CHAPTER I

The beginnings of Greek scientific thinking

SYNOPSIS OF MAIN HISTORICAL EVENTS AND OF CONTEMPORARY THINKERS

Thales of Miletus c. 620-c. 550 BC, Anaximander c. 610-c. 540 BC
612 BC Niniveh is conquered by a coalition of Medes, Babylonians and Persians.
610 BC Ciassarres of Media destroys the last Assyrian king Asur-Uballit of Harran.
585 BC war between the Medians and the Lydians, battle on the river Halys, supposed eclipse announced by Thales and peace between the Medians and Lydians. Solon dictates the new Athenian constitution.
Anaximenes c.580-520 BC; Pythagoras of Samos c. 570-c. 500 BC
561-528/27 BC Pisistratus rules Athens. Final editing of Homeric poems.
550 BC Cyrus the elder creates the Persian empire and conquers Media.
547 BC battle of Pteria and end of the Lydian kingdom, Miletus is allied with the Persians.
Heraclitus (c. 540-c. 475 BC), Parmenides (c. 520-c. 430 BC)
539 BC Cyrus conquers Babylonia and in 538 BC authorizes the reconstruction of the Temple of Jerusalem. Ezra and Nehemiah begin the collection of the Biblical texts.
530 BC Cyrus dies while campaigning against the Sacae (Scythians).
530-522 BC Cambyses king of kings; in 525 BC defeats at Pelusium the Pharaoh Psammeticus III allied with the Athenians and unites Egypt to the Persian empire; however, in the next two centuries Egypt repeatedly regains temporary independence.
522-521 BC Persian civil war, Darius I becomes king of kings.
511 BC the Crotoniates, led by the Pythagorean sect, attack and destroy Sybaris.
Alcmeon of Croton (c. 510-c. 440 BC)
510 BC Hippias is expelled from Athens by Athenian exiles supported by Spartan troops and with the political support of the Oracle of Delphi.
507 BC Athens allies herself with the Persian satrap Artaphernes against Sparta.
500/499-497 BC the Ionian towns revolt against the Persians, only Athens and Eretria send help, but only unitl 498 BC.
495 BC battle and destruction of Miletus.
491 BC the Persian ambassadors who were asking for the submission of these towns are massacred in Athens and Sparta, marking the beginning of the first Persian war.
490 BC the Athenians and Plateians defeat the Persian army led by Hippias, Datis and Artaphernes at Marathon, the Spartan army arrives a few days later.
Anaxagoras of Clazomenae (c. 500-c. 425 BC), Aeschilus (525-456 BC), Sophocles (496-406 BC), Euripides (480-406 BC), Zeno the sophist (c. 495-c. 440 BC), Protagoras (490-420 BC), Gorgias of Lentini (c. 490-c. 420 BC), Empedocles of Agrigentum (c. 480-430 BC)
481 BC beginning of the second Persian war.
480 BC at Salamis the Greeks defeat the Persian fleet, simultaneously the Syracusans defeat at Hymera the Carthaginians, allies of the Persians.
479 BC decisive victories of the Greeks on the Persians at Plathaia and Mycale.

Alberto Mario Simonetta, *Short history of biology from the origins to the 20th century*, ISBN 88-8453-108-X

465 BC Xerxes is killed, civil war in Persia.
467-428 BC Age of Pericles.
449/48 BC peace of Callias, the Persian empire acknowledges Greek supremacy in the Mediterranean, Delian league and pre-eminence of Athens.
Leucippus (c. 450 BC), Socrates (470-399 BC), Democritus of Abdera (c.455 BC).
431-421, 413-404 BC Peloponnesian wars.
412 BC Sparta allies herself with Persia and, supported by Persian gold, finally beats Athens, which surrenders in 404.
399 BC trial and death of Socrates.
386 BC "Peace of the King": the Greek states submit to the arbitration of the Persian king.
Architas of Taras (a. 388-p. 360 BC), Philolaos the Pythagorean (c. 495-c. 395 BC), Plato (429-356 BC)
359-336 BC Philip II is king of Macedonia.
338 BC battle of Chaironeia and Macedonian overlordship of Greece.

Factors which allowed for the development of speculative thought

Before we begin the actual study of the development of Greek thinking, we must first note that, to our present knowledge, this conceptual approach is the only one in antiquity to develop a precise interest in logically rigorous abstract generalisations and for an argumentative treatment of problems.

Scholars who studied the origins of philosophical speculation have often underlined the significance that – in the process – may have had both linguistic and political factors.

It is impossible here properly to discuss either of them, but we may well briefly mention some considerations.

Such scholars who maintain the significance of linguistic factors, have remarked that while other ancient languages, such as classic Hebrew, have both an extremely simple grammar and syntax, in Greek the precise meaning of names in a sentence is defined by both article and declension and that verbs are especially complex. Thus, whenever a common name is united with an article, the meaning is automatically restricted to one or a few, precisely identified, individual objects or beings, whenever no article is used the same word signifies the whole category or class of objects which may be called by that name. At the same time the niceties of verbal flection, such as the use of dual or of aorist, allow for an extreme precision of speech. Obviously this does not mean that the interpretation of a text never poses problems, especially when, as it often happens with philosophical works, they survive as isolated quotations. The significant thing is that, as a language is the work of a whole people, the Greek language testifies, as such, to a generalised interest in clear, unambiguous speech and for the possibility of abstract thought.

As far as politics are concerned, the socio-political organisation of the Greeks is characterised by a more or less early, general evolution towards democratic assemblies. Even the Homeric poems show us chiefs who have to account for their actions at pop-

ular meetings or have to argue and persuade numbers of people in order to win their support for their plans.

We do not know whether this already occurred in Mycenean times, but the arts of persuasive oratory and of clear argument were already vital in archaic Greece. This implied logical argument as a necessary tool in debates in the assembly, and this is a natural premise to an argued philosophy and science. Indeed, traditions indicate that most of the older philosophers were leading political figures in their towns: were they eminent politicians because they were natural philosophers or was it the habit of political debates that led them to debate natural truths as well?

