lating differences which do not correspond to any theoretical gravitational terms. . . . The causes of these differences . . . are matters of conjecture.[1] . . . Still more puzzling are certain oscillations with smaller amplitudes and shorter periods. . . . All that can be done is to make an estimate . . . from the observations of the past few years whenever it is desirable to predict the position of the moon with high accuracy, as in the case of an eclipse of the sun, and alter the values obtained from the Tables accordingly."

When the coming eclipse was first accurately predicted three years ago, a correction of $+7''\cdot0$ was applied to the mean longitude of the moon as derived from Brown's "Tables," but, strangely, no correction was applied to the position of the sun. The Astronomer Royal, Sir Frank Dyson, has quoted the corrections to the longitude of the sun and moon derived from recent Greenwich observations as $+1''\cdot5$ and $+6''\cdot5$ respectively. When these corrections replace those formerly used, the effect is very slight; it amounts to a displacement of the central line and the zone of totality as shown on the Ordnance Survey Eclipse Map, the data for which were computed from the original elements, by just one mile in a north-westerly direction.

[1] Since the above was written, in 1918, several astronomers have suggested that the earth's period of revolution is variable, and have adduced evidence of a correlation between the anomalies in the motions of the Sun, Moon, Mercury, Venus, and Mars.

The residual uncertainty, after the application of these corrections, should be less than half a mile in the case of the central line, and not more than a mile in the case of the northern and southern limits of totality.

The co-ordinates of the central line, and the circumstances of the eclipse along this line, are given in the table below:

G.M.T.	Longitude.	Latitude.	Sun's Altitude.	Sun's Azimuth.	Duration.
	° ′	° ′	°	°	s
5h 23m 0s	+4 55·0	52 32·1	9·8	64·2	20·9
10	4 35·6	52 43·3	10·1	64·5	21·2
20	4 16·7	52 54·3	10·3	64·8	21·5
30	3 58·3	53 5·0	10·6	65·1	21·7
40	3 40·3	53 15·5	10·9	65·4	22·0
50	3 22·8	53 25·8	11·1	65·7	22·3
5 24 0	+3 5·7	53 35·8	11·4	66·0	22·6
10	2 48·9	53 45·7	11·6	66·3	22·9
20	2 32·5	53 55·4	11·8	66·5	23·2
30	2 16·4	54 4·9	12·1	66·8	23·5
40	2 0·6	54 14·2	12·3	67·1	23·7
50	1 45·1	54 23·4	12·5	67·3	23·9
5 25 0	+1 29·8	54 32·5	12·7	67·6	24·2
10	1 14·8	54 41·5	12·9	67·8	24·4
20	1 0·0	54 50·3	13·2	68·1	24·6
5 25 30	+0 45·5	54 59·0	13·4	68·3	24·9

The Recurrence of Solar Eclipses.

By Dr. J. Jackson.

AMONGST the most remarkable of discoveries made by ancient astronomers was that of the recurrence of eclipses at intervals of 18 years and 10 or 11 days. We have no knowledge of the discoverer of this period, known as the Saros, but it was certainly known to the Chaldeans. In view of the irregularities of the early calendar, such a discovery must have presented great difficulties. The fact that the interval has an odd third of a day, so that the region of visibility of an eclipse is shifted about 120° in longitude at each return, greatly increases the difficulties of discovery, and it is possible that a period three times as long as the Saros was first discovered. As the area of the earth from which an eclipse can be seen extends over a large arc in longitude, it is possible for two consecutive members of a series of eclipses to be seen from the same place. The total eclipse visible in England on Aug. 11, 1999, is indeed four Saroses later than that of June 29 of this year, but whereas this year's eclipse is in the early morning, the eclipse of Aug. 11, 1999, will be visible in England shortly before noon.

The circumstances connected with the recurrence of eclipses depend on several variables with different periods, and the apparent irregularity with which eclipses occur results from the incommensurability of the periods and differences in their relative importance. The most important period is that between successive new moons, which on the average is 29·5306 days. An eclipse of the sun would take place at every new moon if the orbital planes of the sun and moon coincided,[1] but as the inclination of the two planes is considerable—varying round 5°—it is only when new moon occurs near the line of intersection of the two planes, known as the line of nodes, that an eclipse can take place. On account of the motion of the plane of the moon's motion, the sun passes through the nodes at intervals of less than six months, the average time being 173·310 days, and this is the second important period in connexion with eclipses. Eclipses take place at intervals which are very nearly multiples of 29·5306 days and are approximately multiples of 173·310 days.

