CHAPTER 23
THE BEGINNING OF THE SCIENTIFIC REVOLUTION

The expression "the scientific revolution," a fairly recent term, is generally employed to describe the great outburst in activity in the investigation of physical nature that took place in the sixteenth, seventeenth, and eighteenth centuries. At the beginning came the important books of Copernicus in astronomy and Vesalius in anatomy, both published in 1543. In 1687 the appearance of Newton's *Principia* provided a sort of climax for previous achievements in astronomy and physics and became the basis for future developments in those fields. Although there had been much work done in antiquity and in the Middle Ages to prepare the way for these achievements, the quality and impact of scientific discovery in Europe in this period exceeds anything ever done in any part of the world. Consequently, modern European and western civilization alone can, in fact, be called a scientific civilization. That is to say, in no other time or place outside of the modern western world has natural science had so profound and pervasive an impact on the way people live and think. We can even divide the history of western civilization into a prescientific and a scientific phase. If we accept this system of periodization, then the scientific revolution marks the point at which the change took place.

The effects of modern science have manifested themselves in various ways. In an obvious sense, the results of scientific knowledge applied in the form of technology are everywhere evident today. Over the years they have revolutionized communication and transportation and increased beyond calculation the power and wealth available to society and those who control and experience its benefits. In the present-day forms of atomic energy and computers, applied science promises or threatens further changes, which may be as far beyond our comprehension as the airplane and television would have been to the contemporaries of Luther, Erasmus, and Elizabeth I.

But these amazing developments do not encompass all the effects of science on the modern consciousness. More subtle, but probably no less important, has been the formation of a particular view of the nature of reality. We look at the world and our place in it in a different way than was possible in the prescientific period. This world view has superseded the one described in this book. It is no doubt more "correct" than the older one; that is, it can be shown to correspond more closely with observable and verifiable facts. For example, it is no longer possible to maintain that the sun revolves about a motionless earth, or that there are four terrestrial elements: earth, air, fire, and water.

On the other hand, two words of caution may be ventured here. First of all, the so-called scientific view of the nature of things is not a complete view. It can account for only those aspects of nature that are accessible to scientific methods of observation and explanation. It is of course possible and many have drawn this conclusion to maintain that nothing is "real" or "true" except what is scientifically verifiable, and that whatever else we seem to see, know, or experience is illusory or imaginary. A more balanced outlook might be that not all truths are "scientific" truths, in the usual sense, and that there are many roads to truth. In the words of Blaise Pascal (1623 62), who among other things made distinguished contributions to science, "The heart has its reasons, which reason does not know."

In the second place, the so-called scientific view of things, widely accepted by today's lay public, may not be truly scientific after all. It may to some extent rest on unproved and unprovable assumptions, like the world view that it superseded. For this, some of the scientists themselves must share part of the responsibility. As E. A. Burtt, author of The Metaphysical Foundations of Modern Physical Science, has pointed out, these scientists were often better scientists than philosophers, but their scientific prestige gave their philosophical views an undeserved authority. These views have affected the course of modern thought, but they may also in the process have misled it somewhat. This chapter will endeavor to explain to some extent how this happened.

Modern science has tended to ask of nature the question how, where the scholars of the Middle Ages asked why. For medieval thinkers it was important to know the "final cause" of a thing, that is, the purpose for which it exists; for modern science, attention has been shifted to an attempt to observe and describe its behavior, and to seek not final causes but rather physical causes. Francis Bacon distinguished the two kinds of causes in his Advancement of Learning (Second Book, VII, 7) by declaring that both causes are true, but one declares an intention, the other a consequence. Medieval philosophers were more interested in intentions; modern scientists are interested in consequences.

