Copernicus, Darwin, & Freud

Copernicus, Darwin, & Freud: Revolutions in the History and Philosophy of Science

Friedel Weinert

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Preface

The present volume originates from seminars the author first gave at Victoria University in Wellington (New Zealand) and later at the University of Bradford (UK). The idea for the seminars and the book goes back to Freud's claim to have completed the Copernican revolution. The seminars and the book were conceived in the spirit of the author's conviction that a tight connection exists between scientific and philosophical ideas.

The completion of the manuscript was facilitated by the award of a Visiting Fellowship in the Department of Philosophy, Logic and Scientific Method at the London School of Economics (June to December 2006). I would like to thank members of the Department for their hospitality. I owe particular thanks to Stephan Hartmann for encouraging me to apply and for acting as my referee for research grant applications. I gratefully acknowledge the financial help from the School of International and Social Studies at the University of Bradford. I also benefited from a Small Research Grant, awarded by the British Academy, which made my LSE visit financially viable. Robert Nola of the University of Auckland (NZ) read the first draft of the manuscript and gave me valuable advice on how to improve it. I hereby express my gratitude to him both for his encouragement and for acting as my referee in research grant applications. I am also grateful to several anonymous referees who provided useful comments on the manuscript. Finally, I owe thanks to Nick Bellorini, Senior Commissioning Editor at Blackwell, for supporting this project. I would also like to thank Annette Abel, my copy-editor, for her careful reading of the manuscript and for stylistic improvements.

I hope the reader will enjoy reading this book as much as I enjoyed writing it.

Friedel Weinert
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Introduction

This book deals with issues in the area of intersection between the history and philosophy of science. Using Copernicanism, Darwinism, and Freudianism as scientific traditions, it aims to show that a tight connection exists between science and philosophy. There are many more connections between Copernicus, Darwin, and Freud than their respective contributions to the completion of the Copernican revolution. The study of Copernicanism, Darwinism, and Freudianism shows that scientific approaches to the world naturally and inevitably lead to philosophical consequences.

Freud saw that scientific ideas change the way we think about the world. With his heliocentric view, Copernicus displaced humans from the physical center of the universe (1543). With his evolutionary theory, Darwin inserted humans into the organismic order of nature (1859). According to Freud, both Copernicus and Darwin dealt severe blows to the proud image of humans as masters of the universe. Freud saw himself as completing the cycle of disparagement by destroying the belief that humans were "masters in their own house" (1916).

But the impact of scientific ideas on human self-images is only a small part of the philosophical consequences that scientific theories typically have. The present book is a study of three revolutions in thought and their philosophical consequences. It is an exercise in an integrated approach to the history and philosophy of science. Chapter I is devoted to the transition from geocentrism to heliocentrism. Chapter II focuses on the momentous shift in views on the nature of organic life that will forever be associated with the name of Charles Darwin. Chapter III discusses Freud's shift from Enlightenment rationality to unconscious motivations as the driving force of human behavior. A glance at the table of contents will show the reader that each chapter selects a number of philosophical issues, which derive from the study of the respective traditions in the history of scientific ideas.

The title of the book, *Copernicus, Darwin, and Freud: Revolutions in the History and Philosophy of Science*, conveys, as illustrated in the discussion of Copernicanism, Darwinism, and Freudianism, a threefold message: first, that human views of the surrounding natural and social world constantly adapt to new scientific discoveries;

second, that as science progresses, the achievements of former ages come under further scrutiny; and third, that philosophical consequences are necessarily implicated in these changes. I do not mean to claim that a process of constant uprooting and rebuilding of the edifice of knowledge takes place. Such a discontinuous view of the growth of scientific knowledge is mistaken, as the discussion of scientific revolutions will attempt to show. I mean that established knowledge will be inserted into new problem situations, which will result in modifications on many levels. Popper was right in saying that all scientific knowledge is conjectural knowledge. And as long as humans inhabit the solar system, it is to be expected that new ways of thinking will emerge and will reevaluate the place of human beings in the wider cosmos. Even though today's humans possess more quantitative knowledge, boast more technological prowess than Newton's contemporaries, Newton's abiding image still rings true: we are still like children, playing with pebbles on a beach, while a vast unknown ocean lies before us.

I

Nicolaus Copernicus: The Loss of Centrality

The mathematician who studies the motions of the stars is surely like a blind man who, with only a staff to guide him, must make a great, endless, hazardous journey that winds through innumerable desolate places. [Rheticus, Narratio Prima *(1540), 163]*

1 Ptolemy and Copernicus

The German playwright Bertold Brecht wrote his play *Life of Galileo* in exile in 1938–9. It was first performed in Zurich in 1943. In Brecht's play two worldviews collide. There is the **geocentric worldview**, which holds that the Earth is at the center of a closed universe. Among its many proponents were Aristotle (384–322 BC), Ptolemy (AD 85–165), and Martin Luther (1483–1546). Opposed to geocentrism is the **heliocentric worldview**. Heliocentrism teaches that the sun occupies the center of an open universe. Among its many proponents were Copernicus (1473–1543), Kepler (1571–1630), Galileo (1564–1642), and Newton (1643–1727).