The maximum angular distance which the sun

[1] If this were the case, however, all central eclipses would take place within the tropics, and the only eclipses that could be seen from England would be extremely small partial eclipses at the new moons near midsummer.

can be from the node at the time of an eclipse (known as the eclipse limit) depends on the distances of the sun and moon from the earth and the actual inclination of the orbital planes. It varies from $15\frac{1}{3}°$ to $18\frac{1}{2}°$. As the sun moves on the average almost exactly $2 \times 15\frac{1}{3}°$ relative to the nodes between successive new moons, and as it is moving most slowly when the eclipse limits are smallest, an eclipse occurs near every passage of the sun through a node. There are thus at least two solar eclipses every year, and there may be as many as five, the latter only occurring when the sun passes through a node near the beginning or end of the calendar year. Eclipses of the moon may take place at the full moons preceding and following eclipses of the sun, although for them the eclipse limits are smaller.

The Saros is connected with the two periods we have just mentioned. We have in fact

$$223 \times 29{\cdot}5306 \text{ days} = 6585{\cdot}32 \text{ days.}$$
$$38 \times 173{\cdot}310 \quad ,, \quad = 6585{\cdot}78 \quad ,,$$

The Saros is 6585·32 days. As the sun travels on the average about 1° a day, it describes in a Saros only about 28′ less than 19 revolutions relative to the nodes. As 28′ is a small fraction of the eclipse limits, we find a large number of eclipses recurring in a series.

The number of eclipses in a series varies one or two either way from seventy and extends over a period of 1200 years. Of these, about twelve or thirteen at each end are only partial eclipses, as the sun is so far from the node that the line going through the centres of the sun and moon passes clear of the earth. For the middle, forty-five or so, this line comes to earth, giving rise to a central eclipse which is total or annular according as the angular diameter of the moon or sun is the larger.

The eccentricity of the apparent orbit of the sun is small, so that the angular semi-diameter of the sun varies only from 15′ 46″ to 16′ 18″. Also we have seen the Saros differs from an exact number of years by about 11 days, so that at the recurrence of an eclipse the apparent diameter of the sun cannot have altered more than 3″. The eccentricity of the lunar orbit is larger, causing the apparent semi-diameter of the moon to vary from 14′ 42″ to 16′ 46″. On account of the rather rapid motion of the moon's apse, amounting to a whole revolution in about nine years, the interval between successive nearest approaches of the moon to the earth is on the average 27·55455 days and

$$239 \times 27{\cdot}55455 \text{ days} = 6585{\cdot}54 \text{ days.}$$

This differs from the Saros by only 0·22 of a day. This is a remarkable and important coincidence. It means that after a Saros the mean anomaly of the moon has altered by only about 2°·8 (decrease), and the apparent diameter of the moon, like the sun, has not altered by more than 3″. The con-

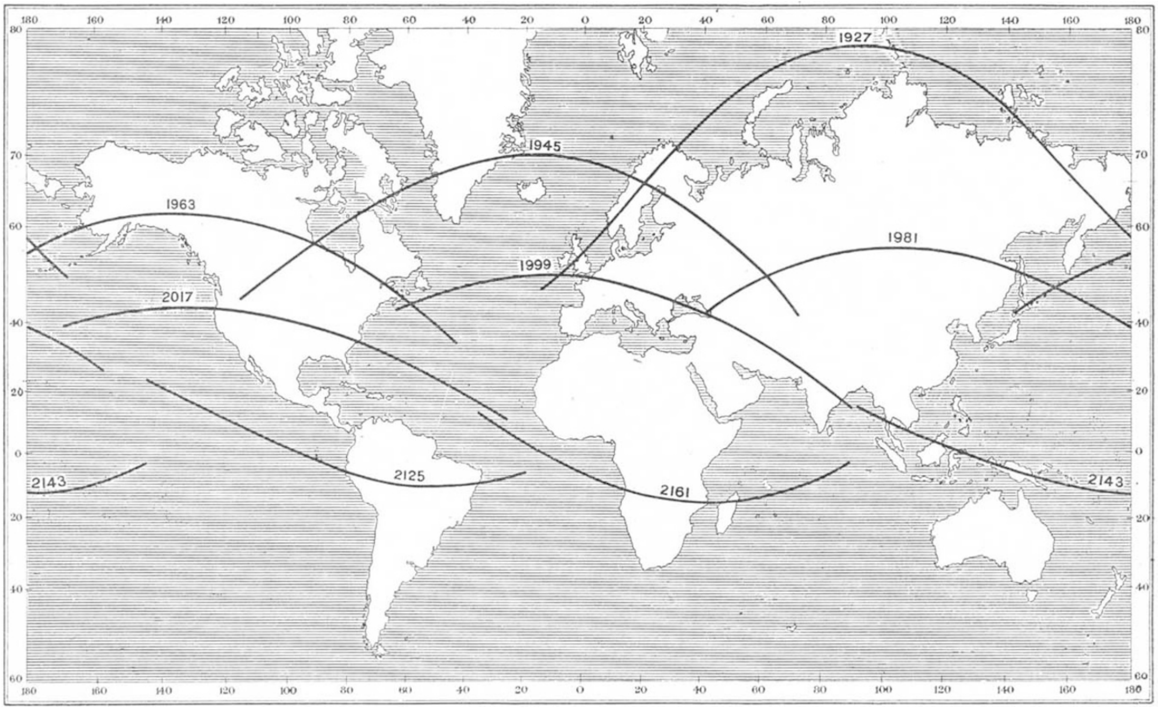

FIG. 1.—Successive tracks of solar eclipses.

