Chapter 1

A Stone with a Soul

The secret of magnets, now explain that to me!
*There is no greater secret, except love and hate.**

Johann Wolfgang von Goethe (*Gott, Gemüt und Welt*)[1]

Magnetism – The First Records

What child has not played with a magnet, amazed at its power to attract iron objects? Who has not felt intrigued with its quasi-magical ability to exert forces at a distance? Forces that appear to act without material mediation, without physical contact; one does not have to touch a piece of iron to move it with a magnet, in contrast with all other usual physical experiences**.

The observation of magnets has accompanied humankind for more than three thousand years, for these wondrous objects were known before the first millenium BC. In ancient Mesopotamia, iron oxides were used in weights from the late third millenium BC[2]. Different iron ores, including the mineral magnetite, were used in the same region to make seals ('cylinder seals') from 2000 BC.

The earliest indication that magnetic phenomena were known in the ancient world is the fact that the magnetic mineral magnetite, the naturally occurring magnetic stone, was referred to in Mesopotamia as 'grasping hematite' or 'hematite that seizes' (shadânu sabitu)[3,4,5]. This term is used in a tablet with a list of commodities[6] from the first half of the second millennium BC, giving an indication that this remarkable property of some iron ores had been observed very early. The expression 'grasping hematite' is also found in the 16th tablet that is

* "Magnetes Geheimnis, erkläre mir das!
Kein grösser Geheimnis als Lieb und Hass".

** Except for the (usually weaker) attraction by rubbed amber, which we will consider in later chapters.

From Lodestone to Supermagnets. Alberto P. Guimarães

ISBN: 3-527-40557-7

part of a series called Har-ra hubullu, containing Sumerian words and the Akkadian equivalent, from the first millenium BC[7]. The phrase 'living hematite' is also recorded.

The first known records of the properties of the magnet were made in Greece. The Greek philosopher Thales of Miletus, who lived in the 6th century BC, was said to have considered that the magnet had a soul.

The origin of the name magnet, according to the Roman poet-philosopher Lucretius (Titus Lucretius Carus) (c. 98–55 BC) writing in the 1st century BC in the didactic poem *De Rerum Natura* ('On the Nature of Things'), was in the province of Magnesia, in Thessaly, northern Greece. Lucretius wrote[8]: "Next in order I will proceed to discuss by what law of nature it comes to pass that iron can be attracted by that stone which the Greek call the Magnet from the name of its native place, because it has its origin within the bounds of the country of the Magnesians." Inhabitants of Thessaly colonized Asia Minor, where there are two provinces with the name Magnesia. Since the lodestone is referred to as 'Lydian stone', in some accounts, including one[9] of the Greek poet Sophocles (496–406 BC), one may relate the discovery to the Magnesia in the region of Lydia[10].

A different account is given by Pliny the Elder (Gaius Plinius Secundus) (AD 23–79), a Roman author who wrote the encyclopedic 'Natural History' (*Historia Naturalis*), a thirty-seven-volume treatise whose influence lasted for some 15 centuries. Pliny compiled many thousands of observations on natural phenomena, plants, animals and places, from his own experience and from more than 2000 earlier texts. He was untiring in this task, studying and writing throughout his whole life. His curiosity finally led to his death as he approached the volcano Vesuvius to observe more closely the eruption of the year AD 79 that destroyed Pompeii. He mentions the property of magnets of attracting iron, and informs that according to Nicander (a Greek poet), "it was known as *magnes* after its discoverer, Magnes, who found the mineral on Mount Ida*. (...) The discovery is said to have been made when the nails of Magnes' sandals and the tip of his staff stuck to the stone as he was grazing his herds."[11]

It is difficult to establish which of the traditional versions on the

* There is a Mount Ida in Asia Minor (Turkey); in the Illiad, Zeus watched the Trojan War from Mount Ida, also known locally as Kaz Dagi.

origin of the word 'magnet' presented above is more reliable. In any case, we know that the first objects to show this amazing property were rocks containing iron oxides, a mineral known as magnetite, basically an iron oxide of formula Fe_3O_4, brown or black, with a metallic luster. The magnetite that behaves as a magnet is known as lodestone, from the word lode, archaic English meaning course or way.

The knowledge of magnetism and magnetic materials was acquired very slowly, from the beginnings of science. Knowledge about minerals had been accumulated since prehistoric times, as Man observed and classified natural materials according to their physical properties, used them, and at a later stage tried to tailor them to his practical needs. The pace of accumulation of knowledge accelerated as the first human groups started to settle, abandoning nomadic life, and began to raise the first crops in Mesopotamia, the region between the rivers Tigris and Euphrates in present-day Iraq, and also along the river Nile, in Egypt. These civilizations learned how to grow wheat and barley, raise cattle, work metals like copper and bronze (an alloy of copper and tin). Iron was initially extracted from metallic meteorites; iron extracted from ore appears in the first half of the third millenium BC[12]. Their way of life required a certain amount of botanical knowledge, knowledge of the cycle of seasons, and physical knowledge about the melting points of the metals, their degree of hardness, malleability, and so on.

The development of the reckoning of time was related to the growth of astronomical knowledge. Time was naturally measured in days, the period from sunrise to sunrise (corresponding to the rotation of the Earth around its axis); a longer period was recognized as the year, the interval from one cycle of seasons to the next (corresponding to the time of revolution of the Earth around the Sun). The determination of how many days were contained in a year led in Mesopotamia and Egypt to the introduction of a calendar that incorporated the yearly periodicity of the seasons, important for the agricultural society; it was convenient to start the seasons on the same day, every year. This demanded the observation of stars, and in general, the acquisition of astronomical data. The division of the day into hours was not so relevant for life in a primitive society, the activities being limited from dawn to dusk. Also, measurement of time on this shorter scale involves creating new instruments and solving many technical problems.

The construction of housing and temples, and the need to measure land led to the development of units of measurement; a system of weights and measures was created in Mesopotamia as early as 2500 BC, and later also in Egypt. The usual units of length were related to parts of the human body: the cubit, the distance from a man's elbow to the fingertip; the span, the length of a fully stretched hand from the tip of the thumb to the tip of the little finger, and so on. One of the earliest units of weight used in Mesopotamia was the mina; another unit was the shekel, equivalent to 1/60 of the mina. The shekel was equivalent to the weight of 120 or 200 grains of wheat[13].