In modern science, accordingly, there has been an insistence on exact observation. No explanation of a fact or event in nature has been acceptable unless it has taken into account all of the observed data. The explanation that has accounted most simply for all the observed facts has been accepted as true. Conceivably, some other type of explanation may be better from some points of view; in modern times, only the scientific type has been acceptable. "For a scientific type of explanation to be satisfying, for it to convince us with a sense of its necessary truth, we must be in the condition of needing and desiring that type of explanation and no other."19

This explanation has tended to be mathematical. Some of the great scientists of the sixteenth century looked to mathematics as the key to the secrets of nature. This meant that nature came to be interpreted in terms of quantities rather than qualities. What lay outside the field in which mathematics can operate came to seem, (in a word that was widely used) "secondary," irrelevant, even unreal. Thus we can see that the scientific revolution had important metaphysical implications that is, it came to influence man's conception of the nature and constitution of basic reality.

ASTRONOMY: COPERNICUS, TYCHO BRAHE, KEPLER

Among the first and most spectacular fruits of the new science was the gradual displacement of the geocentric world picture by the discoveries of a number of great astronomers. The basic outlines of this picture have already been referred to. It may be added that the known planets were Mercury, Venus, Mars, Jupiter, and Saturn, to which the sun and moon were added because they were both thought to revolve around the earth. All these planets moved around the earth once every twenty-four hours, and described an annual motion through the heavens, each then returning to its original place. Beyond the planets lay the stars, which because of their great distance from the earth, were not observed to make an annual motion, but only to circle the earth daily. They were, therefore, called the fixed stars.

These planetary motions were circular, as we have already observed. Each type of being had the kind of motion best suited to it. Thus, of the four earthly elements, fire and air tended to rise, while water and earth naturally fell. Each one was seeking its proper place in the order of the universe. The belief that there were several types of natural motion was an obstacle to scientific progress.

By the time of Copernicus (1473-1543), the prevailing conception of the nature of the universe had become a complex one. It had been clear from ancient times that the motions observable in the heavens could not be satisfactorily explained by the theory of the planets revolving around the earth in simple circular orbits. At some times the planets appeared to be closer to the earth than at others; they seemed to move at varying rates of speed, and even from time to time to be moving in a direction opposite to their normal one (retrograde motion). To meet these difficulties, the devices of the excentric and epicycle were called upon. The excentric meant that the center of a planet's orbit was located at some distance from the earth. Thus, although the planet still revolved around the earth, it was closer at some times than others and appeared to be moving faster.

The epicycle was a circle which the planet, in its motion, described around the larger circle which in turn went around the earth. Thus the planet had two circular motions. The larger one, which went around the earth, was called the deferent. The smaller epicycle, like the excentric circle, helped to explain apparent planetary variations in speed and distance from the earth, as well as retrograde motion.

It was partly the complicated character of the received theory that made Copernicus dissatisfied with it. Furthermore, while studying in Italy, he became acquainted with Domenico Maria Novara (1454 1504), a distinguished Italian astronomer who rejected the Ptolemaic system. Copernicus also came under the influence of humanism and began the study of Greek while he was in Italy. He read the works of those ancient Greek astronomers who believed that the earth, not the sun, was in motion. He also came in contact with Platonic-Pythagorean thought, which conceived of the universe as basically mathematical and constituting a simple and harmonious system.

On his return to Poland, where he had been born and where he took up his career as a priest, Copernicus spent much time in astronomical study and observation. Working with the hypothesis that it is the earth that is actually in motion, he was able to introduce some simplifications into the scheme of the heavens. Since he retained the belief in circular orbits for the planets, however, it was necessary for him to retain some of the old complicating factors, such as epicycles. Throughout his life he worked on an account of his planetary system, and in 1543, the year of his death, he consented to its publication. It was given the title (Copernicus had not named it) of Six Books Concerning the Revolutions of the Heavenly Spheres. It was written in Latin and is often referred to simply as the De revolutionibus.

Copernicus is not notable for the quantity and accuracy of his astronomical observations; in fact, all his data could have been fitted into the geocentric system. He proposed that the earth is one of the planets revolving around the sun, because this theory provided a simpler and more symmetrical mathematical way of explaining the observed facts. This criterion came to be accepted as the test of scientific theory, and had important consequences.

