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(*b*. Minden, Germany, 22 July 1784; *d*. Königsberg, Germany [now Kaliningrad, U.S.S.R.], 17 March 1846)

astronomy, geodesy, mathematics.

Bessel’s father was a civil servant in Minden; his mother was the daughter of a minister named Schrader from Rheme, Westphalia. Bessel had six sisters and two brothers, both of whom became Judges of provincial courts. He attended the Gymnasium in Minden but left after four years, with the intention of becoming a merchant’s apprentice. At school he had had difficulty with Latin, and apart from an inclination toward mathematics and physics, he showed no signs of extraordinary talent until he was fifteen. (Later, after studying on his own, Bessel wrote extensively in Latin, apparently without difficulty.)

On 1 January 1799 Bessel became an apprentice to the famous mercantile firm of Kulenkamp in Bremen, where he was to serve for seven years without pay. He rapidly became so proficient in calculation and commercial accounting that after his first year he received a small salary; this was gradually increased, so that he became financially independent of his parents.

Bessel was especially interested in foreign trade, so he devoted his nights to studying geography, Spanish, and English, learning to speak and write the latter language within three months. In order to qualify as cargo officer on a merchant ship, he studied books on ships and practical navigation. The problem of determining the position of a ship at sea with the aid of the sextant stimulated his interest in astronomy, but knowing how to navigate by the stars without deeper insight into the foundations of astronomy did not satisfy him. He therefore began to study astronomy and mathematics, and soon he felt qualified to determine time and longitude by himself.

Bessel made his first time determination with a clock and a sextant that had been built to his specifications. The determination of the longitude of Bremen and the observation of the eclipse of a star by the moon are among his first accurate astronomical exercises. He learned of observations and discoveries through the professional astronomical journals *Monatliche Correspondenz* and *Berliner astronomisches Jahrbuch*, and thus was able to judge the accuracy of his own observations.

In a supplementary volume of the *Berliner astronomisches Jahrbuch* Bessel found Harriot’s 1607 observations of Halley’s Comet, which he wanted to use to determine its orbit. He had equipped himself for this task by reading Lalande and then Olbers on the easiest and most convenient method of calculating a comet’s orbit from several observations. The reduction of Harriot’s observations and his own determination of the orbit were presented to Olbers in 1804. With surprise Olbers noted the close agreement of Bessel’s results with Halley’s calculation of the comet’s elliptical elements. He immediately recognized the great achievement of the twenty-year-old apprentice and encouraged him to improve his determination of the comet’s orbit by making additional observations. After Bessel had done so, this work was printed, upon Olbers’ recommendation, in *Monatliche Correspondenz*. The article, which was on the level of a doctoral dissertation, attracted much attention because of the circumstances under which it had been written. It marks the turning point in Bessel’s life; from then on he concentrated on astronomical investigations and celestial mechanics. Later, Olbers claimed that his greatest service to astronomy was having encouraged Bessel to become a professional astronomer.

At the beginning of 1806, before the expiration of his apprenticeship with Kulenkamp, Bessel accepted the position of assistant at Schröter’s private observatory in Lilienthal, near Bremen, again on Olbers’ recommendation. Schröter, a doctor of law and a wealthy civil servant, was renowned for his observations of the moon and the planets; and as a member of various learned societies, he was in close contact with many scientists. In Lilienthal, Bessel acquired practical experience in observations of comets and planets, with special attention to Saturn and its rings and satellites. At the same time, he studied celestial mechanics more intensively and made further contributions to the determination of cometary orbits. In 1807 Olbers encouraged him to do a reduction of Bradley’s observations of the positions of 3,222 stars, which had been made from 1750 to 1762 at the Royal Greenwich Observatory. This task led to one of his greatest achievements.

When Friedrich Wilhelm III of Prussia ordered the construction of an observatory in Königsberg, Bessel was appointed its director and professor of astronomy (1809), on the recommendation of Humboldt. He had previously declined appointments in Leipzig and Greifswald. He took up his new post on 10 May 1810. The title of doctor, a prerequisite for a professorship, had been awarded to him without further formalities by the University of Göttingen after Gauss had proposed it. Gauss had met Bessel in 1807 at Bremen and had recognized his unusual ability.

