# 1 Aristotle

The Bronze Age (2000 BC–1000 BC) was a period of major advances and changes in the riverine cultures of Mesopotamia, Egypt, India and China. Exceptional developments in irrigation and agriculture had led to the establishment of large urban civilisations in which arts and sciences were encouraged and patronised. Efficient tax collection and revenue management had freed funds to support a class of people who could devote their time to study, observation and contemplation. The alphabet and numbers were formalised and the practice of keeping records, both civil and military, was well established. Concepts of space and measurement and concerns with heavenly bodies and physical structures led to the development of arithmetic and geometry.

The development of predictive and exact sciences followed from the study of motions of the Sun, Moon and the five visible planets. The periodicity of the motion of these bodies was utilised to establish a quantitative measure of time, and the correlation between the rising and setting of groups of stars and seasons was developed into a calendar, which we use today (in slightly modified form). The systematic study of the motion of the Sun and Moon by the Mesopotamian priest-astronomers enabled them to identify the cause of eclipses and also to predict future eclipses. The discipline of record keeping had been extended to note the occurrences of unusual astronomical events and irregularities in the movements of planets. The belief-systems developed by these cultures defined man's position in the cosmos and his relationship with nature. The ethical system they established led to the development of the concepts of 'cause' and 'effect'. These concepts were later extended to philosophical and scientific speculations and form the basis of modern scientific thought. However, by 600 BC these cultures were undergoing a crisis; the spiritual legacy of the Bronze Age was being questioned. A number of great thinkers of the world were alive at this time: Buddha in India, Pythagoras and the early Greek philosophers, the Old Testament prophets in Israel and Confucius and Lao Tzu in China. Fundamental questions were being asked about the nature and purpose of life. It was also a time of great speculation about the natural world and there seems to have been a recognition of the existence of 'natural laws' in the universe. This was a period of change and it has been called the Axis Age.

## GREEK SCIENCE

In Europe the stirrings of scientific inquiry started among the Ionian Greeks of Asia Minor. In the Western cultures today it is generally believed that Greeks and Greeks alone 'invented' science. This Euro-centric (or Greco-centric) sentiment indicates a fundamental lack of understanding of the nature of scientific inquiry. Scientific inquiry is a process and by its very nature it is progressive. New ideas and discoveries are built on foundations and structures erected by others at earlier times. The Ionians and Greeks generally were in close contact with older cultures further to the East and South, and also in Asia. It is certain that Greek science in its origin was dependent on knowledge and traditions that came from ancient civilisations of Egypt and Mesopotamia. On this the Greeks and in particular the Greek historian Herodotos have insisted, and modern discoveries confirm it. We will never know the full extent of 'borrowing' by the Greeks from other cultures. But to the Greeks we owe the formal and conscious development of science as a discipline and the synthesis of observations or empirical relations to expose fundamental unifying principles.

The Golden Age of Greek science was during the fifth and fourth centuries BC. This was the period of the famous teacher–pupil sequence Socrates, Plato and Aristotle. They laid the foundation of natural philosophy which was to dominate the Islamic and Christian cultures for centuries to come. They believed in the existence of absolute or universal truths, which could be discovered or deduced by a system of logic. The founder of this 'system of thought' was Socrates (470–399 BC), whose overwhelming preoccupation was with 'conduct'. He firmly believed that everything was created and carefully controlled by a Supreme Being. He also stressed the importance of the soul and its persistence after death. The body was regarded as a temporary habitat for the soul (there are strong similarities here with the Indian/Buddhist view of the body and soul). Socrates left no written record but according his pupil, Plato, he was well versed in geometry and astronomy. He believed that astronomy was useful for determining the day of the year or the month, but all speculations about the motion or orbits of planets were regarded as a complete waste of time. In 399 BC Socrates was accused of 'impiety' and was put to death by drinking hemlock. The triumph of the Socratic doctrine held back for a while the development of Greek science and physical philosophy but it also led to the emergence of two giants of science in the fourth-century BC, Plato and Aristotle.

