

Introduction

I. Significance of Galileo's *Dialogue*

1.1. From prehistoric times until the middle of the sixteenth century, almost all thinkers believed that the earth stood still at the center of the universe and that all heavenly bodies revolved around it. By the end of the seventeenth century, most thinkers had come to believe that the earth is the third planet circling the sun once a year and spinning around its own axis once a day. Nowadays, after three more centuries of accumulating knowledge, this modern view is known to be true beyond any reasonable doubt. But the earlier view had been a very plausible belief; for two millennia the earth's motion had been inconceivable or untenable, and then for a century and a half, the discussion of the relative merits of the two views was the subject of heated debate. In fact, the transition was a slow, difficult, and controversial process. We may fix its beginning with the publication in 1543 of Nicolaus Copernicus's book *On the Revolutions of the Heavenly Spheres* and its completion with the publication in 1687 of Isaac Newton's *Mathematical Principles of Natural Philosophy*.

The discovery of the motion and noncentral location of the earth involved not only a key astronomical fact, but was interwoven with the discovery of the most basic laws of nature, such as the laws of inertia, of force and acceleration, of action and reaction, and of universal gravitation. This discovery was also connected with the clarification of some key principles of scientific method. It represents, therefore, the most

significant breakthrough in the history of science; thus, the series of developments starting with Copernicus in 1543 and ending with Newton in 1687 may be labeled the Scientific Revolution.¹

More generally, it would perhaps be no exaggeration to say that this transition represents the most important intellectual transformation in human history.² One reason for this involves the worldwide repercussions of the Scientific Revolution itself; science seems to be the only cultural force which has managed to dominate human societies in all parts of the earth. Another reason stems from the interdisciplinary character of the transition from a geocentric to a geokinetic world view; the transformation involved not only many branches of science but also other disciplines and activities such as philosophy, theology, religion, art, literature, technology, industry, and commerce; indeed it changed mankind's self-image in general. We may thus also call this transition the Copernican Revolution, if we want a label which leaves open its broad ramifications outside science; this label also gives due credit to the one thinker whose contribution initiated the process.³

Galileo Galilei (1564–1642) was a key protagonist of these historical developments. In physics, he pioneered the experimental investigation of motion; he formulated, clarified, and systematized many of the basic concepts needed for the theoretical analysis of motion; and he discovered the laws of falling bodies. In astronomy, he introduced the telescope as an instrument for systematic observation; he made several crucial observational discoveries; and he understood the cosmological significance of these observational facts and gave essentially correct interpretations of many of them. Galileo was also an inventor, making significant contributions to the devising and improvement of such instruments as the telescope, microscope, thermometer, and pendulum clock. In regard to scientific method, he pioneered several important practices, such as the use of artificial instruments (like the telescope) to learn new facts about the world, and the active intervention into and exploratory manipulation of physical phenomena to gain access to aspects of nature which are not detectable without such experimentation; he also contributed to the establishment and extension of other more traditional methodological practices, such as the use of a quantitative approach in

1. For some valuable accounts centered around this theme, see H. F. Cohen (1994), Hall (1954), and Lindberg and Westman (1990).

2. This thesis is generally attributed to Butterfield (1949).

3. For a classic example of this type of general account, see Kuhn (1957).

the study of motion; and he contributed to the explicit formulation and clarification of important methodological principles, such as the disregard of biblical assertions and religious authority in scientific inquiry.⁴

Galileo's *Dialogue on the Two Chief World Systems, Ptolemaic and Copernican* (1632) is one of the most important texts of the Copernican or Scientific Revolution. It also constitutes his mature synthesis of astronomy, physics, and scientific methodology. From the viewpoint of the transition from geocentrism to Copernicanism, the book may be summarized by saying that it strengthened the geokinetic theory by means of theoretical considerations based on Galileo's new physics, observational evidence stemming from his telescopic discoveries, and concrete methodological analyses.

