apparent organometallic characteristics of two basically important materials in plant and animal transformations: chlorophyll and haemoglobin. It seems altogether reasonable to predict that expanding knowledge in the relatively young field of organometallic chemistry will assist materially in advancing our understanding of biological processes and in further controlling various plant and animal diseases.

THE MOTIONS OF THE STARS[1]

By Dr. EVERETT I. YOWELL
PROFESSOR EMERITUS OF ASTRONOMY, UNIVERSITY OF CINCINNATI

THE first observational evidence of stellar motions was given by Sir Edmund Halley[2] in 1718. Comparing the positions of the Almagest with recent observations to determine the precession, he found large changes in the latitudes of Sirius, Arcturus, Aldebaran and Betelguese; he considered these too great to be attributed to errors of observation or reduction and decided that these stars had a motion of their own.

The proper motion is an angle and we need the distance of the star to convert it into linear motion at right angles to the line of sight. The radial velocity is also needed to give the motion with reference to the sun.

If we accept the estimate that errors of observation did not exceed 15′ at the time of Copernicus; that Tycho reduced this limit to 2′ or 3′ and that Flamsted reduced it to 5″, we see how difficult it was to detect any small proper motions in less than a century.

By the end of the eighteenth century we have some proper motions in Maskelyne's "Catalogue of 36 Fundamental Stars" and in Mayer's "Catalogue of 80 Stars." Mayer obtained his motions by comparing his observations with those made by Roemer fifty years earlier.

Sir William Herschel[3] in 1783 used seven of these motions to determine the motion of the sun. He based his method on the fact that the solar motion would impart a parallactic component to each star, in a great circle passing through the star and the apex of the sun's motion. Drawing these great circles, he found that their intersections clustered in and around the constellation Hercules, with the mean point near λ Herculis; this he adopted as the solar apex. He checked this position with Mayer's motions and found 32 favorable and 12 unfavorable to his hypothesis.

Herschel[4] again considered the problem in 1805; he found a provisional apex from six stars of Maskelyne's Catalogue; then modified it by comparison with the other stars of that catalogue. This new value differed from the other by 16° in right ascension and 23° in declination.

Bessel increased the number of known proper motions by reducing the observations of Bradley and comparing them with the results of Piazzi and himself. With the better determined of these motions, he tested the hypothesis of Herschel by a different method. He[5] plotted the poles of the great circles in which these motions took place and found they were scattered all over the sky. Were they largely parallactic, they should have been concentrated along the great circle whose pole was the solar apex. His results did not agree with Herschel's.

Argelander was the first to observe a list of stars, limited to those suspected of having proper motions. His Abo Catalogue of 560 stars contained 390 whose centennial motions exceeded 10″. From these he determined the apex[6]; 259° = A, 32° = D. His method was to compute the position angle of each motion and compare it with the position angle of the parallactic motion with respect to an assumed apex. His equations were based on the assumption that directions of motion were at random. His result confirmed Herschel's and convinced astronomers that the solar motion was real.

Airy[7] published his method in 1859; he resolved the stellar motions along three rectangular axes. When the components were summed he assumed the peculiar motions would cancel, leaving the parallactic components to sum up into those of the solar motion. In Airy's method it was also necessary to make some assumption concerning the distance of the stars. In general the amount of proper motion was assumed to be a better criterion of distance than the visual magnitude.

Thus Stumpe[8] divided his 1,054 proper motions into four groups according to the size of the proper motions; in the first group of 551 stars, he took $''.16 < \mu < ''.32$; in the next group of 340 stars, the limits were ″.32 and ″.64; in group 3 (105 stars) the limits were ″.64 and 1″.28; and the last group had 58

[1] Address of the retiring vice-president and chairman of the section of astronomy of the American Association for the Advancement of Science, Philadelphia, December 31, 1940.
[2] *Phil. Trans.*, 6, 329–330.
[3] Scientific Papers of Sir William Herschel, 1, 108–130.
[4] *Idem*, 2, 317–337.
[5] "Fundamenta Astronomiae," 308–313.
[6] A.N., 16, 45.
[7] *Mem. Royal Astron. Soc.*, 28, 143.
[8] A.N., 125, 385–430.

stars whose motion exceeded 1."28 per annum. The values of A were sufficiently concordant, but those of D were discordant, ranging from 42° for the smallest motions down to 30° for the greatest motions.

