Solar and Sidereal Time

ON THE CONNECTION OF THE PHYSICAL SCIENCES

Pgs. 77-81

BY MARY SOMERVILLE

Astronomy has been of immediate and essential use in affording invariable standards for measuring duration, distance, magnitude, and velocity. The mean sidereal day measured by the time elapsed between two consecutive transits of any star at the same meridian, and the mean sidereal year, which is the time included between two consecutive returns of the sun to the same star, are immutable units with which all great periods of time are compared; the oscillations of the isochronous pendulum measure its smaller portions. By these invariable standards alone we can judge of the slow changes that other elements of the system may have undergone. Apparent sidereal time, which is measured by the transit of the equinoctial point at the meridian of any place, is a variable quantity, from the effects of precession and nutation. Clocks showing apparent sidereal time are employed for observation, and are so regulated that they indicate 0h 0m 0" at the instant the equinoctial point passes the meridian of the observatory. And as time is a measure of angular motion, the clock gives the distances of the heavenly bodies from the equinox by observing the instant at which each passes the meridian, and converting the interval into arcs at the rate of 15° to an hour.

The returns of the sun to the meridian and to the same equinox or solstice, have been universally adopted as the measure of our civil days and years. The solar or astronomical day is the time that elapses between two consecutive noons or midnights. It is consequently longer than the sidereal day, on account of the proper motion of the sun during a revolution of the celestial sphere. But as the sun moves with greater rapidity at the winter than at the summer solstice, the astronomical day is more nearly equal to the sidereal day in summer than in winter. The obliquity of the ecliptic also affects its duration; for near the equinoxes the arc of the equator is less than the corresponding arc of the ecliptic, and in the solstices it is greater (N. 145). The astronomical day is therefore diminished in the first case, and increased in the second. If the sun moved uniformly in the equator at the rate of 59' 8"-33 every day, the solar days would be all equal. The time therefore which is reckoned by the arrival of an imaginary sun at the meridian, or of one which is supposed to move uniformly in the equator, is denominated mean solar time, such as is given by clocks and watches in common life. When it is reckoned by the arrival of the real sun at the meridian it is apparent time, such as is given by dials. The difference between the time shown by a clock and a dial is the equation of time given in the Nautical Almanac, sometimes amounting to as much as sixteen minutes. The apparent and mean time coincide four times in the year; when the sun's daily motion in right ascension is equal to 59' 8"-33 in a mean solar day, which happens about the 16th of April, the 16th of June, the 1st of September, and the 25th of December.

The astronomical day begins at noon, but in common reckoning the day begins at midnight. In England it is divided into twenty-four hours," which are counted by twelve and twelve; but in France astronomers, adopting the decimal division, divide the day into ten hours, the hour into one hundred minutes, and the minute into a hundred seconds, because of the facility in computation, and in conformity with their decimal system of weights and measures. This subdivision is not now used in common life, nor has it been adopted in any other country; and although some scientific writers in France still employ that division of time, the custom is beginning to wear out. At one period during the French revolution, the clock in the gardens of the Tuileries was regulated to show decimal time. The mean length of the day, though accurately determined, is not sufficient for the purposes either of astronomy or civil life. The tropical or civil year of 365d 5h 48m 49s-7, which is the time elapsed between the consecutive returns of the sun to the mean equinoxes or solstices, including all the changes of the seasons, is a natural cycle peculiarly suited for a measure of duration. It is estimated from the winter solstice, the middle of the long annual night under the north pole. But although the length of the civil year is pointed out by nature as a measure of long periods, the incommensurability that exists between the length of the day and the revolution of the sun, renders it difficult to adjust the estimation of both in whole numbers. If the revolution of the sun were accomplished in 365 days, all the years would be of precisely the same number of days, and would begin and end with the sun at the same point of the ecliptic. But as the sun's revolution includes the fraction of a day, a civil year and a revolution of the sun have not the same duration. Since the fraction is nearly the fourth of a day, in four years it is nearly equal to a revolution of the sun, so that the addition of a supernumerary day every fourth year nearly compensates the difference. But in process of time further correction will be necessary, because the fraction is less than the fourth of a day. In fact, if a bissextile be suppressed at the end of three out of four centuries, the year so determined will only exceed the true year by an extremely small fraction of a day; and if in addition to this a bissextile be suppressed every 4000 years, the length of the year will be nearly equal to that given by observation. Were the fraction neglected, the beginning of the year would precede that of the tropical year, so that it would retrograde through the different seasons in a period of about 1507 years. The Egyptian year began with the heliacal rising of Sirius, and contained only 365 days, by which they lost one year in every 1461 years, their Sothaic period, or that cycle in which the heliacal rising of Sirius passes through the whole year and takes place again on the same day. The commencement of that cycle is placed by ancient chronologists in the year 1322 before the Christian era. The division of the year into months is very old and almost universal. But the period of seven days, by far the most permanent division of time, and the most ancient monument of astronomical knowledge, was used by the Brahmins in India with the same denominations employed by us, and was alike found in the calendars of the Jews, Egyptians, Arabs, and Assyrians. It has survived the fall of empires, and has existed among all successive generations, a proof of their common origin.