Galileo's *Dialogue* is also the book which triggered his trial by the Roman Catholic Inquisition in 1633, ending with his condemnation as a heretic and the banning of the book. The trial was the climax of a series of events that began in 1613 and included a related series of Inquisition proceedings in 1615–1616. This twenty-year sequence of developments is now known as the Galileo Affair, and so the book is also an important document in this tragic but instructive episode (of which more below).

Because the Galileo Affair involved a conflict between one of the founders of modern science and one of the world's great religious institutions, it has traditionally been taken as an example of the warfare between science and religion. Whether this is really so is one of the main issues in the controversy that has arisen about the interpretation and evaluation of the Galileo Affair. This issue cannot be resolved here, but two comments are in order. First, even a cursory reading of the relevant documents shows that many churchmen were on his side and many scientists were on the opposite side; thus, there was a split within both science and religion, along the lines of what may be called conservation and innovation; so the real conflict was between a conservative attitude and a progressive one. Second, many of the problems between Galileo and the Church stemmed from the fact that the Church was then not just a religious authority but also a political power and a social institution; thus, the episode illustrates the conflict or interaction between science and politics, between science and society, and between individual freedom and institutional authority.

4. For some good scholarly general accounts see Drake (1978; 1990) and Geymonat (1965); for some interesting popular general accounts see Reston (1994), Ronan (1974), and Seeger (1966).

These remarks highlight the historical significance of the *Dialogue* by way of its connection with the Scientific Revolution, Copernican Revolution, and Galileo Affair. These episodes have such a perennial interest and universal relevance that the book thereby acquires perennial and universal significance. So far this means only that it is worth reading by all educated persons and by every generation in order for them to acquire factual information, come to their own interpretation, formulate their own evaluation, and derive their own lessons. But its perennial and universal importance can be elaborated in more abstract ways that connect it to several general activities of the human mind.

1.2. First, Galileo wrote the book in vernacular Italian rather than in scholarly Latin. His main motive was that he wanted to appeal to a broad audience of educated nonexperts and to suggest that the issues raised were of general cultural significance. This intention does not mean that he was addressing the book only to such readers; rather he wrote it for a professional audience of scholars and specialists, as well as for a lay audience of educated, intelligent, studious, and curious persons. However, what deserves emphasis here is that the book has an explicitly universalist aim.

Moreover, Galileo wrote the book in the form of a dialogue among three speakers: Salviati, an expert who takes the Copernican side; Simplicio, a scholar who takes the geocentric viewpoint; and Sagredo, an intelligent, educated, and inquisitive layman who knows little about the topic but wants to listen to both sides and make up his mind as a result of the critical scrutiny of what they have to say. This feature is in part connected with the Galileo Affair and will be discussed again below. The point to stress here is that the dialogue form reinforces the book's universal appeal inasmuch as the speakers personify the abstract intellectual issues and make it easier for readers to relate to them. But the dialogue form is also directly connected with another important aspect of the book, to which we now turn.

The book's most striking feature is critical reasoning, taking this term to mean reasoning aimed at the analysis, evaluation, and/or self-reflective presentation of arguments.⁵ In fact, Galileo was writing before the

5. This definition has been inspired by Michael Scriven, although it does not represent a mere adoption of his exact definition, but rather a formulation of a concept that I needed to make sense of Galileo's book; cf. Scriven and Fisher (forthcoming). For example, it should be noted that here I am talking of critical *reasoning*, whereas Scriven is talking about critical *thinking*, which I take to be a broader concept and to include also what I call methodological reflection; for more details see the appendix (1.6, 1.8, 2.1, and 2.7).

new Copernican view was conclusively established, when the situation was fluid and controversial; thus, to form an intelligent opinion on the topic required more than mere observation, experiment, calculation, or deduction; it required reasoning, judgment, analysis, evaluation, and argumentation. So it is not surprising that he felt the most fruitful thing to do was to undertake a critical examination of the arguments on both sides of the controversy. His overall conclusion was clearly that the Copernican side was preferable to the geocentric side. But this means only that Copernicanism was more probable or more likely to be true than geocentrism; that is, that the pro-Copernican arguments were stronger than the anti-Copernican ones; or again, that the reasons for believing the earth to be in motion were better than those for believing it to stand still; or finally, that the evidence or support favoring the geokinetic idea outweighed the evidence or support favoring the geostatic one. Galileo's conclusion was not that Copernicanism was clearly true or certainly true or absolutely true or demonstrably true;⁶ nor was it that there were no reasons for believing the earth to stand still; nor was it that the geostatic arguments were worthless. The point is that the book's key thesis is one about the relative merits of the arguments on each side, that this thesis is substantiated and not merely asserted, and that the substantiation proceeds by the reasoned presentation, analysis, and evaluation of the arguments. In short, critical reasoning is a key part of both the book's content and the book's approach.