The theory of Copernicus did not win immediate and universal acceptance even among the learned. The greatest astronomer in the years following the publication of Copernicus's book was the Dane Tycho Brahe (1546 1601), who rejected the heliocentric system for a number of reasons. He thought the earth was too heavy to move and that the Copernican scheme of the heavens contradicted the Bible. His own theory was that the five planets revolved around the sun, with the sun and moon revolving about the earth.

Nevertheless, the work of Tycho Brahe helped to establish the Copernican theory. Unlike Copernicus, he was a great astronomical observer and compiled a vast amount of information about the heavens, including a catalog of 777 stars. His explanation of two phenomena helped to undermine the old system. One of these was the appearance of a new star in 1572. According to the accepted views, no change could take place in the region of the stars, where all was perfect and immutable. Tycho was among those who showed that the new star was a star indeed, and that changes must take place in the stellar regions. He also did work on comets showing that they were solid bodies moving in fixed courses through planetary space. This contradicted the older theory, which held that each planet is encased in a solid and impenetrable sphere.

When Tycho died in 1601, he left his observations to Johannes Kepler, a young astronomer who had worked with him in his last years at the court of Emperor Rudolf II in Prague. Of all the men alive at the time, Kepler was the one best qualified to use these observations for further advances in astronomy. Kepler (1571 1630) was a victim of the religious bigotry of the age. He was a German Lutheran whose unorthodox religious views prevented him from becoming a Lutheran clergyman or a professor at the Protestant University of Tbingen. Add to this that he suffered from Catholic intolerance while living in imperial territory, that his mother was accused of witchcraft, that he had constant financial difficulties, and that his work was not appreciated by his contemporaries, with the exception of Galileo.

Kepler became an adherent of the Copernican system while still a young man. His attitude toward it was not one of cold scientific detachment, but was almost religious. He was struck by its beauty and was especially attracted by the central position of the sun; in fact, Kepler was almost a sun worshipper. Thus impressed by the mathematical symmetry disclosed by the heliocentric universe, he devoted himself with passionate enthusiasm to the discovery of the many other mathematical harmonies that he was sure were there. He was given to all sorts of speculations in this connection, including some that were of a poetic, religious, and musical nature. Many of the harmonies that he found, or thought he found, were scientifically useless. Among them, however, were his three laws of planetary motion, which were of great value to astronomy.

Kepler's first law is that the planets, in their revolutions about the sun, describe ellipses rather than circles (although the planetary orbits are close to circular in form). The second law states that the radius vector drawn from the sun to a planet describes equal areas in equal periods of time. This was a mathematical description of the fact that a planet's speed increases as it approaches the sun and decreases as it gets farther from it. This was later to be important to Newton in working out his law of universal gravitation. The third law, which was especially inspiring to Kepler, is that the squares of the periodic times of the planets are proportional to the cubes of their mean distances from the sun. With this law, Kepler established a mathematical relationship, which he had long sought, between a planet's distance from the sun and the time of its revolution, and thus, as he thought, of the underlying harmony of the universe.

Among the qualities that contributed to Kepler's greatness and made him one of the founders of modern science were his insistence on exact observation and his refusal to accept any conclusion that did not square with all the observed data. He worked for several years on the motions of Mars and finally, assuming circular orbits, produced a description that came very close to the observations he had received from Brahe. Nevertheless, it did not coincide precisely with these observations, so Kepler scrapped his previous work and started over. It was in this investigation that he came to see that the path followed by a planet must be an ellipse. Previous astronomers, including Copernicus, had not insisted on such complete accuracy.

Kepler's discoveries gave support to the Copernican theory, and his thought and outlook mark a further step in the mathematical interpretation of nature. Kepler, like Copernicus, was affected by Pythagorean thought, which was enjoying a revival. For him, the real world is a mathematical harmony, and the real characteristics of things are mathematical, quantitative. Real knowledge must, therefore, be mathematical knowledge.