The day of the new moon immediately following the winter solstice in the 707th year of Rome, was made the 1st of January of the first year of Julius Caesar. The 25th of December of his forty-fifth year is considered as the date of Christ's nativity; and the forty-sixth year of the Julian Calendar is assumed to be the first of our era. The preceding year is called the first year before Christ by chronologists, but by astronomers it is called the year 0. The astronomical year

begins on the 31st of December at noon; and the date of an observation expresses the days and hours which have actually elapsed since that time.

Since solar and sidereal time are estimated from the passage of the sun and the equinoctial point across the meridian of each place, the hours are different at different places: while it is one o'clock at one place it is two at another, three at another, &c.; for it is obvious that it is noon at one part of the globe, at the same moment that it is midnight at another diametrically opposite to it; consequently an event which happens at one and the same instant of absolute time is recorded at different places, as having happened at different times. Therefore, when observations made at different places are to be compared, they must be reduced by computation to what they would have been had they been made under the same meridian. To obviate this, it was proposed by Sir John Herschel to employ mean equinoctial time, which is the same for all the world, and independent alike of local circumstances and inequalities in the sun's motion. It is the time elapsed from the instant the mean sun enters the mean vernal equinox, and is reckoned in mean solar days and parts of a day.

NOTE 145, p. 78. Let N be the pole, fig. 11, e E the ecliptic, and Q φ the equator. Then N n m S being a meridian, and at right angles to the equator, the arc Υ m is less than the arc Υ n.

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CONVERSATIONS ON NATURAL PHILOSOPHY

Pgs. 121-124

BY JANE MARCET

Mrs. B. … I have but one more observation to make to you relative to the earth's motion, which is, that although we have but 365 days and nights in the year, she performs 366 complete revolutions on her axis during that time.

Caroline. How is that possible 1 for every complete revolution must bring the same place back to the sun. It is now just twelve o'clock, the sun is, therefore, on our meridian; in twenty-four hours will it not be returned to our meridian again? and will not the earth have made a complete rotation on its axis!

Mrs. B. If the earth had no progressive motion in its orbit whilst it revolves on its axis, this would be the case; but as it advances almost a degree westward in its orbit, in the same time that it completes a revolution eastward on its axis, it must revolve nearly one degree more in order to bring the same meridian back to the sun.

Caroline. Oh, yes! it will require as much more of a second revolution to bring the same meridian back to the sun, as is equal to the space the earth has advanced in her orbit, that is, nearly a degree-; this difference is, however, very little.

Mrs. B. These small daily portions of rotation are each equal to the three hundred and sixty-fifth part of a circle, which at the end of the year amounts to one complete rotation.

Emily. That is extremely curious. If the earth, then, had no other than its diurnal motion, we should have 366 days in the year.

Mrs. B. We should have 366 days in the same period of time that we now have 365; but if we did not revolve round the sun, we should have no natural means of computing years. You will be surprised to hear, that if time is calculated by the stars instead of the sun, the irregularity which we have just noticed does not occur, and that one complete rotation of the earth on its axis, brings the same meridian back to any fixed star.

