

## ARISTOTLE ON THE HEAVENS

(fragments from Aristotle *On The Heavens*, translated by J. L. Stocks, notes by Șerban Nicolau, adapted by fr. Dan Bădulescu)

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### THE WORLD OVER THE MOON

The uniqueness of heaven

#### ARGUMENTS FOR THE PLURALITY OF THE HEAVENS

We must show not only that the heaven is one, but also that more than one heaven is and, further, that, as exempt from decay and generation, the heaven is eternal. We may begin by raising a difficulty.

#### THE MEANINGS OF THE WORD "HEAVEN"

First, however, we must explain what we mean by 'heaven' and in how many senses we use the word, in order to make clearer the object of our inquiry. (a) In one sense, then, we call 'heaven' the substance of the extreme circumference of the whole, or that natural body whose place is at the extreme circumference (το περιεχόμενον σωμα ὑπο της εσχάτης περιφορας. The sphere of the fixed stars). We recognize habitually a special right to the name 'heaven' in the extremity or upper region, which we take to be the seat of all that is divine. (b) In another sense, we use this name for the body continuous with the extreme circumference which contains the moon, the sun, and some of the stars; these we say are 'in the heaven' (The spheres of the planets, among which the outer one is continuous with the sphere of the fixed stars). (c) In yet another sense we give the name to all body included within extreme circumference, since we habitually call the whole or totality 'the heaven' universe (everything, the whole world: a likely definition is found at Plato, and Aristotle will take this too; the three senses of οὐρανός: the first heaven, the heaven itself and the whole universe). The word, then, is used in three senses. Now the whole included within the extreme circumference must be composed of all physical and sensible body, because there neither is, nor can come into being, any body outside the heaven.

#### The length of the Heaven

Now by its length I mean the interval between its poles, one pole being above and the other below; for two hemispheres are specially distinguished from all others by the immobility of the poles (the two hemispheres, arctic and antarctic, are determined by the poles which, in their turn, are at the extremities of the rotation axis; in that sense we have an absolute up and down of the celestial sphere, and the line between the poles is the length of the cosmos). Further, by 'transverse' in the universe we commonly mean, not above and below, but a direction crossing the line of the poles, which, by implication, is length: for transverse motion is motion crossing motion up and down (the right and the left of the heaven is determined by the perpendicular line on the poles axis).

#### The diversity of the movements and bodies in heaven

#### THE EARTH'S IMOBILITY

Why, then, is not the whole body of the heaven of the same character as that part (i.e. *moved circularly* = κυκλοφορητικόν)? Because there must be something at rest *at the centre of the revolving body*,... Earth then has to exist; for it is earth which is *at rest at the centre* (not the whole heaven is moving circularly; it has to have a fix center around which is the circularly movement; center of which nature has to be different by the heaven nature, „in which something remains fixed according to its nature and which is moved according to nature”, comments Simplicius;... something shall exist then in the center which is φθαρτόν, βαρύ, μόνιμον = destructible, heavy, fix, and which is The Earth). At present we may take this for granted: it shall be explained later.

The sphericity of the heaven  
THE PRIORITY OF THE CIRCLE AND SPHERE

The shape of the heaven is of necessity spherical; for that is the shape most appropriate to its substance and also by nature primary (the idea of the sphericity of the universe is found in the eleatic school and to Plato).

THE SPHERICITY OF THE HEAVEN

The first argument

(The appartenance of the first figure to the first body)

Now the first figure belongs to the first body, and the first body is that at the farthest circumference. It follows that the body which revolves with a circular movement must be spherical... The same again holds of the bodies between these and the centre. Bodies which are bounded by the spherical and in contact with it must be, as wholes, spherical; and the bodies below the sphere of the planets (της των πλανήτων) are contiguous with the sphere above them. The sphere then will be spherical throughout; for every body within it is contiguous and continuous with spheres (i.e. the whole universe is spherical.).

The second argument

(The absence of void and the place outside the universe)

Again, since the whole revolves, palpably and by assumption, in a circle, and since it has been shown that outside the farthest circumference there is neither void nor place, from these grounds also it will follow necessarily that the heaven is spherical.

The third argument

(The celestial movement is the measure of any other movements)

Again, if the motion of the heaven is the measure of all movements whatever in virtue of being alone continuous and regular and eternal, and if, in each kind, the measure is the minimum, and the minimum movement is the swiftest, then, clearly (δηλον οτι), *the movement of the heaven must be the swiftest of all movements*. Now of lines which return upon themselves (ἀφ' αὐτοῦ εφ' αὐτοῦ) the line which bounds the circle is the shortest; and that movement is the swiftest which follows the shortest line (the circular movement is the fastest and the minimal; the movement of the heaven being circular, and the minimal being a measure, it results that this is the measure of the other movements). Therefore, if the heaven moves in a circle and moves more swiftly than anything else, it must necessarily be spherical.

THE PERFECTION BEYOND COMPARISON OF THE COSMIC SPHERE

It is plain from the foregoing that the universe is spherical. It is plain, further, that it is turned (so to speak) with a finish which no manufactured thing nor anything else within the range of our observation can even approach. For the matter of which these are composed does not admit of anything like the same regularity and finish as the substance of the enveloping body.

The uniform movement of the first heaven

THE ITEM OF THE CHAPTER

It will be showed that the movement of the heaven is uniform and regular.

THERE ARE NOT POSSIBLE IRREGULARITIES IN THE CIRCULAR MOVEMENT

If the movement is uneven, clearly there will be acceleration, maximum speed, and retardation (επίτασις (*intensio*) is *este acceleration*, ἀκμή (*summa velocitas*) is *the maximum speed*, and ἀνέσις (*remissio*) is *the retardation* of the translation movement), since these appear in all irregular motions.

