Stellar Magnitudes and their Determination.[1]

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III.—ABSOLUTE MAGNITUDES.

THE absolute magnitude of a star is a measure of its intrinsic luminosity. In order to determine it, the distance of the star must be known. Star distances are so great that it is customary and convenient to express them in angular measure by means of the angle (ϖ) subtended at the star by the radius of the earth's orbit, supposed viewed broadside on from the star. If I is the apparent luminosity of a star at its actual distance, then the apparent luminosity when placed at any definite fixed distance from the sun will give a true relative measure of its intrinsic luminosity: its apparent luminosity being then I/ϖ^2, its absolute magnitude must differ by a constant from

$$-2{\cdot}5(\log I - 2 \log \varpi),$$

or from $m + 5 \log \varpi$. There is not entire uniformity amongst astronomers as to the constant distance to which stars must be considered as placed in order to obtain a definite measure of their absolute magnitude; this non-uniformity is not serious, provided the convention adopted is always explicitly stated. The most common practice is to define the absolute magnitude as the value of the apparent magnitude when the star's parallax (ϖ) is one-tenth of a second of arc. If, then, ϖ is expressed in seconds, the absolute magnitude, M, is given by

$$M = m + 5 + 5 \log \varpi.$$

If, on the other hand, a distance corresponding to a parallax of $1''$ is adopted as the standard, the absolute magnitude is given by

$$M = m + 5 \log \varpi.$$

The magnitude m may be either the visual or the photographic apparent magnitude, although it is more general to use the former. There will be a relative difference in the absolute magnitudes of two stars of different colours according to which apparent magnitude is used. To define absolute magnitudes without any ambiguity, it would be necessary to use a bolometric magnitude which would take account of all the energy emitted by the star, whatever its wave-length might be.

The intrinsic luminosity of a star may also be expressed in terms of the luminosity of the sun as a unit, a means of expression which conveys more meaning to the average person. Various measures have been made of the apparent magnitude of the sun, on the scale used for the stars, and the most probable value is now accepted as $-26{\cdot}5m$. This corresponds to an absolute magnitude for the sun of $5{\cdot}1$M or of $0{\cdot}1$M, according as the distance used in defining absolute magnitude corresponds to a parallax of $0''{\cdot}1$ or $1''$ respectively. These values are uncertain to the same extent that the value of the apparent magnitude is uncertain, and are, therefore, liable to future revision. As it is not advisable that the value of a star's luminosity, in terms of the sun's luminosity as a unit, should be liable to frequent change, it would be preferable to adopt a value $-26{\cdot}6m$ as the apparent magnitude of a hypothetical sun, nearly equal in brightness to our sun, and having the same position in space, and then the absolute magnitude of this hypothetical sun becomes $5{\cdot}0$M or $0{\cdot}0$M, according to the unit of distance adopted. If a distance corresponding to $1''$ (called by general acceptance a *parsec*) is adopted as the unit, then the absolute magnitude will give a direct measure of luminosity in terms of the sun's luminosity as unit, the luminosity being then simply the antilogarithm of $-0{\cdot}4$M. The convenience of having the zero of absolute magnitude to agree with the brightness of the sun is so great that, in spite of the much more general acceptance hitherto of the scale of absolute magnitudes based on a distance of 10 parsecs ($\varpi = 0''{\cdot}1$), the time does not seem too late to change the convention. The matter is one which deserves the attention of the International Astronomical Union.

Since the determination of absolute magnitudes necessarily involved, until recently, the determination of the distance of a star and also of its apparent magnitude, and since the former of these quantities is small and liable to a relatively large error in its determination, it follows that absolute magnitudes could be determined only with a much greater uncertainty than attached to determinations of apparent magnitude. Fortunately, we are not dependent for our knowledge of absolute magnitudes simply and solely upon direct trigonometrical determinations of stellar distances; methods have been devised of recent years by which the problem may be attacked by somewhat indirect means.

One particularly interesting method has been worked out at the Mount Wilson Observatory, mainly by Adams, who succeeded in detecting differences in the relative intensities of certain lines in the spectra of various stars of a given spectral type. These spectral differences within the same spectral type are due to differences in density or in surface brightness or both, and indicate differences in absolute magnitude. By using the best determined trigonometrical parallaxes, Adams was able to standardise these relative intensity differences in terms of absolute magnitudes; and using the standardised basis so found, it becomes possible to determine the absolute magnitudes of stars simply from an examination of their spectra. Since the basis of these determinations is the collective results of direct parallax measures, the result for any given star is liable to a much smaller uncertainty than would be the result derived from a direct determination of the parallax of that star, provided the star is at such a distance that the

[1] Continued from p. 176.

uncertainty in the parallax determination begins to become comparable with the value of the parallax (say, $\varpi < 0''.025$ in the case of modern photographic determinations). Adams, therefore, has replaced the determination of each single parallax by a collective result, and has, in effect, reversed the former procedure, so that now, from a determination of the absolute magnitude and the apparent magnitude, the parallax may be derived with a high order of accuracy.

