Aristotle

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1 Physics

1.1 Introduction (Book 1)

To attain true scientific knowledge, we need to find out the underlying principles or *elements*. Thus we must go from the easily observed, but complicated, particulars to the clear unobscured universals.

Among the philosophers, there have been all possible suggestions:

1. One element (Parmenides' "All is One Being")
2. One substance in motion, with more or less of it;
3. Several substances, with things being mixtures of the various types (Anaximander, Empedocles);
4. Infinite number of substances, either one substance in an infinite number of forms (Democritus), or an infinite number of substances mixed together in one All (Anaxagoras).

We can eliminate the first immediately: nothing can be derived from this supposition; either what is meant is that "all is one" by definition, making the statement a tautology lacking any real content, or it is meant that it is one continuous whole, in which case it is not truly one, but divisible into parts.

The last possibility has its own problems: (i) it makes it impossible to know these substances, as it could always be argued that something is made up of a new type, (ii) the elements cannot be arbitrarily infinite in size at least, because e.g. animals are fixed in size, (iii) the assertion of Anaxagoras that everything consists of different proportions of these infinite types cannot hold, because if water contains flesh particles, either it contains a finite number, in which case it should be possible to extract all of them to leave pure water, or one can never completely clarify water of these particles, in which case there are an infinite number of these finite-size particles, an impossibility, (iv) why postulate an infinite number, when a finite number will do? (v) Democritus has never said what these shapes are, except that fire has spherical particles, and that water and air have different sized atoms, but then how can water become air?

So we settle to the case of several types of elements. Any element gives rise to its opposite, and in fact different thinkers have taken different types e.g. hot/cold, moist/dry, odd/even, or even love/strife.

How many elements should we take? It is difficult to imagine how one element (and its opposite) can give rise to all the different possibilities in nature, but we cannot dismiss it offhand. Three elements seems to be the best bet: one substance and two elements could give rise to air, water, fire, earth. Whether the substance is different from these, or one of them (say air or water) is a matter for discussion. But 4 elements (in two opposing pairs) is too much – which pair is the underlying primary principle?

To answer this question, let us consider what happens when something *changes*. There are various possibilities, (i) a change of shape e.g. bronze becoming a statue, (ii) addition e.g. plants growing from a seed, (iii) subtraction e.g. statue carved from a stone, (iv) putting together e.g. house from bricks, (v) alteration e.g. water from flesh. In all these changes, there is something that survives the change, the *substance*, and something that doesn't (what has actually changed), the *form*. The elements of the change are therefore, in one sense, 3 (the substance + the form + the opposing form), but in another sense 2 (the substance + the form; the opposing form is not independent of the form).

The first philosopher (Parmenides) was guided by the principle that "nothing comes from nothing", from which he concluded that any thing must have already existed before, and that there is no change, no motion. Here we are accepting this, in the sense that the substance does not change, but also refuting this, in that the form changes.

1.2 Causes (Book 2)

There are two types of objects: *natural* things change of their own accord, whereas *artificial* things do not. Thus animals, plants, or stones move and grow by themselves, whereas a bed or picture does not, except in so far as it is made of wood, i.e., a bed moves just as any other wooden object would. It might be countered that a doctor can cure himself, even if being a doctor is not "natural"; but in this case it is just happens that the doctor is the patient, and patients do not cure themselves of their own accord.

That there are natural objects is self-evident (someone asking for proof is like a man blind from birth talking about colors – they talk about it without knowing what it is), but what constitutes the nature of these objects is not. Antiphon put the example of a bed which, planted in soil, sprouts out a shoot – it does not grow into a bed but a tree, showing that its real essence is wood, not its bed-shape. Similarly the primary natural substances are commonly held to be earth, fire, air and water. But objects also have form (shape), and this may more properly be said to be the real nature of an object: a formless piece of wood is not a bed, and a collection of bones and flesh cannot be called a man.

When flesh grows into man, it is the target not the source that has the nature of man.

In contrast with physics[1], mathematics is about abstract static attributes. A line does not move of its own accord! The other branches of mathematics, such as optics and astronomy, are studies in the application of lines.

The nature of things is in both substance (matter) and form. The ancients considered only matter, but just as a builder needs to know his bricks and beams and how they connect together, and a doctor his (bile and phlegm, as well as health), and to make a helm, we need both the helmsman to determine its form and the smith its materials, so a physicist needs to know the substance and the form.

Why do things happen? What is the cause of an action? There are various uses of the term *cause*: (i) the *material*, or parts, that make it up, (e.g. the bronze makes up the statue), (ii) the *form* or definition, (iii) the *source* of the change (e.g. the seed, the adviser), (iv) the *purpose*[2] of the change (e.g. well-being). Furthermore, one must distinguish between general and particular causes, potential and actual causes, etc.

1.2.1 Chance

But some things happen by *chance*. Although some dispute this and insist that everything has a cause, other philosophers have described the origins of animals, even of the world, as spontaneous chance events; yet others include chance as a mysterious unknowable cause.

Let us first clarify what is chance: we say something happens by chance (as a source) when it doesn't happen by necessity, or doesn't normally happen; but also which doesn't happen purposefully or deliberately. For example, a man who is collecting money for a feast, going to see a spectacle, may by chance gather the money, even though he did not go there deliberately for that purpose.

Chance events are special sorts of spontaneous events. Since purpose and deliberation are moral issues, animals, children and stones cannot do things by chance. Rather we say they do things spontaneously, e.g. when a tripod happens to fall upright. Chance events are those that could have been done deliberately, but instead happened incidentally. Incidental in the sense that a flute-playing ability is incidental to a builder for the purpose of building a house. Note that an event may happen both spontaneously and by chance, as when a stone may have been thrown by a man and hits another by chance.

In any case, for a chance event to happen, there must be many other possible causes in existence; thus if the heavens occurred by chance, then nature, with all its causes, must have existed before. So chance is not a cause, and chance events do not happen *because* of chance, but because of an incidental other cause that does not normally occur.

[1] Greek *physis* = nature
[2] Greek *telos*

1.2.2 Purpose

Returning to our discussion, the last three causes are often the same for men, since the purpose is usually in the definition, and the source of the action is himself. We are left with two main physical causes: the matter, and the purpose.

Does nature have a purpose? It certainly does not rain in order that the crops grow, rather things that rise up causes a cooling effect, which in turn causes water to form, which must then fall as rain; and in turn this causes the corn to grow. Yet it seems that teeth grow up the way they do, with sharp incisors and broad molars, for a purpose, in order to cut food and chew it respectively. Empedocles asserted that at first there were all sorts of things fitted randomly, of which survived those that fitted a purpose; the man-ox was not good for anything and perished. But teeth normally form always in the same way; similarly birds build nests for their young, spiders build webs to catch insects, trees grow leaves to shelter their fruit, and roots for nourishment. So even in nature, as for intelligent beings, there may be purposes. This is not to say that mistakes do not happen: just as a doctor may pour the wrong dose, there may be monstrosities in nature. Neither does it mean that natural objects deliberate on their purposes, just as a ship, unknown to itself, has a purpose.

Are things necessarily the way they are? Are walls, and saws, the way they are by necessity? Most believe so: a wall must have the heaviest stones at the bottom, then the earth, then wood at the top, or else it will fall; and a saw must be made of iron in order to cut. But these are only the material causes: by themselves they do not form a wall and a saw. A fuller answer would require the purpose: to shelter and to cut, respectively. The purpose comes first, and then, by necessity, the materials. Necessity here means logical necessity, as in "if A then B"; or rather "if not B then not A". That a saw by necessity is made of iron, depends on the assertion "if a saw is not made of iron, it will not cut". Materials cause the object; but the purpose causes the chosen materials. Thus the quest of physics is to find the primal purpose of things.

