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THE TWO-SPHERE UNIVERSE IN ARISTOTELIAN THOUGHT

The Aristotelian Universe

In order to examine the ancient world view, in which astronomical and nonastronomical concepts were woven into a single coherent conceptual fabric, we must reverse chronological order and return for a while to the middle of the fourth century B.C. At that time the technically developed attack upon the problem of the planets had scarcely begun, but the same two-sphere cosmology that was guiding the mathematical researches of planetary astronomers had already acquired essential nonastronomical functions. Many of these can be discovered in the voluminous works of the great Greek philosopher and scientist, Aristotle (384–322 B.C.), whose immensely influential opinions later provided the starting point for most medieval and much Renaissance cosmological thought.

Aristotle's writings, which have reached us only in imperfect and highly edited form, deal with the scientific subjects now called physics, chemistry, astronomy, biology, and medicine, as well as with such nonscientific fields as logic, metaphysics, politics, rhetoric, and literary criticism. To each of these, particularly biology, logic, and metaphysics, he contributed new ideas that were uniquely his own, but even more important than his many scattered substantive contributions was his organization of all knowledge into a systematic and coherent whole. He was not quite successful; it is not difficult to find inconsistencies and occasional contradictions within the body of Aristotle's writings. But there is a fundamental unity in his view of man and the universe that has never since been achieved in a synthesis of comparable scope and originality. That is one of the reasons why his writings had such immense influence; others will be examined at the end of this chapter.

We first, however, require a brief structural sketch of the Aristotelian universe itself, followed by a more detailed discussion of the multiple functions attributed to the terrestrial and celestial spheres in Aristotelian thought.

For Aristotle the entire universe was contained within the sphere of the stars, or, more precisely, within the outer surface of the sphere. At every point inside the sphere there was some sort of matter – no holes or vacuums could exist in Aristotle's universe. Outside the sphere there was nothing – no matter, no space, nothing at all. In Aristotelian science matter and space go together; they are two aspects of the same phenomenon; the very notion of a vacuum is absurd. That is how Aristotle managed to explain the finite size and the uniqueness of the universe. Matter and space must end together: one need not build a wall to bound the universe and then wonder what bounds the wall. As Aristotle put it in his book, *On the Heavens*:

> It is plain, then, . . . that there is not, nor do the facts allow there to be, any bodily mass beyond the heaven. The world in its entirety is made up of the whole sum of available matter. . . , and we may conclude that there is not now a plurality of worlds, nor has there been, nor could there be. This world is one, solitary, and complete. It is clear in addition that there is neither place nor void . . . beyond the heaven; for in all place there is a possibility of the presence of body, [and] void is defined as that which, although at present not containing body, can contain it. . . .[1]

Like Plato's universe, part of which was briefly described in Chapter 1, the Aristotelian universe is self-contained and self-sufficient, leaving nothing outside itself. But Aristotle differentiates the interior of the universe in far more detail than Plato. The largest part of the interior is filled with a single element, the aether, which aggregates in a homocentric set of nesting shells to form a gigantic hollow sphere whose surfaces are the outside of the sphere of the stars and the inner surface of the homocentric sphere carrying the lowest planet, the moon. Aether is the celestial element – a crystalline solid in Aristotle's writings, though its solidity was frequently questioned by his successors. Unlike the substances known on earth, it is pure and unalterable, transparent and weightless. From it are made the planets and stars as well as the nest of concentric spherical shells whose rotations account for the celestial motions.

Between the times of Aristotle and Copernicus a number of different views prevailed about the form and the physical reality of these celestial spheres that moved the heavens. Aristotle's view was the most detailed and explicit of all. He believed that there were just fifty-five real crystalline shells made of aether and that these shells embodied in a physical mechanism the mathematical system of homocentric spheres developed by Eudoxus and his successor, Callippus. Aristotle almost doubled the number of spheres used by the earlier mathematicians, but the spheres that he added were mathematically superfluous. Their function was to provide the mechanical linkages necessary to keep the whole set of concentric shells turning; they transformed the entire nest of spheres into a gigantic piece of celestial clockwork, driven from the sphere of the stars. Since the universe was full, all spheres were in contact, and the rubbing of sphere on sphere provided drive for the entire system. The sphere of the stars drove its nearest interior neighbor, the outermost of the seven homocentric shells that moved Saturn. That shell drove its next interior neighbor in Saturn's set, and so on, until the motion was finally transmitted to the lowest sphere in the set that carried the moon. This was the innermost of the aetherial shells, the lower boundary of the celestial or superlunary region.

The set of epicycles and deferents, which replaced homocentric spheres for purposes of mathematical astronomy, did not fit very well into crystalline spheres like those proposed by Aristotle. As a result the attempt to find a *mechanical* explanation of the epicyclic motions was often neglected after the fourth century B.C., and the real existence of crystalline spheres was occasionally questioned. It is not, for example, clear from the *Almagest* whether Ptolemy believed in them at all. But in the period separating Ptolemy and Copernicus most educated people, including astronomers, seem to have believed in at least a bastard version of Aristotle's spheres. They allowed one spherical shell for the stars and one for each planet, and they supposed that each planetary shell was just thick enough for the planet to be at its inner surface when closest to the central earth and at its outer surface when farthest from the earth. These eight spheres were nested one inside the other to fill the entire celestial region. The motion of the sphere of the stars provided a precise explanation of the diurnal circles of the stars. The continual rotation of the seven planetary spheres explained the average motion, but only the average motion, of the planets.