To all this we must add a peculiarity of Greek religion: the Greeks lived in a number of entirely independent communities; this clearly favoured the development in each community of local varieties of even the most widespread myths, whereas the lack of a "sacred book" and of an organised and hierarchical clergy made it difficult to charge people with heresy. Such a charge was posed in a few instances, but, as a general rule, thinkers felt free to propose new interpretations and elaboration of traditional myths (as is amply proved by dramatists and comedians) or to propose entirely new myths. In fact when objectively considered, the so-called "scientific theories" of the early philosophers are nothing but myths, as we shall see further on.

Finally, and we shall return to this point as well, the special significance that the "impassible Gods" had in Greek religion must be minded as well. These Deities maintain the laws of the "cosmos", of men and destiny. They watch the order of the universe, can not be prayed to and to them even Zeus must bow.

Greek philosophy and biology before the times of Aristotle; the archaic Greek world

We do not know when Greek thinking began, but it undoubtedly has developed a first precise character and organisation in the Homeric poems.

We now have a precise *terminus ante quem* for the final redaction of a Homeric text in the quotation of some verses in an inscription from Ischia dated 720 BC, almost 200 years before the traditional date of the collation of the texts during the rule of Peisistratus in Athens (around 550 BC), and the fact that it comes from an island off the coast of Southern Italy proves that their knowledge was widespread.

Indeed we can not be certain of how much Homer testifies to the Helladic tradition and how much it portrays the Greek world of the IX-VIII centuries BC. Most modern scholars believe that Homer did in fact know very little of the life and times of the Mycenean lords. However the Mycenean texts, though mere administrative documents as they are, show that he did indeed know something of it, and, most significant, they bear witness of a clearly Greek people. The texts of Pylos etc. are in fact written in an exceedingly archaic Greek, but nevertheless in an unquestionably Greek

language. Besides administrative matters, they relate the names of many Gods, including many of the Olympians and even Dionysos, the god of knowledge alternative to that of Apollo (and that has, incidentally disposed of a time-honoured theory that, as Homer does not mention this God must have entered Greece at a comparatively late date, after the compilation of the Homeric poems).

In recent years some scholars have maintained with good arguments and on the evidence of the decoration of some Mycenean jewels, that the Myceneans must have been familiar with some theorems on the circle and on the hexagon all somewhat more advanced than those known to contemporary Babylonian mathematicians.

However it is significant that what is usually defined as philosophic-scientific thinking, only very gradually distinguishes itself from mythologic tradition (in the literal meaning of a tale or argument about Myths), the two being completely separated in but a very few thinkers before the Hellenistic times.

The first schools of Greek philosophy

Though it is usual to preface the study of the Greek contributions to the sciences by a consideration of what in the various disciplines had been achieved by Egyptians, Sumerians, Assyrians and the other peoples of the Near East, I shall not follow this habit.

From the beginning of history and long before it, all peoples, during their long history, collected a considerable amount of empirical knowledge, and even the oldest surviving texts often mention different animals and give us an account of various medical practices which require a precise knowledge of the pharmaceutical properties of different plants and minerals, of anatomical and physiological data etc. However, all this knowledge, albeit codified and, occasionally, generalised to some extent, is always devoid of any speculative content, as, vice versa, is usually the case with Greek culture. The Greeks eventually derived such information from their neighbours (it was, indeed, an established tradition that the first great Greek thinkers, such as Thales, Pythagoras, etc., had learnt much of their knowledge during their true or supposed voyages in the lands of the Barbarians). However the Greeks were able to reshape it in the guise of theoretical generalisations, which can only be considered the forerunners of proto-philosophic and scientific thinking. At all events, there is very little that can be considered as 'biology' in what we know of the thoughts of the Greek philosopher-scientists preceding Aristotle.

First of all, it is clear that to all presocratic philosophers the distinction between the world of living organisms and that of inorganic, non-living, matter was either obscure or has definitely to be ruled out.

The obvious character which allows these philosophers to separate living from non-living things was the fact that living things are 'self-moving' whereas non-living

objects and corpses have to be moved by something outside them. Now such a criterion was equivocal (to Thales, among others, the lodestone was a living being as it was able to move itself towards an iron object) and left an ambiguity of somewhat intermediate objects, such as eggs or seeds. On the other hand, as they could not explain the apparently spontaneous movements of inorganic bodies, such as earth, water, and especially wind, they naturally tended to attribute them to the whims of 'personalities', perhaps different from those responsible for such 'rational' movements as those of the celestial bodies. As a result we must deem that Thales' statement "The world is full of Gods" is a perfectly rational one.

We must here stress an observation that has had a very lasting significance in the biology and physics of the Greeks: death can easily be identified with the ceasing of breathing, and winds may well look as the breath of the world, on the other hand there is no motion apparently more spontaneous than wind, and its motion moves the seas, the clouds and any other sufficiently light body.

The Greek word 'Pneuma' (πνεύμα) (and of 'pneuma' we shall have much to say) does not mean breath as the act of breathing or the blowing wind, it means 'the breath', independently from what is actually breathing. Thus the concept of 'pneuma' will slowly evolve through the centuries, but it will always remain an important concept in all biological and physical Greek theories.

In order to understand Greek science, philosophy and religion, two other concepts are significant: namely that of 'Noús' (Νοος) and of 'Nomos' (Νόμοζ). Taken together they characterise all that is rational both in men and in the cosmos: This, in the end, was the basis of the progressive identification with Gods of many celestial bodies, who, with their unchangeable and mathematically perfect movements, tell the times of terrestrial events.

All the points raised in the previous sentences, are already implicit in Homeric poems, which are the oldest surviving documents of archaic Greek thought.

Indeed in Homer the word 'soma' (Σώμα), body, is used only for corpses. Living beings are always described by means of their 'composing parts', such as legs, arms, head etc. and of their, so to say 'active parts': Thymos (Θύμοζ), Nous and Psyché (Ψυχή). Thymos is that something which is responsible for emotions, while Nous is what is rational and conscious. Lastly Psyché (literally 'breath, puff', but also 'butterfly') is that which makes an individual alive and, in men, their only immortal part. Thus we often find sentences of the type "he was willing to do that, but his thymos paralysed his legs". On the other side, while 'thymos' is shared by men and animals, 'Nous' is common to men and Gods. We shall see how these ideas were significant in later discussion of the "vegetative soul, the appetitive soul and the rational soul", which had a great influence on the development of systematics, embryology etc. and that are still implicit in many extant legislations.

