ionisation of the earth's atmosphere, would account satisfactorily for most of the anomalies observed.

The observational data of the present investigation are summarised in the following table:—

Spot-Group.					Magnetic Disturbance.	
Appearance.	Date.	Lat.	Long.	Disc-area.	Date.	Character.
I.	1919 Dec. 27–Jan. 5	−6°	96°–113°	9·0	Jan. 1	1 moderate.
II.	1920 Jan. 21–Feb. 3	−6°	108°–133°	18·0	Jan. 28	,,
III.	,, Feb. 17–Feb. 26	−6°	131°	0·6	Feb. 24	2 very great.
IV.	,, Mar. 16–Mar. 29	−6°	114°–150°	34·0	Mar. 22	2 v. very great

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Note on the Secular Accelerations of the Sun and Moon as determined from the Ancient Lunar and Solar Eclipses, Occultations, and Equinox Observations. By J. K. Fotheringham, M.A., D.Litt.

In his paper entitled "The Chief Cause of the Lunar Secular Acceleration," *M.N.*, **80**, 309–317, Dr. Jeffreys uses for the excess of the lunar acceleration over its theoretical value the value $+4''\cdot5 \pm 0''\cdot70$ per century found by Miss Longbottom and myself from the ancient occultations and conjunctions,* and deduces from this a solar acceleration of $+0''\cdot78 \pm 0''\cdot12$ on the theory of tidal friction contained in his paper. He compares the latter with the value $1''\cdot93 \pm 0''\cdot27$ deduced by me from the ancient equinox observations,† and makes the suggestion that either an unknown cause is producing an acceleration of the Sun or that about half the observed solar acceleration is in error.

The observed values used by Dr. Jeffreys are the only values for the lunar acceleration found independently of the solar acceleration, and for the solar acceleration found independently both of the lunar acceleration and of the acceleration of the node of the Moon's orbit, but values obtained from other groups of observations may be used to confirm these or to suggest what errors are possible. I have, therefore, thought it may be worth while to throw the results indicated by different methods together, without waiting for a detailed examination of each group, especially for the benefit of those who may wish to approach the question from another side than that of the ancient observations.

Times of Lunar Eclipses.

The times of lunar eclipses should give us the difference between the lunar and solar accelerations. For reasons given in

* *M.N.*, **75**, 393.

† *M.N.*, **78**, 423.

M.N., **75**, 395, I reject the Babylonian eclipses. I have computed the observed times of the Greek lunar eclipses, and compare them with Dr. Cowell's computed times* in the following table. The correction to acceleration is obtained by multiplying the correction to the time by $-30''\cdot 5/T^2$, where $30''\cdot 5$ is the difference between the mean motions of Moon and Sun in one minute of time, and T is the interval in Julian centuries since 1800 January 0·0. Where an observation is said to have been made in a particular hour ἀρχομένης or λῃγούσης, I have, as in my paper on the ancient occultations, reduced the middle of the first or last third of the hour as the case may be.

Ref. No. and Phase.	Observed G.M.T.	Computed Time.	Correction to Computed Time.	Correction to Acceleration.
	h m	h m	m	″
11 end	6 29·0	6 58·5	−29·5	+2·3
12 beg.	9 27·2	9 41·9	−14·7	+1·1
13 beg.	10 35·7	11 8·3		
13 mid.	12 10·6	12 55·9	−45·3	+3·5
14 beg.	10 57·7	10 52·7 }	+ 2·9	−0·2
14 end	13 20·9	13 20·1 }		
15 beg.	8 16·4	7 40·2	+36·2	−2·9
[15 mid.]	[8 33·5]	[8 22·6]	[+10·9]	[−0·9]
16 mid.	6 26·6	7 9·4	−42·8	+4·7
17 mid.	9 9·2	9 13·9	− 4·7	+0·5
18 mid.	8 47·2	9 14·6	−27·4	+3·0
19 mid.	14 13·5	13 54·4	+19·1	−2·1

I ignore the recorded time for the beginning of No. 11, for, since the eclipse began before the Moon rose, the time must have been found by computation, not by observation. I assume that the time given for the middle of No. 13 is the mean between the observed times of the beginning and end, and use this time for purposes of comparison. There is something wrong with No. 15. The eclipse is said to have begun in the beginning of the 5th hour of seasonal time (*i.e.* between $9^h\ 41^m$ and $10^h\ 4^m$ local solar time), which Ptolemy equates with $9^h\ 40^m$ local solar time. The middle of the eclipse is stated—whether from observation or computation is not apparent—to have been $1\frac{5}{6}$ equinoctial hours before midnight, *i.e.* $10^h\ 10^m$ local solar time. Dr. Cowell finds $42^m\cdot 4$ as the correct interval between these two phases. Manitius † in his note on the passage computes that according to Ptolemy's theory the interval between the two phases should have been 58 minutes. The probable error of a water-clock five hours after sunset should be about one hour. Perhaps the eclipse is best disregarded. No. 16 is treated by Ptolemy as an observation of the middle of an eclipse. As the observation was made at Alexandria in his own time and

* See *M.N.*, **66**, 524–7.

† *Ptolemäus Handbuch der Astronomie*, **1** (1912), 450.

very possibly by himself, there appears to be no reason to go behind his construction of the observation. Newcomb has rejected this observation, and Dr. Cowell has treated it as an observation of the beginning of an eclipse.