Despite the prevalence of critical reasoning, we should not be too one-sided about it; for the *Dialogue* is also full of methodological reflections. By methodological reflections I mean⁷ discussions meant to formulate, clarify, evaluate, and use general principles about the nature of truth or knowledge and about the proper procedure to follow in the search for truth and the quest for knowledge; by calling them reflections I mean to stress that they arise in the context of a particular investigation

6. This interpretation will be elaborated and defended later in the introduction (§) and the appendix (1).

7. This definition of methodological reflection, together with the earlier definition of critical reasoning, makes clear that the two are different; thus I will usually treat them as distinct activities. But for certain purposes it is useful to associate critical reasoning and methodological reflection under the single heading of critical thinking; while the two remain distinct, this association interrelates them; this is discussed in the appendix (1.8, 2.1, and 2.7). On the other hand, I will usually treat "methodological reflection" and "epistemological reflection" as interchangeable terms; and the same holds for "methodology" and "epistemology"; I will do so even though these two things are not completely identical and in some contexts a distinction is drawn between them; this is discussed in the appendix (2.1).

about what is physically true or what we know of physical reality, and so they function to help us understand better what we are doing and decide what we should be doing. That is, issues and principles about truth, method, and knowledge are constantly discussed in the book, not because Galileo intends or pretends to write an abstract treatise about the nature of these concepts, but because the specific scientific questions (about whether or not the earth is standing still at the center of the universe) are so basic that they raise questions about how one is proceeding and about the proper way to proceed. For example, there are discussions about the nature and proper role of authority, observation versus intellectual theorizing, the limitations of human understanding, independent-mindedness and open-mindedness, simplicity, probability, experiments, mathematics, artificial instruments, the Bible, divine purpose and human interest, and causal explanation.

The *Dialogue* is also a gold mine of rhetoric, but here one must be especially careful. In this context, I take rhetoric to mean⁸ the theory and practice of verbal communication, involving not only persuasive argumentation but also such forms and techniques as emotional expression, beautiful language, imaginative description, bare assertion, nuanced assertion, repetition, wit, satire, humor, and ridicule. The wealth and complexity of the book's rhetoric derive in part from its universalist aim, which implies that Galileo is addressing several audiences at once; they derive in part from its dialogue form, which means that there is a certain amount of drama unfolding before the reader; the book's rhetoric also stems from the controversial character of the scientific and methodological issues discussed, which means that we are witnessing a polemical discussion; it also stems from the context of Galileo's struggle with the Church, which means that in writing the book he was taking considerable risk and could not always say what he meant or mean what he said; the rhetoric originates to some extent from the fact that the practice of science at that time was socially and financially dependent for the most part on the patronage of princes, which means generally that Galileo's career was partly that of a courtier and specifically that his book represented an action in an intricate network of patronage involving the Tuscan Medici court in Florence and the Vatican court of Pope Urban VIII in Rome;⁹ finally, the rhetoric originates to some extent from the fact that he was a gifted writer who poured his heart and soul into this work,

8. For more details see the appendix (3).

9. For a brilliant account of this aspect of Galileo's career, see Biagioli (1993).

so much so that many passages achieve a high degree of literary and aesthetic value. Notice that I am *not* equating rhetoric with the art of deception in general, and the skill of making the weaker argument appear stronger in particular;¹⁰ so understood, rhetoric would be an inherently objectionable activity, whereas my definition allows both good and bad rhetoric. Nevertheless, rhetoric does not easily mix or coexist with scientific inquiry, critical reasoning, and methodological reflection; it considerably complicates the proper understanding and evaluation of the text. In this regard, the important thing to do is not to deny the existence of rhetoric in the book, nor to overstress it and neglect the book's other aspects, nor to conflate it with these other aspects, but to learn to detect, analyze, evaluate, and appreciate it. Fortunately, the rhetoric enhances the readability of the book and the enjoyment one can derive from the experience of reading it.

