Means which have been adopted for ascertaining the Velocity of Light and the Sun's Distance, with especial reference to the forthcoming transit of Venus over the Sun's disc, in 1874 *and* 1882.

[Read by Francis Abbott, F.R.A.S., 8th March, 1864.]

By M. Foucault's recent experiments on the velocity of light, astronomy has received a new accession, especially as it applies to the great question concerning the Sun's distance, a correct knowledge of which enables astronomers to mete out the exact distance and dimensions of every planet and satellite, and the distance of those fixed stars whose parallaxes are approximately known. Any error, therefore, in the Sun's distance entails a proportionate error in the distance of all the other heavenly bodies.

I have been induced to bring this subject before the meeting as astronomers have already begun to talk of preparing means and adopting situations for making unremitted observations on the next transit of Venus over the Sun's disc, in 1874 and 1882. It is essential to remark that the transits will take place in the month of December, and at that time the earth's South Pole will be turned towards the sun, and those regions of the earth included between the South Pole, and the southern limit of illumination will be carried by rotation, opposite to the direction of all the northern parts of the earth. Only two transits of this planet over the sun have occurred since Dr. Halley invoked the attention of astronomers to these rare astronomical events, viz., in 1761 and 1769. The transit of 1769 was most favorable, and afforded an opportunity which can only occur once in a lifetime.

Mr. Breen, Assistant Astronomer to the Royal Observatory at Greenwich, has made for the Astronomer Royal drawings both of the ingress and egress, together with the illuminated portion of the earth during the time of each transit. In these drawings, *Tasmania* for the first transit, 1874, is illuminated from beginning to end. This will appear clear by inspection, from the time of conjunction given on the diagram. At the second transit, 1882, the first contact is at 2h. 5m. 54s. a.m., on that day, 7th December, the sun does not rise at Hobart Town until 4h. 28m. a.m., the ingress therefore will not be visible.

So important have these observations appeared to astronomers that at the last transit of Venus, in 1769, expeditions were fitted out on the most efficient scale by the British, French, Russian, and other Governments to the remotest corners of the globe. The celebrated expedition of Captain Cook to Otaheite was one of them; and it is not more certain that this phenomenon will recur than that every provision will be made for observing it in every inhabited quarter of the globe. With the improved instrumental means, and the more accurate methods of observing, - should other things prove favorable—it is expected that the results may furnish an universal standard of astronomical measure.

"In the transit of 1861," says the Astronomer Royal,* "the result depended almost entirely upon an accurate knowledge of the differences of longitude of very distant stations, which are undoubtedly subject to great uncertainty. In the transit of 1769 it happened that the result depended almost entirely upon the observations made by Father Hell, at Wardhoe; and to these great suspicion has attached, many astronomers having, without hesitation, designated them as forgeries. It is evidently desirable to repeat the practical investigation when opportunity shall present itself."

The solar parallax from the observations of 1769—which Encke deduced from an elaborate discussion fifty years after they were made—is 8".57116. This corresponds with a solar distance of 95,360,000 statue miles; and should the forthcoming transit of Venus prove unfavorable, any reduction of the possible error in the sun's parallax within the limit of one hundredth of a second will be hopeless for near two centuries to come.†

In glancing first at the two astronomical methods that have been adopted for measuring the velocity of light, and from which some apparent difficulties arose, owing to the extent of space through which the ray is transmitted, which, in stellar astronomy, surpasses in magnitude even the velocity of light, by which the luminous ray appears to be retarded in its passage, so that a distinction exists between the *actual* and the *apparent* interval of each successive transit. For example, the first satellite of Jupiter revolves round its primary in about 42½ hours, and as it takes light more than 40 minutes to pass over the average distance of Jupiter, the eclipse is not seen until so many minutes, on the average, after it has happened. Now if this delay were con-

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* Monthly Notices, R.A.S.