1.3 Change (Book 3)

Since change is what defines nature, we need to study what it is. It is commonly held that motion is continuous (i.e., infinitely divisible), and requires position, time and void. We take as the definition of motion or change to be the actual realization of a potential. For example, a building as it is being built, or learning, leaping, or ageing, while they occur. The cause of the motion may itself change, as when hot meets cold. Once the end-result is reached and the potential fulfilled, there is not more change.

The other philosophers have found difficulty in defining change: one cannot point to change, and say this is it. An object capable of growth is not changing unless it is actually growing, nor is an object that has already grown. Change is neither potential nor actual, but somewhere indefinite in between.

A mover which acts on a movable object makes it move. The cause is the contact between the two, and as such, causes the mover also to move, if it is capable of motion. It may appear that there is symmetry between a mover and the moved, and someone may counter "how can the same thing be different for the two?" The answer is that a change is not something in itself, but the action of A on B; it is the mover that acts and the movable that is acted upon: teaching and learning are not both present in the teacher, even though they are different aspects of the same thing, just as an uphill AB is another view of the downhill BA. "Acting" and "acted upon" are not the same by definition, but are realized the same.

1.3.1 Infinity

Since motion concerns space and time, and these are, at least potentially, infinite, we must discuss the latter. Plato thought of it as two forms that can be actually realized, while the Pythagoreans went even further and included it as an observable, along with all the numbers. Anaxagoras and Democritus make essential use of it as an attribute of the elements. Everything is either a source, or derived from a source. But the infinite cannot be derived (from the finite), so it must be in the source of everything, uncreated and indestructible, some identify it with the Divine even. Let us first of all identify some examples of the infinity: time, a line (which can be divided indefinitely), nature (it is not diminishing to nothing, so must have an infinite supply), the universe (else the boundary would be out of it), numbers. Some even conclude that as the universe is infinite, there must be an infinite number of worlds to fill it out, otherwise why here and not there?

We should understand how the word *infinite* is used: (i) as something that in principle cannot be exhausted, (ii) as something without an end, (iii) as something that in actuality cannot be reached. Moreover there is the infinitely large, and the infinitely small. The infinite cannot be a substance, since it is divisible into parts; it is akin to numbers and magnitudes, and so is an attribute. Now we must distinguish this mathematical infinity, from the physically infinite. An infinite homogeneous body cannot exist: how can its parts decide whether to move or stay at rest? If an infinite body contains an infinite amount of an element, say air, but a finite amount of fire, the fire would be extinguished; but if it contains an infinite amount of each of the elements, then it would have to be infinitely large and fill out the whole universe. Nor can an infinite body of a single element exist: otherwise we would be able to observe it along with the other elements. And if it were to exist, what would its natural place of rest be, would it be heavy or light, or in what proportion? Just as the infinite is not any particular number, it cannot have any particular position.

Infinite exists as a potential. Not potential in the sense that it can actually be realized, but in the sense that a change towards it can be made, without ever reaching it. It is a process rather than a thing, just like "day", or "Olympic games". As definition, we take an infinite quantity to be that which still exists if we take out a (finite) part, no matter how large.

The infinitely large is in a sense the same as the infinitely small: dividing a line and scaling it up, is the same as adding to a line. But the infinitely large cannot exist, whereas the infinitely small exists potentially. Of course a line may be extended to any magnitude, but never to actual infinity; so geometry's theorems are not affected.

Finally let us answer those who claim the infinity to be actual: (i) nature needs an inexhaustible supply of matter: but it doesn't have to be, one thing may give rise to another, indefinitely; (ii) infinity is possible as a thought: but that is beside the point of this discussion about the physically infinite; (iii) time and magnitude are infinite: but potentially, not actually.

1.4 Space (Book 4)

What is position? Mathematically, space has six directions, all equivalent in pairs. In nature, this symmetry is broken: air and fire go up, earth and water go down. Democritus' void is space without objects; Hesiod's 'chaos' can best be thought of as space, that came before the rest of the universe, so that each could have its position. According to these, it is the primary principle that remains when everything else is removed.

Still, what is it made of? Its characteristics are: (i) it has 3 dimensions: length, breadth, depth; (ii) space contains a body (or a surface, but a point has position only), but it is separate from it – a container that now contains air formerly contained water; (iii) it is not a substance, else two substances would coexist inside each other; (iv) it is not a cause: nothing consists of space, nor has it any form, nor a mover, nor a purpose; (v) if everything that exists has a place (as Zeno said), what is the place of space? (vi) space equals the body in magnitude e.g. that of an enlarging object grows with it.

If space is what contains a body, it is then its shape. If instead it is what is contained in the body, then it is the volume inside; which is why Plato identified space with matter. In fact space is neither, since form and matter of any substance are independent of its place. Like a vessel separate from its contents, space is distinct from the substance it holds. If space is something that belongs to a substance, what happens to the space of air that condenses into water?

Let us investigate how two things can relate: (i) a part is in the whole e.g. finger in the hand, and vice-versa, the whole to the parts, (ii) a particular to the general e.g. man is an animal, and vice-versa, (iii) form is to matter e.g. health is to hot/cold, (iv) events to their causative mover e.g. affairs of Greece to its king, (v) a thing to its purpose, (vi) a thing to its place. To wrap this up, can something be in itself? In a sense yes, because the whole is so because of its parts; we say a man is white when his skin is so. But physically this is impossible. Zeno's problem is waived if place is 'in' something as form is to matter. And since the whole is not equal to any individual part, space cannot possibly be either form or matter.

There are two types of change in space: locomotion (change in position) and change in volume. There are four possible things that space can be: matter, form, volume, or the surface. We have already eliminated form and matter; it is not the volume because when we move an object the volume moves with it, yet space stays behind. The conclusion is that space is the inner boundary of a motionless container; in its greatest extent, it is bounded by the surface of the Earth, and of the sky (although not motionless, its boundary is), which correspond to down and up respectively.

Position may be potential (as an abstract point) or actual (as a real part). Movable objects have a position on Earth, relative to water, which is contained in air, which is in ether, which together form the heaven; but this is not contained in anything else, and so does not as a whole have a position. Our definition solves the problems we iterated before: space is not a substance, it does not grow with an object, points do not have volume, it does not require two bodies to be in each other, it is somewhere namely in the container, it naturally produces an up and a down.

1.4.1 The Void

What is the void, and does it exist? There are those who say it exists, and is the absence of matter; Democritus' void exists between the atoms. They argue that motion would be impossible without a void, as there would be nothing to move or expand into, or to allow one body to absorb another. Then there are those who deny its existence (Anaxagoras) by making experiments that really demonstrate that air exists.

The void has nothing which is perceptible to touch: but what if it contains sound, or light, is it still a void? Most would say yes, since they identify the void with space. Motion would be impossible without a void: but this is contradicted by rotating water, in which one part makes way for another. Bodies can expand or absorb others: but then bodies would consist entirely of void, an absurdity.

Rather the problems are with those that assert that a void exists: how is motion possible in a void? How can an object move with nothing relative to which we can measure position, and in which direction, when up, down, and so on are all the same? What would move an object without anything touching it, and without a natural place of rest? (True that thrown stones continue to move, but it is the air that pushes them.) If motion were possible in a void, it would never stop, for why stop here not there? Moreover, an object moves faster or slower in different media (air, or water, or earth); the time taken to traverse a distance is in proportion to the density of the medium, as this is what causes resistance. But in a void of no density, there is no resistance, and the time taken would be nil! And a heavy object moves faster than a light one in the same medium (in proportion to their weight), because it has more impulse to force its way through. But in a void, there is no resistance and objects move independent of their mass, contradicting the idea of the void as the limit of a rare medium. Finally, where is this void, when all we see is air, water, fire and earth?