Nos. 11–15 range in date from −200 to −140, Nos. 16–19 from +125 to +136. It seems best, therefore, to treat them as two separate groups. Retaining the first phase of No. 15 and giving equal weight to each observation, we get for the correction to the secular acceleration $+0''{\cdot}8 \pm 1''{\cdot}7$. If we reject this eclipse we get $+1''{\cdot}7 \pm 1''{\cdot}1$. As the difference between the two results falls within the probable error, it may be best to retain this doubtful phase. The second group gives the mean correction $+1''{\cdot}5 \pm 2''{\cdot}0$. In my paper on the "Longitude of the Moon" * I have adopted a mean motion at epoch 1800 exceeding Dr. Cowell's value by $+5''$ and a cube term falling short of his by $+0''{\cdot}006$. To compensate for these corrections it will be necessary to raise the correction to the acceleration resulting from the first group to $+0''{\cdot}9$, and that resulting from the second group to $+1''{\cdot}7$. The mean result from the two groups is then $+1''{\cdot}1 \pm 1''{\cdot}3$. Adding this to Dr. Cowell's value for the difference between the lunar and solar accelerations, we get for the difference between the two accelerations resulting from the times of the lunar eclipses:—

$$+6''{\cdot}8 + 1''{\cdot}1 \pm 1''{\cdot}3 = +7''{\cdot}9 \pm 1''{\cdot}3.$$

From Newcomb's treatment of these observations with his arbitrarily selected probable errors I obtained in 1915 † the value $+7''{\cdot}6 \pm 0''{\cdot}44$.

Magnitudes of Lunar Eclipses.

These are consistent with a value of $+1''$ or $+2''$ for the solar acceleration, giving in neither case an error exceeding half a digit. The mean value of the solar acceleration resulting from these observations is $+1''{\cdot}78 \pm 0''{\cdot}45$.‡

Solar Eclipses.

A crucial test for these is the eclipse of Hipparchus. I gave a formula for values satisfying this eclipse in *M.N.*, **69**, 209, accompanied by a not too accurate diagram. The eclipse of Babylon would also appear to be well established. In *M.N.*, **69**, 468, I found that these two eclipses and also that of Archilochus were satisfied by a lunar acceleration of $+10''{\cdot}1$ combined with a solar acceleration of $+1''{\cdot}2$. With Dr. Brown's value for the motion of the node,§ these should be reduced to $+9''{\cdot}9$ and $+1''{\cdot}0$ respectively. Another very crucial test is the eclipse of Plutarch, if, as seems probable, that eclipse, which had an extremely narrow belt of totality, was total either at Delphi or at Chæronea. Herr Schoch of Heidelberg, who had independently proposed slightly different elements, has recently computed all the principal ancient

* *M.N.*, **80**, 305.
† *M.N.*, **75**, 396.
‡ See *M.N.*, **69**, 666–8; **78**, 422.
§ See *M.N.*, **75**, 510.

solar eclipses, using the expression for the longitude of the Moon given by me in *M.N.*, 80, 305, Dr. Brown's values for the other elements in the Moon's motion, and Newcomb's solar elements, with unimportant corrections, except that he took the solar acceleration as $+1''\cdot93$. These values seemed to satisfy the whole series of ancient eclipses of the Sun adequately with the exception of those of Pindar, Hipparchus, and Plutarch. The eclipse of Pindar cannot be satisfied without abandoning eclipses more definitely established as total in a particular place. But Herr Schoch found that in order to add the eclipses of Hipparchus and Plutarch to the list of satisfied eclipses without abandoning the others, it was necessary to reduce the adopted solar acceleration by $1''$. This would give $+10''\cdot53$ for the lunar acceleration and $+0''\cdot93$ for the solar acceleration. The latter figure must be raised to $+1''\cdot0$ if Newcomb's centennial motion of the Sun for epoch 1800·0 is to be retained. Herr Schoch does not accept this result, because he considers that a modification of the centennial motion of the Moon is necessary in order to satisfy the eclipse of +1241.

Occultations and Conjunctions.

From these Miss Longbottom and I found a lunar acceleration of $+10''\cdot6$ or rather $+10''\cdot8 \pm 0''\cdot70$.*

Equinox Observations.

On the assumptions that in the earlier series of equinox observations Hipparchus used an approximately fixed equator, and that at the time of his later equinox observations he used the same equator as in his observations of the declinations of stars, the solar acceleration is found to be $+1''\cdot93 \pm 0''\cdot27$, or $+1''\cdot95$ in excess of the theoretical value.

Comparative Table.

Using L for the lunar acceleration, L′ for the solar, and D for the difference, the following table shows what seem to me the best values obtained hitherto for the different accelerations :—

	Lunar Eclipse Times.	Lunar Eclipse Magnitudes.	Solar Eclipses.	Occultations, etc.	Equinoxes.
L	...	...	$+10''\cdot5$	$+10''\cdot8 \pm 0''\cdot70$	
L′	...	$+1''\cdot78 \pm 0''\cdot45$	$+1''\cdot0$	...	$+1''\cdot93 \pm 0''\cdot27$
D = L − L′	$+7''\cdot9 \pm 1''\cdot3$	...	$+9''\cdot5$		

The evidence seems to point clearly to $+10''\cdot5$ approximately for the lunar acceleration, and $+1''\cdot0$ or a little more for the solar acceleration.

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* *M.N.*, 75, 393, 395.