satisfactorily worked out by the British mathematical astronomers, Jeffreys and Jeans. It may now be said that within the first quarter of the twentieth century, a greater knowledge has been acquired of the distance, size, luminosity, mass, classification, composition, velocity, variability, magnitude and distribution of stars, than had been acquired in all previous centuries.

REPORT ON MARS NO. 28.

By WILLIAM H. PICKERING.

THE AXIS OF MARS.   SEASONAL CHANGES.

In Report No. **26** it was shown that the location of the axis of Mars as given at present in the *Nautical Almanac* and *American Ephemeris* appeared to be in error by nearly 3°. This necessarily introduces a very considerable error into all determinations of latitude and longitude upon the planet. The determination there made was based on sixteen observations of the latitude of each of thirteen different points, 208 observations in all. These observations were all made by means of drawings, a method which proves to be the most accurate and satisfactory for locating points in latitude upon the planet. The drawings were so selected that four should be distributed near each Martian equinox, and eight near the summer solstice. No drawings near the winter solstice were available. As a result of this investigation it was found that the accepted azimuth of the polar axis of the planet with regard to the pole of its orbit was in error by the constant C equal to —2°.95, and its inclination by D equal to —0°.26.

These observations have since been revised, certain drawings being replaced by others which were found to be better adapted to the purpose. This was mainly because it was evident on consideration that for the planetocentric right ascension of the earth, $A_\oplus$, we should substitute what we may call the planetocentric right ascension of the point observed, as measured in the plane of the planet's equator, from its vernal equinox. This quantity we have called A. Six drawings previously used were replaced by others, several were remeasured, and in several cases the best drawing of an evening was substituted for the mean of two. Indeed, in the case of only four of the thirteen stations were no changes made. The changes produced in the two constants C and D by this revision proved, as was to be expected, extremely small, but the method is now believed to be theoretically correct. We may express A in terms of known quantities as follows:

$$A = A_\oplus + \omega - L$$

where $A_\oplus$ is given in the *Ephemeris,* ω is the longitude of the central

meridian of the planet at the time that the observation was made, and L the longitude of the point as computed by the *Ephemeris*. Then by Report No. **26** we have, simply changing $A_{\oplus}$ to A, the corrected latitude of the point

$$B' = B - C \cos A - D \sin A.$$

In the course of the revision it was decided to omit the observed latitude of Solis when located near the summer solstice of the planet. The reason for this was that Solis is situated so far south of the equator that at the average of these observations it was located within one-quarter of the radius of the limb. At that distance not only are the degrees of latitude very much fore-shortened, but, what is worse, the marking is liable to be partially concealed by limb fog, very prevalent in the south at that season, their winter, and making observation difficult. The general effect of such fog would be, by concealing the further portions, to make the marking appear nearer the equator than is really the case, and so we find it to be by the table.

In the preparation of Table I, used in the course of the revision, we took the constant C equal to —2°.9, and D equal to —0°.4, instead of the values given at the end of the first paragraph. The last line of the table, which gives a further approximation, shows that neither of these figures was quite large enough, but the change made in the second constant was evidently an improvement. The difference between the latitudes at the vernal and at the autumnal equinoxes divided by two, with the proper sign attached, gives the latitude at the vernal equinox minus the mean. These numbers are entered in the third column of the table. The latitude at the summer solstice minus the mean latitude at the two equinoxes is entered in the fifth. The fourth and sixth columns give the deviations from the means of the third and fifth. The derived latitudes and approximate longitudes are added in the last two columns. A minus sign in the third and fifth columns indicates that at the vernal equinox and summer solstice the point appears to be south of its mean position. If we reverse all the signs in the third column, the results will give the location of the points at the autumnal equinox relatively to their mean positions.

The deviations given in the fourth column seem to imply that in addition to the error that we have found in the location of the axis, there is a systematic motion of the surface detail between the vernal and autumnal equinoxes towards the south in the longitudes centering about 90° and towards the north in those longitudes about 270°. A comparison of the fourth and sixth columns shows that while the northerly motion between the vernal equinox and summer solstice was very marked, as indicated by the changes in sign between them, after the solstice was past, the change in latitude until the autumnal equinox was reached was comparatively slight.

TABLE I.