In Act One the Italian mathematician and physicist Galileo Galilei shows his assistant Andrea a model of the Ptolemaic system. In the middle sits the Earth, surrounded by eight rings. The rings represent the crystal spheres, which carry the planets and the fixed stars. Galileo scowls at this model. "Yes, walls and spheres and immobility," he complains. "For two thousand years people have believed that the sun and all the stars of heaven rotate around mankind." And everybody believed that "they were sitting motionless inside this crystal sphere." The Earth was motionless, everything else rotated around it. "But now we are breaking out of it," Galileo assures his assistant. In the new model stars are no longer "fixed to a crystal vault"; they are allowed to "soar through space without support." [Brecht 1963; Blumenbach 1981, Vol. III, 762–82]

In Act Two learned scholars, a Mathematician and a Philosopher, visit Galileo in his study to look at the Jupiter moons through the newly discovered telescope. Galileo briefly explains the failings of the Ptolemaic system to them. It simply is not consistent with the facts. The planets are not "where in principle they ought to be." And the motions of the Jupiter moons around their planet, Galileo's great discovery, can simply not be explained on the Ptolemaic system. So much for words! Seeing is better than talking. Rather naively, Galileo asks his learned guests whether they would "care to start by observing these satellites of Jupiter." Unfortunately for Galileo both the Mathematician and the Philosopher refuse Galileo's invitation. Rather than observations, they demand "a formal dispute" in the scholastic tradition. "Mr. Galileo," asks the Philosopher, "before turning to your famous tube, I wonder if we might have the pleasure of a disputation? Its subject can be: Can such planets exist?" Galileo simply wants them to "look through the telescope" and convince themselves. "Of course, of course," says the Mathematician, "I take it you are familiar with the opinion of the ancients that there can be no stars, which turn round centers other than the Earth, nor any, which lack support in the sky?" Brecht only dramatized a real event. In a letter to Johannes Kepler (dated August 19, 1610), Galileo laments the steadfast refusal of scholastic professors, like Cesare Cremonini, a humanist at the University of Padua, to view the moon and the planets through the newly invented telescope. [Blumenberg 1955, 637]

2 A Clash of Two Worldviews

In his play, Brecht captures the clash of two worldviews brilliantly as he charts out the dialogue which might have developed between Galileo and his scholarly visitors. The disputation ends to the dissatisfaction of both parties. Soon the visitors leave without ever having glanced through the telescope. Adherence to the geocentric (Earth-centered) worldview makes Galileo's visitors disparage his appeal to observational evidence. Adherence to the heliocentric (sun-centered) worldview makes Galileo distrust the usefulness of learned disputations. In order to understand how the respective supporters of the two opposing worldviews came to clash so violently, as dramatized in Brecht's play, we have to look more closely at their presuppositions. We have to scrutinize the structure of the geocentric and the heliocentric worldviews.

Geocentrism predates heliocentrism by a millennium and a half. Copernicus knew of an ancient precursor: Aristarchos of Samos, who had proposed the conception of a moving Earth. But geocentrism remained the official explanation of the structure of the universe until its slow erosion in the sixteenth and seventeenth centuries. The dialogue between Galileo and his visitors could have taken place in the summer of 1610. The Copernican hypothesis had been known for 67 years. It would take another 77 years, until the publication of Newton's *Principia* (1687), before the geocentric worldview finally conceded defeat. It took 144 years of active debate and research for the Copernican view to establish itself. Can a scientific revolution take that long? What is important about a revolution is not its length but its depth. What makes a change revolutionary is its upheaval in an established structure, a reversal of viewpoints, a replacement of presuppositions. It is a general rearrangement of elements in a network, be it conceptual, political, or social. Some elements in the system are displaced, some replaced, and others remain. To understand a scientific revolution – the tangle of philosophical and scientific elements – we need to understand the system *before* its rearrangement. So to understand the Copernican revolution, we need to understand the geocentric worldview.

2.1 The geocentric worldview

> *Now the ancients build up one heaven upon another, like layers in a wall, or, to use a closer analogy, like onion skins: the inner supports the outer (…). [Kepler,* Epitome *(1618–21), Bk. IV, Part I, §3 (21)]*