Some put the following argument: air must compress and rarify, otherwise motion would not be possible, or if possible, the outer parts of the universe would have to bulge; and when water becomes air, simultaneously there would have to be air that becomes water to compensate; this compression and expansion is only possible if a void exists between the atoms. In reply, a rare medium moves up, the faster the rarer it is, so that it must be their void that pushes it up. But then a void by itself would move up the fastest; and how can a void move at all, when it is nothing? and if it is the void which pulls objects up, how is motion downwards possible? The problem is turned on its head, and the arguments for the vacuum become vacuous: without a void, compression and expansion are impossible for those who put forward this argument, with the consequences they foresee. Moreover they use density (i.e., the void) to explain both the qualities of heavy/light as well as hard/soft; but these do not always coincide, as in lead and iron.

1.5 Time

Time is a difficult subject, as it is made up of parts, some of which existed and are no more, while other parts will be but aren't yet: none of its parts exist! Is the 'now', which seems to hold the past to the future, permanent, or always changing? If always changing, then they are akin to points on a line, with one moment transforming into another; but how can this be? which point after this one will it change into, when there are an innumerable moments in any interval? But neither can the "now" be permanent, as this would deny the past and the future.

What have others said? (i) that time is the daily movement of the heavens, (what if there are other heavens as some assert, would there be many times?) (ii) time is the universe itself, (iii) time is motion.

This latter is the most common and serious interpretation, for it is clear that time is related to change, as we notice time by noting the changes occurring; if there is no change at all, then we would say that time has stopped, as in one long sleep, unconscious of the time-interval in between. But it also has its problems, namely that motion can be faster or slower, but not so time; rather speed is defined in terms of time. So time is related to change, though it is not change itself.

When something moves along a line, there are the positions held *before*, and *after* (and in between). And time, related to it, also has a before and after, and must therefore be akin to a line. Just like motion, it is not a point in isolation, but a point on a line with a before and an after. It is the continuous enumeration between the before and after, measured by a number. It should be clear now that just as a point connects two lengths, the 'now' connects the past to the future; or, perhaps better, the now is like a dividing mark in a line, not a point in itself. It is both a potential division of time, and a union.

One must distinguish between the two uses of number: as integer (few or many, the smallest being 1), and as a line (short or long, there is no smallest). Numbers are fixed, they are not slow or fast. Similarly time, as measured by number, cannot be fast or slow: the same number (time) measures out different summers, just as the same hundred measures horses or men. Time marks the number of the motion, and conversely a motion can mark time.

Everything that is movable is affected by time, in the sense that everything changes, and this always to the worse, because it is easier to destroy than to create; we never say “we are getting younger”, but “we waste away”. In this sense, time is the cause of decay. Even a body at rest still marks time, and bodies that are no more had a time as well.

The ‘now’ is therefore always changing, as its number increases, but remains the same, since any two points on a line are equivalent. Will time stop, and is time ever different? Time numbers motion, so as long as there is motion which is different, there will be time and it will be different, and this is what we suppose will happen.

What is the relation of time to soul, and to the heavens? If time is number, and only the soul can reason and count, then time can only exist in the mind. If time counts motion, and there are two motions, are there two times? No, just as there is but one number, even if it counts different things. And the best motion to mark time is a uniform one, and of this a circular one. This is why we measure time by the daily motion of the heavens.

1.6 Change (Book 5)

A change occurs when (i) an attribute changes, or (ii) a part changes, or (iii) the body itself changes; the change may be (a) in magnitude (an increase or decrease), (b) in quality (alteration), or (c) in place (locomotion); and the mover causes the change in these three ways. For change to occur there needs to be a moved, a mover, time, a starting point, and an end-result.

A change does not happen when the thing is incapable of change (e.g. the elements), when it greatly resists change (so change is imperceptible), or when it is at rest. Changes occur ultimately to objects or to souls e.g. the change that learning causes is not learning itself.

For the different genera of changes, there are specific types, e.g. whitening, or blackening; in locomotion, linear or circular species.

For every change there is possible the opposite change. The direction of change may be the same even if the starting and end-points are different. For example, a change away from health is in the same sense as a change into disease, even though the end-points are different. We normally name a change from the end-point, in this case ‘sickening’. Thus changes have opposites, as moving up or down, left or right, learning and being misled.

But in another sense, the opposite of change is a state of rest; but which, the initial or the end-point? For discrete things, such as existing or not, we cannot strictly speak of change, since not-existing cannot be a starting point. True changes are those from something to something else, not from nothing to something or vice-versa (becoming and perishing).

Some changes are natural, i.e., occur by themselves, e.g. weight always falls; others are neutral, sometimes occurring, sometimes not, e.g. falling ill or recovering, being born and dying. But even these, some are natural, others ‘violent’ e.g. a man may be killed, a seed may grow without enough soil. Violent locomotion may also occur, as when a weight moves up for a while. Similarly there may be a natural and an unnatural (forced) state of rest.

1.6.1 Continuity (Book 6)

A continuous line is not composed of indivisible points, for they would either have to be in contact or in succession. If the former, the points would have to be the same, while if the latter, the line would have a gap (or another line which begs the question). Thus a line is infinitely divisible, which is what we mean by continuous. The same applies to time, motion, and in general to any magnitude; for time is in direct correspondence to length by speed, and any magnitude is in correspondence to time by alteration. In addition, physically, how can an object with weight consist of weightless points? But if points have weight, what is the weight of a line, unless infinite?

It follows that the present moment, like a point, is indivisible and admits no motion (or rest), because if it does it would first have to move a distance equal to its own dimension, namely nothing (Zeno's arrow argument for the impossibility of motion fails, because it mixes finiteness in length to finiteness in divisibility.)

A change has two notions: in time and in the quality that is changing. There is no moment when motion has begun or stopped, and a thing in motion, is in motion before and after, in fact infinitely often.

A finite length cannot be traversed in an infinite time. For suppose that it takes an infinite time to traverse AB. Then in a time t, it would traverse say AE. But a finite number of the lengths AE will add up to AB, and each length will take a finite time, giving a contradiction [3]. Alternately, if only part of the object is moved, it must take less than infinite time, i.e., a finite time; but then the whole object being a finite multiple of its part, would also take a finite time. By transposing length with time, it follows that an infinite length cannot be traversed in a finite time.

So every motion must eventually reach its end-point, unless it is cyclic in nature so that the end-point is the starting-point and the motion starts again.

1.7 The Mover (Book 7)

Everything that is in motion must by moved by something, if anything because if divided, one part would be moved by the other. But there cannot be an infinite chain of cause and effect, i.e., A is moved by B, which is moved by C, etc. For if A moves a certain distance in some time, then the infinite regress of causes, all in contact with each other, would have moved the same amount, giving an infinite distance moving in a finite time, which was shown to be impossible. So there must always be a first mover.

There are four types of locomotion caused by contact with a mover: to push, to pull, to rotate, as well as to carry. Pushing includes throwing, separating objects, and exhaling; pulling includes inhaling and sucking; twirling is the simultaneous combination of pushing and pulling at close proximity. Similarly alteration is caused by 'contact' with a cause, even if this may involve light, air or flavor.

[3] Aristotle is probably assuming a finite speed at each moment

A change in shape is so drastic we usually give the object a new name, as when 'bronze' becomes 'statue'; it is more a creation than an alteration. A true alteration, as when an object is warmed up, is not given a new name, but is described with an adjective. Similarly for the soul, learning is not an alteration but a creation, whereas pain and pleasure (or their memory) are.

