ART. XXXI.—*On the Determination of the Sun's Distance.*
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[Read 27th June, 1863.]

The sun's distance from the earth forms the great base line of astronomical measurements, and outside the moon all dimensions and distances depend upon it; so that its determination may well be considered the noblest problem in astronomy.

It is a problem, too, in which the conditions to render it determinate with any probability of success, are only presented to us at long intervals; even then it demands all the skill and ingenuity of both the observer and mathematician to obtain the necessary measures, and to deduce from them results unaffected by the complications introduced by the movements of the bodies involved in the determination. At the same time, the object to be attained is of such surpassing interest and importance, that no care or cost can be considered too much to expend in its attainment.

It should be of special interest to Australians, for it was when Captain Cook was sent in command of the expedition to the South Seas, for the purpose of observing the transit of Venus, in order to determine the sun's distance, in 1769, that he re-discovered Australia and New Zealand, and it is more than probable that the colonization of Australia by the British, owes its origin to that very expedition of Captain Cook.

The fact of our Victorian Observatory having taken so prominent and successful a part in the late determination of the sun's distance, will possibly render a brief sketch of the history of this problem, and of the methods hitherto adopted in its solution, not altogether devoid of interest.

Among the Ancients the distance of our great luminary was scarcely anything more than conjecture. The first attempt at its determination appears to have been by Aristarchus of Samos, about 280 B.C., who used a method which only aimed at obtaining the relation of the distances between the earth and the moon, the moon and the sun; it consisted of measuring the angle between the moon and the sun when the former was dichotomized, in other words, exactly half illuminated—literally, cut in two. It is evident that at this time the earth, moon, and sun will form a triangle which will be right angled at the moon. The angle also by which the sun and moon was separated could be observed at the same instant, and hence the three angles of a triangle obtained. Aristarchus took for his unit of measure the distance of the earth from the moon, and arrived at the result that the sun was nineteen times as far from the earth as the moon; we now know it to be nearly four hundred times. The method of Aristarchus, however, did not admit of a precise practical application, inasmuch as the exact instant of dichotomy, or half moon, could not be well determined, and the slightest error in that respect would be fatal to accuracy.

This distance of the sun, namely, nineteen times the moon's distance, was accepted for nearly two thousand years subsequent to its determination. Ptolemy so far accepted it as to combine it with his determination of the moon's distance from the earth, making the sun's distance five millions of miles.

It was not until Kepler's time, in the seventeenth century, that this amount was discovered to be far too small, when that celebrated astronomer arbitrarily multiplied it by three, making it fifteen millions of miles. Notwithstanding this somewhat unscientific and summary proceeding on so grave a matter, astronomy owes to this celebrated astronomer the honour of making the first real step towards the solution of the great problem, by the enunciation of his three great laws of planetary motions, the substantial truth of which the illustrious Newton subsequently demonstrated.

Kepler's third law shows that the squares of the periodic times of the revolutions of the planets around the sun are to each other as the cubes of their mean distances ; therefore, if the periods in which the planets perform their orbits around the sun can be ascertained, the relative distances of the planets from the sun and from each other are determinate. These periods have been observed by most of the ancient astronomers, and indeed in Kepler's time they may be considered to have been almost as well known as at the present day ; although the question of whether the sun's distance was ten, or a hundred millions of miles, was still unsolved, Kepler's law made known the proportional distances of the bodies of our solar system with an accuracy very little behind our knowledge of the present day.

It will be borne in mind, that no absolute distances have yet been spoken of, but from what has been said of Kepler's third law, it will be apparent, that, if the distance of any one planet from the earth, can be accurately determined, the relative distances of the others can be converted into absolute ones. This became the next part of the problem.

The distance of a planet is obtained by ascertaining the angle the earth's radius will subtend at the planet: the larger this angle becomes the more accurate is the result. The nearest planets, of course, will give the largest angles, and for this very sufficient reason Venus and Mars have always been selected for observation in connection with the determination of the sun's distance. The angle above referred to as subtended by the earth's radius is generally known as the *parallax*, and it is by this name I shall now speak of it.

Of course the determination of distance from the parallax of a planet pre-supposes that the length of the earth's radius is known, but, although many geodetic enterprises have been undertaken for this purpose extending so far back as some centuries before the Christain era, Picard's measure of the French meridianal arc, in 1664, was the first undertaking that furnished reliable results. This measurement, performed with great skill and care, and with a better class of instruments than had been previously constructed, is memorable from the fact that the earth's diameter deduced therefrom enabled Newton to establish his laws of gravitation, which laws he had discarded for many years previous, on account of the measures which had been determined from former surveys being so utterly at variance with his theory.

Since Picard's survey of the French arc, others have followed in quick succession, each more exact than the preceding.

The methods adopted in modern times for the determination of the sun's distance are two, involving the parallaxes of the two nearest planets, Mars and Venus.

