75 JOHANNES KEPLER

1571-1630

Johannes Kepler, the discoverer of the laws of planetary motion, was born in 1571, in the town of Weil der Stadt, Germany. That was just twenty-eight years after the publication of *De revolutionibus orbium coelestium*, the great book in which Copernicus set forth his theory that the planets revolved about the sun rather than the earth. Kepler studied at the University of Tübingen, obtaining a bachelor's degree in 1588 and a master's degree three years later. Most scientists of the day refused to accept the heliocentric theory of Copernicus; but while Kepler was at Tübingen he heard the heliocentric hypothesis intelligently expounded, and he soon came to believe in it.

After leaving Tübingen, Kepler was for several years a professor at the Academy in Graz. While there he wrote his first book on astronomy (1596). Although the theory which Kepler propounded in that book turned out to be completely incorrect,

the book so clearly revealed Kepler's mathematical ability and originality of thought, that the great astronomer Tycho Brahe invited him to become his assistant at his observatory near Prague.

Kepler accepted the offer and joined Tycho in January 1600. Tycho died the following year; however, Kepler had made such a favorable impression in the intervening months that the Holy Roman Emperor, Rudolph II, promptly appointed him to succeed Tycho as Imperial Mathematician. Kepler was to hold that post for the rest of his life.

As the successor to Tycho Brahe, Kepler inherited the voluminous records of the careful observations of the planets that Tycho had made over many years. Since Tycho, who was the last great astronomer before the invention of the telescope, was also the most careful and accurate observer the world had yet seen, those records were invaluable. Kepler believed that a careful mathematical analysis of Tycho's records would enable him to determine conclusively which theory of planetary motion was correct: the heliocentric theory of Copernicus; the older, geocentric theory of Ptolemy; or perhaps a third theory propounded by Tycho himself. However, after years of painstaking numerical calculation, Kepler found to his dismay that Tycho's observations were not consistent with *any* of those theories!

Eventually, Kepler realized what the problem was: he, like Tycho Brahe and Copernicus, and like all the classical astronomers, had assumed that planetary orbits consisted of circles, or combinations of circles. In fact, however, planetary orbits are not circular, but rather *elliptical.*

Even after discovering the basic solution, Kepler still had to spend many months in complicated and tedious calculations to make sure that his theory satisfied Tycho's observations. His great book, *Astronomia nova,* published in 1609, presented his first two laws of planetary motion. The first law states that each planet moves around the sun in an elliptical orbit, with the sun at one focus. The second law states that a planet moves more quickly when it is closer to the sun; the speed of a planet varies in such a way that the line joining the planet and the sun sweeps out

equal areas in equal lengths of time. Ten years later, Kepler published his third law: the more distant a planet is from the sun, the longer it takes to complete its revolution, with the square of the period of revolution being proportional to the cube of the distance from the sun.

Kepler's laws, by providing a basically complete and correct description of the motions of the planets around the sun, solved one of the basic problems of astronomy, one whose solution had eluded even such geniuses as Copernicus and Galileo. Of course, Kepler had not explained *why* the planets moved in the orbits they do; that problem was solved later in the century by Isaac Newton. But Kepler's laws were a vital prelude to Newton's grand synthesis. ("If I have seen further than other men," Newton once said, "it is because I stood on the shoulders of giants." Doubtless, Kepler was one of the giants to whom he was referring.)

Kepler's contribution to astronomy is almost comparable to that of Copernicus. Indeed, in some ways Kepler's achievement is even more impressive. He was more original, and the mathematical difficulties he faced were immense. Mathematical techniques were not as well developed in those times as they are today, and there were no calculating machines to ease Kepler's computational tasks.

In view of the importance of Kepler's achievements, it is surprising that his results were almost ignored at first, even by so great a scientist as Galileo. (Galileo's neglect of Kepler's laws is particularly surprising since the two men had corresponded with each other, and since Kepler's results would have helped Galileo to refute the Ptolemaic theory.) But if others were slow to appreciate the magnitude of his achievement, Kepler understood it himself. In a burst of exultation he wrote:

> *I give myself up to divine ecstasy...My book is written. It will be read either by my contemporaries or by posterity—I care not which. It may well wait a hundred years for a reader, as God has waited 6,000 years for someone to understand his work.*

Gradually though, over the course of a few decades, the significance of Kepler's laws became apparent to the scientific world. In fact, later in the century, a major argument in favor of Newton's theories was that Kepler's laws could be deduced from them. Conversely, given Newton's laws of motion, it is possible to rigorously deduce Newton's laws of gravitation from Kepler's laws. To do so, however, would require more advanced mathematical techniques than were available to Kepler. Even without such techniques, Kepler was perspicacious enough to suggest that planetary motions were controlled by forces emanating from the sun.

In addition to his laws of planetary motion, Kepler made various minor contributions to astronomy. He also made significant contributions to the theory of optics. His later years, unfortunately, were clouded by personal problems. Germany was descending into the chaos of the Thirty Years' War, and it was a rare individual that could escape serious difficulties.

One problem he had was in collecting his salary. The Holy Roman emperors had been slow payers even in comparatively good times. In the chaos of war, Kepler's salary fell far in arrears. Since Kepler had married twice and had twelve children, such financial difficulties were serious indeed. Another problem concerned his mother, who in 1620 was arrested as a witch. Kepler spent much time in an eventually successful attempt to have her released without being tortured.

Kepler died in 1630, in Regensburg, Bavaria. In the turmoil of the Thirty Years' War, his grave was soon destroyed. But his laws of planetary motion have proven a more enduring memorial than any made of stone.