PRE-SOCRATIC PHILOSOPHY

The appellation 'pre-Socratic' is a little misleading, since it refers to a number of philosophers who were contemporaries of Socrates, and excludes Protagoras. It actually refers more to a brand of philosophy, dominated by an interest in the Natural world, mathematics, form, etc., and a quest to understand origins, mechanics, and to formulate hypotheses about the world. The ideas of Socrates, developed by Plato, instead allotted much more importance to social, political, and moral questions, and in doing so consciously reacted against the 'pre-Socratics'.

For our purposes the most important thing about the pre-Socratics is (i) the extent to which they anticipated and molded the later Greek ideas (indeed, some of the key ideas of Plato started from Heraclitus and Parmenides on the philosophical side, and from the earlier Pythagorean work in mathematics); and (ii) the fact that their ideas, in many ways, represent the very beginnings of what we now call scientific enquiry. For this latter reason alone they deserve our attention: although the beginnings of any really new area of human thought are always hard to understand, being inevitably somewhat disorganised, they are the crucial leaps that have brought us to where we are now. One learns a great deal by studying such leaps.

Nowadays one can, by a combination of internet searches and avid book reading, find an enormous amount of information and opinion about almost anything in the world. It is then crucial to understand from the outset that our knowledge of pre-Socratic philosophy and science comes to us through only a very few sources, not all of which are reliable. The best of these sources are Plato and Aristotle, along with Aristotle's student Theophrastus; we have almost none of the original writings of the philosophers. This is a great shame, but somewhat inevitable- as we shall see later, we are rather lucky to have *any* of the original contributions of the Greeks.

Certainly the most important source for pre-Socratic philosophy is Aristotle, who made some effort to give a thorough and fair account of the development of early philosophy and science. Not only was Aristotle closer in time to this work than most other commentators whose writings we have, but his understanding of and sympathy for it was far greater. Unlike us, he had most of the original writings of all the pre-Socratics, as well as a far better understanding (based on direct experience) of the life and times in which they were written. Unlike Plato, he did try to separate his own ideas from those whose work he was recounting. He was certainly in a far better position to do so than later Hellenistic and Roman writers, many of whom could hardly escape the intellectual guidelines laid down by Aristotle himself (as well as by Plato).

Herein lies the danger in an uncritical reading of these sources. As we shall see again and again, the power and depth of Plato's and Aristotle's writing was so great, that many later writers found it impossible to escape their influence. Thus, during the subsequent 2300 years, their ideas often acted as intellectual shackles on new developments - both in the intellectual and political spheres. We ourselves have no more than scraps of the original writings of the pre-Socratics, and so barring some remarkable future discovery of, say, the complete works of Anixamander or Democritus, we will always be guessing at what they really said and meant. Given the many other extraordinary distortions of history which we know of, it is likely that at least a few presently accepted views on the early development of philosophy are just plain wrong.

And yet in some ways we are rather lucky. First, to have Aristotle's historical account, rather than those of some much lesser writers. Second, to be living at a time when 4 successive scientific revolutions (the Newtonian, Darwinian, Einsteinian, and quantum revolutions) have freed our minds from many of the philosophical prejudices of the Greeks (although not all, as we will see). Third, to have available an increasing wealth of historical and archeological details on this historical period. Based on some remarkable research over the last 50 years. All of this have given us a much more complex picture of the genesis of Greek philosophy and science that was available to perhaps anyone since Roman times.

For our purposes the most important thing about the pre-Socratics is (i) the extent to which they anticipated both the later Greek ideas (indeed, some of the key ideas of Plato started from Heraclitus and Parmenides on the philosophical side, and from the earlier Pythagorean work in mathematics); and (ii) that their ideas in many ways represent the very beginnings of what we now call scientific enquiry. For this latter reason alone they deserve our attention- for although the beginnings of any really new area of human thought are always hard to understand, being inevitably somewhat disorganised, they are the crucial leaps that have brought us to where we are now. One learns a great deal by studying such leaps.

So how and why did philosophy (and much of science) begin in ancient Greece? What motivated the early philosophers and scientists, what were the important questions for them, and why these particular questions? And why did they give the answers that they did?

Let's begin first with the questions (a good working definition of philosophy is provided by simply listing the main questions that are considered to be important philosophical ones - philosophy is then defined by its questions). According to Aristotle, the crucial break with the past lay in the understanding, by Thales and his school, that proper

philosophical enquiry demanded that one liberate oneself from the prevailing pattern of religious explanations of the world, and from the "*theologi*". These explanations, in terms of myths and supernatural "causes" were then replaced by a search for knowledge of natural causes (the point of view of the "*physici*"). This reference to "causes" bears the sure imprint of Aristotle - it is not clear that the Milesians or the Pythagoreans would ever have used such terms - but the distinctions between natural and supernatural explanations, and between the particular and the universal, would have certainly made sense to them. The key point here is that by adapting this attitude, the Milesians and most later pre-Socratic philosophers were already committing themselves to certain kinds of questions. Amongst these, two important ones were:

(1) The world as we experience it, including ourselves, is at all times characterized by change and transmutation, and by apparent accident. This impermanence and unpredictability was a central theme in the whole religious mythology of the Ancient Greeks. Animals and plants are created and grow, and then die and disappear. The weather changes unpredictably. Only astronomical phenomena display any regularity - the seasons, the motion of the planets, the "fixed stars". But is there some underlying and unchanging "reality", or at least a set of simpler "principles" which are not changing? If so what is the underlying reality, and what are the principles?

(2) Given some underlying reality and/or general principles, why does change take place? The Greeks were very impressed with the "creative" concept of Nature, and neither ordinary Greeks nor the pre-Socratic thinkers saw this as deriving from any kind of intelligent "design" ("$\tau\epsilon\chi\nu\eta$"), or any single set of creation. Instead they saw Nature as having its own generative or creative capacity, so that it contained to evolve. The differences between the *theologi* and the naturalistic philosophers were not large here - both thought of Nature ("$\varphi\upsilon\sigma\iota\zeta$") as an actual primitive essence, which was capable on its own of engendering change. The *theologi* believed that the gods were created from this essence, and the subsequent evolution of the world largely involved the story of the adventures of these gods. The pre-Socratics sought an impersonal explanation, in terms of entirely natural principles. But both sides thought of Nature as in some sense "alive", embodied with its own generative power. The key question for the philosophers was to understand how this worked, how change occurred in Nature. However they were *not* interested in giving Nature a personality.

Perhaps the most important underlying idea running through this - one central to modern science - is the recognition that if one wants to explain the world, then the basic elements of the explanation must be *different* from the world. The early philosophers firmly understood that a theory of the world of appearances and particular phenomena had to be constructed from building blocks, or an underlying reality, that was not like the world of appearances - and not like us. For them, the attempt to personify Nature was to explain nothing, since it left things in the same state as before.

Thus Nature for the early philosophers became impersonal, abstract, colourless, and lonely. Gone were the intrigues, loves, and laughter of the gods, and the comforting idea that "mother Earth" (Gaia) was a benevolent goddess, watched over by Ouranos (the Heavens), whose affairs were driven by gods like Eros. Instead, as Plato has Socrates say (in the *Phaedo*), everything boiled down to the intersections of "airs, ethers, waters and other strange things". The remarkable thing is that these ideas were not considered as subversive by more Greeks at that time.

One should not be left with the impression that the problem of change, and the idea that Nature could be understood in terms of some underlying reality, were the only questions occupying the pre-Socratic philosophers. This may well be the biggest distortion in all of our historical understanding of these figures. Thus, eg, the Milesian philosopher Anaximander was extensively pre-occupied with history and geographical questions, and the interests of both the Pythagareans and the "atomic" school of Leucippus and Democritus extended well beyond questions of natural philosophy. One suspects that their lives were far more interesting and colourful than the pre-occupation with philosophy suggests (certainly this must have been true of Pythagoras and Democritus).

However, the formulation of these 2 key questions set the philosophical and scientific ball rolling in a certain direction, which was very important for subsequent developments.

In what follows we cover those 5 main strands of thought coming from the pre-Socratics that were non-mathematical in their content. This means that only a partial discussion of Pythagoras is given here- a more complete discussion of his mathematics appears in the later section on Greek mathematics.