If a cause moves A a distance d in a time t, then the same cause (with the same force) will move half A to twice the distance $2d$ in the same time t; and half the force will move half A the same distance in the same time. That is, the distance moved in a certain time depends on the ratio of the force (the mover) to the moved object. For divide the force and the object in two, and their equivalence implies they move the same distance. The relation need not be proportional, otherwise we would be saying that a single man could move a large ship if he keeps at it long enough.

How can a thrown stone continue moving upwards when it loses contact with its force? Some say that when a stone is thrown, air is thrown with it and it is this air that pushes it in short bursts until it is exhausted.

1.8 Prime Mover (Book 8)

Does motion start and stop? This is important, as some say that there is one world that was set in motion, or became (Plato), others that is has been forever, while others say that there are many worlds, coming and going, but always moving. Of those that favor a start of motion, it could be either (Anaxagoras) that there was a substance at rest, but then was set in motion at some time (by the Mind, etc), or (Empedocles) that it is alternately set in motion (by Love or Strife) and then at rest.

But, as we have seen, time does not exist without motion, and anything in motion must have been in motion before, and any motion needs an earlier cause. This implies that motion and time are eternal; and moreover a state of complete rest followed by motion is just as impossible for the same reason. To alternately do one thing, then another, is to suppose that when the elements come together, they sometimes do one thing, sometimes another, according to chance, yet this is never seen: a child will always grow into a man.

It may be countered that (i) every change eventually stops; but why is this true, why can't there be an everlasting motion? (ii) in fact stones that are at rest can be set in motion; true but by an external cause; (iii) this holds even more so for animals that once motionless can start moving of their own accord; but even so, living things are always in motion, whether locomotion, respiration, or digestion, so that it is false that they suddenly start to move.

The crux of the matter is, why are some things sometimes at rest, sometimes in motion? That this is the case need not be discussed (although some assert that things are always changing even if imperceptibly, just as a stone is slowly eroded away). How does an inanimate object starts to move? There is little difficulty if it is moved unnaturally, as when a stone is thrown upwards. But what about natural motion? The answer is that it must have had the potential to move before, but for some reason was prevented from doing so. Only when the hindrance is removed, does it start to move. The hindering object is not causing the motion but has brought it about, just as the real cause why a ball rebounds off a wall is the thrower. It must be the case that the mover that starts this whole chain of events must be something that moves itself.

But still the problem remains, how does it actually move by itself? The motion must be imparted by some *prime mover* that is unchanging. For simplicity, we suppose it to be one, eternal, and unvarying. This prime mover cannot have magnitude, else it would have an infinite force and produce instantaneous changes.

The three types of motion: increase/growth, alteration, and locomotion are in increasing order of importance. An increase comes about because of some alteration (such as nourishment, or heat), and this is brought about by some locomotion. Even coming-into-existence must be started by locomotion (although plants and the lower animals spend most of their time motionless, and only acquire motion at the end of growth.)

Every type of locomotion consists of a combination of rectilinear and circular motion. Rectilinear motion cannot be eternal, for either it has to traverse to infinity (trying to reach a place it cannot arrive), an impossibility, or if it oscillates, then at some moment it would cease moving, and start again turning back on itself; the fact that these cannot be the same moment shows that the motion is not continuous, apart from being non-uniform. Only a rotation takes a point to itself without stopping, freely repeating itself. Circular motion is therefore the purest of motions, at the same time eternal and uniform.

2 On the Heavens

2.1 The Three Motions

A continuum is something that can be indefinitely divided. If in one way, it is a line, if in two ways, it is a surface, if in three, a body. There are no more, since 3 is 'all', as the Pythagoreans say, just as everything consists of a beginning, a middle, and an end. If we could go to four, it would cease to be a complete magnitude, but be defective.

The number three also manifests itself in the different types of motion: linear away from the center, linear down towards it, or circular around it. Every other motion consists of these. Now each element (a simple substance) moves in a simple manner, the light ones up, and the heavy ones down; but there are bodies that move naturally in a circular manner: it follows that there must be an element, called ether, whose natural motion is circular, and consequently more divine. It cannot have the properties of lightness or heaviness (otherwise it would move up or down); and since circular motion has no opposite motion to which it can change to, it follows that ether is indestructible; this is in fact borne out by observing that the heavens have never changed, as far as inherited records show.

It cannot be countered that the opposite of a circular motion is one in the opposite direction. For this is no change at, both starting and ending at the same point. But even if it were so, the heavens would have a preponderance of one of them, leading to one natural direction of rotation anyway.

This ethereal element cannot be infinite in extent, for if it were, its outer regions would traverse arbitrarily large distances, and sweep out infinite areas, for every revolution, an impossibility. But one can also prove this: consider an infinite fixed line BB, and an infinite radius CE moving uniformly in a circle about C; then it would intersect BB for a finite time T, yet one cannot point out the first and last points of intersection: the radius refuses to escape the line. Moreover, a finite line L will take an infinite amount of time to traverse an infinite fixed line M; but by duality, keeping L fixed and moving M, it follows that an infinite line takes an infinite time to traverse a finite line, even the smallest. Another argument is that just as there can be no infinite motion without an infinite magnitude, so an infinite circular motion would require an infinite circle, a meaningless concept.

Similarly the other simple elements are finite in extent; in fact, one end of their motion, down, is terminated at the center. If they were infinite, they would have to be infinitely heavy or light: for if it had a finite weight W, and a finite part of it had a weight w, then a finite number of the parts weighing w would give the same weight W. But as we had seen earlier, a body moves a distance in a time inversely proportional to its weight; so an infinite weight would take no time at all, and a zero weight would take forever.

It follows that neither can a composite body, consisting of simple ones, be infinite in extent, or one of its simple elements would be infinite. More generally, if a finite body A modifies or moves another B in a time T, then it would move a body larger than B in a longer time, and by inference, it would move an infinite body in an infinite time, that is to say, not at all. Similarly, by increasing A this time, an infinite object would change a finite one instantaneously. And an infinite body cannot move another infinite one (else it would move a smaller part of it in the same time); but also where would these infinite bodies be situated, and would one infinite mover move by itself, thus being an animal?

Democritus' world consists of atoms in an infinite void. But these atoms are all the same, except for their shape; consequently they must all move in the same manner and have the same property. They are either all heavy, or all light, thus all bodies would move to the center, or all upwards. Apart from the fact that living in an infinite void, there would be no natural motion at all – where would they go to? To answer these, the atomists would have to give different properties to their atoms, defeating their original purpose.

2.2 Places of Rest

Can there be another world like ours, with a rotating heaven? All things move in a natural way (not forced) until they reach a place of natural rest. Now our Earth is resting naturally at the center. Any other world, being composed of the same matter, would also move until it reaches this place of rest; and its "earth" would move upwards in their strange world. To suppose that the simple substances have different places of rest is to suppose that they have different natures. If it be said that the places of rest are the same in nature, but not numerically, we answer that actual objects on Earth would then move towards the center, but when taken to this other world, would move to another center, thus supposing that a single object has many goals, or that the different centers are the same, in which case there is one heaven still.

That light objects also have a place of rest should be clear by analogy with heavy objects: these move down and faster the closer they get to the center; similarly fire goes up, and faster the farther from the center; if it were to continue going up, it would keep on going up with ever increasing speed, meaning increasing lightness, until it has no weight. That objects move naturally and not constrained should be clear from the fact that if heavy objects were constrained by some force to move down, then it would take the same force a longer time to move a heavier object, and the reverse is seen; it ought to moreover to diminish in speed as it moved away from its constraining force.

