INTRODUCTION

Although Heliocentric Theory is well known, describing it without the use of unwarranted or unjustified assumptions is not easy. Simply put, the theory suggests that the earth has two motions, a rotation on an axis and an orbital motion about the sun. Further, it maintains that the sun is central to, although not exactly in the center of, the orbits of all those heavenly bodies known as the planets, of which the earth is one. The physical reference frame used to determine the motions of this "solar" system is the frame of the fixed stars, bodies that do not appear to change their positions relative to one another. In this theory the dual motions attributed to the earth are considered to be in some sense real.

The Geocentric View of Eudoxus

Although not really interested in astronomy, the philosopher Plato had a great influence on the course of its early history. Because he perceived the heavens to be more perfect than the earth, Plato urged astronomers to describe celestial motions in terms of the most perfect of geometrical shapes, the circle. In fact, for Plato, the most perfect motion would be uniform circular motion, motion in a circle at a constant rate of speed.

One of Plato's pupils, Eudoxus of Cnidus (409 B.C.–356 B.C.), was the first astronomer to follow Plato's recommendation. Blending careful observation with sophisticated mathematical constructs, Eudoxus sought to describe the motions of the heavens in terms of a series of concentric spherical shells, with the earth geometrically at the center of those shells. His model consisted of twenty-seven spheres, three each for the sun and the moon and four for each of the five known planets; Mercury, Venus, Mars, Jupiter, and Saturn. The final sphere carried all the "fixed" stars and presumably contained the whole universe. Each sphere turned on an axis at a uniform rate of speed and was attached to adjacent spheres at its axis. Since the axes of the spheres were in different planes and since the spheres could transmit their motions to one another through the axes, Eudoxus was able to "account" for the rather complicated motions that had been observed—for example, the retrograde motions of Mars, Jupiter, and Saturn. In this process the earth was not only considered to be in the center of these shells but also totally immobile and the reference point of all perceived motions.

The Aristotelian Cosmology

As mentioned, Eudoxus was somewhat successful in explaining observations of the heavens. Another of Plato's students, the philosopher Aristotle, found that the theory of Eudoxus fit nicely with his overall philosophy of nature, and he transformed it into a physical theory. Aristotle saw nature as dynamic, powerful, and teleological. Each object in nature tended toward a certain set of ends or goals, and nature as a whole tended toward a goal that was the result of the motion of the individual objects. What this meant was that each of the four inanimate elements—earth, water, air, and fire—had a natural place or equilibrium position in the universe, a place where it belonged. If nature were left alone Aristotle felt each element would move "naturally" to its proper place and nature as a whole would achieve an ideal structure.

Using this understanding of natural place and natural motion, Aristotle built a picture of the universe as a whole. Since for him there was no such thing as empty space, every object had to be surrounded by some medium. By observation it could be seen that heavy objects move naturally toward the surface of the earth and light objects move away from the earth's surface; for example, a rock falls in air, and air bubbles rise to the surface of water. More precisely, these motions appeared to be along lines perpendicular to the surface of the earth.

Now the ancient Greeks had become convinced through observations of lunar eclipses and measurements of shadows cast by sticks in the ground at various locations that the earth as a body was a sphere. Thus, the downward motions of heavy objects were directed toward the center of the earth, while the upward motions of light objects were directed away from the center of the earth. Further, since the earth as a body was made of the heaviest element—earth—its natural place would be in the center of the natural world. The center of the earth was literally, then, the center of the universe and the reference point for all motions.

The other three elements, water, air, and fire, arranged themselves accordingly in the vicinity of the spherical earth and below the moon. In this sublunar region of the universe, natural objects could undergo radical (substantial) changes. But such changes did not appear to take place in the heavens. In fact, the only change that did take place in the heavens was change of place—the heavens seemed to move in circles about the earth. Because substantial changes did not take place in the heavens and because their motion was circular, Aristotle decided that the heavens were more perfect than the sublunar region and were made of a fifth element called the ether. Since the heavens were more perfect it was fitting that they would have the most perfect motion, namely, uniform circular motion.

The marriage between Aristotle's philosophy of nature and the model of the universe of Eudoxus can now be seen. The shells of Eudoxus became hollow transparent spheres that carried the sun, moon, and five planets around the earth. Aristotle used fifty-five crystalline shells in all. Rather, Aristotle needed these additions because his model was, in effect, an interconnected quasi-mechanical system. He used a set of counteracting spheres in order to offset the one-way effects of the outer spherical shell motions upon the movements of inner shells and the planetary bodies they carried. The outermost sphere in this system, called the celestial sphere, carried all the stars and enclosed a finite universe.

In the eternal universe of Aristotle, the earth was perfectly at rest. If it ever had any translational motion, it would have eventually come to rest in the center, its natural place. Further, it could not be spinning on an axis because circular motion was only appropriate for the more perfect heavens, not for the imperfect entities of the sublunar region. The sun, the moon, and the planets all maintained the same distance from the earth at all times. Because the stars were all attached to the celestial sphere they maintained the same distance from the earth and the same relationship to one another at all times.

Early Theories of a Moving Earth

Despite the fact that a stationary earth theory is consistent with ordinary experience, there were some contemporaries of Aristotle who were willing to speculate that the earth might in reality be moving. Heraclides of Pontus (388 B.C.–315 B.C.) suggested that the daily motion of the stars could be accounted for equally well by the rotation of the earth on an axis. He maintained that the rotation of the earth would be far less *violent*, an Aristotelian technical term for unnatural motion, than any rotation of the much larger celestial sphere carrying the stars. Heraclides also thought that the motions of the so-called lesser planets, Mercury and Venus, could be better explained if they revolved around the sun rather than the earth.