Geocentrism is much more than the view that the Earth resides motionless at the center of the universe. It amounts to a worldview that emerged in two phases. First, Aristotle provided a physical cosmology – the larger architecture of the cosmos. His cosmology included an important theory of motion. Aristotle advanced some unsatisfactory ideas about the motions of the planets. In a second phase Ptolemy furnished the mathematical astronomy – the geometry of the planetary motions. The Greek division of labor between physical cosmology and mathematical astronomy hindered the development of astronomy for centuries. [Dikjsterhuis 1956, §77, 146; Mittelstraß 1962, Ch. 4.4; de Solla Price 1962] For it separates the dynamic question of physical causes – why planets move in particular ways – from the kinematic question of motion – how the motion of these bodies can be described mathematically. In his *Almagest* (published around AD 150), Ptolemy explicitly embraces this distinction. Physics deals with the corruptible bodies on Earth; it amounts to no more than guesswork, which is due to the "unclear nature of matter." Mathematics, however, provides certain knowledge, since it investigates the nature of "divine and heavenly things." [Ptolemy 1984, 36] This separation was to last until Kepler's discovery of planetary laws at the beginning of the seventeenth century. As a worldview, geocentricism claimed to provide a scientific account of what was then regarded as the cosmos. It engaged its adherents in a number of philosophical commitments. It presented to its believers a comprehensive and coherent view of the universe. So did heliocentrism. With so much at stake, Brecht's play rightly depicted the frosty encounter of three scholarly men in 1610 as a clash between worldviews.

2.2 Aristotle's cosmology

Aristotle constructs his cosmology on the basis of a two-sphere universe and a theory of motion. Later Ptolemy provided some mathematical refinements.

1 Aristotle constructs a **two-sphere universe**. It is divided into the *supralunary sphere*, which includes the moon and the region lying beyond it, and the *sublunary sphere*. This is the region between the Earth and the moon. The Earth is a tiny sphere suspended stationary at the geometric center of the much larger

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Figure 1.1 The circular orbs and order of the planets in Antiquity. The sun is situated among the other planets. The Earth sits motionless at the center

rotating sphere which carries the stars. The stars are markings on the outer sphere. In this picture it is the steady rotation of the outer sphere that produces the daily (diurnal) circles of the stars. Between the outer sphere and the Earth, smaller concentric spheres carry the then known six planets, including the sun. [Figure 1.1]

The supralunary sphere is, according to Aristotle, a region of utmost *perfection*, *symmetry*, and *regularity*. The Greeks ordained the *circle* as a perfect geometric shape. It is therefore in accordance with the perfection of the supralunary sphere that the stars and planets should move in perfect circles. By contrast, the sublunary sphere is the region of *change*, *flux*, and *decay*. The sublunary sphere is filled with four elements: earth, water, fire, and air. If undisturbed, they would settle in concentric shells around the central region of the Earth. But owing to the movement of the sphere of the moon, the elements get mixed throughout the sublunary world.

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Aristotle (354–322 BC)

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Figure 1.2 A simple homocentric model. The Earth is located centrally. Nesting concentric rings or shells (orbs) envelop it. [See Andersen/Barker/Chen 2006, Ch. 6.4; Barker 2002] These carry the planets. The outer ring carries the distant stars. The model fails because planets move at varying distances from the Earth

The motions of the lunar sphere are therefore responsible for all change and almost all variety observed in the sublunary world. [Kuhn 1957, 82–3]

This cosmology of a "cosmic onion" sounds very obscure to modern ears. To ancient eyes Aristotelianism presented the most comprehensive and convincing theory of the architecture of the cosmos. It seemed to account for some of the naked-eye observations available at the time. The centrality of the Earth, so it seemed, could be inferred from the path of falling objects on Earth and the circular motion of the stars.

Following the Greek philosopher and astronomer Eudoxos (408–355 BC), Aristotle assumed that the planets and the stars moved in concentric shells (or orbs) around the central Earth. [Figure 1.2] On closer inspection, this simple model must fail. It did not even fit Greek observations. For instance, if the sun were carried around the central Earth on a concentric shell, night and day would always retain equal lengths. Yet the Greeks knew from their observations that day and night have variable lengths, depending on the seasons. [See Section 3.2] The Greeks also noticed that planets move at varying distances around the Earth. The model of homocentric spheres had to be dropped. It was in contradiction with elementary observations. It was Ptolemy's achievement to have constructed a geometric model on the basis of the more complicated geometry. It involved the invention of new geometric devices: eccentrics, epicycles, deferents, and equants. [Dijksterhuis 1956, §68, 147; Rosen 1959, Introduction; Copernicus, *Commentarioulus* 1959, 57; Copernicus 1543, Bk. V, §3; Dreyer 1953, 143]

2 Although Aristotle's rudimentary views of planetary orbs were quickly replaced, his **theory of motion** proved to be a much more lasting contribution. Aristotle devised his influential theory of motion to support his cosmology. His model of the cosmic "onion" made the Earth a central, stationary object. How could this centrality be justified? The theory of motion claimed to provide a physical mechanism to account for the trajectory of all objects – earthly and celestial.

According to the Aristotelian theory of motion, objects either remain at rest or move in a straight line. A stone will fall back toward the center of the universe, occupied by the Earth. Smoke will rise upward toward the sky, in search of its natural place. The upward and downward motions constitute the object's *natural* motions. In order to deflect objects from their natural motions an external push or force is needed. To move, objects need a mover, which moves them. There is no motion without a mover: *Omne quod movetur ab alio movetur*. [Aristotle 1952a, Bk. VII, VIII] Of course, Aristotle could observe that projectiles do not behave in this way. A stone hurled through the air or an arrow released from a bow will normally fly in a parabola before returning to Earth. Aristotle could explain the projectile's motion. After the release of the object from the mover, disturbed air became the source of the external push. It prolonged the projectile's motion.[1] Eventually the object would succumb to its inclination to return to the Earth.

