THE ECLIPSE EXPEDITION

OF THE

CREIGHTON UNIVERSITY

TO

WASHINGTON, GEORGIA.

BY

WILLIAM F. RIGGE, S. J.

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CREIGHTON UNIVERSITY has contributed its share towards the scientific observation of the total solar eclipse of May 28, 1900, so far as its means and circumstances permitted. As this great event occurred toward the end of the college year when its professors were unusually occupied with class duties and examinations, the Professor of Astronomy, the writer of the present account, was the only one who could be devoted to the work. Having invited the Professors of Astronomy of sister colleges to participate in the noble cause, Rev. Charles Charroppin, S.J., and Professor Aloysius Frumveller, S.J., of St. Louis University, St. Louis, Missouri, and Professor William P. Quinlan, S.J., of St. Xavier College, Cincinnati, Ohio, recognizing Creighton's initiative and its judicious selection of the site, freely offered a hearty coöperation. Washington, Georgia, was chosen as the place of observation, and the elegant little pastoral cottage attached to the St. Joseph's Academy and Orphanage, the occupant of which had just died in a hospital in Baltimore, was placed at our entire disposal, and every facility was offered for our work.

The observatory of Creighton University, at Omaha, Nebraska, while surpassed but by few students' observatories in the country, is not equipped with special eclipse instruments. Its 5-inch Steward equatorial, its 3-inch Fauth transit and meridian circle reading to tenths of a second, with its chronograph and its Howard mean time and Fauth sidereal clocks, are not portable, and as time and means were limited, their transportation and remounting were out of the question. The writer therefore had to content himself with an excellent chronometer and a 3-inch telescope with a tripod and an ordinary altazimuth mounting. But with this comparatively meager instrumental outfit, he was determined to do his best. To do work of real service to astronomical science, he further restricted himself exclusively to the observation of the four contacts. Then, as a professor of astronomy, he devoted the rest of his energy to the visual observation of the corona and other phenomena of the eclipse. The other members of the party had mounted six cameras upon one support, and were intent upon the photographic reproduction of the corona.

STATION.

Upon the grounds of the St. Joseph's Orphanage and Academy at the western end of Washington, Georgia, there are four main buildings connected by a private walk. Of these the Orphanage is at the northern end, the little cottage which served as our headquarters is next, then comes the Catholic church, and lastly the Academy at the southern end. While the rest of my party had erected their cameras in front, or east of the cottage, I took up my station on the walk halfway between the church and the residence, where, as I had planned, I was absolutely alone and entirely unbiased by the doings of others. Afterwards, when I realized that my observations were better than I had anticipated, I engaged Mr. Wiley G. Tatom, the Surveyor of Wilkes County, to connect my station with that of the Massachusetts Institute of Technology at the southern end of the town. Under date of June 22, 1900, he sent me the following field notes :

	Bearings.			Distances. Chains.
1	S.	66°	E.	5.00
2	S.	86½°	E.	43.60
3	S.	5°	W.	28.00
4	S.	60°	E.	7.30

The departures and differences of latitude are as follows, the distances being expressed in feet :

	Bearings.	Distances.	N.	S.	E.	W.
1	S. 66° E.	330	....	134	302	....
2	S. 86½° E.	2,878	....	176	2,872	....
3	S. 5° W.	1,848	....	1,841	....	161
4	S. 60° E.	482	....	241	417	
				2,392	3,591	161
					161	
				2,392	3,430	

FIG. 1. — METHOD OF OBSERVATION.

According to the Smithsonian Geographical Tables, 1894, these distances are equivalent to 23.7″ and 2.71*s*. respectively. Hence

	Latitude.	Longitude.
Massachusetts Institute of Technology	33° 43′ 49″	5*h*. 30*m*. 56.2*s*.
Reduction	+ 23.″7	+ 2 7*s*.
Creighton University	33° 44′ 13″	5*h*. 30*m*. 58 9*s*.

The station of the Massachusetts Institute of Technology was therefore 4,180 feet S. 55° 7′ E. of that of the Creighton University.

The Method of Observation.