The first complete heliocentric theory came from Aristarchus of Samos (310 B.C.–250 B.C.), who is known as the Copernicus of antiquity. In addition to its rotational motion, Aristarchus suggested that the earth itself was also a planet that moved in a circular orbit about the sun. In fact, he placed the sun at the center of the celestial sphere, which in turn he thought to be at rest.

The heliocentric theory devised by Aristarchus attempted to deal with two continuing problems whose solution had still not been adequately resolved by the existing geocentric theory. These problems were

1. *Retrograde motion of the planets*. Some planets in their eastward movement through the stars can be perceived to slow down, come to a standstill, reverse direction, and eventually begin to move again in their original direction.
2. *Variations in planetary brightness during the year*.

Critical problems, however, also beset the heliocentric theory of Aristarchus. One such problem was the failure to observe variation in stellar brightness. If the earth actually orbited the sun, then the stars should appear to vary in brightness, since they would no longer be equidistant from the earth. Further, if the earth moved among the fixed stars, the angular separation of stars should vary. However, this phenomenon, called stellar parallax, was not observed. To explain the absence of stellar parallax within the framework of heliocentrism would require the hypothesis that the earth's orbit be insignificantly small relative to the distances of the stars. This was a move the ancients were unwilling to make, especially because the heliocentric theory was at odds with our common experience of motion. If the heliocentric theory is correct, the earth and its inhabitants would have to be spinning like a top and hurtling through space at incredible rates of speed. Yet there is no experience of these motions. A reasonable person in ancient Greece, looking at all the evidence, would have to side with geocentrism.

The Geocentrism of Claudius Ptolemy

The geocentric theory achieved its greatest expression in the publication of Claudius Ptolemy's *Almagest*. This book, which was written in Alexandria, Egypt, in about A.D. 150, is the greatest surviving astronomical work bequeathed to us from antiquity. Ptolemy, however, did not simply inherit Aristotle's version of the geocentric theory. In the interim, other important contributions were made with regard to geocentric theory and method. Two individuals worthy of note in preparing the way for Ptolemaic astronomy were Apollonius of Perga, who lived in the latter half of the third century B.C., and Hipparchus of Nicea (second century B.C.), whom many scholars of astronomy rank as the greatest astronomer of antiquity.

Apollonius is credited with being the Greek mathematician who made the greatest contribution to the study of the conic sections; namely, the figures of the ellipse, parabola, and hyperbola. He is also credited with having invented the mathematical constructs called epicycles and deferents that became important parts of the Ptolemaic and post-Ptolemaic descriptive framework of geocentric, as well as Copernican heliocentric, cosmology. Without getting into the philosophical debate about actual ontological commitments, one can safely say that Apollonius not only contributed important aspects of the mathematical apparatus of ensuing geocentric theory, but did so in such a way as to bracket the issue of the physical existence of spherical shells.

Hipparchus made extraordinary contributions to astronomical methodology as well as to theoretical astronomy. He is credited with having invented or at least developed trigonometry into an important tool for numerically calculating the relationships that exist between and among the geometrical figures used to represent celestial motions. He also made extensive use of the Apollonian epicycles and deferents, and of eccentric circles, setting the stage for Ptolemy. His great contributions to lunar and solar astronomy enabled him to contribute to our understanding of the precession of the equinoxes, a phenomenon in which the sun, in its journey around the celestial plane known as the ecliptic, returns to a particular point on the ecliptic in advance of where it is expected to be relative to the background of the stars.

The completion of the mathematization of astronomy fell to Ptolemy in the second century A.D. For Ptolemy, astronomy was a mathematical exercise designed to "save the phenomena," to account for the observations of the activities of the heavenly bodies by use of mathematical hypotheses concerning their motions. This he accomplished with great success in the *Almagest*, in which Ptolemy rejected the heliocentrism of Aristarchus because stellar parallax was not observable and because the stars did not vary in brightness. He affirmed the Aristotelian arguments that the earth is completely at rest and in the center of the universe. Computationally it was possible for the earth to occupy other positions in the universe, but Ptolemy concluded that if the earth was not in the center of the universe, then the "order of things" would be "fundamentally upset." Although he agreed with Aristotle and Plato that the heavens move spherically, he eliminated all the hollow transparent spheres, but not the celestial sphere. He considered the sun, moon, and five planets to be independent bodies, while he kept the stars attached to the celestial sphere that enclosed the universe.

To account for solar, lunar, and planetary motions Ptolemy used the following mathematical devices:

1. Eccentric Circles.
   No celestial bodies move with simple uniform circular motions. Both the sun and the moon appear to speed up and slow down, while the planets at times appear to move in opposing directions. Eccentric circles are circular paths of motion that are meant to be observed from some internal point displaced from the circle's center. This allows for better approximations of celestial motions, as celestial objects, such as the sun, appear to move faster and slower, toward perigee and apogee, while supposedly orbiting uniformly around the circumference of the circle.
2. Epicycle/Deferent System.
   This system is far more powerful than that of eccentrics, although Apolloinus had already shown them to be geometrically equivalent, with the latter being a special case of the former. In this system a celestial body revolves uniformly around a smaller circle called an epicycle, the center of which itself revolves uniformly around a larger circle called a deferent. The observer is then situated at the center of the deferent circle. Ptolemy considered the epicycle/deferent system to be more powerful than eccentric circles since they possess a greater degree of freedom for representing observed motions. Epicycles were found to explain variations in brightness much better than eccentrics. Epicyclic movement consisted of a kind of looping motion that enabled Ptolemy to explain the retrograde motions of the outer planets.