The natural motion for heavenly objects is circular. Circular motion is continuous and infinite. Aristotle states that continuous motion – the rotatory locomotion of the planets – is caused by an unmoved mover, a Deity. [Aristotle 1952a, Bk. VIII, §10]

Thus things have natural and unnatural motions. They also occupy natural places in the universe. Aristotle held that the four building blocks of the universe – earth, water, fire, and air – hold natural positions on and near the Earth. If wrestled from their natural positions, the elements *strive* to regain their natural position. When a stone is lifted from the ground and released, it seeks to regain its natural position. When a fire is lit, flames and smoke leap up toward their natural positions at the periphery of the terrestrial region. The natural position of the Earth is at the geometric center of the universe. For something at rest must exist at the center of the revolving heaven. Therefore, Aristotle concludes, the Earth must exist. [Aristotle 1952b, Bk. II, §3] A piece of Earth will always fall to where it naturally belongs, i.e., the geometric center of the universe. From these arguments from terrestrial physics Aristotle derived not just the centrality of the Earth but also its stability and sphericity. [Aristotle 1952b, Bk. II, §§13–4] In lunar eclipses, he points out, the outline of the Earth's shadow on the moon "is always curved"; and as observers travel north and south along a longitude, different stars become visible to them in the sky. Later Ptolemy added some further arguments. The sun, the moon, and the stars are seen to rise earlier for inhabitants of eastern regions of the globe than "for those toward the west." [Ptolemy 1984, §I.4]

Aristotle's physical cosmology and his theory of motion form a logical link. The theory of motion renders the cosmology reasonable. And his cosmology provides the necessary framework for physical phenomena to be arranged into two separate spheres. The Aristotelian laws of motion govern the sublunary sphere. In the sublunary sphere terrestrial physics rules. The laws of motion account for the apparent observations in this region of space: the drop of heavy objects and the

[1] Kuhn [1957], 119; Dijksterhuis [1956], I, §§30–9. Contrast this account with the Newtonian explanation. According to Newton's First Law objects are either at rest or perform a constant rectilinear motion (if undisturbed). Rectilinear motion has become a "natural" motion, for which no external force is required.

rise of light objects. In the supralunary sphere celestial physics rules. This is the region of perfection. It admits only of spherical shapes and circular motion. It is a finite region. In Brecht's play Galileo complains about the "walls" and "immobility" of the geocentric universe. The distance to the stars was estimated to be 20,000 Earth radii, which is less than today's Earth–sun distance. [Zeilik 1988, 29–31] The outer boundary is marked by the sphere of fixed stars. Although this sphere rotates in a period of 24 hours once around the motionless Earth, the stars appear fixed because after each rotation they reappear in the same location as in the previous periods. The planets, by contrast, are "wandering stars," because they perform observable, traceable movements across the sky. The Aristotelian cosmos is an energy-deficient universe. Its energy-deficiency is a direct consequence of Aristotle's theory of motion. There is no motion without a mover. Heavenly bodies are moved on their spheres by a mover, residing outside the outer sphere. The Aristotelian universe requires an energy-input from beyond the fixed stars – it is finite. As we shall see, the Copernican universe is also finite but it is no longer energy-deficient.

2.3 Ptolemy's geocentrism

Aristotle gave us a cosmology and a theory of motion. This was the first step in the construction of the geocentric worldview. The second step was completed several hundred years later. It took a consummate geometer to do it: Claudius Ptolemy. Ptolemy was the first astronomer to design a complete mathematical system of the universe, which accurately predicted planetary motions to within 5° of modern values. His was a *geocentric* model, built by means of *geometric* reasoning. Later Copernicus would construct a *heliocentric* system, also built by means of *geometric* reasoning. Ptolemy uses geometry to describe astronomical observations. He agrees with Aristotle that the celestial spheres, which carry the planets, perform *uniform* motions. He assumes that the Earth is *spherical*, at the *center* of the cosmos, and *stationary*. If the Earth were not central, he argues, the equinox would not occur, and "intervals between summer and winter solstice would not be equal." [Ptolemy 1984, §I.5] Ptolemy offered perfectly good reasons for rejecting as ridiculous any motion of the Earth. Aristarchos of Samos (310–230 BC) is said to have taught the daily and annual rotation of the Earth. [Dreyer 1953, Ch. VI, 136–48; Dijksterhuis 1956, Ch. I, §§78–9; Kuhn 1957, Ch. I; Koestler 1964, 50–2] But if the Earth moved, its inhabitants would feel the effects drastically – objects thrown straight up into the air would not return in a straight line to the spot from where they had been launched; buildings would crumble under the force of the motion; birds would never fly from west to east. [Ptolemy 1984, §I.7; cf. Copernicus 1543, Bk. I, §7] To the Greek mind it was commonsense that the Earth was at rest.

