society. It is embedded in institutions such as schools, princely courts, government departments, and even in the training of soldiers. As such, we have tried to relate scientific work to the society in which it took place, tracing the interplay of social interest with personal interest. This has guided our areas of emphasis so that, for example, we give alchemy a greater allocation of space than some other histories of science because it was more socially significant than topics such as astronomy or physics in the same period. There were far more alchemists than astronomers, and they came from all ranks and classes of people, from peasants to popes. In the longer term, the transformation of alchemy into chemistry had a very great impact on the quality of everyday life. This is not to say that we neglect astronomy or physics, but rather that we have tried to focus on what was important to the people of the era and to avoid projecting the importance of later work on earlier ages.

In each chapter, we have highlighted one aspect of this interaction of science and society, from politics and religion to economics and warfare, under the heading

"Connections." While each of these vignettes is part of the larger narrative of the book, they can also be read as individual case studies.

It is from the two perspectives of utility and social place that our subtitle comes. As we began to look at the work of natural philosophers and scientists over more than 2,000 years, we found ourselves more and more struck by the consistency of the issue of the utility of knowledge. Plato disdained the utility of knowledge, but he promoted an understanding of geometry. Eratosthenes used geometry to measure the diameter of the Earth, which had many practical applications. In the modern era, we have seen many cases of scientific work unexpectedly turned into consumer goods. The cathode ray tube, for instance, was a device created to study the nature of matter, but it ended up in the heart of the modern television. Philosophers and scientists have always walked a fine line between the role of intellectual and the role of technician. Too far to the technical side and a person will appear to be an artisan and lose their status as an intellectual. Too far to the intellectual side, a person will have trouble finding support because they have little to offer potential patrons.

Although the tension over philosophy and utility has always existed for the community of researchers, we did not subtitle our book "Philosophy *and* Utility." This is because the internal tension was not the only aspect of philosophy and utility that we saw over time. Natural philosophy started as an esoteric subject studied by a small, often very elite, group of people. Their work was intellectually important but had limited impact on the wider society. Over time, the number of people interested in natural philosophy grew, and as the community grew, so too did the claims of researchers that what they were doing would benefit society. Through the early modern and modern eras, scientists increasingly promoted their work on the basis of its potential utility, whether as a cure for cancer or as a better way to cook food. And, in large part, the utility of science has been graphically demonstrated in everything from the production of colour-fast dyes to the destruction of whole cities with a single bomb. We have come to expect science to produce things we can use, and, further, we need scientifically trained people to keep our complex systems working—everything from testing the purity of our drinking water to teaching science in school. Our subtitle reflects the changing social expectation of science.

We have also made some choices about material based on the need for brevity. This book could not include all historical aspects of all topics in science or even introduce all the disciplines in science. We picked examples that illustrate key events and ideas rather than give exhaustive detail. For instance, the limited amount of medical history we include looks primarily at examples from medicine that treated the body as an object of research and thus as part of a larger intellectual movement in natural philosophy. We also chose to focus primarily on Western developments in natural philosophy and science, although we tried to acknowledge that natural philosophy existed in other places as well and that Western science did not develop in isolation. Especially in the early periods, Western thinkers were absorbing ideas, materials, and information from a wide variety of sources. By the seventeenth and eighteenth centuries, Western scholars were interacting with other cultures and exchanging information, although not on an equal footing. In later periods, Western science became a powerful tool for modernization and internationalization of countries around the world. *A History of Science* tells a particular—and important—story about the development of this powerful part of human culture, which has and continues to transform all our lives. To study the history of science is to study one of the great threads in the cloth of human history.

## CHAPTER TIMELINE

| | |
|---|---|
| **C. 2560 BCE** | Great Pyramid built |
| **C. 600 BCE** | Thales of Miletus starts Ionian school |
| **C. 550 BCE** | Pythagoras teaches world as numbers and geometry |
| **C. 500 BCE** | Heraclitus of Ephesus and Parmenides of Elea propose competing theories of change |
| **C. 410 BCE** | Democritus proposes "atomic" theory of matter |
| **399 BCE** | Death of Socrates |
| **385 BCE** | Plato founds the Academy |
| **334 BCE** | Aristotle founds the Lyceum |
| **C. 300 BCE** | Euclid writes mathematic treatise *Elements* |
| **C. 290 BCE** | Aristarchus proposes heliocentric theory—largely ignored |
| **C. 240 BCE** | Eratosthenes of Cyrene measures circumference of the Earth |
| **212 BCE** | Death of Archimedes |

# 1

# THE ORIGINS OF NATURAL PHILOSOPHY

The roots of modern science are found in the heritage of natural philosophy created by a small group of ancient Greek philosophers. The voyage from the Greeks to the modern world was a convoluted one, and natural philosophy was transformed by the cultures that explored and re-explored the foundational ideas of those Greek thinkers. Despite intellectual and practical challenges, the Greek conceptions of how to think about the world and how the universe worked remained at the heart of any investigation of nature in Europe and the Middle East for almost 2,000 years. Even when natural philosophers began to reject the conclusions of the Greek philosophers, the rejection itself still carried with it the form and concerns of Greek philosophy. Today, when virtually nothing of Greek method or conclusions about the physical world remains, the philosophical concerns about how to understand what we think we know about the universe still echo in our modern version of natural philosophy.

To understand why Greek natural philosophy was such an astounding achievement, we must consider the conditions that led to the creation of a philosophy of nature. Since the earliest times of human activity, the observation of nature has been a key to human survival. Knowledge of everything—from which plants are edible to where babies come from—was part of the knowledge acquired and passed down through the generations. In addition to practical knowledge useful for daily life, humans worked to understand the nature of existence and encapsulated their knowledge and conclusions in a framework of mytho-poetic stories.

Humans have always wanted to know more than just what is in the world; they want to know why the world is the way it is.

## Early Civilizations and the Development of Knowledge

With the rise of agriculture and the development of urban civilization, the types of knowledge about nature were diversified as new skills were created. There arose four great cradles of civilization along the river systems of the Nile, the Tigris-Euphrates, the Indus-Ganges, and the Yellow. They shared the common characteristic of a large river that was navigable over a long distance and that flooded the region on a periodic basis. The Nile in particular flooded so regularly that its rise and fall was part of the timekeeping of the Egyptians. These floods renewed the soil, and the lands in temperate to subtropical zones were (and are) agriculturally abundant, providing food to support large populations.

A growing group of people were freed from farm work by the surplus the land provided. These people were the artisans, soldiers, priests, nobles, and bureaucrats who could turn their efforts to the development and running of an empire. The mastery of these skills required increasingly longer periods of study and practice. Artisans required apprenticeships to acquire and master their arts, while the priest class took years to learn the doctrine and methods of correct observance. The military and ruling classes required training from childhood to grow proficient in their duties. Because the empires were long-lasting, especially the Egyptian empire, the rulers planned for the long term, thinking not just about the present season but about the years ahead and even generations into the future. Thus, these civilizations could take on major building projects such as the Great Wall of China or the Great Pyramid of Giza.

In addition to the obvious agricultural and economic advantage provided by the rivers, they had a number of subtle effects on the intellectual development of ancient civilizations. Dealing with large-scale agricultural production required counting and measurement of length, weight, area, and volume, and that led to accounting skills and record-keeping. Agriculture and religion were intertwined, and both depended on timekeeping to organize activities necessary for worship and production, which in turn led to astronomical observation and calendars. As these societies moved from villages to regional kingdoms and finally became empires, record-keeping exceeded what could be left to memory. Writing and accounting developed to deal with the problems of remembering and recording the myriad activities of complex religions, government bureaucracies, and the decisions of judges at courts of law.

Another aspect of intellectual development that came from the periodic flooding had to do with the loss of local landmarks, so skills of surveying were developed. Rather than setting the boundaries of land by objects such as trees or rocks, which changed with every inundation, the land was measured from objects unaffected by the flooding. In addition to the practical skills of land measurement, surveying also introduced concepts of geometry and the use of level and angle measuring devices. These were then used for building projects such as irrigation systems, canals, and large buildings. In turn, surveying tools were closely related to the tools used for navigation and astronomy.