In short, Galileo's *Dialogue* can and should be read for what it tells us about the history of the Copernican Revolution, the Scientific Revolution, and the Galileo Affair, and for what it can teach us in general about critical reasoning, scientific methodology, and the art of rhetoric.

2. The Geostatic Worldview

2.1. The worldview accepted until the middle of the sixteenth century contained two main theses. One was that the earth is motionless, and so we may speak of the *geostatic* worldview, or more simply of geostaticism. The other asserted that the earth is located at the center of the universe, and so we may call it the *geocentric* theory, or more simply, geocentrism.

Although it is now known that the geocentric view is not true, it corresponds, even today, to everyday observation and common sense intuition; and, although it has this natural appeal, its technical elaboration was the result of arduous work by some of the greatest thinkers of antiquity. Two individuals made contributions which were so important

10. This seems to be the notion of rhetoric presupposed by Feyerabend (1975), Hill (1984), and Koestler (1959). They do not literally say this, but they tend to focus on situations where rhetoric is allegedly used for the purpose of deception; it is this tendency of theirs that creates the impression. Clearly, it is as wrong to claim that scientists never use deceptive rhetoric as to claim that they always do; my point is simply that scholars who usually study cases of (allegedly) deceptive rhetoric convey the impression that this is all there is to rhetoric.

that their names became synonymous with this view of the universe. Aristotle (384–322 B.C.) was a pupil of Plato who lived in Athens during the period of classical Greek civilization; he contributed primarily by elaborating the cosmology, the physics, the general philosophical principles, and the qualitative astronomical ideas of the geostatic worldview. Ptolemy lived in Alexandria in the second century A.D., at the end of the Hellenistic phase of Greek culture; he contributed primarily the mathematics and the quantitative details of the astronomical system, forging a synthesis of the observational, mathematical, and theoretical discoveries of the five intervening centuries. Thus, we may also label the old view the *Aristotelian* or the *Ptolemaic* theory of the universe. Furthermore, since the Aristotelians acquired the nickname of Peripatetics, geocentrism was also traditionally labeled the Peripatetic worldview.

These remarks suggest that the geostatic worldview was not just an astronomical theory, but contained parts belonging to philosophy, physics, and cosmology. The explanation of its details will make this interdisciplinary mixture more obvious.

Moreover, the geocentric view was not a monolithic entity, but rather a theory that underwent two thousand years of explicit historical development comprising five centuries before and fifteen centuries after the birth of Christ (not to speak of its prehistory). Thus, there are many versions of the theory; for example, Aristotle's and Ptolemy's versions differ not only in emphasis but also in substantive detail. The version expounded below is not a synopsis of any one work, but rather a reconstruction of the most widespread beliefs at the start of the sixteenth century, in a form useful for understanding the *Dialogue* and its role in the historical events it represents.¹¹

2.2. Let us begin with the question of the earth's *shape*. The geostatic view held that the earth is a sphere, so that its surface is not flat but round; this is, of course, true. In fact, the arguments proving this fact were known to Aristotle and can be found in his writings. Although uneducated persons or primitive peoples at the time of Aristotle or Galileo may have believed that the earth was flat, scholars had settled the question a long time ago; thus, it should be clear that the Copernican controversy had nothing to do with the shape of the earth but rather was concerned with its behavior and location.

11. My account has been inspired by Galileo's own *Treatise on the Sphere, or Cosmography*, a short elementary textbook of traditional geostatic astronomy that he wrote and used in the early part of his teaching career but never published (cf. Favaro 2:205–55). My account also relies on I. B. Cohen (1960), Kuhn (1957), and Toulmin and Goodfield (1961).

