of good students. If either supply fails, it is not geography alone, but all sciences and studies, that will be damnified; for all require the best of the help she can give in proportion as her science grows and improves. History will be able to call but indifferent geography to her assistance if this science has been understaffed and discouraged by official reluctance to allow it a place of its own in the sun. Is there not still some such reluctance on the part of the Board of Education, of some of our universities, and of the Civil Service Commissioners?

Stellar Parallax.

By J. JACKSON, Chief Assistant, Royal Observatory, Greenwich.

THE determination of stellar distances is fundamental to the investigation of the sidereal universe. When once the distance of a star is known, we can calculate its transverse speed in kilometres a second from its proper motion in seconds of arc per century, and we can determine its absolute brightness from its apparent brightness. For binary stars at known distances we can determine the separation of the components in kilometres, and this, together with the period, enables us to compute the mass of the system. Recent work at Mount Wilson has shown that it is practicable to determine the angular diameter of the larger stars, and for such stars a knowledge of the parallax will enable us to compute the linear diameter. Many of the investigations about the sidereal universe made during the last twenty years have been possible only through the increase in the number of stars the distances of which are known with reasonable accuracy, and the results obtained have been of such importance that in an increasing degree the energy of astronomers is being directed to supply the required data.

The direct determination of stellar distances depends on triangulation from the earth at different positions in its annual path round the sun. The apparent motion of a star can be analysed into a linear component due to the relative motion of the sun and the star, and a periodic motion due to the motion of the earth round the sun. The parallax of a star is the angle subtended by the earth's radius at the distance of the star, and is equal to the semi-major axis of the apparent ellipse described by the star as a result of the earth's orbital motion. It is therefore determined from observations made as nearly as practicable at the times when the star is at the ends of the major axis of the "parallactic ellipse."

The principle to be used in the determination of stellar distances was obvious as soon as the Copernican theory of the solar system was recognised. The difficulty in applying the principle is due to the extreme minuteness of the change in angle which is to be measured after a six months' interval. Had it been known or assumed that the stars were comparable in real brightness with our sun, although they appeared about a million million times fainter, it could have been calculated that their parallaxes were less than a second of arc. Successive attempts to measure the parallaxes of selected stars for long necessarily met with failure, although they led to many important discoveries. In the first half of the eighteenth century Bradley made a remarkable series of observations of the meridian zenith distance of the star γ Draconis—a star which passed the meridian near the zenith so that the angles to be measured were relatively small, while errors introduced by varying atmospheric conditions were reduced to a minimum. He discovered aberration and later nutation through these observations, and proved that the parallax of this star was less than a second. Observations of the same kind might later have led to the discovery of latitude variation. The attempt made by Sir William Herschel towards the end of the eighteenth century may also be noted here. Instead of attempting to determine the absolute parallax of separate stars which involves the measurement of large angles from the vertical or some other direction which it is supposed can be accurately identified after a six months' interval, he attempted only to discover relative parallaxes from the relative displacements of stars in nearly the same direction, but probably at very different distances. The method is essentially that now used almost exclusively; but where Herschel applied it to pairs of stars actually at different distances, his observations were not sufficiently accurate to reveal the parallactic motion. His most extensive series of observations were made of fairly bright pairs of stars within a few seconds of arc, and the motion he actually discovered was orbital motion of the stars, which proved that they were really close together in space and revolving round one another under gravitational attraction. This discovery led to the systematic study of double stars.

Success in the determination of stellar parallax was obtained almost simultaneously about 1838 by three observers employing different methods on different stars. The principal credit is usually given to Bessel for his determination of the parallax of 61 Cygni—a pair of faint stars with large proper motion—relative to faint neighbouring stars by means of the heliometer. This instrument consists of an ordinary telescope with the object glass cut in two along a diameter, and means are supplied for rotating the object glass and for sliding the two halves along their common diameter. With this instrument each star forms two images, and the observation consists in bringing an image of one star into coincidence with the other image of the other star. The heliometer can be used to measure angular distances of several minutes with an accuracy second only to that of the modern photographic telescope. The other determinations of parallax were by Struve, who observed *α* Lyræ relative to faint stars in its neighbourhood by means of a position micrometer as used for double stars, and by Henderson, who used meridian observations in both co-ordinates of *α* Centauri.