Claudius Ptolemy (AD 100–75)

But there was a problem. The Earth-bound observer does not observe the uniformity of planetary motion against the background of the fixed stars. Equipped with his basic presuppositions, Ptolemy, like other astronomers before him, had to explain two main variations in the motions of the planets. *First*, there was their **nonuniform motion** and *second* their **retrograde motion**. The problem arises because the observations do not conform to the Ptolemaic presuppositions about planetary motions. The basic problem of ancient astronomy is to construct geometric models, which satisfy the a priori presuppositions and seemingly account for the apparent motions of the planets. It is the *problem of saving the appearances*, rather than constructing realistic models of the solar system. Like his Greek predecessors, Ptolemy relied on geometric models to solve these problems. Ptolemy tried to fit the observations to his unquestioned presuppositions: the circular motion of celestial objects and the Aristotelian theory of motion. But Ptolemy improved the usefulness of the models. Some of Ptolemy's predecessors, like Hipparchus (190–125 BC), had invented new geometric devices to deal with these problems. *Eccentric motion* was used to solve the first; *epicyclic motion* was used to solve the second. In his *Almagest* Ptolemy made frequent references to Hipparchus's work, usually with the intention of improving it. He introduced a new geometric device (the equant) to achieve a better geometric model of the appearances. He treated each problem separately. For instance, in dealing with the apparent annual motion of the sun around the Earth, he ignored its apparent daily motion. Unlike the Copernican model, the Ptolemaic model does not present a system in which the appearances are due to a common factor – like the motion of the Earth around the sun.

The first problem was the **nonuniform motion** of the planets through the zodiac, irrespective of the effect of retrograde motion. As Kepler later showed, planets do not orbit the sun at uniform speed. The nearer they are to the sun the faster they move, and the further they are away from the sun the more slowly they amble. But the Greeks could not accept such nonuniform motion as real. It had to be apparent.

How can uniform circular motion account for apparent nonuniform motion? The answer is eccentric motion. [Figure 1.3]

The sun is modeled as moving around the Earth on an eccentric circle at uniform speed. The circle is called *eccentric* because the Earth does not occupy its center. While the sun moves around the center of the eccentric, the Earth is slightly displaced from its center. The distance between these two points accounts for the appearance of variation in motion. As seen from the center of the eccentric, the planet moves through equal angles in equal times. But as seen from the Earth, the planet sweeps through different angles in equal times. For the Earth-bound observer, when the planet is closer to the Earth, it *seems* to be moving faster.

The second problem is the apparent anomalous westward motion of a planet with respect to the stars: its **retrograde motion**. It is accompanied by a change in brightness. For outer planets it occurs near the time of opposition, when the planet is opposite the sun in the sky. For inner planets, like Mercury and Venus, it occurs at inferior conjunction, when they are seen close together with the sun in the sky.

Figure 1.3 Eccentric motion. Explanation of apparent non-uniform motion on the assumption of uniform motion. The sun moves uniformly around point (*Ecc*). Seen from the Earth (*E*), however, the uniform motion looks non-uniform. At point 1 the sun appears furthest away from the Earth (apogee), while at point 2 it appears at its closest approach to the Earth (perigee)

The ordinary eastward path of planets seems interrupted – for a time, observers see the planets go westward. [Figure 1.4]

The appearance of nonuniform retrograde motion was solved by using the geometric device of epicyclic motion. The planets are carried on smaller circles (epicycles) moving on larger ones (deferents). Although the Greeks observed retrograde motion, it was only apparent, not real motion. The real motion of celestial objects required uniform circular motion. The task consisted in constructing models that fitted the observations without violating the presuppositions. Epicyclic motion is modeled by introducing a *deferent*, with the Earth at the center, and a smaller circle, an epicycle, mounted on the deferent. [Figure 1.5a] The radii of both epicycle and deferent move in the same direction. For an observer on Earth the planet performs a retrograde motion as it passes through the lower part of the epicyclic motion. This model, however, is too simple. It cannot account for the observational variations in retrograde motion of the planets. To explain the variations, Ptolemy invented a new device: the *equant*. [Figure 1.5b] This is an imaginary point on the other side of the center of the deferent as seen from the Earth. At the equant, an observer would see the planet move around its orbit through the sky at a uniform speed relative to the stars. But from a viewpoint on Earth away from the circle's center, the motion appears nonuniform.