3. Equant Point.
   Ptolemy introduced the device known as the equant, a point displaced from the center of a deferent circle. The earth is positioned equidistant from this center, but on the opposite side from the equant. With the help of the equant, Ptolemy was able to work out the motions of the planets. Copernicus would later eliminate the equant from his astronomical repertoire of mathematical techniques because he thought it to be in violation of the Platonic ideal to preserve uniform circular motion. Relative to the equant Ptolemy could conserve uniform angular motion, in that a revolving body would sweep out equal areas around the equant in equal times. As a result, however, observation from the perspective of the earth would no longer be uniform. It can accurately be said that the equant point, in allowing for greater mathematical manipulation of epicyclic movement, contributed to Ptolemy's view that the epicycle/deferent system was superior to the eccentric.

Using these mathematical devices, Ptolemy was able to produce the first comprehensive and systematic quantitative account of celestial motions. Ptolemy's astronomical ambitions included not only accounting for past and present celestial motions, but also predicting future celestial and planetary motions as well. As new and more precise data became available, Ptolemy's eccentrics, equants, and epicycles would be adjusted to fit that data if necessary. All in all, the theory of Ptolemy became quite accurate and extremely useful (e.g., it could be used as a basis for keeping track of time). If Ptolemaic geocentric theory was to be dethroned and replaced by another theory, it would have to be for powerful and practical reasons. For in addition to its entrenchment and pedigree within the scientific community, the Ptolemaic-Aristotelian cosmological model had been embraced as a theory of the heavens by Christianity.

The Copernican Heliocentrism: A Revolution in Astronomy and Physics

Between the time of Ptolemy and Copernicus, astronomy underwent more than a millennium of normal geocentric activity in which the principles of the theory went relatively unquestioned, and in which most of the research and investigative work was aimed at applying the theory and not undermining it. There were some minor rumblings about geocentrism during this time, most notably from Nicholas Oresme in the fourteenth century and Nicholas of Cusa in the fifteenth. However, neither man rejected geocentrism. But Oresme's views at least can be characterized as a definite stepping stone on the conceptual path to heliocentrism. He argued in his *Le Livre du ciel et du monde* that observed astronomical phenomena can be explained in a computationally equivalent manner by the assumption of a rotating earth or by the rotation of the heavens about the earth. He further argued that it would not be possible by reason or experience to confirm either hypothesis. Concerning the argument that only a motionless earth squared with Aristotelian physics, Oresme pointed out that such physical reasoning was based upon a theory of motion that had never been confirmed.

Despite his concerns, Oresme never really considered committing himself to the reality of a rotating earth. By the turn of the sixteenth century, geocentrism was as entrenched as a scientific paradigm could possibly be. However, it was also at this time that the first difficulties with Ptolemy's astronomy began to appear. For example, predictions of planetary locations were becoming noticeably inaccurate.

Early in the sixteenth century a Polish clergyman name Nicholaus Copernicus set out to revise the existing astronomical tables and remove the inaccuracies therein. He was a realist who believed that if he could hit upon "the one true form of the heavens," he could bring perfect accuracy to astronomy. But Copernicus quickly realized that the problems with Ptolemy's astronomy involved much more than the sizes and speeds of epicycles. To him, Ptolemy's astronomy seemed to be internally inconsistent and incoherent. In his efforts to "save the phenomena," Ptolemy had sometimes used incompatible hypotheses for the same heavenly body to account for different sets of data. In addition, his system showed a strange kind of incoherence in the orbital times of the heavenly bodies. The moon, which was closest to the earth, completed its orbit in four weeks, while the sun, which was farther away, took only one day. Jupiter, one of the outer planets, spent 300 years completing its trips around the earth, while the celestial sphere, the farthest body from the earth, completed its revolution in just one day.

As a realist, Copernicus felt that the elimination of these internal problems would lead to a greater precision and accuracy in astronomy. Placing the sun in the center of the universe and giving the earth two motions, a rotation on an axis and an orbit about the sun, he found that he could account for all the data associated with each heavenly body without resorting to inconsistent hypotheses. Further, he found that, with the sun as the central reference point, the orbital speeds of the planets varied inversely with their distance from the sun, and that the apparent retrograde motion of the outer planets was due to these variations in orbital speeds. He was even able to eliminate the awkward equant points and return astronomy to the "strict" use of uniform circular motion. Certainly Copernicus's system had an internal coherence that Ptolemy's system did not. But he still had to use a complex array of cycles and epicycles, and so his theory retained an air of artificiality.

Despite his success in bringing coherence and consistency to astronomy, Copernicus was not able to shed new light on the problems that plagued a moving earth theory. To explain why we do not experience any dynamical effects due to the motion of the earth, he suggested that the atmosphere and everything in it participates in these motions, but he did not tell us why this happened. The earth does not disintegrate as it rotates for the same reason that the celestial sphere did not disintegrate in the old view, whatever that reason was. Stellar parallax was not observed, he said, because of the immense size of the universe, ignoring the attendant problems with this view. But the biggest problem for Copernicus and his moving earth theory was this: in the end his astronomical system was not significantly simpler nor more accurate than the revised Ptolemaic view of his time. Since he had set the accuracy of prediction as the crucial test for his theory, Copernicus realized that he did not have a strong enough argument to get the approval of the scientific community.

Copernicus developed his heliocentric theory between 1510 and 1514. During that time he prepared his *Commentariolus*, or First Commentary, which contained his basic assumptions and arguments. Although Copernicus circulated the *Commentariolus* among some of his friends and students, he refrained from publishing it primarily because its basic hypothesis was at odds with Christian theology. During the next twenty years, Copernicus prepared his definitive work, *De Revolutionibus Orbium Caelestium*. In 1540, an enthusiastic disciple Georg Joachim Rheticus, published a brief technical description of Copernicus's heliocentric system called *Narratio Prima*, which set the stage for the publication of *De Revolutionibus* in 1543. When it was finally published, it was accompanied by an unsigned preface written by a friend of Copernicus named Andreas Osiander. In the preface Osiander sought to deflect any potential criticisms from Aristotelians and theologians by suggesting that the heliocentric theory was not necessarily true but was of considerable instrumental value; it provided, for example, a correct basis for calculation and was "more convenient" to use. Once published, the *De Revolutionibus* did not cause much of a stir in either religious or scientific circles.