Men who did not know or care about the irregularities of planetary motion could take the thick spheres quite literally: each planet was fixed in and carried around by its sphere. Planetary astronomers used epicycles, deferents, equants, and eccentrics to account for each planet's motion within its own thick spherical shell. For them the shells usually had at least metaphorical reality, but they rarely bothered with a physical explanation of a planet's motion within its sphere.

Five centuries or more after Aristotle's death this conception of thick nested spherical shells added one important technical ingredient to the astronomy of the post-Ptolemaic period. It enabled astronomers to compute the actual size of the individual planetary spheres and therefore of the universe as a whole. Observations of a planet's motion among the stars enables an astronomer to determine only the *relative sizes* of its epicycle and deferent or the *relative amount* of its eccentricity. Shrinking or expanding a planet's system of compounded circles does not change the position at which the planet appears against the ecliptic, provided that the relative dimensions of epicycle, deferent, and eccentric are held constant. But if each spherical shell must be just thick enough to contain the planet both when it is closest and when it is farthest from the earth, then a knowledge of the relative dimensions of epicycle, deferent, and so on, suffices to determine the ratio of the inside and outside diameters of each sphere. Furthermore, if the spheres must nest so that they fill the entire celestial region, the outer diameter of one must be equal to the inner diameter of the next, and the ratio of the distances to all the intershell boundaries can be computed. Finally, these relative dimensions can be transformed to absolute distances by utilizing the distance to the sphere of the moon determined during the second century B.C. by the technique discussed in the Technical Appendix, Section 4.

Estimates of size based on the conception of space-filling spheres just large enough to house each planet's set of epicycles and other circles do not appear in the astronomical literature until after Ptolemy's death, presumably because the first planetary astronomers were skeptical about the reality of such spheres. But after the fifth century A.D., estimates of this sort became quite common, and once again they helped to make the entire cosmology seem real. One widely known set of cosmological dimensions was provided by the Arab astronomer Al Fargani, who lived in the ninth century A.D. According to his calculation the outer surface of the moon's sphere was $64\frac{1}{6}$ earth's radii from the center of the universe, the outer surface of Mercury's sphere was 167 earth's radii from the center; of Venus's, 1120 earth's radii; of the sun's, 1220; of Mars's, 8867; of Jupiter's, 14405; and of Saturn's, 20110. Since Al Fargani gave the earth's radius as 3250 Roman miles, he placed the sphere of the stars more than 75 million miles from the earth. It is an immense distance but, by modern theory, almost a million times smaller than the distance to the nearest star.

A glance at Al Fargani's measurements shows that the terrestrial region, the space below the underside of the moon's sphere, is but a minuscule portion of the universe. Most of space is the heavens; most matter is the aether of the crystalline spheres. But the small size of the sublunary region does not make it unimportant. Even in Aristotle's version, and to a far greater extent in the medieval Christian revision of Aristotelian cosmology, the tiny central core of the universe is the kernel for which the rest was made. It is man's abode, and its character is very different from that of the celestial region above it.

The sublunary region is filled not with one element but with four (or, in later writers, some other small number), and the distribution of these four terrestrial elements, though simple in theory, is extremely complex in fact. According to the Aristotelian laws of motion, to be discussed below, the elements would, in the absence of any external pushes and pulls upon them, settle into a series of four concentric shells like the aetherial spheres of the fifth element surrounding them. Earth, the heavy element, would move naturally into a sphere at the geometric center of the universe. Water, also heavy but not so heavy as earth, would settle in a spherical shell about the central region of earth. Fire, the lightest element, would rise spontaneously to form a shell of its own immediately below the moon's sphere. And air, also a light element, would complete the structure by filling the remaining shell between water and fire. Having achieved these positions, the elements would rest in place with their full elemental purity. Left to itself, undisturbed by outside forces, the sublunary region would be a static region, mirroring the heavenly spheres in its structure.

But the terrestrial region is never undisturbed. It is bounded by the moving sphere of the moon, and the movement of this boundary

constantly pushes the layer of fire beneath it, setting up currents which jostle and mix the elements together throughout the sublunary world. Therefore, the elements can never be observed in their pure form. The continual chain of pushes, deriving immediately from the sphere of the moon and ultimately from the sphere of the stars, keeps them mixed together in various and varying proportions. The structure of shells is still approximated; the appropriate element predominates in the appropriate region. But each element contains at least traces of the others, and these transform its character, giving rise, according to the proportions of the mixture, to all of the varied substances that can be discovered on the earth. The motions of the heavens are therefore responsible for all change and almost all variety observed in the sublunary world.