Dr. Porter[9] repeated the solution, using similar limits and similar groups, but his 1,340 motions were taken from his own Cincinnati Catalogue. His results were similar; good agreement in A, but disagreement in D; his values of D had a greater range—from 54° to 35°. Porter's comment that "the evidence for a common drift of the nearer stars seems to be strong" calls attention to the probability that the underlying hypothesis that motions are at random may be invalid.

We must notice some of the difficulties faced by those who computed proper motions. The earlier observations were subject to large accidental errors as well as systematic ones; among these were errors in refraction, precession, aberration, nutation and fundamental star positions, not to mention instrumental peculiarities. Bessel devised ways of determining the instrumental imperfections and correcting them. The constants were improved by successive approximations as more material became available. The list of fundamental stars was improved by increasing the number of stars in it and also increasing the precision of their positions; but our most important systems—Boss, Eichelberger and FK3—are not yet in complete harmony.

The great number of star catalogues that appeared in the nineteenth century furnished many positions at different epochs, but only the bright stars were well observed. To supply this deficiency, the Astronomische Gesellschaft planned to observe all stars brighter than the 9th magnitude and determine their positions for 1875.0. Not all of the participants finished their work on time, and some of the catalogues were issued early this century for the epoch 1900.0. A greater work was planned for 1900.0– to determine the positions by photography of all stars down to the 11th magnitude; some zones of this Astrographic Catalogue are still incomplete.

Small proper motions of poorly observed stars are unreliable, due to the errors of the positions on which they depend. Computers of the solar motion frequently reject these, although they run the risk of a systematic error in their apex.

We must note that certain assumptions had to be made in handling this problem of the solar motion. Quite generally it was assumed that the *motus peculiares* of the stars were haphazard in direction and so would neutralize one another when large groups were considered. Some assumption as to distance also had to be made, especially in Airy's method. How much these assumptions might invalidate the result could not be determined.

9 A.J., 12, 93.

Let us turn back to our second unknown quantity, the distances of the stars. Bessel[10] published the parallax of 61 Cygni in 1838. The number of parallaxes grew slowly until the introduction of the photographic method. At the end of the century less than 100 reliable parallaxes were known. Schlesinger's work at Yerkes is especially noteworthy in developing the method of obtaining reliable photographic parallaxes, and our American observatories have contributed largely to our knowledge of parallaxes. These are trigonometric parallaxes; to them must be added those determined in other ways, such as spectroscopic and dynamical parallaxes. With these we change our proper motions into linear motions; they also enable us to correct our assumptions as to the distances of the stars in our solar motion problem.

The second component of a star's motion—the motion in the line of sight—remained unknown until the discovery and application of the laws of spectroscopy, especially the Doppler-Fizeau principle. Shortly after Kirchhoff announced his results, some astronomers began to apply them to stellar objects. Progress was slow until photographic methods had replaced visual ones. Our first reliable and extensive catalogue of radial velocities was that of Campbell at Lick.[11] During this century there has been a continual increase in the number of radial velocities available, and again we are indebted to American observatories for a great number of these results.

The variable proper motions of Sirius and Procyon led Bessel to predict their duplicity. The orbits, computed for the unseen companions, proved satisfactory after these were discovered.

Some members of the Pleiades have a common proper motion; so do five stars in the Big Dipper. An early investigation of the Taurus cluster (Hyades group) was made by Lewis Boss[12]; he found 39 stars that shared this common motion toward the vertex A = 92°, D = 7°, moving through space with a common velocity of 46 km per second. R. E. Wilson in 1932 found 136 stars to be members of this moving cluster, and 221 more were members of the group.

Klinkerfues in 1878 found the convergent of the five stars in Ursa Major; Herzsprung added 8 to this group, of which Sirius was the most important as both its parallax and radial velocity were known. Rasmuson uses 28 stars to find the vertex A = 308°, D = –40°, and a speed of 19 kilometers per second. The sun is within the limits of this group, so the parallaxes may vary widely.