While the observatory in Königsberg was being built (1810–1813), Bessel made considerable progress in the reduction of Bradley’s observations. In 1811 he was awarded the Lalande Prize of the Institut de France for his tables of refraction derived from these observations, and the following year he became a member of the Berlin Academy of Sciences. In 1813 Bessel began observations in Königsberg, primarily of the positions of stars, with the Dollond transit instrument and the Cary circle. The observatory's modest equipment was markedly improved by the acquisition of a Reichenbach-Ertel meridian circle in 1819, a large Fraunhofer-Utzschneider heliometer in 1829, and a Repsold meridian circle in 1841. Bessel remained in Königsbergfor the rest of his life, pursuing his research and teaching without interruption, although he often complained about the limited possibilities of observation because of the unfavorable climate. He declined the directorship of the Berlin observatory, fearing greater administrative and social responsibilities, and nominated Encke, who was appointed in his stead. Of Bessel's students, several became important astronomers; Argelander is perhaps the most famous.

Bessel married Johanna Hagen in 1812, and they had two sons and three daughters. The marriage was a happy one, but it was clouded by sickness and by the early death of both sons. Bessel found relaxation from his intensive work in daily walks and in hunting. He corresponded with Olbers, Schumacher (the founder of the *Astronomische Nachrichten*), and Gauss, and left Königsberg only occasionally.

From 1840 on, Bessel's health deteriorated. His last long trip, in 1842, was to England, where he participated in the Congress of the British Association in Manchester. His meeting with important English scientists, including Herschel, impressed him deeply and stimulated him to finish and publish, despite his weakened health, a series of works.

After two years of great suffering, Bessel died of cancer. He was buried near the observatory. Bessel was small and delicate, and in his later years he appeared prematurely aged because of his markedly pale and wrinkled face. This appearance altered, however, as soon as he began to talk; then the force of a strong mind was evidenced in brilliant, rapid speech, and his otherwise rigid expression revealed mildness and friendliness.

Newcomb, in his *Compendium of Spherical Astronomy* (1906), has called Bessel the founder of the German school of practical astronomy. This German school started with astrometry and, after Bessel's death, was expanded to astrophysics by Bunsen and Kirchhoff's discovery of spectral analysis. Foremost among the interests of this school were the construction of precision instruments, the study of all possible instrument errors, and the careful reduction of observations. Bessel's contributions to the theory of astronomical instruments are for the most part restricted to those instruments used for the most accurate measurement of the positions of the stars and planets. The principles he laid down for the determination of errors were biter followed so painstakingly by less gifted astronomers that the goal to be achieved—the making of a great number of good observations—was relegated to the background in favor of important investigations relative to the instruments themselves. Such was never Bessel's intention; he was undoubtedly one of the most skillful and diligent observers of his century. His industry is well illustrated by the twenty-one volumes of *Beobachtungen der Königsberger Sternwarte*.

Bessel recognized that Bradley's observations gave a system of very accurate star positions for the epoch 1755 and that this could be utilized in two ways. First, a reference system for the measurement of positions of stars and planets was required. Second, the study of star motions necessitated the determination of accurate positions for the earliest possible epoch. Tobias Mayer had determined fundamental star positions from his own observations around the middle of the eighteenth century, but Bradley was never able to reduce his own numerous observations.

The observations of star positions had to be freed of instrumental errors, insofar as these could be determined from the measurements themselves, and of errors caused by the earth's atmosphere (refraction). The apparent star positions at the time of a particular observation (observation epoch) had to be reduced to a common point in time (mean epoch) so that they would be freed of the effects of the motion of the earth and of the site of observation. For this a knowledge of the precession the nutation, and the aberration was necessary. Bessel determined the latitude of Greenwich for the mean epoch 1755 and the obliquity of the ecliptic, as well as the constants of precession, nutation, and aberration. To determine precession from proper motions, Bessel used both Bradley's and Piazzi's observations. Bessel's first published work on the constant of precession (1815) was awarded a prize by the Berlin Academy of Sciences.

The positions of Bradley's stars valid for 1755 were published by Bessel as *Fundamenta astronomiae pro anno 1755* (1818). This work also gives the proper motions of the stars, as derived from these observations of Bradley, of Piazzi, and of Bessel himself. It constitutes a milestone in the history of astronomical observations, for until then positions of stars could not be given with comparable accuracy: through Bessel's work, Bradley's observations were made to mark the beginning of modern astrometry. During this investigation Bessel became an admirer of the art of observation as practiced by Bradley; and because Bradley could not evaluate his own observations, Bessel followed and also taught the principle that immediately after an observation, the reduction had to be done by the observer himself. Further, he realized that the accurate determination of the motions of the planets and the stars required continuous observations of their positions until such motions could be used to predict "the positions of the stars … for all times with sufficient accuracy."

Later, when many unpublished observations of Bradley's were found and when, about 1860, Airy had made accurate observations of the same stars at the Royal Greenwich Observatory, Auwers improved Bessel's reductions and derived proper motions of better quality. Auwers' star catalog was published in three volumes (1882–1903).