It is within this Aristotelian universe, whose scope and adequacy are scarcely represented by the preceding sketch, that we must search for the strength of the pre-Copernican astronomical tradition. Why, despite the real difficulties encountered by the Ptolemaic system, did astronomers continue for so long to assume that the earth had to be the stable center of the universe and of at least the average planetary orbits? One familiar answer to this question is already apparent: Aristotle, the greatest philosopher-scientist of antiquity, had declared the earth to be immobile, and his word was taken with immense seriousness by his successors, for many of whom he became "the Philosopher," the first authority on all questions of science and cosmology.

But Aristotle's authority, though important, is only the beginning of an answer, because Aristotle said a great many things which later philosophers and scientists did not have the least difficulty in rejecting. In the ancient world there were other schools of scientific and cosmological thought, apparently little influenced by Aristotelian opinion. Even in the late centuries of the Middle Ages, when Aristotle did become the dominant authority on scientific matters, learned men did not hesitate to make drastic changes in many isolated portions of his doctrine. The list of alterations introduced by later Aristotelians into Aristotle's original teachings is almost endless, and some of these alterations were far from trivial. As we shall see in the next chapter, a few of the criticisms directed at Aristotle by his successors play a direct and causal role in the Copernican Revolution.

Yet no later Aristotelian suggested that the earth was a planet or that it was located away from the center of the universe. That innovation proved a peculiarly difficult one for an Aristotelian to conceive or to accept, because the concept of a unique central earth was interwoven with so many other important concepts within the fabric of Aristotelian thought. An Aristotelian universe can be built as well with three or five terrestrial elements as with four and very nearly as well with epicycles as with homocentric spheres, but it cannot and did not survive the modification that made the earth a planet. Copernicus tried to design an essentially Aristotelian universe around a moving earth, but he failed. His followers saw the full consequences of his innovation, and the entire Aristotelian structure crumbled. The concept of a central and stable earth was one of the few major constitutive concepts in a closely knit and coherent world view.

The Aristotelian Laws of Motion

A first example of the integration of astronomical and nonastronomical thought is provided by Aristotle's explanation of terrestrial motion. As we have already noted, Aristotle believed that, in the absence of external pushes derived ultimately from the heavens, each of the terrestrial elements would remain at rest in that part of the terrestrial region natural to it. Earth rests naturally at the center, fire at the periphery, and so on. In fact, the elements and the bodies composed of them are constantly wrested from their natural positions. But that requires the application of a force; an element resists displacement; and, once displaced, it strives to regain its natural position by the shortest possible path. Pick up a rock or some other earthy material and feel it tug away, attempting to reach its natural position at the geometric center of the universe. Or watch the flames of a fire leap upward on a clear night as they strive for their natural place at the periphery of the terrestrial region.

We shall examine later the psychological sources and the strength of this Aristotelian explanation of terrestrial motion. But first notice the bulwark that these doctrines, drawn from terrestrial physics, provide for the earth-centered universe of the astronomer. In an important passage from *On the Heavens* Aristotle derives the sphericity, stability, and central location of the earth from them. We have previously seen them derived by astronomical arguments, but note how secondary a role astronomical considerations play here.

The natural motion of the earth as a whole, like that of its parts, is towards the center of the Universe: that is the reason why it is now lying at the center. It might be asked, since the center of both is the same point, in which capacity the natural motion of heavy bodies, or parts of the earth, is directed towards it; whether as center of the Universe or of the earth. But it must be towards the center of the Universe that they move. . . . It so happens that the earth and the Universe have the same center, for the heavy bodies do move also towards the center of the earth, yet only incidentally, because it has its center at the center of the Universe. . . .

From these considerations it is clear that the earth does not move, neither does it lie anywhere but at the center. In addition the reason for its immobility is clear from our discussions. If it is inherent in the nature of earth to move from all sides to the center (as observation shows), and of fire to move away from the center towards the extremity, it is impossible for any portion of earth to move from the center except under constraint. . . . If then any particular portion is incapable of moving from the center, it is clear that the earth itself as a whole is still more incapable, since it is natural for the whole to be in the place towards which the part has a natural motion. . . .

Its shape must be spherical. . . . To grasp what is meant we must imagine the earth as in process of generation. . . . It is plain, first, that if particles are moving from all sides alike towards one point, the center, the resulting mass must be similar on all sides; for if an equal quantity is added all round, the extremity must be at a constant distance from the center. Such a shape is a sphere. But it will make no difference to the argument even if the portions of the earth did not travel uniformly from all sides towards the center. A greater mass must always drive on a smaller mass in front of it, if the inclination of both is to go as far as the center, and the impulsion of the less heavy by the heavier persists to that point. . . .