The parallax of Venus will give the largest angle, and consequently the most accurate result, but she only attains a position favourable for its measure at certain conjunctions, when her latitude is so small that she appears to a terrestial observer to transit across the sun's disc. This forms the best of all conditions for determining the sun's distance from her parallax, but, unfortunately, such occurrences are few and far between.

The celebrated astronomer Halley, in 1725, was the first to propose the observation of the transit of Venus across the sun's disc as a means of determining the sun's distance. The method consisted of observing at two different stations, separated by a considerable arc of latitude, the intervals of time occupied by Venus in passing across the sun's disc. The time occupied would be different to each observer in proportion to their distance apart, indicating that the path of Venus described parallel chords of different lengths ; the difference of times, therefore, would afford a measure of the separation of these two cords, which itself gives the parallax of Venus in terms of the distance between the two observers, and as by Kepler's third law we know that the proportional distances of Venus and the sun are as twenty-eight to seventy-two, all the necessary data for computing the sun's distance can be obtained.

The practical solution of the problem of course involves the nicest calculations and many mathematical difficulties connected with the elliptical motions of both Venus and the earth. This method is, nevertheless, without doubt the best of any known, but, unfortunately from the rare occurrence of the transits of Venus, ages almost elapse between the opportunities of its application. Since it was first proposed by Halley, in 1725, only two have occurred, namely, in 1761, and 1769. The next will take place in 1874, and again in 1882. They generally, not always, occur in pairs.

The method of determining the sun's distance from the measurement of the parallax of Mars, although not susceptible of quite so high a degree of accuracy as that by the transit of Venus, has, however, the great advantage of being practicable at every opposition of Mars, which occurs about every two years ; it must, however, be mentioned that the oppositions in which Mars approaches nearest to the earth (as in 1862) are much more favourable than the distant oppositions, from the fact of the parallactic angle being larger.

The method may be thus briefly described : when Mars is in opposition, observers, separated by large arcs of latitude, obtain the differences of declination between it and certain fixed stars situated near him selected for the purpose ; it is then found that Mars appears in a somewhat different position at the same instant among the stars to the different observers, due to their difference of latitude. The distance between the observing stations being known, and the amount of displacement of Mars being measured, the parallax, and hence the distance, are determinate.

There is another advantage in this method by Mars, viz., that the observations need not be confined to a short space of time, as is requisite in the case of Venus, but many repetitions may be made, both as the planet is approaching and receding from opposition, and in combining many observations a greater amount of accuracy is obtained. Were it not for this, the Mars method would claim far less reliability than, with the beautiful graduated instruments now available, it seems entitled to.

This method appears to have been first used for determining the sun's distance, in 1672, when Richer was sent to Cayenne to observe the planet in conjunction with astronomers in Europe; the result obtained gave the sun's distance eighty-six millions of miles; although one-sixteenth less than was subsequently found from its nearer approach to the truth than had hitherto been reached, the value of the method was clearly indicated. Cassini shortly afterwards obtained nearly the same result by observing Mars parallax in right ascension, or its displacement with respect to the stars, due to the distance in space an observatory is moved through during a large portion of the earth's revolution. For, suppose the position of Mars with respect to certain fixed stars, be observed when it is far east of the meridian; when it appears far west of the meridian, the earth will have moved through a considerable amount of space, which can be very easily calculated. Its position with regard to the same stars is then observed, the change in position, combined with base line described by the observatory in the course of the earth's rotation with the motion of Mars in that time, then gives all the data for computing its parallax. A great advantage of this method is, that it can be fully carried out at a single observatory with one observer, but, on the other hand, dependance has to be placed on the absolute stability of the instrument used for many hours, and this is a most difficult condition to obtain in instruments mounted in a way suitable for such observations. Nevertheless, unusual precautions may be taken to secure it, as was done during the late opposition by Mr. Airy, when he most successfully used this method.

The transit of Venus, which took place in 1761, was observed at the Cape of Good Hope and in Lapland; the sun's parallax deduced from the observations was 8″·53, equal to a distance of 95,141,830 miles. For the transit of Venus, of 1769, great efforts were made by most of the

European governments to secure good observations, and expensive expeditions were fitted out for all parts of the world, the celebrated one under command of Captain Cook being dispatched to the South Seas. The transit was fully observed in both hemispheres, the resulting parallax being calculated as 8″·58, corresponding to a distance of 95,023,000 miles. This distance has been accepted up to within the last two or three years. Mr. Airy, however, in a paper read before the Royal Astronomical Society, in May, 1857, stated that great doubts were attachable by many astronomers to this result, inasmuch as "it happened that it depended almost entirely upon the observations made by Father Hell, of Wardhoe, and to these great suspicion has been attached, many having without hesitation designated them as forgeries."