The internal contacts were observed with the naked eye. The external contacts were observed by projecting the sun's image upon a white screen secured by two light wooden rods beyond the eye-piece of the 3-inch telescope (see Figure 1). I prefer this way of observing the sun to the more usual direct-vision method by means of a sunshade or helioscope, because the projection method does away with the heat and glare of the sun, admits of the use of both eyes and of any desirable magnifying power, is equal, if not superior in accuracy of observation, and especially because it enables the observer to mark the point of first contact upon the screen and thus obtain the advantages of a position micrometer from a telescope of the most ordinary construction and mounting.

The Chronometer.

The chronometer was the box chronometer without its box, H. H. Heinrich, No. 502, beating half seconds. It kept central, or 90th meridian, time. The correction and rate were obtained from the 75th meridian noon signals at the railroad depot, which was at about a five minutes' walk from our cottage. As the signals were less than a tenth of a second in error, being 0.04*s*. late on May 26, and 0.02*s*. fast on May 28, their correction has been neglected. The chronometer corrections were as follows:

May 26, 1900	+ 1*m*.	1.2*s*.
May 28, 1900	+ 0	47.0

Hence the rate was 7.1*s*. a day gaining, or 0.3*s*. in one hour.

THE TIMES OF THE CONTACTS.

	I.			II.			III.			IV.		
	h.	*m.*	*s.*	*h.*	*m.*	*s.*	*h.*	*m.*	*s.*	*h.*	*m.*	*s.*
Chronometer face	6	32	30	7	40	2	7	41	28	8	58	31
Correction at 11*h*. . . .	+		47.0	+		47.0	+		47.0	+		47.0
Rate to observed time . .	+		1.3	+		1.0	+		1.0	+		0.6
Central times	6	33	18.3	7	40	50.0	7	42	16.0	8	59	18.6

Comparison of Computed and Observed Times.

In preparation for the eclipse, the erroneous values of 33° 40′ 46″ for the latitude, and 5*h*. 30*m*. 49.5*s*, for the longitude, as measured from the government eclipse map, had been used. As soon as the true co-ordinates of my position became known to me, I recomputed the times of the phases and obtained the following results:

Central Time.	I.			II.			III.			IV.		
	h.	*m.*	*s.*	*h.*	*m.*	*s.*	*h.*	*m.*	*s.*	*h.*	*m.*	*s.*
Computed	6	33	17.0	7	40	57.1	7	42	23.0	8	59	29.8
Observed	6	33	18.3	7	40	50.0	7	42	16.0	8	59	18.6
Computed — Observed . .	—		1.3	+		7.1	+		7.0	+		11.2

Central Time.	Mid Totality.			Duration of Totality.		Duration of Whole Eclipse.		
	h.	*m.*	*s.*	*m.*	*s.*	*h.*	*m.*	*s.*
Computed	7	41	40.0	1	25.9	2	26	12.8
Observed	7	41	33.0	1	26.0	2	26	0.3
Computed — Observed . . .	+		7.0	—	0.1	+		12.5

Comparison of Times as Observed by Creighton University and Massachusetts Institute of Technology Parties.

A very interesting and useful part of the observations of the contacts in an eclipse is the comparison of the times as observed by different parties. It was only on November 23, 1900, that a reprint from the *Technology Quarterly*, Vol. XIII, No. 3, September, 1900, containing the account of the "Eclipse Expedition of the Massachusetts Institute of Technology to Washington, Georgia," came into my hands. It had been kindly sent to me by Mr. G. L. Hosmer. As soon as I saw the observed times of the phases, I set to work at once to compare them with my own. For this purpose a reduction had to be computed which would make the observations at both stations comparable with one another. As this computation involved a considerable amount of labor, I thought a somewhat extended explanation of my method would be acceptable to the readers of this journal. I shall try to be brief without being obscure.

Reduction of the Times of the Exterior Contacts.

For the external contacts sufficient accuracy is secured by measuring the direction of the tangent to the moon's penumbra as given for every two-and-a-half minutes for the beginning, and every five minutes for the end of the eclipse, on the government map in the supplement to the *American Ephemeris*, 1900, and then supposing the direction of the penumbral motion to be at right angles to this tangent. The velocity was obtained by measuring the number of miles run in a minute, or the number of feet run in a second, on either side of Washington on the map. This gave the following results:

Penumbral front moved 3,942 feet a second from S. 14° W.
Penumbral rear moved 2,587 feet a second from S. 53° W.