(1) The MILESIAN SCHOOL: Differentiated Unities

This school of thought existed in Miletus, on the coast of Asia Minor (now western Turkey- see map), in the period from roughly 590-530 BC. The influences on this school came from Babylonia (particularly Babylonian mathemat-

ics and astronomy), Egypt, and father East. The technology developed by these earlier civilisations also strongly influenced the Milesian philosophers. As noted above, in an important and very non-trivial step, they consciously rejected the prevailing religious picture of the day, according to which the heavens were inhabited by anthropomorphic Gods, and the world was full of magic, manipulated in mysterious and often capricious ways by these Gods, and the explanation for events were buried in the myths and legends extending over the previous millenium. Instead of seeking explanations in terms of ineffable divine causes, the Milesian philosophers turned to the natural world, looking for causes entirely inside this world, and inventing explanatory hypotheses and general frameworks to deal with the amazing variety of phenomena at their doorstep. This was a radical shift, and of course not accomplished all at once. Their ideas were still strongly influenced by the older cosmogony, according to which the world originated from an undifferentiated or amorphous unity (a theme which continues to appear in religious writings up to the present day). This idea was central to the texts then existing in Hebrew, Egyptian, Babylonian, and Greek (in Babylonian and Egyptian cosmogony, the universe began as an undifferentiated infinity of watery cloud).

(a) Miletus and the Beginnings of Philosophy

Miletus was at that time a prominent port and trading centre between East and West. At the time of the Milesian philosophical school, Miletus was already 500 years old, and it exercised a considerable cultural and economic influence in the Ionia region. According to Pliny, no less than 90 Milesian colonies had been founded ("generated" in Pliny's words) by Miletus during this period, around the Aegean and even further afield. Historians and archaeologists have definite evidence for over 45 of these. Miletus would have been, for its day, a rather pleasant place. Although much smaller than the trading ports of the Netherlands that would prosper 2000 years later, it resembled them in many ways (except for the climate, which was considerably balmier than that of NW Europe!). Miletus at the time was militarily secure, having come to terms with the kingdom of Lydia to its East; this arrangement continued even after Lydia was absorbed into the Persian empire in 546 BC, near the end of Thales's lifetime. Like the future ports of Venice, Genoa, Amsterdam, and Hong Kong, this security was founded on accumulated wealth from trading, as well as from the export of locally manufactured wooden goods. In fact Miletus acted as a clearing house and crossroads for commerce and travelers from far off to the East, through large parts of Asia Minor and deep into the Persian Empire. From this point of view peaceful relations between Persia and Miletus were advantageous to both - Miletus provided Persia with a retail outlet to the prosperous Aegean city states, with whom Miletus had shared links for hundreds of years.

The social structure and attitudes of people in this city will seem familiar to anyone who had visited a thriving port. Economic power was in the hands of a merchant class, whose attitudes were pragmatic and whose values were strongly materialistic. There was a clearly perceived need for skilled artisans, as well as a range of other skills ranging from engineering, medicine, metallurgy, and architecture, to financial management. The richer members of this affluent Milesian society constituted a sort of leisure class, whose needs extended to encompass poets, writers, and musicians, as well as arts and crafts. For an artist, a craftsman, a musician, or any lover of "$\sigma o \varphi \iota \alpha$" (translated as "knowledge" or "wisdom", but which in Miletus would have also connoted some skill or set of skills), Miletus would have been a pretty good place to live in around 550 BC.

Conspicuously absent from this mixture of pragmatism and cultivated luxury was any kind of theocratic government. In comparison to the ancient empire of Egypt, run by a despotic priesthood class with a stifling control over every aspect of Egyptian life, the cosmopolitan freedom of thought in Miletus would have seemed infinitely preferable to the Greeks. The melange of cultures would have also included a heady mix of religious doctrines. Oriental ideas ranging from the monotheistic worship of the sun god R$\bar{a}$ (embodied by the living pharaoh) to the Persian mysticism of the Magi and Zorocaster, would have been counterbalanced by the plethara of Greek gods, along with Orphic elements just as mystical as anything an offer from the East. All the evidence indicates that these religious had little effect on the Milesian way of life. The leading citizens of Miletus lived in cosmopolitan luxury, tempered by materialistic attitudes which recognized that their privileges came not from the gods but from human resource and entrepreneurial initiative.

Writing 2 centuries later, both Plato and Aristotle emphasized the importance of this material wealth, in providing time and freedom for intellectual pursuits. Aristotle in his *Metaphysics*, remarked that "it was only after the provision of the chief necessities, not only for life but an easy life, that the search for this intellectual satisfaction began". He even extended this idea to previous cultures, writing that "this knowledge first arose where men had leisure. That is why the mathematical arts first took their rise in Egypt, for there the priestly caste was free to enjoy leisure".

From our modern perspective, in a world where hundreds of millions of people enjoy leisure beyond Aristotle's dreams, yet where truly creative endeavour is still confined to a few remarkable centres, we can see that Aristotle goes too far in advancing one of his favourite ideas. In fact, from a comparison of the Milesian school of philosophy with other cultural centres at that time, as well as with later centres of scientific and philosophical creation, we can discern the following interesting features:

(i) Miletus provided an environment with some cultural depth, in which, because it was a port and stood at an important nexus between Oriental and Mediterranean influences, Milesians were exposed to a rich intellectual and cultural heritage.

(ii) The wealth of Miletus, and the power held in the hands of a mercantile aristocratic class, provided those who wanted it with the security to pursue their interests, and the time to do so. Moreover the pragmatic attitude of the merchants fostered and nurtured those skills on problems of scientific interest, ranging from engineering and medicine to astronomy. Thus men with intellectual interests and skills had an interested audience.

(iii) Miletus was relatively free of the influence of religious doctrine - many of those in power regarded religion with suspicion, and obsession with the supernatural was viewed at least in some quarters with distaste. Aristotle, to whom we owe most of our knowledge of the Milesian school, felt that Thales and his students had been the first to break away from the older fixation on mythical explanations and on the dogmas of the "the "*theologi*", and to focus on a new philosophy of natural causes. Miletus provided them with an environment in which such ideas would not be viewed with hostility.

These pre-conditions for untramelled philosophical enquiry then led, in ancient Miletus, to the founding of what is commonly thought to be the world's first genuine school of philosophy. Plato and Aristotle were in no doubt as to what this meant. They both argued that the ultimate source and stimulus to philosophical enquiry lay in feelings of wonder and curiosity about the world (Plato in the *Theatetus*, and Aristotle in his *Metaphysics*). This was characterized as a love of truth and knowledge for their own sake, completely independent of practical or utilitarian motives. Certainly they were in no doubt that this pursuit of "$\varphi\iota\lambda o\sigma o\varphi\iota\alpha$" would lead ultimately to broad practical consequences of great import. However they felt that this was irrelevant. Aristotle went further, distinguishing between the *theologi*, who slaked their thirst for enlightenment by indulging their curiosity and feelings of wonder in useless "mystical sophistry", and the true seekers of truth, who search for the true objects of knowledge. For Aristotle this meant searching for "universals" and natural "causes".

As we shall see later, Aristotle's point of view was very similar to that of a modern scientist looking for general laws governing Nature. It is a measure of the enormous influence of Plato and Aristotle that we still look at philosophy and science in this way. Nevertheless we have to be careful in reading Aristotle's account of the Milesian school and the beginnings of philosophy. In spite of his scrupulous regard for historical detail, he was pushing a point of view, and it is unlikely that the distinction between "theology" and "physics" was viewed in quite the same way by the Milesian philosophers (and certainly not by the Pythagorean school).

(b) The Milesian Philosophers

(a) **THALES** (c. 640-550 BC): The dates of Thales are not well known, and are inferred from commentators. Not much is known for sure about his life beyond the writings of later commentators. He was originally an engineer of some sort, and an advisor to the Milesian king, as well as being active in commerce. In mid-life he apparently went to Egypt as a merchant, but stayed there to study astronomy and geometry- on his later return he gave up commerce, and devoted his time to philosophy and mathematics, and founded the Milesian school. Many stories are told by Aristotle and others of his business acumen in his earlier life (eg., a story of the monopolisation of olive presses, and another of how he diverted the river Halys by constructing an embankment). He is also supposed to have measured the distances of ships out at sea; but he is best known for his prediction of a solar eclipse in 585 BC, which gave him a considerable reputation. This, and his mathematics, are discussed in the later section on Greek mathematics.