Another indirect method, discovered independently and almost simultaneously by Hertzsprung and Russell, enables a hypothetical value to be derived for the parallax of any physical double star of which the components show even a trace of relative motion. If w is the observed relative motion in seconds of arc per year and s the observed separation of the components in seconds of arc, then the parallax is given by $\varpi^2 = sw^2/14{\cdot}6m$, where m denotes the combined mass in terms of that of the sun as a unit. The masses of the stars do not show a wide variation, and Russell finds that, assuming the mass of the binary system to be double that of the sun, the resulting error in the absolute magnitude deduced from this hypothetical parallax will not exceed $\pm 1{\cdot}0$M in 89 per cent. of all the cases.

A third method of some interest may also be briefly referred to. There is a type of variable star the light variation of which is characterised by certain peculiarities which seem to indicate that the variation is due to an actual pulsation in the star. Such variables are termed Cepheids, after the typical example, δ Cephei. In the Magellanic clouds is a large number of these variables, and it was discovered by Miss Leavitt that there is a definite relationship between the periods of these Cepheids and their apparent magnitude, or, since they are all at appreciably the same distance, between their period and absolute magnitude. Their absolute magnitude, however, is not *a priori* known, but the near Cepheids may be used to fix a point on the curve, and then the absolute magnitude of any Cepheid can at once be found if its period is determined. This has the following important application: the large majority of the variables which occur in stellar clusters are of the Cepheid type, and this relationship, therefore, provides a basis for the determination, with a relatively small uncertainty, of the distances of stellar clusters. The result is the more valuable because the clusters are at such great distances that there is, at present, no reasonable expectation of the possibility of their direct determination. With the aid of the large reflectors at Mount Wilson, much valuable work has been done in determining the apparent magnitudes of cluster stars and, the parallax of the clusters having been determined, these can at once be turned into absolute magnitudes.

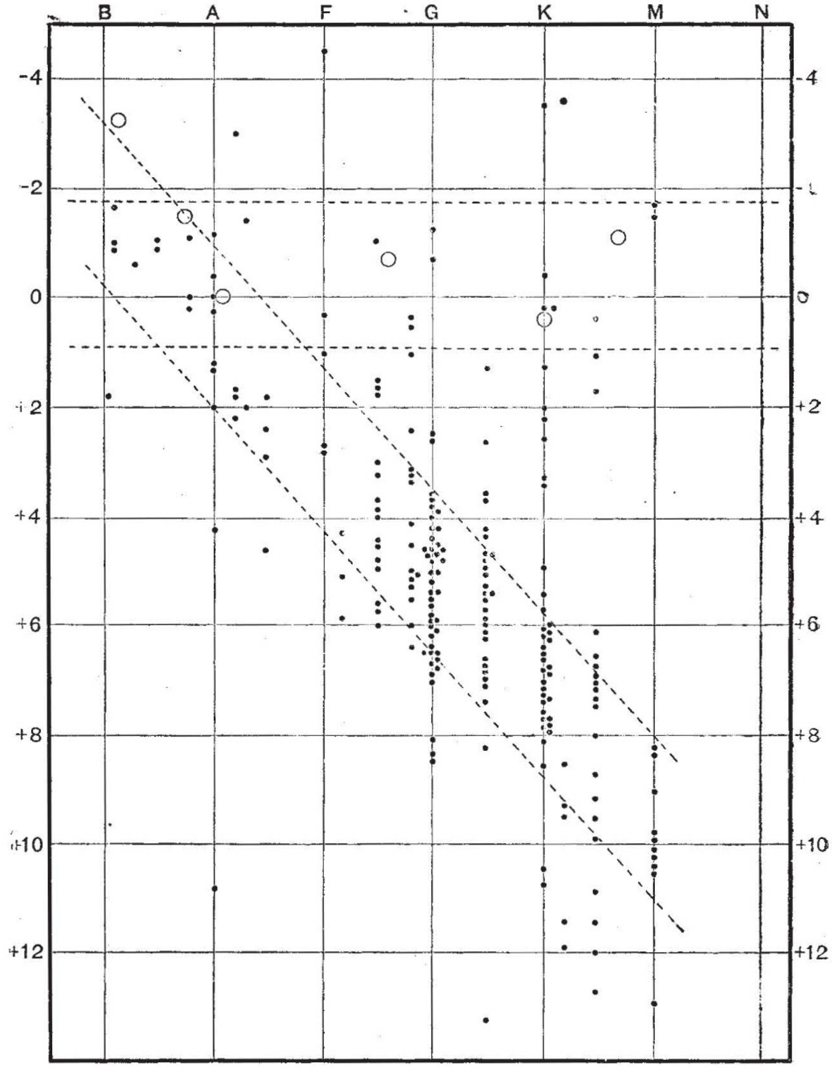

FIG. 6.—Absolute magnitudes of stars in relation to spectral type.