Similarly, the maritime voyages and geographical discoveries of Columbus and others at the end of the fifteenth century and thereafter did provide additional confirmation of the earth's spherical shape; but this was only a more direct, experiential proof of the earth's roundness. Those voyages also provided new evidence about the earth's size, structure, and composition; and this evidence affected cosmological and astronomical thought.¹² But this means that the geographical discoveries may have been a factor in the Copernican Revolution, not that the issue was about the earth's shape or size.

The size and shape which did become part of the dispute were those of the whole universe. The old view held that the universe was a sphere much larger than the earth but of *finite* size, the size being slightly larger than the orbit of the outermost planet; that is, the distance from the outermost planet to the stars was about the same as the distance between one planet and another. The stars were all at the same distance from the center, attached to the surface of the *stellar sphere*. This sphere (also called *celestial sphere*) enclosed the whole universe, and outside of it, there was nothing physical. That is, the size and shape of the universe were defined in terms of the size and shape of a sphere to which were attached about six thousand fixed stars visible with the naked eye. This contrasts with the classical modern view that the universe is infinite, space goes on without end, stars are scattered everywhere in infinite space, and so it does not even make sense to speak of the shape, size, or center of the universe.

The finite spherical universe was based on the same set of observations that led to the belief that at the center of the stellar sphere was the motionless earth. This was the phenomenon of *apparent diurnal motion*: the earth feels to be at rest; the whole universe appears to move daily around the earth in a westward direction; thousands of stars visible with the naked eye at night appear to undergo no change in size or brightness, but rather seem to be at a fixed distance from us; they appear to

12. For example, Margolis (1987) suggests that learning about the existence of large land masses in the western hemisphere made it difficult to continue believing that the terrestrial globe consisted essentially of a series of concentric spherical layers of the elements earth, water, air, and fire; as explained below, the latter thesis was an important part of the geostatic view. The connection was that if one believed that land emerged out of the oceans only in a small part of the earth's surface or on one side of the globe, then one could regard this as a minor exception to the rule that the natural place of the element earth is below the element water; but if one knows that there is another continent in the western hemisphere, this implies that land emerges out of the oceans on opposite sides of the earth, and it becomes harder to believe that the normal arrangement is or should be to have the element earth below water.

move in unison, so that their relative positions remain fixed; they appear to move in circles that are larger for stars lying closer to the equator and smaller for those lying closer to the poles. In short, the stars appear to move as if they were attached to a sphere that rotates daily westward around a motionless earth at the center. Given the plausible principle that what appears to normal observation corresponds to reality, one had the fundamental argument in support of the basic tenets of the geostatic worldview.

In the spherical finite universe, position or location or place had an absolute meaning. The geometrical center of the stellar sphere was a definite and unique place, and so was its surface or circumference; and between the center and the circumference, various layers or spherical shells defined various intermediate positions. The part of the universe outside the earth was called *heaven* in general, and to distinguish one heavenly region from another, one spoke of different heavens (in the plural); for example, the stellar sphere was the highest heaven, which meant the most distant one from the earth and which was also called the firmament; whereas the closest heaven was the spherical layer to which the nearest heavenly body (the moon) was attached, and so the lunar sphere or sphere of the moon was the first heaven. Between the lunar and the stellar spheres, six other particular heavens or heavenly spheres were distinguished; one was for the sun, and there was one for each of the other five known planets (Mercury, Venus, Mars, Jupiter, and Saturn). Details about the motion of the planets will be discussed later.

Here it is important to distinguish a *heavenly sphere* from a *heavenly body*: a heavenly sphere was one of the eight nested spherical layers surrounding the central earth, each of which was the region occupied by a particular heavenly body or group of heavenly bodies, and to each of which these heavenly bodies were respectively attached; whereas a heavenly body was a term referring to either the sun, the moon, a planet, or one of the fixed stars. The two terms are confusing because heavenly bodies were considered to be spherical in shape, and so they were spheres in their own right; but the term heavenly sphere referred only to one of the spheres concentric with the center of the universe to which the (spherical) bodies of the sun, moon, planets, and fixed stars were attached.¹³

13. This clarification has been made by Rosen (1959; 1992), who stressed that the title of Copernicus's book refers to spheres concentric with the center of the universe and not to heavenly bodies.