These kinds of practical skills contributed to a conception of the world based on abstract models. In other words, counting cattle contributed to the concept of arithmetic as a subject that could be taught independent of any actual object to be counted. Similarly, getting from place to place by boat led to the development of navigation. The skill of navigation started as local knowledge of the place a pilot frequently travelled. While a local pilot was useful, and the world's major ports still employ harbour pilots today, general methods of navigation applicable to circumstances that could not be known in advance were needed as ships sailed into unknown waters. The skill of navigation was turned into abstract ideas about position in space and time.

The various ancient empires of the four river systems mastered all the skills of observation, record-keeping, measurement, and mathematics that would form the foundation of natural philosophy. While historians have increasingly acknowledged the intellectual debt we owe these civilizations, we do not trace our scientific heritage to the Egyptians, Babylonians, Indians, or Chinese. Part of the reason for this is simply chauvinism. Science was largely a European creation, so there was a preference for beginning the heritage of natural philosophy with European sources rather than African or Asian ones.

There is, however, a more profound reason to start natural philosophy with the Greeks rather than the older cultures, despite their many accomplishments. Although these older cultures had technical knowledge, keen observational skills, and vast resources of material and information, they failed to create natural philosophy because they did not separate the natural world from the supernatural world. The religions of the old empires were predicated on the belief that the material world was controlled and inhabited by supernatural beings and forces, and that the reason for the behaviour of these supernatural forces was largely unknowable. Although there were many technical developments in the societies of the four river cultures, the intellectual heritage was dominated by the priests, and their interest in the material world was an extension of their concepts of theology. Many ancient civilizations, such as the Egyptian, Babylonian, and Aztec empires, expended a large proportion of social capital (covering such things as the time, wealth, skill, and public space of the society) on religious activity. The Great Pyramid, built as the tomb for the Pharaoh Khufu (also known as Cheops), rises 148 metres above the plain of Giza and is the largest of the pyramids. It is an astonishing engineering feat and tells us a great deal about the power and technical skills of the people who built it. But the pyramids also tell us about a society that was so concerned about death and the afterlife that its whole focus could be on the building of a giant tomb.

The very power of the four river centres may have worked against a change in intellectual activity. Social stratification and rigid class structure kept people in narrowly defined occupations. Great wealth meant little need to explore the world or seek material goods from elsewhere since the regions beyond the empire contained little of interest or value compared to what was already there. Although it was less true of the civilizations along the Indus-Ganges and Tigris-Euphrates river systems, which were more affected by political instability and invasions, both the Egyptian and Chinese civilizations developed incredibly complex societies with highly trained bureaucracies that grew increasingly insular and inward-looking.

## The Greek World

It is impossible to be certain why the Greeks took a different route, but aspects of their life and culture offer some insight. The Greeks were not particularly well-off, especially when compared to their neighbours the Egyptians. Although unified by language and shared heritage, Greek society was not a single political entity but a collection of city-states scattered around the Aegean Sea and the eastern end of the Mediterranean. These city-states were in constant competition with each other in a frequently changing array of partnerships, alliances, and antagonisms. This struggle extended to many facets of life, so that it included not just trade or military competition but also athletic rivalry (highlighted by the athletic and religious festival of the Olympics); the pursuit of cultural superiority by claiming the best poets, playwrights, musicians, artists, and architects; and even intellectual competition as various city-states attracted great thinkers. This pressure to be the best was one of the spurs to exploration that allowed the Greeks to bring home the intellectual and material wealth of the people they encountered.


1.1 THE GREEK WORLD

Another factor was the degree to which Greek life was carried out in public. Much of Greek social structure revolved around the marketplace or *agora*. This was not just a place to shop but a constant public forum where political issues were discussed, various medical services were offered, philosophers debated and taught, and the news and material goods of the world was disseminated. The Greeks were a people who actively participated in the governance of the state and were accustomed to debate and discussion of matters of importance as part of the daily course of life. Greek law, while varying from state to state, was often based on the concept of proof rather than the exercise of authority. The public exchange of ideas and demand for individual say in the direction of their political and cultural life gave the Greeks a heritage of intellectual rigour and a tolerance for alternative philosophies. The vast range of governing styles that coexisted in the city-states, from tyranny to democracy, show us a willingness to try new methods of dealing with public issues.

Combined with the competitiveness of the Greeks, this meant that they were not only psychologically prepared to take on challenges but also accustomed to hearing and considering alternative views. They absorbed those things they found useful from neighbouring civilizations and turned them to their own needs.

Greek religion also differed from that of their neighbours. For the Greeks, the gods of the pantheon were much more human in their presentation and interaction with people. Mortals could argue with the gods, compete against them, and even defy them, at least for a time. Although the Greek world was still full of spirits, Greeks were less inclined to imbue every physical object with supernatural qualities. While there might be a god of the seas to whom sailors needed to make offerings, the sea itself was just water. The religious attitude of Greeks was also less fatalistic than that of their neighbours. While it might be impossible to escape fate, as the story of Oedipus Rex shows, it was also the case that the gods favoured those who helped themselves. At some fundamental level, the Greeks believed that they could be the best at everything, and they did not want to wait for the afterlife to gain their rewards.

Although there were many positive things about Greek society, we should also remember that the Greeks had the time and leisure for this kind of public life because a large proportion of the work to keep the society going was done by slaves. Although the conditions of slavery varied from city-state to city-state, even in democratic Athens (where democracy was limited to adult males of Athenian birth), most of the menial positions and even the artisan class were made up of slaves. Those who worked with their hands were at the bottom of the social hierarchy.

## Thales to Parmenides: Theories of Matter, Number, and Change

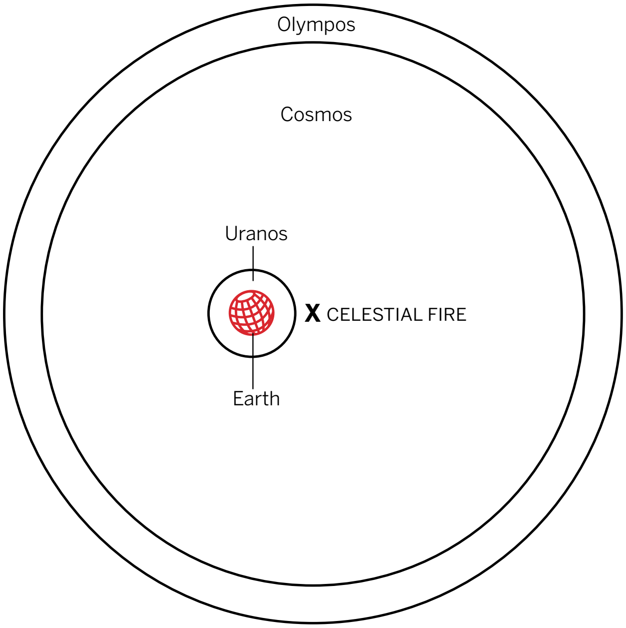
Whether these elements of Greek society and social psychology are sufficient to explain why the Greeks began to separate the natural from the supernatural is difficult to prove. Yet this separation became a central tenet for a line of philosophers who began to appear in Ionia around the sixth century BCE. The most famous of these was Thales of Miletus (c. 624–c. 548 BCE). We know very little about Thales or his work. Most of what comes down to us is in the form of comments by later philosophers. He was thought to have been a merchant, or at least a traveller, who visited Egypt and Mesopotamia where he was supposed to have learned geometry and astronomy. Thales argued that water was the prime constituent of nature and that all matter was made of water in one of three forms: water, earth, and mist. He seems to be borrowing from the material conception of the Egyptians, who also considered earth, water, and air to be the primary constituents of the material world, but he took it one step further by starting with one element. Thales pictured the world as a sphere (although it might have been drum-shaped) that floated on a celestial sea.