Figure 2 represents the comparative location of the two observing stations and the direction of motion of the moon's penumbra at the external contacts. It will be seen that the first contact occurred 0.38*s*. sooner, and the fourth contact 0.50*s*. later, at the Massachusetts Institute of Technology station than at the Creighton University station. Hence the correction to the observed M. I. T. (Massachusetts Institute of Technology) times is + 0.4*s*. and — 0.5*s*. respectively, to reduce them to the C. U. (Creighton University) station.

Reduction of the Times of the Interior Contacts.

There are, in general, two kinds of solutions, according as the Fundamental Plane or the Washington Horizontal Plane is taken as the basis of computation.

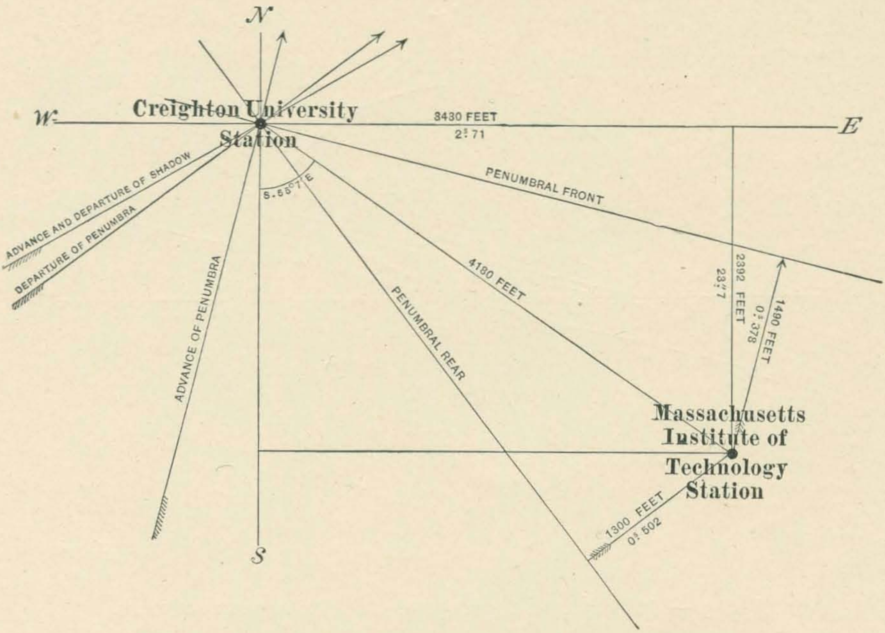

FIG. 2. — COMPARATIVE LOCATION OF THE ECLIPSE STATIONS.

I. The Fundamental Plane. — The Fundamental Plane is the plane, at right angles to the sun's rays, passing through Washington or the centre of the earth.[1] Figure 3 represents the shadow circle upon this plane with its radius equal to 0.00543 at the assumed instant of Greenwich time, 1*h*. 41.6*m*., or 7*h*. 41*m*. 36.0*s*., A.M., Central time. *O* is the centre of this circle, *C* is the position of the Creighton University station, *M* that of the Massachusetts Institute of Technology, *G H* and *P Q* are the shadow chords which swept over the stations with *F* and *K* as their middle points. The little dot close to the centre of the shadow circle is the position of Washington as given on the eclipse map. The radii marked a, b, a', b', in parentheses, will be referred to afterwards. The numerical values of some of the quantities for both stations are as follows, the notation of the *American Ephemeris* being used throughout:

[1] This is not, strictly speaking, the Besselian Fundamental Plane used in the computation of eclipses, since the latter is normal to the line joining the centres of the sun and *moon* instead of the centres of the sun and *earth*, but as the angle between these two planes was only 6.6″ at mid-totality, the difference between them is too small to affect my present purpose.