REDUCTION OF OBSERVATIONS.

| No.	Station	Vernal	Dev.	Summer	Dev.	Lat.	Long.
		°	°	°	°	°	°
8	Thymiamata S.	—2.95	—0.07	—2.33	+1.54	— 1.07	20
10	Aromatum S. p.	—2.45	—0.57	—1.71	+0.92	— 0.15	31
11	Acidalium S.	—0.69	—2.33	—0.99	+0.20	+41.69	31
12	Niliacus S.	—2.80	—0.22	—1.90	+1.11	+29.00	35
23	Solis c.	—0.65	—2.37	(+2.49)	(—3.28)	—28.26	88
41	Titanum N.	—3.80	+0.78	—1.69	+0.90	—17.75	166
50	Elysium N.	—3.19	+0.17	—2.44	+1.65	+36.34	214
52	Elysium S.	—4.50	+1.48	+1.16	—1.95	+12.58	215
63	Nepenthes m.	—3.32	+0.30	+1.15	—1.94	+11.94	272
74	Syrtis N.	—4.61	+1.59	+0.44	—1.23	+24.81	285
82	Hammonis S. p.	—5.50	+2.48	+0.12	—0.91	—12.30	319
86	Ismenius C.	—1.35	—1.67	—2.06	+1.27	+46.65	331
89	Edom S.	—3.50	+0.48	+0.78	—1.57	— 3.88	348
		—3.02	±1.12	—0.79	±1.27		
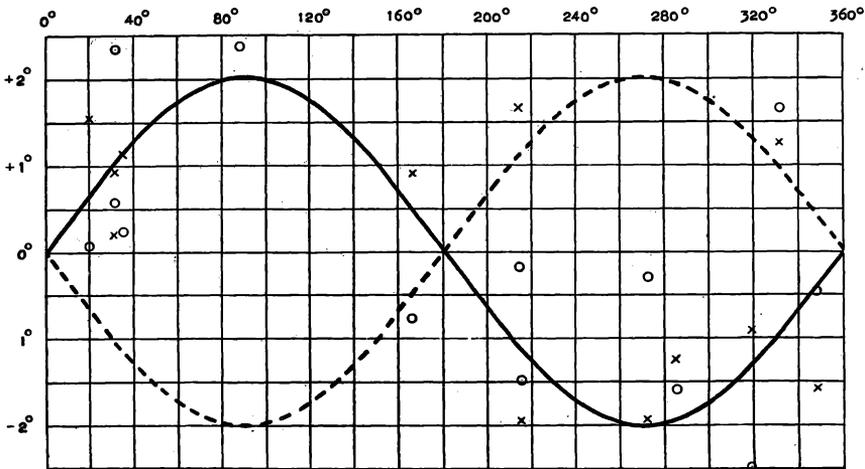
FIG. 1.

In Figure 1 we have plotted these results, reversing the signs in the fourth column, so that the ordinates represent the deviations at the autumnal equinox. These have been plotted as circles, while those deviations in the sixth column are plotted as crosses, along the Martian longitudes indicated by the abscissas. A sine curve was next drawn, and it will be seen that twenty-one observations out of the twenty-five recorded coincide with it within less than 1°.5, or 55 miles, which is as close an agreement as we could fairly expect. It will also be noted that for five out of the thirteen points selected, the two deviations are less than 1° apart, indicating a nearly stationary position of the point in latitude between the summer solstice and autumnal equinox.

If the curve represents a genuine phenomenon on the planet, then it should vibrate back and forth with the seasons, as indicated by the

dotted line, which corresponds to the vernal equinox, and should agree with the planet's winter solstice, the nodes being located near longitudes 0° and 180°. In such a case points located near these longitudes, such as Edom, —3°.50, and Titanum, —3°.80, would be best adapted for determining the position of the axis of the planet, while points located near longitudes 90° and 270°, such perhaps as Thaumasia N. and Nepenthes, would be best suited to determining the extent of the seasonal change. If a real seasonal change of this sort exists, it is probably in some way related to the pole from which the point in question receives its chief supply of water.

Returning now to the discussion of the location of the axis of Mars, for which data are given in Table I, we thought it wise to endeavor to confirm our results by securing if possible further statistics from an examination of our record books. Beginning with the apparition of 1914, which was the first one observed from the Jamaica Station, we there find that we have obtained, during the five apparitions ending with 1922, some 260 drawings which are suitable for our investigations of position. None have been accepted, save those noted in Report No. **26**, in which the diameter was less than 10″. A number of others were rejected, either on account of difficulty with the orientation, or unfavorable atmospheric conditions. From the accepted ones it was found possible to secure 536 determinations of the longitude, and 697 of the latitude of 90 different points upon the surface of the planet. On these determinations we have based two other independent investigations of the errors in the location of the axis, as given in the *Ephemeris*. In addition to the drawings used in our first investigation, many others of these same 13 points were thus secured, which were not quite so favorably placed with regard to the equinoxes and solstices, or more accurately speaking did not permit the values of *A* to approach so closely to the three quantities 0°, 90°, and 180°.