Just as there are three simple elements, so there are places of rest: heavy objects go towards the center, the weightless ether goes round the center, yet staying in its place of rest, the circle, and light objects go to their place of rest, intermediate between the two.

Is the universe unique? In a sense, one can always imagine other universes, just as we imagine different circles, but since the universe is defined as that which contains all matter, there cannot *physically* be another universe. And its outer region is the heaven, that sphere made of ether. There is nothing outside it because there are no other places of rest, and nothing from this universe can go outside the heaven. Outside there is no void (i.e., no space), no time (since there are no bodies and no change).

A false statement is not the same as an impossible one: to say that one is standing when in fact he is sitting is a false statement but not impossible; to say that he is sitting *and* standing is not only false but impossible. Now, something that exists forever cannot have the capacity of being destroyed: how are we to know it has this capacity, unless it be destroyed ending its existence? Things have a power of existence, just as man can live up to a maximum but no more. If something is ungenerated, it lacks the capacity of non-being, and so is indestructible. To see it another way, there is a whole line of intermediates between "something is eternal" and "something does not exist at all"; anything which is generated, or which is destroyed, is such an intermediate, and conversely, any intermediate is both generated and destroyed. So, either something exists forever, or it will sometimes exist then be destroyed.

The weightless Heavens are neither held by an Atlas, as in the old tale, nor given such a speed which overpowers its tendency to fall down, as Empedocles said; nor can it be forced in that motion by some necessarily restless and tormented soul.

Heaven itself has an up and down, namely the poles, and a right and left, namely from where the stars rise and set. Could it be that the whole world is heaven? No, because, by its very nature, a rotating sphere would have a center eternally at rest, which is inherently different from all other parts of heaven. This center is then the natural place of rest of another substance, the Earth. And once this exists, so must its opposite, namely Fire; and indeed of the intermediates between Earth and Fire. But these being opposites, they are capable of destroying each other, and as we've seen, this capacity implies they must have been generated at some point. Furthermore, if their motion is not eternal, as it is not, then they cannot themselves be eternal, in contrast to heaven and its eternal motion.

Which shape is the simplest? The simplest plane bounded by a curve is the disk because it contains only one line-boundary. Similarly, the sphere is the body with the simplest boundary. It follows that the primary body, heaven, is spherical; but not only this, every body under it must retain the same shape, shaped so to speak by it. Which is why the Earth for instance is spherical. The sphere moreover has the property that it remains the same while rotating. Another argument is to say that water flows down towards the center, and necessarily takes a spherical shape (otherwise there would be parts that could flow down); even more so would the lighter air which moves upwards, take on the shape of its container, namely a sphere.

The rotation must be regular, for else we would have to explain why it accelerates to a maximum, then decelerate. But heaven, moving itself, and eternal, admits no such irregularities. There are no irregularities in its parts, for the stars have never been observed to move relative to each other; neither is there an irregularity in its motion as a whole, since it cannot decelerate, else it would have to come to a stop contradicting its eternal status, nor can it accelerate, else it would do so to infinity; nor is it sometimes accelerating sometimes decelerating, else we would observe this.

2.2.1 The Stars

The stars, being in heaven, are made of ether. They may appear fiery, as some have commented, but this fire is the result of their motion through the air, causing it to spark, in a similar manner that missiles of lead causes it to melt. Their twinkling is due to the prolonged distance from them to the Earth, causing their rays to be weak (but not that of the planets, which are closer). Since it is obvious that the Earth is motionless, it must be the stars that are in motion. They cannot do so independently of the heavenly sphere, else those away from the ecliptic would move faster than they do. The conclusion is that the stars are fixed to this sphere and move with it. That the stars do not have any proper motion is clear from the fact that even the Moon always presents the same unchanging face.

The Pythagoreans think that the Sun and Moon, being so large, and the stars, being so numerous, must make some sound; they say that being so regular, this sound is a constant harmony, which we don't hear because we have so adapted to it since we were born. But this cannot be all: such a sound must produce some other observable effect, just as a thunder can split rocks. The explanation is simple: there is no noise, because the stars are fixed. Also, being motionless, their most natural shape would be of a sphere, as in fact observed in the Moon.

The heavenly sphere thus moves in its daily course, Earth remains motionless, and intermediate objects move at intermediate speeds. The strangest problem to solve is why is it that these intermediate planets have such weird motions: perhaps one might add motions to them in addition to the heavenly motion; but then why is it that the Sun and Moon, being even closer (e.g. the Moon can be seen to pass in front of Mars), should again have a simple motion? Also, why are there such a huge multitude of fixed stars, yet a few chosen ones are given special motions? These are difficult questions, especially since we are so far from them. In our view, it seems natural that the ethereal stars, being perfectly conditioned, should need no action; yet that the planets, a bit removed from it, should move. We can think of them as lesser stars, being closer to Earth, with earthly things having the most complicated motions. But the Earth as a whole is motionless, and it could perhaps be the case that the heavenly bodies immediately above it, namely the Moon and Sun, can only achieve a simple motion, just as some of us get healthy by doing exercise, yet others get thinner but not healthy this way. As to the second question, there is also a certain order, in that there is a single motion to many bodies, and many motions to single bodies.

2.2.2 The Earth

Most say that the Earth is motionless at the center. But the Pythagoreans think it is the Sun which is at the center, and the Earth which moves and rotates about it, thereby giving day and night; to them, the center is Zeus, and the Sun guards it eternally; they add moreover a counter-earth (as a balance) directly opposite; they also add several other bodies adjacent to Earth, which we cannot see because of the Earth's curvature, in order to explain why there are more lunar eclipses than solar. It is clear that they add not according to observation but to suit their theory. Others agree that fire is more precious than earth, and so deny Earth its central position. But the center is defined by the rotation of the sky, not some fancy thinking, and it is clear that it is inside the Earth.

As to its shape, some say it is cylindrical, from the fact that the horizon is not curved. But they disregard the possibility that the circumference of the Earth may be so large that it would appear so. They also say that it is a great wonder that if even the smallest weight should move, yet here is this great weight of Earth and it is at rest. There have been some silly suggestions to explain this: Xenophon's that the Earth is infinite under us, or Thales' that the Earth is still by floating on water. Democritus says it is flat, and supported by pressurized air inside it. Empedocles imagines that the Earth is motionless for the same reason that when one whirls a bucket of water it will not come splashing down but stay where it is (but then why do stones fall, and fires rise?) Anaximander reasoned that a body at the center has no preference for motion in any direction – it must needs stay at rest; although this is true, it does not explain why it is earth and not fire which is at the center.

Now if it were the case that the natural motion of the Earth is around the Sun, or some other center, then *every part of it* would have the same natural motion – they would all go around this center, with the result that they would not appear to fall to the Earth, as they in fact do. Moreover the stars would appear to have a secondary motion, something which contradicts the fact that they always rise and set at the same place of the horizon. A second observation, that stones thrown directly up fall to exactly the same spot, irrespective of where you do this on Earth, shows that they are moving towards the center of the Earth.

The simple answer is that the natural motion of earth is to the center, and once it reaches there it remains at rest. If no portion of earth can move naturally away from the center, so much more the Earth as a whole. The shape is spherical as every weight tries to reach the center. Observations also bear this out, since the shape of a lunar eclipse is always circular, not sometimes gibbous or straight. Also its size is not that tremendous compared to the stars, since in Egypt the stars follow a visibly different inclination; indeed there are some stars visible in Egypt but not in Greece. One should not find it too incredible that the ocean beyond Spain is the same one as that in India. This is supported by two facts: that elephants are found both in Libya and India; and that mathematicians have calculated that Earth's size is 400 000 stadia.