For Thales everything in the material world was some form of water- this for him was the result of a search for some kind of all-embracing unity. The search for such a unity was certainly not original, but the idea that it should be entirely material apparently was. He also had the rather odd idea (which again predated him, coming from the Egyptians) that the Earth floated on water. According to his main hypothesis, water could take on many forms- indeed, it was capable of transforming itself and differentiating into all that we see in the material world. We have no real details of how this hypothesis is supposed to have worked in practise.

(b) **ANAXIMANDER** (610-546 BC): In common with Thales, Anaximander also did serious astronomical and cartographic work. He was the first Greek to make a world map, prepared the first Greek star map, and also built a celestial sphere, with a cylindrical earth at the centre, and concentric celestial circles outside, thereby making a model of the universe. The earth remained at rest at the centre because it was in the centre of symmetry- he apparently imagined that there would be some kind of balance of forces at this point. Anaximander also write a book ("*On the Nature of Things*"), in which he laid out his astronomical and philosophical ideas.

This astronomical hypothesis went in hand with his cosmology. According to Anaximander, the primeval or fundamental 'stuff', which he called '*apeiron*' (meaning 'boundless' or 'limitless'), was everlasting and infinite, and also imperceptible- a kind of ineffable ether. He gave an elaborate theory of how everything 'grew' out of *apeiron*; this

involved in an essential way 2 pairs of opposite principles, called Hot/Cold, and Wet/Dry. According to Anaximander, various things were 'spun off' from the *apeiron*, by these principles- this began with a sphere of fire, which itself differentiated to form the heavenly bodies, themselves wheel-like compressed air, full of fire, with orifices from which this fire issued (eclipses being explained as blockages of these orifices). The process of separation continued to form land, sea, air, and everything else on earth, including living things- he even postulated a kind of evolution of species.

The idea of *apeiron* is interesting- he recognised that this primeval stuff had to be different from everything we are aware of- it had to be everlasting, the generator of all transient and perishable things in the world. Otherwise it would not be fundamental, but just another part of Nature. Anaximander also saw *apeiron* as governing the whole of the cosmos and its changes- in this way it held the earth at its centre, and provided the motive power and energy which drives all things. For him it was ageless, immortal, and divine, and the mover/creator of everything that exists.

(c) **ANAXIMENES** (died 528-526 BC): Little is known about the life of Anaximenes. His philosophy was in some ways a reversion to that of Thales- instead of water he postulated air as the primitive stuff. All things then came from the compression, rarefraction, or transformation of this air. All these transformations are accomplished by "Hot' and 'Cold'. In contradistinction to Anaximander, these principles are not something that separate off from the primitive stuff, or even just agents of change and transformation- they are instead 'attributes' of air, ie., properties of it. In the same way as Anaximander, Anaximenes apparently also gave an elaborate theory of how various things were formed on earth and in the heavens, starting from these ideas.

The most important contribution of the Milesians was to introduce the idea of a fundamental stuff, which some process of differentiation gave the natural world. This was a big step away from the previous cosmogonies, which were essentially religious and usually anthropomorphic. Instead one had a natural philosophy, with natural causes, regular mechanism of operation, speculative physical hypotheses, and the idea that the primal cause and 'substance' could be imperceptible and all-pervasive. The idea of Anaximander, to make this divine, was to have great influence later on.

Perhaps the most interesting thing, from our point of view, is that the Milesians were dealing with empirical propositions based to some extent on observations about the world. Thus we are talking about the act of "hypothesizing" about the world, in a pre-scientific way.

(2) PYTHAGORAS and HERACLITUS: Ideas about 'Form'

The problem with exclusive concentration on the natural world is that it is impermanent, in a state of constant flux- if one is seeking an explanation for all things, it cannot therefore be found in the world of everyday phenomena. This was of course recognised by the Milesians, but they did not attempt to get to grips with the structure and form of the ineffable underlying 'stuff', treating it as undifferentiated.

In what may be one of the most important intellectual steps ever taken by mankind, such studies were initiated by the Pythagorean school, in a move which led to the creation of crucial parts of ancient mathematics. The later ideas of Heraclitus were in part a reaction to both Pythagorean and Miletian work.

(a) **PYTHAGOREAN SCHOOL**: Pythagoras was born around 570 BC on the island of Samos, in Ionian Greece just off the coast of Asia Minor (what is now the Turkish coast), near the coastal towns of Miletus and Ephesus. It is said by some that he was a student of Anaximander of Miletus. Pythagoras left Asia Minor, apparently because of the policies of the tyrant Polycrates, and travelled widely, eventually settling in Croton, in Southern Italy. The school he founded there was very influential (notably on Plato); adherents wore a star pentagram symbol, and were distinguished by a strongly mystical philosophy. The school was initially very influential in Croton and environs, but after a revolt led by Cylon, in which a number of the school were killed, Pythagoras fled to Metapontum, and the school was reconstituted- however it was later persecuted and the survivors were dispersed as far afield as Thebes (southern Egypt), Phleius, and Tarentum. A split appears to have occurred at some point between 2 branches of the sect- the *acusmatiki* and the *mathematiki*. We do not have much direct evidence of their activities (much of what we know comes from Plato, Aristotle, and their students), since the sect appears to have been somewhat secretive in both its activities and the arcane knowledge and ideas it possessed. All this alerts us to the utterly different culture we are dealing with here- instead of a group of armchair mathematicians or philosophers in a university lab, we are talking about a secretive religious sect with various hidden political and social aims, as well as a variety of rituals and taboos. One should get used to this in trying to understand the beginnings of science- Newton was hardly different in his approach to Nature.

From what we know of Pythagoras he appears to have been one of the greatest intellects of the Ancient world, perhaps of all time, held in some awe by later Greek thinkers- his influence on Plato and Aristotle, some 150 yrs later, was enormous. His philosophy fused Orphic religious traditions with a belief in rational inquiry into the nature of the *kosmos*. The latter was viewed by him as *alive*, a living creature. For Pythagoras, the cosmos was a whole, without *telos* (end); we are all part of it (at least our souls are). The Pythagoreans believed in transmigration of souls- meat was forbidden, as were beans, since they might conceal the soul of a former friend (at least according to later parodies). Philosophy is the attempt to study and understand the cosmos- and in the end, philosophy is assimilation of the pupil to the divine cosmos. The *kosmos* represented for Pythagoras a kind of inherent order or structural perfection, a divine pattern or form. This was a remarkable new idea which broke completely from the Milesian school, which was essentially materialist and interested in the constituents of matter.

The essential tool for this study of form and structure was mathematics- which revealed the form of the cosmos (for more on the mathematics of Pythagoras, see section on Greek mathematics). Numbers were viewed as divine, the key to the *kosmos*, and their properties thereby revealed patterns in the cosmos. For Pythagoras, *everything* in the cosmos was an emodiment of number, even things like justice. Most notable of the patterns found in the cosmos was the harmonic relation, also revealed in music- this led to the whole idea of the music of the spheres, in which the planetary orbital periods corresponded to musical intervals. The living cosmos had no end but it did have a beginning- it began with a 'seed' in the infinite, which was afire in its centre- this proceeded to grow by drawing in the infinite from outside itself, and giving it structure by numbers. This process of drawing in was called 'inspiration' (ie., breathing in). Later neo-Pythagoreans like Philolaus (5th-century BC) even argued that the earth was a planet revolving around this eternal fire- a remark which was picked up 2000 yrs later by Copernicus (we come to this in later notes).

Much of what we know about Pythagoras came from later writers like Plato, and it is hard to sort out what he or his followers really said. His influence on Plato was very great- Plato adopted wholesale the Pythagorean ideas of the immortality of the soul, and the mathematical basis of the cosmos- he also followed Pythagoras in viewing philosophy as a means of reaching towards the divine, lending to it an exalted status which was terribly influential in Socrates, Plato, and much subsequent work. The most important philosophical idea from Pythagoras was that the most fundamental explanations were not in terms of matter or 'stuff', but in terms of abstract form. This was a hugely important step, whose consequences were to be worked out by Plato in some detail. The antithesis between matter and form, and the central role of mathematical form, is absolutely central to modern physics, as we shall see.