The fact that 'Psyché' and 'Pneuma' are to some extent synonyms led to a line of thought, which began with a fragment of Anaximenes written around 546 BC and

which literally reads "Just as soul (psyché) is our air (pneuma) and keeps us together (but one may also translate "controls us") by that, so air and breath keep together (or "control") the whole world". It then passed through stoic and neoplatonic philosophers, and had a considerable impact on the development of the ideas of the relationship between Macro- and Microcosmos and went into vitalism down into the 20th century.

Obviously the Greeks could not overlook the significance of the relationship between the 'soma' (material body) of living beings and non-living bodies. So we shall shortly begin to consider the evolution of concepts concerning the nature of what is 'material' in the world, and more properly the increasing credit of the theory of the four 'stoicheia' (singular Στοιχεῖον), commonly translated as 'elements', but more properly 'material principles'.

According to the essentials of the theory; all objects including the bodies of living beings, are composed of matter, and in this we can identify a certain amount of dry substance, that is of 'earth', mixed with a certain amount of 'water'. The breath or vital pneuma ('air') gives them life, and as they are moderately hot, they must contain also some 'fire'.

In fact the theory of the four elements: earth, water, air and fire and of the four qualities, opposed two to two, heat and cold, dampness and dryness, was expounded by Empedocles, but has almost certainly much older roots. It was finally developed fully by Aristotle (and, as we shall see, while it was accepted by many, it was questioned even by Aristotle's friend Theophrastus). Furthermore, the theory had a great importance in the whole development of sciences until modern times.

All the hypotheses advanced by ancient peoples in order to explain the origin and nature of things are myths, and it is fascinating to follow how the ancient cosmogonies of purely religious pattern (at least in the sense we currently give to these terms), such as those of Hesiod, gradually change because of the unstated growing requirement of empirical plausibility, and eventually become what we may term as scientific hypotheses or theories. The Gods, not only for what concerns the first origin of things, but as rulers of the present course of phenomena, change from somewhat whimsical players with things and men into the rational guardians of a universal Nous.

Greek religious attitude was particularly apt for this change as, even since our earliest testimonies, the Impassive Deities: Ananke, the Moirae, Dyke, Themis, who all may be subsumed under the Latin term of 'Fatum' (=that which must be and cannot be otherwise), must be obeyed even by Zeus.

There is no doubt that since the earliest times the Greeks were quite convinced of an ambivalence in the relationship between the individual man and the events which befell him: man may well make his choices, but this only within the limits of what has been decreed by the impassive Deities, first of these Ananke, and the Moirae, and by the 'laws': Themis and Nomos. A choice different from the one so expected was

indeed possible, but it was the supreme offence (hybris) upon the Gods and the implacable Nemesis was there to punish it. In this context the reply of Achilles to Thetis, who is urging him to avoid his destiny leaving alone Hector and Troy, is typical: "Should I do it, I would no more be Achilles!".

This attitude almost naturally led to the belief in the existence of immutable laws in the universe, a concept that is the very core of all scientific thinking as we conceive it. The alternative is occasionalism, which was, indeed, advocated by quite a few Christian and by many Islamic thinkers. They maintained that everything that happens is directly the doing of God, who plays with men and things as puppets and that God's laws are not really laws, but simple sequels of events that might be changed at any time by God's will[1].

Starting from the religious beliefs that we have summarised, Greek thought developed and, not surprisingly, reached its greatest achievements in Mathematics and Astronomy, fields where, because of the extreme regularity and comparative simplicity of phenomena, the implementation of a rigorous conceptual framework could better succeed.

Chemistry and Biology approached themselves to the ideal models of science only later and to a limited extent because of the complexity of biological phenomena, and, in the case of chemistry, because of the difficulty of quantitative controls in the absence of sufficiently precise instrumentation.

Aristotle is quite clear in his distinction between science and empiricism; he maintains that science (or philosophy) is the asking and answering the questions of how and why the observed phenomena happen, while empiricism merely observes the phenomena and possibly cares for the practical utilisation of the observations.

We must here remind the reader of a special difficulty in the understanding of the early Greek philosophers. This is that, in order to explain their ideas, they usually use comparisons with familiar phenomena, and it is not clear whether they thought of these comparisons as real analogies or as rough approximations.

So, for instance, by the statement of Empedocles that sounds are moving air that hits inside our ear onto a membrane hanging "like a rattle", it is not clear whether he did in fact know of the tympanum and had made a shrewd guess at its working, or whether his was a fantastic idea such as the kind of connections that he believed to obtain between the eye, fire and vision.

The oldest Greek philosophers called themselves 'physiologists', from the Greek words 'physis'[2], that is Nature and 'logos', discourse, meaning that they were arguers

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[1] On this we have a curious *Quaestio quodlibetalis* by St. Thomas Aquinas: "Can God restore virginity to a girl who has lost it?", The answer being that though he may indeed restore the physical features of it, even God can not cancel the fact that such loss had happened

[2] φὐσιζ is a term that, in the oldest authors, like Hesiod, derives from the verb φυναι that means to give birth, to generate, thus it is used literally with the meaning of 'birth of things'.

about Nature. And, indeed, their main problem is the origin and nature of things. It was only much later - and when it had already reached a high complexity - that philosophy became interested in other problems, such as that of the nature of the human mind, of the principles underlying knowledge, and of morality. Anyway, the problem of Nature, including biology, is always the foundation of Greek philosophy, even in those schools that left it rather in the background.

Ionic philosophers

A time-honoured and amply justified tradition rooted in Aristotle's writings considers that philosophy began with the teachings of three Milesian thinkers: Thales, Anaximander and Anaximenes.

In Thales' times many Greek towns flourished along the coast of Asia Minor. These were most, but not exclusively of Ionian origin, and originated by the wave of settlements which occurred in the wake of the 'return of the Heraklids', that is the Doric invasions, which apparently caused the collapse of the Mycenean civilisation. Such colonisation had been further enlarged and strengthened by new settlements during the great age of colonial foundations in the 7th century BC.

A sort of symbiosis had developed between the Greek cities of Asia Minor and the kings of Lydia. Miletos was probably the richest and more powerful of them.