A giant step in the development of early human society was the invention of writing by the Sumerians, one of the peoples of Mesopotamia. This started as a pictographic representation, where an ox was represented by a picture of the head of the animal, and later took a more abstract form, in the so-called cuneiform language, around 3000 BC. This name is given because of the shape of the short strokes used (from the Latin *cuneus*, 'wedge'). The next stage in the evolution of writing was the shift from representation of things to representation of sounds.

Thales and the Beginnings of Greek Science

The beginnings of science are usually placed in Greece, in the 6th century BC. There is a certain degree of arbitrariness in this choice, since scientific and technical developments were, of course, also made in Egypt, Babylonia and China. However, it is generally accepted that the kind of knowledge, or rather the approach towards knowledge itself, of the first investigators in Greece had the seeds of the scientific endeavor*.

Why Greece? Why did it not occur in Egypt? It is known that in Egypt, despite the wealth of practical knowledge accumulated, there is no evidence of systematic theorizing about natural phenomena. In Egypt, the identification of the gods to the kings, with the priests being

* "To the extent that it is explicative and ontological [i.e. related to the being], science is a creation of the Greek genius – and if one considers these two aspects as essential, one can assert that science was born in Greece." (R. Taton, *Histoire Générale des Sciences*', vol. I, Presses Universitaires de France, Paris, 1966, p. 204).

both religious and secular authorities, did not contribute to creating a climate that stimulated free speculation about the universe[14]. In China, on the other hand, law did not guarantee individual rights; customs and a 'natural law' prevailed, without the existence of prescribed sanctions for different crimes[15]. It has been speculated that since there was no immediate connection in China between human acts and their legal sanctions, the relationship between the natural phenomena and general laws that governed them was not easily perceived; the concept of laws of nature, therefore, was not valued[16].

In the Greek world, one of the elements that contributed to the emergence of science was the fact that the gods were not associated with secular power, and as a consequence, they could be more easily removed from the privileged role of major actors that determined the course of natural events. In the early mythical accounts, nature tended to be endowed with the power to evolve from within, a useful characteristic to open the way for the causal explanation of natural phenomena[17]. The creation of the universe, as described in Hesiod's Theogony, is not the act of gods, but rather resulted from the action of "relatively abstract entities", such as Chaos, Earth and Eros[18] (Theogony means an account of the origin and descent of the gods).

Political factors have also been pointed out as relevant for this development: the Greek city-states enjoyed a variety of constitutional forms of organization, among these the novel democratic regime, which allowed the development of an atmosphere of free speculation. Indeed, in the case of Athens, the constitution permitted a high level of participation in the political life of the city[19]. The extent of the maritime trade, with the exchanges between different cultures, particularly with the Egyptians and the peoples of Mesopotamia, may have worked in favor of expanding the horizons of the first thinkers. A higher level of literacy in Greece, as compared with Egypt and Babylonia, was another favorable factor[20].

The Greek world in Antiquity was constituted of cities scattered on the edges of the Mediterranean Sea (Figure 1.1); Egyptian civilization was concentrated on the banks of the Nile, relatively isolated from other societies by the desert, east and west of the river. Both in Egypt and in Greece, however, intellectual life could develop only when society spared some of its members from productive activities, allowing them to enjoy free time for leisure, as first pointed out by the philosopher Aristotle: "Hence, when all such inventions were already estab-

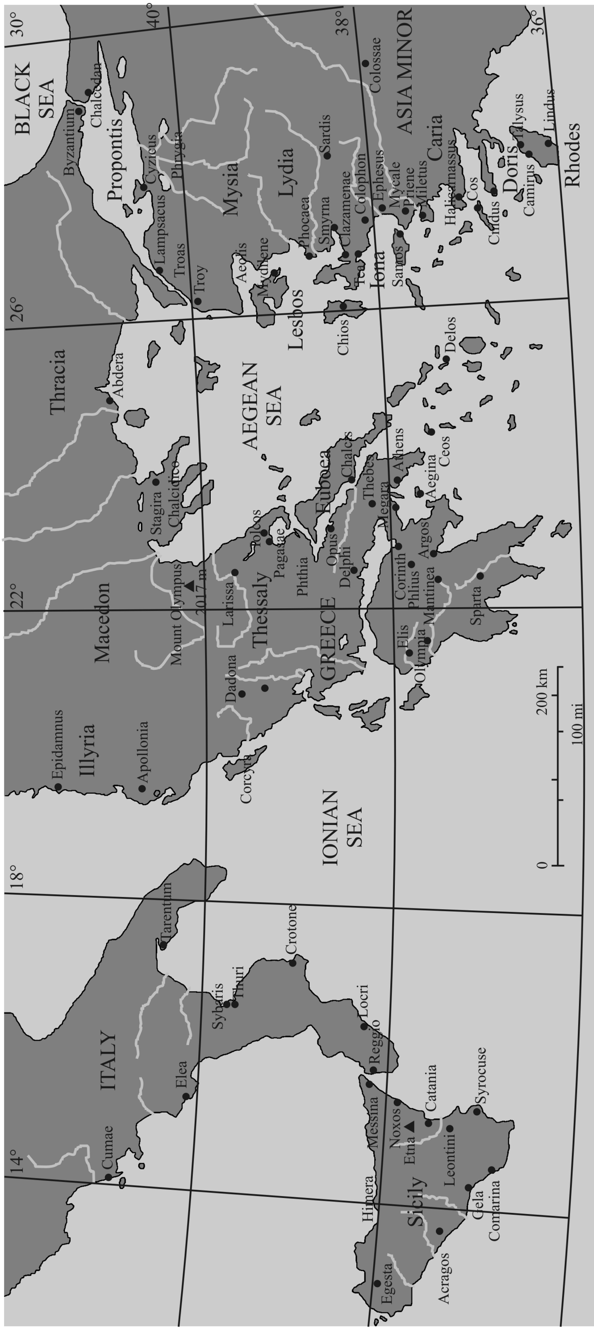

Figure 1.1 The Greek world.

lished, the sciences which do not aim at giving pleasure or at the necessities of life were discovered, and first in places where men first began to have leisure. This is why the mathematical arts were founded in Egypt; for there the priestly caste was allowed to be at leisure."[21] And furthermore "(...) for it was when almost all the necessities of life and the things that make for comfort and recreation had been secured, that such knowledge began to be sought."