(b) **HERACLITUS**: Almost nothing original survives from Heraclitus, who was active sometime between 500-460 BC, in his hometown of Ephesus. The crucial idea we are interested in is his attempt to deal with the obvious fact that in the world we are aware of, everything seems to be changing in one way or another. Heraclitus regarded this dynamic quality as fundamental rather than illusory- arguing that in some sense instability was basic to the world.

According to Heraclitus, everything in the perpetual world takes place according to the '*Logos*', which here is translated roughly as a combination of principles and truths about things, 'natural laws', proportions, or in a modern terminology, 'formulae'. What form did this take? For Heraclitus the fundamental *logos* was the unity of opposites, and the existence of balanced strife between the opposites- one can say that the *logos* was opposition and strife. This *logos* had a material aspect, which it is not correct to think of as 'stuff'- it was not material. This was fire- and this apparently because it was the means by which things were transformed from one form to another- Heraclitus remarked that 'Fire steers all things'. Examples of opposites that he gave were beginning/end, day/night, young/old, living/dead, awake/asleep, hot/cold, wet/dry. The idea is that all change comes from the transformation between opposites, and that without some sort of 'dynamical equilibrium' between the opposites, so that the opposition was unbalanced, all strife and indeed change would eventually cease. Thus everything is in a perpetual state of flux, and no thing is ever the same. His famous aphorism, that 'one never steps in the same river twice' refers to the material aspect of the river (that its material, the river water, is in constant flux)- this of course begs the question of what it is that is constant, when we refer to the river.

The ideas are difficult because expressed in the form of aphorisms, such as "All things come out of the one, and the one out of all things"; or as paraphrased by Plato, "nothing ever is, everything is becoming". The basic point, however, raised by Heraclitus, is to explain how there can be a fundamental and unchanging stuff if we have no evidence for it, since all we see is in flux. For Heraclitus, even souls were in flux- they were like Fire, and he remarked that it was 'death to Souls to become water'.

The most important immediate result of Heraclitus's work was its influence on Plato, leading him to the conclusion that 'particulars' (ie., particular instances of things, like a particular river) were not only not knowable, but not even *real*. Aristotle later denigrated Heraclitus for his sloppy arguments. Nevertheless, the few fragments of Heraclitus we possess have been very influential, and their ideas have an interesting similarity to modern ideas in physics about thermodynamics.

(3) ELEATIC SCHOOL: an Unchanging Reality

(a) **PARMENIDES** (c. 515-445 BC): Our knowledge of Parmenides is derived mainly from (i) the discussion of his ideas by Plato, notably in the dialogues *Parmenides, Theaetetus*, and the *Sophist*; and (ii) from the fragments of a short book he wrote in verse (usually called "*On Nature*"). Later pre-Socratics also referred often to his ideas. The meeting between an old Parmenides (roughly 65), Zeno (roughly 40), and a very young Socrates, described by Plato, took place around 450 BC.

The poem of Parmenides is a remarkable work. It describes a journey to the home of a goddess, the goddess Justice, taken in a chariot- the journey is begun in darkness and ends in light, escorted by the Sun Maidens (daughters of the Sun) from the Halls of night into the daylight, until they come to a gate which the goddess opens, escorting him in, where she tells him that he was right to come, and that here he will learn 'the unshakeable heart of well-rounded truth, and the beliefs of mortals, in which there is no true reliability'.

The goddess reveals to him 3 ways to truth- telling him that 2 of these are false, and that only the 1st of the 3 is correct. The 2nd way is described as "that *it* is not, and must necessarily not be- this I tell you is a way of total ignorance". The idea is that it is impossible to know something that does not exist- *something* must either exist or not, and therefore *it* must exist. The 3rd way is described by "to be and not to be is the same and not the same". This way is followed by mortals, who treat existence and non-existence in the same way. They suppose there is change (ie., that things can pass from existence to non-existence), and that there are differences between things (that some things contain less or more of 'being' or existence than others). The 1st and true way is then revealed- that "*it* exist and must exist", ie., that reality (the '*it*') is ungenerated and indestructible (must always exist), and that no distinctions can be made within it (no 'degrees of being, it is everywhere the same). So there is no beginning in space and time, and what exists is single, indivisible, homogeneous, and eternal. There is no motion or change- which would imply destruction of one thing for another, and hence non-existence. This what exists remains the same, "held fast in the bonds of limit by Necessity". Parmenides then makes the analogy of a perfect sphere- this seems to be an attempt to portray an isotropic, homogeneous universe. The rest of the poem deals with what is revealed by the 3rd way of mortals- this is essentially a descriptive and constructive phenomenology of the world- it is not clear why it is in the poem, since it is held to be illusory.

The whole story has heroic overtones, reminiscent of Homer, and of the journey of Odysseus down to Hades. One is also reminded of the idea of a dream in which truth is revealed. Yet Parmenides did not mean to be mystical- he recounts how the goddess enjoins him to 'use his reason to judge her words'. This is strong stuff for an Greek living at this time.

The important argument for us is that leading to the idea that the universe is "One", an indivisible and infinite which is present everywhere. The basic Metaphysical argument is that anything that can be thought of must exist- that the objects of all our ideas must be real. Moreover, since we can think of them at any time, they must always exist. It is nonsensical to suppose that "nothing" could exist. This then leads to the conclusion that there can be no void anywhere, that all of space must be filled, that there can be no change (since this would involve objects coming and going) and that one thing cannot change into another. Thus change must be illusory.

The importance of all of this lies in the argumentation- an attempt to derive general properties of the world through logical argument. Nowadays we might wish to call into question the attempt to extrapolate from the structure of language to statements about the nature of the world. The mere fact that we can think of something is not perhaps a good argument for its existence, and we are now rightfully suspicious of any attempt to derive statements about the world through purely metaphysical arguments. However the arguments of Parmenides still have great force in the metaphysical realm, once one starts discussing, eg., the ultimate nature of 'reality'.

(b) **ZENO of ELEA** (born c. 490 BC); It is believed that Zeno produced his work in a single book, sometime around 460 BC. He produced a number of notorious arguments, both metaphysical and semi-mathematical, which are still discussed today. At the time Zeno's main goal was to both to extend the arguments of Parmenides, and to attack the arguments of the 'pluralists' (see below), who were contemporaries of his, and who tried to deny the main thesis of Parmenides. His famous arguments and paradoxes were presented in dialectic form- this appears to be the first use of this style of argument.

Zeno's Arguments against pluralism: There are a number of these, and although the basic idea behind all of them is very similar, it is worth repeating several of them:

(i) *1st argument- divisibility 1*: This argument begins by pointing out that if an object is divisible into parts, each of which is a 'unity' (ie., no longer further divisible), then each part must have zero size- otherwise it would be further divisible. Moreover there will be an infinity of these parts (we would now think of these as mathematical points). But he then goes on to point out that such parts, when added together, would still yield zero size- adding nothing to nothing gives nothing. So they must have some size- however, if they do have size, then adding them together then

gives an object of infinite size. The conclusion of this argument is that reality cannot be divisible, and must be one.

(ii) *2nd argument- number of existents*: Zeno argues first that if the world is divided into some definite number of parts, then this number must be a finite number. But he then goes on to argue that in this case, one can always find numbers (ie., parts) in between the original ones. But this process can be continues *ad infinitum*- therefore, the number must be infinite. Again, this is an argument for the One.

(iii) *3rd argument- divisibility 2*: This argument, which is repeated by Aristotle (the original has been lost), is very similar to the first. It says that if an 'existent' is infinitely divisible, then it can be divided exhaustively (ie., as far as possible); and this must give parts of zero extension. But then again, the argument goes, no finite object can be constructed by adding together parts of zero extension.

Zeno's Arguments against motion: These are the most famous- they survive today in elementary schools and in nursery tales, as well as in serious mathematical discussion. They are all arguments designed to show that motion is impossible, ie., that existence must be unchanging.