### THERE ARE NO IRREGULARITIES CAUSED BY THE MOVER OR THE MOVED

Further, since everything that is moved is moved by something, the cause of the irregularity of movement must lie either in the mover or in the moved or both... It follows then, further, that the motion cannot be irregular.

### THERE IS NO PARTIAL OR TOTAL IRREGULARITY OF THE CELESTIAL MOVEMENT

It follows then, further, that the motion cannot be irregular. For if irregularity occurs, there must be change either in the movement as a whole, from fast to slow and slow to fast, or in its parts (Its parts are the fixed stars.). That there is no irregularity in the parts is obvious, since, if there were, some divergence of the stars would have taken place before now in the infinity of time, as one moved slower and another faster: but no alteration of their intervals is ever observed. (Simplicius, *In de caelo*, 428,1-2: „...nowhere is seen a change of succession in the natural disposition of the stars related to each other, nor any difference of their distance...”)... since acceleration involves retardation (These are relative notions, „...like more or less, or the greatest and the smallest”)

The stars

Their nature and composition

### THEIR NATURE AND COMPOSITION OF THE STARS

In so saying we are only following the same line of thought as those who say that the stars are fiery (Plato, *Timaios*, 40a) because they believe the upper body to be fire, the presumption being that a thing is composed of the same stuff as that in which it is situated. The warmth and light which proceed from them are caused by the friction set up in the air by their motion... the upper bodies are carried on a moving sphere, so that, though they are not themselves fired, yet the air underneath the sphere of the revolving body is necessarily heated by its motion, and particularly in that part where the sun is attached to it (the sphere of which is attached the star). Hence warmth increases as the sun gets nearer or higher or overhead. (The sphere of the fixed and wandering stars – the planets – are not made by fire, but from aether; through the rotation movement the sphere heats the air bellow it, especially in the place where is located the sphere by which the sun is fixed; near the last inner sphere is the fire, the easiest element of the sublunar world, which burn the air bellow it as a kind of combustible matter (ὑπέκκαυμα).

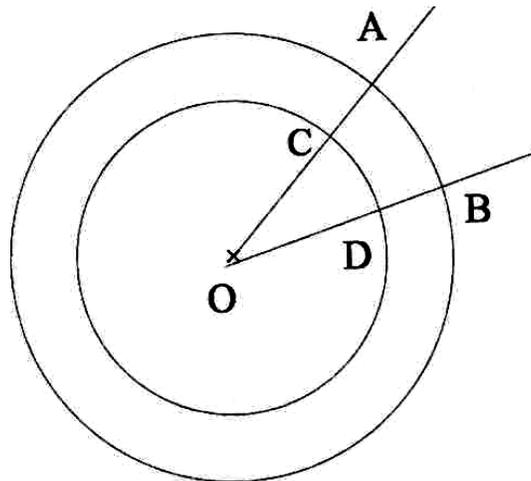
The stars

Their movement

### THE STARS ARE MOVED BY THEIR CIRCLES AND NOT BY THEMSELVES

Since changes evidently occur not only in the position of the stars but also in that of the whole heaven, there are three possibilities. Either (1) both are at rest, or (2) both are in motion, or (3) the one is at rest and the other in motion (3 hypotheses are considered and refuted in turn: the first, heaven and stars are at rest; the second, heaven and stars are both in motion; the third, heaven is at rest and the stars in motion). (1) That both should be at rest is impossible; for, *if the earth is at rest*, the hypothesis does not account for the observations (the first hypothesis: the immobility of the earth and heaven does not account for the observations, τα φαινόμενα; duet o these and considering the earth as fixed it results that only heaven moves); and we take it as granted that the earth is at rest. It remains either that both are moved, or that the one is moved and the other at rest. (2) On the view (the second hypothesis: heaven and stars are both in motion), first, that both are in motion, we have the absurdity that the stars and the circles move with the same speed (if the fixed stars are observed, we notice that those closet o the pole run in one day a circle smaller than those closet o the equator, whose circle is greater; so, the speed of those closet o the equator is proportionally greater than the speed of those closet o the pole, because the different size circles are passed in the same time, one day; starting

from this argument, Aristotle thinks that the stars also, wandering against the fixed stars of the last circle, have to move not by themselves, but in the same time with the spheres by which they are fixed and which revolve in one day too), i.e. that the pace of every star is that of the circle in it moves. For star and circle are seen to come back to the same place at the same moment; from which it follows that the star has traversed the circle and the circle has completed its own movement, i.e. traversed its own circumference, at one and the same moment. But it is difficult to conceive that the pace of each star should be exactly proportioned to the size of its circle. That the pace of each circle should be proportionate to its size is not absurd but inevitable: but that the same should be true of the movement of the stars contained in the circles is quite incredible. For if, on the one hand, we suppose that the star which moves on the greater circle is necessarily swifter, clearly we also admit that if stars shifted their position so as to exchange circles, the slower would become swifter and the swifter slower. But this would show that their movement was not their own, but due to the circles. If, on the other hand, the arrangement was a chance combination, the coincidence in every case of a greater circle with a swifter movement of the star contained in it is too much to believe. In one or two cases it might not inconceivably fall out so, but to imagine it in every case alike is a mere fiction... (3) The same absurdity (the third hypothesis: heaven, with its circles, is at rest and the stars in motion) is equally plain if it is supposed that the circles stand still and that it is the stars themselves which move. For it will follow that the outer stars are the swifter, and that the pace of the stars corresponds to the size of their circles. *Since, then, we cannot reasonably suppose either that both are in motion or that the star alone moves, the remaining alternative is that the circles should move, while the stars are at rest and move with the circles to which they are attached. Only on this supposition are we involved in no absurd consequence* (once the three hypotheses rejected, remains what was to be proved: the circles are in motion and the stars are fixed and attached by those, moving only together). For, in the first place, the quicker movement of the larger circle is natural when all the circles are attached to the same centre. Whenever bodies are moving with their proper motion, the larger moves quicker. It is the same here with the revolving bodies: for the arc intercepted by two radii will be larger in the larger circle, and hence it is not surprising that the revolution of the larger circle should take the same time as that of the smaller. And secondly, the fact that the heavens do not break in pieces follows not only from this but also from the proof already given of the continuity of the whole.



