Chapter 1

Early Ideas about the Universe

> To deride the hope of progress is the ultimate fatuity, the last word in poverty of spirit and meanness of mind.
>
> —Sir Peter Medewar (1915–1987)

1.1 The earth

In early times, most scholars regarded the earth as the center of the universe. This is only natural, as the earth appears huge to our senses. Everything in the heavens looks tiny by comparison, even the sun. In various cultures, the earth was regarded either as a flat disk or as a sphere. It is also understandable why some civilizations thought the earth was flat except for irregularities, such as mountains, on its surface. The reason, of course, is that the earth is so large that we cannot normally see the curvature of its surface. This is the first of many instances in which we shall find that the universe is quite different from the way it appears to our senses.

We can get a clue that the surface of the earth is curved. If we look at a ship approaching us far away at sea, the top of the ship comes into view first, when the part at the waterline is still below the horizon.

In modern times, we have had ample evidence that the earth is a sphere (to a good approximation). A few hundred years ago explorers circumnavigated the earth with sailing ships. More recently, airplanes and manned artificial satellites have flown around the earth. The fact that the earth looks round from every vantage point shows that it is a sphere. If the earth were some other shape, for example, a round disk, it could be viewed edgewise and appear to be thin. A sphere has more symmetry than any other shape because it is the only shape that looks round no matter from where it is viewed. Of course, the view has to be from far enough away that we can see the earth's roundness. The earth is so large that from its surface it appears flat, or rather, lumpy, with mountains and valleys.

It is interesting that many people who thought the earth was flat regarded it as a disk rather than a square or some irregular shape. Also, most of the flat-earth people thought they stood on the top side of the earth, the top being toward the heavens. What was below was only guessed at. People who believed in a flat earth thought that it was possible to fall off its edge, but, somehow, nobody ever saw the edge, and so they must have thought that they were always far away from it. The alternative view, that the flat earth was infinite in size (in other words, that there was no end to the earth in any direction) does not seem to have been seriously considered by most flat-earth advocates.

Those who regarded the earth as a sphere (apart from irregularities such as mountains) knew that it could be finite in size without having an edge. We now know that the earth is not quite a sphere, as it bulges outward at the equator because it is rotating on its axis once a day. With a spherical or almost spherical earth, the direction "down" is toward the center of the earth. People thought either that it was "natural" for bodies to fall toward the earth or that bodies fell because of some "influence" (later called gravity). There is not as much difference between these two points of view as appears, because gravity is a natural influence. Today we realize that a quantitative description of how bodies fall is very useful.

1.2 The heavens

According to many of the ancients, the heavens are what we see above the earth. These consist of the sun, the moon, the planets, the stars, and other objects occasionally, like comets and meteors. Even in early times, the planets were distinguished from the stars by their motion. They moved relative to the stars, and the name "planet" in Greek means "wanderer."

One of the earliest civilizations to have ideas about the universe was the Babylonian, located in what is now Iraq. We know from ancient writings that by 1700 BCE the Babylonians knew the length of a year to within a few minutes. The Babylonians divided the year into twelve lunar months. A lunar month is the time for the moon to go from full moon to full moon, as observed on earth, a time of somewhat more than 29 days. Because a year is a little longer than 12 lunar months, the Babylonians included a leap month every few years.

The Babylonians divided the circle into 360 degrees, each degree into 60 minutes, and each minute into 60 seconds. We still use these units of angular measurement, but we also use others. In Figure 1.1 we show a cirlce with angles of 30 degrees and 90 degrees marked off. A degree is abbreviated °.

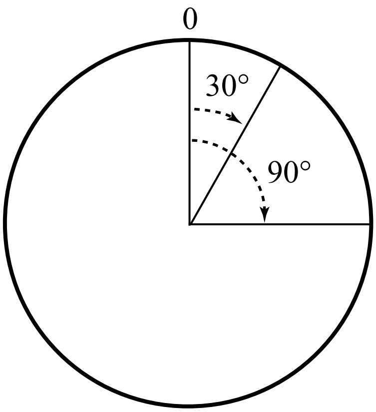

Figure 1.1: A circle, showing angles of 30 degrees and 90 degrees.

1.3 The views of Aristotle and Aristarchus

We skip over the accomplishments of the Chinese and Indian astronomers and pass directly to the Greeks. The most influential Greek philosopher was Aristotle (384–322 BCE). He proclaimed that knowledge of nature should be based on observation, an idea that was a great advance over that of Plato, who insisted that knowledge should come primarily from pure reason. However, Aristotle did not always follow his own precepts, often slipping into the patterns of thought of Plato. Furthermore, Aristotle often drew wrong conclusions from his observations.