(i) *1st argument- The Race Course*: According to this argument, a runner in a race can never finish it. Zeno notes first that the course can be infinitely divided (using, eg., the argument for the infinite number of existents given above). However this means that the runner must pass between an infinite number of different positions to get to the end- and this is impossible, since an infinite sequence of acts in a finite time is impossible. So the race can never finish.

(ii) *2nd argument- Achilles and the Tortoise*: Thisa argument is similar to the first one- however it imagines a very fast Achilles starting, eg., 100 metres from the finish, racing against a tortoise which starts 1 metre from the finish. The construction assumes that Achilles runs 100 times faster than the tortoise. Then Zeno breaks up the race into an infinity of steps. The first step brings Achilles to where the tortoise started- at which time the tortoise is now only 1 cm from the finish. The 2nd step brings Achilles to this point- at which time the tortoise is now only 0.1 mm from the finish. It is easy to see that one can continue this process *ad infinitum*, each time reducing the distance to the finish by a factor of 100. Then says, Zeno, this process can never finish. In modern form for children, this is sometimes called the race between the Hare and the Tortoise (the form devised in Aesop's fables).

(iii) *3rd argument- The Arrow*: In this argument, Zeno begins by arguing that at any given instant, an arrow must occupy a definite place, and no other, and that therefore it had to be considered as being at rest. But this argument, according to Zeno, is true even for a moving arrow- therefore a moving arrow must be at rest. Again, this is taken to mean that motion is impossible.

There are a number of other arguments of this sort attributed to Zeno (eg., the 'millet seed' argument, the 'moving blocks' argument, or the 'Argument against place', all of which are recounted by Aristotle). From a modern perspective all of them are concerned with infinitesimals and with infinite sets. Some of them are very subtle, hence the continued interest in them; others have rather obvious flaws. From a historical standpoint, their main importance was threefold. First, they influenced the Atomists (see below) and Aristotle (section 1.6), particularly in forcing them to see the problems associated with spatial extension. Second, they introduced a very important new style of argument in intellectual discourse, in which a logical argument is developed by developing a thesis, looking at arguments for and against it, making logical inferences, and arriving eventually at a logical conclusion. This style had a huge influence on all subsequent philosophy and mathematics, and its development was widely attributed to Zeno (eg., by Aristotle). Finally, Zeno's arguments and the style of their development, in which one tried to develop a logical proof for an assertion, had a large influence on the development of mathematics- particularly on what we now call number theory, and on axiomatic geometry.

(4) EMPEDOCLES and ANAXAGORAS: a plurality of 'Elements'

(a) **EMPEDOCLES** (c. 490-430 BC): Empedocles was a Sicilian- his philosophical approach had the merit of being the first to posit a number of different fundamental kinds of matter or 'stuff'. This was the first theory to involve what we now call 'elements'. His ideas are known from 2 poens, one entitled "On the Nature of Things", and the other "Purifications"; the latter was more religious in nature. In his theory of the world, Empedocles apparently proceeded from the observations that (i) one could put, eg., water and air together without them mixing (NB- not entirely true- air dissolves in water!), and (ii) one had somehow to explain how one could get so many different materials and forms (often by mixing them). The natural hypothesis was that there were several elements. The choice of fire, water, earth, and air was presumably made on the basis of observations of different changes taking place.

These 4 elements are, in line with previous ideas, held to be eternal, indestructible, and ungenerated (ie., without

beginning and end in time); all changes in Nature come from the mixing or separation of these 4 elements. Thus all the more complex phenomena we see (mountains, stars, trees, people, etc., are not in themselves 'real', but merely ephemeral combinations of the 4 elements. Apparently Empedocles accepted the Eleatic arguments for the impossibility of empty space, but felt that movement was still possible- this happened by the interchange of different elements or mixtures between different parts of space.

There remained the question of what drives or motivates the various changes that are constantly occurring in the world. Here Empedocles showed a somewhat more mystical side, arguing that there were 2 basic principles in operation- these being called Love and Strife. Love was ultimately responsible for bringing elements together, whereas Strife tended to force them apart. The interesting thing here is that Empedocles in no way thought of these motivating causes or principles as abstract or inanimate- nor were they purely mechanical in their actions. Indeed, in this poem on "Purifications", they acquire a moral dimension- strife is evil and Love is good, and the universe is constantly moving from a stage where Love is predominant, to one where Strife holds sway. Empedocles was an optimist- he felt that at his time, Love was on the ascendant, and that humans had in fact fallen from a previously blessed state in which our souls were at one with each other. This fall was caused by strife, principally the sin of eating animals (it is not known whether Empedocles was a vegetarian!). Empedocles even apparently thought that humans needed to find Love again by going through a series of reincarnations, divesting themselves of Strife and seeking at least parts of Love, unadulterated by Strife. In his other writings on human physiology and human nature, Empedocles gave a medical turn to his philosophy - some of his speculations are quite fascinating, but we have no space for them here.

Empedocles was one of the most interesting of the Greek philosophers, and his ideas were extremely influential. Both Plato and Aristotle accepted the idea of 4 elements, and the principle of Love and Strife - indeed these ideas have held their grip on the Western imagination ever since. His spiritual blend of cosmogony and the reincarnation of human souls, via a striving towards Love, was also strongly influential, and found its way into later religious canons, along with the later ideas of Plato and Aristotle.

(b) **ANAXAGORAS** (c. 500-428 BC): Unfortunately not enough is known abut Anaxagoras- even the time at which he lived is controversial. He was a well-known personality in Athens at the time of Pericles, and indeed part of the circle of writers associated with him- he also had some influence on Euripedes. Only one work of his is known, almost entirely through fragments and commentaries on it provided by Aristotle and Simplicius. It appears that perhaps around 450 BC he was ejected from Athens for his atheism and/or impiety, and died in exile some time later.

The philosophy of Anaxagoras had none of the religious overtones of that of either the Eleatics or the pluralists- in this respect it had more affinity with the older Milesians. The 2 distinguishing features of his philosophy that we know of are (i) the introduction of an entirely non-material 'first cause' of all motion and change in the world, which he identified with 'Mind'; and (ii) a form of pluralism in which all objects in the world contained elements of all others, in greater or lesser proportion.

The first step is important, in that it introduces Mind as a separate entity, and separates it entirely from the physical world. In his approach, Mind is the initiating cause of the world and its structure, and is still the cause of the actions of all living things- but it is entirely absent now from the material world, except for its presence in living things. In the beginning of the world, Mind was responsible for initiating, in the primeval undifferentiated mass, a vortex-like rotational movement which began to separate out different parts of the mass, creating the extremely inhomogeneous result we now see. However all the different things we see today were supposed to be initially present - in particular, organic elements like hair, or skin, are now everywhere present to some degree, but we are only aware of them in the hair or skin we see because they are elsewhere in very small concentrations. Thus quite generally, every material we see contains some fraction of every other (the total number of the different kinds of material is left undetermined!). This rath4er peculiar theory was apparently inspired in some part by Anaxagoras's observations of living things- notably the transformation of the things we ingest (food, drink) into living tissue.

Anaxagoras was unimpressed by Zeno's objections to plurality- remarking that "of the small, there is no smallest", ie., that things (including number) were infinitely divisible. It is hard at first glance to see why his ideas led to his exile from Athens- apparently the chief crime was to assert that the sun was merely a burning rock "larger than the Peloponnese", rather than being a divine being. Subsequent thinkers were most influenced by his idea of Mind as a prime mover - this step had a large impact on Western thought and religion.

(5) LEUCIPPUS and DEMOCRITUS: The Atomic School

Atomists like Democritus and Leucippus before him wrote on a number of things (eg., Democritus made some mathematical discoveries) but the work for which they are most important is that of atoms. As with all the pe-

Socratics, almost all of what we know comes from later commentators; and as usual, much of what we know comes from Aristotle, although there are also many scattered remarks from writers including Theophrastus, Diogenes Laertius, and Cicero, a catalogue of Deomocritus's work by Thrasylus, and fragments given by Sextus Empiricus. It is not always easy to separate the contributions of Leucippus and Democritus, but from everything written by later commentators, it is clear that the basic idea of atomism was due to Leucippus, but that most of the important details were worked out by Democritus.

