*ANTECEDENT'S TO FECHNER'S LAW:
THE ASTRONOMERS J. HERSCHEL, W. R. DAWES,
AND N. R. POGSON*

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The history of the stellar magnitude scale is briefly traced from the second century B.C. until the middle of the nineteenth century. It becomes clear that astronomers formulated "Fechner's Law" by about 1850. While Fechner is credited with the grander view of things, the contention is made that the astronomers John Herschel, W. R. Dawes, and N. R. Pogson have not been given their due by historians of psychology.

Key words: Fechner's Law, history of psychology, John Herschel, W. R. Dawes, N. R. Pogson, astronomy, stellar magnitude

Materials on the history of psychology relate the work of Gustav Theodor Fechner (1801-1887) primarily to the earlier work of Ernst Heinrich Weber (1795-1878). The relationship between the Weber ratio and Fechner's Law is so well known that no review is needed here. A first-hand acquaintance with the details of the topic may be gained by consulting Fechner's *Elements of Psychophysics*, first published in 1860 and recently translated by Helmut Adler (1966). But there were important antecedents to Fechner's Law in the science of astronomy, and historians of psychology do not adequately discuss those events. Since becoming involved in teaching both history of psychology and introductory astronomy, I have been uneasy about the frequent omission by historians of any mention of those antecedents to Fechner's Law. The purpose of the present note is to outline briefly the relevant history.

Hipparchus (160-127 B.C.) was, perhaps, the greatest of the Greek astronomers. He was a keen observer of the heavens, and among his many accomplishments was the construction of the first naked-eye star catalogue in western science. The star catalogue had about 850 en-

tries, each listed by position in the sky and by apparent brightness or magnitude. Hipparchus' magnitude scale was intended to involve approximately equal sensation intervals (Stevens, 1975), with first-magnitude stars the brightest and sixth-magnitude stars the dimmest. (Stars of the sixth magnitude are still considered to be at the threshold of human naked-eye vision.)

In the second century A.D., the Alexandrian astronomer Claudius Ptolemy (A.D. 90-168) divided each of Hipparchus' classes into three subclasses, to obtain a finer subdivision of stellar magnitudes. (Ptolemy is most renowned for his *Great Syntaxis of Astronomy*, or *Almagest* (Greatest Book) in Arabic translation. This 13-volume work established the details of a geocentric view of the universe that was not seriously challenged until Copernicus, a millennium and a half, less a hundred years, later.)

The stellar magnitude scale did not receive unusual attention until the latter part of the eighteenth century. Interest in the scale was spurred by work on variable stars, *i.e.*, stars whose magnitude varies over time. John Goodricke (1764-1786) did important work here (he was born mute and died at age 22). Goodricke discovered in 1784 the precisely cyclic variable star delta Cephei, which belongs to a class of variables that serve as distance indicators in our own and to nearby galaxies.

At about this time, Sir William Herschel (1738-1822), professional musician and amateur astronomer turned professional as Royal Astronomer to George III, based on his dis-

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covery of Uranus in 1781, was establishing stellar astronomy through his studies on the distribution of stars in space. His work was continued by his son Sir John Herschel (1792-1871), who spent the years 1834-1838 near Cape Town at the Cape of Good Hope (Buttman, 1970), where he established an observatory to study and catalogue the southern skies. It was there that J. Herschel performed an important experiment in stellar photometry, *i.e.*, the measurement of light received from stars. Based on that work, astronomers began to appreciate the relation between the amount of light received from stars and their perceived or apparent magnitudes.

The question Sir John Herschel asked was direct: how much more light do we receive from a first-magnitude star than from one of the sixth magnitude? Today, such a question would be answered by photoelectric, or even photographic, techniques. Lacking those procedures, J. Herschel used visual methods. One was the method of reduced apertures, which capitalizes on the fact that the relative light grasp of two astronomical mirrors is given by the ratio of their areas. Thus, he varied—stopped down—the aperture of a mirror until a first-magnitude star appeared as bright as a sixth magnitude star under full aperture (method of average error, limits?). In other words, he used his eye as a null instrument and found that if the surface areas are in the ratio of 100 to one, a first-magnitude star seen with the smaller mirror was equal in sensation brightness to a sixth-magnitude star seen with the larger. He concluded that we receive about 100 times the light from a first-magnitude star as is received from a sixth-magnitude star.