Around 1400 BC the first writing system based on the sounds of the words was invented in Greece. This evolved some centuries later to become an alphabetic system, where syllables were formed with consonants and vowels[22].

In the 6th century BC there appeared in written form the Iliad and the Odyssey, epic poems attributed to Homer, a poet-singer who would have lived some centuries before, possibly on Chios, an island in the coast of Asia Minor or Anatolia, the Asian portion of Turkey. Initially transmitted through oral tradition, these masterpieces of Greek literature were centered on the adventures of the legendary characters Achilles and Ulysses (Odysseus); in the Iliad, the history of the Trojan War is told (Ilion is one of the names of Troy). Besides their great literary value, these works are important as they reveal a certain knowledge of natural phenomena, of medical and agricultural practices prevalent in Greece at that time[23]. The Iliad and the Odyssey helped to consolidate the Greek language, and became part of the education of every literate Greek for many centuries. Two other poems, the *Theogony*, and *Works and Days*, are attributed to Hesiod, who may have lived in Ascra, in Boeotia, mainland Greece, around 700 BC. Herodotus, the Greek historian who lived in the 5th century BC, expressed the importance of Hesiod and Homer in shaping Greek culture with the following words: "It is they who created a theogony for the Greeks, gave the gods their names, distributed their privileges and skills, and described their appearance."[24] Or, in the words of Xenophanes, a philosopher and religious thinker from Colophon, in Ionia (the central part of the coast of Asiatic Turkey), who lived in the sixth to 5th century BC: "What all men learn is shaped by Homer from the beginning."[25] The poems of Hesiod and Homer, that mingled myth with practical knowledge, mark the transition of Greece into a new intellectual era.

This era opened in the 6th century BC, as some inquisitive men started to ask new questions about the world that surrounded them, and furthermore, tried to search for answers that did not contain the usual elements of lore and mythology; this meant trying to find natural causes for the natural phenomena. In these first bold endeavors lie the origins of scientific thought. These men were the philosophers, or lovers of wisdom, in Greek; Aristotle would later on refer to them as *physikoi*, from *physis*, nature. From their standpoint, they avoided the attitude common in pre-scientific societies, of mistaking "association of ideas in their minds" for "causal relations between things", in the words of the nineteenth-century British anthropologist James Frazer[26]. First of all, they began to view the world not as some disordered, or arbitrary, aggregate of things or sequence of events, but as an object of knowledge and explanation. The word *kosmos*, from a verb meaning 'to order', was used to describe the universe; the very fact that a word was required to designate the totality of things represents in itself an important move in this new direction. Their attitude is summed up in the words of W. K. C. Guthrie[27], author of *A History of Greek Philosophy*: "Philosophy started in the faith that beneath this apparent chaos there exists a hidden permanence and unity, discernible, if not by sense, then by the mind."

It is very difficult for us nowadays to apprehend the magnitude of the change in world view that the attitude of the early philosophers entails, since so much of their contribution has become a tacit part of our intellectual inheritance*. We are used to searching for natural causes of phenomena without having to make the conscious choice between a mythical and a scientific standpoint; under most circumstances, the choice between *mythos* and *logos* is immediate.

The first philosophical ideas appeared in the eastern and in the western frontiers of the Greek world (Figure 1.1): in the East, along the cities of the coast and in the islands of Asia Minor, and in the West, in Sicily and mainland Italy. Very little original written work or even fragments of works of the early philosophers has survived to our days. Most of their ideas reach us through the writings of commentators or historians, who lived centuries after them, and who did not have access to the original manuscripts; to make things worse, even these

* The philosopher Karl Popper places the originality of the first philosophers not so much in the fact that they abandon the myths, but in their critical attitude: they substitute the "traditional preservation of the dogma", for a "tradition of criticizing theories" (K. R. Popper, *Objective Knowledge*, Oxford University Press, Oxford, 1975, pg. 348).

later accounts were preserved in the form of copies of copies of texts[28].

The first of these thinkers is Thales of Miletus (c. 640–546 BC), who is regarded as the founder of Greek science and philosophy. He made the daring move of proposing that there was something common to the entire universe; in this first unified view of the universe, he posited, according to Aristotle*, that "all things are water". The choice of water as the element that formed everything in the universe may have arisen from the fact that water can present itself as a solid, as a liquid, and as a gas. This choice for the prime element of the universe may also have resulted naturally from the importance of water in the life of animals and plants; the relevance of the sea for the economic activity of the peoples in the region may have also played some role. This idea had antecedents, since many early myths involved sea and water deities, and Babylonian cosmology around perhaps 2000 BC already assumed a primacy of water[29]. It was also part of these myths that the Earth itself was regarded as floating on an infinite pool of water.

Thales thus proposed the first vision of the universe that lacked mythological elements, gods or demons, as essential constituents. He had a reputation as a mathematician, and he was the first man to be considered responsible for specific mathematical discoveries[30]. However, some of his alleged scientific exploits are not generally accepted today, such as the famous prediction of a solar eclipse[31] in 585 BC; it is argued that there simply was not sufficient astronomical knowledge at the time to allow such a prediction.

Two other thinkers constitute, with Thales, the School of Miletus: they are Anaximander (610–550 BC) and Anaximenes (550–486 BC). Anaximander elaborates on the world view of Thales, assuming a single element as the principle of everything, but in his view, this was an abstract element, the *apeiron*, or infinite. This choice represents a more sophisticated attempt at the comprehension of the principle, or *physis*, of the universe, since it shifts from known material substances to a pure abstraction. Simplicius, a commentator and philosopher of

* "Most of the first philosophers thought that principles in the form of matter were the only principles of all things. (...) Thales, the founder of this kind of philosophy, says that it is water (that is why he declares that the earth rests on water)." Aristotle, Metaphysics 983b6–11, 17–27, in J. Barnes, *Early Greek Philosophy*, Penguin, London, 1987, p. 63.

the Neoplatonist school, who was born in the second half of the 5th century AD, wrote[32] of Anaximander: "Of those who hold that the first principle is one, moving and infinite, Anaximander, son of Praxiades, a Milesian, who was a successor and pupil of Thales, said that the infinite is principle and element of the things that exist. He was the first to introduce this word 'principle'. He says that it is neither water nor any other of the so-called elements but some different infinite nature, from which all the heavens and the worlds in them come into being. And the things from which existing things come into being are also the things into which they are destroyed, in accordance with what must be."