(a) The Atomist Philosophers

(a) **LEUCIPPUS**: Not much is known about the founder of the atomistic philosophy- he was probably born in Miletus, and is believed to have been active roughly in the period 450-420 BC. He seems to have worked for a time with Zeno, perhaps as a student of his, and thereby learned the Eleatic doctrines. Only 2 manuscripts are attributed to him - "*On Mind*", and "*the great World-System*" (the latter was however also assigned to Democritus by Thrasylus). The original atomic theory of Leucippus was apparently (at least according to later writers like Theophrastus) an attempt to deal with the Eleatic arguments against change, and was influenced by or drew upon ideas from the pluralists as well as being influenced by the Pythagorean school. It seems fairly clear that Leucippus was at some time a teacher to Democritus, and that an importanbt part of the atomistic ideas came initially from him. However it is hard to know how to separate them, particularly as Democritus was so much better known and wrote a great deal. In some cases we can separate them - for example, the astronomical ideas of Leucippus seem to have been fairly crude- he assumed the earth to be flat, and the sun to be the most distant heavenly body. The astronomical ideas of Democritus (described below) were more sophisticated.

(b) **DEMOCRITUS of ABDERA** (c. 460-359 BC). Democritus lived for a long time, and according to Thrasylus, wrote at least 60 different works, on a wide variety of topics. He traveled very widely at various points in his life, and is believed to have visited Egypt, Chaldea, and the Red Sea, as well as different parts of the Greek world. Many stories about him, perhaps unreliable, circulated around the Greek and later Roman world- he was known later as the 'laughing philosopher', who had at one point saved the Abderites from a plague.

Democritus enormously developed the ideas of Leucippus, elaborating the atomic hypothesis to encompass a large variety of natural phenomena, including the different sensations that we have (taste, smell, vision, etc.), as well as astronomical and cosmological phenomena, and extremely detailed work on biological and medical topics. He also tried to extend these ideas to discuss the soul, and gave what would now be thought of as a 'theory of knowledge' to explain how we come to know various things. Democritus also came up with various ideas on ethics and politics, and he also had a strong interest in mathematics, which undoubtedly helped him to formulate his version of the atomic theory.

In later Hellenistic and Roman times Democritus acquired an almost legendary reputation, based on the encyclopaedic character of his writings, on his claimed discoveries of medical, alchemical, and even magic phenomena, and the later influence of his ideas on, eg., the Epicureans. It is clear that the depth and breadth of at least part of his work matched that of Aristotle. Given the colossal influence of Aristotle on subsequent European (and to some extent Islamic) history, it is sobering to realise how different things might have been if it had been the writings of Democritus that had survived instead of those of Plato and Aristotle. Certainly the use by the later Christian church, of Platonic and Aristotelian ideas as a philosophical model, would have been unthinkable with the atomic theory.

(b) The Atomic Theory

From a modern standpoint, the atomic theory looks like a colossal intellectual achievement. Certainly it did not come from nowhere, and at numerous points of specific detail it burrowed from earlier work of Empedocles and Anaxagoras. Historians of philosophy usually follow Aristotle and other Greek commentators, and treat the atomic theory as a response to the intellectual stalemate provided by Eleatic philosophy. The rather radical introduction of "the void" is then viewed as a way of allowing motion and change in the world, and the introduction of atoms as a way of dealing with the variety of things, as well as addressing the problems created by Zeno's paradoxes.

As we shall see, this point of view is oversimplified. However one views the genesis of the theory, it is above all an astonishingly creative work, which was the first philosophical/scientific theory attempting to give a detailed understanding of all aspects of the world around us, in a fully naturalistic way. For this reason I develop it is some detail here, starting first with the basic idea of atoms and the void, and the explanation of motion and causation. We then we go to look at cosmology, astronomy, and the physical world. The key questions of how sensation and perception are to be understood, and the resulting epistemology this led to, are then dealt with. These lead naturally to the ideas of Democritus on the soul, life and biology, medicine, and religion. The mathematical work of Democritus

is discussed in a later chapter, and his ideas on music, the arts, language, politics and ethics, are described very briefly above.

(1)ATOMS MOVING in the VOID: The idea of invisible atoms was clearly influenced by earlier Pythagorean ideas about the role of numbers and geometry in Nature. However for the atomists, Nature was material, composed of a single primitive stuff (the "One" of Parmenides, or the "*apeiron*" of Anaximander). However instead of the world being a single Eleatic unchanging undifferentiated unity, it was divided into an infinite number of finite-sized atoms, which came in different shapes and sizes. Most indications are that (i) all the atoms were so small as to be invisible to us, and (ii) that the number of possible shapes was infinite (ie., these were not just simple geometric objects like cubes or spheres).

Because they were constituted of the basic substance, and because they were assumed to be the fundamental units of Nature, the atoms themselves were held to be immutable, everlasting, and indivisible - they could have no parts. The argument quoted in Aristotle (*G & C*) went as follows: "*If a body is divisible, let it be so divided. What then is left? A magnitude? No, for if so it can be further divided. Infinite divisibility then implies that magnitudes can come from non-magnitudes, which is absurd*". This argument is not mathematically sound (nor did Aristotle think it was) but the problem was too mathematically subtle for the Ancient Greeks; and it served its purpose, which was to justify the idea of finite but indivisible atoms.

More detail on the atoms can be found elsewhere in Aristotle. He remarks (in de Caelo) that "*They can be differentiated by their shapes, but their substance* ("$\varphi\upsilon\sigma\iota\zeta$", or "physical nature") *is one, just as if each were a separate piece of gold*". Elsewhere Aristotle adds (*Metaphysics*): "*they say that the differences in the atoms are responsible for everything. These, according to them, are threefold: shape, arrangement, and position.for example, A differs from B in shape, AB from BA in arrangement, and C from B in position.*"

Crucially, however, we note that the atom is completely characterized by its size and shape - it possesses no other properties or qualities. The logical argument is simple and goes back to the Milesian, but here it is developed properly. Assume there is a substance, or "*apeiron*" which serves as the underlying substrate of all things - things which themselves do possess qualities like taste, colour, smell, weight, hardness, etc. However this underlying substance cannot have any of these qualities (otherwise it would not be fundamental). Note the importance of this argument - it says that everything in the world - from rocks and plants to animals, to the perception of sound and smell, to thoughts and emotions, to life and death - all of these objects or processes must result from different combinations of atoms, and the collective motions of these atoms.

This brings us to the dynamical properties of the atoms. The key of course is the void, allowing all manner of motions. It is remarkable that at that time, this argument was viewed by many as completely novel, and very daring. One reason for this is that the Greeks, at that time, assumed almost universally that motion, and heat, were associated with life, so it was hard to conceive of something that was in constant motions without being alive. The kinds of possible motions were recounted by Aristotle, and later by Simplicius:

"*These atoms, separate from one another in the infinite voidare in motion, overtaking one another and colliding. Some rebound at hazard, others become entangled when their shapes, sizes, positions, and ordering are favourable; and thus it comes about that composite things are generated.*"

To understand how the atoms might become entangled, it was assumed that their shaped could fit together, or they could be otherwise attached; as Aristotle says, in *de Caelo*: "*....some are irregular, some hooked, some hollow, others convex, and others have innumerable other differences*". Aristotle, in his discussion of previous views of the soul, (in "*de Anima*"), writes:

"*Democritus said that soul is a sort of fire or hot substance. His "forms" or atoms are infinite in number; those which are spherical he calls fire and souls, and compares them to the dust motes in the air which we see dancing in shafts of light coming through windowsthe small spherical atoms are identified with soul because they are best adapted to permeate everywhere, and to set all the others in motions by being themselves in movement.*"

We note two important points here. First, the atomists did follow their predecessors in assuming that motion and life were connected, but they differed radically in assigning no cause for this motion - not only was there nothing like "Love vs. Strife" (Empedocles) or "Mind" (Anaxagoras) to drive change, but there were no natural causes either. We return to this below - it was a real problem for Aristotle and subsequent writers.

The second point is that the atomists envisaged almost everything as being a composite of different atoms; as Aristotle in *de Caelo* put it "*air, water and the rest they distinguished by size, considering their nature to be a* "seed collection" *(panspermia) of all the atoms*". Only the atoms making up soul were of a single kind.