Further proof is obtained from the evidence of the senses. (i) If the earth were not spherical, eclipses of the moon would not exhibit segments of the shape they do. . . . (ii) Observation of the stars also shows not only that the earth is spherical but that it is of no great size, since a small change of position on our part southward or northward visibly alters the circle of the horizon, so that the stars above our heads change their position considerably, and we do not see the same stars as we move to the North or South. Certain stars are seen in Egypt and the neighborhood of Cyprus, which are invisible in more northerly lands, and stars which are continuously visible in the northern countries are observed to set in the others. This proves both that the earth is spherical and that its periphery is not large, for otherwise such a small change of position could not have had such an immediate effect. For this reason those who imagine that the region around the Pillars of Heracles joins on to the regions of India, and that in this way the ocean is one, are not, it would seem, suggesting anything utterly incredible.[2]

Passages like this indicate that astronomy and terrestrial physics are not independent sciences. Observations and theories developed for one become intimately entangled with those drawn from another. Therefore, though difficulty in solving the problem of the planets might have provided an astronomer with a motive for experimenting *in astronomy* with the conception of a moving earth, he could not do so without upsetting the accepted basis of terrestrial physics in the process. The very notion of a moving earth would be unlikely to occur to him, because, for reasons drawn from his nonastronomical knowledge, the conception seemed so implausible. That seems to be what Ptolemy and his successors meant when they later described the astronomical hypotheses of Aristarchus, Heraclides, and the Pythagoreans as "ridiculous" even though astronomically satisfactory.

Examine, for example, the following passage from the *Almagest*, in which Ptolemy rejects Heraclides' theory that the sphere of the stars is stationary and that its apparent westward diurnal motion is due to a real eastward diurnal rotation of the central earth. Ptolemy begins with arguments for the sphericity and central position of the earth much like those given by Aristotle in the passage quoted above. Then he continues:

> Certain thinkers, though they have nothing to oppose to the above arguments, have concocted a scheme which they consider more acceptable, and they think that no evidence can be brought against them if they suggest for the sake of argument that the heaven is motionless, but that the earth rotates about one and the same axis from west to east, completing one revolution approximately every day. . . .
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> These persons forget however that, while, so far as appearances in the stellar world are concerned, there might, perhaps, be no objection to this theory. . . , yet, to judge by the [terrestrial] conditions affecting ourselves and those in the air about us, such a hypothesis must be seen to be quite ridiculous. . . . [If the earth] made in such a short time such a colossal turn back to the same position again, . . . everything not actually standing on the earth must have seemed to make one and the same movement always in the contrary sense to the earth, and clouds and any of the things that fly or can be thrown could never be seen travelling towards the east, because the earth would always be anticipating them all and forestalling their motion towards the east, insomuch that everything else would seem to recede towards the west and the parts which the earth would be leaving behind it.[3]

The gist of Ptolemy's argument is the same as Aristotle's, and many

other arguments were derived from the same principles during the Middle Ages and the Renaissance. Unless it is pushed, a body will move straight toward its natural position and then rest there. These natural positions and the lines by which bodies move to them are determined entirely by the intrinsic geometry of an absolute space, a space in which each position and direction is permanently labeled whether or not the position is occupied. Therefore, as Aristotle says elsewhere in *On the Heavens*, "If the earth were removed to where the moon is now, separate parts of it would not move towards the whole, but towards the place [the center] where the whole is now."[4] The natural motion of a stone is governed by space alone, not by the stone's relation to other bodies. Therefore, a stone thrown vertically upward moves away and returns along a straight line fixed once and for all in space, and if the earth moves while the stone is in the air, the stone will not rejoin the earth at the point from which it departed. By the same token, clouds which already occupy their natural positions would be left behind as the earth rotates. Only if the moving earth carries the air with it, could a cloud or stone follow the earth at all, and even the motion of the air would not push a stone hard enough to keep it in step with the earth's rotation.

There are, of course, difficulties in this Aristotelian theory of motion, and some of them will later play a significant role in the Copernican Revolution. But, like the two-sphere universe itself, Aristotle's theory of motion is an excellent first step toward an understanding of motion, and it does necessitate a central stationary earth. Advocates of a planetary earth will therefore require a new theory of motion, and until such a theory is invented, as it was during the Middle Ages, a knowledge of terrestrial physics will inhibit the astronomical imagination.

The Aristotelian Plenum

A second illustration of the blinders fitted to the astronomer by the coherent interrelations between his astronomical and nonastronomical knowledge is provided by the Aristotelian conception of a full universe or plenum. This example is more typical than the last, for the ties between the various strands of knowledge are here both more numerous and less binding than those illustrated above. The complex pattern of Aristotelian thought now begins to emerge.

The ancient conception of the fullness of the universe is often referred to as the *horror vacui*, nature's abhorrence of a vacuum. As an explanatory principle it can be paraphrased to read: Nature will always act to prevent the formation of a vacuum. In this form the Greeks derived it from and used it to explain a large variety of natural phenomena. Water will not flow from an open bottle with a small neck unless a second hole is made in the bottle, because without a second hole at which air can enter the emerging water would leave a vacuum behind it. Siphons, water clocks, and pumps were economically explained on the same basis. Some ancient thinkers applied the *horror vacui* to the explanation of adhesion and to the design of hot-air and steam engines. The experimental basis of the principle could not be challenged. Convincing approximations to vacuums cannot be produced on earth without apparatus of which the Greeks knew nothing. There were no pneumatic phenomena to challenge the principle until, with the large-scale development of deep mining during the sixteenth century, it was discovered that lift pumps will not raise water more than 30 feet. Rejecting the *horror vacui* necessarily meant destroying a thoroughly satisfactory scientific explanation of a host of terrestrial phenomena.