During the next fifty years a number of observers made parallax determinations by these three methods, but although they showed great skill in their work and prosecuted it with the greatest assiduity, it cannot be said that many trustworthy results were obtained. The errors to which even the best results are liable are shown by the following seven determinations of the parallax of Procyon made by Elkin with the Yale heliometer:—

0·257″ ± 0·018″
0·461 ± 0·035
0·367 ± 0·018
0·366 ± 0·023
0·503″ ± 0·049″
0·294 ± 0·019
0·228 ± 0·020

Soon after the first application of photography to astronomy it was found that star places could be determined with great accuracy from photographic plates. It was only natural that attempts should be made to apply the new method to parallax determination. The initial results showed no greater accuracy than those obtained visually, but gradually the difficulties have been overcome, and a remarkable degree of accuracy attained. It might have been supposed that the development of a photographic plate would lead to a distortion sufficiently great to vitiate the results, but apparently this is not the case. In fact, the distortion is less than 0·001 millimetre and can be ignored. The difficulty is to eliminate systematic errors in the apparent centres of the star images on the plates so as to get the photographs to faithfully represent the heavens at the different epochs. Provision must be made for the automatic elimination of every imaginable source of systematic error, since every preconceived source of possible error has turned out to be a reality. The most important precautions to be taken were pointed out about twenty years ago by Kapteyn in the first of the Groningen Publications. These include the taking of all the photographs under as nearly as possible the same instrumental conditions—the telescope should always be on the same side of the pier, and as nearly as possible in the meridian. These precautions are now obvious, as not only is the objective liable to behave differently in different positions, but the atmospheric effect might vary differently for the different stars, as they are not all of the same colour. A more serious source of error, called the "guiding error," was pointed out by Kapteyn. For the brighter stars an impression is produced on the photographic plate more quickly than for the fainter stars, so that if during the exposure an error in guiding allows all the stars to be slightly displaced for a short time, the brighter stars will show an elongated image with a displaced centre while the fainter stars will show round undisplaced images. For this reason Kapteyn urged the importance of good guiding. But it is impossible to guide sufficiently well, and the difficulty was satisfactorily surmounted only when Schlesinger introduced the occulting shutter. This is a sector which is made to rotate rapidly in front of the star the parallax of which is to be determined. By reducing the opening in the sector, the time during which the "parallax star" is exposed is reduced relatively to the other stars. It is usual for the comparison stars to be of the 10th or 11th magnitude, while the "parallax stars" are generally considerably brighter. It is possible by means of the rotating sector to cut down the brightness by five magnitudes. For the very bright stars this is not enough, and some observers have used two rotating sectors to give the required reduction. Another method is to place a screen in front of the brighter stars. It is now generally recognised that it is most important to have the parallax star and the comparison stars forming images of nearly equal size and density. At the same time, every care is made to have the guiding as accurate as possible. In this connection the exposure should be as short as will produce readily measurable images—two or three minutes with photographic refractors with an aperture of 20 or 30 in.

Kapteyn's plan was to photograph the region under consideration at three different epochs on the same plate, which was stored between the exposures and developed only after the third epoch. The times of exposure were chosen so as to give maximum parallactic displacement in one direction at the first and third epochs, and maximum parallactic displacement in the opposite direction at the middle epoch. For example, a region might be given three exposures in May of one year, six in the following September, and three in the next May. The telescope would be moved slightly between the exposures, and for each star there would be twelve images on the plate. As all the images of each star would lie close together, it would only be necessary to measure very small distances on the plate, while by a symmetrical arrangement of the images any possible distortion of the film would be eliminated. This method is ideal, and was applied to some extent, but on account of bad weather interfering with the exposures it has practically been abandoned. The photographs at the different epochs are now taken on separate plates, and this method allows of greatest weight being given to those exposures made under the best atmospheric conditions.

The difficulties to be overcome having been fully realised, and the necessary precautions having been devised, a large scheme for the determination of parallaxes has been undertaken. In this work the Allegheny, Dearborn, Greenwich, McCormick, Mount Wilson, Sproul, and Yerkes Observatories take part. The following table shows the aperture and focal length of the telescopes used:—

	Aperture. Inches	Focal length. Feet
Allegheny	30	46
Dearborn	18½	23
Greenwich	26	22½
McCormick	26	32½
Mount Wilson ...	60	80
Sproul	24	36
Yerkes	40	62½

The telescope used at Mount Wilson is a reflector, while the others are refractors. It will be seen that the focal length varies considerably from one instrument to another, but the probable error of a parallax determined from about fifteen plates is in all cases about 0·01″ or a little less. The explanation given is that with average conditions of working the images are larger for the longer telescopes. The aperture is also a point of some importance, as with larger aperture the duration of the exposure can be cut down, and with it the "guiding error." However, as some of the larger telescopes are really visual telescopes, and require a colour screen or special plates, the advantage they would otherwise have is reduced.