Plato (427–367 BC) was a student of Socrates and like him he was concerned with ethical motives. He believed that true morality was as immutable and objective as geometry, and discernible by use of reason. His school, the Academy, persisted for many centuries and was chiefly preoccupied with metaphysical discussions. Plato drew a distinction between reality and appearance and between knowledge and opinion. To him the everyday world of senses was worthless because it was a product of opinion. True knowledge was in the mind and consisted of pure ideal form. By implication the human body itself was a shadow; only the soul was real. This became the central tenet of the Neoplatonist Christians in the Middle Ages. But Plato was also an accomplished mathematician ('Let none who has not learnt geometry enter here' was inscribed over the entrance to the Academy) and had Pythagorean teachers. Many of Plato's thoughts have a mathematical guise. Plato appealed to other sciences to exhibit the certitude and exactness demonstrated by mathematics. He also had high regard for astronomy because in his opinion the heavenly bodies, in their motion, demonstrate the perfect geometric forms favoured by Pythagoreans. However, Plato wanted to explain the universe, not simply describe it, and his emphasis was on the theoretical aspects of astronomy rather than observations. Plato regarded the irregularities of planetary motion to be inconsistent with his view of the perfect universe. These irregularities had, in his opinion, to be explained in terms of simple circular motions. Plato accordingly set his students to seek out the rules by which the motion of planets could be reduced to simple circles and spheres. This task was to preoccupy astronomers for the next two thousand years.

One of the first students of Plato to distinguish himself in science, and in astronomy in particular, was Eudoxus (409–356 BC). He was an observational astronomer and not a theorist, as preferred by Plato. He accurately determined the length of the solar year to be 365 days and 6 hours (this was already known to the Egyptians). But his most influential contribution was in following up Plato's contention that the orbits of the heavenly bodies *must* be perfect circles. Eudoxus proposed that the heavenly bodies move on a series of concentric spheres with the Earth (which was assumed to be a sphere) at the centre. Each planetary sphere rotates around an axis, which is attached to a larger sphere that rotates around another axis. The secondary sphere was succeeded by a tertiary and a quaternary sphere, as required to explain the annual and the retrograde motion of a planet. For the Sun and Moon, Eudoxus found that three spheres were sufficient. To explain the movements of other planets, four spheres were required. The motion of the fixed stars could be explained with just one sphere. In all, 27 spheres were required to explain the movements of all known bodies in the sky. More spheres were added as further irregularities of the heavenly bodies were discovered. Another pupil of Plato, Heracleides (388–315 BC), first suggested that the Earth completed one full rotation on its axis in 24 hours. He also correctly attributed the motion of Mercury and Venus to their revolution round the Sun. It is not known whether he realised that this was also true of the other planets. It was almost another 1800 years before the ideas of Heracleides were generally accepted.

Aristotle (384–322 BC) was born in Stagira in Macedonia. He arrived at Plato's Academy in 367 BC when he was 17 years old. On Plato's death in 347 BC he moved to the Aegean island of Lasbos because of the increasing anti-Macedonian sentiment in Athens. In 343 BC he returned to Macedonia to tutor the young Alexander, then 13 years old. In 336 BC Alexander embarked on his career of conquest and Aristotle returned to public teaching in Athens. There he owned a garden called the Lyceum where he established a school, later called the Peripatetic (Greek for 'walking around'), where he lectured and taught. He and his associates and students carried out research on scientific and philosophical topics. Under his direction the school also produced a monumental account of the constitutions of Greek city-states. In 323 BC Alexander died and Athens once again became hostile to Macedonia and Macedonians. Aristotle was accused of impiety (the charge that had been levelled against Socrates) and he was forced to flee north to Chalcis, a Macedonian stronghold, leaving the Lyceum in the hands of his colleagues. He is said to have remarked that he would 'not allow the Athenians to sin twice against philosophy'. Removed and isolated from the cultural stimulation of Athens and his school, Aristotle died a lonely man in 322 BC at the age of 62.

Aristotle was driven by a desire for knowledge and understanding in every possible realm. His works cover every topic from (A)stronomy to (Z)oology and they are teeming with detailed observations about the natural world and also abstract speculations. He believed, and this was his unique gift to the world, that the universe was not controlled by blind chance or magic, but by a set of rational laws, which could be discovered, analysed and catalogued to guide human behaviour. His output of work was prodigious, but sadly only about a quarter of it has survived. His earliest work was on biological subjects, which was probably written during his stay on Lesbos. Most of his later work was probably written during his second stay in Athens.

