1958

4. Kepler

Robert L. Bloom
Gettysburg College

Basil L. Crapster
Gettysburg College

Harold A. Dunkelberger
Gettysburg College

See next page for additional authors

Bloom, Robert L. et al. "4. Kepler. Pt. VIII: The Development of Modern Science." Ideas and Institutions of Western Man (Gettysburg College, 1958), 47-52.

4. Kepler

Abstract
Tycho Brahe (1546-1601), a Dane, spent nearly his entire life making careful measurements of the positions of the stars and planets. Most of his work was done at Copenhagen under the patronage of the Danish king. He developed and refined astronomical instruments to an accuracy that was far superior to anything previously done. In his late years at Prague, he started on the reduction to order of the systematic observations that he had made over a period of decades. In 1600 a young German mathematician and astronomer, Johannes Kepler (1571-1630), visited Tycho and then stayed to help in the mammoth task that had begun. [*excerpt*]

Keywords
Contemporary Civilization, Universe, Science, Tycho Brahe, Johannes Kepler, Astronomy

Disciplines
Astrophysics and Astronomy | History | History of Science, Technology, and Medicine

Authors
Robert L. Bloom, Basil L. Crapster, Harold A. Dunkelberger, Charles H. Glatfelter, Richard T. Mara, Norman E. Richardson, and W. Richard Schubart

4. Kepler

Tycho Brahe (1546-1601), a Dane, spent nearly his entire life making careful measurements of the positions of the stars and planets. Most of his work was done at Copenhagen under the patronage of the Danish king. He developed and refined astronomical instruments to an accuracy that was far superior to anything previously done. In his late years at Prague, he

started on the reduction to order of the systematic observations that he had made over a period of decades. In 1600 a young German mathematician and astronomer, Johannes Kepler (1571-1630), visited Tycho and then stayed to help in the mammoth task that had begun.

Kepler and Tycho had only one year together before Tycho died. Kepler had been named imperial mathematician by the German Emperor Rudolf II (1576-1612) during this year, and he inherited all of Tycho's detailed data. He began to construct new astronomical tables that were finally published in 1627 as the Rudolphine Tables. At the same time, Kepler struggled to bring the Copernican system into complete agreement with Tycho's careful observations. He searched for geometric and numerical relationships which he hoped would show him the key to the entire problem. Not only did he fail to bring the Copernican scheme into agreement with Tycho's data, he discovered with astonishment that the observed orbit of the planet Mars could not be described within Tycho's accuracy by any Copernican scheme of circular motion. He was but eight minutes of arc from a good match. While the data available to Copernicus was in error by amounts much greater than this, Kepler had complete faith in Tycho. He wrote:

> For our part, since divine goodness has given us in Tycho Brahe such a painstaking observer, from whose observations an error in these Ptolemaic calculations amounting to 8 minutes is revealed, it is fitting that we should gratefully recognize and use this gift of God. That is to say we should labour...finally to trace out the true nature of the celestial motions.... For if I had believed these 8 minutes in longitude to be negligible, I should already have sufficiently corrected the hypothesis set out in [an earlier work]. But as that error cannot be neglected, these 8 minutes alone have shown the way to the complete reformation of astronomy; they have been made the material for a great part of this work. *

In 1609 he published his New Astronomy with Commentaries on the Motion of Mars which contained the first two of his famous laws of planetary motion. They are:

(1) The planets move round the sun in orbits which are ellipses, the sun being at one of the foci.

(2) Each planet moves in its orbit in a non-uniform way, but in such a way that a line drawn from the sun to that planet sweeps out equal areas in the ellipse in equal time intervals.

* Quoted in A. Wolf, A History of Science, Technology, and Philosophy in the 16th and 17th Centuries (London: George Allen and Unwin Ltd., 1950), p. 137. Used with permission.

The diagram in Figure V (a) depicts Kepler's scheme for our solar system.