Considering two concentric with O as center and two radii OA and OB in the large circle, intersecting the circumference of the small circle in C and D, respectively, a point through the arc AB in the same time while another point passes through the arc CD, results that the speed of the first point will be greater than the speed of the second point, because the arc AB is longer than the arc CD, so the movement of the larger circle to accomplish a revolution will be faster than the smaller circle.

THE STARS HAVE NOT THE MOVEMENTS OF THE SPHERES

Again, since the stars are spherical, as our opponents assert and we may consistently admit, inasmuch as we construct them out of the spherical body, and since the spherical body has two movements proper to itself, namely rolling and spinning κύλισις (*volutatio*, rolling is the movement of the rolling forward of a sphere; δίνησις, *conversio, circumgyratio*, spinning is the movement of spinning of a sphere around its own axis; „...*the spinning* of the sphere occurs on the same place around its own axis, while the *spinning* changes the place”), it follows that if the stars have a movement of their own, it will be one of these. But neither is observed. (1) Suppose them to spin. They would then stay where they were, and not change their place, as, by observation and general consent, they do. Further, one would expect them all to exhibit the same movement: but the only star which appears to possess this movement is the sun, at sunrise or sunset, and this appearance is due not to the sun itself but to the distance from which we observe it. The visual ray being excessively prolonged becomes weak and wavering. The same reason probably accounts for the apparent twinkling of the fixed stars and the absence of twinkling in the planets. The planets are near, so that the visual ray reaches them in its full vigour, but when it comes to the fixed stars it is quivering because of the distance and its excessive extension; and its tremor produces an appearance of movement in the star: for it makes no difference whether movement is set up in the ray or in the object of vision (reference to Empedocles' theory saying that the eye contains an inner fire from where starts emissions to objects, which Aristotle too seems to admit. This place is an example of how Aristotle understands the scientific knowledge from the difference between science of *the fact* and science of *the proceedings*. Not only *that* (οτι) something exists, but also *why* (διότι) gives full scientific knowledge of the proceeding, understood as rationale (*ratio essendi*) and also reason to know (*ratio cognoscendi*).

The example of the planets whose light does not flash due to greater proximity to Earth, is transformed by Aristotle into an example of syllogism that gives proof of the cause: Everything which is close (B) does not flash (A). The planets (C) are close to (B). So the planets (C) do not flash (A).

Therefore, not the lack of blinking is the cause of the near planets, but the place of the planets is the cause of their lack of blinking. The same distinction between knowing of *the fact* (το οτι) and the knowledge of *the cause* (το διότι) when the sphericity of the moon is demonstrated from its phases). On the other hand, it is also clear that the stars do not roll. For rolling involves rotation: but the 'face', as it is called, of the moon is always seen. Therefore, since any movement of their own which the stars possessed would presumably be one proper to themselves, and no such movement is observed in them, clearly they have no movement of their own.

#### THE SPHERICITY OF HEAVEN AND STARS

This is just why it seems proper that the whole heaven and every star should be spherical. For while of all shapes the sphere is the most convenient for movement in one place, making possible, as it does, the swiftest and most self-contained motion, for forward movement it is the most unsuitable, least of all resembling shapes which are self-moved, in that it has no dependent or projecting part, as a rectilinear figure has, and is in fact as far as possible removed in shape from ambulatory bodies. Since, therefore, the heavens have to move in one place, and the stars are not required to move themselves forward, it is natural that both should be spherical—a shape which best suits the movement of the one and the immobility of the other.

#### THE STARS ARE NOT SELFMOVED

But not only is the explanation evident; it is also a corroboration of the truth of the views we have advanced (The aristotelic theory according to which the stars are at rest and move in the same time with the spheres on which they are fixed)... That the stars are spherical and are not selfmoved, has now been explained.