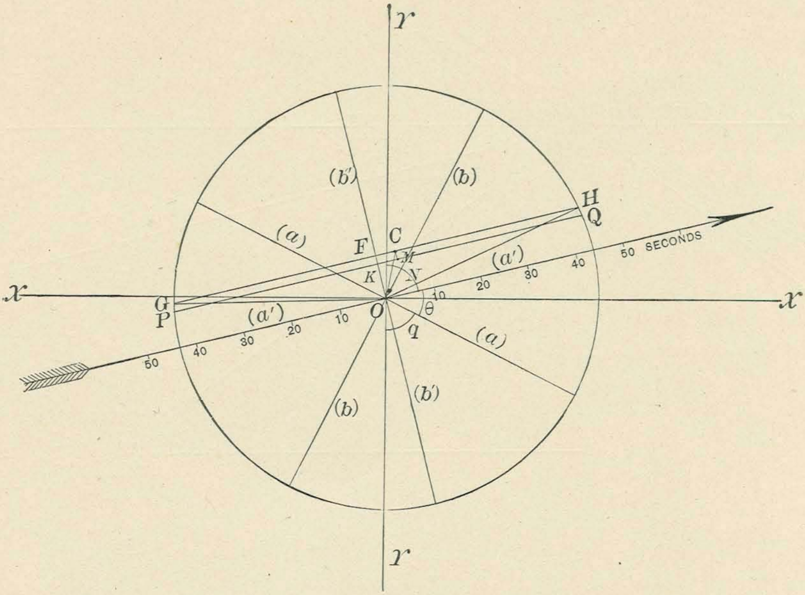

FIG. 3. — THE SHADOW CIRCLE UPON THE FUNDAMENTAL PLANE.

	Creighton University.	Massachusetts Institute of Technology.
$x - \xi$	— 0. 000 22	— 0. 000 23
$y - \eta$	— 0. 00 120	— 0. 00 107
M	190° 23′ 20″	192° 7′ 53″
N	76° 12′ 43″	76° 12′ 43″
$M - N$	114° 10′ 37″	115° 55′ 10″
m	0.00 12200	0 00 10944
n	0.00 74248	0.00 74248
ψ	11° 49′ 40″	10° 26′ 39″

The remaining quantities and the reductions will be given later on.

II. The Washington Horizontal Plane. — 1. Upon this plane the outline of the moon's shadow is an ellipse. The semi-minor axis, b, on Figure 4, is the same as the radius of the shadow circle on the Fundamental Plane (b), on Figure 3, and equal to 0.00543 in terms of the earth's equatorial radius as unity, or 21.560 miles. The semi-major axis $= a = b \sec \zeta = 34.245$ miles, ζ being the sun's zenith distance.

The local azimuth of this major axis is evidently that of the sun N. 88° 31′ 54″ E. The direction of motion, *a*, of the shadow ellipse