The philosopher Anaximenes, in his turn, chooses air (or breath) as this prime element. He proposes mechanisms of condensation and rarefaction as the processes of formation of the variety of qualities and material aspects of the universe. Condensation of air produces cold, further condensation creates wind, cloud, rain, earth and rock. In an ancient text falsely attributed to Plutarch[33], one reads: "Anaximenes, son of Eurystratus, a Milesian, asserted that air is the first principle of the things that exist; for everything comes into being from air and is resolved again into it. For example, *our souls*, he says, *being air, hold us together, and breath and air contain the whole world* ('air' and 'breath' are used synonymously)".

Another great philosopher of importance in the history of science was Pythagoras; he was born on Samos, in Ionia, on the island closest to the continent, probably about the year 570 BC. To flee from the tyranny of Polycrates he migrated to Croton, in Southern Italy, where he established his school. He was then forty. His presence in Croton coincided with a period of increase in the influence of this city-state. At the end of the 6th century, after a rebellion in Croton, Pythagoras migrated again, ending his days in Metapontum, also in Italy, in the Gulf of Tarentum.

Besides being a philosopher and a political leader, Pythagoras created a religious sect; the facts of his life are entangled with many myths concerning his person. There is no certainty that Pythagoras left written works; a veil of secrecy covered his religious society, where members were obliged to take a five-year vow of silence[34]. His philosophical work was apparently accessory to his religious interests[35]: "What we may safely say is that for Pythagoras religious and moral motives were dominant, so that his philosophical inquiries were destined from the start to support a particular conception of the best life and fulfil certain spiritual aspirations.“

For the Pythagoreans, numbers had an independent existence, and were more important than the natural phenomena; these were important insofar as they reflected the pre-eminence of numbers[36]. This supreme position of the numbers was described by the philosopher Aristoxenus (fl. 4th century BC) as having arisen from Pythagoras' interest in the practical side of commerce; Aristoxenus also considered him responsible for the creation of a system of weights and measures.

One of the first authors to write on the Pythagoreans was Aristotle, born in 384 BC; commenting on their relation with numbers he affirms[37]: “since, then, all other things appeared to have been modeled on numbers in their nature, while numbers seemed to be the first things in the whole of nature, they supposed that the elements of numbers were the elements of all the things that exist, and that the whole heaven was harmony and number“. Although Pythagoras and the Pythagoreans are nowadays believed to have contributed little to the techniques of mathematics[38], the importance of their contribution to the conceptual foundations of mathematics is undisputed. One of these contributions is the fuller realization of the abstract nature of numbers and geometric figures, and the recognition that theses are entities that belong to a class separate from that of physical objects.

Before the appearance of the first philosophers, Egyptians and Babylonians had a practical knowledge of mathematics, which was used in trade and in keeping the accounts of the temple, and for the measurement of agricultural land. Although arithmetical operations with numbers were used, the meaning of the numbers was not discussed or examined in depth. The development of the number concept is related to the Pythagoreans; although numbers were used in reckoning from much earlier ages, the use of expressions such as ‘two oxen’ did not imply knowledge of the full meaning of the word ‘two’. In other words, mathematical concepts such as the number concept could only be understood when one abstracted something that was common in ‘two oxen’ or ‘two people’, and so on. The same process involves the geometrical concepts: a rectangular table and a rectangular plot of land have something in common that has to be identified as the rectangular shape; in this way, the concepts of rectangle, square, circle, etc. were born. Geometrical properties of simple figures were known, including the fact that in a right triangle the sum of the squares of the lengths of the sides adjacent to the right angle is equal to the square of the length of the opposite side, a theorem known nowadays as 'Pythagoras' theorem'.

The development of the number concept and the importance of numbers in the Pythagorean world view have been associated with the introduction of coins, which first appeared in Lydia, in Anatolia, in the 7th century BC. One consequence of the emergence of a monetary economy, with the substitution of concrete goods by their abstract representation as numerical values in monetary units, may have been a stimulus for the Pythagorean discovery of the importance of numbers. The universalization of a system of weights and measures contributes in the same direction, helping to reveal the number as an abstraction. Measuring the weight of different goods with the same unit, for example, allows the same kind of association provided by currency: concrete goods of different nature may have the same weight, i.e. may correspond to the same number. In ancient Greece many of the units were the same as those used in Egypt and in the east; the cubit as unit of length, and the talent, unit of weight corresponding to about 58 pounds (25.8 kg) are examples. These units are already found in the verses of Homer, and were therefore in use by the 7th century BC.

Although the abstract nature of numbers was then recognized, numbers still retained a certain connection to physical objects; this appears, for example, in the representation of numbers by the Pythagoreans with pebbles or dots[39] (Figure 1.2). Among numbers of special interest were those that could be represented by a triangular array of dots, like 1, 3, 6, 10 and so on, called triangular numbers (the number 1, of course was a 'point-like' triangle). There were also the square numbers: 1, 4, 9 and so on. Some remains of this vision of the numbers have survived to our days, in the naming of the second power of a number as 'square' of the number, and the third power as 'cube'.

Pythagoras, or the Pythagoreans, established, probably using a monochord instrument, the *kanon*, that the musical intervals corresponded to some prescribed lengths of the string, which was varied by changing the position of a moveable bridge. The frequency of the musical notes was inversely proportional to these lengths. Thus, the intervals of Greek music corresponded to the frequency ratios 1:2 (octave), 3:2 (fifth) and 4:3 (fourth), again confirming to them that the

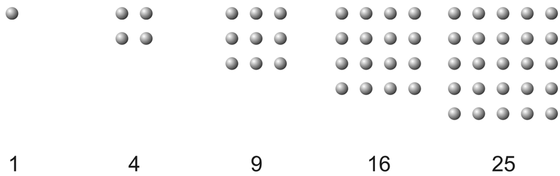

Figure 1.2 Pythagorean representation of square numbers: $1 = 1^2$, $4 = 2^2$, $9 = 3^2$, $16 = 4^2$, $25 = 5^2$.

first four integers 1, 2, 3 and 4 played a fundamental role in the world order[40].