The stars  
Their order

### THE ORDER OF THE STARS

With their order (Aristotle sets out the principles of his purely deductive method, leaving the observations to the astronomers; those whose theories he could have known them are Eudoxos, a contemporary of Plato, and Callippos, the disciple who, together with Aristotle completes, traditionally, his system) - I mean the position of each, as involving the priority of some and the posteriority of others, and their respective distances from the extremity - with this astronomy may be left to deal, since the astronomical discussion is adequate. This discussion shows that the movements of the several stars depend, as regards the varieties of speed which they exhibit, on the distance of each from the extremity. It is established that the outermost revolution of the heavens is a simple movement and the swiftest of all, and that the movement of all other bodies is composite and relatively slow, for the reason that each is moving on its own circle with the reverse motion to that of the heavens (As was said, the movement of the sphere of the fixed stars is from east to west, while the movement of planet spheres is on the contrary, west to east). This at once leads us to expect that the body which is nearest to that first simple revolution should take the longest time to complete its circle, and that which is farthest from it the shortest, the others taking a longer time the nearer they are and a shorter time the farther away they are (the proximity or remoteness of the planets from the sphere of the fixed stars; the Moon is closest to Earth at the center of the world, and further from the sphere of fixed stars; it follows in ascending order of closeness to the fixed stars, Mercury, Venus, Sun, Mars, Jupiter and Saturn, the closest). For it is the nearest body which is most strongly influenced, and the most remote, by reason of its distance, which is least affected, the influence on the intermediate bodies varying, as the mathematicians show, with their distance. (Aristotle's theory explains how the movement of the latter sphere, that of the fixed stars, going contrary, slows the motion of the planetary spheres more so as they are closer to it and away from Earth; the sphere of Saturn, the furthest from the Earth and the first from the fixed stars, will have the slowest movement and revolution in the longest time; the Moon closest to Earth and further from the last heaven will have the fastest movement and revolution during the briefly, 24 hours; for the intermediate, the movement speed is directly proportional and inversely proportional to the revolution in the sphere of fixed stars distance).

The stars  
Their sphericity

### THE SPHERICITY OF THE STARS

With regard to the shape of each star, the most reasonable view is that they are spherical... Again, what holds of one holds of all, and the evidence of our eyes shows us that the moon is spherical. For how else should the moon as it waxes and wanes show for the most part a crescent-shaped or gibbous figure, and only at one moment a half-moon? And astronomical arguments give further confirmation; for no other hypothesis accounts for the crescent shape of the sun's eclipses (during eclipses of the sun the round shape of the moon is observed). One, then, of the heavenly bodies being spherical (The moon is, according to astronomical observations, spherical and other stars will therefore be the same), clearly the rest will be spherical also.

The Earth  
Doxography

### THE SUBJECT OF THE CHAPTER

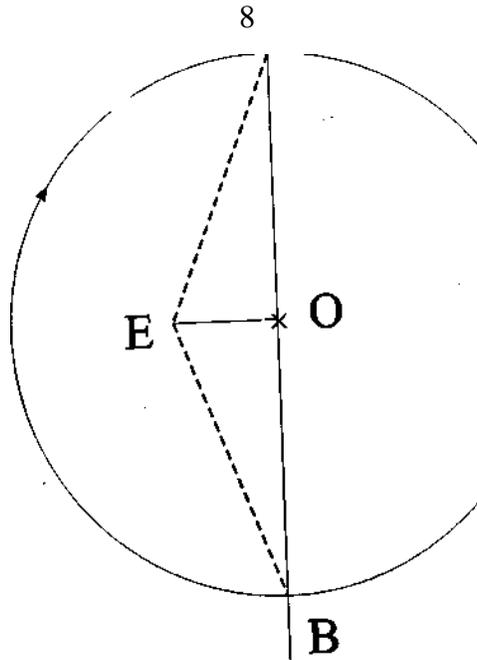
It remains to speak of the earth, of its position, of the question whether it is at rest or in motion, and of its shape.

## THE POSITION

As to its position there is some difference of opinion. Most people-all („...such as Empedocles, Anaximandros, Anaximenes, Anaxagoras, Democritos and Plato...”), in fact, who regard the whole heaven as finite - say it lies at the centre. But the Italian philosophers known as Pythagoreans take the contrary view. At the centre, they say, is fire, and the earth is one of the stars, creating night and day by its circular motion about the centre. They further construct another earth in opposition to ours to which they give the name counterearth. In all this they are not seeking *for theories and causes to account for observed facts, but rather forcing their observations and trying to accommodate them to certain theories and opinions of their own* (the Pythagorean cosmological system, usually attributed to Philolaos - approx. 470-400 BC - or anonymous authors, had the fire in center, on the closest orbit moved the Counterearth, followed by Earth, Moon, Mercury, Venus, Sun, Mars, Jupiter and Saturn, and the sphere of the fixed stars at the end. The system of the 9 planets, from the Counterearth formed, together with the sphere of the fixed stars the number 10 which, according to the Pythagorean doctrine, was the perfect number - the sum of the first four - . The idea that number 10 is the perfect number of celestial bodies led to the invention of the Counterearth, unnoticed and somewhere in the heaven and which, said Pythagoreans, is invisible to us as opposed to the Earth). But there are many others who would agree that it is wrong to give the earth the central position, looking for confirmation rather to theory than to the facts of observation. Their view is that the most precious place befits the most precious thing: but fire, they say, is more precious than earth, and the limit than the intermediate, and the circumference and the centre are limits. Reasoning on this basis they take the view that it is not earth that lies at the centre of the sphere, but rather fire. The Pythagoreans have a further reason. They hold that the most important part of the world, which is the centre, should be most strictly guarded, and name it, or *rather the fire* ("Of bodies, fire is the noblest, and to the most noble of the bodies belongs the noblest of places".) which occupies that place, the 'Guardhouse of Zeus' ("Philolaos says that there is a fire in the center and calls the whole heart, house of Zeus, mother of gods, altar, advocate and extent of nature"), as if the word 'centre' were quite unequivocal, and the centre of the mathematical figure were always the same with that of the thing or the natural centre...