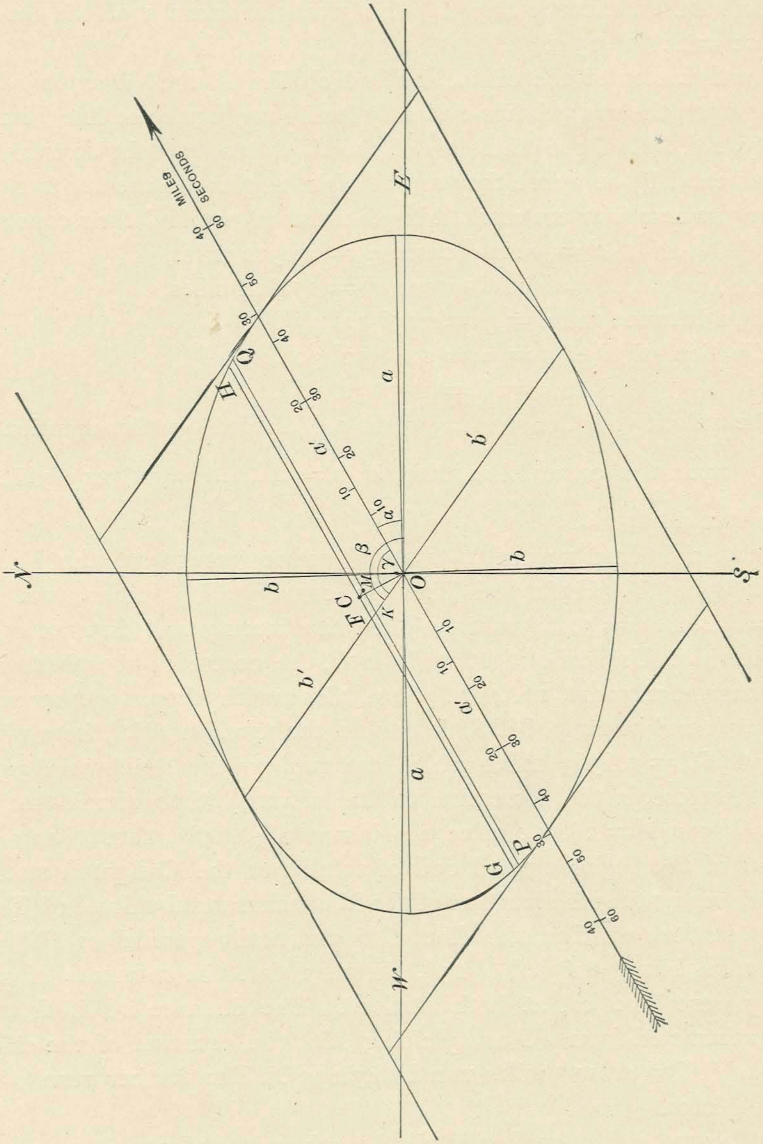

FIG. 4.—THE SHADOW ELLIPSE UPON THE WASHINGTON (GA.) HORIZONTAL PLANE.

with reference to the sun's azimuth, may be found from the formula

$$\tan a = \cos \zeta \tan \theta,$$

in which $\theta = 180° - (N + q) = 40° \ 25' \ 44''$ (see Figure 3) is the angle between the direction of motion of the shadow on the Fundamental Plane with reference to the sun, N is the Ephemeris N, and q is the sun's local parallactic angle. This gives the azimuth of the shadow advance = S. 60° 19′ 24″ W.

The diameter of the ellipse, $2a'$, which lies in the direction of its motion upon the ground, has evidently for its conjugate the line of mid-totality, $2b'$. As these diameters of the ellipse are brought up from the Fundamental Plane where they are at right angles to one another (see Figure 3, where they are marked in parentheses), we find their constants to be

$$a' = b \sin\theta \operatorname{cosec} \alpha = 29.512 \text{ miles},$$
$$b = b \cos\theta \operatorname{cosec} \alpha' = 27.614 \text{ miles},$$

the angle between them $= \gamma = 115° \; 19' \; 37''$,
in inclination of a' to $a = \alpha = 28° \; 12' \; 30''$,
and of b' to $a = \beta = 143° \; 32' \; 7''$.

The velocity of the shadow, v, is $2a'$ divided by the duration of totality upon the central line, that is, $v = \dfrac{a'}{43.88s.} = 0.67413$ mile or 3,559 feet a second.

As all right lines parallel to a' and b' are projected from the Fundamental upon the Horizontal Plane in corresponding ratios, we find $OF = b' \sin \psi = 5.660$ miles. Then the bearing and distance of C, the Creighton University Station, from O, the centre of the shadow at the assumed moment, 1*h.* 41*m.* 36.0*s.*, Greenwich time, together with the length and bearing of OF, determine the triangle FOC, from which we find $FC = 2.6563$ miles which are run by the shadow in 3.94*s.* This, therefore, is the correction to the assumed time of mid-totality. $GF = a' \cos \psi = 28.952$ miles, and is run in 42.948*s.*, thus giving the instants of the beginning and end of totality at the Creighton station.

In investigating the position of the Massachusetts Institute of Technology station, we find the line CM practically parallel to FO, the divergence being only 0° 6′ 25″, showing that the moments of mid-totality were identical at both stations. The distance of M from C being subtracted from FO and yielding KO, the equation of the ellipse gives us $PK = 29.117$ miles run in 43.193*s.* The further results will be seen later.

In this method, as well as in all the others, the dimensions, velocity and direction of the shadow ellipse may be assumed to remain constant for one minute without introducing any sensible error into the computation.