Bessel's first and very important contribution to the improvement of the positions and proper motions of stars consisted of the observations of Maskelyne's thirty-six fundamental stars. As Bradley's successor, Maskelyne had chosen these stars to define the system of right ascensions. Bradley had been able to make differential measurements of positions with such accuracy that the star positions for 1755 and those determined by Airy for 1860 resulted in proper motions with the excellent internal accuracy of about one second of arc per century. Greater difficulties were experienced, however, with the measurement of positions with respect to the vernal equinox as zero point of the right ascensions. The continuously changing position of the vernal equinox had to be determined at the time of the equinoxes from the differences in time of the transits of bright stars and the sun through the meridian. In 1820 Bessel succeeded in determining the position of the vernal equinox with an accuracy of .01 second by observing both Maskelyne's stars and the sun. This can he verified by measurements made in the twentieth century.

In *Tabulae Regiomontanae* (1830), Bessel published the mean and the apparent positions of thirty-eight stars for the period 1750–1850. He added the two polar stars α and δ Ursae Minoris to Maskelyne's thirty-six fundamental stars. The foundations for the ephemerides were the mean positions for 1755 and the positions derived for 1820 from observations at Königsberg. The position of the vernal equinox for 1822, as determined by Bessel, served as the zero point for counting the right ascensions. Bessel derived the ephemeriedes of the *Tabulae Regiomontanae* without using a specific value of the constant of precession, for in order to find a third position from two given positions of a star, it is necessary to know only the annual variation of precession, not the value of precession itself. Therefore Bessel's ephemerides are correct (aside from errors in observation) up to and including the first magnitude for the proper motions and up to the second magnitude for precession. Only for the two polar stars did Bessel determine the proper motions and also give the values, since for these stars the terms of higher order in proper motion and precession could not be neglected. In calculating the data of the *Tabulae Regiomontanae* Bessel improved his 1815 determination of the precession by utilizing his Königsberg observations of Bradley's stars.

The star positions given for one century in the *Tabulae Regiomontance* constitute the first modern reference system for the measurement of the positions of the sun, the moon, the planets, and the stars, and for many decades the Kénigsberg tables were used as ephemerides. With their aid, all observations of the sun, moon, and planets made since 1750 at the Royal Greenwich Observatory could be reduced; and thus these observations could be used for the theories of planetary orbits.

During observations of the stars α Canis Major (Sirius) and α Canis Minor (Procyon), which are among Maskelyne's fundamental stars, Bessel discovered the variation of their proper motions. He concluded that these stars must have dimmer companions whose masses, however, were large enough to make visible the motions of the brighter double-star components around the center of gravity. Arguing from the variation of the proper motion, more than a hundred years later astronomers discovered stars with extremely low luminosity, called dark companions.

Observing the positions of numerous stars with the Reichenbach meridian circle, Bessel pursued two aims: the determination of the motions of the stars in such a way that their positions could be predicted for all time, and the definition of a reference system for the positions of the stars, Between 1821 and 1833 he determined the positions of approximately 75,000 stars (brighter than ninth magnitude) in zones of declination between –15° and +45°. With these observations he also developed the methods for determining instrumental errors, including those of the division of the circle, and eliminated such errors from his observations. He published all measurements in detail, and thus they can be verified. These observations were continued by Argelander, who measured the positions of stars in zones of declination from +45° to +80° and from –16° to –32°. The work of Bessel and Argelander encouraged the establishment of two large-scale programs: Argelander's *Bonner Durchmusterung* and the first catalog of the Astronomische Gesellschaft (*AGK I*) with the positions of the stars of the entire northern sky. The *Bonner Durchmusterung* is a map of the northern sky that contains all stars up to magnitude 9.5, and the catalog is the result of meridian circle observations made at many observatories.

One of Bessel's greatest achievements was the first accurate determination of the distance of a fixed star. At the beginning of the nineteenth century, the approximate radius of the earth's orbit (150,000,000 km.) was known, and there was some idea of the dimensions of the planetary system although Neptune and Pluto were still unknown. The stars, however, were considered to be so faraway that it would be hopeless to try to measure their distances. The triangulation procedure was already known, and for this the diameter of the earth's orbit could serve as the base line, since its length was known. It was also known that the motion of the earth around the sun must be mirrored in a periodic motion of the stars within the period of a year, in such a way that a star at the pole of the ecliptic would describe a circular orbit around the pole, stars at ecliptical latitudes between 0° and 90° would describe ellipses, and stars at the ecliptic would undergo periodic variations of their ecliptical longitudes. This change of position of the stars, as evidenced by the motion of the earth, was considered to be immeasurably small, however. The radius of the circle, of the ellipse, or of the ecliptical segment of arc—the so-called parallax figure—is the parallax of the star; the parallax π is the angle subtended by the radius of the earth's orbit at the position of the star. If this angle π can be measured, then the distance r of a star can be obtained from $\sin \pi = a/r$, where a represents the radius of the earth's orbit. An angle of $\pi = 1''$ corresponds to 206,265 radii of the earth's orbit (or $3.08 \cdot 10^{13}$ km., or 3.26 light-years).