The terrestrial region too had its own layered structure. This is related to a threefold meaning for the term *earth*. In saying earlier that the earth is a sphere, I was referring to the terrestrial globe consisting of land and oceans; this globe is a sphere, not in the sense of a perfect sphere, but only approximately because the land is above the water and is full of mountains and valleys; such an approximation is very good because the height of even the tallest mountain is insignificant compared to the earth's radius. But it was only natural to distinguish water from earth, taking the latter term to mean just land, rocks, sand, and minerals; when so understood, earth was obviously only a part of the whole globe. It was also natural to count the air or atmosphere surrounding the globe as part of the terrestrial region; and so by earth one could also mean the whole region of the universe near the terrestrial globe, up to but excluding the moon and the lunar sphere. In short, *earth* had three increasingly broad meanings: it could refer to just the solid part of the terrestrial world; or to the globe consisting of both land and oceans; or to land plus oceans plus atmosphere.

Terminology aside, the substantive point is that the earth (namely, the place where mankind lives) is not a body of uniform composition, but contains three main parts: a solid, a liquid, and a gaseous part. These three parts (earth, water, and air) were labeled *elements* to signify their fundamental importance. In regard to their arrangement, the element earth sinks in water, and so earth must extend to the central inner core of the world and must make up most of what exists below the surface; but most of the surface of the globe is covered with water, and the element water mostly surrounds the element earth. This was expressed theoretically by claiming that the *natural place* of the element earth was a sphere immediately surrounding the center of the universe, and that the natural place of the element water was a spherical layer surrounding the innermost sphere. As for air, simple observation tells us that it surrounds the spheres of the first two elements, and so its natural place was a third sphere surrounding the first two.

There was a fourth terrestrial element, which was called fire; but it required a more roundabout explanation. Just as we see earth sink in water and water fall through air, we see flames shoot upwards through air when something is burning, currents of heat move upwards through air during hot summer days, and smoke generally rise; we also see trapped fire escape upwards in volcanic eruptions. Such observations were taken as evidence that the natural place of fire was a fourth spherical layer above the atmosphere and just below the lunar sphere.

The existence of the element fire was also derived from considerations about basic physical qualities.¹⁴ There were two fundamental pairs of physical opposites: hot and cold, and humid and dry. The element earth was a combination of cold and dry; the element water a combination of cold and humid; the element air a combination of hot and humid; so there had to be a combination of hot and dry, and that was what constituted the element fire.

In summary, from the point of view of location in the geostatic finite universe, there were twelve natural places, each consisting of a sphere or spherical layer with a common center. The four terrestrial spheres were the natural places of the four terrestrial elements (earth, water, air, and fire). The eight heavenly spheres were the natural places of the heavenly bodies; they ranged from the lunar sphere to the stellar sphere, with six intermediate spheres for the sun and the five planets. The stellar sphere enclosed everything, and the earth was at the focus of it all.

As with position, direction had an absolute meaning in the finite universe. There were three basic directions: toward the center of the universe, called *downward*; away from the center of the universe, called *upward*; and around the center of the universe. Thus, one important way of classifying motions was in these cosmological terms: bodies could and did move toward, away from, and around the center of the universe.

Geometrically, motion could be simple or mixed. Simple motion was motion along a simple line. A simple line was defined as a line every part of which is congruent with any other part. Thus, there were only two such lines—circles and straight lines; and there were two types of simple motion—straight and circular. Mixed motion was motion which is neither straight nor circular.

Another way to classify motions was in terms of the motions characteristic of the elements, namely, the motions that the elements underwent spontaneously. This categorization was meant to correspond with the two other classifications as follows. For example, earth and water characteristically moved straight downward, while air and fire characteristically moved straight upward. Now, since heavenly spheres and heavenly bodies moved characteristically with circular motion around the center, this meant that they were composed of a fifth element; the term *aether* or *quintessence* was used to refer to this heavenly element.