For our later philosophical exploration we should note several points. Ptolemy was very well aware of the role of representational models in his theory. His usual method is to use geometric models but in order to represent the fixed stars he chooses a solid globe as a scale model. [Ptolemy 1984, Bk. VIII.3] At the same

Figure 1.4 A simplified scheme of the appearance of retrograde motion of Venus as seen from by an Earth-bound observer. The observer "marks" the position of Venus against the background stars as the planet prepares to overtake Earth in its orbit – position 1. When Venus has overtaken Earth, the observer makes a second observation: as expected, Venus has moved from west to east – position 2. But at a later stage, a third observation reveals an apparent and abnormal retracing of the orbit of Venus toward the west. In a heliocentric view this is due to the relative position of the Earth with respect to Venus around the sun. [See Zeilik 1988, 40; Copernicus 1543, Bk. V, §35]

time, Ptolemy worried about the fit of his geocentric hypotheses. He was skeptical enough to warn his readers not to expect his geometric models to properly represent the celestial phenomena. [Ptolemy 1984, 600–1] In the spirit of Aristotle's two-sphere cosmology he cautioned that geometric models invented by an inhabitant of Earth could not do justice to the perfection of the heavenly phenomena. As we shall see, the question of how models manage to represent physical reality is of great interest to philosophers. Finally, Ptolemy agreed with the Greek tradition that the epicyclic and eccentric models were equivalent devices. [Ptolemy 1984, §§III.3, IV.5, XI.5; Rosen 1959, 37; 1984, 27; Dijksterhuis 1956, I, §71] Either of these two hypotheses will account for the appearance of irregular motion of the planet to the Earth-bound observer. Nevertheless, Ptolemy adopts the principle that only the simplest hypothesis be used. [Ptolemy 1984, §§III.1, XIII.2] The acceptance of equivalence raises interesting philosophical issues regarding explanation and representation. If the eccentric circle is as good a representation as the deferent–epicycle device, is there no way of deciding which one fits the actual physical system better than the alternative? Such concerns belong to the philosophical consequences of scientific theories.

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Figure 1.5 (a) Epicyclic motion. Retrograde motion occurs when the planet moves from P1 to P2 on its epicycle; (b) The equant. Explanation of retrograde motion with a new geometric device, the equant. [See Copernicus 1543, Bk. III, §15–16; Ptolemy 1984, §IX.6; Andersen/Barker/Chen 2006, Ch. 6.3] This representation is supposed to be a closer fit of the model to the data than the elementary model. From the point of view of the equant, the motion of the planet on the epicycle would appear uniform. Further flexibility is introduced by letting the Earth either sit at the center of the deferent or off-center, as indicated in the diagram

Before we mention some of the developments of the thirteenth and fourteenth centuries, which created the conditions for the emergence of the Copernican revolution, we should add another historical dimension. This is the synthesis between *Aristotelianism* and *Theology*. Only this further historical dimension could bring to a head the clash between Galileo and the Church in the seventeenth century. The synthesis was worked out by Thomas Aquinas (1225–74), Albertus Magnus (1206–80), and others.

According to Acquinas, real knowledge is based on sense experience. Albertus Magnus also stresses that the study of nature is based on sense experience, which provides the highest form of proof. Where we lack knowledge we have to appeal to revelation. The perfection of the heavens, postulated in the Greek tradition, is now identified with Divinity. Consequently our knowledge of the world is restricted to the sublunary sphere. The perfection of the heavens transcends our reasoning powers. Aquinas welcomes the systematic study of nature because he sees in it a means to acquire knowledge of the wisdom of God. To put it drastically, Aquinas hopes that a systematic study of nature will help to eradicate superstition. Couched in these terms, no conflict between Reason and Revelation is permitted to arise, for our reason is weak and faulty and in questions of doubt has to submit to the eternal Truth as expressed in the Revelation. This is a common attitude in the Middle Ages. Roger Bacon (c.1210–92) defends a similar idea. The value of science lies in its contribution to the interpretation of the Bible. It helps to glorify God. Once the Church had embraced Aristotelianism, all criticism directed at the geocentric worldview would also be a criticism of theology and the Church.

Nevertheless, progress was made and some developments took place toward the end of the Middle Ages. Progress, however, depended on the ability to overcome unquestioned presuppositions, which impose constraints on permissible models. This need to clear away presuppositions before progress could occur could be expressed in Kantian terms. Kant asks very generally in his Copernican turn in philosophy, "What are the conditions of the possibility of knowledge?" By analogy we can ask, "What are the conditions of the possibility of the Copernican, the Darwinian, and the Freudian revolutions?" Which new presuppositions were needed for the Copernican view to be able to arise? The questioning of ancient presuppositions happened in two stages: the Aristotelian theory of motion attracted critical scrutiny before the ideal of circular motion was questioned.

2.4 A philosophical aside: Outlook

Let us regard the Aristotelian theory of motion and his physical cosmology or the Ptolemaic devices as instructions in a toolkit, with which we try to build a model of the universe. Our building blocks are fixed stars and planets, circular spheres, a stationary Earth. Our instruction sheet contains a further restriction: the model we build must be as close as possible to naked-eye observations. Most strikingly, we observe the movement of the planets against a background of stars, the succession of the seasons, and the regular sequence of day and night. With these elements at hand we can build only a *geocentric* model. The sun, the planets, and even the fixed background of distant stars must parade before our eyes. The Earth must therefore be located at the center of these movements, for otherwise we could not account for them. [Figure 1.1]

Our ability to build *one* type of model, if we follow the instructions, is at the same time an inability to construct a *different* model. We can think of the toolkit as creating a space, more precisely a *constraint space*, to accommodate cosmological models. Such a constraint space is a logical space, because it creates certain possibilities, whether they materialize or not, for model-building. Geometric-type models will be allowed to inhabit the space; other types of models are excluded. This play of possibilities and impossibilities is regulated by the constraints we accept. Aristotle operated under the constraints of his theory of motion and his two-sphere cosmology. If we change the constraints, a different logical space will appear, which will accommodate other types of models. **Constraints** can be understood as restrictive conditions, which symbolic statements must satisfy in order to qualify as admissible scientific statements about the natural world. This teaches us some lessons, which will interest the philosopher of science.