Even in this fragmentary record of Thales' philosophy, two things stand out. First, nature is completely material; there are no hints of supernatural constituent elements. This does not mean that Thales discarded the gods but rather that he thought that the universe had a material existence independent of supernatural beings. The second point is that nature functions of its own accord, not by supernatural intervention. It follows that there are general or universal conditions governing nature and that those conditions are open to human investigation and understanding.

Following Thales was his student and disciple Anaximander (c. 610–c. 545 BCE). Anaximander added fire to the initial three elements and produced a cosmology based on the Earth at the centre of three rings of fire. These rings were hidden from view by a perpetual mist, but apertures in the mist allowed their light to shine through, producing the image of stars, the sun, and the moon. Like Thales, Anaximander used a mechanical explanation to account for the effects observed in nature. His system presented some problems since it placed the ring of fire for the stars inside the rings of fire for the moon and the sun. He may have addressed these issues elsewhere, but that information is lost to us.

Anaximander also tried to provide a unified and natural system to account for animal life. He argued that animals were generated from wet earth that was acted upon by the heat of the sun. This placed all four elements together as a prerequisite for life. This conception of spontaneous generation was borrowed from earlier thinkers and was likely based on the observation of events such as the appearance of insects or even frogs from out of the ground. Anaximander took the theory a step further by arguing that simpler creatures changed into more complex ones. Thus, humans were created from some other creature, probably some kind of fish. This linked the elements of nature with natural processes rather than supernatural intervention to create the world that we see.

The Ionian concern with primary materials and natural processes would become one of the central axioms of Greek natural philosophy, but by itself it was insufficient for a complete philosophical system. At about the time




1.2 THE UNIVERSE ACCORDING TO PYTHAGORAS

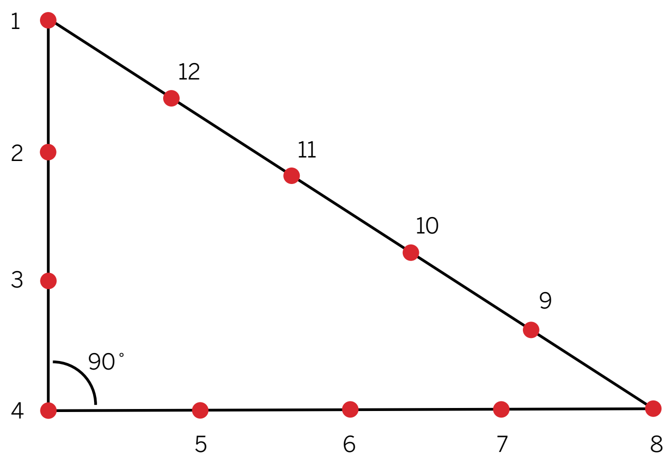
Anaximander was working on his material philosophy, another group of Greeks was developing a conception of the world based not on matter but on number. This thread of philosophy comes down to us from Pythagoras (c. 582–500 BCE). It is unclear if there actually was a single historical figure named Pythagoras. Traditionally, he was thought to have been born on the island of Samos and to have studied Ionian philosophy, perhaps even as a student of Anaximander. He was supposed to have threatened the authority of the tyrant Polycrates on Samos and was forced to flee the island for Magna Graecia (Italy).

Because Pythagoras's followers became involved in conflicts with local governments, the Pythagoreans should not be regarded as simply a wandering band of mathematicians. Their lives were based, in fact, on a religion full of rituals. They believed in immortality and the transmigration of souls, but at the heart of Pythagoreanism was the conception of the universe based on number. All aspects of life could be expressed in the form of numbers, proportions, geometry, and ratios. Marriage, for example, was given the number five as the union of the number three representing man and the number two representing woman. Although there were mystical aspects of the number system, the Pythagoreans attempted to use mathematics to quantify nature. A good example can be seen in their demonstration of musical harmony. They showed that the length of a string determined the note produced, and that note was then related exactly to other notes by fixed ratios of string length.

The Pythagoreans developed a cosmology that divided the universe into three spheres. (See figure 1.2.) Uranos, the least perfect, was the sublunar realm or terrestrial sphere. The outer sphere was Olympos, a perfect realm and the home of the gods. Between these two was Cosmos, the sphere of moving bodies. Since it was governed by the perfection of spheres and circles, it followed that the planets and fixed stars moved with perfect circular motion. The word "planet" comes from the Greek for "wanderer," and it was used to identify these spots of light that constantly moved and changed position against the fixed stars and relative to each other. The planets were the Moon, Sun, Mercury, Venus, Mars, Jupiter, and Saturn. The fixed stars orbited without changing their position relative to each other, and it was from these that the constellations were formed.

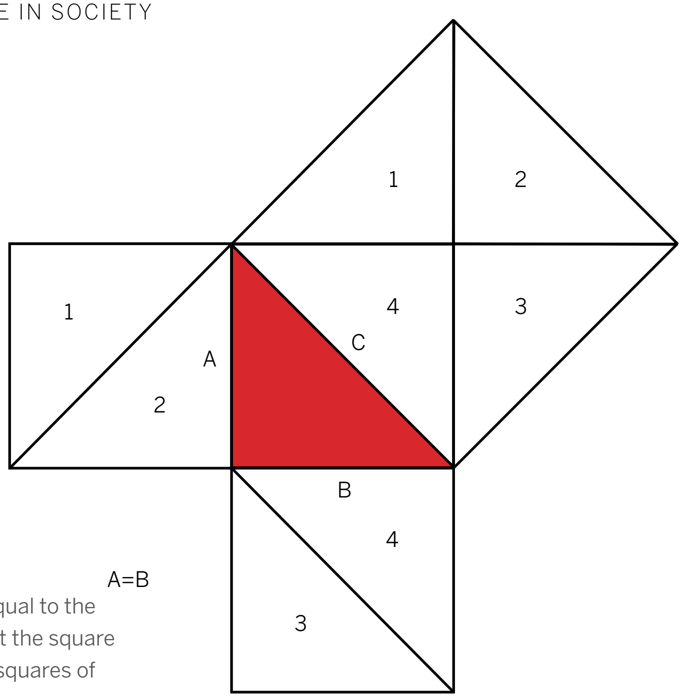
While this arrangement was theologically satisfying, it led to one of the most perplexing problems of Greek astronomy. The philosophy of perfect circular motion did not match observation. If the planets were orbiting the Earth at the centre of the three-sphere universe, they should demonstrate uniform motion—and they did not. To resolve this problem, the Pythagoreans moved the Earth out of the centre of the sphere and created a point—home to a celestial fire—that was the centre of uniform motion. This kept the Earth motionless and resolved the issue of the observed variation in the velocity and motion of the planets. The desire to keep the Earth at the centre of the universe and preserve the perfection of circular motion led most of the later Greek philosophers to reject the Pythagorean solution. A radical solution to this problem was proposed by Aristarchus of Samos (c. 310–230 BCE), who argued for a heliocentric (sun-centred) model, but his ideas gained little support because they not only violated common experience but ran against religious and philosophical authority on the issue.

One of the most famous geometric relations comes down to us from the Pythagoreans, although they did not create it. This is the "Pythagorean theorem" that relates the length of the hypotenuse of a triangle to its sides. This relationship was well known to the Egyptians and the Babylonians and probably came from surveying and construction. The relationship can be used in a handy instrument by taking a rope loop marked in 12 equal divisions that when pulled tight at the 1, 4, and 8 marks produces a 3–4–5 triangle and a 90° corner. (See figure 1.3.) The Pythagoreans used geometric proof to demonstrate the underlying principle of this relationship.




**1.3** USING THE PYTHAGOREAN RELATION TO CREATE A RIGHT ANGLE

A rope with 12 evenly spaced knots when pulled at 1, 4, and 8 creates a right angle at 4. This simple device was known to the Egyptians and used for surveying and building.




**1.4** GEOMETRIC DEMONSTRATION OF THE PYTHAGOREAN RELATIONSHIP

The large square 1234 is made up of triangles equal to the small squares 12 and 34. This demonstrates that the square of the hypotenuse C is equal to the sum of the squares of the sides A and B.