For Aristotle and most of his successors, however, the *horror vacui* was more than a successful experimental principle applicable on and near the surface of the earth. Aristotle held not only that there are *in fact* no vacuums in the terrestrial world, but that there can *in principle* be no vacuums anywhere in the universe. The very concept of a vacuum was to him a contradiction in terms, like the concept "square circle." Today, when everybody has seen a "vacuum" tube and heard of a "vacuum" pump, Aristotle's logical proofs of the impossibility of a void convince almost no one, though it is frequently difficult to discover the faults in his arguments. But in the absence of the experimental counterevidence, which we now possess, they seemed convincing, for they arose from a genuine difficulty inherent in the words with which we discuss problems of matter and space. Apparently space can be defined only in terms of the volume occupied by body. In the absence of material body there is nothing in terms of which to define space; it cannot apparently exist by itself at all. Matter and space are inseparable, two sides of the same coin. There can be no space without matter. In Aristotle's more cumbersome words, "there is no such thing as a dimensional entity, other than that of material substances." [5]

The theory of a full universe therefore entered ancient science with the combined authority of logic and experiment, and it immediately became an essential ingredient of cosmological and astronomical theories. It is, for example, involved in the Aristotelian explanation of the endurance of motion within the sphere of the stars. If any one of the celestial or terrestrial shells were replaced by a void, all motion within that shell would cease. The rubbing of shell on shell produces all motion, except return to natural position, and a void would break the chain of pushes. Again, as we have already noted, the impossibility of a void is the basis of the universe's finitude. Beyond the sphere of the stars is neither space nor matter – nothing at all. Without a concept that indissolubly united matter and space, the Aristotelian would be forced to admit the infinity of the universe. Matter could be bounded by void, and void could, in turn, be bounded by matter, but there could be no terminus, no last boundary at which the universe ended once and for all.

But an infinite universe could scarcely remain an Aristotelian universe for two reasons. An infinite space has no center: every point is equally distant from all points on the periphery. And if there is no center, there is no preferred point at which the heavy element earth can aggregate, and there is no intrinsic "up" and "down" to determine the natural motion of an element returning to its proper place. In fact there is no "natural place" in an infinite universe, for each place is like every other. The whole Aristotelian theory of motion is, as we shall see more fully later, inextricably bound to the conception of a finite and fully occupied space. The two stand or fall together.

Nor are these the only difficulties presented to an Aristotelian by the infinitude of space. If space is infinite and there is no special center point, it is scarcely plausible that all the earth, water, air, and fire in the universe should have aggregated at one and only one point. In an infinite universe, it is natural to presume that there are other worlds scattered here and there through all of space. Perhaps there are plants, men, and animals on these other worlds. Thus the earth's uniqueness vanishes; the peripheral force that drives the whole disappears with it; man and the earth cease to be at the focus of the universe. Both in antiquity and in the Middle Ages, most of those philosophers who, like the atomists, believed that the universe was infinite felt themselves impelled to accept the reality of the void and a plurality of worlds as well. And until the seventeenth century no one who embraced this set of concepts produced a cosmology able to compete with the Aristotelian in the explanation of everyday terrestrial and celestial phenomena. The infinite universe may be a common-sense universe today, but today common sense has been reëducated.

The multifarious roles of the conception of a full universe in Aristotelian thought is our one full-dress example of the coherence of a cosmology or a world view. The plenum is implicated in pneumatics, the endurance of motion, the finitude of space, the laws of motion, the uniqueness of the earth. The list could be extended. Note that the plenum does not logically necessitate either the uniqueness, or the central position, or the immobility of the earth. It simply fits into a coherent pattern in which the unique, central, and immobile earth is a second essential strand. Conversely, the earth's motion does not necessitate either the existence of a vacuum or the infinity of the universe. But it is no accident that both these views won acceptance shortly after the victory of the Copernican theory.

Copernicus himself believed in neither. As we shall see, he tried to preserve most of the central features of Aristotelian and Ptolemaic cosmology. But by giving the earth an axial motion, he made the sphere of the stars immobile, depriving it of physical function. And by giving the earth an orbital motion, he made necessary a vast increase in the size of the sphere. Copernicus' cosmology thus took away from interplanetary matter many of its essential Aristotelian functions and simultaneously demanded that there be vastly more of it. His successors soon fractured the now functionless sphere, scattered the stars through all of space, admitted a vacuum or something very like it between them, and dreamed of other worlds inhabited by other men in the vast expanses beyond our solar system. Even the terrestrial principle of the *horror vacui* did not survive for long. In the new universe it was very much easier for scientists to recognize that practical miners had for a century been producing a terrestrial vacuum at the top of overlong water pumps. Air pressure soon replaced the vacuum in the pneumatic conceptions of the seventeenth century. Many other forces played an essential role in the modification of pneumatics – the story is complex – but the new astronomy of Copernicus is a necessary ingredient of its plot. Once again astronomical theory displays its intimate entanglement with the theories of other sciences, and those other sciences condition the astronomical imagination.