However, though in 585 BC the Lydians had succeeded in throwing back a first onslaught by the Medians (battle of Halys); forty years later, in 545 BC, Croesus, king of Lydia, was attacked by the Persians, a new power who, after co-operating with the Medians and Babylonians in the destruction of the Assyrian kingdom, had turned against their former allies, had crushed them and had embarked on a course of unlimited imperialism. The tradition relates that Thales, in his time, had advised the Greek towns to support the Lydians; nevertheless the Greeks either remained neutral or actively supported the Persians, and, when the Persians crushed the Lydians (battle of Pteria), they discovered that they had exchanged a peaceful neighbour with an oppressive power who would, at most, leave them limited autonomy.

At this point the Greek towns rose in arms, gained some limited support from Athens and a few other towns from the motherland, but were equally beaten and in 494 BC Miletos was temporarily destroyed.

This is the historical framework in which the early Ionic philosophers operated. As with many other Greek philosophers, we do not know the dates of their birth and death: the Greek historians did not care about such things and they tell us, instead, when was the "Acme", that is the culmination of the activities of the person they quote.

Thus the Acme of Thales, son of Praxiades, was around 580 BC, and we, therefore, presume that he may have been born around 620 and died around 545 BC The

Greeks themselves did not know of any writing of his, but they traditionally credited him with some geometrical theorems and said that he maintained that the Cosmos is an ordered and intelligible system.

Apparently Thales was the first to think that everything was the embodiment of a single material principle or 'Arché', and he supposed that this was water. His idea brilliantly developed an old tradition, which is clearly expounded in the Homeric poems, where it is stated that the Earth is surrounded by Oceanus and that its movements, including earthquakes, are due to the aquatic God 'par exellence', Poseidon.

Apparently Thales conceived all matter as potentially animated and he especially considered the lodestone (natural magnetite) as fundamentally a living thing, because it was capable of self-movement towards iron objects. It is typical of this kind of trend in thought both to study the rationale in Cosmos, as the foundation of all scientific research, and to cry "the world is full of Gods!"

Anaximander, a junior fellow citizen of Thales (born perhaps in 610 and died around 540 BC) held the same basic feeling, later termed ilozoism or ilopsychism.

Anaximander held that the basic substance of which the universe was built could not be defined. He thought that whatever substance you choose it implies the exclusion of 'something'. Therefore he calls the basic substance 'Apeiron', that literally means 'without limits', a universal substance which is the substratum of everything. According to Anaximander things become identifiable by the opening of spaces or by the emerging of quantities inside the Apeiron. It was starting from this hypothesis that he imagined a complex cosmogony and from this he developed a chain of hypotheses which explained every phenomenon.

As to the origin of living beings, as far as we can gather from the quotations of later scholars and especially of Aristotle, he had some precise ideas. Anaximander believed that there was a progressive desiccation of Earth. Living beings came from a primaeval mud which originally covered the whole Earth. First animals and plants were formed, then mankind. Both men and animals originally lived in water and were sheathed by a scaly cover. When they left the water, the terrestrial animals lost the protective shell. Clearly this hypothesis was needed considering that had the first terrestrial animals and especially man been born from earth as they are now born from their mothers, they could not possibly have survived by themselves, therefore they must have first emerged from water as adults. We do not know whether Anaximander derived this idea from the observation of the metamorphosis of tadpoles into frogs.

Some scholars have argued that the ideas of Anaximander foreshadow some evolutionary ideas. Neither the surviving fragments of Anaximander, nor the accounts that later authors give of his idea provide any support to this interpretation. In fact the name of Anaximander creeps up in some discussions on transformism in the 18th and early 19th century, but as a gratuitous assumption.

Anaximenes was also a Milesian and a pupil of Anaximander, and his Acme is around 550 BC. He considered Air as the Arché, but this was in the sense that he saw

in air both the limitless Apeiron and the principle of life and movement. So his is the first formalisation of the pneumatic theory. We have no idea of what Anaximenes thought about living beings.

Now that Miletos was conquered and destroyed by the Persians, and the cultural centre that had been there did not survive. Yet the Ionic school had some late followers. Among them we must mention Diogenes of Apollonia, a Cretan physician, who lived around 430 BC (to be distinguished from Diogenes of Sinope, the famous cynic philosopher). Diogenes of Apollonia is said to have made both anatomical and embryological researches. He described the ramifications of the vascular system in Man (or, more probably, in some mammals) and his description survives. He also studied the development of the embryo in the uterus. Diogenes is also known as 'the eclectic', as he attempted a synthesis of the various Ionic theories, mainly following Anaximenes, with the Eleatic theory of an immutable cosmos; he is a convinced pneumatist. For him the principle of everything is Air, an increate substance, unlimited and rational. Thinning air gives rise to fire, whereas by condensation it changes both into water and earth. The air is also the soul and as such the principle of life and movement. Warm air, not as hot as the sun, but warmer than atmospheric air, flows in the vessels and heats the body. All living things, Man included, originated from mud under the influence of the sun's heat. All differences among things result from minor changes in the basically immutable air, by the action of different qualities; these are relative to each other and to the observer. So, for instance hot is relative to cold, and, anyway different persons will judge differently about how hot or cold a thing may be.

Another physician, contemporary of Diogenes is Hippo, and we know that he made embryological observations and that, as Thales, he considered water, or rather dampness, to be the principle of life.

Pythagoras and the Pythagoreans

The Pythagorean school was begun by Pythagoras of Samos (who migrated to Croton in Calabria and died around 500 BC).

While Pythagorism is extremely important in physics and mathematics, its contribution to biology is a minor one. However, we must still mention the Pythagorean theory of numbers, of harmony and of opposing qualities, as they were relevant to the medical Hippocratic school and also to later medical schools.

Since it was the habit of the Pythagoreans to credit all their discoveries and ideas to Pythagoras, it is impossible to tell apart the contributions of the various members of the sect.

The influx of the Pythagorean ideas on numbers is complex. The Pythagoreans believed that the unit had an objective reality, they thought of it as a sort of numeric 'atom' and that all reality was made up of such atoms. They had remarked that by an

orderly arrangement of points (equated with units), one could build all the regular figures and the combinations of these did produce solid (three dimensional) figures. Among these only four, the so-called 'Pythagorean solids' (the fifth was discovered only much later) were characterised by all equal faces. Thus they thought that these figures, apart from the circle and the sphere, must have a special significance. Most thinkers, therefore, assumed that the elementary particles were either made in the shape of the elementary flat figures (and this was the opinion of atomists such as Democritus), 'things' being made by the assemblage of flat atoms. The believers in the four elements naturally identified Air, Fire, Earth and Water with the four Pythagoric solids.