2.3 Fire and Earth

Parmenides held that nothing is generated or destroyed, but others assert that everything is generated.

That everything has a natural motion: it is clear that we are not all falling down; something is holding us up, implying that eventually there is something down there which is at rest. But if this rest is natural to it, all earthy objects would also want to move to that place of rest. Empedocles said that water can be motionless even if not at rest; so similarly Earth could be motionless held by the vortex of heaven around it. But without this vortex, what would happen to Earth? It cannot have the force to move in a line to infinity. Just like any moving thing, it must eventually come to rest, and that place of natural rest. Could disorderly motion be the norm? This world of view where disorder is natural, and order unnatural, is contrary to observation.

What causes things to move is their weight or lightness. A weightless object cannot move up or down, for things fall faster the heavier they are, and rise faster the lighter they are.

We conclude that nothing can be generated or destroyed; a substance may change into another, such as fire into air, but not come into existence out of nothing.

An element is a substance that does not consist of simpler material. For example, wood both contains fire and earth because we see both come out of it, but we never see wood come out of fire or earth. Anaxagoras denies this; rather he says that earth consists of seeds of everything from flesh to bone etc., which is how worms, for example, are generated from soil. In our view, however, every body has a natural motion, and the elements correspond to the simple motions.

Many regard fire as the primary element, as it "penetrates" every other. But there cannot be *one* primary element, or else there will be one natural motion, and all would move in the same way.

Even simple substance undergo a process of analysis: such processes cannot continue forever, or else so would the opposite process of synthesis, and two mutually exclusive infinities are impossible. The process must then stop at some stage – the question is why? Since the residue is smaller, one would expect the process to consume it even more. The only explanation is that the elements can be destroyed and changed into another, so that the process stops when there is no more element to change.

Now we observe that when water turns to vapor in a sealed container, it bursts it because the air takes a larger volume than the water. This shows that the air was not already present in the water, but must have changed from the water. Those that give a shape to each of the elements are misguided, for there are but 3 shapes, namely the triangle, the square and the hexagon which fill out the plane, and similarly only the cube and the pyramid[4] which fill out space, and these are not enough for all the elements. Moreover how can these elements with these shapes, intermingle to produce say flesh?

By heavier and lighter one must distinguish a relative sense: increase or decrease in density; and an absolute sense: things that move down or up. That objects have different density, in that some small objects weigh more than other bigger ones, is not in dispute. But density cannot by itself explain how things move up, for air in small bubbles move up in water at a slower rate than air in large bubbles. It is not the lower density that pushes the air up, but its natural motion. Some use the void to explain the difference in density, but then how do they explain the absolute heavy. For if fire is light because it contains a little of a heavy substance and a lot of void, then if you take enough of it, it would be as heavy as a little water; yet fire always moves up and water down.

Fire is absolutely light, earth absolutely heavy. Air and water have both weight and lightness, but more weight than lightness. They are relatively lighter than earth, and heavier than fire. Other compounds of these elements take on intermediate densities depending on the mixture. It is possible that a large amount of wood weigh more than a small amount of lead in air, yet that it weighs less (floats) in water. The explanation is that wood contains more air, so its natural place is in between air and water; lead being predominantly earth sinks below the water. Water can sometimes move up (as when it goes up into a vessel which has been heated) but earth can never do so.

It will be observed that earthen dust and flat thin pieces of iron can float; but this does not happen in air. They do not really float, but their shape prevents them from falling immediately. Air is much easier to divide than water. So a flat piece of iron will find it difficult to separate the water to start sinking. If you take a needle of iron its sharp point separates the water, it will sink easily.

[4] i.e., the tetrahedron

Thus water (and to a lesser extent air) gives a resistance, and only when this is greater than the weight of the iron, does it cause it to float.

3 History of Animals

[The *History of Animals* is a lengthy book, containing a large amount of observational detail concerning the parts, behavior, breeding, and diseases of animals, taken mostly from his own observations as well as those of peasants, fishermen, bird-catchers, travelers, doctors, and other authors. Here, only a short account of the more interesting general ideas is given.]

The genera of animals are of two types, blooded: viviparous quadrupeds[5], birds, reptiles, snakes, fish, whales; unblooded: hard-shelled (e.g. oysters, snails), soft-shelled (crabs, lobsters), mollusks (e.g. cuttlefish), insects.

Apart from the familiar animals, one might mention the camel, leopard, lion, crocodile, bison, the chameleon, as well as the ape, the baboon, and the monkey, which somewhat resemble man. There are also some unusual animals: the wryneck (a type of woodpecker with the tongue of a snake), the elephant (which eats with its trunk), the parrot from India, the salamander (which can walk in a fire); in Cyprus, there is a winged animal that can hop into fire unharmed.

3.1 The Parts of Animals

Animals have similar parts throughout a genus, perhaps with different position, shape or color, others are particular to species; some parts of different genera are analogous, as feathers and scales.

3.1.1 Blooded Animals

The head has a bony skull, containing the brain, and a forehead with eyebrows and eyes. In general the shape of these is a sign of the person's character (e.g. harshness, jealousy, etc.) At the back, the brain has a different texture, the cerebellum. The brain has no blood and veins, and so is cold. It is enclosed by two sheaths, one thin and full of veins, the other thicker over it. The eyes have three pairs of ducts: the larger two pairs go to the cerebellum. The ear is shaped inside like a trumpet to convey the sound to a vein to the brain. Most animals can hear, even if some do not have an ear but a simple passage (e.g. birds), which may be even covered (e.g. dolphin).

In the neck are two pipes, the windpipe in front of the oesophagus. The windpipe can be closed by the epiglottis, and leads down, divides into the lungs. In mammals the lungs are touching, but in reptiles they are separate. Fish do not have lungs and windpipe, but gills.

[5] Lacking a natural name, Aristotle calls mammals 'viviparous quadrupeds', and reptiles and amphibians, 'egg-laying quadrupeds'.

Animals take in food by a mouth, passed onto the belly and an alimentary canal. The elastic oesophagus leads to the stomach, which connects to the convoluted bowel, which broadens at its bottom part. On top of the bowel is a fatty mesentery, which has a lot of veins. Horned mammals have four stomachs, with a honeycomb structure inside, one leading to the other. Birds have a wide oesophagus, in some appearing like a sack. Fish have various blind appendages to the gut.

The heart has 3 cavities, the largest one is connected to the great vein, and to the middle one, which in turn is connected to the aorta. From the lungs come air-carrying veins, one set to the left and another to the right part of the heart (for fish the veins come from the gills).

The thorax is divided into the upper chest and the lower abdomen. Separating the two is a thick fleshy diaphragm. Below lie the liver and the spleen, both connected to the great vein (the spleen is very small in reptiles and birds); there is sometimes a gall bladder present near the liver. Mammals, but not fish, birds and reptiles (except the turtle), have two kidneys connected to both the aorta and the great vein; inside is a small cavity that leads to a duct to the bladder, which has another duct that leads to the private parts; it is used to remove watery waste. Reptiles do not have kidneys or bladders, instead they use their anus.

There are also the reproductive organs, which we will discuss later.

The main tissues of animals are: blood, flesh, bones (and fish-bones), fat, skin, and hair/horns/nails; and the excretions: dung, phlegm (coughed up), yellow bile, black bile. Blood contains a fibrous material that allows it to coagulate (except deer, whose blood simply thickens). The blood lies in the veins and heart, although when an animal dies, all its blood flows away and it is hard to ascertain this fact; conversely when blood is removed, the animal faints. Diseased blood is black, or develops haemorrhoids in the nose or anus.