Brahe and Kepler

Copernicus died believing that the moving earth hypothesis was correct. But he had not convinced the scientific community. It took the next hundred years and the work of four exceptional scientists to tip the argument in his favor.

Tycho Brahe was a first-rate astronomer of the late sixteenth century who continually made systematic and sophisticated observations and measurements of the heavens over long periods of time. From his observations he was able to conclude that if the earth moved in orbit about the sun, as Copernicus suggested, it would travel approximately 200 million miles in a year. Brahe could not understand why, if the earth traveled so far, that stellar parallax would not be observed. In the end he offered a hybrid theory in which the other planets (Mercury, Venus, Mars, Jupiter, and Saturn) all orbited the sun while the sun orbited the stationary earth. The celestial sphere was retained to carry the stars around the earth.

Although he could not accept the Copernican hypothesis, Brahe did make two extraordinary observations that began the process that led to the ultimate rejection of the Aristotelian-Ptolemaic universe. In 1572 he observed a bright new star that remained visible even during the day for a brief period of time. We now know that star to have been a supernova. What these phenomena showed clearly was that changes did occur in the heavens, even radical changes. The heavens were not the immutable region that Aristotle had envisioned.

In 1577 Brahe began careful calculations of the motions of comets. After three years of study he was able to prove that the comets moved well into the heavens beyond the orbits of the moon and several of the planets. This was further evidence that the hollow transparent spheres of Aristotle did not exist.

But perhaps the greatest contribution of Brahe to astronomy was the great fund of information about the heavens that he passed on to his research assistant Johannes Kepler. Unlike his teacher, Kepler was a convinced Copernican. Upon studying the planetary records within the perspective of a moving earth theory, Kepler confirmed that the farther the planets were from the sun the more slowly they moved in orbit. His conclusion was that some force or power in the sun was moving the planets and that this force or power diminished with distance. For the first time the sun was seen as a controlling factor in the planetary motions.

Kepler's originality and insight did not end there. Given the records of the motion of the planet Mars by Brahe for analysis, Kepler sought and found a single simple shape for the planet's orbit. This shape turned out to be an ellipse with the sun located at one of its focal points. If this were the actual motion of the planet Mars, then its velocity would have to vary in orbit. Kepler found that the speed of the planet Mars varied in proportion to its distance from the sun just as the speed of the different planets had varied in proportion to their distances. Kepler published these results in 1609 in a book called *Astronomia Nova*. The book contained his first two laws of planetary motions.

1. Each planet describes an elliptical orbit with the sun at one of the focal points of the ellipse.
2. The radius vector (line joining the sun and the planet) sweeps out equal areas in equal times. This is the distance-velocity law.

Ten years later Kepler added a third law of planetary motion: T^2 is proportional to $\bar{R}^3$, where T is the time it takes for the planet to complete its orbit about the sun and $\bar{R}$ is the mean distance of the planet from the sun.

With these laws Kepler had placed heliocentrism in its final form. The sun was indeed central but not in the exact center of every planetary orbit. All the planets, including the earth, moved in orbits about the sun that were elliptical rather than circular. As accurate as this picture turned out to be, however, it was still far from achieving final acceptance.

Galileo and Newton

In the end it took two additional developments to guarantee heliocentrism a permanent place in the scientific world picture. The first development was the invention of the telescope in 1610. An Italian astronomer, Galileo, became aware that such an instrument had been produced in Holland and decided to build one himself to explore the heavens. With his telescope he observed mountains and valleys on the moon suggesting that the heavens were not unlike the earth. He observed the appearance and disappearance of dark spots on the sun, confirming that the heavens can undergo significant changes like earthly objects. These observations were enough to cause the rejection of the Aristotelian cosmology of a perfect heaven once and for all.

But that was just the beginning. Galileo also observed the phases of the planet Venus, which could only be explained if Venus was in orbit about the sun. He discovered four satellites or moons of the planet Jupiter and found that they were in orbit about that planet with velocities that varied with their distance. This showed that the earth was certainly not the center of all orbits, and by analogy it supported the heliocentric argument of Copernicus. Finally, Galileo's discovery of new stars indicated that stars were independent bodies at various distances from the earth. The celestial sphere was gone forever. This meant that the universe had no spatial boundary. Theoretically the universe was now considered to be infinitely large.

Based upon his telescopic discoveries, Galileo became a convinced Copernican and so sought to argue that case to the scientific community. In 1632 he published his *Dialogue on the Two Chief World Systems*, in which he gave a thorough critique of geocentrism from which it never recovered. He then went on to enrich the Copernican argument with his telescopic observations and his own analysis.

With the work of Galileo there was no doubt that Heliocentric Theory held the dominant position in astronomy. What was lacking was a physical theory to explain its main features. That theory was invented by Isaac Newton between 1666 and 1687. In those years Newton developed the first great science, the science of mechanics, which was published in 1687 with the title *The Mathematical Principles of Natural Philosophy*. In his science Newton sought to explain the motions of all material objects in the universe. He started by distinguishing natural states, which could maintain themselves, from coerced states, which required an outside force. Using absolute space as a theoretical reference frame, Newton held that rest and uniform rectilinear motion were natural states that could maintain themselves. Changes in those states, called accelerations, required an unbalanced force.