Quite naturally these guesses, like those on the circle and the sphere in astronomy, had a lasting influence on the evolution of scientific ideas.

As the Pythagoreans studied the laws of consonance of sounds, they evolved the theory of the 'harmony of celestial spheres' (which had such a great significance in directing the work of Kepler towards the discovery of his basic astronomic 'laws'), and this, in turn was a powerful factor in the development of 'humoral' theories in medicine and biology. The four basic 'humours' being yellow bile, black bile, phlegm and blood) were supposed to be the equivalents in living beings of the four elements. Their balance or unbalance determined whether an individual was healthy or sick.

We may conclude that, while the Pythagoreans contributed almost nothing to biology, their physico-mathematical ideas had an indirect lasting influence on medicine and hence on biology. Their other beliefs on the transmigration of souls, their magic prescriptions for living, so dear to the Acusmatic sect of the Pythagorean school, are practically irrelevant in the history of biology.

The school of Elea

Xenophanes of Colophon (who, after journeying through many countries, came to settle in Elea, in Magna Grecia) was both a poet and a philosopher, and is considered as founder of the Eleatic school. Among the philosophers of this school it is Xenophanes who is worth remembering in a history of biology. To support his thesis of the marine origin of all things and of dry lands having gradually emerged from the seas, he quotes some examples of clearly marine fossils found well inland. Apparently he was the first to give a correct interpretation of these finds, which became the subject of lively debate for centuries.

As late as in the times of Steno and Leibniz scholars considered two alternative hypotheses: a) that these were true remains of animals which had once been alive (it does not matter whether they were marine or terrestrial, even though the commonest fossils in Europe are marine). They had been changed into stone by some local power, which was usually called in the Latin texts a *vis* or *virtus petrefaciens*; or b) if one

assumed the possibility of spontaneous generation of organisms from mud, fossils were organisms which had not succeeded in completing their development and had thus remained in a mineral state.

Nothing significant for biology was said by the other Eleatic philosophers, whose chief contributions are in the field of logic.

Other philosophers and scientists

Some other thinkers of relevance, who cannot be grouped under any school's label, deserve some attention.

The earliest is Alcmeon of Croton, who is usually quoted in histories of medicine and of biology and is generally labelled a Pythagorean, because he was a Crotoniate and lived at approximately the time when Pythagoras was active in Croton. Actually we know very little of him. There is no doubt that, as a physician, he was among the earliest students of many anatomical and biological problems, but, although we know which they were, we do not know what he actually thought of them.

Another extremely important philosopher was Heraclitus of Ephesus (born c. 540 BC). He was famous as the advocate of general and perpetual motion and change. His 'Arché' was fire. It seems that he must also have written on problems of biology, but nothing survives of these writings.

We are, however, reasonably well informed on the biological opinions of Empedocles of Agrigentum.

Empedocles maintains the reality of change against the Eleatic philosophers who hold that change is basically an illusion. He also thinks that there are just four roots of things ('stoicheia'): earth, water, air and fire. There are two basic forces at work in the world: the one which mixes and unites and the one that separates and destroys. Both plants and animals were born from earth in a sort of gradual way: first their various parts originated, later these, by the virtue of 'philia' (this is commonly translated as 'love', but its proper translation is rather 'friendship, concord, uniting power') joined between themselves at random. The result was there appeared a multitude of different individuals, many of them monstrous: Most of these individuals were incapable of surviving and vanished, only those which happened to have a well balanced structure could survive, reproduce and now their progeny prospers.

Just as with Anaximander, some scholars claimed that we have here an embryonic evolutionary theory, including the survival of the fittest. Now a true evolutionary concept is impossible for Empedocles, who believed in a series of cycles repeating themselves, where Philia first prevails until the perfectly homogeneous 'Sphairos', the sphere of unity, is achieved. At this point Neikos (Neikos is hostility, quarrel, opposition) gradually gets the upper hand, until everything is again plunged into complete Chaos and from this a new cycle begins. Whether these ideas of Empedocles had any

influence on Charles Lyell's early theories on geological cycles (see chapter X) is debatable.

We do not know much about the anatomical and naturalistic knowledge of Empedocles, but all sources agree in stressing his great interest in the study of living beings.

According to later quotations from his writings he maintained that respiration took place not only through the lungs, but also through the pores of the skin. He argued that during embryonic development the foetus receives some of its parts from the male sperm and other from female's sperm and the two unite as the two parts of a broken ring; growth in young animals depends on the increase in bodily heat, while the weakness of old people stems from on their low temperature. Empedocles maintains that sensations depend on extremely minute particles which become detached from the object and must join with the same kind of particles contained in sensors; he maintains, that each minute particle of in the image that travels from the perceived object to the observer must be perceived by the corresponding particle occurring in the sense organ of the observer; consequently the earthly part of the perceived object is sensed by the earthly parts of the sensory organs of the percipient, the fiery by the fiery parts etc. (this last interpretation is however doubtful, if we rely on a sentence on the nature and functioning of the eye, which is quoted by both Plato and Theophrastus as being by Empedocles).

Heraclitus also believed that thought is a function of the body and that it is located in the blood, as this is the part of the body which is richest in all the different elements.

It is clear that Empedocles' ideas were pure guesses, but though guesses, they testify to a genuine interest in the mechanisms of life. I must, however, stress that many modern historians of philosophy have falsified the true attitude of Empedocles, describing him as a materialist. We have enough of his fragments concerning the Gods to show that while, in true Greek style, Empedocles considered them as parts of the Cosmos, nevertheless he mentions them with veneration, and especially Aphrodite, who, rather than Philia, is often recalled as the cause of union and harmony.

Traditionally the last philosopher of the Ionic trend was Anaxagoras of Clazomenae (c. 500-428 BC), who lived and worked mainly in Athens in close association with Pericles. It appears that the political enemies of Pericles charged him of impiety just because of their friendship in the same political campaign which saw Pheidias charged with theft. To avoid prosecution at a delicate political moment, Anaxagoras fled Athens and went to Lampsacus, where he died shortly afterwards. It is said that when he was dying the town's magistrates asked him how they could best honour his memory, and he replied that he desired that on the anniversaries of his death, schoolchildren should get a holiday, so that they could joyfully remember him.