## THE MOTION

As to the position of the earth, then, this is the view which some advance (the Pythagoreans), and the views advanced concerning its rest or motion are similar. For here too there is no general agreement. All who deny that the earth lies at the centre think that it revolves about the centre, and not the earth only but, as we said before, the counter-earth as well. Some of them (the Pythagoreans) even consider it possible that there are several bodies so moving, which are invisible to us owing to the interposition of the earth. This, they say, accounts for the fact that eclipses of the moon are more frequent than eclipses of the sun: for in addition to the earth each of these moving bodies can obstruct it. Indeed, as in any case the surface of the earth is not actually a centre but distant from it a full hemisphere, there is no more difficulty, they think, in accounting for the observed facts on their view that we do not dwell at the centre, than on the common view that the earth is in the middle. Even as it is, there is nothing in the observations to suggest that we are removed from the centre by half the diameter of the earth (if the earth would not be located in the center of the universe, says Aristotle, the observation of celestial phenomena - τα φαινόμενα - would not have a satisfactory explanation. In reply, the Pythagoreans argued saying that the live on the spherical surface of the Earth which is not punctual, without dimensions, but has a diameter like every sphere has; so the distance of an observer from the center of the earth is a hemisphere, as Aristotle admits, or half the diameter).



Consider - see fig. - a sphere of fixed stars representing heaven, the center O, two diametrically opposite points A and B on the equator and an observer located in the point E different by the center; as seen from E, a star which moves from B to A on the circle C in half a day seems a distance longer than the distance from a to B on the circle D; in reality, this perception does not exist, because the observer's E distance from the center of the Earth, equal to its radius, is negligible versus the distance from the fixed stars heaven. Therefore, both arguments are worthless.

Others, again, say that the earth, which lies at the centre, is 'rolled', and thus in motion, about the axis of the whole heaven, So it stands written in the *Timaeus*.

#### THE SHAPE

There are similar disputes about the shape of the earth. *Some think it is spherical* (the certain date of the discovery of the Earth's sphericity was the subject of much controversy, aroused primarily because the confused testimony from the Presocratic Greek philosophy sources. The Pythagorean tradition assigns primacy. If we were to give credence to Diogenes Laertios, even Anaximander believed that the earth is spherical, clearly a false information. Certainly it can be said that the discovery of sphericity is not before the end of the 5<sup>th</sup> century. It really belongs to the Pythagorean school at the end of the 5<sup>th</sup> century and the beginning of 4<sup>th</sup> century, probably to Philolaos. But the first mention of a spherical Earth belongs to Plato who describes it as a colored ball and twelve pieces of leather ball: *ωσπερ αι δωδεκάσκυτοι σφαιραι*, thinking perhaps of a regular dodecahedron. In the Pythagorean doctrine developed on the time of Philolaos, the regular dodecahedron was one of the five regular convex polyhedra considered, with tetrahedron, cube, octahedron and icosahedron, cosmic bodies. Although Pythagorean in origin, they were called in sec. the 4<sup>th</sup> century BC the five platonic bodies because Plato describes them calling the embodiments of the four elements. The regular dodecahedron was the embodiment of everything body or the universe), others that it is flat and drum-shaped (Anaximenes believed that the earth is shaped like a drum with the width of three times the height; further confirmation of the shape at Hippolitos and Aëtius; Anaxagoras claimed to have flat shape. The place confirms that flat earth theory still had many adherents even in the days of Aristotle). For evidence they bring the fact that, as the sun rises and sets, the part concealed by the earth shows a straight and not a curved edge, whereas if the earth were spherical the line of section would have to be circular. In this they leave out of account the great distance of the sun from the earth and the great size of the circumference, which, seen from a distance on these apparently small circles appears straight. Such an appearance ought not to make them doubt the circular shape of the earth. But they

have another argument. They say that because it is at rest, the earth must necessarily have this shape. For there are many different ways in which the movement or rest of the earth has been conceived (the spherical shape is favorable to the movement - εὐκίνητόν - while the flat disk shape is favorable to rest).

#### RETURNING TO EARTH MOTION AND REST

Antinomy. For there are many different ways in which the movement or rest of the earth has been conceived. The difficulty must have occurred (the difficulty of conceiving Earth at rest) to every one. It would indeed be a complacent mind that felt no surprise that, while a little bit of earth, let loose in mid-air moves and will not stay still... the whole earth, free in midair, should show no movement at all. Yet here is this great weight of earth, and it is at rest...

The proposal solutions

#### Thales

Others say the earth rests upon water. This, indeed, is the oldest theory that has been preserved, and is attributed to Thales of Miletus. It was supposed to stay still because it floated like wood and other similar substances, which are so constituted as to rest upon but not upon air. As if the same account had not to be given of the water which carries the earth as of the earth itself! It is not the nature of water, any more than of earth, to stay in mid-air: it must have something to rest upon.

#### Rebuking

Again, as air is lighter than water, so is water than earth (I wrote "earth" when Aristotle speaks of the earth element, as is the case here, but I used "Earth" when referring to the heavenly body): how then can they think that the naturally lighter substance lies below the heavier? Again, if the Earth as a whole is capable of floating upon water, that must obviously be the case with any part of it. But observation shows that this is not the case. Any piece of earth goes to the bottom, the quicker the larger it is.