Our second investigation was based on the exclusive use of these additional drawings. One of the original 13 points, Niliacus, was ruled out, however, because it was necessary to have at least one good drawing giving a value for *A* within 45° of each of the three required values 0°, 90°, and 180°. All the other observations were treated in the manner already described in Report No. **26**. On account of the varying number of observations for the different stations however, it was now necessary to weight the different results. Since they were of different objects it was decided to weight them as the square roots of the number of observations of each. The number of observations of the different stations were as follows: Thymiamata S. 17, Aromatum S. p. 7, Acidalium S. 12, Solis c. 4, Titanum N. 14, Elysium N. 10, Elysium S. 13, Nepenthes m. 11, Syrtis N. 10, Hammonis S. p. 19, Ismenius c. 15, Edom S. 9. Total, 141. As a result, the corrections to the position of the axis in azimuth and inclination were found to be —2°.53 and —1°.05.

Still a third investigation was made of 12 other points which had not been as fully observed as the 13. These 12, and the number of observations of each are as follows: Siloe c. 5, Oxia c. 10, Margaritifer N. 16, Thaumasia p. 4, Juventae c. 11, Solis N. 4, Thaumasia S. 4, Solis f. 5, Olympia m. 5, Nilosyrtis p. 3, Nilosyrtis, junction with Syrtis 4, Aeria p. 3. Total, 74. The corrections to the *Ephemeris* determined from these points are —2°.38 and —0°.89.

The total number of observations of the 25 points here considered give us an idea of their relative visibility and suitability during that portion of the planet's year lying between the vernal and autumnal equinoxes. They range from Hammonis 35 to Nilosyrtis p. 3, and Aeria p. 3. In the majority of cases in the second and third investigations, the location of a station near either 0°, 90°, or 180° depended upon a single drawing. It was evident therefore that the results obtained from them were of distinctly inferior weight to those obtained from the first. Although the second investigation involved twice as many drawings as the third, yet since the same points were used as in the first, and it was very certain that some of these points had an appreciable proper motion of their own, over the surface of the planet, thus injuriously affecting our result, it was decided to weight these two determinations equally.

TABLE II.

Corrections to the Ephemeris.

Determination	Number	Weight	C	D
1	208	10	—3°.02	—0°.79
2	141	1	—2.53	—1.05
3	74	1	—2.38	—0.89
Weighted means			—2.92	—0.82

In Table II the results of these three determinations of the corrections to the azimuth and inclination are compared, C and D being the constants employed in the formula as already explained, for correcting the latitudes of the stations. The resulting values we see are —2°.92 and —0°.82. The resulting inclination of the planet's equator to the plane of its orbit becomes 24° 58′, lying between Struve's value, based on the motion of the orbits of the satellites 25° 13′, and the values found by Schiaparelli and Cerulli, 24° 42′ and 24° 45′ respectively, based upon the polar snows. It differs appreciably, however, from the two remaining modern values as determined by Lohse 23° 57′ and Lowell 23° 16′, which have been already mentioned in Report No. **26**. The corresponding position of the pole of the axis lies in *a* 315° 14′ and δ +51° 51′. Having corrected the latitudes of the various points, their corrected longitudes can now be computed by the ordinary formulae for spherical triangles.