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Aristotle's biological work is based on first-hand observations of living things, and it is this research which established him as a man of science. In his *History of Animals* he describes a scheme for the classification of all living things, from plants to humans. This was a grand synthesis and remained the ultimate authority for many centuries after his death. In his second Athenian phase he turned to the investigation of physical and astronomical problems and set forth a general view of the universe. But in stark contrast to his biological studies his investigations of physical and astronomical problems were devoid of observations or personal knowledge. His physical and astronomical conceptions had profound influence on the centuries that followed, but his biological work was neglected and eventually forgotten, to be rediscovered only in recent times. His writings on natural philosophy suggest that he was attempting to synthesise, in a general scheme, the structure of the material world, not unlike his earlier biological synthesis. Aristotle was looking for an order in both the physical and the biological worlds, and to him these two were related.

Aristotle's world-view, which was to dominate the European view of nature for two thousand years, was based on a common-sense picture of the universe. This can be summarised thus:

Matter is continuous

There was considerable speculation on the nature of matter even in pre-Socratic Greece. In the fifth century BC, Democritus (470–400 BC) and his followers the Epicures had postulated an atomic nature of matter. According to this theory all matter is composed of solid *atoms* and the space or *voids* between them. To Democritus the voids were as much a primary reality as the atoms themselves. The atoms were considered eternal, indivisible and invisibly small. They were also considered incompressible and homogeneous and differed only in form, size and arrangement. Movement or rearrangement of atoms produced the qualities that distinguish things. Democritus and his followers showed little tendency to extend their scientific ideas further and the atomic theory was practically forgotten until the eighteenth century.

Opposed to the atomists were the continuists, among them the fifth-century scientist and philosopher Anaxagoras (488–428 BC) and later Aristotle (and also Socrates and Plato). The continuists believed that all matter was composed of a primordial stuff called *hyle*. Aristotle's stature was such that his views acquired dogmatic authority in the medieval Christian church and the atomic view of matter became particularly abhorrent.

In Aristotle's universe, below the sphere of the Moon

> All matter is made of four fundamental 'elements', earth, water, air and fire that interact and are capable of transforming into one another. Each element is characterised in turn by four 'qualities', heat, cold, dryness and moisture and these occur in pairs.

This concept was not original to Aristotle and is of considerably more ancient origin. It appears to be based on the observation that everything in nature and everyday life has a fourfold division: four seasons, four directions, the four ages of man. This concept fits in well with Jewish, Christian and Islamic thought and became part of orthodox medieval theology. The concept of four qualities was not challenged until the seventeenth and eighteenth centuries.

In this universe

> Planets, stars and the Moon are made of a different kind of matter, a fifth element – *quintessence*. The natural movement of the fifth element is circular and it is eternal. The heavenly bodies are attached to crystal spheres that rotate with a uniform circular motion around an axis passing through the stationary Earth which is at the centre. Each sphere is influenced by the spheres outside it.

The sphere of atmosphere surrounds the Earth and around that are respectively spheres of earthy exhalations, water, air and fire. These spheres are pure elements and are not accessible to humans. Beyond the sphere of elemental fire is a sphere of even more exotic substance, the *ether* (Greek: 'shining') or *quintessence*, which enters into the composition of the heavenly bodies. Beyond the sphere of ether are in succession the seven spheres of the Moon, Sun and the five planets then known and beyond these the sphere of the fixed stars. Finally, beyond all these spheres is the sphere whose divine harmony keeps all the other spheres in motion. Aristotelian teaching maintained that at creation the 'Prime Mover', God, had set the heavens in perfect and eternal circular motion. The crystalline spheres moved, he said rather obscurely, by 'aspiring' to the eternal unmoved activity of God. In order for this 'aspiration' to be possible he assigned a 'soul' to these spheres. Motion was communicated from the Prime Mover to the sphere inside it, and so on to the inner spheres. There was no such thing as empty space, as all space was filled with God's presence. Aristotle, like Plato, was influenced by Pythagorean concepts of 'perfect forms and figures' and in particular circles and spheres as being 'more perfect' than most. His world-view was, therefore, based on these concepts. The heavenly spheres he conceived were in agreement with the mathematical scheme of Eudoxus.