Unlike Aristotle, who saw circular motion as a natural state for the heavens, Newton saw the somewhat circular orbital motions of the planets as involving a constant acceleration directed toward the center of the orbits, the sun. Since he rejected any distinction between terrestrial and celestial mechanics, Newton felt that the force causing objects to fall in the vicinity of the earth was of the same nature as the force causing the planets to constantly change their direction of motion. This force, which he called gravity, was mathematically formalized in his Law of Universal Gravitation. According to the law, material objects appear to exert an attractive force upon one another that varies proportionally to the product of their masses and inversely with the distance between them squared. Newton was then able to show that his law of gravity, along with his three laws of motion, could explain Kepler's three laws of planetary motion. Thus the reason why the velocity of a planet in orbit varies inversely with its distance from the sun is because the attractive force of gravity between the sun and the planet diminishes with the distance. Heliocentrism now had a physical theory to explain its features.

The Final Word

In the end it was not the discovery of stellar parallax, or the development of a satisfactory explanation for why we have no experience of the double motion of the earth, that led to the complete acceptance of heliocentrism. Rather it was the fact that heliocentrism was consistent with the great new science of mechanics, while geocentrism was not, that ended the competition once and for all. When stellar parallax was finally observed in 1838 by the German astronomer Friedrich Bessel, it was anticlimactic. By then Heliocentric Theory had become a permanent part of the scientific landscape.

1
— Aristotle —
(384–322 B.C.)

Aristotle, a Greek philosopher born in Stagira, in northern Greece, was the son of the court physician to the King of Macedon. While known primarily for his contributions to Western philosophy, Aristotle was also a brilliant naturalist and marine biologist who devoted a great deal of time and effort to the study of the natural world. Aristotle's physical works include the Physics, On the Heavens, On Coming-to-be and Passing-Away, *and the* Meteorology.

His influence on premodern natural science is immeasurable, most notably in the area of astronomy and cosmology. The universe that Aristotle depicts for us is one that is finite, hierarchically and purposefully ordered, in which every thing has its proper place. Most significantly, Aristotle maintains the natural place of the earth to be at the center, hence the geocentric universe. According to Aristotle, the earth remains stationary, while the other celestial bodies rotate around it in concentric circles. These heavenly spheres are made of the incorruptible ether.

Motion is at the heart of Aristotelian physics; according to Aristotle, all motion is caused. This applies no less to the universe as a whole, including the celestial bodies, than it does to the individual object. To avoid an infinite regress of cause of motion, Aristotle postulates the notion of an Unmoved Mover, the discussion of which is found primarily in the Physics *and the* Metaphysics. *This Unmoved*

Mover is of primary importance in the movement of the heavens in that it is the source of (inspiration for) eternal and regular motion of the celestial sphere.

In this reading Aristotle provides the physical foundations for the geocentric theory, including a discussion of the nature of motion, the circular motion of the heavenly bodies, and the natural position of the earth at rest and in the center of the universe. He also discusses the opposing theory of the Pythagoreans that the earth is in motion around a more precious fire. The reading comes from Aristotle's On the Heavens.

THE PHYSICAL FOUNDATION FOR THE GEOCENTRIC UNIVERSE

The question as to the nature of the whole, whether it is infinite in size or limited in its total mass, is a matter for subsequent inquiry. We will now speak of those parts of the whole which are specifically distinct. Let us take this as our starting-point. All natural bodies and magnitudes we hold to be, as such, capable of locomotion; for nature, we say, is their principle of movement. But all movement that is in place, all locomotion, as we term it, is either straight or circular or a combination of these two which are the only simple movements. And the reason is that these two, the straight and the circular line, are the only simple magnitudes. Now revolution about the centre is circular motion, while the upward and downward movements are in a straight line, "upward" meaning motion away from the centre, and "downward" motion towards it. All simple motion, then, must be motion either away from or towards or about the centre. This seems to be in exact accord with what we said above: as body found its completion in three dimensions, so its movement completes itself in three forms.

Bodies are either simple or compounded of such; and by simple bodies I mean those which possess a principle of movement in their own nature, such as fire and earth with their kinds, and whatever is akin to them. Necessarily, then, movements also will be either simple or in some sort compound—simple in the case of the simple bodies, compound in that of the composite—and the motion is according to the prevailing element. Supposing, then, that there is such a thing as simple movement, and that circular movement is simple, and that both movement of a simple body is simple and simple movement is of a simple body (for if it is movement of a compound it will be in virtue of a prevailing element), then there must necessarily be some simple body which moves naturally and in virtue of its own nature with a circular movement. By constraint, of course, it may be brought to move with the motion of something else different from itself, but it cannot so move naturally, since there is one sort of movement natural to each of the simple bodies. Again, if the unnatural movement is the contrary of the natural and a thing can have no more than one contrary, it will follow that circular movement, being a simple motion, must be unnatural, if it is not natural, to the body moved. If then the body whose movement is circular is fire or some other element, its natural motion must be the contrary of the circular motion. But a single thing has a single contrary; and upward and downward motion are the contraries of one another. If, on the other hand, the body moving with this circular motion which is unnatural to it is something different from the elements, there will be some other motion which is natural to it. But this cannot be. For if the natural motion is upward, it will be fire or air, and if downward, water or earth. Further, this circular motion is necessarily primary. For the complete is naturally prior to the incomplete, and the circle is a complete thing. This cannot be said of any straight line:—not of an infinite line; for then it would have a limit and an end: nor of any finite line; for in every case there is something beyond it, since any finite line can be extended. And so, since the prior movement belongs to the body which is naturally prior, and circular movement is prior to straight, and movement in a straight line belongs to simple bodies—fire moving straight upward and earthy bodies straight downward towards the centre—since this is so, it follows that circular movement also must be the movement of some simple body. For the movement of composite bodies is, as we said, determined by that simple body which prevails in the composition. From this it is clear that there is in nature some bodily substance other than the formations we know, prior to them all and more divine than they. Or again, we may take it that all movement is either natural or unnatural, and that the movement which is unnatural to one body is natural to another, as for instance is the case with the upward and downward movements, which are natural and unnatural to fire and earth respectively. It necessarily follows that circular movement, being unnatural to these bodies, is the natural movement of some other. Further, if, on the one hand, circular movement is *natural* to something, it must surely be some simple and primary body which naturally moves with a natural circular motion, as fire moves up and earth down. If, on the other hand, the movement of the rotating bodies about the centre is *unnatural*, it would be remarkable and indeed quite inconceivable that this movement alone should be continuous and eternal, given that it is unnatural. At any rate the evidence of all other cases goes to show that it is the unnatural which quickest passes away. And so, if, as some say, the body so moved is fire, this movement is just as unnatural to it as downward movement; for any one can see that fire moves in a straight line away from the centre. On all these grounds, therefore, we may infer with confidence that there is something beyond the bodies that are about us on this earth, different and separate from them; and that the superior glory of its nature is proportionate to its distance from this world of ours. . . .