Plato and Aristotle

One of the most important Greek philosophers was Plato, one of the greatest figures of the history of ideas. He was born around the year 428 BC, and came from an important family in Athens; the young Plato was an admirer of Socrates, a friend of the family and a major Greek thinker. Socrates had discussed the possibility of Man attaining knowledge, and also how to lead a life according to ethical principles. Socrates had shifted his mind from the themes of interest of the preceding philosophers, in cosmology and the physical world, to the problems that had Man at their center. One may assert schematically that he moved from the problem of the reality of nature, which was at the center of the investigation of the Milesians, to the problem of man; this steered him into an ethical inquiry that would ultimately take his life. Socrates was tried in 399 BC and condemned to die by poisoning with hemlock for his questioning of the Greek ruling authorities. This episode shook Plato and further stimulated him to follow his own path as a philosopher.

Plato's writings were in the form of dialogues, and have survived to this day as pieces of great philosophical and literary value. Plato established his school around the year 387 BC outside Athens; the institution became known as the Academy, apparently because it was established in a place named after the hero Hekademas.

Discussing the possibility of knowing the external world, Plato[41] "thought that the reason for our ability to know the outer world is that the same *simplicity* and *order* that please us in our *ideas* are also found in the *objective world*." Plato thought that the objects of knowledge did exist, although they were not to be identified with anything in the perceptible world[42]. They were the forms, or ideas, of which the concrete objects of the world were but imperfect copies. In one of the dialogues, the *Meno*, Plato argues that knowledge is in fact a process of recollection; the immortal soul knows, for example, geometry, and this can be shown by properly questioning even an illiterate person.

Another giant among the Greek philosophers who left his mark in the birth of science was Aristotle. Aristotle was born in Stagira, presently Stavró in the north of Greece, on the Chaldice peninsula, in the year 384 BC. At the age of 18, he entered the school of Plato in Athens, where he remained until Plato's death. He then moved from Athens to Mysia and after a while to Mitylene, on the island of Lesbos. In 342 or 343 BC King Philip of Macedonia, who had been educated in Greece, invited him to Pella, capital of the kingdom, to tutor his son Alexander, then a 13-year-old boy. Alexander would grow up to become Alexander the Great, the king who would lead the Macedonians to conquer Persia, Babylonia, Egypt and extend their empire to India. Aristotle took this position, and after eight years, when Philip died, returned to Athens and founded his own school, where he lectured on rhetoric, sophistic and politics, and for a smaller number of students, on logic, physics and metaphysics. He used to discuss with the students while he walked, and from this fact, the school became known as the 'Peripatetics', (from the Greek *peripatein*, to walk up and down).

Aristotle left an extensive written work that can be divided into three parts: the scientific treatises, some separate texts related to those, and works of a more popular character. Among these treatises, the most important is the group of works known as the *Organon* ('Tool'), then the natural history works such as the *Historia Animalium*, as well as the Metaphysics, the Nicomachean Ethics, and the Politics. Aristotle chose for his works not the form of dialogues, but that of lecture notes. He classified theoretical knowledge into a) natural philosophy, b) mathematics, c) first philosophy (metaphysics).

In the first part of his treatise of logic, the Prior Analytics, and in the second, called the Posterior Analytics, he discusses the syllogism, with the goal of establishing the conditions for scientific knowledge[43]; with this work Aristotle set the foundations of formal logic. The syllogism, in its simplest form, is a series of three propositions, in which the first two are premises that lead to the third, the conclusion. The classic example is 1) "All men are mortal"; 2) "Socrates is a man"; 3) "Therefore Socrates is mortal". If the first two statements are valid, the third (conclusion) follows. This is a special case of deduction, or deductive reasoning, seen by Aristotle as a reasoning that goes from the general to the particular (a view not accepted nowadays by most philosophers[44]). Induction, on the other hand, goes from the particular to the general*; deduction and induction are two logical processes essential in the scientific discourse.

Aristotle valued observation and to a certain extent experimentation; he developed his doctrine starting from his knowledge of biology. On account of the interest in biological studies of the members of his school – the Lyceum – he kept a collection of zoological specimens, obtained in part from the travels of Alexander.

Aristotle's way of constructing his science is exemplified by Gillispie[45], speaking of his physics: "It was a serious physics, a consistent and highly elaborated ideation of natural phenomena. It started from experience apprehended by common sense, and moved through definition, classification, and deduction to logical demonstration. Its instrument was the syllogism rather than the experiment or the equation. Its goal was to achieve a rational explanation of the world by showing how the myriad subordinate means are adapted to the larger end of order."

He considered the existence of four different causes, using the word in a different sense than it has today; of these, the final cause, he called "prime mover". This prime mover was often called God, but it represented more a natural principle than a religious God; it was not a source of force, but an object of desire[46]. For example, the stars turn in the sky because of their desire to reach perfection, which is attained with their circular motion.

The point of view of Aristotle and followers contrasts with the vision of Plato. In the words[47] of the science historian Alexandre Koyré (1892–1964): "If you claim for mathematics a superior status, if more than that you attribute to it a real value and a commanding position in Physics, you are a Platonist. If on the contrary you see in mathematics

* Aristotle usually speaks of induction, however, not progressing from individuals (e.g. "this man", "this horse"), but from species ("man", "horse") to genus (i.e. "mammals", "living beings") (D. Ross, *Aristotle*, Methuen & Co, London, 1974, p. 39).

an abstract science, which is therefore of a lesser value than those – physics and metaphysics – which deal with real being; if in particular you pretend that physics needs no other basis than experience and must be built directly on perception, that mathematics has to content itself with the secondary and subsidiary rôle of a mere auxiliary, you are Aristotelian."