† No other transits of Venus over the sun's disc will take place until June, 2004, and June, 2012.

stant, the interval of successive eclipses would not be altered. But in the course of six months the distance of the earth from Jupiter increases by the diameter of the earth's orbit, and in the next six months' changes back again. When the earth is nearest to Jupiter, the eclipse reaches us in abont 32 min., but when the earth is at the greatest distance, it takes 50 minutes to reach us.

It is clear from this that the intervals between successive eclipses are variable, being sometimes longer and sometimes shorter than the real intervals. Delambre discussed 1000 of these eclipses, observed between the years 1662 and 1802, from which he calculated the velocity of light to require 493.2 seconds to pass over the mean distance of the Sun. If this time, then, divides 95,360,000 statute miles, which is the Sun's distance, deduced from the transits of Venus in 1761 and 1769, the quotient 193,350 statute miles is the velocity of light in one second.

The second process which astronomy has supplied for obtaining the velocity of light, requires not *space* but a *velocity* which is commensurable with the velocity of light. In nature the velocity of the earth is compounded in this way with the velocity of light, and imparts to light an apparent path, differing by a small angle from the true path. The angular displacement thus caused between the apparent and the real places of a star is called *aberration*, from which Bradley explained anomalies in observation which had been until that time considered accidental. The displacement of a star works contrary ways at opposite seasons of the year. Half the difference between the extreme places is the distance from the apparent to the true place, or the *constant of aberration.* This, when known as an observed fact, establishes the ratio between the velocity of light and the velocity of the earth, and enables the astronomer to assign the value of the one with all the accuracy which pertains to his knowledge of the other.

The result of aberration obtained by Struve is 20″·35, from which the velocity of light is calculated to be 10,088 times as great as the velocity of the earth. The mean velocity of the earth is known from the magnitude of its orbit, that is, of the sun's distance.

Assuming the distance derived from Enck's parallax to be the most correct, the velocity of the earth in one second of solar time is 18,977 miles. This multiplied by the above ratio gives 191,513 miles for the velocity of light by Bradley's principle. It appears, therefore, that the velocities by these two astronomical methods differ by 1837 miles, a small quantity comparatively, being only *one per cent.* of the whole velocity.

The experiment on the velocity of electricity by Professor Wheatstone, published in 1834, suggested the possibility of measuring in a similar way the velocity of light, and to this purpose it was afterwards made applicable by Fizeau, from the results of which the French Academy referred the subject to a scientific commission. F. Arago next made experiments on rapid rotation, and, being aided by the refined skill of Briguet, he realised velocities in the mirror of 1000 turns in a second of time. These experiments have been of late much improved by M. Foucault, in causing a pencil of solar light reflected into a horizontal direction by a heliostat to fall upon a micrometric mark, which is made the real standard of measure. The rays which traverse this initial surface fall next upon a series of rotating mirrors, to which a constant velocity is imparted with air supplied by a high pressure belows.

M. Foucault's experimental results by means of this ne w apparatus, which he says has been purged of uncertainty, gives the velocity of light in space as 298,000 kilometres in a second of mean time. This value reduced to statute miles gives the velocity of light as 185,177 miles in a second—which is less by 6336 miles than the velocity admitted by science as computed from aberration. This difference between the result of experiment and those of astronomical observation, which come nearest to it, is three times greater than the variation between the velocity deduced from aberration and that derived from eclipses.

M. Foucault states that the mean results by his experiment can be trusted to the fraction of 1-500. Now the aberration of 29″·45, adopted by astronomers, cannot be at fault more than one 1,800th of the whole. How, then, is the velocity of light to be reconciled with the value of aberration. Is it possible there can be an uncertainty of three per cent. in the velocity of the earth? If there is an error in the velocity of the earth it is an error in space, and to diminish the earth's velocity sufficiently by a change of time would require an increase of nearly eleven days in the length of the year. The only other way of reaching the velocity of the earth is by diminishing the earth's orbit, and that would change proportionately the mean radius of the orbit—that is, the sun's mean distance. Can the sun's distance from the earth, then, be considered uncertain to the extent of three per cent. of the whole?