In the first half of the eighteenth century Bradley had attempted to determine the parallaxes of the stars γ Draco and η Ursa Major by measurements of the angular distances of these stars from the zenith (zenith distances). Both stars culminate in the vicinity of the zenith of Greenwich and thus are particularly suitable for the accurate measurement of zenith distances. The "absolute" parallax of the stars—that is, the parallactic change of position with respect to a fixed direction on earth (direction of the plumb line at Greenwich)—should be determinable from the variation of the zenith distances. Bradley found an annual variation with an amplitude of twenty seconds of arc, but the phase was shifted by three months from the expected parallactic change of position. He correctly interpreted the phenomenon as a change in direction—arising from the motion of the earth in its orbit—of the stellar light that reaches the earth, and thus discovered the aberration of light. However, he could not detect parallaxes of the stars, but could only conclude that the parallaxes must be smaller than .50 second of arc for the stars he observed.

As a result of this knowledge of the small size of the parallaxes to be expected, the measuring procedures were changed in later experiments, for the accuracy of the measurements of zenith distances was obviously inadequate for the purpose. The angular distance between two stars very close together on the sphere could be determined much more accurately. If one star of a star pair is very far from the sun and the other is near the sun, then the parallax figure of the nearer star must become visible as a result of frequent measurements of the angular distances between the two stars. It was therefore suggested that astronomers measure “relative” parallaxes, that is, the parallactic changes in the position with reference to other stars that can be assumed to be very far away. Herschel’s attempts to measure stellar parallaxes in this way led to the discovery of the physical double stars; he found that the components of most star pairs are near to each other in space, as is shown by their motion around the common center of gravity. Herschel’s attempt to determine parallaxes failed, however.

This lack of success led to a search for signs that one of the stars would be especially near. With great brightness of an individual star regarded as an indication of its great nearness. (This assumption would be correct if all stars had the same luminosity and if there were no inhomogeneous interstellar absorption. Since both of these conditions are not fulfilled, the relation between apparent magnitude and distance holds only in the statistical mean.) In determining proper motions, Bessel found that individual stars are marked by especially great motions and that these stars are not among the brightest. He concluded that great proper motions are, in most cases, the result of small star distances. Therefore, in order to determine the parallax, he selected the star with the greatest proper motion known to him (5.2″ per year), a star of magnitude 5.6, which had been designated as 61 Cygni in Flamsteed’s star catalog.

To determine the parallax Bessel used the Fraunhofer heliometer, an instrument intended primarily for the measurement of the angular diameter of the sun and the planets. The heliometer is a telescope with an objective that can be rotated around the optical axis. The objective is cut along a diameter; both halves can be shifted along the cutting line and the displacement can be measured very accurately. Each half of the objective acts optically as a complete objective would, so that upon moving the halves, two noncoincident images of one object arise. The distance of two stars, A and B, that are in the field of view is measured by sliding the halves so that the image of A coincides with the image of B produced in the second half; thus the two stars appear as one. In Bessel’s day this procedure of coincidence determination permitted more accurate measurements than did the customary micrometer determinations with an ordinary telescope; the latter were used to determine the angular distances of the components of double stars. Further, with the heliometer one could measure greater angular distances than with the micrometer (up to nearly two degrees with Bessel’s heliometer). For determining the parallax of 61 Cygni, Bessel selected two comparison stars of magnitude 9–10 at distances of roughly eight and twelve minutes of arc. 61 Cygni is a physical double star whose components differ in brightness by less than one magnitude. The distance of sixteen seconds of arc between the components favored the accuracy of the determination of the parallax because pointing could be carried out with two star images. After observing for eighteen months, by the fall of 1838 Bessel had enough measurements for the determination of a reliable parallax. He found that $\pi = 0.314''$ with a mean error of ±:0.020″. This work was published in the *Astronomische Nachrichten* (1838), the first time the distance of a star became known. Bessel’s value for the parallax shows excellent agreement with the results obtained by extensive modern photographical parallax determinations, which have yielded the value $\pi = 0.292''$, with a mean error of ± = 0.0045″. The distance of 61 Cygni thus amounts to $6.9 \cdot 10^5$ earth’s orbit, or 10.9 light-years.