Encke, the well-known astronomer and mathematician, has discussed these observations on the transits of Venus with every possible care, and the numbers given above are the results of his computations ; and all reliance may be placed on their correctness as far as the calculation is concerned, but circumstances have since arisen, apart from the suspicions which some attach to the genuineness of some of the northern observations of these transits, which indicate very strongly that the sun's distance derived from them is too large.

The well-known French philosopher, Foucault, from some recent experiments on the velocity of light, with apparatus from which all uncertainty appears to be excluded, has come to the conclusion that we have hitherto attributed too great a velocity to light, and that instead of 192,000 miles it moves through only 185,170 a second. Now, from eclipses and other phenomena, we know exactly that light takes 8m. 18s. to move from the sun to the earth's surface, from which, by a simple calculation, the sun's distance becomes a little over 92,000,000 of miles, giving a parallax of 8″·86 ; being more than 3,000,000 of miles less than the accepted distance. Again, Mons. Le Verrier, the Director of the Imperial Observatory at Paris, some time since arrived at the conclusion that, in order to satisfy the theory of some of the planetary perturbations, the sun's distance must be diminished, and theoretically assigned, on purely physical grounds, irrespective of instrumental measures, a parallax of 8″·95, equal to a distance of 91,066,350 miles, less, by over 4,000,000 miles, than that previously adopted. I must here anticipate, to draw attention to the singular coincidence, that the purely theoretical determination of the sun's parallax agrees closely with the practical one accomplished during the opposition of Mars, in 1862, the theoretical parallax being 8″·95, while that deduced from the Mars observation here and at Greenwich was 8″.95.

The near approach of Mars to the earth in its opposition of 1862, offered a most favourable opportunity for a determination of the sun's distance, more especially as several southern observatories had become possessed of graduated instruments of the highest class, and their geographical positions much more exactly known than at previous favourable oppositions.

Our Observatory, geographically speaking, was most favourably situated to co-operate with the great European observatories in this interesting undertaking, for between here and Greenwich is included a base line of nearly twice the earth's radius ; and fortunately a few months prior to receiving a request from Europe to join in the work, our beautiful transit circle arrived, which placed the Observatory in the position of doing so on more equal terms with our friends at the antipodes.

The Observatory, too, at the Cape of Good Hope was well situated, and ready with its magnificent instrumental appliances to take the lead in the Southern Hemisphere. The Observatory at Santiago, in Chili, under Dr. Moesta, also lent its aid. Unfortunately, the Sydney Observatory had lost its astronomer, in the retirement of Mr. Scott, or Australia might have claimed even a greater share of the honour of helping in this great work.

The observatories of Greenwich, Pulkowa, and Washington were the principal northern ones which shared in the undertaking.

The correspondence from Greenwich, Pulkowa, and Washington, in which our co-operation was asked, had furnished the necessary directions to secure proper concert in observing, so that at the commencement of the arranged period all possible precautions to secure success at our Observatory had been made. The whole series of observations, extending from August 25th to November 16th, were obtained most satisfactorily. Out of the allotted period, eighty-nine nights, Mars and its companion stars were observed on sixty-six nights, which, considering the great prevalence of cloudy weather during that portion of the year, was more than was expected. The Cape Observatory was less fortunate, and I believe that our Observatory obtained, by a considerable amount, the largest number of observations.

The sun's parallax, derived from the combination of the results obtained at Greenwich with those of our Observatory, was 8″·93, while from the combination of those at the Cape with the Pulkowa observations gave 8″·96.

It is a matter of the highest scientific interest that the results arrived at by the co-operation of these four observatories should correspond so nearly with each other, so exactly with those deduced theoretically by Mons. Le Verrier, and so nearly approaches that arrived at by another distinct method by Faucoult, viz., from his experiments on the velocity of light.

The distance of the sun arrived at from the Williamstown and Greenwich observations is, according to Mr. Stones', (of Greenwich,) calculation, 91,512,649 miles, or over 3,000,000 of miles less than has hitherto been assumed.

In conclusion, I may remark that satisfactory in the highest degree as these results appear to be, astronomers are looking forward to the transit of Venus, in 1874, to ratify them or to determine with greater exactitude than the Mars method is susceptible of, the more precise amount by which our hitherto accepted distances of the sun requires to be diminished.

This transit of Venus will take place soon after mid-day, on December 9th, 1874. Melbourne is admirably situated for observing it. European astronomers are already taking steps to secure proper co-operation in the Southern Hemisphere, and I trust that our Observatory, so liberally furnished with some of the finest instruments in the world, will do as well for science, and for the credit of Victoria, as it was permitted to do in the determination of the Sun's distance, in 1862.

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## ART. XXXII.—*Notes on the Geology of Hobart Town.*

By THOMAS HARRISON.

[Abstract. Read 8th August, 1864.]

Tasmania is, as it were, connected with Victoria by two chains of islands, running in a northerly direction, respectively, from Cape Portland and Cape Grimm to Wilson's Promontory and Cape Otway. The lines of these two chains are afterwards continued in the several mountain systems of Tasmania and Australia.