Anaxagoras was undoubtedly a true naturalist in the widest sense. Thus he extended the ideas of the Milesians in astronomy, and maintained that the Sun was a burning stone larger than the Peloponnesus and that it was further away than the Moon,

but nearer than the stars. He held that meteorites were fragments of celestial bodies which had been detached from their originating planetary body by some earthquakes and that light was generated during their flight by the heat of the vortex of air they were crossing (an idea probably suggested by the familiar heating of a wheel or disc rotating on a spike).

Anaxagoras developed some ideas concerning biology in order to answer to some of the logical difficulties which had been raised by the Eleatics. Anaxagoras assumed that, instead there being just one or a few 'Arché', substances were infinite and immutable. However they were composed by an infinite number of infinitely small particles, which he called 'sperms' (literally 'seeds'). The visible changes in things were simply due to the disaggregation and re-aggregation of sperms. So, for instance, when we eat, our organism chooses among all the innumerable sperms which are in the food, in Anaxagoras' example bread, the sperms of meat, of hairs or of bones and assimilated them in their proper place. To us the interest of this hypothesis is double: on one hand it introduces for the first time the idea of a particulate universe, which was later developed by the atomist Democritus of Abdera, on the other it is a first approach to the concept of Homoiomery, which was developed by Aristotle and which brought the Stagirite pretty close to the concept of tissue, such as was envisaged by later biologists between the 18th and the 19th century (see chapter X).

Another important step made by Anaxagoras, developing previous ideas, was his concept of the Nous as a principle of movement provided with a natural rationality and that, as it occurs everywhere in the cosmos, explains its natural order. This last concept gained him the nickname 'Nous', and is the original core of the concept of Universal Pneuma of the Stoics.

As for the other biological views of Anaxagoras which are quoted in our sources, there is little that is new: he follows the common opinion that all living beings originated from mud which had been fertilised by appropriate sperms coming from the air or from the ether.

The atomists

As we have seen, to say that the Greek philosophers were sanguine in suggesting their explanations of the basic natural history problems and on the past and future story of the Cosmos is certainly, by modern standards, a blatant understatement. Indeed they had absolutely no way of verifying their ideas. However, great is our debt to their unflagging optimism, as the credit they won in the minds of later scholars led these to reinvestigate with much more adequate techniques their daring hypotheses and find that a number of them happened to have almost hit the target. Among such pioneer theories the atomic one of Leucippus and Democritus is unquestionably among the most historically significant.

Leucippus may be practically dismissed as we do not know anything of him except that he was the master and inspirer of Democritus. Unfortunately exceedingly little survives also of the vast production of Democritus of Abdera (c. 460-360 BC), but both his critics, his Epicurean admirers and the doxographers (= writers who collected and recorded the opinions of the ancient Greek philosophers) of Roman and Byzantine times relate most of his ideas, except, unfortunately, for those on biology.

By tradition he was a pupil both of Leucippus and of Anaxagoras.

Democritus held that the universe was made of atoms and vacuum. Atoms are extremely small, but yet they have a precise size and shape and the number of these shapes is limited. It seems that he conceived this number as corresponding to that of the Pythagorean solids and the sphere or, rather, of the flat figures which made up these solids. So they came to correspond in number to the traditional 'stoicheia'. If he conceived of flat atoms, than the various kinds of matter would result by their assemblage into regular and irregular solids. Just as Anaxagoras with his spermata, in order to meet the requirements of Eleatic logic, Democritus assumed that the atoms were unchangeable, eternal and indivisible and the substance forming each one of them is homogeneous in that it is the basic 'undefined matter', only their shape and size are different. They move spontaneously at random in an infinite vacuum (an idea probably suggested by the sight of the fine dust particles dancing in a sun's ray). Matter is neither created nor can it be destroyed and nothing exists but atoms. All properties and changes in visible things depend on the movements and chance aggregations of various kinds of atoms.

In addition actions at a distance, like the influx of the lodestone, are due to atoms and our sensations are also due to them, Soul itself is made up of round and smooth atoms, like those of fire.

The Democritean cosmos is both rigidly mechanistic and stochastic, and it even forecasts the continuous formation and disintegration of other worlds. Most subsequent philosophers, first and foremost Plato (who wished the total destruction of Democritus' writings; which did in fact occur probably as a result of the merging of Christian and Neoplatonic trends in late antiquity) hated Democritus. However Aristotle, though basically dissenting from Democritus, had a great respect for the Abderite.

For anti-Democritean philosophers, who were in the majority until the 18th century, the cosmos appeared as a basically harmonious construction, where everything had a precise meaning and purpose, something which looked incredible, should the world have a basically stochastic origin. Anyway, just in the field of biology, well into our century, scholars like Rosa, Father Teilhard de Chardin, etc., advocated 'programmed' models of evolution and even the evolution by regular dichotomies of Willy Hennig is basically anti-Democritean.

Our sources all state that Democritus paid much attention to the study of human and animal nature, but we only know in some detail, as related by doxographers, his

theory of human cultural evolution, which is very well argued and factual. Otherwise it seems that he maintained that also the smallest of living beings must have had a well-developed structure and organs, though not visible to the human eye; he paid attention to embryological development and to the problem of the sterility of mules. Democritus maintained that the brain was the seat of thought (Aristotle, instead thought that it was an organ which function was to cool the blood). Finally he may have been the first to suggest the division of animals into 'Enaima' (with blood, vertebrates) and 'Anaima' (without blood, invertebrates), and to argue that all animals were capable of some reasoning.

The Sophists

In every observation or experience there is a subjective factor. This was one reason why the Eleatic philosophers denied all possible change in the 'Being' and maintained that all such change as we experience was deceitful. Anaxagoras and Democritus were very clear about it as they distinguished between the essential qualities of their sperms or atoms and of their aggregations on one side, and our perceptions, which, so to say, 'read' them as colours, smells and so on.

This problem was central to the Sophist's school. They posed as the cornerstone of their theories that the individual man is the measure of all things, and concluded that there is no absolute truth, but only the individual's truth and, therefore, that real knowledge of absolute truth is impossible. Protagoras of Abdera (485-415 BC), a compatriot and contemporary of Democritus, was the first and foremost advocate of this thesis.