Another important philosophical movement that flourished in Athens was that of the Stoics; they were a group of philosophers that got this name from the place where they used to meet, the *Stoa poikile*, or Painted Porch. They were influenced by the ideas of the pre-Socratic philosopher Heraclitus (who was active around 500 BC) and their most important leader was Zeno of Citium (c. 334–262 BC), who was born on Cyprus and founded the school around 300 BC. They regarded the universe as a living being, filled with a fluid, the *pneuma*. They believed all matter to be formed from the four elements: earth, water, fire, and air. The Stoics were responsible for advances in logic and linguistics. Their doctrine, Stoicism, remained an important philosophical school well into the Roman era, when their leading thinkers were the Roman emperor Marcus Aurelius (AD 121–180), the writer Seneca (c. 2 BC–AD 65), and the philosopher Epictetus (c. AD 55–c. 135). In its later form, Stoicism reflected an increasing concern with ethical and moral questions.

Side by side with the philosophers, Greece also produced men who had practical concerns, who created or perfected tools and machines. One of the greatest among these creators was the inventor and mathematician Archimedes, who was born in 287 BC. He lived in Syracuse, a Greek colony in Sicily, and left many treatises in arithmetic, mechanics, astronomy and optics. Archimedes is best known for the machines that he built, like catapults and other military engines. He is also said to have proposed the use of concave mirrors to set the Roman navy on fire. He was killed as the Romans conquered and sacked Syracuse in 212 BC.

Magnetism in Greece

There are but few references to magnetism in the writings of the early Greek philosophers; the comment on the magnet attributed to Thales, quoted at the beginning of this chapter, is the first ever recorded. Some philosophers, besides their considerations on other natural phenomena, not only described magnetism, but also attempted to explain the cause that lay behind the bizarre behavior of the lodestone. A statement to this effect was reported by Aristotle, in his treatise *De Anima* ('On the Soul'): "Thales, too, to judge from what is recorded about him, seems to have held the soul to be a motive force, since he said that the magnet has a soul in it because it moves the iron".[48]

In Diogenes Laertius' *Lives of the Philosophers* (early 3rd century AD), the same idea is attributed to Thales[49]: "Aristotle and Hipias say that he ascribed souls to lifeless things too, taking the magnet and amber as his evidence." This idea attributed to Thales has been interpreted either as meaning that Thales shared the traditional beliefs of his contemporaries, or that he had altogether abandoned them; the latter view is based on the fact that he had reserved this identification with spiritual beings only for admittedly abnormal objects, like the magnets[50].

Laertius lists amber side by side with the magnet, as notable materials that are the object of Thales' remark. Amber is fossil tree resin, of yellow to orange color, transparent or milky, and is known for the property of attracting small objects when rubbed, due to the appearance of an electric charge. Amber is also mentioned by Pliny the Elder; in his words[51], "it attracts straw, dry leaves and bark from the linden tree, just as a magnet attracts iron" (see Chapter 3).

In the Dialogues of Plato, one finds a description of how a magnet makes a piece of iron it touches behave as a magnet to another piece of iron, a phenomenon usually known as induction[52]: "(...); there is a divinity moving you, like that contained in the stone which Euripides calls a magnet, but which is commonly known as the stone of Heraclea. This stone not only attracts iron rings, but also imparts to them a similar power of attracting other rings; and sometimes you may see a number of pieces of iron and rings suspended from one another so as to form quite a long chain: and all of them derive their power of suspension from the original stone."

The Greek philosophers after Thales also tried to explain why the magnet had the power to attract iron. The philosopher Empedocles (c. 490-c. 430 BC) was one of them; he appealed to 'effluences', or vapors, in his explanation. According to the book *Quaestiones*, written by a philosopher who was active around AD 200, Alexander of Aphrodisias, this was Empedocles' idea for explaining magnetic attraction:

"On the reason why the lodestone attracts iron. Empedocles says that the iron is attracted to the stone by the effluences which issue from both, and because the pores of the stone are commensurate with the effluences from the iron. The effluences from the stone stir and disperse the air lying upon and obstructing the pores of the iron and when this is removed the iron is drawn on by a concerted outflow. As the effluences from the iron travel towards the pores of the stone, because they are commensurate with them and fit into them the iron itself follows and moves together with them."[53]

Along the same line, Democritus of Abdera (c. 460-c. 370 BC), a Greek philosopher best known for his atomistic view of matter, also appeals to effluences to explain the properties of the magnet. In the words of Alexander of Aphrodisias: "Democritus also says that there are effluences and that like bodies are attracted to like, but adds that all are attracted to a void. Having made these hypotheses, he supposes that the lodestone and iron consist of similar atoms, but those of the stone are smaller and it is of rarer texture than the iron and contains more void. For this reason, its atoms being more mobile are attracted more quickly to the iron (for they are moving to their similars), and entering the pores of iron disturb the atoms in it as they pass between owing to their small size. The atoms of the iron, thus disturbed, stream outside towards the stone because of their similarity and because it has more void. The iron [as a whole] follows them in their wholesale expulsion and movement and is itself drawn towards the stone. The reason why the stone does not move any more towards the iron is that the iron does not contain so much void." [54]

Epicurus of Samos (341–270 BC), the philosopher known for his teachings that pleasure, or rather absence of pain, was the essence of life, had a different theory; according to the physician and philosopher Galen (c. AD 130-c.200)[55], "His view is that the atoms which flow from the stone are related in shape to those flowing from the iron, and so they become easily interlocked with one another; (...)".

In every case, the proposed explanations involve mechanical actions, attraction by the void, interlocking of atoms, and so on, (or maybe also animistic considerations, in the case of Thales with his remark on the "soul of the magnet"). Mechanical processes were certainly insufficient to explain magnetic effects; students of magnetism would have to wait for more than 20 centuries for a sound explanation of the phenomenon.

Chinese Records on Magnetism

Some of the earliest references to the lodestone come from the East, more specifically from China, where it was called 'tzhu shih' – the loving stone[56]. The first practical application of magnets – the compass – also originated in China, where it may have been used for navigation in the 10th century AD.

The first Chinese dynasty was the Shang dynasty, in the period from the 18th to 12th centuries BC, in the Chinese Bronze Age. Inscriptions found in pottery point to the origin of Chinese written language as early as 4000 BC. The unification of China did not occur until 221 BC, as the powerful feudal state of Ch'in established its dominance over the other states; in the process of unification, the written language was standardized.