2. Another method of examining the instantaneous constants of the shadow ellipse is to determine the lengths and inclinations of the conjugate diameters from the formulæ

$$\tan \alpha \tan \beta = -\frac{b^2}{a^2},$$

$$a'^2 + b'^2 = a^2 + b^2,$$

$$a' \, b' \sin \gamma = ab.$$

These give

$$a' = 29.62 \text{ miles},$$

$$b' = 27.58 \text{ miles},$$

$$\alpha = 28^\circ \; 12' \; 30'',$$

$$\beta = 143^\circ \; 32' \; 7'',$$

$$\gamma = 115^\circ \; 19' \; 37'',$$

$v = 0.67504$ mile, or 3,564 feet a second, in which the angles are the same as in the previous method, but the lengths of the lines are slightly different.

From the known length of CO and the angles in the triangle FOC, we find $FC = 2.6758$ miles run in 3.964*s*., and $OF = 5.7015$ miles. The formula of the ellipse then gives $FG = 28.980$ miles run in 42.932*s*. Knowing the distance and bearing of M from C, we find the difference of the times of mid-totality to be 0.0024*s*. Then the usual equation of the ellipse gives $KP = 29.144$ miles run in 43.174*s*.

3. A third method consists in measuring the necessary data from the government eclipse map. The distance between the mid-totality lines gives the velocity of the shadow equal to 42.2 miles per minute, or 3,712 feet per second, and its direction as from S 60° W. As the duration of totality on the central line was here 1*m*. 27.8*s*., the semi-major axis of the shadow ellipse was found to be $= a' = 30.25$ miles. By measurement parallel to the mid-totality lines, the conjugate semi-minor axis was found to be $= b' = 26.75$ miles, and the angle between the axes $= \gamma = 111^\circ \; 30'$. With these data, the formulæ

$$a' \, b' \sin \gamma = ab,$$

$$a'^2 + b'^2 = a^2 + b^2,$$

$$c = \sqrt{a^2 - b^2},$$

$$e = \frac{c}{a},$$

$$x' = \sqrt{\frac{a^2 - b'^2}{e^2}},$$

$$\cos \alpha = \frac{x'}{a'},$$

$$\beta = \gamma + \alpha,$$

gave

$$a = 33.60 \text{ miles},$$
$$b = 22.42 \text{ miles},$$
$$\alpha = 25^\circ\ 30',$$
$$\beta = 137^\circ\ 0'.$$

4. By using the sun's azimuth and the formula

$$\tan \alpha = \cos \zeta \tan \theta,$$

we find

$$\alpha = 28^\circ\ 23'\ 44'',$$
$$\beta = 143^\circ\ 19'\ 10'',$$
$$\gamma = 114^\circ\ 55'\ 26'',$$
$$a = 33.97 \text{ miles},$$
$$b = 21.56,$$
$$a' = 29.34,$$
$$b' = 27.53.$$

The further reduction of the results in these two last cases is by the same method as in the second solution. But as measurements on a map cannot compete in accuracy with computed values, no use has been made of these results except as checks upon the computation.

COMPARISON OF THE RESULTS OF THE METHODS OF REDUCTION.

	Creighton University.			Massachusetts Institute of Technology.		
	Fund. Plane.	Horizontal Plane. 1.	Horizontal Plane. 2.	Fund. Plane.	Horizontal Plane. 1.	Horizontal Plane. 2.
Assumed Central Time of Mid-totality. 7*h*. 41*m*.	*s.* 36 00	*s.* 36 00	*s.* 36.00	*s.* 36.00	*s.* 36.00	*s.* 36.00
Time to run *FC* and $KM = + t_2$	4.04	3.94	3.96	3.87	3.94	3.96
Mid-totality. 7*h*. 41*m*.	40.04	39.94	39 96	39.87	39.94	39.96
Time to run *FG* and $PK = \pm t_1$	42.95	42.95	42.93	43.15	43.19	43.17
Beginning of totality. 7*h*. 40*m*.	57.09	56.99	57.03	56.72	56.75	56.79
End of totality. 7*h*. 42*m*.	22.99	22.89	22.89	23.02	23.13	23.13
Reduction of M. I. T. to C. U. — Beginning,	....	....	....	+0.37	+0.24	+0.24
Reduction of M. I. T. to C. U. — End	....	....	....	−0.03	−0.24	−0.24
Duration of totality	85.90	85.90	85 86	86.30	86.38	86 34
Difference	....	....	....	−0.40	−0 48	−0 48