Aristotle regarded the earth, the sun, and the moon as spherical, and said that the heavenly bodies move in circles around the earth, which is stationary and at the center of the universe. In this scheme, the sun and the stars go around the earth once every day, whereas we now know that the earth rotates around its axis once a day, giving rise to the apparent motion of the sun and stars.

Aristotle took over most of his ideas about the earth and the heavens from earlier Greek philosophers, including Pythagoras and Plato. Who can blame Aristotle? From our vantage point it certainly looks like the earth is the center of the universe.

The first Greek I know of who claimed the earth is spherical was Pythagoras (d. 497 BCE). Pythagoras did not give any evidence for his belief, but made his claim on esthetic grounds. On the other hand, Aristotle had several reasons for believing that the earth is spherical, the most compelling one being that during a lunar eclipse, the shadow of the earth appears as part of a circle as it moves across the surface of the moon.

Somewhat later, Eratosthenes (b. around 276 BCE, d. ?), who was born in what is now Libya and lived in Athens and Alexandria, made a measurement that enabled him to estimate the circumference of the earth. He had heard that on the summer solstice (June 21), the sun was directly overhead at noon in a place called Syene, now Aswan, Egypt. Eratosthenes, then living in Alexandria (which is north of Syene), found that the shadow of a stick made an angle of about 7 degrees, or about 1/50th of a complete circle. (The angle is the one made between the vertical and the line connecting the top of the stick to the end of the shadow.) He was able to find out the distance between between Syene and Alexandria, and calculated that the circumference of the earth was about 50 times as great. We are not sure of the exact size of the units of distance used by Eratosthenes, but he came pretty close to determining the circumference of the earth to be around 25,000 miles, its present value.

We return to Aristotle. In his view, the earth and its neighborhood are made of four elements: earth, air, water, and fire. The heavens are made of a fifth substance, which he called "ether" or "quintessence." Today we know that Aristotle was naive in his assertions. For example, there are many different substances in what he called "earth," as it is easy to tell by just looking at the large variety of different objects on the earth. We now know that these different objects are made of fewer than 100 naturally occuring substances called "elements." We shall discuss the elements in much more detail in later chapters.

The Greek astronomer Aristarchus of Samos (310–230 BCE), deduced the relative sizes of the earth, sun, and moon by geometrical means. Finding that the sun is much larger than the earth, he concluded that the earth must move around the sun, because he could not believe that the greater body moves around the lesser one. The notion that the earth revolves around the sun is called the "heliocentric" view.

Aristarchus also believed that the earth rotates on its axis, causing day and night, and that the earth's axis is tilted with respect to the ecliptic (the name given to the plane of the earth's orbit around the sun). We do not have the writings of Aristarchus to support his conclusions, but he is quoted by the great Greek physicist Archimedes (287–212 BCE).

In the following centuries, Aristarchus's ideas were not widely appreciated, in part owing to the influence of the Aristotle, who had common sense on his side. If the earth is moving, why do we not feel that it is moving? Why do we not fall off? The Greeks at the time of Aristotle had no answers to these questions because they did not understand the ideas of inertia and of gravity. These concepts were understood only after the sixteenth century and will be discussed in later chapters.

After Aristarchus, the greatest Greek astronomer was Hipparchus, who lived in the second century BCE. Using trigonometry, he refined Aristarchus's work, obtaining the relative sizes of the earth, sun, and moon more accurately. Nevertheless, Hipparchus accepted Aristotle's view that the sun moves around the earth, rather than the reverse.

The reason for Hipparchus's conclusion is that if the earth moves around the sun, then the stars should appear to shift their positions as seen from the earth. This shifting is known as "stellar parallax," and Hipparchus did not observe it. To understand parallax, hold a finger a foot in front of your face, and look at the finger, alternately with one eye closed and then with the other eye closed. The finger appears to be in different positions relative to the background in the two cases. The reason is that the two eyes, being separated, view the finger from different angles. The angular separation of the two apparent positions of the finger is known as parallax. Knowing the separation of the eyes, one can calculate the distance of the finger from the difference in observed angle. The farther away an object is from us, the smaller the angular separation when we view it from different positions. We are not confined to the diffeernt angles seen by our two eyes. For far-off objects, we can move to different places on earth, and see how the angle changes. Then we can calculate the distance of the object by how much the angle differs when viewed from the two places.