1. Scientific theories come with certain *constraints*: empirical and theoretical constraints, which can be further subdivided into mathematical, methodological, and metaphysical constraints. Scientific theories operate under such constraints. With the exception of empirical constraints, these constraints form *presuppositions.* Presuppositions are fundamental assumptions, which, at least for the time being, are protected from critical inquiry. They are accepted as "true." They serve as historical a priori. They are not unquestionable but they remain unquestioned for certain periods of time. Whether true or false, they channel research into particular directions. The Aristotelian toolkit contains such presuppositions. The two-sphere cosmology and his geometric devices, including the theory of motion, form the Aristotelian presuppositions. Presuppositions can be exposed to doubt. This happened when Aristotle's concentric shells were replaced by other devices. Under such scrutiny, constraints will be amended or rejected. Already a modification of the model instructions, keeping the elements, will change the possibilities for model construction. The adoption of epicycles, for instance, created the space for the Ptolemaic model. Sometimes a modification of a constraint is more far-reaching. A questioning of the Aristotelian theory of motion and its replacement by the so-called *impetus* theory liberated the constraint space for the development of new theories. It is difficult to imagine how heliocentrism could have emerged, if some fundamental presuppositions had not changed. [Blumenberg 1965, Ch. I] Copernicus, for instance, was able to reject some of the classic objections against the motion of the Earth, because he no longer shared the Aristotelian theory of motion. The development of the impetus theory allowed him to regard the motion of the Earth as natural.
2. We can also see that constructing a cosmological model is not a matter of simply reading it off the available observational data. It cannot be, if presuppositions are as much a reality of scientific thinking as its methods and established results. [Weinert 2004] So a simple inductive view of the scientific method will not do, at least not in the case of scientific revolutions. Let us call the view that sees science as a straightforward generalization from observations

and experiments *induction by enumeration*. Francis Bacon already criticized this view. There is a more sophisticated way, called *induction by elimination*. Francis Bacon recommended this view as a fruitful scientific method. It is called *eliminative induction* because alternative or rival models are confronted with empirical evidence and other forms of constraints. The model, which fares better in view of these constraints, will gain in credibility while the rival model will lose credibility. So this view requires that there are at least two models available, which face the evidence. As we shall see, the Copernican and Darwinian revolutions come about by a progressive elimination of unsuccessful models in the face of an increasing number of constraints. The difficulty with Freudianism is precisely that the available evidence is unable to credit some model at the expense of its competitors. Is the overwhelming method of science eliminative induction or the more familiar method of falsificationism, as proposed by Karl Popper?

Even at this early stage of the argument, it is good to raise these philosophical questions because – and this is one of the **central theses** of this book – philosophical issues are inseparable from more scientific and historical concerns. In other words, *scientific revolutions have philosophical consequences*. We shall witness this logic at many points along the road.

3. An immediate question springs to mind, not just for the philosophically inclined. Do these geometric devices actually represent physical spheres, while the nonuniform variations are just appearances? Do these geometric devices – the epicycle and the deferent, the equant and the eccentric – describe some physical mechanism, which exists in nature? This is the question of the *representational* force of scientific models, which already exercised Ptolemy. Does the distinction between appearance and reality, between how the planets appear to move according to naked-eye observations and how they are said to move according to the Greek presuppositions, correspond to a physical feature of the universe? If we are interested in what science is and does, such questions, although philosophical in nature, are inescapable. Whatever position we adopt in response to these questions, they actually do some real work. The proponents of the geocentric worldview were divided on this question. Aristotle thought that the spheres were real physical spheres. They possess a natural motion: circular rotation. The natural motion of these spheres drives all the heavenly bodies. They depend on an unmoved mover for their energy requirements. Ptolemy was much less certain of the physical reality of the crystal spheres, the epicycles and deferents, which he was employing as geometric devices. True, they served to *save the appearances*. But Ptolemy did not think that the geometric devices fitted the heavenly phenomena very well. [Ptolemy 1984, 600–1; Dreyer 1953, Ch. IX] The Greek models try to match naked-eye observations with a priori presuppositions about the physical world. The postulation of uniform circular motion, of the two-sphere universe, of geometric devices is not based on observations. On the contrary: the observations seemed

to contradict the presuppositions. So much worse for the observations! The separation between physical cosmology and mathematical astronomy did not encourage Greek astronomers to think of observations as tests for the mathematical models. The question is whether models can achieve more than saving the appearances. This question leads to considerations of *instrumentalism* and *realism*, *explanation* and *representation*.