From a purely logical point of view it is fairly obvious that if one assumes that the atoms are eternal and immutable, then there is no need for some initial stimulus or "first cause" to explain what set them into motion. In fact such a first cause would contradict the assumption of a universe whish was fundamentally unchanging. Nevertheless this caused big problems for Plato and Aristotle, and for all subsequent Hellenistic and Roman commentators. The difference

between the atomists and everyone else is highly illuminating. The atomists put forward an idea which, much later, would come to be called "determinism", and which was summed up by Leucippus in a well-known remark, viz., that

"*Nothing occurs at random ($\mu\alpha\tau\eta\nu$), but everything for a reason and by necessity*".

What is meant here is that even though all of the motions of the atoms may have seemed complicated and perhaps random, they were in fact rigorously determined. What upset Aristotle so much was that he saw Nature and natural processes as having a purpose. His approach was basically teleological - natural processes were directed towards some goal. Note that for the Greeks this seemed a much more natural idea then determinism. Thus, eg., a seed was destined to grow into a tree, an egg to a bird, and rivers were destined to flow downhill; the explanation for these processes was in terms of a Final Cause. As Aristotle correctly observed, for the atomists, processes and the evolution of events were not directed to any goal - in this respect they are blind, and the results are "accidental", governed only by mechanical necessity. As he remarks (*de Caelo*), "*Leucippus and Democritus, who say that the primary atoms are always in motion in the infinite void, should tell us what kind of motion, and what is their natural motion*"; and then in the *Metaphysics* he writes: "*but from what cause* (is their motion) *they do not say, nor what kind it is, nor the reason why it is in this direction or that*".

There are really two points that are being made here, and with the benefit of 2300 years of hindsight, both are very revealing. First, Aristotle is really asking for some kind of "law of dynamics", ie., some way of saying predictively how the atoms will move. But such a formulation was so far out of reach of the Greeks, that he could not even express himself in this way. Second, Aristotle believed that any such explanatory law would have to be given in terms of final causes. Note that there is no mention of initial causes, a creator, or intelligent design in Aristotle - but there is always purpose. To really appreciate what he meant, we have to understand the Aristotelian theory of causes (for which see chapter on Aristotle).

As a matter of fact Democritus did have some notion of how the atoms moved. In analogy with the way pebbles or sand grains, of different sizes and shapes, will sort themselves into groups of similar sizes when shaken, he argued that atoms of like size and shape would collect together in patterns. This is particularly clear in his theory of vortices, which is discussed below when discussing his cosmological ideas. It is a pity we do not have the original manuscripts of the atomist's theory of motion - it is hardly likely that Democritus did not attempt to develop the details, in the same way that we know he analysed biological phenomena.

(2) COSMOLOGY, ASTRONOMY, and the NATURAL WORLD: Not content with a general theory, the atomists took the enormous step of elaborating a detailed discussion of its consequences for the natural world. The result is a mixture of ideas which are astonishing in their perspicacity. The universe was infinite; according to Democritus:

"*there are innumerable worlds of different sizes. In some there is neither sun nor moon; in others they are larger than in ours, and others have more than one. These worlds are at various distances, move more in one direction than another; and some are flourishing, some are declining. Here they are born, there they die, or are destroyed by collision with one another. Some worlds have nor life nor water.*"

According to Diogenes Laertius, Leucippus had a picture of the origin of our world (which Diogenes took from Theophrastus), as follows:

"*The world is infinite ... parts are full and parts are empty. Worlds unlimited in number are formed and dissolved therein. The manner of their formation is as follows. Many atoms of all shapes stream into a void, and when collected in a mass produce a vortex, following which they collide and revolve in many ways and begin to be sorted, like with like. But when their numbers* (ie., their density) *are too great, they can no longer be carried in equilibrium, and the small atoms pass out to the void outside, as if passing through a filter. The rest become entangled and move together in a spherical mess. From this complex a kind of membrane detaches, containing bodies of every kind, which whirl around in proportion to the resistance of the centre; and the membrane stretches thin as contiguous bodies flow together by contact in the vortex. In this way the earth was formed.*"

Leucippus goes on to extend this formation to the stars, and then finished by saying "*just as a cosmos is born, so it grows, declines, and perishes by some sort of necessity*". Unsurprisingly, Democritus was unconvinced of any underlying purpose in the universe.

This is breathtaking stuff. The resemblance to our modern picture of the universe, and of star formation, should not obscure some of the more idiosyncratic aspects of this theory. The membranes are peculiar, and are connected with the atomistic theory of perception (see below); but they also recall the idea of an embryonic membrane, and the atomistic version of biology (see below).

Democritus gave many further details of this cosmology. He apparently wrote a whole book on the planets, in which he also discusses the likelihood of undiscovered planets. He correctly ordered the moon, sun, planets, and stars in increasing order of distance, and correctly understood that the Milky Way was a vast collection of faint stars, and that comets were passing heavenly bodies. He followed Anaxagoras in the view that the moon contained mountains

and valleys, illuminated by the sun's light. He also opined that the earth's rotation came from the rotational motion of the primeval vortex, and argued that the tilt in the earth's axis was due to differential heating between southern and northern altitudes (he was not too clear on the earth's shape, and seemed to think it was some kind of oval solid).

The explanation of earthbound natural processes burrowed heavily from earlier writers, but in all cases the idea was to show compatibility with the atomic theory. The annual Nile flooding was explained by the evaporation of water from snow or the sea, to form clouds which deposited rain in the mountains over Europe and further south. Other typical meteorological phenomena were likewise explained in terms of evaporation and the motion of high pressure gas to lower pressure - and our pressure was understood as a higher density of air atoms. While none of this was in any way quantitative, the basic idea was right. The explanation of thunder and lightning involved an idea from Anaxagoras about a downward rush of fire (ie. fire atoms), and the mythological explanation (Zeus) was explicitly rejected. Earthquakes were caused when cavities in the earth filled with water after a flood - this idea came from Anaxamines. Magnetism was explained by the motion of atoms towards voids and through pores. And so on. In many cases it would have been quite impossible for the atomists to give anything like a correct explanation of simple natural phenomena - the important point is that they made the attempt using a single general theory.

Finally, in view of the modern association of space and time in relative theory, it is interesting to see that the atomists relegated time to a rather secondary place in their scheme. The most important novelty is that they abandoned the standard Greek idea that time was cyclical, and simply assumed that it was infinite in both directions (past and future). This was a significant break - the existence of seasons, and the periodic motion of a heavenly bodies, was terribly impressive to the Greeks, and it was assumed by most people (and almost all pre- and post-Socratic philosophers) that the cosmos and even all of human history would repeat itself. For Plato, the cyclical motions in the heavens were permanent, and connected with the perfection of higher forms - he thought them to be the products of a higher intelligence (*Timaeus*). But for Democritus none of this would last - sun and stars eventually die and disintegrate, along with everything else.

(3) SENSATION, PERCEPTION and EPISTEMOLOGY: The atomists naturally sought to explain sensations like hearing, taste and vision in atomistic terms. The depth of their thinking is evident in their understanding that an atomistic theory of perception implied significant limitations on human knowledge. There are hints, from some of the fragments of Democritus's writings, that he may have held that atoms *necessarily* had to be invisible to us, simply because visual perception involved them and therefore its mechanism would necessarily involve processes at a larger scale than individual atoms. This limitation on human experience would not have bothered Democritus, who held (like almost all Greeks) the opinion that the only true and certain kinds of knowledge were those arrived at by rational thought (inference and deduction). This, even though these conclusions concerned the natural physical world (the only world that existed for Democritus), not some ideal world of Platonic forms.

Noting the "relativity" of sensations (eg. The way in which water can feel cool to one person and warm to another, depending on whether they are hot or cold), the atomists argued that perception and sensation necessarily involved properties of both the subject (the perceiver) and the object of perception. Thus, eg. "heat" is not a substance or thing having its own intrinsic nature, but a purely subjective feature of collections of atoms in a "hot" body interacting with an observer. For the atomists heat consisted in the properties of round small atoms that could easily move between other atoms - it is not clear if they had any idea that it simply was the rapid random motion of atoms (certainly Aristotle did not, since he felt that different atoms were at different temperatures according to their shape). The taste of honey depended on which sorts of atoms in the honey (considered to be mainly a mixture of large smooth atoms producing sweet sensations, and small rough ones causing bitterness) were able to penetrate through "*porοi*" (passages or pores) into the body, in a kind of filtering mechanism.