Despite the mystical aspects of a world composed of number, the foundation of Pythagorean thought places the essential aspects of natural phenomena within the objects themselves. In other words, the world works the way it does because of the intrinsic nature of the objects in the world and not through the intervention of unknowable supernatural agents. Ideal forms, especially geometric objects such as circles and spheres, existed as the hidden superstructure of the universe, but they could be revealed, and they were not capriciously created or changed by the gods.

The degree to which the Pythagoreans desired a consistent and intrinsically driven nature can be seen in the problem created by "incommensurability," referring to things that had no common measure or could not be expressed as whole number proportions such as 2:3 or 4:1. The Pythagoreans argued that all nature could be represented by proportions and ratios that could be reduced to whole-number relationships, but certain relationships cannot be expressed this way. In particular, the relationship between the diagonal and the side of a square cannot be expressed as a ratio of integers such as 1:2 or 3:7. As figure 1.4 demonstrates, the relationship can be shown geometrically, but the arithmetic answer was not philosophically acceptable since it required a ratio of $1:\sqrt{2}$, which could not be expressed as an integer relation. No squared number could be subdivided into two equal square numbers, nor in the case of √2 can the number be completely calculated.[1] According to legend, the Pythagorean Hippapus, who discovered the problem, was thrown off the side of a ship by Pythagoras to keep incommensurability secret.

The problems of Greek mathematics were compounded by two practical issues. The Greeks did not use a decimal or place-holder system of arithmetic but used letters to represent numbers. This made calculations and more complex forms of mathematics difficult. In addition, even though the Greeks and the Pythagoreans in particular were extremely powerful geometers, they did not have a system of algebra, and proofs were not based on "solving for unknowns." Geometric proofs were created to avoid unknown quantities. These two aspects of Greek mathematics put limits on the range of problems that could be addressed and probably encouraged their concentration on geometry.

While the Ionians investigated the material structure of the world and the Pythagoreans concentrated on the mathematical and geometric forms, another aspect of nature was being investigated by Greek thinkers. This was the issue of change. Motion, growth, decay, and even thought are aspects of nature that are neither matter nor form. No philosophy of nature could be complete without an explanation of the phenomena of change. At the two extremes of the issue were Heraclitus of Ephesus (c. 550–475 BCE) and Parmenides of Elea (fl. 480 BCE). Heraclitus argued that all was change and that nature was in a constant state of flux, while Parmenides asserted that change was an illusion.

Heraclitus based his philosophy on a world that contained a kind of dynamic equilibrium of forces that were constantly struggling against each other. Fire, at the heart of the system and the great image of change for Heraclitus, battled water and earth, each trying to destroy the others. In a land of islands, water, and volcanoes, this had a certain pragmatic foundation. Heraclitus's most famous argument for change was the declaration that you cannot step into the same river twice. Each moment, the river is different in composition as the water rushes past, but, in a more profound sense, you are as changed as the river and only the continuity of thought gives the illusion of constancy.

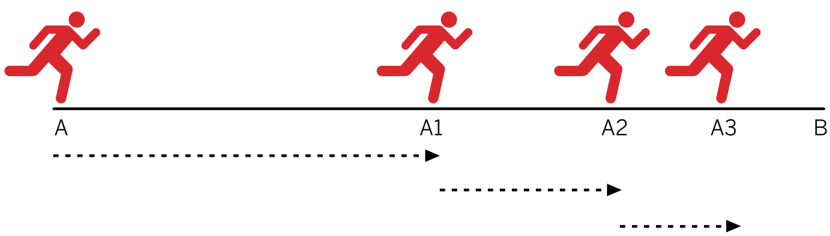
For Parmenides, change was an illusion. He argued that change was impossible since it would require something to arise from nothing or for being to become non-being. Since it was logically impossible for nothing to contain something

1. Like π, √2 is part of a collection of numbers that were later called "irrational," because they do not form proper ratios.

(otherwise it would not have been nothing in the first place), there could be no mechanism to change the state of the world.

Parmenides' best-known pupil, Zeno (fl. 450 BCE), presented a famous proof against the possibility of motion. His proof, called Zeno's paradox, comes in a number of forms but essentially argues that to reach a point, you must first cover half the distance to the point. To get to that halfway point, you would first need to cover half the distance (i.e., one-quarter of the full distance), and therefore one-eighth, one-sixteenth, and so on. Since there are an infinite number of halfway points between any two end points, it would take infinite time to cover the whole distance, making it impossible to move. (See figure 1.5.)

Our modern perception seems to favour Heraclitus over Parmenides, but they share a common concern. Each philosopher was attempting to establish a method for understanding the events in the world based on the intrinsic or natural action of the world. They were also attempting, as the Ionians and the Pythagoreans did, to establish a method for determining what certain knowledge was. Statements about the condition of the world had to be supported by a proof that could be examined by others and did not rely on special knowledge. They were asking epistemological questions, that is, questions about how someone could come to know something and just what that "something" could be. The Greek natural philosophers did not frame their questions as inquiries into the behaviour of gods or supernatural agents but rather asked such questions as: What in the world around us is fundamental and what is secondary? What system (outside revelation) can a thinker use to determine what is true and what is false? To what degree should the senses be trusted?




**1.5** ZENO'S PARADOX

As the runner covers half the distance from "A" to "B," he must first cover the distance from "A1" to "B," then half the distance from "A2" to "B," and so on. Since there are an infinite number of halfway points, and it takes a finite amount of time to move from point to point (even though the time to cover the distance is very small), it will thus take an infinite amount of time to get from "A" to "B."

For Parmenides, the senses were completely untrustworthy and only logic could produce true or certain knowledge. Heraclitus at first seemed to have more faith in the senses, but in fact he reached a very similar conclusion. Any appearance of stasis, even something as simple as one rock resting on another, is an illusion, and only logic can be relied upon to make clear what is actually happening in nature.

## Socrates, Plato, Aristotle, and the Epicureans: The Ideal and the Real

The philosophical threads of Thales, Pythagoras, Heraclitus, Parmenides, and many others came together in the work of the most powerful group of Greek thinkers, who were at the intellectual hub of Athens in the fifth century BCE. Socrates (470–399 BCE) established a context for natural philosophy by completely rejecting the study of nature as being largely unworthy of the philosopher's thought and by creating the image of selfless dedication to the truth that helped form the image of the "true" intellectual to this very day. Socrates' rejection of the study of nature mirrored the increasing disdain the intellectual elite felt for the merchant and craft class and their material concerns. Philosophy was supposed to be above the petty concerns of the day-to-day world, and philosophers were not, both literally and figuratively, to get their hands dirty.

For Socrates, the real world was the realm of the Ideal. Since nothing in the material world could be perfect, it followed that the material world must be secondary to the ideal. For example, while one could identify a beautiful person, the concept of beauty must have been present prior to the observation or we would be unable to recognize the person as beautiful. Further, while any particular beautiful material thing must necessarily fade and decay, the concept of beauty continues. It thus transcends the material world and is eternal.

This idealism also applied to the comprehension of the structure of the material world. Any actual tree was recognizable as a tree only because it reflected (imperfectly) the essence of "tree-ness," or the form of the ideal tree. These ideal forms were available to the human intellect because humans had a soul that connected them to the perfect realm. Socrates believed that, because of this, we actually had within ourselves the knowledge to understand how things worked. With skillful questions, this innate knowledge could be revealed, and from this process we get the Socratic method, a form of teaching based not on the instructor giving information to the student but asking a series of questions that guides the student's thoughts to the correct understanding of a topic.

Socrates' philosophy led him to question everything, including the government of Athens. He was convicted of corrupting the city's youth, but rather than asking for exile, he chose death. He drank a potion of the poison hemlock, with the firm belief that he was leaving the imperfect, corrupt material world for the perfection of the Ideal realm.