#### Anaximenes, Anaxagoras, Democritus

Anaximenes ("Anaximenes claims that the Earth is shaped like a table", "Anaximenes says that the Earth, because its width is supported by air") and Anaxagoras ("The Earth is flat in shape and remains suspended because of its size because it is not empty and that is very strong, the air surrounding the Earth keeps it afloat.") and Democritus ("according to Democritus, is shaped like a flat disc and hollow inside," "For the first time Democritus... recognized that the Earth has an elongated shape with a length equal to one and a half width") give the flatness of the earth as the cause of its staying still. Thus, they say, it does not cut, but covers like a lid, the air beneath it. This seems to be the way of flat-shaped bodies: for even the wind can scarcely move them because of their power of resistance. The same immobility, they say, is produced by the flatness of the surface which the Earth presents to the air which underlies it; while the air, not having room enough to change its place because it is underneath the earth, stays there in a mass, like the water in the case of the water-clock (clepsydra - κλεψύδρα - spoken of here has nothing in common with it than the name of measuring instrument. Aristotle refers to a container neck long and narrow, with curved bottom and holes, immersed in a vessel with liquid left to fill the holes in the bottom, baring the neck elongated fluid could carry. The Earth is held in the air just as water in clepsydra is supported by air underneath it). And they adduce an amount of evidence to prove that air, when cut off and at rest, can bear a considerable weight.

#### Rebuking

Now, first, if the shape of the earth is not flat, its flatness cannot be the cause of its immobility. But in their own account it is rather the size of the earth than its flatness that causes it to remain at rest. For the reason why the air is so closely confined that it cannot find a passage, and therefore stays where it

is, is its great amount: and this amount great because the body which isolates it, the earth, is very large. This result, then, will follow, even if the earth is spherical, so long as it retains its size. So far as their arguments go, the earth will still be at rest.

#### The broadening of the debate

In general, our quarrel with those who speak of movement in this way cannot be confined to the parts; it concerns the whole universe (the argument must refer to an entire universe and not to consider only one or two items such as earth and water). One must decide at the outset whether bodies have a natural movement or not, whether there is no natural but only constrained movement. Seeing, however, that we have already decided this matter to the best of our ability, we are entitled to treat our results as representing fact. Bodies, we say, which have no natural movement, have no constrained movement; and where there is no natural and no constrained movement there will be no movement at all. This is a conclusion, the necessity of which we have already decided, and we have seen further that rest also will be inconceivable, since rest, like movement, is either natural or constrained. But if there is any natural movement, constraint will not be the sole principle of motion or of rest. If, then, it is by constraint that the Earth now keeps its place, the so-called 'whirling' movement by which its parts came together at the centre was also constrained (cf. theories of Anaximenes, Anaxagoras and Democritus about the immobility of the Earth due to his support by air from below, so forcibly) the so-called 'whirling' movement by which its parts came together at the centre was also constrained (δίνησις is the act of turning, the whirl, the vortex). The form of causation supposed they all borrow from observations of liquids and of air, in which the larger and heavier bodies always move to the centre of the whirl. This is thought by all those who try to generate the heavens to explain why the earth came together at the centre. They then seek a reason for its staying there; and some say, in the manner explained, that the reason is its size and flatness, others, with Empedocles, that the motion of the heavens, moving about it at a higher speed, prevents movement of the earth, as the water in a cup, when the cup is given a circular motion, though it is often underneath the bronze, is for this same reason prevented from moving with the downward movement which is natural to it.) But suppose both the 'whirl' and its flatness (the air beneath being withdrawn) cease to prevent the earth's motion, where will the earth move to then? Its movement to the centre was constrained, and its rest at the centre is due to constraint; but there must be some motion which is natural to it. Will this be upward motion or downward or what? It must have some motion; and if upward and downward motion are alike to it, and the air above the earth does not prevent upward movement, then no more could air below it prevent downward movement. For the same cause must necessarily have the same effect on the same thing.

#### Empedocles

##### Rebuking

It is absurd too not to perceive that, while the whirling movement may have been responsible for the original coming together of the art of earth at the centre, the question remains, why now do all heavy bodies move to the earth. For the whirl surely does not come near us. Why, again, does fire move upward? Not, surely, because of the whirl. But if fire is naturally such as to move in a certain direction, clearly the same may be supposed to hold of earth. Again, it cannot be the whirl which determines the heavy and the light. Rather that movement caused the pre-existent heavy and light things to go to the middle and stay on the surface respectively. Thus, before ever the whirl began, heavy and light existed; and what can have been the ground of their distinction, or the manner and direction of their natural movements?...

#### Anaximander

...but there are some, Anaximander, for instance, among the ancients, who say that the earth keeps its place because of its indifference (ἴσότης - indifference - is associated with ἰσοποπία - balance - borrowed from Plato, *Phaidon*). Motion upward and downward and sideways were all, they thought, equally inappropriate to that which is set at the centre and indifferently related to every extreme point; and to move in contrary directions at the same time was impossible: so it must needs remain still.

## Rebuking

This view is ingenious but not true. The argument would prove that everything, whatever it be, which is put at the centre, must stay there. Fire, then, will rest at the centre: for the proof turns on no peculiar property of earth. But this does not follow. The observed facts about earth are not only that it remains at the centre, but also that it moves to the centre. The place to which any fragment of earth moves must necessarily be the place to which the whole moves; and in the place to which a thing naturally moves, it will naturally rest. The reason then is not in the fact that the earth is indifferently related to every extreme point: for this would apply to any body, whereas movement to the centre is peculiar to earth. Again it is absurd to look for a reason why the earth remains at the centre and not for a reason why fire remains at the extremity. If the extremity is the natural place of fire, clearly earth must also have a natural place. But suppose that the centre is not its place, and that the reason of its remaining there is this necessity of indifference... even so, it still remains to explain why fire stays at the extremities. It is strange, too, to ask about things staying still but not about their motion, - why, I mean, one thing, if nothing stops it, moves up, and another thing to the centre. Again, their statements are not true.