Since circular motion is not the contrary of the reverse circular motion, we must consider why there is more than one motion, though we have to pursue our inquiries at a distance—a distance created not so much by our spatial position as by the fact that our senses enable us to perceive very few of the attributes of the heavenly bodies. But let not that deter us. The reason must be sought in the following facts. Everything which has a function exists for its function. The activity of God is immortality, i.e., eternal life. Therefore the movement of God must be eternal. But such is the heaven, viz. a divine body, and for that reason too it is given the circular body whose nature it is to move always in a circle. Why, then, is not the whole body of the heaven of the same character as that part? Because there must be something at rest at the centre of the revolving body; and of that body no part can be at rest, either elsewhere or at the centre. It could do so only if the body's natural movement were towards the centre. But the circular movement is natural, since otherwise it could not be eternal; for nothing unnatural is eternal. The unnatural is subsequent to the natural, being a derangement of the natural which occurs in the course of its generation. Earth then has to exist; for it is earth which is at rest at the centre. (At present we may take this for granted: it will be explained later.) But if earth must exist, so must fire. For, if one of a pair of contraries naturally exists, the other, if it is really contrary, exists also naturally, and has a nature of its own (for the matter of contraries is the same). Also, the positive is prior to its privation (warm, for instance, to cold), and rest and heaviness stand for the privation of lightness and movement. But further, if fire and earth exist, the intermediate bodies must exist also; for each element stands in a contrary relation to every other. (This, again, we will here take for granted and try later to explain.) With these four elements generation clearly is involved, since none of them can be eternal; for contraries interact with one another and destroy one another. Further, it is unreasonable that a movable body should be eternal, if its movement cannot be naturally eternal: and these bodies possess movement. Thus we see that generation is necessarily involved. But if so, there must be at least one other motion; for a single movement of the whole heaven would necessitate an identical relation of the elements of bodies to one another. This matter also will be cleared up in what follows; but for the present so much is clear, that the reason why there is more than one circular body is the necessity of generation, which follows on the presence of fire, which, with that of the other bodies, follows on that of earth; and earth is required because eternal movement in one body necessitates eternal rest in another.

The shape of the heaven is of necessity spherical; for that is the shape most appropriate to its substance and also by nature primary.

First, let us consider generally which shape is primary among planes and solids alike. Every plane figure must be either rectilinear or curvilinear. Now the rectilinear is bounded by more than one line, the curvilinear by one only. But since in any kind the one is naturally prior to the many and the simple to the complex, the circle will be the first of plane figures. Again, if by complete, as previously defined, we mean a thing outside which nothing can be found, and if addition is always possible to the straight line but never to the circular, clearly the line which embraces the circle is complete. If then the complete is prior to the incomplete, it follows on this ground also that the circle is primary among figures. And the sphere holds the same position among solids. For it alone is embraced by a single surface, while rectilinear solids have several. The sphere is among solids what the circle is among plane figures. Further, those who divide bodies into planes and generate them out of planes seem to bear witness to the truth of this. Alone among solids they leave the sphere undivided, as not possessing more than one surface; for the division into surfaces is not just dividing a whole by cutting into its parts, but division into parts different in form. It is clear, then, that the sphere is first of solid figures.

If again, one orders figures according to their numbers, it is most reasonable to arrange them in this way. The circle corresponds to the number one, the triangle, being the sum of two right angles, to the number two. But if one is assigned to the triangle, the circle will not be a figure at all.

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 then will be true of the body continuous with it; for that which is continuous with the spherical is 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 lower bodies 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.

Again, since the whole seems—and has been assumed—to revolve 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. For if it is to be rectilinear in shape, it will follow that there is place and body and void without it. For a rectilinear figure as it revolves never continues in the same room, but where formerly was body, is now none, and where now is none, body will be in a moment because of the changing position of the corners. Similarly, if the world had some other figure with unequal radii, if, for instance, it were lentiform, or oviform, in every case we should have to admit space and void outside the moving body, because the whole body would not always occupy the same room.

Again, if the motion of the heaven is the measure of all movements 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 the movement of the heaven must be the swiftest of all movements. Now of lines which return upon themselves the line which bounds the circle is the shortest; and that movement is the swiftest which follows the shortest line. Therefore, if the heaven moves in a circle and moves more swiftly than anything else, it must necessarily be spherical.

Corroborative evidence may be drawn from the bodies whose position is about the centre. If earth is enclosed by water, water by air, air by fire, and these similarly by the upper bodies—which while not continuous are yet contiguous with them—and if the surface of water is spherical, and that which is continuous with or embraces the spherical must itself be spherical, then on these grounds also it is clear that the heavens are spherical. But the surface of water is seen to be spherical if we take as our starting-point the fact that water naturally tends to collect in the more hollow places—and the more hollow are those nearer the centre. Draw from the centre the lines *AB, AC*, and let them be joined by the straight line *BC*. The line *AD*, drawn to the base of the triangle, will be shorter than either of the radii. Therefore the place in which it terminates will be more hollow. The water then will collect there until equality is established. But the line *AE* is equal to the radii. Thus water lies at the ends of the radii, and there will it rest; but the line which connects the extremities of the radii is circular: therefore the surface of the water *BEC* is spherical.