While Sophists were basically concerned with pure logic and gave no contribution to empirical sciences like biology, they were feared by people like Socrates, who thought the relativism and subjectivism of the Sophists a danger for morality.

Many later naturalists, including a number of present day scientists, maintain that that relativism and emphasis on the subjective side of knowledge either implicitly or explicitly denies the possibility of a science of nature. This position was typical of positivist philosophers and of not a few idealists some fifty or a hundred years ago, but it is still debated by philosophers of science.

Socrates and Plato

While Socrates (470-399 BC) may solely be mentioned as the master who outlined the philosophical principles which were fully developed by Plato (428-347 BC), the latter, though he was not interested in biology as such and gave no positive contribution to it, had such a pervasive influence also on biologists during the following

centuries, even though his teachings were distorted almost beyond recognition, so that we must give him some attention.

Plato was mainly interested in purely rational approaches to problems, rather than in empirical observations, but he was sure that philosophy was a single, coherent system covering at one time mankind and all its problems as well as all natural phenomena.

Moreover the Academy, Plato's school, was the environment where Aristotle developed his genius, and to him we owe the tradition of the prominent place that the study of nature must have in philosophy.

Almost all Plato's ideas in the field of natural history are expounded in the Timaeus, possibly the worst of his 'dialogues'. This is extremely long and tedious, but, nonetheless, had a great importance, as its Latin translation by Calcidius was the only Platonic dialogue known in the West during early medieval times.

This dialogue, also because of the continuous influence of Neoplatonic tradition on scientists until the 17th century, had a far greater influence than it deserves.

All in all, if we consider biology properly, Plato could effectively be disregarded, as he never made any observation on animals and plants and barely mentions biological problems. However, since the idealistic approach of Plato had a great influence on the subsequent development of biology and more generally on the sciences and caused a considerable change in outlook on its problems as well.

Plato, in order to refute the Sophists, takes his start from their gnoseologic doubts and their taking man as the yardstick by which all things shall be measured; but he then created an anthropocentric system where the paramount values are spiritual ones. If we limit ourselves to natural sciences, and we ignore his ethics and his theories of knowledge, Plato's anthropocentric philosophy had a damaging influence on the development of sciences, though neither he nor Socrates, in true Greek fashion, ever supposed that the universe had been created for the benefit of mankind, as was believed by not a few thinkers of monotheistic faith.

Also the Platonic concept of 'Eidos', which is that the Archetype of anything, its idea, pre-exists to the thing itself played a negative role in sciences, in spite of the prompt criticism by Aristotle.

On the whole it is difficult to estimate the precise influence of Platonism on biology which was, nevertheless, considerable. In a sense, even if it may look like a paradox, Plato might be considered as the founder of systematics or, at least of that type of systematics where the concept of 'archetype' is more or less presumed in the formal description of a taxon. Linnean systematics are often quoted as an example of this type of systematics, but, as we shall see, this is a complete misunderstanding of Linnaeus' ideas.

Plato maintains that a horse, for instance, meaning any particular horse we see, is just a more or less accurate material expression of an ideal 'horse' which exists and is, in itself perfect and eternal. Therefore the naturalist should, according Plato, strive to

understand and know that pre-existing and eternal idea or form of horse by studying as many individual horses as he can (and Chrysippus commented: "Oh, Plato, I can see the horses, but not the horseness!"

There is no question that Plato succeeded admirably in showing the imperfection of the knowledge that we can get from our sensations. But from that he derived a gratuitous corollary: that true knowledge can be reached only by pure reasoning. He therefore gave the naturalist the task of acquiring, starting from observable things, the knowledge of ideas and of laws, which are both unchangeable and eternal. This little devil lingered in the practice of biology and is at the root of what is erroneously called the typological concept of taxa, which should more correctly be termed 'the idealistic concept'.

Some general remarks

In the next chapters we shall see how the balance between observation and theoretical developments evolved through classical times, but we must here point to a technical problem and to its consequences. We shall see that after Aristotle, while sciences such as mathematics and astronomy with the highest rational content and less need for detailed empirical observations made considerable progress, the natural sciences had an increasing tendency to become subservient to medical 'praxis'.

The lack of optical instruments in classical times had a paralysing effect on biology. As a matter of fact the Romans had some knowledge of lenses and of their properties; but magnifying instruments were not employed until spectacles came into use in the 13th century and the first to use lenses as an aid to biological observation was apparently Gesner, well into the 16th century.

It is equally true that where the Greek astronomers made their worst mistakes, this was not the result of a faulty method, but a consequence of wrong measurements due to the lack of sufficiently accurate instruments. When these became available, the revision and refutation of old theories was immediate.

Early Greek medicine

The close connections between biology and medicine through all the period covered by this book, compel us to sometimes consider studies and events that, though more significant to the student of the history of medicine, can not be conveniently ignored by the student of the history of biology.

We must, therefore, pay some attention to the early development of Greek medical science.

If we turn again to the Homeric texts, we find that, although in the 8th century BC, both health and disease (and particularly epidemics) were bestowed by the Gods,

there already was a tradition of medical practitioners independent, to some extent, from temples and religious ceremonies. Though the Gods might give some help in aiming the spear or the arrow, this was accessory to a man-made wound which men could cure by merely practical means. So Asklepios (in Latin Aesculapius) in the Homeric poems is still a mere hero and a Thessalian prince, as purely human as are his sons Podalirius and Machaon, both renowned surgeons. It was much later that Asklepios became a God and the son of Apollo. His cult was introduced in Athens only in 429 BC and in Rome in 292 BC.

We owe the traditional emblem of apothecaries to the cult of Asklepios, the snake coiled around a staff. The snake was his sacred animal, and occasionally was even considered his epiphany, that is his earthly manifestation (the use of two snakes coiling around the winged caduceus, presently often used as a symbol with the same meaning is a gross mistake, as this is the symbol of Hermes in his function of 'psychopompus', the guide of souls to the underworld!).

Around the cult of Asklepios grew many sanctuaries, and some of them became famous as healing places. There, as we know from a variety of documents, including votary gifts and tablets relating cures and healings, both religious practices and medical care were administered and, though we have no evidence of a direct connection between the two, some medical schools existed within the precints of some of the most important sanctuaries. Moreover, several famous families of physicians are known to have been known as Asklepiads, that is descendants of Asklepios. Both Hippocrates of Cos and Aristotle were Asklepiads.