During Chinese antiquity, there were enormous advances in the knowledge of natural phenomena, and in different technologies. Astronomical knowledge reached a very high level, mostly stimulated by the need to perfect the calendar, and also for divination purposes. By 1400 BC, the Chinese had already determined the duration of the year as $365\frac{1}{4}$ days (the accepted value today is 365.242199 days), and the period of the lunar cycle of phases (called synodic month, or lunation) as $29\frac{1}{2}$ days (known today to be 29.530588 days). They had a 354-day year, and from time-to-time added an extra month with 29 or 30 days to keep the calendar in line with the motion of the Earth around the sun. They kept registers of astronomical phenomena that are invaluable today for the study of past astronomical events: they had recorded eclipses since 720 BC, sunspots since 28 BC, comets since 613 BC, and novae and supernovae since 352 BC[57]. The collection and preservation of these records can in general be attributed to the activity of the state, and this strong presence of the state is a distinguishing mark of the early Chinese scientific development[58].

The Chinese started to make objects of cast iron as early as the 6th or 4th century BC, thanks to the invention of piston bellows that provided a steady flow of air into the smelting furnace. Among other technological breakthroughs, one may include paper, invented in China around AD 100, a mechanical clock in the 8th century, and gunpowder in the 9th century. In many technical fields, the Chinese led Europe until the 16th century.

The first important thinkers in ancient China were the Confucians and the Taoists, but there were also relevant contributions from members of other philosophical schools, known as Mohists, Legalists and Logicians. The Confucians were the followers of K'ung-fu-tzu, or in Latinized form, Confucius, who lived from 552 BC to 479 BC. The Taoists (from Tao, 'The Way'), followed the teachings of Lao-tzu, said to have lived some time between the 6th and 4th centuries BC, and the Mohists were followers of Mo-tzu (479–381 BC). Although Confucians and Taoists were the most influential schools in Chinese intellectual history, and their teachings eventually evolved into two religions, Mohists, Logicians and Legalists were more immediately related to the development of scientific ideas in China. The Mohists studied optics and mechanics, and developed, together with the Logicians, the fundamentals of a scientific logic[59]. They discussed the different forms of acquisition of knowledge: through hearsay, by inference, by direct observation, and by deliberate action, that is, by experimentation[60]. The Legalists, who flourished around 300 BC, preached in favor of laws that would strictly determine human conduct, and came close to the concept of laws of nature. They also contributed to an incipient scientific attitude with their preoccupation with measure and quantification[61].

According to an anonymous manuscript at the time of the Han dynasty (206 or 202 BC to AD 220), Chinese mathematical knowledge included the computation of areas of geometric figures, volume of prisms, pyramids, cylinders, the solution of equations of the first degree, solution of systems of linear equations, and application of Pythagoras' theorem.

The Chinese studied the properties of magnets from a very early date, and also developed the first applications of magnetism*. The first written record on the magnet is found in the *Lü Shih Chhun Chhiu* ('Master Lü's Spring and Autumn Annals'), written by a group of scholars and published in 240 BC, in the Chou period. It describes the property of the lodestone and asserts[62]: "The lodestone draws to itself iron particles." Other texts contain further observations on the lodestone: for instance, that it does not attract other metals or non-metallic objects[63]. As in this quotation from *Huai Nan Tzu* ('The Book of the Princes of Huai Nan'), written before 120 BC: "If you think that be-

* This section relied heavily on J. Needham's monumental study *Science and Civilisation in China*, see Further reading and Ref 56.

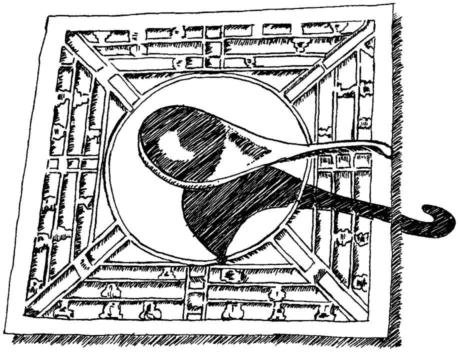

Figure 1.3 Chinese divination board with "south-pointing spoon" made of magnetite.

cause the lodestone can attract iron you can also make it attract pieces of pottery, you will find yourself mistaken. (...) Fire is obtained from the sun by the burning-mirror, the lodestone attracts iron, crabs spoil lacquer, the mallow [malvaceous plant] turns its face to the sun. Such effects are very hard to understand." Also, from the same book: "Some effects are more pronounced at short range and others at long range. Rice grows in water but not in running water. The purple fungus grows on mountains, but not in stony valleys. The lodestone can attract iron but has no effect on copper. Such is the motion (of the Tao)."[64] And from the *Lun Hêng* ('Discourses Weighed in the Balance'), book of AD 83: "Amber picks up mustard-seeds and the lodestone attracts needles."[65]

In the 3rd century BC, the Chinese used a diviner's board for fortune telling. It consisted of two parts, the upper one (circular) representing the heavens, resting on a square board representing the Earth, with divisions corresponding to the compass points. The diviner threw small stones or figures onto the lower part, and told the future from the positions they occupied. Among the figures used, one represented the constellation of the Great Bear (The Northern Dipper), in the shape of a spoon, made of wood, pottery or stone. In the 1st century AD, (and possibly even earlier, in the 2nd century BC) the spoon was made of lodestone, and from its behavior, became known as the 'south-pointing spoon' (Figure 1.3). This was the first example of an application of the property of a magnet of orienting itself in the Earth̀s magnetic field. A remark on the property of this spoon is found in the *Lun Hêng*[66]: "But when the south-controlling spoon is thrown upon the ground, it comes to rest pointing at the south." Chinese texts also mention a cart with a figure mounted on it that always pointed to the same direction. According to Needham, this had nothing to do with magnetism; it was a purely mechanical device[67].

In the 1st century AD lodestones mounted on a pin, which allowed them to turn more freely, were common; in the 7th or 8th century, iron needles magnetized through contact with the lodestone substituted the pieces of rock, becoming the first needle compasses. The application of this early compass to navigation may have occurred in the 10th century, but the instrument was certainly being used by the 11th century. The first Chinese description of a magnetic needle compass is from around AD 1080, 100 years before the first European written records of such devices[68]. One of the first Europeans to discuss the use of the compass was the Englishman Alexander Neckam (1157–1217), in his book *De Nominibus Utensilium* ('On the Names of the Tools'), written around 1175–1183.