It is plain from the foregoing that the universe is spherical. It is plain further, that it is so accurately turned that no manufactured thing nor anything else within the range of our observation can even approach it. 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; since with each step away from earth the matter manifestly becomes finer in the same proportion as water is finer than earth.

Now there are two ways of moving along a circle, from *A* to *B* or from *A* to *C,* and we have already explained that these movements are not contrary to one another. But nothing which concerns the eternal can be a matter of chance or spontaneity, and the heaven and its circular motion are eternal. We must therefore ask why this motion takes one direction and not the other. Either this is itself a principle or there is a principle behind it. It may seem evidence of excessive folly or excessive zeal to try to provide an explanation of some things, or of everything, admitting no exception. The criticism, however, is not always just: one should first consider what reason there is for speaking, and also what kind of certainty is looked for, whether human merely or of a more cogent kind. When any one shall succeed in finding proofs of greater precision, gratitude will be due to him for the discovery, but at present we must be content with what seems to be the case. If nature always follows the best course possible, and, just as upward movement is the superior form of rectilinear movement, since the upper region is more divine than the lower, so forward movement is superior to backward, then front and back exhibits, like right and left, as we said before and as the difficulty just stated itself suggests, the distinction of prior and posterior, which provides a reason and so solves our difficulty. Supposing that nature is ordered in the best way possible, this may stand as reason of the fact mentioned. For it is best to move with a movement simple and unceasing, and, further, in the superior of two possible directions.

We have next to show that the movement of the heaven is regular and not irregular. This applies to the first heaven and the first movement; for the lower spheres exhibit a composition of several movements into one. If the movement is uneven, clearly there will be acceleration, maximum speed, and retardation, since these appear in all irregular motions. The maximum may occur either at the starting-point or at the goal or between the two; and we expect natural motion to reach its maximum at the goal, unnatural motion at the starting-point, and missiles midway between the two. But circular movement, having no beginning or limit or middle without qualification, has neither whence nor whither nor middle; for in time it is eternal, and in length it returns upon itself without a break. If then its movement has no maximum, it can have no irregularity, since irregularity is produced by retardation and acceleration. 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 in both. For if the mover moved not always with the same force, or if the moved were altered and did not remain the same, or if both were to change, the result might well be an irregular movement in the moved. But none of these possibilities can occur in the case of the heavens. As to that which is moved, we have shown that it is primary and simple and ungenerated and indestructible and generally unchanging; and it is far more reasonable to ascribe those attributes to the mover. It is the primary that moves the primary, the simple the simple, the indestructible and ungenerated that which is indestructible and ungenerated. Since then that which is moved, being a body, is nevertheless unchanging, how should the mover, which is incorporeal, be changed?

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. 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. Nor again is a change in the movement as a whole admissible. Retardation is always due to incapacity, and incapacity is unnatural. The incapacities of animals, age, decay, and the like, are all unnatural, due, it seems, to the fact that the whole animal complex is made up of materials which differ in respect of their proper places, and no single part occupies its own place. If therefore that which is primary contains nothing unnatural, being simple and unmixed and in its proper place and having no contrary, then it has no place for incapacity, nor, consequently, for retardation or (since acceleration involves retardation) for acceleration. Again, it is unreasonable that the mover should first show incapacity for an infinite time, and capacity afterwards for another infinity. For clearly nothing which, like incapacity, is unnatural ever continues for an infinity of time; nor does the unnatural endure as long as the natural, or any form of incapacity as long as the capacity. But if the movement is retarded it must necessarily be retarded for an infinite time. Equally impossible is perpetual acceleration or perpetual retardation. For such movement would be infinite and indefinite; but every movement, in our view, proceeds from one point to another and is definite in character. Again, suppose one assumes a minimum time in less than which the heaven could not complete its movement. For, as a given walk or a given exercise on the harp cannot take any and every time, but every performance has its definite minimum time which is unsurpassable, so, one might suppose, the movement of the heaven could not be completed in any and every time. But in that case perpetual acceleration is impossible (and, equally, perpetual retardation; for the argument holds of both and each), if we may take acceleration to proceed by identical or increasing additions of speed and for an infinite time. The remaining possibility is to say that the movement exhibits an alternation of slower and faster; but this is a mere fiction and quite unreasonable.

Further, irregularity of this kind would be particularly unlikely to pass unobserved, since contrast makes observation easy.

That there is one heaven, then, only, and that it is ungenerated and eternal, and further that its movement is regular, has now been sufficiently explained.

We have next to speak of the stars, as they are called, of their composition, shape, and movements. It would be most reasonable and consequent upon what has been said that each of the stars should be composed of that substance in which their path lies, since as we said, there is an element whose natural movement is circular. In so saying we are only following the same line of thought as those who say that the stars are fiery 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. Movement tends to create one in wood, stone, and iron; and with even more reason should it have that effect on air, a substance which is closer to fire than these. An example is that of missiles, which as they move are themselves fired so strongly that leaden balls are melted and if they are fired the surrounding air must be similarly affected. Now while the missiles are heated by reason of their motion in air, which is turned into fire by the agitation produced by their movement, 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. Hence warmth increases as the sun gets nearer or higher or overhead. Of the fact, then, that the stars are neither fiery nor move in fire, enough has been said.

Since changes evidently occur not only in the position of stars but also in that of the whole heaven, there are three possibilities: either both are at rest, or both are in motion, or the one is at rest and the other in motion.

That both should be at rest is impossible; for, if the earth is at rest, the hypothesis does not account for the phenomena; 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.