The Majesty of the Heavens

The extra-astronomical entanglements of astronomical theory are not, however, exclusively ties to other sciences. As our previous discussions of the motives for celestial observation have repeatedly hinted, the ancient astronomical tradition is partially indebted for its very existence to a widespread primitive perception of the contrast between the power and stability of the heavens and the impotent insecurity of terrestrial life. This same perception is incorporated into Aristotle's cosmology by the absolute distinction between the superlunary and sublunary regions. But in Aristotle's highly articulated version the distinction comes to depend explicitly upon both the central position of the earth and the perfect symmetry of the spheres that generate both the stellar and planetary motions.

According to Aristotle, the underside of the sphere of the moon divides the universe into two totally disparate regions, filled with different sorts of matter and subject to different laws. The terrestrial region in which man lives is the region of variety and change, birth and death, generation and corruption. The celestial region is, in contrast, eternal and changeless. Only aether, of all the elements, is pure and incorruptible. Only the interlocked celestial spheres move naturally and eternally in circles, never varying their rate, always occupying exactly the same region of space, forever turning back upon themselves. The substance and the motion of the celestial spheres are the only ones compatible with the immutability and majesty of the heavens, and it is the heavens that produce and control all variety and change on earth. In Aristotle's physical description of the universe, as much as in any primitive religion, the encircling heavens are the locus of the perfection and the power upon which terrestrial life depends. *On the Heavens* puts the point unequivocally:

> From what has been said it is clear why . . . the primary body of all [that is, celestial matter] is eternal, suffers neither growth nor diminution, but is ageless, unalterable and impassive. I think too that the argument bears out experience and is borne out by it. All men have a conception of gods, and all assign the highest place to the divine, both barbarians and Hellenes, as

many as believe in gods, supposing, obviously, that immortal is closely linked with immortal. It could not, they think, be otherwise. If then – and it is true – there is something divine, what we have said about the primary bodily substance [namely that it is weightless, indestructible, unalterable, and so on] is well said. The truth of it is also clear from the evidence of the senses, enough at least to warrant the assent of human faith; for throughout all past time, according to the records handed down from generation to generation, we find no trace of change either in the whole of the outermost heaven or in any one of its proper parts. It seems too that the name of this first body has been passed down to the present time by the ancients. . . . Thus they, believing that the primary body was something different from earth and fire and air and water, gave the name *aether* to the uppermost region, choosing its title from the fact that it "runs always" and eternally.[6]

Aristotle himself carried the conception of the majesty and divinity of the celestial regions little further. Both the matter and the motions of the heavens are perfect; all terrestrial change is caused and governed by a succession of pushes initiated by the uniform motions of the celestial spheres which symmetrically enclose the earth. Already a significant nonscientific argument for the earth's unique central location is apparent, and, in the centuries after Aristotle's death, this argument was reinforced by elaborating the conception of the perfect heavens and integrating it with two other important sets of beliefs, both of which had originated independently. One of these developments – the detailed integration of Aristotelian cosmology with Christian theology – we must postpone until its proper chronological position in the next chapter. It resulted in a universe each of whose structural details carried religious as well as physical significance: Hell was at the geometric center; God's throne was beyond the stellar sphere; each planetary sphere and epicycle was turned by an angel. But another significant application of the concept of celestial majesty – the science of astrology – is older than the Christian-Aristotelian cosmology, and it had an even more immediate impact on practitioners of astronomy. Because it involved them professionally, astrology may well have been the most important of the forces binding astronomers to the conception of the earth's uniqueness.

We have already noted the principal roots of astrological belief and their relation to the Aristotelian conception of the power of the heavens. Distance and immutability make the heavens a plausible locus for the gods who can intervene at will in men's affairs. Disruptions of

celestial regularity – particularly comets and eclipses – were regarded from an early date as portents of unusual felicity or disaster. In addition, there is good observational evidence for celestial control of at least some terrestrial events. It is hot when the sun is in the constellation Cancer and cold when it is in Capricorn; the varying height of the tide follows the variation of the moon's phases; the menstrual cycle of women throughout the earth recurs at intervals coincident with the length of the lunar month. In an era when man's need to understand and control his fate immeasurably transcended his physical and intellectual tools, this apparent evidence of celestial power was naturally extended to the other celestial wanderers. Particularly after Aristotle supplied a physical mechanism – the frictional drive – through which heavenly bodies could produce terrestrial change, there was a plausible basis for the belief that an ability to predict the future configurations of the heavens would enable men to foretell the future of men and nations.

Before the second century B.C., ancient records show few signs of a fully developed attempt to predict the details of terrestrial affairs from the observed and computed positions of the stars and planets. But after this relatively late start, astrology was inseparably linked to astronomy for 1800 years; together they constituted a single professional pursuit. The astrology that predicted the future of men from the stars was known as judicial astrology; the astronomy that predicted the future of stars from their present and past was known as natural astrology; those who gained fame in one branch were usually well known in the other as well. Ptolemy, whose *Almagest* exhibited ancient astronomy in its most developed form, was equally famous for his *Tetrabiblos*, antiquity's classic contribution to judicial astrology. European astronomers like Brahe and Kepler, who late in the Renaissance put Copernicus' system into something very like its modern form, were supported financially and intellectually because they were thought to cast the best horoscopes.