There are two main veins running along the spine, called the great vein and the aorta, furnishing the left and right sides of the body; they start from the heart, branching one to the lungs, and another up to the neck and arms, and down to each leg; veins branch off them to the organs and arms, and most keep dividing into smaller veins. In most cases, there is another smaller pair of veins running alongside the bigger ones, also dividing. (see picture) The branching of the great vein and of the aorta are very similar, except that the former are more conspicuous, and the latter are finer and hollow; also there is no connection from the aorta to the liver, or from the big vein to the womb.

Sinews are elastic tissue attached to bones and flesh. They can easily be cut lengthwise but not across. They are only discernible in fish near their tails.

The bones are all connected together, ultimately to the backbone of vertebrae. Inside some have marrow. Even the dolphin has bones. Fish have a spine made of fish-bone, even weaker in sharks; reptiles are intermediate between bone and fish-bone. Horns and teeth are extensions of bone.

Flesh is between the bones and skin. When underfed, it disappears, when overfed, it is fatty. Fat comes in two types: one associated to flesh is called suet, and coagulates when cold, whereas fat proper is between the flesh and skin, and remains fluid. The livers can be fatty (especially of sharks), as also the kidneys, and sometimes the brain; in between the liver, stomach and guts is the omentum, full of fat. Every organ and bone is covered in a thin membrane.

Animals have an even number of feet, wings or fins. Flying animals have wings with feathers (birds), or membrane (some sheathed as the beetle, others not as the bee), or leather (bats). But in most cases blood animals move with four points of action (quadrupeds, or two legs and two wings, or 4 contacts for the snake), while bloodless animals move with more. And they all move in the same way – cross-cornerwise.

The feet have five toes in general, with the front limbs flexing forward, and the hind ones flexing backwards. The elephant is different: it has stubby toes, and a trunk that can be coiled, with which it eats, drinks, and uplifts trees. The seal's feet are webbed, but still have nails.

Mammals have hair, mostly on their back, less so on their belly. Of those that have horns, most have two. Only two species, the oryx and the Indian ass, have one. Only the deer renews them yearly. In general, hair, nails, claws and beaks grow longer with age. The color of the skin in general remains the same, except for a slight change with age, but birds and sheep may be affected by the water they drink e.g. there are two rivers in Antandria, one leading to white sheep, the other to black.

Breasts: two, or more; large or small; under belly or thigh. Rarely, even males can produce milk. Different pastures affect the amount and quality of milk.

Man is exceptional in many ways (relative to his size): he can use his hands, he has buttocks, lower eyelashes, heavier menstruation, more sperm, colored eyes.

Other blooded animals have the same parts as mammals, except they have no ears, just a passage; no breasts, penis, or hair. The snake is very similar to a lizard, except it is elongated and has no legs: all its organs are elongated, including the gut which is not convoluted.

3.1.2 Bloodless Animals

Bloodless animals have a weaker watery lymph instead; they do not have fat. The genera are:

Mollusks: octopus, squid, cuttlefish (and the shelled nautilus); have a small brain, an oesophagus that leads to a stomach, then to a coiled gut back to the mouth. They are able to excrete a black fluid when agitated. Most have a hard 'bone' at the other end. They produce large eggs.

Crustaceans: crayfish, lobster, shrimp, crab, all with many varieties; hard on the outside, mostly with 5 pairs of feet, one possibly a claw; a mouth, stomach and straight gut, to anus.

Testaceans: snails, oysters, univalves (e.g. limpet) and bivalves (e.g. mussel), urchins, sea squirts; have a shell of various shapes, with flesh inside. The snails have a head with a sharp tongue, a stomach, leading to the innermost parts of the shell, then a gut leading out. The univalves and bivalves are similar but smaller. The hermit crab is curious in that it resembles a crustacean, yet lives in a shell. The urchins are different, having spines, and a mouth at the bottom, no flesh inside and excrete at the top. The sea squirt is also different, having a complete leathery shell. The sea anemones are peculiar, because they resemble an oyster without a shell; they produce a stinging feeling when touched.

Insects: bees, beetles, flies, centipedes, scorpions, spiders; have a head, thorax (could be multiple or none) and trunk. If the head is cut off, they still live. Their only sense is visual. They have a hard body, but not as hard as a shell or crust. They have a simple gut (the cicada has no mouth but feeds off dew only).

3.2 Behavior

There is no demarcation line between lifeless things and animals. Plants live only to procreate, without any sensations. Next up the grade, even the simplest rooted animals have the sense of touch (e.g. sponges, anemones). With more senses, animals can move about, bear their young, then quit them after. At the highest scale, animals with intelligence and memory take care of their young. Thus procreation and feeding are the two activities that all animals do, modified by the climate.

There are five senses: sight, hearing, smell, taste, touch. Mammals, reptiles and fish have all of them (with the exception of the mole). That fish have all these senses (even if only the eye as an organ) can be attested by fishermen who use baits to lure them, and know that sounds scare them. Similarly, dolphins can smell and are afraid of noise.

The mollusks, crustaceans and insects can see (poorly), smell, taste and touch. For example, bees can smell honey from afar, many insects will quit their nests with the smell of origanum or brimstone, mollusks are attracted to bait, but repelled by the fleabane daisy. Testaceans can smell, taste and touch, and maybe even see (e.g. scallops will close if you put a finger next to it); but urchins, sea-squirts and barnacles do not seem to smell well.

Voice: vowels are produced by the larynx, and consonants by the tongue and lips. So, for the most part it is blooded animals that have a voice; insects make a noise by rubbing their legs, or by air-friction while flying; some fish may squeak or grunt (e.g. cuckoo fish); dolphins make vowels; reptiles make a feeble sound, some turtles hiss, and frogs croak; some snakes squeak; birds make all sorts of voices, especially of the smaller chirping kind; some birds have been noticed to teach songs to their nestlings. Mammals make grunts, roars etc. but only man has language.

All mammals sleep, even closing their eyes and dreaming. Reptiles, fish, mollusks and crustaceans sleep by lying motionless (they have no eyelids). In fact, a sleeping fish can easily be caught, as tunny are at night, and a fish has to be careful else it is attacked by sea-fleas this way. Whales sleep with the blow-hole above the surface (some have even been heard snoring!) Insects also sleep: bees do not fly at night, while a sleeping fly will disregard a candle.

3.2.1 Propagation

Some animals are viviparous, giving birth to young, such as men, whales and sharks. Others are oviparous, laying eggs; others give rise to grubs that grow to adults.

Many, but not all, have a male/female distinction. Males secrete sperm into the female, which has a womb. The exceptions to this are: testaceans, the eel (none have been found with eggs inside) and some other fishes. In most genera, the female is bigger and grows older than the male, except most mammals, where the male is bigger and stronger.

In some, testicles are exterior, in others interior (e.g. elephant, birds, reptiles). They are connected by ducts to the aorta and the kidneys. Another larger duct connects to a penis, which in some is attached to the belly, in others further back, sometimes hardly conspicuous (birds). Fish and snakes do not have testicles, but have two ducts that connect to the midriff, which may be filled with sperm.

The womb is two-pronged, each ending in a twist containing the eggs.

There are two types of propagation: hereditary (begotten from parents) or spontaneous (grow from mud). The hereditary type involves a copulation in land animals; dolphins and fish also copulate; the male fish strokes the female, which then lays eggs; reptiles coil around each other to copulate, especially snakes. Most animals breed once a year, mostly in summer. Most mammals are sexually mature after a year, but the bigger ones take longer: the horse takes 3 years, the elephant 10. Without copulation, bird eggs never form birds. Sharks and the like have internal eggs, that hatch inside.