In order to avoid all unnecessary computation, however, we may determine the correction to the *Ephemeris* result by means of the curves given in Figures 2, 3, and 4. In Figure 2 the abscissas are values of
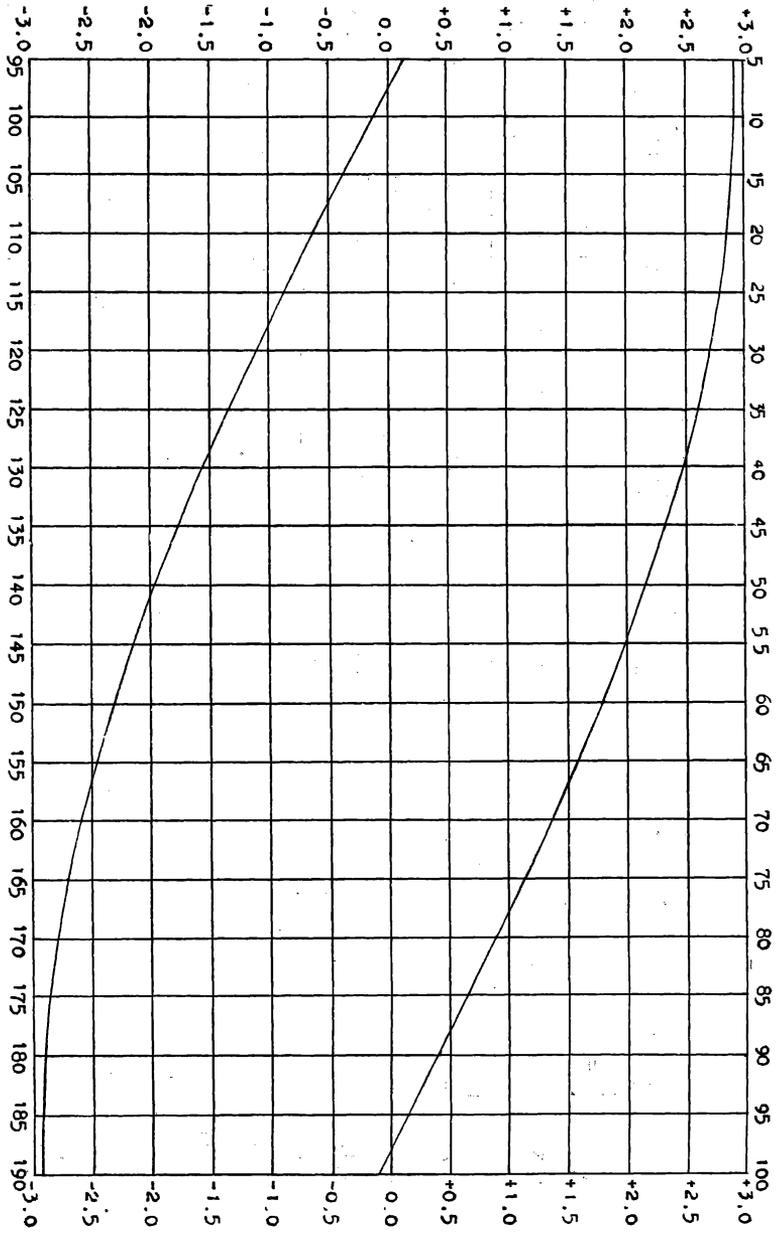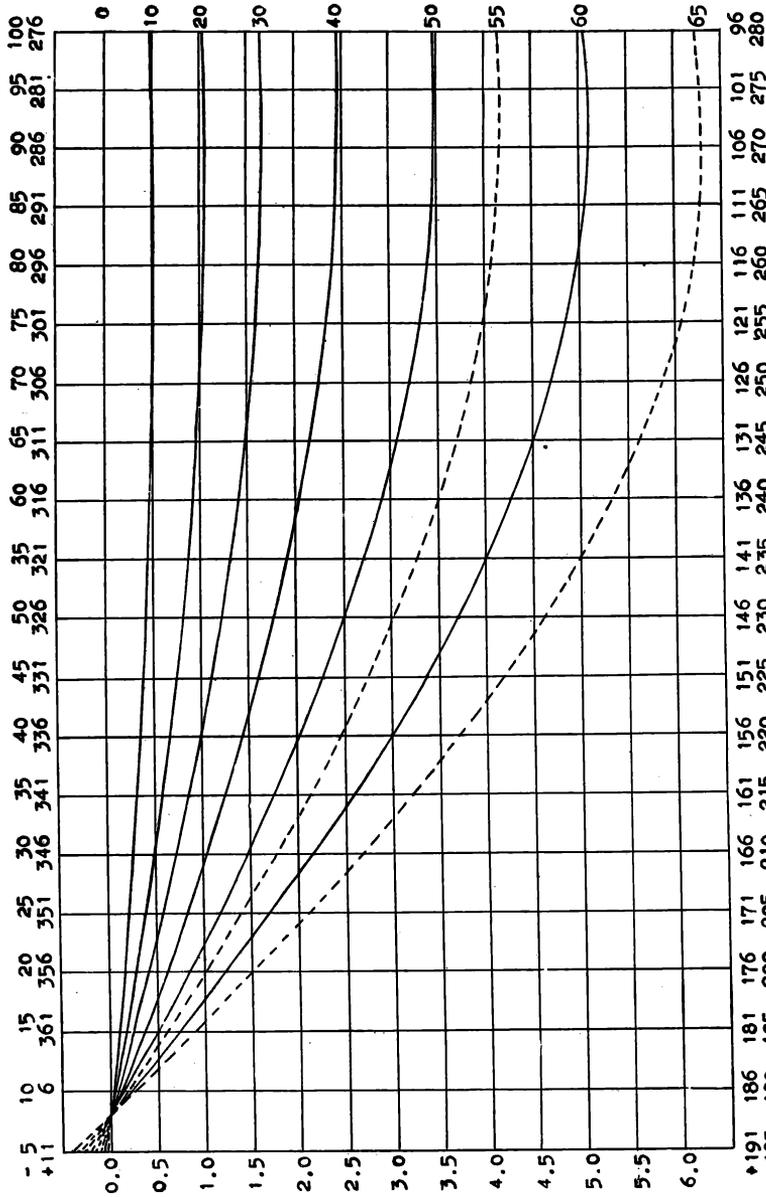
Fig. 2.