Considerable progress has already been made in carrying out this scheme of co-operation, and probably at least 200 parallaxes a year are being determined. The value of this contribution to our knowledge of stellar distances is realised when we recall that in 1880 we knew the parallaxes of only about twenty stars, while as late as 1915 the number had risen only to about 200. As one of the recent large publications we may instance the 260 determinations made at the McCormick Observatory in the five years 1914 to 1919.[1]

Let us consider the first star in this list. It is β Cassiopeiæ, a star of magnitude 2·4 with a proper motion of 55″ a century. The parallax was found from the rather large number of twenty-eight plates exposed as follows:—

1914	July	1	1916	Aug.-Sept. ...	4
	Nov.-Dec. ...	5		Nov.-Dec. ...	5
1915	Aug.	3	1917	Aug.	3
	Nov.-Dec. ...	3		Nov.-Dec. ...	4

The parallax found was 0·058″ ± 0·011″, in satisfactory agreement with other determinations, of which we may quote 0·051″ ± 0·015″ determined by Smith with the heliometer, and 0·074″ ± 0·011″ found by photography at the Allegheny Observatory. The proper motion in right ascension was found to be +0·524″, as compared with +0·529″ found by Boss from meridian observations extending through about 150 years. But the agreement is not always so satisfactory. Consider, for example, the star γ Ceti, which forms the double Σ 299. The components are of magnitudes 3·6 and 6·8, and are separated by about 3″. The duplicity of the star might well lie at the root of the trouble, although with suitable exposures the fainter star should not be seen. The parallax found with the Yale heliometer was 0·119″ ± 0·017″, that by photography at Allegheny 0·014″ ± 0·008″, and that at the McCormick Observatory 0·037″ ± 0·008″. The photographic parallaxes may be considered as in fair agreement, but the proper motion in right ascension was found to be −0·059″ (from plates extending 1½ years), as against −0·147″ found by Boss from observations extending 150 years. The photographic proper motion was checked by plates giving an interval of 3½ years, during which time the difference in proper motion amounted to no less than 0·3″. This cannot be explained by the orbital motion of the components, which is extremely slow, and it is difficult to attribute it to all four comparison stars, which on examination showed no appreciable proper motion. Results of this kind are by no means uncommon, and the greatest caution has to be used in applying small parallaxes from single determinations.

It may be considered that parallaxes greater than 0·05″ may be used in calculations concerning individual stars. For smaller parallaxes the accidental errors will make the results untrustworthy. It has been estimated[2] that there are about 2000 stars with a parallax as great as 0·05″, although most of them will be as faint as the 10th magnitude and not attract notice. As the number of stars to this magnitude is of the order of a million, it will be difficult to identify the stars which are near, but faint. Stars chosen at random will therefore generally give very small parallaxes. Most observing programmes, therefore, contain specially selected stars, such as very bright stars, stars with large proper motion, and binary stars in rapid orbital motion for which a fairly large parallax may be expected.

On account of this selection of the stars great care has to be exercised in discussions based on the measured parallaxes. Many facts, however, have been brought to light. The most important of these correlate what may be called the apparent qualities of a star with its absolute qualities. By the former we mean those qualities which can be found from observation without a knowledge of the distance, such as the nature of the light a star emits, or its angular motion, and by the latter the intrinsic qualities, such as real brightness, mass, and linear speed. Probably the most important results are those which have been reached at Mount Wilson, where for the later-type stars the relative intensity of certain spectral lines has been correlated with the absolute brightness. It is then a simple matter to deduce the distance from our knowledge of the absolute and apparent brightness. Parallaxes determined in this way are called "spectroscopic parallaxes," and recently a list of 1646 of these has been published by the Mount Wilson observers. Again, for double stars with known orbits and known parallax the mass of the system can be computed. It is found that the mass of all systems does not differ widely from twice that of the sun. Assuming this mass, we can compute "hypothetical" or "dynamical"

---

[1] Publications of the Leander McCormick Observatory of the University of Virginia, vol. 3.