And so the universe came to be increasingly seen as a vast machine operating according to mathematical laws. These laws, and the aspects of nature that could be formulated in terms of these laws, were the truth. Whatever else seems to exist, but cannot be expressed in terms of mathematical laws, cannot claim to possess objective existence. To quote Galileo: "...tastes, odors, colors, and so on are no more than mere names so far as the object in which we place them is concerned, and...they reside only in the consciousness."20

The continuing success of great scientists in discovering laws of nature helped to give greater prestige and wider currency to these ideas. The work of Galileo and Newton helped to make it clear that there were not different kinds of motion for different kinds of beings, but that one set of laws governed both celestial and terrestrial motion. And so the vast universe came more and more to be seen and felt as a collection of physical bodies moving through space according to immutable mathematical laws.

As this process continued, men's conceptions of divinity changed. None of the early scientists questioned the existence or providence of a personal God. More and more, however, the Almighty was cast in the role of the author of mathematical law or as a sort of celestial mechanic. He had created the machine, which could then be counted on to operate by itself. However, as long as all natural phenomena could not be explained by any known laws, there appeared to be irregularities in the mechanism, and God was needed to make the necessary adjustments. With the progress of scientific knowledge, the irregularities tended to disappear, as they were seen to be explainable in terms of newly discovered laws and, therefore, no longer irregular at all.

In the light of all these facts, there would eventually come a time when some of the more daring thinkers no longer saw the necessity of postulating the presence of a deity to explain the workings of the universe. God was rejected, and a universe that consisted of matter in motion was accepted as self-explanatory. These developments took centuries to unfold, and were far in the future from the period with which we are concerned.

As has been pointed out, the Copernican theory had a difficult time gaining acceptance. It met with either indifference or opposition. Luther opposed it. The Catholic church at first paid little attention to it. In England, in 1551, there appeared a book by Robert Recorde, The Castle of Knowledge, which expounded the Copernican system, but other Englishmen were opposed to it. It was not until the next century, when Galileo made observations with his telescope that tended to confirm the new system, that it made much impact on the imagination by Englishmen. In Spain, interestingly enough, the atmosphere was more hospitable to Copernican ideas than in other countries; from 1561, students at the University of Salamanca could be taught the heliocentric system if they wished.

In 1600 Giordano Bruno was burned at the stake for heresy in Rome. One of his numerous offenses was that he taught a philosophy inspired by the Copernican system, a philosophy that involved the idea of an infinite universe. In 1633 the great Galileo was interrogated by the Holy Office for his advocacy of the Copernican system, and forced under threat of torture to abjure it. By the end of the eighteenth century, the system had been widely accepted, though the works of Copernicus, Kepler, and Galileo remained on the official Roman Index of Prohibited Books until the nineteenth century.

ANATOMY: VESALIUS

In the Renaissance, as we have seen, art and science were not sharply distinguished as they are today. Some of the chief problems faced and solved by artists were what we would refer to as scientific problems, and the artists had scientific interests. This can be most clearly seen in artists like Piero della Francesca and Leonardo da Vinci who wrote on scientific subjects, but it is also true of artists in general. The problems of perspective and anatomy are the most obvious examples of scientific problems faced by the artists.

In order to represent the human body accurately, artists made careful anatomical studies, sometimes by means of the dissection of corpses. In the process, they were responsible for important scientific discoveries. Leonardo was the first to make accurate drawings of the human embryo. Professor Erwin Panofsky refers to Leonardo as "the founder of anatomy as a science." The mastery of perspective has an importance in the history of anatomy, because it made possible the production of accurate drawings indispensable to the progress of anatomical study. The invention of printing was also important in this connection, providing for the reproduction in large quantities of the accurate drawings that were becoming available.

Another service performed by printing was the production and widespread distribution of the correct texts of classical authorities that humanistic scholars were preparing. These texts were not an unmixed blessing, however; while on the one hand they made it possible to know more accurately than before what a Greek or Roman author had said, they also helped to perpetuate his errors.

In the fields of anatomy, physiology, and medicine, the greatest authorities were Aristotle and, above all, Galen (c.129 c.200). In spite of his undisputed greatness, some of Galen's ideas were erroneous and led students astray for centuries. He had never had the opportunity to dissect a human body, and, therefore drew conclusions about human anatomy from animals available to him. He was also too much affected by the idea of final cause or purpose, which came chiefly from Aristotle. In the case of Galen, this preoccupation meant that his research was directed toward finding the purpose of each part of the body and showing how well it was adapted to this purpose.