An important paper for our purpose was presented in 1851 by the Rev. W. R. Dawes (1799-1868) to the Royal Astronomical Society. In that paper, Rev. Dawes bemoaned the fact that there was little uniformity among the magnitude scales employed by astronomers: "I am not aware upon what principles the scales of telescope magnitude employed by some of the observers of the most extensive catalogues have been formed. It is evident that Lalande, Piazzi, Bessel, and Argelander, have not referred their estimations to precisely the same standard; . . . But the adoption of a particular numerical magnitude to represent a certain degree of brightness has been, as far

as I know, purely arbitrary" (Dawes, 1851, pp. 188-189).

After some further discussion, Dawes stated his proposal: "Let, then, the numerical magnitudes of telescopic stars be assumed, so that one star of the sixth magnitude shall equal two stars of magnitude $6\frac{1}{2}$; and one star of magnitude $6\frac{1}{2}$ = two stars of magnitude 7, and so on" (p. 191). Dawes, then, after a suggestion of J. Herschel, constructed a scale that related arithmetic changes in apparent (sensory) magnitude to geometric changes in light intensity. He suggested a factor of two for each one-half change in magnitude, or a factor of four for a change of one full magnitude. That factor, whatever be its value, has been termed the "light ratio".

In 1856, Norman R. Pogson (1829-1891), Assistant at the Radcliffe Observatory, Oxford, presented a paper to the Royal Astronomical Society in which he reported research by himself and by others that indicated the light ratio to be closer to 2.5 than to four. He suggested the adoption of the value 2.512 (called "Pogson's ratio"). That value accords with the work of Sir John Herschel, who, it will be recalled, found that a five-magnitude change corresponded with a change in light intensity by a factor of 100; 2.512 is the fifth root of 100.

Thus, by 1856, a scale for stellar magnitude was completed. It related an arithmetic series for magnitude and geometric series for light flux. The scale was slow in being adopted, but is in general use today. Needless to say, the scale extends to stars dimmer than the sixth magnitude and brighter than the first magnitude. There are zero-magnitude stars and, even, stars with negative magnitudes. Sirius, for example, is the brightest star in the night sky at apparent magnitude -1.47 . The brightest star of all is the closest star, the sun, at apparent magnitude -25.5^2

Consider two stars M and N of apparent magnitudes m and n , and let I_m and I_n rep-

²Astronomers distinguish between apparent and absolute magnitude. Apparent magnitude, which we have been discussing, depends on a star's intrinsic luminosity and its distance from us (assuming no interstellar material such as dust between us and the star). Absolute magnitude is used to compare intrinsic luminosities among stars, and it is defined as apparent magnitude adjusted to a standard distance of 10 parsecs (which is 32.6 light years). In terms of absolute magnitude, our Sun is a $+5$ magnitude star.

resent the light flux received from them. According to the principle of Herschel and Dawes, and the light ratio of Pogson, the ratio of light intensities is given by

$$I_m/I_n = 2.512^{(n-m)},$$

$$\text{and, } \log(I_m/I_n) = (n-m) \log 2.512.$$

The logarithm of 2.512 is 0.4, since 2.512 was chosen as the fifth root of 100. Rearranging terms gives

$$n-m = 2.5 \log (I_m/I_n).$$

The equation just shown is Fechner's Law stated as the difference between two sensations, with the constant K of the well-known $S = K \log R$ set at 2.5. Thus, Fechner's Law is identical with the principle stated by Herschel and W. R. Dawes. Further, Dawes paper was published in 1851, less than a year after the fateful morning of October 22, 1850, when Fechner resolved to make "the relative increase of bodily energy the measure of the increase of the corresponding mental intensity". But the paper appeared about eight or nine years before Fechner stated his well-known conclusion.

There is little reason to question that the grander view of things belonged to Fechner. He concerned himself with the nature of sensory function in general (his metaphysics aside), and the astronomers were concerned only with a scale for stellar magnitude. But it is really not clear that the works of Bouguer (1760), of Delezenne (1827), and possibly even of Weber (1834) were motivated by a grand view. (See Herrnstein and Boring, selections No. 15, 16, 17.)

References to John Herschel concern his work on color, and occasionally Pogson is referenced for his work on the light ratio. Boring (1942) does mention the work of Steinheil and Herschel in connection with Fechner's Law, but he relegates that mention to the small print in the note section at the end of a chapter. The 1851 paper by W. R. Dawes has not been referenced anywhere, so far as I have been able to find, not even by Fechner, who in *Elements* acknowledged prior work that established the principle we call Fechner's Law.

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