[2] Eddington, "Stellar Movements," p. 15.

parallaxes from double stars for which the relative motion is known. Again, although the linear speed differs considerably from one star to another, the proper motions of stars can be considered as an index to the distance—a much better index than the apparent brightness.

In these and other indirect ways our knowledge of stellar distances is being rapidly advanced. It must be remembered that it is all ultimately based on measured or trigonometric parallaxes. The larger trigonometric parallaxes can be applied directly to the individual stars concerned, but for the smaller parallaxes the discussions must be of a statistical nature, as the errors of observation are too great. The indirect methods can, however, be pushed to stars at very great distances if only they appear bright enough for the necessary observations to be made.

Obituary.

JOHN ROBERT PANNELL.

JOHN ROBERT PANNELL, who was killed in the disaster to the airship R38 while making observations on behalf of the National Physical Laboratory, was the only surviving child of Mr. and Mrs. Pannell, of Nutley. He was born in 1885. A delicate childhood, which none would have suspected from his adult physique, interfered greatly with his education, but after courses at the Northampton Institute and some engineering works experience he joined the National Physical Laboratory in 1906 as a student assistant.

His best-known work is that carried out in conjunction with Mr. Stanton on dynamical similarity in the flow of liquids in pipes, which has become classical as the most complete demonstration of that principle in its important applications to hydrodynamics. With Mr. Stanton he also investigated with great elaboration the strength of welded joints; but most of his work is to be found in reports to the Advisory Committee for Aeronautics covering almost the whole range of experimental inquiry in aerodynamics. When problems of airship construction became prominent in 1916 he took part in most of the model measurements on resistance and the efficiency of controls; and when, again, after the war, it became possible to compare the results of model and full-scale tests, Pannell took charge of the latter and was constantly making observations on airships in flight.

In a science so little amenable to general theory the ability to make long and tedious series of routine measurements without allowing familiarity to breed carelessness is of special importance. This ability Pannell possessed in the highest degree. He had that genial serenity and evenness of temper often associated with one of his gigantic stature; neither the perversity of apparatus nor the impatience of petulant colleagues could make him relax for a moment the precautions that are the first necessity of such work. If the human tragedy of the R38 is partially compensated by a gain to science, that gain will be largely due to merits in Pannell's work which are too often eclipsed by more brilliant but not more useful achievements.

In private life the most lovable of men, he radiated kindness and good temper. He was of tireless physical energy, and his war-time leisure, devoted to a small farm, shamed the full-time occupation of many men. He leaves a widow, the true partner of all his labours, with whom all will feel sympathy in the exact measure of their acquaintance.

N. R. C.

WE learn, with regret, of the death on September 10, from drowning near Ottawa, of Mr. F. W. L. SLADEN, author of "The Humble-bee: Its Life-history and How to Domesticate It." Mr. Sladen was forty-five years of age.

THE death of Mr. JOHN PEARCE ROE took place on September 2. Mr. Roe was born in 1852, and was the chairman and managing director of Ropeways, Ltd., of London. He carried out a large amount of work in connection with the transporting of materials by means of aerial ropeways.

Notes.

THE *Chemical Age* announces that Sir William Pope has been elected an honorary fellow of the Canadian Institute of Chemistry.

IT is announced that the annual meeting for 1922 of the British Medical Association will be held at Glasgow on July 21–29. The authorities of Glasgow University have given the association permission to use the University buildings, and offers of assistance should be addressed to Dr. G. A. Allen and Dr. J. Russel at the University.

WE learn from the *Lancet* of September 17 that the Health Committee of the League of Nations is constituted as follows:—Dr. Léon Bernard, professor of hygiene in the University of Paris; Dr. G. S. Buchanan, senior medical officer of the British Ministry of Health; Prof. A. Calmette, director of the Pasteur Institute in Paris; Dr. Carozzi, medical director of the International Labour Bureau; Dr. Henri Carrière, director-general of the Swiss Public Health Service; Sir Havelock Charles, president of the Medical Board for India; Dr. Chodzko, Minister of Health for Poland; Dr. Lutrario, director-general of the Italian Public Health Service; Dr. Th. Madsen, director of the State Institute of Serotherapy at Copenhagen; Prof. Miyajima, of the Kitasato Institute for Infectious Diseases, Tokyo; Dr. Pulido, president of the Spanish Royal Council of Public Health;