The limits of accuracy by which the sun's distance from the earth has been best determined is by solar parallax, or the angle between two or more stations at considerable distances from each other, in the northern and southern hemispheres, whose geographical positions are well known, and from which stations two astronomers point their telescopes, when looking at the sun, at the same moment. As the distance of the object increases, as for sun, or star, the base line is to be enlarged, and the angle thus obtained is the means by which solar parallax is associated with the sun's distance. In the case of the sun, the base line is measured on the earth's surface ; and in the case of a star from the extremes of the earth's orbit. The astronomer then makes use of Kepler's third law, which establishes a relation between the distances of the different planets from the sun, and their periods of revolution ; if either distance is found by observation, the other can be computed by this law.

The choice lies between Venus, at inferior conjunction, and Mars at opposition. The parallax of Mars may vary from 20"·7 to 19"·1, according to the position of Mars and the earth with respect to the perihelion of the orbit at the time of opposition. The parallax of Venus at conjunction may vary for the same reasons from 33"·9 to 29"·9. Venus, therefore, may be nearer to the earth than Mars, and the parallax more favorable. But Venus cannot be seen at conjunction, except when its latitude is so small that a transit across the sun's disc occurs. Then the two observers refer its place not to a star but to the sun, and the quantity determined is the difference of parallax between Venus and the sun, which will vary from about 21" to 25". The difference of parallax is not measured directly, but through the influence it produces on the duration of the transit at the two stations, and consequently upon a much enlarged scale.

The solar parallax may be derived from the parallax of Mars, when this planet is in opposition; Lacaille was sent in 1740 to the Cape of Good Hope for the purpose, and the parallactic angle observed between the direction of Mars as seen from that station and from the Observatory at Prais. The solar parallax then found was 10"·20, with a possible error not exceeding 0"·20. Henderson comparing his own observations of the declination of Mars at its opposition in 1832 with corresponding observations at Greenwich, Cambridge, and Altona, computed the solar parallax at 9"·028.

The solar parallax is also computed from the law of universal gravitation by means of the disturbed motion of the moon round the earth, and the unequal attraction of the sun on the two bodies. The magnitude of the disturbance is in some proportion to the distance of the disturber when compared with the relative distance of the two disturbed bodies; and this ratio of distances is the inverse ratio of the parallax of the sun and moon. By selecting one of the perturbations in the moon's longitude adapted to this purpose, Mayer, in 1760, computed the solar parallax at 7"·8. In 1824, Burg calculated this parallax at 8"·62. Laplace gives it at 8"·61.

The following table‡ gives the values of solar parallax and the sun's distance by the different methods of astronomy and by experiment :—

Observer or Computer.	Method.	Parallax "	Distance. Miles.
Encke	By Venus (1761)	8·53	95,141,830
Encke	,, ,, (1769)	8·59	95,820,610
Lacaille	By Mars	10·20	76,927,900
Henderson	,, ,,	9·03	90,164,110
Gillis and Gould	,, ,,	8·50	96,160,000
Mayer	By Moon	7·80	104,079,100
Burg	,, ,,	8·62	94,802,440
Laplace	,, ,,	8·61	94,915,970
Pontecoulant	,, ,,	8·63	94,689,710
Lubbock	,, ,,	8·84	92,313,580
Lubbock	,, ,,	8·81	92,652,970
Hansen	,, ,,	8·88	91,861,060
Leverrier	,, ,,	8·95	91,066,350
Foucault	By Lights	8·86	92,087,342
Fizeau	,, ,,	8·51	95,117,000
Velocity of Light	By Eclipses	—	193,350
,, ,,	By Aberration	—	191,513
,, ,,	By Fizeau's experiments	—	194,667
,, ,,	By Foucault's ,,	—	185,177

‡ This table, together with some other datum, is taken from a recent article on the subject compiled by Professor Joseph Lovering, of Harvard College.