Socrates left no written material, so what we know of his teachings largely comes to us from his most famous pupil, Plato (427–347 BCE). The son of an aristocratic Athenian family, Plato wrote a series of dialogues based on Socrates' ideas and likely drawn from actual discussions. Although Plato's later work shifted away from its Socratic roots, he preserved the general premise of Ideal forms. One of Plato's other teachers was Theodorus of Cyrene, a Pythagorean, who taught him the importance of mathematical idealism. Although Plato accepted the primacy of the Ideal, he did not go as far as Socrates in his rejection of the material world.

Plato's primary interests were ethical and political. In his most famous work, *The Republic*, he explored what he considered ideal society and the problems of social organization. He did introduce natural philosophy, but it was in a lower realm of consideration and used mostly as a tool for consideration of the underlying structure of the cosmos. In the allegory of the cave, found in Book VII of *The Republic*, Plato argued that people are like prisoners in a dark cave who, from childhood, see only a strange kind of shadow play. Because the prisoners have no other reference, the shadows are taken to be reality. To see reality, the prisoners must free themselves and look upon the real world under the light of the sun. In this story, Plato argued that what we perceive through our senses is an illusion, but logic and philosophy can reveal the truth. The material world was explored in more detail in his *Timaeus*, where he presented a system of the four terrestrial elements of earth, water, air, and fire. The supralunar or celestial realm was made of a perfect substance, the ether, and was governed by a different set of physical rules. This system gained general acceptance among Greek philosophers and became one of the axioms of natural philosophy.

Plato, unlike his teacher Socrates, was not content to espouse his philosophy in the *agora*. The solution to the problems of society was education, which meant training students in a philosophy based on logic and a pursuit of knowledge of the Ideal. To this end, Plato founded a school in 385 BCE. Constructed on land once owed by the Athenian hero Academos, it became known as the Academy. It did

## CONNECTIONS

### Natural Philosophy and Patronage: Aristotle and Alexander the Great

The relationship between patron and client has been an important part of the development of natural philosophy and science from the time of the Ancient Greeks. Aristotle was heavily influenced by the materials he received from Alexander the Great, and his fame spread even farther because of the king's patronage.

In 343 BCE, King Philip II of Macedon asked Aristotle to join his court as the tutor to his son Alexander. Aristotle's father had been Philip's personal physician, so there was already a connection between Aristotle and Philip's family. The call to go to Macedon came at a time when Aristotle was pursuing biological and philosophical research on his own because he had quit his teaching position at the Academy, the school established by Plato in Athens.

Aristotle remained at court for seven years, teaching the sons of Macedonian nobles. Aristotle found Alexander a good, if somewhat mercurial, student who wanted to be the best at whatever he did. When Philip was assassinated in 336 BCE, Alexander became the king and went on to conquer Greece and then most of the known world, including Asia Minor, Egypt, and Persia. He remained close friends with Aristotle, corresponding with his teacher throughout his life. He also sent Aristotle hundreds of samples of plants and animals, and over 10,000 scrolls from distant lands.

In 334 BCE Aristotle returned to Athens and established a new school called the Lyceum. Under the patronage of Alexander, the school thrived and Aristotle wrote a number of his most important works in this period, including *Physics*, *Parts of Animals*, and *De Anima*. The vast library created from Alexander's gifts helped Aristotle with his philosophical work, while the plant and animal samples helped him with his biological research. Aristotle described fish, for example, that were not noted again in Europe for hundreds of years, and developed a robust classification system because of this wide experience.

Alexander was a philosopher-king: literate, well-educated, and curious about more than just the necessities of warfare and politics. His relationship with Aristotle became a model of patronage that many later natural philosophers from Alcuin to Descartes hoped to find for themselves.

not have the formal structure of modern schools, but in many ways it was the foundation for the concept of higher education. Students who had already been tutored in the basic principles of subjects such as rhetoric and geometry travelled to the Academy to engage in discussion and debate under the auspices of a more senior philosopher in a kind of seminar atmosphere.

Plato's most famous student was Aristotle (384–322 BCE). A brilliant thinker, Aristotle had expected to become the head of the Academy when Plato died, but this position was denied him, going instead to Plato's cousin Speusippas, of whom little is known. Disappointed at having been passed over, Aristotle left Athens and travelled north. In 343 BCE he became the tutor to Alexander, son of Philip II, King of Macedon. When Philip died, Alexander became the leader of the Macedonians and proceeded to unify (that is, conquer) all of Greece. Once that was accomplished, he set out to conquer the rest of the world. With the patronage of Alexander the Great, Aristotle returned to Athens and founded a rival school, the Lyceum, in 334 BCE. It was sometimes called the peripatetic school because the instructors and scholars did their work while walking around the neighbourhood.

Aristotle did not reject all of Plato's philosophy, sharing a belief in the necessity of logic and some aspects of Platonic Idealism. He was, however, far more interested in the material world. Although he agreed with Plato that the world was impure and our senses fallible, he argued that they were actually all we had. Our intellect could be applied only to what we observed of the world around us. With this as a basis, Aristotle set out to create a complete system of natural philosophy. It was a powerful and extremely successful project.

At the heart of Aristotle's system were two fundamental ideas. The first was a system to provide a complete description of natural objects. The second was a system to verify knowledge that would satisfy the demands of proof necessary to convince people who lived in a competitive, even litigious, society. The combination of these two components produced the apex of Greek natural philosophy. No aspect of Aristotle's philosophy depended on supernatural intervention, and only one entity, the unmoved mover, existed outside the system of intrinsic or natural action.

The first step in the description of natural objects was identification and classification. Aristotle was a supreme classifier. Much of his work was on biology, and among other things he grouped what we call reptiles, amphibians, and mammals by their characteristics, even grouping dolphins with humans. He also observed the development of chicks in hen eggs and tried to make sense of sexual reproduction.

As astute as many of his observations were, Aristotle saw them as an examination of a level of superficial distinction; it was the job of the philosopher to look beyond these secondary characteristics and seek the underlying structure of nature. To do this, it was necessary to determine what aspects of nature could not be reduced to simpler components. The simplest material components were the four elements, and all material objects in the terrestrial realm were composed of these four substances. The superficial distinction between objects was the result of the different proportions and quantities of the elements that made up the objects in the world.

The elements by themselves were not sufficient to account for the organization and behaviour of matter. Matter also seemed to have four irreducible qualities, which Aristotle identified as hot/cool and wet/dry. These were always present as pairs (hot/wet, cool/wet, hot/dry, cool/dry) in all matter, but were separate from the material. A loose analogy would be to compare the bounce of a basketball and a bowling ball. The degree of bounce of a basketball and a bowling ball are very different and depend on the material that each is made of, but the "bounciness" of the two balls can be studied separately from the study of the materials that compose the two types of ball.

While the four elements and the four qualities could describe the matter and quality of composed things, they did not explain how a thing came to be. For this, Aristotle identified four causes: formal, material, efficient, and final. The formal cause of a thing was the plan or model, while the material cause was the "stuff" used to create the object. The efficient cause was the agent that caused the object to come into being, and the final cause was the purpose or necessary condition that led to the object's creation.

Consider a stone wall around a garden. The formal cause of the wall is its plans and drawings. Without a plan detailing dimensions, it is impossible to know how much stone will be required to build it. The material cause of the wall is the stones and mortar. These materials impose certain restrictions on the finished wall; it might be possible to draw a plan for a 30-metre high wall with a base only 20 centimetres wide, but such a wall cannot be constructed in reality. The efficient cause is the stonemason; again, certain restrictions will be imposed on the wall by the limits of the mason's abilities. The final cause is the reason to build the wall—to keep the neighbour's goat out of our garden, for example.

Although Aristotle and Plato's conception of the four elements could be reduced to a kind of particle model with a geometric structure (fire, for example, was composed of triangles), in general they treated the elements as a continuous substance. This view was challenged by the Epicureans, who proposed an even more materialistic model of nature. The philosopher Epicurus (342–271 BCE), like Plato, was from an aristocratic Athenian family. He founded a philosophical school known as the Garden and revived the work of an earlier philosopher, Democritus (c. 460–c. 370 BCE). Democritus had argued for a materialistic understanding of the universe, and the Epicureans pictured the world as constructed of an innumerable (but not infinite) number of atoms that were indestructible. The appearance and behaviour of matter were based on the varying size, shape, and position of the particles.