Men start their sperm production at 14-21 years, and become fertile thereafter; women become fully ripe at 21 years. Thin spermatic fluid is not fertile, when clotted it is fertile and liable to give males, when watery, liable to give females. Conception is possible up to a week after copulation; to avoid it some put cedar oil (or olive oil with frankincense and lead) in the womb. If there is conception, the female discharge finds its way to the breasts to become milk. Up to 40 days after, the embryo may abort; it is as big as a large ant, complete with eyes, limbs and organs; female embryos take longer than males to grow and differentiate and the pregnancy, including labor, is usually more difficult with female babies. The womb closes up until the 8th month; a pregnancy may vary from 7 to 11 months (although it is difficult to ascertain when conception occurred), with 9-10 being the most common, although those born 7-8 months normally perish (except in Egypt). Embryos abort more likely at 4 or 8 months, and with the latter it often happens that the mother also perishes. Most women have single infants, although twins are common (especially in Egypt), and it is said that once a woman had 20 children in 4 quintuplets. But normally, very few twins survive, unless they are both male, or both female. When pregnant, a second conception is highly unlikely, but not impossible: it is said that a woman, having committed adultery, gave forth two babies, each resembling its father; also another woman, having twins, conceived a third one, which were all born together, but the last was born at 5-month growth and so perished. In general embryos of animals lie stretched out, but of birds and humans they are bent, with knees to their face.

Children are apt to inherit their parents' characteristics, including their disabilities (thus blind from blind, etc., but the children of cripples are mostly healthy.) And in certain cases, if not directly from their parents, perhaps from their grandparents (e.g. a woman committed adultery with a black man, but instead of child, it was her grandchild who was dark). Some women have a tendency for their children to take after themselves, others after the husband.

Mollusks also copulate at the mouth, but how is not known exactly. Crustaceans also, by the tail. These all lay eggs, from which come large numbers of the tiny animals, most of which perish. Insects also copulate, although it is the female that penetrates the male, remaining attached for long times. She lays eggs, but the eggs hatch out grubs, not other insects (except spiders); these grow and form a chrysalis, from which comes the insect.

Spontaneous propagation: some species grow from mud and decaying matter or dung e.g. grey mullet, testaceans, hermit crabs, sponges, sea-anemones, intestinal worms. For example, tiny mullet fish and eels grow from the mud in the first rain ponds, after this had been dry for months, yet they don't appear in stagnant ponds in the dry season: it is clear that they must arise from rain; in fact eels arise from earthworms. Lice and fleas generate from the flesh and excrement of other animals.

3.2.2 Feeding

Animals have a mode of subsistence, actions and habits; for example whether they live on land or in water, partly or essentially, or whether they move or are attached, with wings or with feet, solitary or group together or are social, carnivorous or herbivorous or omnivorous or have a special diet, some have a home, nocturnal or not, tame or wild, emit a sound or are silent, some live in the fields or in the mountains etc., some have lots of sex, some aggressive others defensive, some ferocious others good-tempered, cautious or crafty etc.

Animals can also be divided as to where they live: terrestrial, aquatic, or amphibious (feed in water, but breathe and breed in air: turtles, hippos, crocodiles, but most of all the whales). Only the water-newt breathes in water (has gills), yet is capable of walking on land to feed. Small changes in organs can have a big difference in the animal: castration can change a male into a female animal; similarly small changes in certain organs can change an aquatic creature into a land one (e.g. tadpoles), or vice-versa.

The anemone, the murex and the sea-turtle feed on fish. The crustaceans feed on everything from excrement to flesh. It is curious that the crawfish can capture the larger conger-eel, which in turn can devour an octopus, which in turn terrifies to death the crawfish! Mollusks eat fish and testaceans. Some fish eat seaweed, others are carnivorous (even eating their own kind), others omnivorous. Birds likewise can be carnivorous, the smaller ones eating grubs, or eat plants and fruit; others live by the sea, eating fish or water-plants (birds drink very little, if at all). Reptiles are omnivorous; snakes are gluttonous carnivores, swallowing the animal whole, extracting its juices, and excrete it whole. Mammals may be strictly carnivorous, as wolves, lions and seals, or omnivorous, as the pigs and bears (which can kill even a bull, but also eats ants, fruit and honey), or herbivorous, as cattle and sheep. Insects are omnivorous, but those without a mouth drink liquids only.

Birds migrate to avoid cold winters, and hot summers, with the weaker species first. Fish also migrate, say to the Black Sea, some go up rivers; one type of fish, the trichiae, only go one way into the Black Sea, and come out one way from the Adriatic: they must be going up the Danube, and cross over to the Adriatic.

Many animals hibernate in the peak of summer or winter, especially the testaceans and insects, but also reptiles (including the crocodile), birds and some mammals and fish. Reptiles molt their outer skin when they emerge; insects and crustaceans also molt.

Animals are affected by the weather: birds thrive in dry seasons, fish in warm rainy ones, but the murex cannot even taste fresh water. They also age, and have diseases, such as lice, but also diseases that resemble ours – some look sickly; even bees have sicknesses. Some animals have been known to seek remedies, as when a dog eats nettles to induce vomiting, or a leopard eats excrement against leopard's bane, or deer eat crabs if bitten by a venom-spider; a tortoise is said to eat marjoram to neutralize the venom of a snake it eats. The venom of snakes differs in strength, but is worst when a snake has eaten a scorpion.

Varieties of species come about by varieties of land. There are adjacent districts, and rivers, that have different species. This is not by chance, since when an animal, such as a hare, is transported to another place it will die soon after. Thus, each place has its own species and varieties. But abundance of food, and the cold, also makes a difference. In general, Asian animals are wildest, European ones boldest, and Libyan[6] ones most diverse. Mountain animals are also fiercer and bolder.

Long-lived animals can be said to have temperament: some can learn. Among these, there is a difference between males and females, with the latter in general more gentle and cunning and keener to learn, and the former more courageous, helpful and spirited (with the exception of the bears and leopards). There is general enmity between carnivores and the rest of the animals, and between particular species: the eagle and the snake, the crow and the owl (which steal each others' eggs), the basse and the mullet; the aegithus and the ass, for the latter disturbs its nest, while the ass is at war with the lizard, which gets in its nostrils when sleeping. In times of food shortages, there is war between tribes of the same kind; in the extreme, animals may dissociate from each other and live solitary. It can be said that enmity arises from competition for food, and if food were plentiful, all animals would be tame (as seen by the tame crocodiles in Egypt). But other times animals ally together, as when the raven helps the fox fight the merlin. The crocodile has a small bird that cleans its teeth, and it takes great care not to bite it.

[6]The world was divided into these three 'continents', Libya being modern Africa

Sheep are naturally dumb, for they will stand still in a snowstorm and die, unless moved by the shepherd. Smaller animals tend to be cleverer than bigger ones e.g. the swallow has a great ability to build like a man, partridges will lure a man away from her chicks by pretending to be lame, cranes have lookouts at night. The cuckoo is a coward, flying away from smaller birds, and laying her eggs in those of others. Hunters are in general cunning, each with its stratagem for catching its prey; even the swiftest fall prey to ambushes. The fishing frog fishes with a filament coming out of its eyelids. Wolves have been known to tear fishermen's nets if the spoil is not shared! Bees are extremely industrious with their hives, each doing its job, and have a king without which they disperse and die; they have special treatment for the drones, but will kill them if they lack provisions; and they all go to sleep at the same time. Lions are ferocious, but civets are naturally tame, and elephants the gentlest.

Animals are averse to incest: a male camel bit its keeper to death, and a male horse jumped down a precipice, after finding they had been mated with their partially concealed mothers. Dolphins take great care to defend their young from predators; then again, for no reason at all, they run aground.