An ellipse can be drawn very easily with the aid of a piece of string and two pins. Pin down the ends of the string a distance apart less than the string's length. Now draw the string taut with a pencil point, and move the pencil over all possible positions keeping the string taut at all times. The closed path generated is an ellipse. A circle is generated in the special case that both ends of the string are pinned down at the same point. Each of the points at which the string is pinned down is called a focus. Kepler found that the ellipses describing the orbits of the planets had their foci rather close together, so that the ellipses were not long and narrow but close to the shape of a circle. Kepler had broken away from the traditional preoccupation with circles which had hounded even Galileo. For the first time someone simply looked at the orbits of the planets about the sun without any preconceptions.

The ellipse was known to the Greeks as a conic section. The ellipse defined as the intersection of a plane and a right circular cone is also shown in Figure V (b). Pythagoras and Plato must have cheered from their resting places, for they both believed that God was a geometer. While they had also believed that observations were not necessary to know what was true, we, at this late date, can be gracious enough to recognize that they would have been pleased with Kepler's great discovery. Who would have dreamed that a geometrical figure, constructed and defined without any thought to describe anything physical, should find itself describing the very paths followed by the planets?

The third law of planetary motion was published by Kepler in 1618. It was a quantitative law describing the rate at which the planets traversed their orbits:

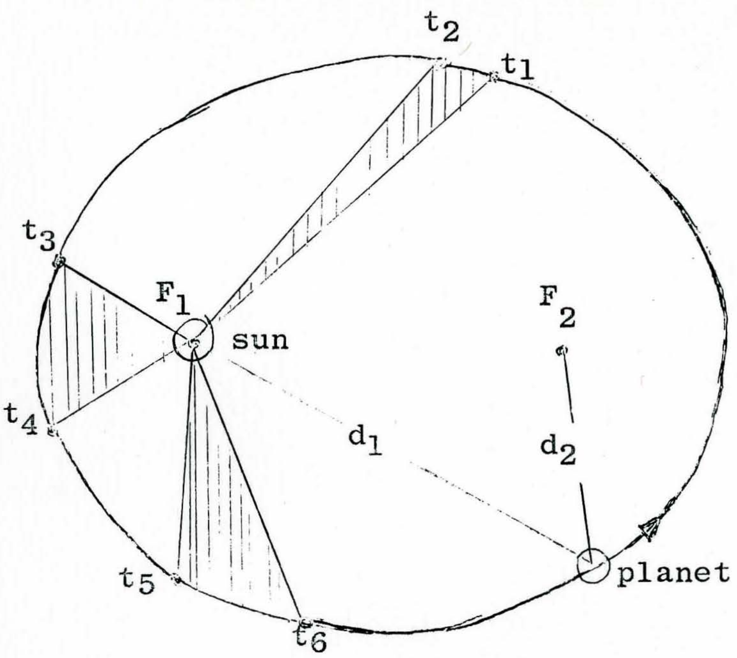
(3) The ratio of the square of the time period (time to make one complete cycle of the orbit) of revolution round the sun to the cube of the mean distance to the sun for each planet is the same for all planets.

This law can be written as a concise equation:

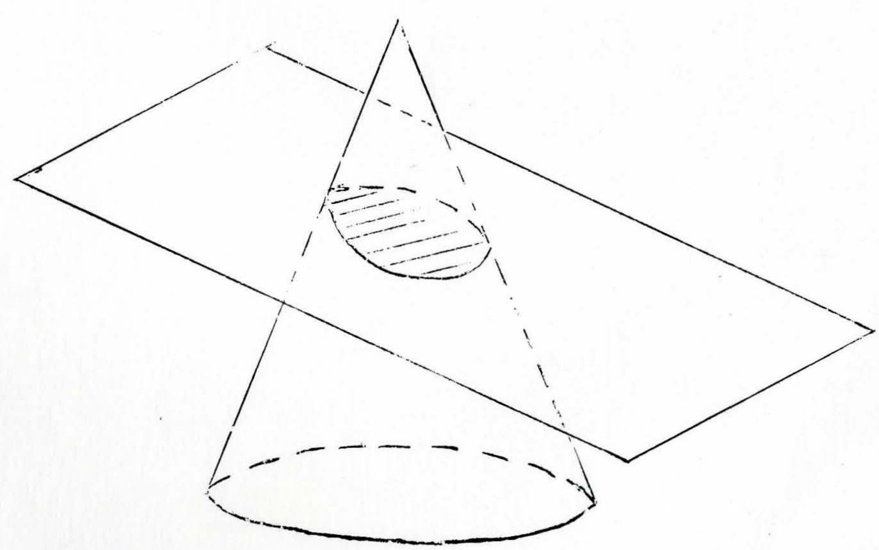
$$\frac{T^2}{R^3} = C$$

where T is the time period of revolution of a planet, R is the mean distance between the planet and the sun, and C is a constant that is the same for all planets.

Kepler had lived a life filled with personal tragedy, and when finally the third law came to him he was exultant:



(a) A planet moves in an elliptical path with the sun at one of the foci. If F_1 and F_2 are the foci, then the sum of the distances d_1 and d_2 is constant over the path. Kepler's second law states that if the time the planet takes to traverse the distance t_1 to t_2 is the same as that to traverse t_3 to t_4 and t_5 to t_6, then the three shaded areas are equal.



(b) An ellipse as the intersection of a plane and a right circular cone.

FIG. V. KEPLER'S THEORY

> What I prophesied two-and-twenty years ago, as soon as I discovered the five solids among the heavenly orbits -- what I firmly believed long before I had seen Ptolemy's Harmonies -- what I had promised my friends in the title of this book, which I named before I was sure of my discovery -- what sixteen years ago, I urged as a thing to be sought -- that for which I joined Tycho Brahe, for which I settled in Prague, for which I have devoted the best part of my life to astronomical contemplations, at length I have brought to light, and recognized its truth beyond my most sanguine expectations. It is not eighteen months since I got the first glimpse of light, three months since the dawn, very few days since the unveiled sun, most admirable to gaze upon, burst upon me. Nothing holds me; I will indulge my sacred fury; I will triumph over mankind by the honest confession that I have stolen the golden vases of the Egyptians to build up a tabernacle for my God far away from the confines of Egypt. If you forgive me, I rejoice; if you are angry, I can bear it; the die is cast, the book is written, to be read either now or by posterity, I care not which; it may well wait a century for a reader, as God has waited six thousand years for an observer. *

Kepler had given the observed data their due respect, and he was rewarded in return. This lesson Kepler helped to teach the world. We forget it even now only at great peril. Also Kepler cast his laws in the language of geometry and algebra. His third law can be written as an equation, and this too serves as a signpost along the path taken by the modern physical sciences. Like Galileo, he invoked no angels to move his planets, and he first sought a quantitative description of the planets' motions. Kepler did search to find a physical cause for these motions, but success in this venture was to elude everyone but Newton.

Galileo and Kepler were the giants whose vision and integrity helped to carry science through the transition from medieval obscurantism to a respect for experimentation and preciseness of theory. Each had one foot in the old tradition and one foot in the new. In many ways a mystic, Kepler found a rich source of symbolism in his three laws. But fortunately for the future of science, he satisfied his mysticism only after he had carefully constructed his laws, and not before. The following selections from Kepler's Epitome of Copernican Astronomy (1618-1621) show his tendency to shift from one tradition to the other. The book is written in a question and answer form. Note how at times the answers have the ring of a contemporary scientist's and how at times they are as obscure as those of a medieval mystic:

---

* Quoted in Oliver Lodge, Pioneers of Science (London: Macmillan and Company, Limited, 1893), pp. 74-75.