Epicurean natural philosophy was the most mechanistic Greek philosophy. In addition to challenging the material foundation of nature, the Epicureans also challenged the path to knowledge of nature, arguing that knowledge could only come from the senses. Because knowledge of nature did not require the intellectual refinement of logic or mathematics, it was knowledge open to all, not just learned men. This belief in knowledge from the senses contributed to the reputation of the Epicureans as sensualists, which did not help the philosophy when it was attacked as atheistic and decadent by Jewish, Islamic, and Christian scholars in later years. Although there was suspicion of all Greek philosophy by later theological thinkers, Aristotle's system was more easily revised than the Epicurean because it ultimately depended on axioms that could be ascribed to God. Thus, Epicurean thought was largely condemned or ignored until the seventeenth century when it gained a titular place as the foundation of modern studies of matter because of its proto-atomic model. Thus, it is seen as the ancient precursor to modern chemistry.

## *Aristotelian Theories of Change and Motion*

The three fundamental aspects of matter (elements, qualities, and causes) in the Aristotelian system cannot assemble themselves into the universe; to bring everything together there must be change and motion. There are two kinds of motion. The first, natural motion, is an inherent property of matter. In the terrestrial realm all elements have a natural sphere, and they attempt to return to their natural place by moving in a straight line. However, because many objects in the world are mixtures of the four elements, natural motion is restrained in various ways. A tree, for example, contains all four elements in some proportion, but it grows a certain way with the roots going down because the earth element wants to go down while the crown grows up as its air and fire elements try to go up.

Plato and Aristotle accepted the Pythagorean idea that the matter in the celestial realm was perfect and that its inherent natural motion was also perfect, travelling in a uniform and immutable circle, which was the perfect geometric figure. Aristotelian astronomy thus required the objects in space to move according to this dictum. While this was a reasonable assumption for most of the objects that could be observed, such as the sun, moon, and stars, it created problems for later astronomers. (See figure 1.6.)


1.6 THE ARISTOTELIAN COSMOS

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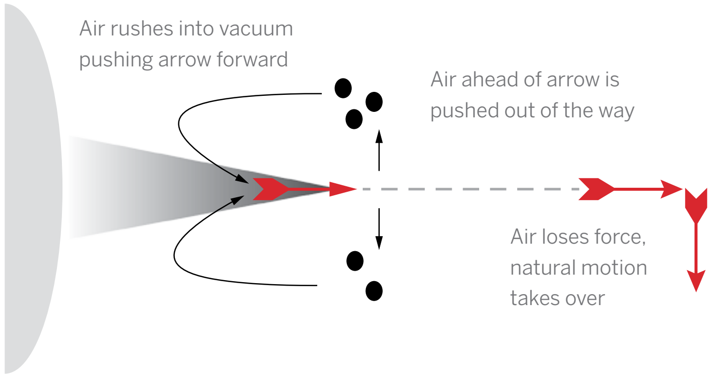
Other forms of motion, particularly locomotion, required motion to be introduced to the universe. For this, Aristotle traced a chain of motion back from observation to origin. Anything moving had a mover, but that mover had to have something moving it, and so on. Take as an example an archer shooting an arrow. We see an arrow fly through the air, and we can observe that it was the bow moving that moved the arrow. The archer makes the bow move by the motion of muscles, and the muscles are made to move by the will of the archer. The mind thinks (which is a kind of motion as well) because of a soul, and the body exists because it was the product of the athlete's parents. Birth and growth are also forms of motion. The archer's parents were created by the grandparents, and so on. To prevent this from becoming a completely infinite regress, there has to be some point at which a thing was moved without being moved itself by some prior thing. This is the unmoved mover. In a sense, the unmoved mover kick-started motion in the universe by starting the great chain of action by a single act of will.

Let us return to the arrow as it flies along. As long as the bow is in contact with it, we can see that it is the bow and the muscles that are making it move, but what keeps it moving after it has left the bowstring? The aspect of its motion toward the ground is covered by its natural place as the heavy earth element of the arrow attempts to return to its proper sphere. The continuation of motion,




1.7 THE ARROW'S MOTION ACCORDING TO ARISTOTLE

The arrow interacts with the air as it moves to continue its "unnatural" motion. This system may seem awkward, but it was likely based on observation of motion through water. An oar pulled through water seems to compress the water (it clearly mounds up) on the front surface, while eddies and voids seem to form around the back surface of the oar. The water in front then rushes around the oar to fill in the space at the back.

Aristotle reasoned, had to have something to do with motion being added to the object as it moves. He concluded that the arrow was being bumped along by its very passage through the air. The arrow was pushing the air out of its natural place, in effect compressing it at the front and creating a rarefied or empty area at the back. The air rushed around the arrow to restore the natural balance and, in doing so, bumped the arrow ahead. Since the air resisted being moved from its natural place, it would eventually stop the forward flight of the arrow. (See figure 1.7.)

It also followed from Aristotle's system that the amount of element in an object governed its rate of motion. An arrow, constructed of wood and thus not containing a large amount of earth element, would stay in motion over the ground longer than a rock composed almost completely of earth element. This led Aristotelians to argue that if a small rock and a large rock weighing ten times as much were dropped together, the large rock would fall ten times faster than the small rock.

## *Aristotelian Logic*

While understanding the structure of matter and motion was important, such knowledge was not by itself sufficient to understand the world. This was, in part, because the senses could be fooled and were not entirely accurate, but it was also because observation was confined to the exterior world and could not by itself reveal the underlying rules or structure that governed nature. That could be discovered only by the application of the intellect, and that meant logic. While Aristotle returned to the subject of logic repeatedly, his logic was most clearly presented in his two works on the subject, the *Posterior Analytics* and the *Prior Analytics*. At the heart of his logical system was the syllogism, which offered a method to prove a relationship and thereby produce reliable or certain knowledge. We continue to use syllogistic logic today as a method of verifying the reliability of statements. One of the most famous syllogisms says:

| | |
|---|---|
| 1. All men are mortal. | *Major premise, derived from axioms or previously established true statements.* |
| 2. Socrates is a man. | *Minor premise. This is the condition being investigated.* |
| 3. Therefore, Socrates is mortal. | *Conclusion, which is deduced from the premises.* |

The syllogism was a powerful tool to determine logical continuity, but it could not by itself reveal whether a statement is true, since false but logical syllogisms can be constructed.

1. All dogs have three legs.
2. Lassie has four legs.
3. Therefore, Lassie is not a dog.

The second syllogism is as consistent as the first, but because the major premise is false, the conclusion is false. The axiom "dogs have three legs" does not stand the test of observation or definition, and so the syllogism fails. Thus, it is not surprising that Greek philosophers expended a great deal of effort on the discovery and establishment of axioms. Axioms were irreducible, self-evident truths. They represented conditions that must exist if the world was to function, but recognizing them was difficult. Aristotle concluded that axioms could be recognized only by the agreement of all learned men, which echoed Greek political discourse. An example of an axiom is the operation of addition, which must be accepted as a necessary mathematical operation or all of arithmetic collapses. The property of addition cannot be broken down into simpler operations; multiplication, on the other hand, can be broken down into repeated addition and is thus not axiomatic.

The problem of what was axiomatic and how to be sure of axiomatic statements was at the centre of debates over natural philosophy and science, in part because the axioms of previous generations often became the target of investigation and reduction for new thinkers. The philosophical and practical attacks on axioms at times made some scholars unsure whether any knowledge was reliable, while it set others, such as René Descartes (1596–1650), on a search for a new foundation of certainty.

The power of Aristotle's system was its breadth and completeness. It integrated the ideas that had been developed and philosophically tested, in some cases for several hundred years, with his own observations and work on logic. It presented a system for understanding the world that was almost completely intrinsically derived. With the exception of the unmoved mover, no part of his system required supernatural intervention to function, and further, it was based on the belief that all of nature could be understood. The comprehensibility of nature became one of the characteristics of natural philosophy that separated it from other studies such as theology or metaphysics.