The cosmology of Aristotle was a product of the Greek anthropocentric world-view. The Greeks and, following them, the European Christians were obsessed with the notion that man was central to God's creation and to them the centrality of Earth in cosmology was self-evident. This belief prevailed until the time of Copernicus in the fifteenth century and elaborate schemes were developed both by the Greek and European thinkers to accommodate it. Also, in Aristotle's universe

> Circular motion is perfect and represents changeless, eternal order of the heavens. In contrast, motion in a straight line is confined to our changing and imperfect world.

The basis of this concept is that the heavenly bodies, which were set in motion by divine intervention, appear to be in circular motion, which therefore must be perfect and unaffected by external causes or agents. The four sub-lunar elements tend to move in a straight line: earth downward towards the centre of the universe, fire towards the extreme, and air and water towards intermediate places. Once in its natural place, each of the four elements remains at rest unless caused to move. The difference in the motion of the heavenly bodies and those on the Earth remained a puzzle till the end of seventeenth century when Newton provided a self-consistent explanation of both motions.

Aristotle differed sharply from medieval and modern thinkers in that he believed that

> The universe is finite in space, the outer limit being defined by the 'sphere of divine harmony', but infinite in time, there being neither creation nor destruction as a whole.

The questions of whether space and time are finite or infinite arise when one contemplates the universe at large. These questions have been considered for centuries but, even now, we cannot claim to have a definitive answer. Aristotle concluded that the material universe must be spatially finite. His reasoning was quite simple: if the stars extended to infinity then they could not perform a complete revolution around the Earth in twenty-four hours. Space itself must also be finite because it is only a receptacle for material bodies. Aristotle also asserted that the universe was temporally infinite, without beginning or end, since it is imperishable and can be neither created nor destroyed. These concepts became the backbone of the Christian Church in the Middle Ages. In the sixteenth century Giordano Bruno challenged this view. He asked a simple and obvious question: if there is an edge or a boundary to the universe, what is on the other side? For his curiosity (or impertinence!) Bruno was burned at the stake (see Chapter 2, Kepler).

Aristotle coined the word 'physics' from the Greek word *physis,* or nature, to designate the study of nature. He was perhaps the first scientist/philosopher to consider the concepts of motion, inertia and gravity. To him motion was fundamental to nature; he was to declare, 'To be ignorant of motion is to be ignorant of nature'. Aristotle's physics was accordingly the science of *natural* motion: that is, motion resulting spontaneously when a body is released from all constraints.

Heavy bodies had natural motion downwards, the natural motion of light bodies was upwards. He regarded the motion of the celestial bodies and the behaviour of the four elements as 'natural' motions; all other motions were 'violent motions'. To him the natural state of a body was to be stationary; nothing moves unless it is pushed. But his laws of motion were not based on observations or experiments: they were stated as being self-evident. He believed that:

> The application of 'force' (*dunamis*) displaces a body by a distance proportional to the time of application of the force.
>
> Objects in motion seek their natural place of equilibrium

Aristotle believed that a body moving at constant speed requires a force to act on it continuously and that force can only be applied by contact with the body – a proximate cause. He also believed that the four elements had an inherent force, which drove them to their natural place of rest. A solid body (made of the first element, earth), on being dropped, will fall vertically in a straight line to its natural place of rest, the centre of the universe (or Earth). A heavy body will fall faster than a light body and the speed of fall is proportional to the size of the body. Since Aristotle's physics was not concerned with forced motion, he gave no plausible explanation for the continued motion of a thrown object after it leaves the hand. Because he had postulated physical contact with a mover to account for any motion that was not natural, he suggested that the medium through which a body moves assists the motion of the body. The idea was that if a body is projected through air then the air that is displaced will rush round behind the body to provide the motive force for the body. Aristotle also had no concept of composition of motion or force; he argued that if a running man threw an object vertically up it would fall down and land behind the man. He had clearly conjectured this and not taken the trouble to observe it, a significant departure from the methodology he employed in his biological work. Aristotle's laws of motion could not be used to learn more about how bodies move. His physical science was also nonmathematical; it was