Bessel’s conjecture that the stars with the greatest proper motions are among the nearest was later proved correct, and the amount of proper motion has remained a criterion for the choice of stars for parallax programs. Only one year after the completion of Bessel’s work, two other successful determinations of parallaxes were made known. F. G. W. Struve in Dorpat determined the parallax of the bright star α Lyra (Vega) by means of micrometric measurements. The value he found, $\pi = 0.262'' \pm 0.037''$ (m.e.) nevertheless deviates considerably from the now reliably known value $\pi = 0.121'' \pm 0.006''$ (m.e.). In addition, Thomas Henderson had observed the bright star α Centaurus at the Cape Observatory and had found a parallax of approximately one second of arc. The reliable value for this today amounts to π = 0:75″. The pioneering work of Bessel, Henderson, and Struve not only opened up a new area of astronomical research but also laid the foundation for the investigation of the structure of our star system.

Bessel was also an outstanding mathematician whose name became generally known through a special class of functions that have become an indispensable tool in applied mathematics, physics, and engineering. The interest in the functions, which represent a special form of the confluent hypergeometric function, arose in the treatment of the problem of perturbation in the planetary system. The perturbation of the elliptic motion of a planet caused by another planet consists of two components, the direct effect of the perturbing planet and its indirect effect, which arises from the motion of the sun caused by the perturbing planet. Bessel demonstrated that it is appropriate to treat the direct and the indirect perturbations separately, so that in the series development of the indirect perturbation, Bessel functions appear as coefficients. In studying indirect perturbation, Bessel made a systematic investigation of its functions and described its main characteristics. This work appeared in his Berlin treatise of 1824. Special cases of Bessel coefficients had been known for a long time; in a letter to Leibniz in 1703, Jakob Bernoulli mentioned a series that represented a Bessel function of the order 1/3. In addition, in a work on the oscillations of heavy chains (1732) Daniel Bernoulli used Bessel coefficients of the order zero, and in Euler’s work on vibrations of a stretched circular membrane (1744) there was a series by means of which $J_n(z)$ was defined. Probably a work by Lagrange on elliptical motion (1769), in which such series appear, had led Bessel to make these investigations. The impulse, however, did not come from pure mathematical interests, but from the necessity of applying such series in the presentation of indirect perturbations. Bessel left few mathematical works that do not have some practical astronomical application.

Like nearly all great astronomers of his era, Bessel was obliged to spend part of his time surveying wherever the government wished. In 1824 he supervised the measurement of a 3,000-meter base line in the Frischen Haff because he liked to spend a day in the fresh air once in a while. In 1830 he was commissioned to carry out triangulation in East Prussia, after Struve had completed the triangulation of the Russian Baltic provinces. Bessel designed a new measuring apparatus for the determination of base lines that was constructed by Repsold; he also developed methods of triangulation by utilizing Gauss's method of least squares. Bessel's measuring apparatus and method of triangulation have been widely used. The triangulation in East Prussia and its junction with the Prussian-Russian chain of triangulation was described in a book written with J. J. Baeyer (1838). From his own triangulations and from those of others, Bessel made an outstanding determination of the shape and dimensions of the earth that won him international acclaim.

Among Bessel's works that contributed to geophysics were his investigations on the length of the simple seconds' pendulum (1826), the length of the seconds' pendulum for Berlin (1835), and the determination of the acceleration of gravity derived from observing the pendulum. Bessel achieved the standardization of the units of length then in use by introducing a standard measure in Prussia, the so-called Toise (1 Toise = 1.949063 meters). The necessity of a standard of length had become apparent to him during his work on triangulation in East Prussia, as did the necessity of an international organization to define the units of measures. This need led to the founding of the International Bureau of Weights and Measures.

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II. Secondary Literature. A bibliography of sketches of Bessel's life and astronomical works is given in *Abhandlungen*, III, 504. Noteworthy are C. Bruhns, in *Allgemeine deutsche Biographie*, pt. 9 (Leipzig, 1875), 558–567; and Sir William Herschel's addresses delivered to Bessel on presenting honorary medals of the Royal Astronomical Society, in *Monthly Notices of the Royal Astronomical Society*, **1** (1829), 110–113, and **5** (1841), 89. A biography of Bessel in anecdotal style is J. A. Repsold, in *Astronomische Nachrichten*, **210** (1919), 161–214. An excellent review of the first determination of a stellar parallax is H. Strassl, "Die erste Bestimmung einer Fixsternentfernung," in *Naturwissenschaflen*, 33rd year (1946), 65–71.

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