One can summarize this idea in Democritus's own words: "*In our belief there appear to be bitter and sweet, hot and cold, and colour; but in truth there are only atoms and void*"; and: "*in reality we grasp nothing precisely, but only as it shifts according to the disposition of our body and the things that enter into it and press upon it*". Aristotle remarked that for Democritus "colour" did not exist - it is simply a matter of the dispositions of the atoms" (*G & C*); and that for the atomists "*there is no black or white without sight, not flavour without tasting*" (*de Anima*). Nevertheless Democritus recognized that one required a detailed theory of what kind of atoms were involved in producing different tastes and colours. His obviously abundant interest in the natural world allowed him to respond to this challenge. In the discussion of hearing he recalled the general ideas of Empedocles and Anaxagoras on the structure of the ear chamber, but then added the idea that atoms from an emitting body would strike atoms of the intervening air and mold their motion to the likeness of the "sound atoms"; ie, he understood that sound was transported through an intervening medium.

All of these ideas were inevitable in their theory, since for the atomists, there was no action at a distance - all influences and physical interaction came via the collision and recoil or entanglement of atoms through direct contact. This led to a complex theory of human physiology (see below). Democritus's theory of colour (in which there were 4 primary colours: black, white, red and yellow/green) involved fascinating detail; for example:

"*Gold, bronze and similar hues are composed of (atomic complexes) of red and white. From the white comes their brightness and from the red their ruddy sheen, for in combination the red sinks into the spaces between the white. If we then add yellow/green ($\chi\lambda\omega\rho o\sigma$) a beautiful colour is produced;, but only with small additions, for the white-red combination will not allow a large admixture. The colour will vary with the proportions*".

All of this seems sensible. Where it is harder to follow the atomists is in their ideas that vision involved films or membranes of atoms being thrown off continuously by objects, and which retained, at least approximately, the shape of the emitting objects, and thereby were "images" of them. The difficulty is that we have no detail here - it is hard to know what was meant. Alexander of Appolonia, commenting on Aristotle's commentary on this, says that "*Democritus believed that to see, means to receive the "reflection" (image) form which is seen - this is the shape which appears in the pupil, just as it does in any other bright thing which can retain a reflection*".

Further detail appears in the remarkable poem "*de Rerum Natura*" "or the Nature of Things" by the Roman Lucretius. However this was nearly 400 years later, and influenced more by Epicurus, who had his own later brand of atomism; and Lucretius was not a philosopher. So we can only guess at how, eg., Democritus envisioned the interaction of 2 membranes that passed through each other (he would have had to explain why they didn't appreciably interfere), and at other details of his ideas about vision (note at this time the Greeks apparently had no clear understanding of optics - this came later, at the time of Euclid).

The theory of the atomists concerning perception and sensation was necessarily connected with their epistemology. This was sceptical- Democritus held that "we know nothing truly about anything". As noted above, he held that there were 2 modes of understanding- knowledge based on perception, which was imperfect, and 'legitimate' knowledge, of things that were imperceptible (like atoms or the void); this was arrived at through reasoning as well as via perception. Remarkably, he argued that only 'legitimate' knowledge was of real things (even though it was imperfect); perceptual knowledge was governed by 'convention', and was of secondary things. Apparently the idea here was that immutable atoms and the void were real, whereas everything else was a construction from these, and could be looked at or analysed in different ways. All of this is in line with his other ideas

(4) The SOUL, LIFE, and BIOLOGY: For the atomists, as for most Greeks, life involved a soul, which was more than just the mind. For Democritus, the mind was a concentration of soul atoms in the head (not the heart, as it was for Plato!). These atoms, as noted above, were small and round, and could easily move through others - and thus could easily escape the body. Life was then maintained by breathing, which continually brought more soul atoms into the body.

This led to Democritus to remarkable ideas about death, which for him was a slow leaking out of soul particles from the body, under pressure from the atmosphere. This led to various conclusions, quoted by later writers. For example "*Democritus says that all things share in some sort of soul, even dead bodies, which plainly retain some warmth and sensitivity when most of it has been breathed out*"; and later on "*Democritus, rather than accepting that there are certain symptoms of approaching death, declared that there was no certain indications by which doctors could be satisfied that life had ceased*".

Thus life did not cease abruptly. Democritus was apparently impressed by the many stories of resurrection "after death" that he came across, as well as by the observation that nails and hair continue to grow for a certain time after death.

Clearly the atomists did not believe in an afterlife. Curiously, Democritus did not simply reject religion as the ravings of the *theologi*; he instead argued that since all bodily sensations have a cause, human ideas about gods and demons must have a basis in membranous images thrown off by something (although not necessarily by what the receiver might have thought). But whether received in dreams or in some other way, these "images" were not hallucinations - for the atomists, *all* experience was equally subjective, and came from visual images or other real sensations. What Democritus really thought about the source of these images (ie; whether they came from real gods or were just stray distorted images received in dreams) we do not know.

The total published work by Democritus on all aspects of biology, medicine, and physiology was apparently huge, perhaps equal in size and scope to that of Aristotle. Unfortunately it is almost entirely lost to us - we have only later commentaries to go on. There is a story that Democritus met an aging Hippocrates, and that they discussed the entrails of animals that Democritus had been dissecting. Where this is true or not, there is little doubt that Democritus owed a good part of his reputation in Ancient Greece to his extensive knowledge of biological and medical matters. The commentaries indicate a wealth of physiological detail on a large variety of animals. Examples include his description of the way spiders generate silk from a fluid secreted from inside their body (a description which Aristotle incorrectly contradicts); and a lengthy description of the way horns grow in cattle and deer, including the manner in which the horns are nourished via a network of channels coming from the heads of the animals (he apparently did not understand the nature of the circulatory system). There is also great detail about his ideas reproduction, embryology, and the origin of life - while of considerable interest to the history of early medical science it is not essentially related to the atomic theory.

This whole theory is quite remarkable for several reasons. It was able to explain many details of the behaviour of the surrounding world, and had the interesting feature of being deterministic, not requiring any motivating force or "cause" (eg., Love + Strife) to drive things along. The extension of an entirely mechanical theory to encompass all natural phenomena was amazing, as was the appeal to geometry to explain the different fundamental atoms. From a modern perspective one sees the extraordinary anticipation of many modern ideas. The Greeks saw it more as an attempt at a rational synthesis of ancient ideas on form, substance, and the antithesis of change and immutability.

There were obvious problems for other philosophers- in its attempt to bridge the gap between pluralist theories like those of Empedocles and the monism of Parmenides, the Atomists offended almost everyone, by substituting an idea which contradicted all of the others, and which did not apparently answer all of the questions raised by them. The atomistic answer to the problem of apparent change, the introduction of a void, had been specifically denied by Parmenides, for reasons given above. The lack of motivating forces or external causes led to the criticism that atomism did not explain why things happened. That a more limited "mechanical" explanation could be given of details did not impress Aristotle and Plato, who felt that they could get to either ultimate (ie., 'final') or initial causes. Their ideas later led western thought down a long path, in which either teleological or 'first cause' explanations were sought for the world. Greek religion and mysticism also played a role in this, and strongly influenced the later Catholic and other Christian dogmas- all of this will be discussed later on.

Democritus et al. were surely aware of most of these arguments (including the supposed lack of any explanation of "initial causes", or any other kind of cause). But they had found a new way of inquiry- to look for explanation of the details in a *hypothesis* about the structure of the world of appearances. And the style of inquiry was crucial- pursue the hypothesis IN SPITE OF the obvious philosophical problems (eg, the presence of a void), to see how far one could get. From a modern perspective we can see that they attempted a more limited goal than that of ultimate truth- and were rewarded with considerable success. The accuracy of some of their conclusions, even in many details, was quite incredible, and shows that the Greeks were not prevented from arriving at these conclusions by any limitations on 'experimental methods' or available experimental tools. Unfortunately, the rejection of atomistic ideas by Aristotle, the subsequent prevailing style of philosophy advocated by Socrates and Plato, and the later conflict between faith and reason engendered by Catholic dogma, all conspired to reduce the influence of these ideas until much later on.