Magnets in Pre-Columbian Mesoamerica

The first complex culture that appeared in the Americas was that of the Olmecs, in about 1200 BC, centered in the coastal areas of Mexico, in the present states of Vera Cruz and Tabasco. The main sites are along the Gulf of Mexico: San Lorenzo, La Venta, Laguna de los Cerros and Tres Zapotes. The Olmec culture attained a high degree of sophistication, with a knowledge of building techniques and the manufacture of implements. They influenced the later civilizations that developed on the continent, especially the Aztecs and the Mayas.

The Olmecs left impressive archeological remains, the most remarkable being their characteristic colossal stone heads, weighing over 15 tons; some sixteen of these have been found. The Olmec society was able to mobilize manpower on a large scale for building and earth-moving work. The stone for some of the heads was quarried some 80 km away, in the Tuxla mountains, floated down a river and dragged overland, a feat in itself.

Archeologists have found Olmec objects made of iron ore, dating from the Early Formative period (1500–900 BC) in sites in San José Mogote and San Lorenzo[69]. These are small polished plates or mirrors, plane or concave, up to 10 cm (4 inch) in diameter, which were apparently used as body adornments[70]. It is quite possible that the manufacture of the mirrors made of magnetite could lead to the observation of magnetic behavior, for example, the adherence of the residues resulting from the process of cutting and polishing the objects.

One of the most interesting Olmec objects, found in strata dated 1400–1000 BC, was a polished bar of 3.5 cm (1 1/3 inch) that is magnetic, and has led to speculations that this was the earliest known compass[71]. If true, this would mean that the Olmecs had anticipated the Chinese by more than one thousand years.

Further evidence that the Olmecs knew about the properties of magnetic ores was the discovery in the coastal plain of Guatemala of a statue of a jaguar with magnetic poles in each raised paw, and a crude statue of two seated men made of a single block of stone, with magnetic poles on either side of the navel. The latter statue is dated from 2000–1500 BC, therefore it would represent the oldest known magnetic artifact in the world[72]. In Izapa, in a site corresponding to the Late Formative period (300 BC-AD 100), a carved stone turtlehead of 1.1 × 1.2 m (45 × 48 inch) that is also magnetic was found, with one of the magnetic poles coincident with the snout of the animal[73]. Although the magnetization through the impact of lightning is a possibility, it seems unlikely in view of the significance of the location of the magnetic poles in the different objects.

Roman Sources

The expansion of Rome in the 3rd and 2nd centuries BC led to the Roman occupation of the Greek towns in the South of the Italian peninsula, after the Pyrrhic War (280–275 BC), and later, after the Macedonian Wars (214–148 BC), assured complete control of Macedonia and mainland Greece. The Romans incorporated the achievements of Greek culture in the arts, in philosophy and in science. However, no blossoming of creative ideas to match the Greek phenomenon is recorded. A representative of the scientific tradition of the Roman world was the philosopher Lucretius (c.98-c.55 BC), already mentioned. He described in his book *De Rerum Natura* ('On the Nature of Things') some properties of the magnet, and how its power can be felt through a metallic obstacle: "I have seen Samothracian iron rings even jump up, and at the same time filings of iron rave within brass basins, when this Magnet stone had been placed under; such a strong desire the iron seems to have to fly from the stone.“[74]

Another important Roman author was Pliny the Elder (AD 23–79), also quoted above. He was a writer and an investigator who left several treatises, the most famous of all being the Natural History. Pliny showed a deep interest in the magnet, for its “striking properties“: “For what phenomenon is more astonishing? Where has nature shown greater audacity?”[75] He describes the types of magnetic stones, distinguishing them as ‘male’, or ‘female’, according to the strength of their magnetic effects. He even speaks of a mythical stone from Ethiopia – *theamedes* – that “repels every kind of iron“[76]. He tells tales of two mountains near the River Indus, one that attracts iron, other which repels it. Therefore, if a man has nails in his shoes, on one mountain “at each step he is unable to tear his foot away from the ground and on the other he cannot put his foot down[77]”.

The only way one can observe repulsion with a magnet, of course, is by approaching another magnet, with North pole near North pole, for example. There appear to be no reports of interaction between magnets in the ancient texts, and consequently no genuine observation of magnetic repulsion[78].

“There is a stone, colorless and without brilliance, (...) but it is preferred to all the most precious products of the Orient by those who know it virtues and its wonders.“ Thus wrote another Roman author, the fourth-century poet Claudian, or Claudius Claudianus (c. 370-c. 404) in a text[79] that extolled the magic qualities of the magnet. He continued: “Iron gives it life; iron recognizes and nourishes it; when the iron is withdrawn, it experiences the torments of hunger and thirst; it dies (...) Iron and the loadstone are drawn together and united. What can be this subtil flame which, entering these two metals, can give rise to this sympathy? What is the unknown charm which can unite them with a common will and a single desire?”

When Greek science entered a declining phase after the 2nd century AD, its tradition was continued by the Arabs, whose scientific thought was strongly patterned after the Greeks[80]. Their scientific contribution will be discussed in Chapter 2.

The next great step in the development of scientific explanations, after the Greeks had laid the groundwork, required a new critical attitude, a scientific revolution that enthroned the experimental method and the criticism of the classics as prime tools in the search for knowledge, in the 16th and 17th centuries. A revolution that brought with it a new view of the universe, with the Earth at the same time integrated into it, and removed from its privileged position.

Further reading

J. Barnes, *Early Greek Philosophy*, Penguin, London, 1987.

M. R. Cohen and I. E. Drabkin, *A Source Book in Greek Science*, Harvard University Press, Cambridge, 1966.

W.K.C. Guthrie, *A History of Greek Philosophy*, vol. I, Cambridge University Press, Cambridge, 1967.

J. Needham, *Science and Civilisation in China*, vol. 4, part I, Cambridge University Press, Cambridge, 1972.

J. M. Roberts, *The Penguin History of the World*, 3rd edition, Penguin Books, London, 1997.

C. A. Ronan, *The Cambridge Illustrated History of the World's Science*, Cambridge University Press, Cambridge, 1984.