## The Earth

### Aristotle's theory

#### THE CENTRAL PLACE AND THE EARTH' IMMOBILITY

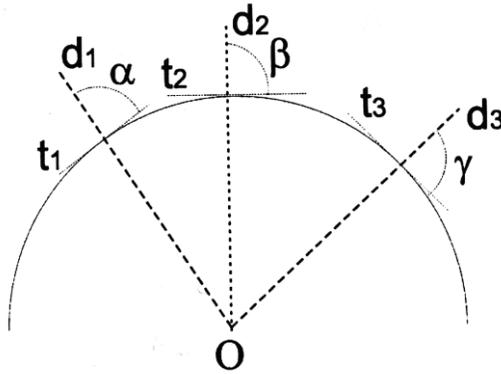
The rebuking of the theories about its motion

Let us first decide the question whether the earth moves or is at rest. For, as we said, there are some (the Pythagoreans) *who make it one of the stars*, and others who, setting it at the centre (Plato, *Timaios*), suppose it to be 'rolled' and in motion about the pole as axis. That both views are untenable will be clear if we take as our starting-point the fact that the earth's motion, whether the earth be at the centre or away from it, must needs be a constrained motion... Again, everything that moves with the circular movement, except the first sphere, is observed to be passed, and to move with more than one motion. The earth, then, also, whether it move about the centre or as stationary at it, must necessarily move with two motions. But if this were so, there would have to be passings and turnings of the fixed stars (πάροδος - movement, passing - it probably refers to the side movement of the rise and set points of the fixed stars). Yet no such thing is observed. The same stars always rise and set in the same parts of the earth (the second argument: in the system adopted by Aristotle of homocentric spheres, except the fixed stars moved by a single sphere, the first, all other stars are moving in rotation composed of several spheres; the first sphere rotates from east to west, the second rotates in the ecliptic plane from west to east having the axis oblique with the axis of the first sphere, which explains the regression - ὑπολειπόμενα - of the interior movement; if the Earth were one of the planets, its motion would be composed of at least two revolutions - in the text, circular movements - the first of which would be the sphere of fixed stars from east to west, and second, the axis of rotation perpendicular to the ecliptic plane, retrograde, from west to east; so the plan of the equator of the fixed stars sphere will be inclined to the plane of the Earth's equator; the motion of the fixed stars will therefore have the same phases as the movement of the sun in year's periods; between the vernal equinox and summer solstice the sun rises from the equator to the Tropic of Cancer, goes down to the equator between summer solstice and autumn equinox, and from the equator to the Tropic of Capricorn to the winter solstice, to remount to the equator between winter solstice and spring equinox; if so, the axis of rotation of the Earth would be identical to the axis of rotation other planets, the fixed stars would have the same movements as the Sun and other planets and therefore would not rise and set in the same places of the horizon. But observation disproves this, so the Earth is motionless).

A difficulty regarding the central position

Further, the natural movement of the earth, part and whole alike, is the centre of the whole-whence the fact that it is now actually situated at the centre-but it might be questioned since both centers are the same, which centre it is that portions of earth and other heavy things move to. Is this their goal because it is the centre of the earth or because it is the centre of the whole? The goal, surely, must be

the centre of the whole. For fire and other light things move to the extremity of the area which contains the centre. It happens, however, that the centre of the earth and of the whole is the same. Thus they do move to the centre of the earth, but accidentally, in virtue of the fact that the earth's centre lies at the centre of the whole. That the centre of the earth is the goal of their movement is indicated by the fact that heavy bodies moving towards the earth do not parallel but so as to make equal angles, and thus to a single centre, that of the earth.



The movement of the heavy bodies

ὁμοίας γωνίας: same angles, the same value, equal; προς ὁμοίας γωνίας (by the same angle) is equated with προς τας ἰσας γωνίας (by equal angles); equal angles are right angles ( $\alpha$ ,  $\beta$ ,  $\gamma$ ) consisting of different directions moving to the center of the Earth ( $d_1$ ,  $d_2$ ,  $d_3$ ) and its surface tangents to the curve ( $t_1$ ,  $t_2$ ,  $t_3$ ,) see fig.

Additional argument

It is clear, then, that the earth must be at the centre and immovable, not only for the reasons already given, but also because heavy bodies forcibly thrown quite straight upward return to the point from which they started, even if they are thrown to an infinite distance (if the Earth would move, between the moment of the projection of a body to vertical - κατα σταθμην - perpendicular to the tangent of the ground, - see fig. above - and the moment of its falling vertically, it would go through, no matter how small is time, a distance; so that the designed body could not fall in exactly the same place, as it happens, Aristotle believed; in fact, the Earth stays still).

The Earth's immobility

From these considerations then it is clear that the earth does not move and does not lie elsewhere than at the centre. From what we have said the explanation of the earth's immobility is also apparent... For a single thing has a single movement, and a simple thing a simple: contrary movements cannot belong to the same thing, and movement away from the centre is the contrary of movement to it... Since, then, it would require a force greater than itself to move it (by forced movement against nature - παρα φύσιν), it must needs stay at the centre. This view is further supported by the contributions of mathematicians to astronomy, since the observations made as the shapes change by which the order of the stars is determined, are fully accounted for on the hypothesis that the earth lies at the centre (the order of the wandering stars, planets, and the fixed stars, as determined in the universe, where the stability of observed facts - τα φαινόμενα - and, moreover, the central hypothesis of immobility and the Earth is the only position that explains, is that the Earth is immobile in the center of the universe). Of the position of the Earth and of the manner of its rest or movement, our discussion may here end.