As the *American Ephemeris* gives its data only to five decimal places, differences of tenths of a second in the reduction can hardly be relied upon. However, giving the reductions computed upon the Fundamental Plane half the weight of either of those obtained from the Horizontal Plane, we find that we must add + 0.3*s*. and — 0.2*s*. to the observed times at the Massachusetts Institute of Technology station in order to reduce them to those observed at the Creighton University station, and hence for all four contacts the reductions are

I.	II.	III.	IV.
+ 0.4*s*.	+ 0.3*s*.	— 0.2*s*.	— 0.5*s*.

The Observations of the Contacts made by the Massachusetts Institute of Technology Reduced to the Creighton University Station.

The *Technology Quarterly* quoted above (September, 1900), on pages 171 and 172, gives the times of the contacts as observed by Mr. Hosmer and Professor Robbins. As these are expressed in Washington local mean time, we add to them the Greenwich longitude of the place, 5*h*. 30*m*. 56.2*s*., and then subtract 6*h*. 0*m*. 0*s*., in order to reduce them to Central time, and lastly add also the above-computed reductions in order to reduce them to the Creighton University station. The results are then as follows :

George L. Hosmer.	I.	II.	III.	IV.
	h. m. s.	*h. m. s.*	*h. m. s.*	*h. m. s.*
Washington time	7 2 22.7	8 9 52.0	8 11 18.2	9 28 26.9
Greenwich longitude	+5 30 56.2	+5 30 56.2	+5 30 56.2	+5 30 56.2
Red. to Central time	—6 0 0.0	—6 0 0.0	—6 0 0.0	—6 0 0.0
Red. to C. U. Station	+ 0.4	+ 0.3	— 0.2	— 0.5
Central time at C. U. Station . .	6 33 19.3	7 40 48.5	7 42 14.2	8 59 22.6

ARTHUR G. ROBBINS.	I.	II.	III.	IV.
	h. m. s	h. m. s	h. m. s.	h. m. s
Washington time	7 2 16.4	8 9 53.1	8 11 18.4	9 28 16.1
Greenwich longitude	+5 30 56.2	+5 30 56.2	+5 30 56.2	+5 30 56.2
Red. to Central time	−6 0 0.0	−6 0 0.0	−6 0 0.0	−6 0 0.0
Red. to C. U. Station	+ 0.4	+ 0.3	— 0.2	— 0.5
Central time at C. U. Station	6 33 13.0	7 40 49.6	7 42 14.4	8 59 11.8

GENERAL COMPARISON OF COMPUTED AND OBSERVED TIMES.

Central Times.	Contacts. I.	Contacts. II.	Contacts. III.	Contacts. IV.	Mid-totality.	Duration of totality.	Duration of whole eclipse.
	h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.	m. s.	h. m. s.
Computed	6 33 17.0	7 40 57.1	7 42 23.0	8 59 29.8	7 41 40.0	1 25.9	2 25 72.8
Observed by Rigge	18.3	50.0	16.0	18.6	33.0	1 26.0	60.3
Observed by Hosmer	19.3	48.5	14.2	22.6	31.4	1 25.7	63.3
Observed by Robbins	13.0	49.6	14.4	11.8	32.0	1 24.8	58.8
Computed Minus Observed — Rigge	−1.3	+7.1	+7.0	+11.2	+7.0	−0.1	+12.5
Computed Minus Observed — Hosmer,	−2.3	+8.6	+8.8	+ 7.2	+8.6	+0.2	+ 9.5
Computed Minus Observed — Robbins,	+4.0	+7.5	+8.6	+18.0	+8.0	+1.1	+14.0
Hosmer — Rigge	+1.0	−1.5	−1.8	+ 4.0	−1.6	−0.3	+ 3.0
Robbins — Rigge	−5.3	−0.4	−1.6	− 6.8	−1.0	−1.2	− 1.5
Hosmer — Robbins	+6.3	−1.1	−0.2	+10.8	−0.6	+0.9	+ 4.5

CREIGHTON UNIVERSITY,
Omaha, Neb., January 1, 1901.