FIG. 3.

A, and the ordinates give the correction to the latitude directly. In the case of abscissas not marked on the chart, 180° must be added to them and the signs of the ordinates reversed. This curve and the two following it are reproductions on a smaller scale of the ones actually used in computing the corrections to the latitudes and longitudes of the ninety points whose positions have been determined upon the planet. They are based on the values $C = -2°.9$ and $D = -0°.4$. The values above given, $C = -2°.92$ and $D = -0°.82$, deduced from this table are perhaps rather more accurate, but not sufficiently or certainly so, to justify a recomputation of the location of the ninety points. It is believed that these curves will serve every purpose until it is possible to apply suitable corrections to the *Ephemeris.*

Figures 3 and 4 give the corrections for longitude to be applied to the *Ephemeris* results. The abscissas as before indicate values of *A,* and the ordinates the corrections. The curves are drawn for every 10°, and later 5° of latitude up to 65°. For higher latitudes the corrections must be computed individually. Excepting for Olympia, the large isolated snow area near the north pole, this computation was found to be necessary in the case of only one point, Boreosyrtis N. The abscissas for the northern hemisphere are given at the top of the figure, those for the southern hemisphere at the bottom. On the left of each row of figures the sign + or — indicates whether the corrections given by the ordinates should be added to or subtracted from the *Ephemeris* value. The short portion of the curve beyond the cusp has been inserted and dotted merely to make the nature of the correction clear and complete. It need not be used, but if it were, the sign of the correction would have to be reversed.

In conclusion we may give our reasons for believing that the errors in the location of the planet's axis according to the *Ephemeris* are greater than the uncertainties of modern observations justify. We believe further that unless they are corrected, these errors will lead to far greater divergencies in our observations, than would occur simply owing to errors in the observations themselves. To begin with, the *Ephemeris* is based on a method of locating the planet's axis which assumes that the polar cap extends equally far from the pole along both the eastern and western limbs. This assumption we now know to be erroneous. Therefore there is no reason to suppose that the axis should be correctly located at present.