## THE SPHERICITY

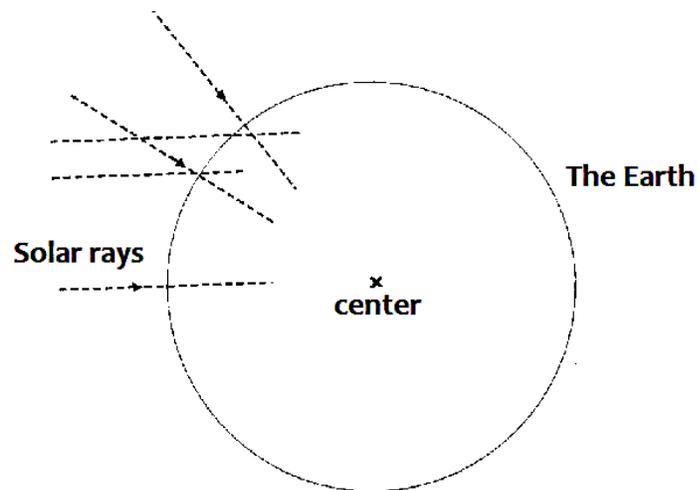
Argument resulted from the weight laws  
Its shape must necessarily be spherical...

### The solution of a difficulty

In this we have also the solution of a possible difficulty. The Earth, it might be argued, is at the centre and spherical in shape: if, then, a weight many times that of the earth were added to one hemisphere, the centre of the earth and of the whole will no longer be coincident. So that either the earth will not stay still at the centre, or if it does, it will be at rest without having its centre at the place to which it is still its nature to move....

### Argument resulted from the falling bodies

But the spherical shape, necessitated by this argument, follows also from the fact that the motions of heavy bodies always make equal angles, and are not parallel.



By convention the sun rays fall parallel to any latitude on Earth. At the summer solstice a stick held vertically in a tropical point leaves no shadow, but the same stick moved to a northern latitude leaves a shadow. Therefore, if at the tropic the direction of the sun rays coincides with the perpendicular to that place, at different latitudes the sun rays are perpendicular to some angle on the site, which is only possible if the Earth's surface is spherical (see fig.).

This would be the natural form of movement towards what is naturally spherical. Either then the earth is spherical or it is at least naturally spherical...

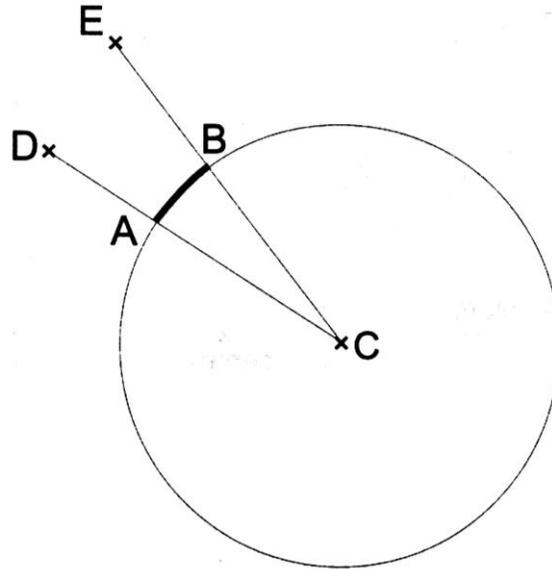
### Argument from the moon eclipses

The evidence of the senses further corroborates this. How else would eclipses of the moon show segments shaped as we see them? As it is, the shapes which the moon itself each month shows are of every kind straight, gibbous, and concave-but in eclipses the outline is always curved: and, since it is the interposition of the earth that makes the eclipse, the form of this line will be caused by the form of the earth's surface, which is therefore spherical.

### The size

Again, our observations of the stars make it evident, not only that the earth is circular, but also that it is a circle of no great size. For quite a small change of position to south or north causes a manifest alteration of the horizon. There is much change, I mean, in the stars which are overhead, and the stars seen are different, as one moves northward or southward. Indeed there are some stars seen in Egypt and in the neighbourhood of Cyprus which are not seen in the northerly regions; and stars, which in

the north are never beyond the range of observation, in those regions rise and set. All of which goes to show not only that the earth is circular in shape, but also that it is a sphere of no great size: for otherwise the effect of so slight a change of place would not be quickly apparent... Also, those mathematicians who try to calculate the size of the earth's circumference arrive at the figure 400,000 stades.



Measuring the size of Earth became a problem with acceptance of its sphericity. The size of 400,000 stadia which Aristotle gives here probably relates to Eudoxos' calculations. Although nothing is known precisely, it seems that the method used for these calculations was the one that will be used several years later by Dicearchos of Messenia, peripatetic philosopher, geometrist and cartographer. The method is based on measuring the difference in declination (the celestial equator with angle of sight leading to a star) between two stars at the zenith passing through two points on the same meridian, but at different latitudes, and measuring the distance between the two points. The difference in declination between stars D and E at the zenith to the ground points A and B is the angle DCE situated towards the circle at the same ratio as the arc AB to the circumference of the same circle C. Knowing the distance AB it can be calculated the terrestrial circle length (see fig.). The problem of the ancient measurements was inaccuracy in calculating distances between two points distant enough (AB), the methods being quite approximate. The Olympic stadia of Aristotle probably here included 600 feet and was 184.18 m, leading to a terrestrial meridian of 73,672 km. Archimedes, Hipparchus and Posidonius gave figures much closer to reality. Eratosthenes (ca. 284-192 BC, librarian at Alexandria), creator of geodesy, was amazingly accurate to calculate longitude at 250,000 stadia, or 39,690 km, calculating after stadia 158.76 m, to 40,009 km by modern calculations.

This indicates not only that the earth's mass is spherical in shape, but also that as compared with the stars it is not of great size.