Aristotle's system was a masterful use of observation and logic, but it did not include experimentation. Aristotle understood the concept of testing things, but he rejected or viewed with distrust knowledge gained by testing nature, because such tests only showed how the thing being tested acted in the test rather than in nature. Since testing was an unnatural condition, it was not part of the method of natural philosophy, which was to understand things in their natural state. It is tempting to find fault with Aristotle because of his rejection of experimentation, but this would be to argue that Aristotle's objectives must have been the same as those of modern science. The object of study for Aristotle and modern science was nature and how nature functions, but the forms of the questions asked about nature were very different. One of the central questions for Aristotle and other natural philosophers was teleological, asking "To what end does nature work?" They assumed that only through observation and logic could this question be answered.

## Euclid and the Alexandrians

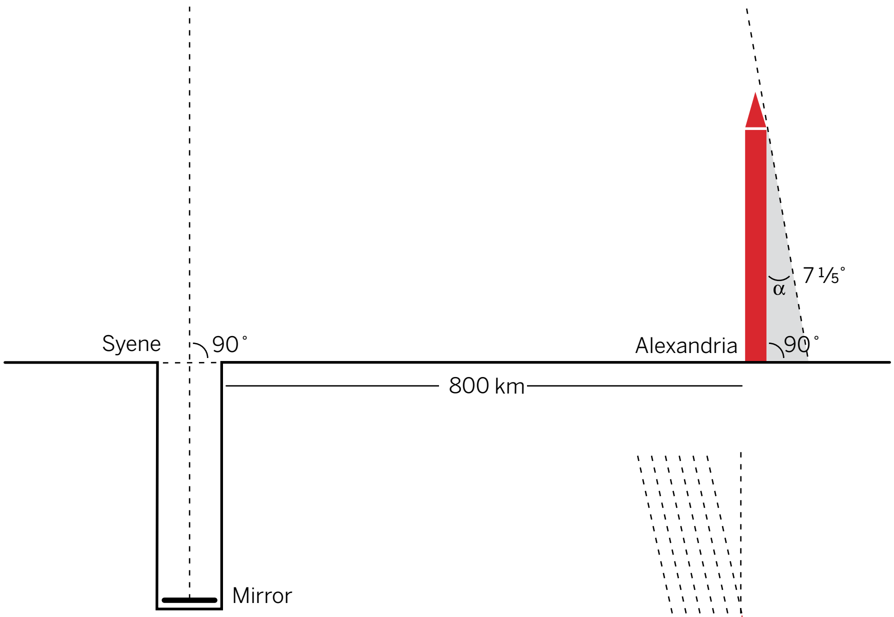
After the death of Aristotle, both the Academy and the Lyceum continued to be major centres for philosophical education, but the heart of Greek scholarship began to shift to Alexandria. This movement was spurred after 307 BCE when the ruler of Egypt, Ptolemy I (who had been one of Alexander's generals) invited Demetrius Phaleron, the deposed dictator of Athens, to move to his capital at Alexandria. Alexandria was an ideal location as a trade hub that linked Africa, Europe, the Middle East, and Asia. Demetrius was credited with advising Ptolemy to establish a collection of texts and establish a temple to the Muses, who were the patrons of the arts and sciences. Although its exact founding and early history are unclear, the temple to the Muses became the Museum, from which our modern use of the term descends. Part of the Museum was the library, which became increasingly important and eventually overshadowed the Museum in historical recollection. The Great Library of Alexandria eventually housed the greatest collection of Greek texts and was the chief repository and education centre for Aristotelian studies after the decline of Athens.

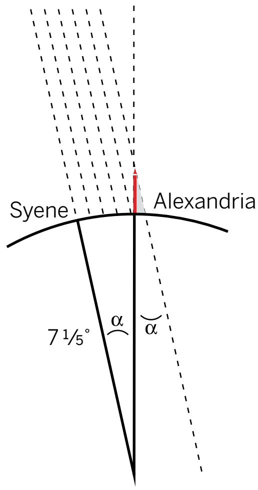
One of the great figures to be associated with the Museum was Euclid (c. 325–c. 265 BCE).[2] His most enduring work was the *Elements*, a monumental compilation of mathematical knowledge that filled 13 volumes. While the majority of the material in the *Elements* was a recapitulation of earlier works by other scholars, two factors raised it above a kind of mathematical encyclopedia. The first was the systematic presentation of proofs, so that each statement was based on a logical demonstration of what came before. This not only gave the mathematical proofs reliability but also influenced the method of presenting mathematical and philosophical ideas to the present day. These proofs were based on a set of axioms such as the statement that parallel lines cannot intersect or that the four angles created by the intersection of two lines are two pairs of equal angles and always equal 360° in total.

The second factor was the scope of the work. By bringing together the foundation of all mathematics known to the Greeks, the *Elements* was a valuable resource for scholars and became an important educational text. It covered geometric definitions and construction of two- and three-dimensional geometric figures, arithmetic operations, proportions, number theory including irrational numbers, and solid geometry including conic sections. In a time when all manuscripts had to be copied by hand, the *Elements* became one of the most widely distributed and widely known texts.

Greek natural philosophy was most notable for its philosophical systems, but those systems should not be seen as being removed from the real world or as some kind of irrelevant intellectual pastime. One of the purposes of Aristotelian natural philosophy was to make the world known, and a known world was a classified and measured world. Eratosthenes of Cyrene (c. 273–c. 192 BCE) set out to measure the world. Eratosthenes was a famous polymath who worked in many fields, especially

2. Like Pythagoras, there is some dispute as to whether Euclid was a real person or a name applied to a collective of scholars. From later commentators and internal evidence, Euclid may have been educated in Athens, perhaps at Plato's Academy, and then moved to Alexandria.




**1.8** ERATOSTHENES' MEASUREMENT OF THE EARTH
When the sun appears in the mirror at the bottom of the well at Syene, its light forms a 90° angle with the Earth. At the same moment, a shadow cast by the tower at Alexandria has an angle of $7\frac{1}{5}°$. This can then be mapped onto the Earth using simple geometric relationships.

$7\frac{1}{5}° = \frac{1}{50}$ of the circumference
50 × 800 = 40,000 kilometres
(Based on modern measurements)

mathematics, and who became the chief librarian of the Museum in Alexandria about 240 BCE. He applied his concepts of mathematics to geography and came up with a method to measure the circumference of the Earth. That the Earth was a sphere was long understood by the Greeks and was taken as axiomatic in Aristotle's philosophy, but an accurate measurement was a challenge. Eratosthenes reasoned that by measuring the difference in the angle of a shadow cast at two different latitudes at the same moment, he could calculate the circumference. By knowing the angle formed by the two lines radiating from the centre of the Earth to the measuring points and the distance between the two points at the surface, he was able to determine the proportion of the globe that distance represented.

(See figure 1.8.) From this, it was a simple matter to work out the circumference of the whole globe. His answer was 250,000 *stadia*. There has long been an argument about just how accurate this measurement was, since it is not clear what length of stadia Eratosthenes was using, but it works out to about 46,250 kilometres, which is close to the current measurement of 40,075 kilometres at the equator.

## Archimedes, the Image of the Philosopher

The intellectual heritage of the Greeks, particularly that of Aristotle and Plato, was profound, but it was not solely their thought that they contributed. The Greeks also helped to create the image of the philosopher, an image that persists in various forms to the present day. Long before students have learned enough to comprehend the complex ideas of the philosophers, they have been exposed to the image. Even more famous than Socrates accepting death, the story of Archimedes (c. 287–212 BCE) has shaped the cultural view of philosophers.

Archimedes lived most of his life in Syracuse. He may have travelled to Alexandria and studied with Euclidean teachers at the Museum; it is clear that later in his career he knew and corresponded with mathematicians there. Among his accomplishments Archimedes determined a number for *pi*—relating the circumference, diameter, and area of a circle—and then extended this work to spheres. He established the study of hydrostatics, investigating the displacement of fluids, asking why things float, and the relationship between displaced fluids and weight. This has come down to us as Archimedes' principle that a body immersed in a fluid is buoyed up by a force equal to the weight of the fluid displaced by the body. Archimedes also determined the laws of levers through geometric proof.