It will be evident from the preceding remarks that our knowledge of the absolute magnitudes of stars has within recent years increased very rapidly. What are the absolute magnitudes of the stars in the neighbourhood of the sun? The values show a very marked dependence upon the spectral type of the star. It was shown by Russell that for any given type there is a limiting absolute magnitude below which, in general, stars of that type do not occur. The redder the star, the fainter may its absolute luminosity be. One of Russell's diagrams, in which the absolute magnitudes are referred to a distance of 10 parsecs, is reproduced in Fig. 6. In this diagram the small dots represent individual stars, the large circles mean values for bright stars of small proper-motion and parallax. It will be seen that the general distribution of the dots is along two lines inclined at an acute angle and intersecting at type B; that this distribution is not the result of the selection of stars for parallax determination on the ground of brightness or size of proper-motion was conclusively shown by Russell. It will also be seen that for the red stars there is a complete separation between the two classes, so that a very red star is intrinsically either very bright or very faint. These facts have given rise to the "giant" and "dwarf" hypothesis, and have led to a recasting within the last few years of the ideas as to stellar evolution which were formerly generally accepted.

The following results emerge from Russell's investigation: (1) Stars of all types occur brighter than zero absolute magnitudes,[2] and mostly between 0 and −2M—say, about 150 times the luminosity of the sun. These are called "giant" stars. (2) There are no B-type stars, and very few A-type stars, fainter than zero absolute magnitude, or, in other words, all the white stars are intrinsically very bright. (3) All the faint stars, less than, say, 1/50 the luminosity of the sun, are red and of types K and M. These are called "dwarfs," and comprise all the near stars of large proper-motion. (4) In the intermediate classes, F and G, there is no separation between the giants and the dwarfs. Our sun (5·0M) is a typical G-type star. In view of these remarks, it is obvious that no precise meaning attaches to a statement such as "The average absolute magnitude of all stars is +2·7M."

[2] The unit of absolute magnitude used here is that which corresponds to a parallax of one-tenth of a second of arc.

Shapley's work on the magnitudes of stars in clusters, combined with his determination of the distances of clusters, has shown that the giant stars in clusters, which are the only ones sufficiently bright to appear on the photographs, are of about the same magnitude as the giant stars in our more immediate neighbourhood. Two further points of interest emerge from the investigation: one is that in all the clusters examined in detail the intrinsically brightest giant stars are red stars; this may also be true for the stars near the sun, although the determinations of their absolute magnitude are probably not sufficiently accurate to show it; the other point is the apparent importance of an absolute magnitude of about −0·2M. Shapley finds that all Cepheid variables and cluster variables exceed this brightness; moreover, in the luminosity curve which connects the number of stars of any given absolute magnitude with the magnitude, there is a maximum in the curve corresponding to the same magnitude. In Shapley's opinion, this magnitude—corresponding to a luminosity of about 100 times that of the sun—indicates a critical stage in stellar evolution, and, in all probability, is of significance in the theory of a gaseous star. It seems, in fact, probable that by the new methods recently discovered for estimating great distances, combined with the advantages afforded by the large reflecting telescopes at Mount Wilson, we may learn more about absolute magnitudes from a study of clusters at distances corresponding to parallaxes of the order of 0″·00005 than from the study of the stars which immediately surround us.

Dynamics of Golf Balls.

THE physical principles underlying the flight of a golf ball were clearly laid down by the late Prof. Tait between the years 1890 and 1896.[1] In view of the present agitation over the standardising of the golf ball, it may be of advantage to reconsider some of the problems attacked by Tait and largely solved by him. The investigation led him into a series of researches on impact so as to obtain data for measuring the resilience of the material of which golf balls were then made. Also, by means of a specially constructed ballistic pendulum, measurements were made of the speed of a golf ball impinging on the pendulum placed at a distance of about 6 ft. from the tee. By attaching a tape to the ball, Tait was able to obtain direct measurements of the amount of underspin communicated to the ball at the instant of striking it. Outside observations were also made of the heights of the trajectories of well-driven balls, and of the ranges and times of flight. All these data were skilfully introduced into the mathematical discussion of the form of the trajectory, a problem so difficult as to be capable of solution only by approximate methods. This was done before the days of the rubber-cored ball, and the steady improvement in the manufacture of the golf ball has enabled even very ordinary players to exult in lengths of drive which in Tait's days were beyond the powers of the mightiest exponents.

[1] "On the Path of a Rotating Spherical Projectile." Trans. R.S.E., 1893 and 1896; "Some Points in the Physics of Golf," NATURE, vols. xlii., xliv., and xlviii.; "Long Driving," *Badminton Magazine*, 1896.

What Tait established beyond all controversy was that the range of the trajectory of a properly driven ball depended as much upon the underspin as upon the speed of projection. The combined effect of the linear speed and the rotation about a horizontal axis brought into play a force perpendicular to the direction of motion of the ball. Tait gave sound reasons for regarding this force as being proportional to the product of the velocity and the spin. Thus, although the possibility of a long trajectory depends primarily upon the velocity of projection, the range actually attained in any particular case will be governed by the amount of underspin communicated to the ball. If this is too great, the ball will rise too high, and the range will be correspondingly diminished. If the underspin is too small, gravity will pre-