If the earth moves around the sun, then the positions of stars should appear different in winter and summer, when the earth is at opposite sides of its orbit. The difference in observed position relative to more distant stars is called "stellar parallax." We illustrate steller parallax in Figure 1.2.

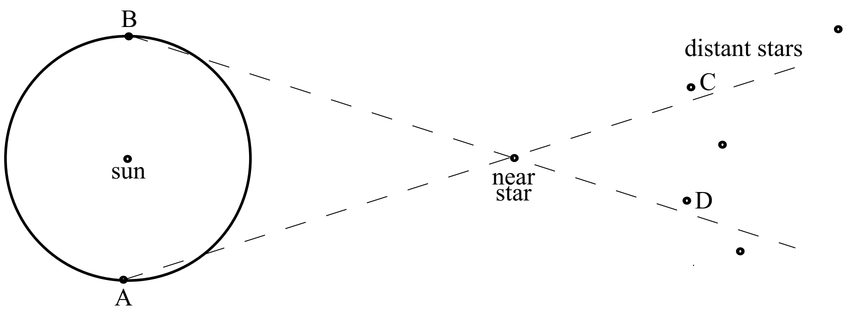

Figure 1.2: Stellar parallax. When the earth is at A in its orbit, a nearby star seems near distant star C, but when the earth is at B, the nearby star seems near distant star D. So the nearby star apparently moves with respect to distant stars. The figure is not drawn to scale.

But Hipparchus did not observe stellar parallax and so concluded that the earth did not move. Hipparchus's idea to look for stellar parallax was a good one, and with telescopes we can observe stellar parallax for the closer stars. But the amount of parallax decreases with distance of the observed object, and even the closest stars are too far away for Hipparchus to have observed parallax with the measuring instrument he had at his disposal: namely, his eyes. So Hipparchus missed the heliocentric view of the sun and planets because he could not believe that stars were so far away from us.

The astronomer Claudius Ptolomy of Alexandria, who flourished in the second century CE, codified the prevailing ideas of his time and added ideas of his own as a result of his observations. According to the Ptolomaic system, the earth is a stationary globe at the center of the universe. The basic motions of the sun, moon, stars, and planets are circles around the earth. The stars are fixed on a ″celestial sphere,″ which rotates once every twenty-four hours. The planets could not be stationary on the same celestial sphere because they move with respect to the stars.

In order for the picture to agree with careful observations, Ptolemy had to assume that the planets move in small circles, called "epicycles," whose centers move in large circles around the earth. Epicycles were first proposed some four hundred years before Ptolemy, when it was realized by observation that the planets do not move in Aristotelian circles. However, the circle was supposed to be a "perfect" curve, and therefore, the description of the motion of the planets was described by circles within circles.

After the Ptolomaic system was explained to King Alfonso X of Castile and Leon (1221–1284), the king is supposed to have said, "If the Lord Almighty had consulted me before embarking upon Creation, I should have recommended something simpler."

1.4 The Copernican revolution

Despite the skepticism of King Alfonso and others, the Ptolomaic system was widely believed until the Polish astronomer, Nicolaus Copernicus (1473–1543) revived the Aristarchan heliocentric view of the sun and planets. All the planets, according to Copernicus, revolve around the sun. He boldly explained the absence of stellar parallax by assuming that the stars were too distant for parallax to be observed. Copernicus completed his treatise around 1530, but it was not published until just before he died. It appeared under the title, *De Revolutionibus Orbium Coelestium (On the Revolution of the Celestial Sphere)*. The title, which seems to contradict the main ideas of the book, was the choice of the publisher.

Because Copernicus assumed that the planets go around the sun in circles (their paths are actually approximate ellipses), he also had to postulate the existence of epicycles. In fact, the Copernican model was almost as complicated as the Ptolemaian model, and the predictions were not much more accurate. However, Copernicus was able to calculate the relative speeds and distances of the planets from the sun, something that did not seem possible in the earch-centered model.

We speak of the "Copernican revolution" because his work began a profound change in the way we look upon the universe. Copernicus shifted our point of view from the earth to the sun, but later it was realized that the sun is just one star in a vast collection of stars known as the Milky Way. Still later it was understood that the Milky was is just one huge collection of stars (called a galaxy) out of many.

For complicated reasons (which we do not care to go into), the Catholic Church had adopted the Aristotelian view that the earth is the center of the universe. At the time of Copernicus, the Church took the view that not only religion but science came under its purview, and it tried to supress the ideas of Copernicus. Despite these attempts, Copernicus's work survived and was the first in a series of great scientific revolutions that deeply changed the way we think about the unvierse.