Finally, another important classification was in terms of the opposition between natural and violent motions. *Violent motion* was motion

14. Galileo, *Cosmography*, in Favaro (2:213).

caused by some external action; *natural motion* was motion that a body underwent because of its nature, so that the cause was internal. For example, the downward motion of earth and water, the upward motion of air and fire, and the circular motion of heavenly spheres and heavenly bodies were all cases of natural motion; whereas rocks thrown upward, rain blown sideways by the wind, a cart pulled by a horse, and a ship sailing over the sea were all cases of violent motion.

More fundamentally, motion was the opposite of rest. Rest was the natural state of bodies, and so all motion presupposed a force in some way. Natural motion was essentially the motion of a body toward or within its proper place; only when displaced from its proper place by some force would a terrestrial body engage in natural motion up or down; and only if started by some mover would a heavenly sphere rotate around the center of the universe, thus carrying its planet or stars in circular motion. On the other hand, violent motion was motion that was not toward the body's proper place, and such motion could happen only by the constant operation of a force.

From what has been said, it is apparent that earth and heaven were very different; indeed this radical difference was enshrined in an idea that needs to be made explicit and that deserves a special label. The key term is the *earth-heaven dichotomy*; but one can equivalently speak of the dichotomy between the earthly or terrestrial or sublunary or elemental region of the universe on the one hand, and the heavenly or celestial or superlunary or aethereal region on the other. We have already seen that one difference between the two regions was location, which was absolute in the finite spherical universe: terrestrial bodies occupied the central region of the universe below the moon, whereas heavenly bodies occupied the outer region from the lunar to the stellar sphere. Similarly, there was another difference in regard to natural motions: earthly bodies moved naturally straight toward or away from the center of the universe, whereas celestial bodies moved circularly around the same center.

We have also seen that the two regions differed in regard to the elements of which bodies were composed. Sublunary bodies were made of earth, water, air, and fire. On the other hand, in the superlunary region things were made of aether, or various concentrations thereof; that is, aether in low concentration made up the heavenly spheres, which were invisible; whereas, aether in a highly concentrated state generated the moon, sun, planets, and stars, which were the visible heavenly bodies.

Just as the natural places and the natural motions of the two regions obviously corresponded to each other, the elements in the two regions

also corresponded to the natural places and motions. That is, the natural places and the natural motions of terrestrial bodies could be conceived as defining the essential properties of the terrestrial elements, while the natural places and motions of celestial bodies could be conceived as defining the essential properties of aether. Other differences between earth and heaven could be defined in terms of additional properties of the different elements. For example, whereas superlunary substances had no weight, sublunary bodies obviously did; or to be more exact, whereas aether was weightless, earth and water had weight (and so they were called *heavy bodies*), and air and fire had *levity* (namely, the tendency to go up) and so they were called *light bodies*. Moreover, aether was intrinsically luminous, namely, capable of giving off its own light; but, earthly elements were dark, namely, incapable of emitting their own light; even fire did not emit an inherent light of its own but only temporarily produced light when it was in the process of escaping from lower regions to move to its natural place just below the lunar sphere.

Of the many differences between earth and heaven, two deserve special attention: natural motion and susceptibility to qualitative change. Natural motion has always been regarded as an essential or defining characteristic of a physical body. This seems to have remained unchanged even by the Copernican Revolution; from this viewpoint, what changed was the type of natural motion attributed to bodies. Since the geocentric view attributed different natural motions to terrestrial and celestial bodies, it is no surprise that it included the earth-heaven dichotomy.

To elaborate, one must first understand why the geostatic universe was *not* a trichotomy, given that there were three visible kinds of natural motions (namely, downward for earth and water, upward for air and fire, and around the center of the universe for aether). The answer implied by the discussion above is that downward and upward natural motions were both straight, and so were conceived as two minor subspecies of the same fundamental kind, namely, rectilinear motion. Geometrically, there were only two lines with the property that all parts are congruent with any other part—the circle and the straight line; thus, what was common to both upward and downward natural motions (straightness) was more important than what distinguished them (toward and away from the universal center).