The Sun's mean horizontal equatorial parallax has since been computed by E. J. Stone, Esq., from observations made at the Royal Observatory, Greenwich, and the Government Observatory, Williamstown, Victoria, during the last opposition of Mars, in 1862. The mean result is 8″·932, with a probable error of 0·032.

It is clear from these resultants that the three astronomical methods, even if we select the most trustworthy, differ by three or four millions of miles—three or four per cent. of the whole quantity. The commonly received distance of the Sun is based upon Encke's profound discussion on the observations made at the last two transits of Venus. Encke decided from the weights of che observations, discussed on the mathematical principle of *least squares*, that the probable error in the Sun's distance, as given by the transits, does not exceed 1-230th of the whole quantity, Astronomers have also reason to believe that the adopted value of observation is correct within 1-1800th of the whole quantity. Foucault's is confident that with his improved apparatus he can banish all errors greater than 1-6000th of the whole quantity. It follows then, that one of these three elements, either the velocity of light, aberration, or the Sun's distance must be in error to the extent of three or four per cent. Which of the three must be changed?

This question remains to be answered by astronomers at the next two transits of Venus—December the 8th, 1874, and December the 6th, 1882*—for which purpose England, France, Russia, and America have already taken some preliminary steps for sending out scientific expeditions. In a paper read April 8th, 1857, before the Royal Astronomical Society, by the Astronomer Royal, rules are laid down, instruments described, and localities fixed upon—amongst the latter Van Diemen's Land is very favorably mentioned, but Professor Airy expresses a doubt whether the longitudes of any of the stations named, excepting those in Europe, are yet known with sufficient accuracy. Sir Henry Young (our late Governor) on being made acquainted with the opinion of the Astronomer Royal, at one of our Monthly Meetings, suggested that I should confer with Lieut. Brooker, and try to remove the doubt from the mind of Professor Airy. The result of this interview with Mr. Brooker was the deductions of the following resultant from Captain Kay's observations, made for the Magnetic Observatory, one copy of which was forwarded by agreement to the Royal Astronomical Society, and another copy to the Admiralty, 17th December, 1861:—

Captain Kay's communication to the Royal Society of Van Diemen's Land, in 1852, of the geographical position of the magnetic observatory, Hobart Town, gives such an elaborate detail of the means adopted for ascertaining its latitude and longtitude, that with verification by chronometric measurements, and—what may be possibly thought—accidental accordance from the measurements obtained between the Cape of Good Hope and Hobart Town, it may be fairly and reasonably assumed that the longitude of the observatory is (if not correctly known) but very little in error—less than half a mile; for in his tabulated record of the numerous observations by eclipses of the sun, by Jupiter's satellites, by moon-culminating stars, and by chronometric measurements, extending over a period of several years, by several observers, the extreme range of difference amounting to only 3½ miles. However, by the means of eight general results, it is reduced to less than half a mile of the probable truth. To attain a greater certainty would necessitate the establishment of a fixed observatory, with the best instruments,† and careful observations by experienced scientific observers."

Her Majesty's ship "Herald," Captain Denham, was in these waters on a scientific cruise in the year 1859, and in December of that year was stationed at Garden Island, Sydney. The result of the observations taken at that time by the officers of the "Herald" gave the longitude for Garden Island 10h. 5m. 1·9s. This would make the longitude for Hobart Town 9h. 49m. 28·8s., whereas Captain Kay's observations give it 9h. 49m. 29·6, making a difference of 8-10 of a second, which may be accounted for by the observations of the "Herald" being referred to the harbor, and Captain Kay's to the observatory. Trifling as 8-10 of a second may appear, unless accounted for, it would entail a considerable error in the sun's distance. The solar parallax is only about eight seconds and a half, and an error of 1-10 of a second includes an error of more than a *million of miles* in the sun's distance, in which a correction of three per

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* A reconnaissance of Wilk's Land is also required to be effected, included between Sabrina Land and Repulse Bay, occupying an extent of about 400 miles. To secure observations both of ingress and egress in this track is considered indispensable.