sequence of all this is that the duration of totality in a series of eclipses varies slowly from one eclipse to the next, and that we have a series of total eclipses, or of annular eclipses. If the period of rotation of the lunar apse were twelve years instead of nine years, annular and total eclipses would alternate. It might be noted here that as a result of the moon returning to approximately the same distance from the earth after a Saros, its parallax is only slightly altered, and so the eclipse limits only slightly altered.

Let us now consider the series of eclipses to which that of June 29 of this year belongs. At the new moon of May 26, 1873, the central line from the sun to the moon passed just north of the earth and there was a large partial eclipse near the north pole. If we work backwards from this date at intervals of 18 years and 10 or 11 days, we find a series of decreasing partial eclipses near the north pole. Going forwards, we find that on June 6, 1891, the central line passed over the north pole but came to earth in northern Asia, producing an eclipse at midnight. This was an annular eclipse very nearly total, and was the first central eclipse of the series to which the eclipse of this year belongs. Eighteen years later, on June 17, 1909, there was an eclipse which crossed the earth near the pole. This eclipse was just total, although it was scarcely certain beforehand that it would be so. We then come to the total eclipse of this year. Proceeding onwards, we get a series of eclipses gradually lengthening in duration and working equatorwards, while the longitude on the earth where the eclipse takes place moves about 120° westward from each eclipse to the next.

The "Nautical Almanac" gave the semi-diameters of the sun and moon as seen from the centre of the earth for the eclipses of 1891, 1909, and 1927 as follows :

	Moon.	Sun.
1891 June 6 . .	15′ 42″·2	15′ 47″·5
1909 June 17 . .	43″·1	44″·3
1927 June 29 . .	46″·7	44″·0

These figures indicate the way in which the apparent diameter of the moon is gradually increasing relative to that of the sun. Also on the eclipse track the apparent diameter of the moon must be larger than from the earth's centre, so that the total eclipses of this series will be steadily lengthening.

The following table indicates the change of position of the point on the earth where central eclipse occurs at noon, for a few eclipses belonging to the series of the eclipse of this year. The longitudes are measured towards the east. It will be seen that the track moves about 8° southward each year and a little more than 100° in longitude. After two hundred years, when the track is near the equator, the movement is about 5° southward and 120° westward each year.

	Longitude E.	Latitude.
1909 June 17 . .	187°	+88°
1927 June 29 . .	84	+78
1945 July 9 . .	340	+70
1963 July 20 . .	234	+62
1981 July 31 . .	127	+54
1999 Aug. 11 . .	18	+46
....	......	......
2107 Oct. 16 . .	39	+ 2
2125 Oct. 26 . .	276	− 4
2145 Nov. 7 . .	150	− 9
2161 Nov. 17 . .	23	−14

The map (Fig. 1) shows the track of the approximate central line for the eclipses of 1927, 1945, 1963, 1981, 1999, 2017, and 2125, 2143, 2161. In each case the eclipse begins at the western end of its track at sunrise and finishes at the eastern end at sunset.

Future Total Solar Eclipses in the British Isles.

By Dr. A. C. D. Crommelin.

An article by Dr. W. J. S. Lockyer in Nature for Jan. 15 last described and illustrated the total solar eclipses in the British Isles from A.D. 878 to A.D. 1999. The present article continues this investigation for another thousand years. In view of the very long interval of two centuries that has elapsed since there has been a British totality, it is interesting to determine the average interval between these events. Mr. J. Maguire's list, used by Dr. Lockyer, has a few omissions. I therefore had recourse to the maps in Oppolzer's Canon of Eclipses. These indicate 63 British totalities in 3370 years (1208 B.C. to A.D. 2161), or 19 in a thousand years, giving an average interval of 54 years between totalities. I am aware that the maps in the Canon show the tracks as circular arcs not quite agreeing with the true ones, but for statistical purposes this is of no importance ; we clearly gain as many as we lose by the distortion.

As a check I find that Otto Schrader gives 21 eclipses as total in the British Isles in the period A.D. 2133 to A.D. 3045. Four of these are doubtful ; the central line lying outside these islands : giving