In the latter part of the century, Boss and Kapteyn computed apices from proper motions depending largely on Bradley stars. These agreed in right ascen-

10 A.N., 16, 65–96.
11 L.O.B., 229.
12 A.J., 26, 31–36.

sion but differed by 15° in declination; this led Kapteyn to investigate the cause of the disagreement. At the St. Louis Congress of Arts and Sciences,[13] he presented an address in which he showed that the stellar motions were not at random, but showed preference for two directions; one toward A = 85°, D = -11° and the other toward A = 260°, D = -28°. He suggested that there were two streams of stars moving in different directions and commingling; in each stream we can assume that the motions of the individual stars are at random. This two-stream or two-drift hypothesis at once took a prominent place in discussions of the stellar system. An alternative interpretation was offered by Schwarzschild: if the frequency of velocities in any direction be represented by a vector, the surface outlined would be an ellipsoid, with major axis in the direction of the vertices of preferential motion.

Eddington, using the stars from Grombridge, confirmed Kapteyn's results; so did Dyson, using the stars in the Cape Astrographic and also the stars in Carrington's Catalogue.

Kapteyn said that we have two new weapons in the twentieth century—photography, which dreads no numbers, and spectroscopy, which does not care for distances.

Campbell in 1900, using provisional values of the radial velocities for 280 stars, found the apex A = 277°.5, D = 20°, and the solar velocity V = 19.9 km/sec. The solar motion is obtained directly from these radial velocities. In his volume "Stellar Motions" Campbell gives a result from 1,047 radial velocities; A = 272°, D = 27°.4, V = 17.8 km/sec. When he classifies these radial velocities according to the type of spectra, he finds an increase in velocity in going from the earlier spectral type to the later:

O and B	9.0 km/sec
A	9.9 "
F	13.9 "
G and K	15.1 "
M	16.5 "

In 1928, Campbell and Moore[14] published and discussed 2,149 radial velocities of stars brighter than magnitude 5.5. Again their values are nearly the same: A = 270°.6, D = 29°.2 and V = 19.6 km/sec. Again they note that the average residual velocity of the star increases with the spectral class:

B	8.7 km/sec
A	9.9 "
F	12.5 "
G	14.8 "
K	15.3 "
M	16.1 "

Most of these stars are giants, and a few dwarfs occur only in classes F and K. When the solar motion was determined for each spectral class, the groups B and M gave a larger value—22 km/sec—than those from A to K, which averaged 18.7 km/sec.

With the increasing material available, we find the space motions of the stars under investigation in the decade from 1920 to 1930. Thus Strömberg,[15] in considering the distribution of velocities, found 1,300 stars whose proper motions, parallaxes and radial velocities had been determined so that their space motions relative to the sun were known. He found that the solar motion depended on the spectral type and absolute magnitude; that dwarf stars gave a larger solar motion than giants, and high velocity stars than low velocity stars. A study of peculiar velocities was made after correcting these space motions for a solar motion of 20 km/sec toward the apex, A = 270°, D = 30°. He states that the giant stars of types F to M form a single group or stream with approximately ellipsoidal distribution. In addition about 20 per cent. have a stream motion coinciding with the Taurus moving cluster; these are scattered all over the sky. "There is marked asymmetry in the distribution of the velocities around the most frequent velocity vector"; and stars of high velocity move toward the region limited by galactic longitudes 134° to 334°.

Studying this asymmetry in a second paper, Strömberg used a quantity $H = m + 5 \log \mu$ as a basis for his division into groups. He found that the group motion changed continuously with velocity dispersion along an axis in the direction $\alpha = 309°.8$, $\delta = 57°.1$; it varied from 9.0 km/sec for Cepheids of long period to 300 km/sec for fast-moving objects, globular clusters and spiral nebulae. The galactic latitude of this axis is 9°, showing the prevalence of motions parallel to the Milky Way.

Wilson and Raymond[16] made a comprehensive study of the motions of 4,233 stars, three times the number used by Strömberg and twice the number used by Campbell and Moore. It was necessary to use statistical parallaxes for only 10 per cent. of the material. Using a provisional apex—275°, 30°—and a solar velocity of 19 km/sec, the space velocities were corrected for the solar motion, and the resulting peculiar velocities were divided into groups with a velocity range of 5 kilometers. For the groups 0 to 25 km/sec, the velocities were random; for the groups 25 to 45 km/sec, Ursa Major and Taurus streaming was superposed on the random motion; for the groups 45 to 65 km/sec, streaming of the giant G, K, M was superposed on the random motion. After we pass 60 km/sec, the values for the apex increase in both right ascension and declination; also the velocity of solar

13 Congress of Arts and Sciences, 4, 413.

14 Publ. Lick Obs. 16, Introduction.

15 A.J., 59, 228; 61, 363.

16 A.J., 40, 121–142.

motion increases. The values for velocities greater than 250 km/sec are: A = 328°, D = 53° and V = 284 km/sec. It is to be noted that .90 per cent. of these motions can be considered as at random or as random and stream motion combined; only 10 per cent. were asymmetric. The increase of stellar speed with advancing type holds for the main sequence. The low solar speed found for the A group was due to the Ursa Major stars; the small declination of the apex for the F group was due to stars of both streams.