As powerful as Archimedes' mathematics and philosophical work might have been, it was the legends that grew up around him that made him a memorable figure. His work was not confined to intellectual research, since he also created mechanical devices. Chief among these were the war machines he built to help defend Syracuse from the Romans during the Second Punic War. These included various ballistic weapons and machines to repel ships from docking. Although Archimedes did not invent Archimedes' screw (which consists of a rotating spiral tube used to lift water), his name was attached to it as the kind of thing he would have invented.

The famous story about Archimedes inventing burning mirrors or using polished shields to set fire to Roman ships using the reflected light of the sun was a myth created long after his death. Although theoretically possible, most modern recreations of the burning mirrors have shown that it would have been at best impractical, requiring the Roman ships to remain still for a significant period, and having no Roman notice the fire until it was large enough to have done significant damage.

Archimedes in the bath is the best-known tale from the philosopher's life. Hiero, the king of Syracuse, was concerned that the gold he had given craftsmen to make a crown had been adulterated with less valuable metal, but once the crown was made, how could the fraud be detected? Archimedes was supposed to have solved the problem while in the public baths when he realized that it was a hydrostatic problem. The gold would displace less water than a similar weight of silver because the gold was denser. He leapt from the bath and ran naked through the city, exclaiming "Eureka!" meaning "I have found it." No historical record exists that this happened, and it would have been difficult to use the displacement method with the tools available to Archimedes, but he could easily have solved this problem using a hydrostatic balance, a device that he wrote about and used.

Archimedes' death also became the stuff of legend. Plutarch (45–120 CE) tells the story in *Plutarch's Lives*:

> Archimedes, who was then, as fate would have it, intent upon working out some problem by a diagram, and having fixed in his mind alike and his eyes upon the subject of his speculation, he never noticed the incursion of the Romans, nor that the city had been taken. In this transport of study and contemplation, a soldier, unexpectedly coming up to him, commanded him to follow to Marchellus; which he declining to do before he had worked out his problem to a demonstration, the soldier, enraged, drew his sword and ran him through.[3]

Whether the legends are based on actual events is less important than the image of the ideal scholar they have come to represent. While the historical image of Archimedes has ranged from absent-minded philosopher to man of action to the "Divine Archimedes" as Galileo called him, the image of the true philosopher is that of a person above mundane concerns or personal self-interest. He is selfless, absorbed in study to the exclusion of all else, and perhaps a touch socially unaware. While Archimedes made mechanical devices and thus has also been associated with engineers, he was far more interested in philosophy than such contrivances. He

3. Plutarch, *Plutarch's Lives*, trans. John Dryden (New York: Random House, 1932) 380.

became the exemplar of a good scientist who can turn his hand to both theoretical and practical projects. While Aristotle and Plato can be revered as great intellects, they seem a bit distant and dry, always theorists looking at the big picture, while Archimedes is a much more comfortable role model for the modern experimentalist.

## Conclusion

By the time the Greek world came under the control of Rome, a powerful group of Greek thinkers had completed the creation of the study of nature as a discipline and removed all but the most tangential connection to supernatural beings or forces. They made the universe measurable, and thus it could be known. They set the framework for intellectual inquiry that would be used in the Mediterranean world for over 1,000 years, and a number of ideas from Aristotle and Plato still provoke debate to this day. Under Roman control, Alexandria became even more important as a centre of learning, and the basis of Aristotelian philosophy was exported to the far-flung reaches of the Empire, from Roman Britain to the Fertile Crescent in the Middle East. Along with the philosophy went a new image of the sage, the scholar, the intellectual, whose job was not to interpret the mysteries of a world full of spirits but to read and reveal the text of the book of nature.

### Essay Questions

1. Why did natural philosophy develop in the Greek world rather than in Egypt or the Fertile Crescent?

2. What were the principle concerns of Greek natural philosophers?

3. Comparing Plato's and Aristotle's systems, what were similar concerns and how did they differ?

4. What was Aristotelian logic and why was it so important for natural philosophy?

## CHAPTER TIMELINE

| | |
|---|---|
| **753 BCE** | Traditional date for founding of Rome |
| **146 BCE** | Greece comes under Roman control |
| **C. 50 BCE** | Lucretius writes *De rerum natura* |
| **31 BCE** | Egypt comes under Roman control |
| **C. 7 BCE** | Strabo writes *De situ orbis* |
| **79 CE** | Pliny the Elder writes *Natural History* |
| **C. 148** | Ptolemy writes *Almagest* and *Geographia* |
| **162** | Galen moves to Rome |
| **250** | Mayan Empire flourishes (250–950) |
| **286** | Roman Empire divided into east and west |
| **392** | Christianization of Roman Empire |
| **476** | End of Roman rule in western empire |
| **529** | Lyceum and Academy closed by Emperor Justinian |
| **622** | Muhammad travels to Yathrib (Medina). The *Hegira* marks beginning of Islam |
| **762** | Baghdad established |
| **C. 815** | *Bait al-hikmah* (House of Wisdom) created |
| **C. 820** | al-Kindi translates *Geographia* |
| **C. 890** | al-Razi writes *Secret of Secrets* alchemical text |
| **C. 900** | Founding of Balkhi school of geographic thought |
| **950** | |
| **C. 1000** | Almost all surviving Greek medical and natural philosophical texts translated into Arabic |
| **C. 1037** | Ibn Sina dies |
| **1426** | Aztec Empire flourishes (1426–1520) |
| **1520** | |

# THE ROMAN ERA AND THE RISE OF ISLAM

2

While the Greek philosophers were struggling with the structure of the cosmos, across the Adriatic Sea a small group of people living on the east bank of the Tiber River were in the process of creating a powerful military state. Traditional legends claim Romulus and Remus founded Rome in 753 BCE, but the origins of the city were probably Etruscan. Around 500 BCE Etruscan rule ended and Roman rule began. Rome expanded its area of control through the fourth and third centuries BCE, conquering or absorbing its neighbours. When Rome fought the Punic Wars against Carthage between 264 and 146 BCE, it established its military prowess and began its rise to empire.

As Rome expanded, it came into contact with Greek culture both through Greek colonies on the Italian peninsula and later by conquest of Greece itself. Roman dominance of Greece was completed by 146 BCE, and with the occupation the intellectual heritage of Greece came largely under the control of the Roman Empire. Greek scholarship was not destroyed by Rome, and in fact the Roman elite adopted Greek education and studied Greek philosophy, holding many Greek philosophers in high regard. This regard was not generally for the sake of philosophy but for a more practical purpose. Mastering Greek philosophy was seen as a good method to discipline the mind just as the legionnaires disciplined the body; both prepared the elite of Rome for their role as masters of the world. The Romans were at heart a people interested in practical knowledge. Their engineers created buildings, roads, aqueducts, and many other magnificent structures that have


2.1 THE ROMAN EMPIRE

survived into the modern world. As impressive as the end products of Roman industry were, even more important was the power of the organizational system that could conceive, manage, and expand the enormous empire. In the Roman Empire nature was to be bent to useful ends.

The study of nature for the Romans was, therefore, oriented more toward practicality than philosophical speculation. Roman intellectuals were more concerned that a thing worked than about demonstrating the truth of the knowledge of that thing. Thus, they were more concerned with machines, studies of plants and animals, medicine, and astronomy than epistemology or philosophy. The Roman Empire was not based, as the Greek city-states had been, on public discourse and democracy but on public demonstrations of power. Making nature do your bidding was more essential than right reasoning. The Romans took the Greek heritage, in natural philosophy as in much else, and transformed it to aid their own objectives.

For the Roman elite, learning Greek philosophy might not be an end in itself but a way of training the mind. Intellectual acuity, even if the ends were material, still required a sound foundation. This heritage led a number of Roman intellectuals to preserve and propound Greek thought. For example, around 75 BCE the