During most of the period with which the rest of this book is concerned, astrology exercised an immense influence upon the minds of the most educated and cultured men of Europe. Early in the Middle Ages it was partially suppressed by the Church, whose doctrinal insistence that men are free to choose the Christian good was incompatible with astrology's strict determinism. But during the five centuries centering on the birth of Christ, and again during the late Middle Ages and the Renaissance, astrology was the guide of kings and of their people, and it is no accident that these are just the periods during which earth-centered astronomy made most rapid progress. The elaborate tables of planetary position and the complex computational techniques developed by planetary astronomers from antiquity to the Renaissance were the main prerequisite for astrological prediction. Until after Copernicus' death these major products of astronomical research had little other socially significant application. Astrology therefore provided the principal motive for wrestling with the problem of the planets, so that astrology became a particularly important determinant of the astronomical imagination.

Astrology, however, and the perception of celestial power that underlies it lose much plausibility if the earth is a planet. A planetary earth will act as forcefully on Saturn as Saturn can act on it; the same argument applies to the other planets; and the terrestrial-celestial dichotomy breaks down. If the earth is a celestial body, it must share the immutability of the heavens, and the heavens in turn must participate in the corruptibility of earth. It cannot be coincidence that astrology's stranglehold upon the human mind finally relaxed during just the period in which the Copernican theory first gained acceptance. It may even be significant that Copernicus, the author of the theory that ultimately deprived the heavens of special power, belonged to the minority group of Renaissance astronomers who did not cast horoscopes.

Astrology and the majesty of the heavens therefore provide one more example of the indirect consequences of the earth's stability and uniqueness, consequences that have been repeatedly illustrated but by no means exhausted in this extended discussion of the multiple functions of a central stable earth in the Aristotelian world view. It is, of course, precisely these consequences and others like them that make the Copernican Revolution a revolution. To describe the innovation initiated by Copernicus as the simple interchange of the position of the earth and sun is to make a molehill out of a promontory in the development of human thought. If Copernicus' proposal had had no consequences outside astronomy, it would have been neither so long delayed nor so strenuously resisted.

The Aristotelian World View in Perspective

The Aristotelian world view was the single most important source and support for the pre-Copernican tradition of astronomical practice. But Aristotle's day is not our day, and a real mental transposition is therefore necessary in approaching his writings, particularly those dealing with physics and cosmology. Failure to make this transposition has resulted in some strained and distorted explanations of the endurance of Aristotelian physics in antiquity and during the Middle Ages.

We are, for example, often told that it is only because medieval scientists preferred the authority of the written word, preferably ancient, to the authority of their own eyes that they could continue to accept Aristotle's absurd dictum that heavy bodies fall faster than light ones. Modern science, on this prevalent interpretation, began when Galileo rejected texts in favor of experiments and observed that two bodies of unequal weight, released from the top of the tower of Pisa, struck the ground simultaneously. Today every schoolboy knows that heavy bodies and light bodies fall together. But the schoolboy is wrong and so is this story. In the everyday world, as Aristotle saw, heavy bodies do fall faster than light ones. That is the primitive perception. Galileo's law is more useful to science than Aristotle's, not because it represents experience more perfectly, but because it goes behind the superficial regularity disclosed by the senses to a more essential, but hidden, aspect of motion. To verify Galileo's law by observation demands special equipment; the unaided senses will not yield or confirm it. Galileo himself got the law not from observation, at least not from new observation, but by a chain of logical arguments like those we shall examine in the next chapter. Probably he did not perform the experiment at the tower of Pisa. That was performed by one of his critics, and the result supported Aristotle. The heavy body did hit the ground first.

The popular story of Galileo's refutation of Aristotle is largely a myth, motivated by a failure of historical perspective. We like to forget that many of the concepts in which we believe were painfully drummed into us in our youth. We too easily take them as natural and indubitable products of our own unaided perceptions, dismissing concepts different from our own as errors, rooted in ignorance or stupidity and perpetuated by blind obedience to authority. Our own education stands between us and the past. Particularly it stands between us and Aristotelian physics, frequently leading us to misinterpret the nature and source of Aristotle's immense influence on subsequent generations.

Part of the authority of Aristotle's writings derives from the brilliance of his own original ideas, and part derives from their immense range and logical coherence, which are as impressive today as ever. But the primary source of Aristotle's authority lies, I believe, in a third aspect of his thought, one which it is more difficult for the modern mind to recapture. Aristotle was able to express in an abstract and consistent manner many spontaneous perceptions of the universe that had existed for centuries before he gave them a logical verbal rationale. In many cases these are just the perceptions that, since the seventeenth century, elementary scientific education has increasingly banished from the adult Western mind. Today the view of nature held by most sophisticated adults shows few important parallels to Aristotle's, but the opinions of children, of the members of primitive tribes, and of many non-Western peoples do parallel his with surprising frequency. Sometimes the parallels are difficult to discover, because they are hidden by Aristotle's abstract vocabulary and by his elaborately logical method. These are the elements of Aristotelian dialectic, and only their rudiments can be found in primitives and children. But Aristotle's substantive ideas about nature, in contrast to the way he expresses and documents them, do show important residues of earlier and more elementary perceptions of the universe. Unless alert to these residues we may miss the meaning and will surely miss the force of important segments of Aristotelian doctrine.