However, this geometrical reason was not the only justification for making the essential distinction to be the twofold one between straight and circular natural motions rather than the threefold one among up-

ward, downward, and around. There was also the cosmological reason that, unlike circular natural motion, straight natural motion could not be perpetual. For once a rock had reached the center of the universe, its nature would make it remain there rather than continue moving past the center, which would constitute upward and thus unnatural motion for the rock; similarly, once a fiery body had reached the region above the terrestrial atmosphere just below the lunar sphere, it had reached its natural place; it had no place to go because to continue moving would bring it into the first heavenly sphere reserved for the aethereal moon where the element fire could not subsist.

Finally, there was a theoretical reason why upward and downward natural motions could belong to the same fundamental region of the universe but were essentially different from natural circular motion. The theory in question was the theory of change as contrariety, according to which all change derives from contrariety, and no change can exist where there is no contrariety; by contrariety was meant such oppositions as hot and cold, dry and humid. Now, up and down, together with the related pair of light and heavy, was another fundamental contrariety. Thus, a region full of bodies some of which moved naturally downward and some upward was bound to be full of all sorts of qualitative changes; and indeed observation obviously revealed that the terrestrial world is full of birth, growth, decay, generation, destruction, weather and climactic change, and so on. On the other hand, the circular natural motion of the heavenly bodies was thought to have no contrary; consequently, the heavenly region lacked an essential condition for the existence of change. Add to this the belief that the opposition between hot and cold and between dry and humid belonged only within the four terrestrial elements, and one could claim that the region of aether lacked any of the proper conditions for change. And observation confirmed that claim, too, because no physical or organic or chemical changes were easily detected in the heavens, and none were said to have ever been seen; the only essential phenomenon in the heavens was motion, but all heavenly motion was regular and involved the rotation of concentric spheres, which thus remained in place, so that there was not even change of place; what changed was only the relative position of the various bodies attached to these celestial spheres.

This analysis clarifies how natural motion and qualitative change provided the basis for the earth-heaven dichotomy. There were many differences between earth and heaven, but two interrelated ones were crucial: in the terrestrial world bodies moved naturally with straight motion and

underwent qualitative change, whereas in the celestial region things moved naturally with circular motion and were not subject to qualitative change.

To summarize the discussion so far, the Aristotelians and Ptolemaics believed that the earth was spherical, motionless, and located at the center of the universe; that the universe was finite, was bounded at the outer limit by the stellar sphere, and was structured into a series of a dozen nested spheres, all inside the stellar sphere and surrounding the central sphere of the solid earth; that there was a fundamental division in the universe between the earthly and the heavenly regions; and that these regions consisted of bodies with very different properties and behavior, such as different natural places, natural motions, elemental composition, and possibilities for qualitative change. Two things must now be added to this general cosmological picture: the details of the physics of the motion of terrestrial bodies and the astronomical details of the heavenly bodies. Let us begin with the former.

2.3. In the terrestrial region, the natural *state* of bodies was rest. To be more exact, it was rest at the proper place, depending on the elemental composition of the body: at the innermost core for the element earth; just above that for water; above water for air; and above air for fire. This meant that, whereas no cause was sought to explain why a body rested at its proper place, when a body was in motion or at rest outside its proper element, an explanation was required.

The explanation for why a body was in motion could be that it was going to rest at its proper place; this was the case of natural motion like rocks and rain falling or smoke rising through air. Or the explanation could be that the body was being made to move by an external agent; this was the case of violent motion, for example, a cart pulled by a horse, a boat sailing over the water, rain blown by the wind, or weights being lifted from the ground to the top of a building. But both natural and violent motions required a force; the only difference was that in natural motion the force was internal to the body, whereas in violent motion the force was external. For example, falling bodies fell because of their inherent tendency to go to their natural place if they were not already there; this internal force was termed *gravity* and was measured by the weight of an object. On the other hand, for a sailboat, the wind was obviously the external force, and for a cart, the horse.

Sometimes "violent motion" was equated with "forced motion," but in such cases it was understood that by "forced motion" one meant motion caused by an *external* as distinct from an *internal* force. Since all mo-