The uncritical acceptance of Galen's authority hindered anatomical advances. Yet the subject was not studied from a purely theoretical standpoint. In the medical faculties of universities, especially in northern Italy, bodies were dissected for students' instruction, and as early as the second decade of the fourteenth century, a work on anatomy was written based on human dissection. Yet even those who performed or witnessed dissections were under Galen's influence.

There were signs of a more empirical attitude and a willingness to challenge ancient authority. Giovanni Manardo of the University of Ferrara insisted that the authority of reason and truth must be preferred to that of any man, alive or dead. Yet even those who had empirical evidence to guide them still regarded Galen with reverence. This was true of the man who dared to criticize Galen's errors and who did more than any other person to establish the science of anatomy, Andreas Vesalius of Brussels (1514 64).

Vesalius came from a medical family; his father was personal apothecary to the emperor Charles V. Vesalius himself, after study in Louvain and Paris, went to Padua, where he received the doctorate in 1537 and became professor of anatomy and surgery before his twenty-third birthday. He was thoroughly trained in the tradition of Galen, whose works he later published.

Early in his career at Padua, he began work on his masterpiece, De humani corporis fabrica (On the Fabric of the Human Body), which was published in 1543, the same year as the De revolutionibus of Copernicus. It was not until he had become fairly well advanced in his work on this book that he was forced to realize that Galen's ideas would have to be opposed in many ways. The De Fabrica is a complete description of the human body, illustrated by woodcuts prepared under Versalius's direction and sometimes even better than the text. No other work on the subject had ever been so full and accurate. There are errors, based sometimes on inadequate observation, sometimes on a reluctance to disagree with Galen. It has been said that he followed Galen's errors much more often than he corrected them.

Vesalius was not alone in his aims and methods. Contemporaries were moving in the same direction, and some preceded him in the qualities that characterize his work: a willingness to contradict Galen on the basis of firsthand observation; the practice of dissection as a means of acquiring such observation; and the use of accurate illustrations to complement their texts. His book was outstanding; it was more complete and thorough than the others. It established, better than any other work, the proper method for the study of anatomy; it gave future researchers the tools to go further, and it provided the techniques to correct its errors. Modern anatomy had begun its career.

CONCLUSION

The men and movements discussed briefly in this chapter represent only a fraction of the scientific progress of the period, which sees the birth of our modern scientific civilization. It is instructive to draw parallels to the work of Copernicus and Vesalius, different as they are in many respects. Both men were dependent to some extent on the work and ideas of contemporaries and predecessors. Both worked in a climate of thought and feeling that was ready for their contributions. They were not isolated phenomena, bright stars flashing across a night of darkness. The way was prepared for them; even so, they did not entirely abandon older and erroneous patterns of thought.

This is not to minimize their contributions or the contributions of other workers at the time. The element of individual achievement of genius cannot be discounted. As in the case of the religious revolution started by Luther, we must be careful about the use of the word "inevitable." Genius is a difficult term to define or understand; but it exists, and it is not inevitable. The time must be ready for the great man, but he can do things in his time that other men cannot.

The scientific revolution, ushering in the modern scientific age, has profoundly influenced patterns of thought. By making possible ever increasing control of physical forces, it has helped to instill a confidence that people can master nature for their own purposes. By providing rational explanations for phenomena previously unexplained, the scientific revolution has helped to overcome superstitious fear of mysterious supernatural and occult forces. From this point of view, the present day interest in magic and various forms of the occult is a long step backwards. The scientific revolution was an important factor in promoting the trust in reason as the most reliable guide for human affairs. To some extent, this exaltation of science and reason has led to a downgrading of the claims of sentiment, emotion, art, music, and religion. Intentionally or not, the rise of a more scientific consciousness is partly responsible for the secularization of the modern world.

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