The nature of the primitive residues and the manner in which they are transformed by the impact of Aristotelian dialectic are clearly illustrated in Aristotle's discussions of space and motion. The world views of primitive societies and of children tend to be animistic. That is, children and many primitive peoples do not draw the same hard and fast distinction that we do between organic and inorganic nature, between living and lifeless things. The organic realm has a conceptual priority, and the behavior of clouds, fire, and stones tends to be explained in terms of the internal drives and desires that move men and, presumably, animals. Asked why balloons go up, one child of four answers, "Because they want to fly away." Another, age six, explains that balloons go up because "they like the air. So when you let go they go up in the sky." Asked why a box falls to the ground, Hans, age five, answers, "Because it wants to go there." Why? "Because it is a good thing [for it to be there]."[7] Primitives frequently give similar explanations, though they are often harder to unravel because expressed in myths which cannot be taken quite literally. We have already examined the Egyptian explanation of the sun's motion as that of a god sailing in his boat across the heavens.

Aristotle's stones are not alive, though his universe frequently seems to be, at least metaphorically. (There are passages in Aristotle reminiscent of the passage from Plato's *Timaeus* quoted in the first chapter.) But his perception of the stone leaping from the hand to achieve its natural place at the center of the universe is not so very different from the child's perception of the balloon that likes the air or of the box that falls to the ground because it is good for it to be there. The vocabulary has changed; the concepts are manipulated with adult logic; animism has been transmuted. But much of the appeal of the Aristotelian doctrine must lie in the naturalness of the perception that underlies the doctrine.

Animism is not, however, the entire psychological base of Aristotle's explanation of motion. A subtler and, I think, more important element derives from the Aristotelian transmutation of a primitive perception of space. To the members of prehistoric civilizations and primitive tribes, space seems very different from the Newtonian space in which we were all brought up, usually without knowing it. The latter is physically neutral. A body must be located *in* space and move *through* space, but the particular part of space and the particular direction of motion exert no influence on the body. Space is an inert substratum for all bodies. Each position and each direction is like every other. In modern terminology, space is homogeneous and isotropic; it has no "top" or "bottom," "east" or "west."

The space of the primitive, in contrast, is often more nearly a life space: the space in a room, or in a house, or in a community. It has a "top" and "bottom," and "east" and "west" (or "front" and "back" – in many primitive societies words for direction derive from words for parts of the body and reflect the intrinsic differences of these parts). Each position is a position "for" some object or "where" some characteristic activity occurs. Each region and direction of space is characteristically different from every other, and the differences partially determine the behavior of bodies in each region. Usually the primitive's space is the active dynamic space of everyday life; distinct regions have distinct characteristics.

Egyptian cosmology provided an example: the region of the circumpolar stars became the region of eternal life, of those who never die. A similar perception of space provides one important source of astrological thought. The nature and power of planets depends upon their position in space. One old Babylonian text states: "When the star Marduk [the planet Jupiter] is in the ascendant [that is, low on the eastern horizon], it is then Nebo [the god Mercury]. When it has risen . . . [number omitted] double hours, it is Marduk [the god Jupiter]. When it stands in the middle of the heavens, it is Nibiru [the highest one, the omnipotent god]. Each planet becomes this at its zenith." [8]

The primitive residues inherent in the Aristotelian conception of space are seldom so clear. But examine the following discussion of motion from Aristotle's *Physics*:

> The typical locomotions of the elementary natural bodies – namely fire, earth, and the like – show not only that place is something, but also that it exerts a certain influence. Each is carried to its own place, if it is not hindered, the one up, the other down. . . . It is not every chance direction which is "up," but where fire and what is light are carried; similarly, too, "down" is not any chance direction but where what has weight and what is made of earth are carried – the implication being that these places do not differ merely in relative position, but also as possessing distinct potencies.[9]

This passage is an almost perfect summary of the conception of space that underlies the Aristotelian explanation of motion: "place . . . exerts a certain influence"; "places do not differ merely in relative position, but also as possessing distinct potencies." These are places in a space that has an active and dynamic role in the motion of bodies. Space itself supplies the push that drives fire and stones to their natural resting places at the periphery and the center. The interactions of matter and space determine the motion and rest of bodies. To us this is an unfamiliar notion, because we are the heirs of the Copernican Revolution, which made it necessary to discard and re-

place the Aristotelian conception of space. But the concept is not implausible. Perhaps by mere coincidence, the spatial concepts embodied in Einstein's general theory of relativity are, in important respects, closer to Aristotle's than to Newton's. And Einstein's universe may, like Aristotle's and unlike Newton's, be finite.

Aristotle's world view was not the only one created in antiquity, nor was it the only one that gained adherents. But Aristotle's was far nearer to many primitive conceptions of the world than its ancient competitors, and it corresponded more closely with the evidence of unaided sense perception. That is another reason why it was so immensely influential, particularly during the late Middle Ages. Having isolated at least part of its appeal, we can better appreciate the strength that Aristotelian cosmology contributed to the ancient astronomical tradition. Now we must discover what happened to that tradition to prepare the way for Copernicus.