Secondly, as we pointed out in Report No. **26**, owing to this error, chiefly in the azimuth, each one of the thirteen points there investigated apparently moved northward between the vernal and autumnal equinoxes an average distance of nearly 6°, or 218 miles, with a probable error for the series of only ±13′ measured on the surface of the planet. We have now investigated twelve other points, and of these eleven apparently moved northerly nearly as far. Only one, Solis f., appeared to move southerly, and in that case the total distance traversed was but
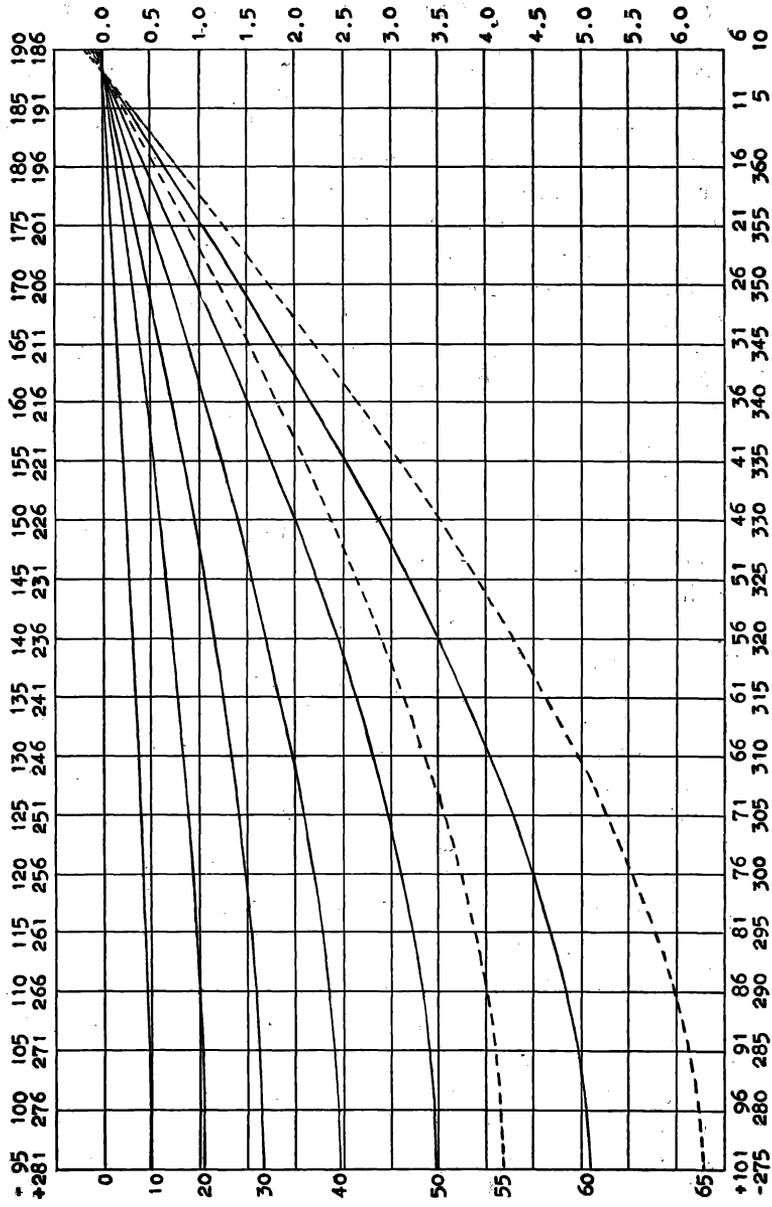
Fig 4.

1°, or 37 miles. It is not likely that the whole surface of the planet is moving northwards, and we therefore believe that this apparent motion is due to this error in the *Ephemeris,* which would fully account for it.

Oddly enough ever since the days of Schiaparelli, according to the observations of Lohse, Cerulli, Lowell, and the writer, the azimuth of the pole appears to have steadily diminished at the rate of $6'.9$ per terrestrial year. Nevertheless, this apparent change cannot be real, and must be due to errors involved in the method employed in locating the axis. A third reason for doubting the accuracy of the *Ephemeris* is that Struve's location of the axis, published in 1895, and based on the motions of the orbits of the satellites, lies about half-way between that given in the *Ephemeris* and that advocated here. The change in azimuth that his position implies, $—1°.5$, is certainly desirable, and in the right direction, but not enough. In 1896 Marth adopted this position for his ephemeris, and it is a great pity that it was ever changed, since it was certainly much more nearly correct than the one in use at the present time.

On account of the diverse proper motions of the spots, it appears probable that at some future date, when more observations of the satellites have accumulated, Struve's method of locating the axis will be the one finally adopted. Possibly, observations made during the present apparition will permit this to be done. In the mean time accurate determinations of the location of the most clearly defined markings, by means of transits and drawings will be of the greatest value, as furnishing a permanent record of their migrations over the surface.

The next two apparitions, in 1926 and 1928, will bring the planet back nearly to the position in its orbit that it occupied in 1914, when this series of observations was begun. Should the points all move southerly in this interval to near their original positions, that fact would further emphasize our view that the accepted location of the planet's axis requires revision. It is desirable that drawings by the same observer should be employed for this purpose, and if the writer can secure a suitable telescope it will be done.

Mandeville, Jamaica, B. W. I., Sept. 1, 1924.

A DOG-DAY NIGHT.

Behind a wooded wold which walls the west,
  The sunset glow has faded into night,
Above a shrouded knoll's long, treeless crest,
  A cloudless moon is rising, full and white;
A breathless air oppresses vale and hill,
  And sultry silence slumbers o'er the lea,
Unseen, is heard a purling meadow rill,
  And crickets chant their dreamy monody.
                              —CHARLES NEVERS HOLMES.
41 Arlington Street, Newton, Mass.