On the view, first, that both are in motion, we have the absurdity that the stars and the circles move with the same speed, i.e., that the pace of every star is that of the circle in which 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 reversed 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 unreasonable 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 unreasonable. For if the star which moves on the greater circle is necessarily swifter, clearly if the 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 unreasonable. In one of two cases it might not inconceivably fall out so, but to imagine it in every case alike is a mere fiction. Besides, chance has no place in that which is natural, and what happens everywhere and in every case is no matter of chance.

The same absurdity 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 circles.

Since, then, we cannot reasonably suppose either that both are in motion or that the star alone moves, it remains 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. For, in the first place, the quicker movement of the larger circle is reasonable 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 reasonable 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.

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, it follows that if the stars have a movement of their own, it will be one of these. But neither is observed. 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, it would be reasonable for 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.

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.

There is, further, the absurdity that nature has bestowed upon them no organ appropriate to such movement. For nature leaves nothing to chance, and would not, while caring for animals, overlook things so precious. Indeed, nature seems deliberately to have stripped them of everything which makes self-originated progression possible, and to have removed them as far as possible from things which have organs of movement. This is just why it seems reasonable 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 reasonable that both should be spherical—a shape which best suits the movement of the one and the immobility of the other. . . .

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.

As to its *position* there is some difference of opinion. Most people—all, 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 counter-earth. 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. 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 which occupies that place, the "Guardhouse of Zeus," 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. But it is better to conceive of the case of the whole heaven as analogous to that of animals, in which the centre of the animal and that of the body are different. For this reason they have no need to be so disturbed about the world, or to call in a guard for its centre: rather let them look for the centre in the other sense and tell us what it is like and where nature has set it. That centre will be something primary and precious; but to the mere position we should give the last place rather than the first. For the middle is what is defined, and what defines it is the limit, and that which contains or limits is more precious than that which is limited, seeing that the latter is the matter and the former the essence of the system.

As to the position of the earth, then, this is the view which some advance, 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 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. 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*.

There are similar disputes about the *shape* of the earth. Some think it is spherical, others that it is flat and drum-shaped. 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 difficulty must have occurred 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, and the more there is of it the faster it moves, the whole earth, free in mid-air, should show no movement at all. Yet here is this great weight of earth, and it is at rest. And again, from beneath one of these moving fragments of earth, before it falls, take away the earth, and it will continue its downward movement with nothing to stop it. The difficulty then, has naturally passed into a commonplace of philosophy; and one may well wonder that the solutions offered are not seen to involve greater absurdities than the problem itself.

By these considerations some, like Xenophanes of Colophon, have been led to assert that the earth below us is infinite, [saying that it has "pushed its roots to infinity"] in order to save the trouble of seeking for the cause. Hence the sharp rebuke of Empedocles, in the words "if the deeps of the earth are endless and endless the ample ether—such is the vain tale told by many a tongue, poured from the mouths of those who have seen but little of the whole." 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 water 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. Again, as air is lighter than water, so is water than earth: 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. These thinkers seem to push their inquiries some way into the problem, but not so far as they might. It is what we are all inclined to do, to direct our inquiry not by the matter itself, but by the views of our opponents: and even when interrogating oneself one pushes the inquiry only to the point at which one can no longer offer any opposition. Hence a good inquirer will be one who is ready in bringing forward the objections proper to the genus, and that he will be when he has gained an understanding of all the differences.

Anaximenes and Anaxagoras and Democritus 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. And they adduce an amount of evidence to prove that air, when cut off and at rest, can bear a considerable weight.

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 is 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.

In general, our quarrel with those who speak of movement in this way cannot be confined to the parts; it concerns the whole universe. 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. (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.

Further, against Empedocles there is another point which might be made. When the elements were separated off by Hate, what caused the earth to keep its place? Surely the "whirl" cannot have been then also the cause. It is absurd too not to perceive that, while the whirling movement may have been responsible for the original coming together of the parts 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? In the infinite chaos there can have been neither above nor below, and it is by these that heavy and light are determined.

It is to these causes that most writers pay attention: but there are some, Anaximander, for instance, among the ancients, who say that the earth keeps its place because of its indifference. 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. 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 it remaining there is this necessity of indifference—on the analogy of the hair which, it is said, however great the tension, will not break under it, if it be evenly distributed, or of the men who, though exceedingly hungry and thirsty, and both equally, yet being equidistant from food and drink, is therefore bound to stay where he is—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. It happens, indeed, to be the case that a thing to which movement this way and that is equally inappropriate is obliged to remain at the centre. But so far as their argument goes, instead of remaining there, it will move, only not as a mass but in fragments. For the argument applies equally to fire. Fire, if set at the centre, should stay there, like earth, since it will be indifferently related to every point on the extremity. Nevertheless it will move, as in fact it always does move when nothing stops it, away from the centre to the extremity. It will not, however, move in a mass to a single point on the circumference—the only possible result on the lines of the indifference theory—but rather each corresponding portion of fire to the corresponding part of the extremity, each fourth part, for instance, to a fourth part of the circumference. For since no body is a point, it will have parts. The expansion, when the body increased the place occupied, would be on the same principle as the contraction, in which the place was diminished. Thus, for all the indifference theory shows to the contrary, earth also would have moved in this manner away from the centre, unless the centre had been its natural place.

We have now outlined the views held as to the shape, position, and rest or movement of the earth.

2
— Aristarchus —
(ca. 310–230 B.C.)

Aristarchus of Samos was an ancient Greek mathematician and astronomer and a contemporary of Archimedes. He was the first among the Greeks to clearly formulate a model of the universe based upon the heliocentric hypothesis, in which the earth both rotates and revolves around the sun. This is why he is often referred to as the Copernicus of antiquity. The heliocentric model of Aristarchus