Beside the religious, moral, psychological and medical cures that were practised at the sanctuaries, the Askepieia, we know that in Greece there were a number of lay physicians; these were free men who, in order to get a licence to open a consulting room (called 'iatreia') had to prove that they had followed the teachings of a qualified physician for some years. We also have some records of medical officers who derived a regular salary from the community. There were also wandering medical practitioners, the 'periodeutae', but they were commonly held to be hardly better than quack-doctors, though they often practised 'Lithotomy', that is the removal of bladder stones, a kind of surgery which the celebrated 'Hippocratic Oath' forbids to medical practitioners, as there was a real danger of damaging the spermatic ducts, and thus causing sterility.

Among the most celebrated early medical schools was that of Croton, whose most famous master was Alcmeon of Croton, whom we have already mentioned, and who is quoted as the first to dissect the human corpse, or, at least, some part of it. His book *On Nature* is lost, but some scholars consider it likely that some of the earliest texts of the *Hippocratic corpus* may actually derive from his teachings. Tradition credits Alcmeon with the statement that the brain and not the blood was the seat of mind and with the distinction between veins, which are full of blood, and arteries, which contain air; finally he may have maintained that when the blood concentrated in the heart, sleep

would begin and that death had a somewhat similar mechanism. Some other anatomical discoveries are credited to Alcmeon by extremely dubious traditions.

Again to Alcmeon is credited the idea, of Pythagorean origin, that health depends on the correct balance of all the substances in the body, so that the medical practitioner must aim, in order to heal, to rebuild that balance, which is upset in diseased conditions.

To the school of Alcmeon belonged Philolaus of Taras, who lived in the 5th century BC. He seems to have restricted the concept of disease to some inbalance of the four basic humors of the body (thus pioneering one basic concept of the Hippocratic school) and that the balance was ordinarily kept by the soul.

Similar concepts in pathology were advocated by Empedocles of Agrigentum. There are also stories about this philosopher which describe him as fighting epidemics by reclamation of marshes and public fumigations, but as with most of the stories concerning Empedocles, they are probably groundless.

Other famous schools of medicine of the 5th century BC were at Cyrene, Rhodss, Cnidus and Cos. The oldest was probably the North African school of Cyrene, and we know the names of some of the Cnidan masters, but, by far the most important school is that of the island of Cos.

The fame of Cos is linked with that of its most renowned master: Hippocrates, son of Heraclides (c.460-c.375 BC). We do not know which connections existed between the famous temple of Aesculapius in Coos and its medical school, but it is at least certain that the great number of pilgrims who visited the sanctuary to seek healing must have offered ample opportunity for observations, and the fact that Hippocrates belonged to the sacred Asclepiad family and that his father was a physician gave this most remarkable man the best opportunities. A large *corpus* of some 70 treatises credited to Hippocrates have survived. They are very different in nature and style and, as the earliest commentators of early Alexandrian age knew, only of some thirty, there is a good chance that only about one third of them really belongs to Hippocrates, some being earlier (probably including the famous *Oath*), while others were later. However, it seems that the Hippocratic corpus was consolidated by the end of the century following Hippocrates' death, when the various writings were collected and to some extent edited to be copied for the Library of Alexandria. Ancient scholars were well aware of the fact that not all 'Hippocratic' treatises were genuine and tried to sort them out. It is a great pity that the work that Galen dedicated to this problem is lost (it survived into the 8th century AD as we know that it was translated first in Syriac and from that into Arabic. Neither of these translations has, so far, been recovered).

While all students of the Hippocratic corpus, both ancient and modern, have hailed it as an invaluable source of information, wise advice and sound practice, we shall only consider such items in it that concern biology, and exclude both diagnostics and medical treatments.

We must first praise, as everyone did, the emphasis there is through the books both on accurate observation and exact reporting. The corpus is notable also for the factu-

al analysis of observed symptoms and for the fact that it does not concern itself with any magical or religious practice, though we know from other sources that these were both familiar to sick Greeks.

Hippocratic pathology and, by consequence, therapeutics, were based on the theory of complexions, that is of the kind of basic humour that was assumed to predominate in the patient's complexion. Thus we owe to Hippocratic medicine terms familiar to everyone, such as the Sanguine, Phlegmatic, Melancholic and Bilious complexions, just as for a number of medical terms such as 'crasis', 'discrasia', 'crisis', 'prognosis', etc.

As for the scientific knowledge of the Hippocratic school, it was not great. They had some knowledge of the anatomy of bones, but their anatomy was still rudimentary: nerves, vessels and tendons are not clearly distinguished; both the trachea and the bronchi were called arteries and likewise, true arteries were considered to be pneumatic vessels and air was supposed to pass from the bronchi to the heart by an arterial vessel and there, mixing with blood, it created heat, which was the cause of life. They also supposed that from the left side of the heart, where the blood was heated, thus acquiring its vital powers, blood reached the liver. As far as reproduction was concerned, while the Hippocratics considered the uterus of women to be bicornuate like that of many mammals, they thought, alternatively, either that sex was determined by the development of the embryo either in the right or in the left horn of the uterus, or that it depended on sperm coming either from the right or from the left testicle. They also thought that the embryo derived from the union of both parents' sperms (as they considered vaginal and vulvar secretions to be a sort of feminine sperm). Male sperm accumulated in the testicles, but, as maintained, for instance, by Anaxagoras, it was made of innumerable, infinitesimal particles coming from the various parts of the body.

Indeed, while, the therapeutic practices of the Hippocratic school were sound, their observational principles good and their ideal of an empirical medicine equally good, they contributed little to the advancement of biology. However, just because of their principles, they are at the root of that splendid age of biology that opens with Aristotle and practically closes with Galen in the 2nd century AD. Naturally medical practice did not get frozen with Galen, and we shall see, throughout the late classical times and even in the early medieval times, here and there new techniques were perfected, new drugs were added to the existing lists, some new knowledge was added. However a truly scientific approach to life studies had to wait exactly 1,000 years before truly scientific enquiries in life sciences were resumed, such being the span separating Galen from Saint Albert the Great (Albertus Magnus).