In the last dozen years another result has been obtained from stellar velocities—galactic rotation A term, depending on motion along the galaxy, had been introduced in the equations for precession or solar motion, by some computers in the last century; but it always came out vanishingly small. Theoretical results in this century pointed to such a rotation; certain other results, such as the asymmetry of high velocities, the great solar motion with reference to the globular clusters, the variation of the K term with galactic longitude pointed in the same direction. I believe the first determination from radial velocities was made by Oort;[17] he found the center about which rotation took place was in longitude 326° and the velocity of rotation was 275 km/sec.

Plaskett and Pearce,[18] using proper motions of 881 stars and radial velocities of 849 stars of types O to B7, confirmed the results of Oort; they found $1_0 = 324°$, $V_0 = 275$ km/sec, P = 224000000 years, R = 10000 parsecs.

In a recent paper, Wilson finds similar results; he used Cepheid variables, non-Cepheid c-stars as well as B and O type stars; he adopted a mean galactic absorption of 0.65 mag/kpc. He concluded that the value of V was between 275 and 300 km/sec.

As a rule radial velocities have been preferred to proper motions. The effect of galactic rotation is best seen in distant stars; these have small proper motions, whose accuracy is impaired both by accidental and systematic errors. Van de Kamp and Vyssotsky[19] have used the proper motions of 18,000 stars to determine the solar motion and the galactic rotation. These motions were referred to Boss stars and were corrected for systematic errors due to Newcomb's equinox and precession. The stars were faint stars and their magnitudes extended from 7.5 down to 12.5. They found a value for the solar apex of A = 285°, D = 36°; both values are larger than those usually found for bright stars. For the several spectral classes, their latitudes were systematically greater than those found by Wilson and Raymond.

Values of the solar motion still show dependence on the group used and seem to show variation with spectral type and with magnitude. The results for galactic rotation, either from proper motions or radial velocities, agree quite well.

OBITUARY

HENRY HURD RUSBY

DR. HENRY HURD RUSBY, long an outstanding specialist in the field of pharmacognosy, died on November 18, 1940, at his home in Sarasota, Florida. He was born at Franklin, New Jersey, on April 26, 1855, and until 1938 was a resident of Newark, N. J.

While his early life was that of the average American boy in the rural sections, he even then showed a marked interest in plant life. Fortunately, this natural inclination was stimulated through contact with a teacher in the country school which he attended. Although his formal study of botany was meagre, this was more than compensated by his ability to learn at first hand and from plants themselves rather than from text-books.

The objectives of his botanical explorations were the establishment of new sources of supply for drugs and the search for new drug plants. On the first of the South American journeys from La Paz to Para in 1885–86, supplies of coca leaves, chequen, pichi and cocillana were sought. In addition an extensive study of cinchona cultivation was made and a complete collection of cinchona species acquired. The second journey in 1896 was a general botanical survey of that portion of Venezuela south of the Orinoco. The third of these surveys was in Mexico and was chiefly concerned with the discovery of possible rubber-yielding trees. The fourth and last exploration, in 1919, covered in part the same territory as the first and gave opportunity for comparisons with the conditions of thirty-five years previous. Dr. Rusby was then 64 years of age and had recently recovered from pneumonia. His family and many friends went to the steamer on the blustery March day of his departure. For most of us it was a rather sad occasion with the thought that he would not survive the journey uppermost in our minds. Despite his indomitable will he was forced to return ahead of the main party and continue his studies of the botanical results of the trip in the laboratory rather than in the field.

Dr. Rusby was professor of materia medica at the Columbia University College of Pharmacy from 1888 to 1930. Coincident with that appointment he taught materia medica in the New York University Medical School and the New York Veterinary College for

[17] B.A.N., 120.
[18] M.N., 679–713.
[19] Publ. Leander McCormick Obs., Vol. 7.