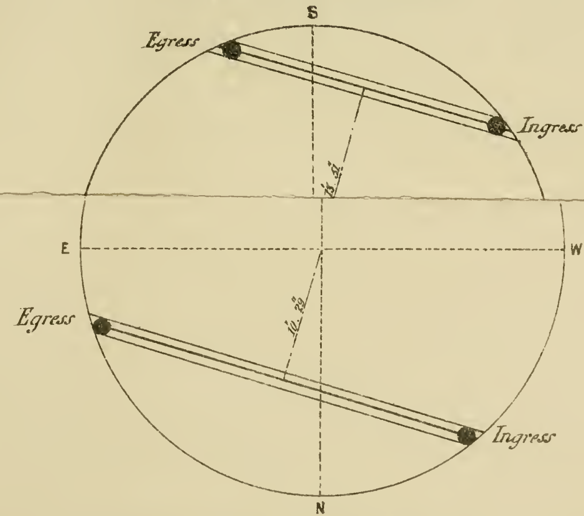
† The telescope used at the magnetic observatory was a portable achromatic by Dolland, 42 inch focal length, and 2¾ inch apperture, on a pillar and claw stand.

cent. only would run up to six hundred thousand millions of miles in the distance of the nearest fixed star. This enormous amount will appear clear when we consider that the base line applied is the diameter of the earth's orbit as computed by Encke, from the last transit of Venus, at 190,000,000 of miles, which is something utterly insignificant—a mere point which only produces a parallax on the star Sirius of 0″230.

Seeing, then, that a revision of the problem of the sun's distance is required, and that the colony of Tasmania is well situated for one of these stations, it might be advisable for either the Colonial Government, or the Council of the Royal Society supported by the Government, to make known to all those nations who are likely to send out expeditions the means by which the geographical position of Hobart Town has been arrived at, the result drawn from the mean of those observations, and the favorable position of the place for both transits.

Private Observatory, Hobart Town,
March 8th, 1864.

TRANSIT OF VENUS 1874 DEC^R 9^TH



HOBART TOWN MEAN TIME OF TRANSIT

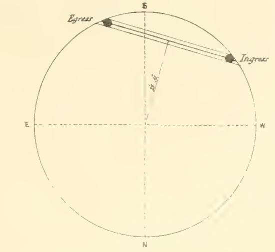
		h m s
1882 Dec^r 7^th	*Conjunction*	2 . 5 . 54 a m
	Semiduration of Transit	3 . 1 . 43

The aberration of Venus, and small equations of the Sun's place, are omitted, which will give about 2′. 20″ to be added to the time of conjunction F. Abbott.

Survey Department. Hobart Town.

F. C. Piguenit. Draughtsman

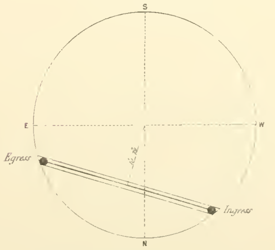
TRANSIT OF VENUS 1874 DEC^R 9^TH



HOBART TOWN MEAN TIME OF TRANSIT

		h m s
1874 Dec^r 9^th	*Conjunction*	1 57 54 p.m.
	Semiduration of Transit	2 4 40

TRANSIT OF VENUS 1882 DEC^R 7^TH



HOBART TOWN MEAN TIME OF TRANSIT

		h m s
1882 Dec^r 7^th	*Conjunction*	2 . 5 . 54 a.m.
	Semiduration of Transit	3 . 1 . 43

The aberration of Venus, and small equations of the Sun's place, are omitted, which will give about 2 23 to be added to the time of conjunction F. Abbott

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