The uncertainty as to the physical reality of the geometric models plagued the geocentric worldview until the moment of its definite demise. Especially the Arab world, which preserved the tradition of Greek astronomy throughout the Middle Ages, voiced much opposition against the "reality" of the geometric devices. [Rosen 1984] But they remained in use for some 1,400 years. They predicted planetary positions to the accuracy needed by astronomers who relied on naked-eye observation. And they conformed to Aristotle's theory of motion and cosmology.

As we can see, the description of the Aristotelian–Ptolemaic geocentric worldview points to some general philosophical issues, which are difficult to separate from the scientific material.

2.5 Shaking the presuppositions: Some medieval developments

(…) by the purpose of movement it is proved "that movement belongs to the Earth as the home of the speculative creature." [Kepler, Epitome of Copernican Astronomy *(1618–21), Bk. IV, Part I, §5, 75]*

In Brecht's play Galileo clashes with the representatives of scholastic learning. Galileo is a believer in heliocentrism, observations, and the independence of the scientific method. The Mathematician and the Philosopher represent a world in decline: they put their faith in bookish learning, in the authority of the ancients, and cling to their belief in geocentrism. Galileo attempts to shake his visitors' beliefs. But they are not shallow opinions. They are based on philosophical presuppositions, which define their constraint space. In this constraint space certain models can be accommodated but others cannot. In the fourteenth century, some outstanding scholars became critical of the established doctrines: Nicolas d'Autrecourt (died after 1350), Johann Buridan (c.1300–58), Nicolaus of Oresme (c.320–82) at the University of Paris, and William of Ockham (c.1295–1349) at the University of Oxford. Two developments are particularly noteworthy: 1) Nicolas d'Autrecourt argued that philosophy and theology should be kept apart – a suggestion later taken up by Galileo and Pascal. The general idea is that natural philosophy should investigate the natural world and theology the spiritual world. 2) The Aristotelian theory of motion comes under critical scrutiny. Oresme and Buridan suggested, as Copernicus was later to do, that the diurnal motion of the Earth cannot be disproved by arguments derived from the Aristotelian theory of motion. According to Aristotle, the Earth rests motionless at the center of the world, because it inhabits its natural place. If it were to move, Earth-bound observers should feel the effect of this unnatural motion. Jean Bodin, a famous sixteenth-century political philosopher, echoes this age-old reasoning in 1597, fifty years after the publication of Copernicus's book (1547):

> No one in his senses, or imbued with the slightest knowledge of physics, will ever think that the Earth, heavy and unwieldy from its own weight and mass, staggers up and down around its own center and that of the sun; for at the slightest jar of the Earth, we would see cities and fortresses, towns and mountains thrown down. [Quoted in Kuhn 1957, 190]

As we have seen, Ptolemy advanced similar arguments involving the fall of objects and the destruction of buildings. The rejoinder in all these cases was to make the daily and yearly rotation of the Earth, to which Bodin refers, a *natural* motion. If we participate in this motion, Oresme and Buridan argue, then we do not perceive it. It is not a violent motion, says Copernicus, as Ptolemy thought. True, violent motion has the effect of breaking things up. But the rotation of the Earth "accords naturally with its form," so that every part of the Earth, "the clouds and the other things floating in the air or falling or rising up" take part in this natural motion of the Earth. [Copernicus 1543, Bk. I, §8] Copernicus employs impetus ideas to rebut the ancient, commonsense argument. If the air envelope travels along with the Earth and shares in its natural motion, the lack of violent winds is to be expected. Today we no longer accept the impetus theory. We are, however, all familiar with such phenomena. In constantly moving vehicles, our actions – drinking coffee, playing cards, reading books – happen as if the vehicles were stationary. Galileo's relativity principle serves as our explanation. The impetus theory was an important step toward the modern explanation of motion.

The *impetus* theory of motion was developed in the fourteenth century as an alternative to the Aristotelian theory of motion. According to this theory, as Oresme and Buridan explained it, a motive force is impressed upon an object, which carries it along. Then the argument against the motion of the Earth falls flat. Buridan first argues against the Aristotelian view of motion. If both a blunt and a sharp object are propelled along the same parabola, the air could not push in the same way on the sharp object as on the blunt one. It is better to say that a projector (internal propellant) impresses a certain *impetus* or motive force onto the moving body and that the projectile moves in the direction of the impetus. But air resistance and the "gravity" of the projectile decrease the impetus "till it is so diminished that the gravity of the stone wins out over it and moves the stone down to its natural place."[2]

The impetus theory played an essential role in the Copernican revolution: it was one of the conditions that made it possible. Buridan's pupil, Oresme, also based his refutation of Aristotle's central argument for the immobility of the Earth on the

[2] Quoted in Kuhn [1957], 120; according to Jeans [1943], 106, Hipparchus (c.140 BC) already held an impetus theory; on the impetus theory see the studies of Wolff [1978], Mittelstraß [1962] and Drake [1975].