Emily. That seems quite unaccountable; for the earth advances in her orbit with regard to the fixed stars the same as with regard to the sun.

Mrs. B. True, but then the distance of the fixed stars is so immense, that our solar system is in comparison to it but a spot, and the whole extent of the earth's orbit but a point; therefore, whether the earth remained stationary, or whether it revolved in its orbit during its rotation on

its axis, no sensible difference would be produced with regard to the fixed stars. One complete revolution brings the same meridian back to the same fixed star; hence the fixed stars appear to go round the earth in a shorter time than the sun by three minutes, fifty-six seconds of time.

Caroline. These three minutes, fifty-six seconds is the time which the earth takes to perform the additional three hundred and sixty-fifth part of the circle, in order to bring the same meridian back to the sun.

Mrs. B. Precisely. Hence the stars gain every day three minutes, fifty-six seconds on the sun, which makes them rise that portion of time earlier every day. When time is calculated by the stars it is called sidereal time, when by the sun, solar or apparent time. *

Caroline. Then a sidereal day is three minutes, fifty-six seconds shorter than a solar day of twenty-four hours.

Mrs. B. I must also explain to you what is meant by a sidereal year. The common year, called the solar or tropical year, containing 365 days, five hours, forty-eight minutes, and fifty-two seconds, is measured from the time the sun sets out from one of the equinoxes, or solstices, till it returns to the same again; but this year is completed before the earth has finished one entire revolution in its orbit. * If one clock should be so well regulated as to show the time to be XII at noon this day, and on the 365th day afterward; and another clock should be so well regulated as to show the time to be XII every day or night when any given star is on the meridian, the latter clock would gain three minutes, fifty-five seconds, and fifty-four sixtieth parts of a second upon the former in each revolution of the same star to the meridian.

Emily. I thought that the earth performed one complete revolution in its orbit every year; what is the reason of this variation?

Mrs. B. It is owing to the spheroidal figure of the earth. The elevation about the equator produces much the same effect as if a similar mass of matter, collected in the form of a moon, revolved round the equator. "When this moon acted on the earth in conjunction with or in opposition to the sun, variations in the earth's motion would be occasioned, and these variations produce what is called the precession of the equinoxes.

Emily. What does that mean? I thought the equinoctial points, or nodes, were fixed points in the heavens, in which the equator cuts the ecliptick.

Mrs. B. These points are not quite fixed, but have an apparently retrograde motion, that is to say, instead of being every revolution in the same place, they move backwards. Thus if the vernal equinox is at A, (fig. 1, plate XI.) the autumnal one will be at B instead of at C, and the following vernal equinox at D instead of at A, as would be the case if the equinoxes were stationary at opposite points of the earth's orbit.

Caroline. So that when the earth moves from one equinox to the other, though it takes half a year to perform the journey, it has not travelled through half its orbit.

Mrs. B. And, consequently, when it returns again to the first equinox, it has not completed the whole of its orbit. In order to ascertain when the earth has performed an entire revolution in its orbit, we must observe when the sun returns in conjunction with any fixed star; and this is called a sidereal year. Supposing a fixed star situated at E, (fig. 1, plate XI.) the sun would not appear in conjunction with it till the earth had returned to A, when it would have completed its orbit.

Emily. And how much longer is the sidereal than the solar year?

Mrs. B. Only twenty minutes; so that the variation of the equinoctial points is very inconsiderable. I have given them a greater extent in the figure in order to render them sensible. In regard to time, I must further add, that the earth's diurnal motion on an inclined axis, together with its annual revolution in an elliptick orbit, occasions so much complication in its motion, as to produce many irregularities; therefore, true equal time cannot be measured by the sun. A clock, which was always perfectly correct, would in some parts of the year be before the sun, and in other parts after it. There are but four periods in which the sun and a perfect clock would agree, which is the I5th of April, the 16th of June, the 23d of August, and the 24th of December.

Emily. And is there any considerable difference between solar time and true time?

Mrs. B. The greatest difference amounts to between fifteen and sixteen minutes. Tables of equation are constructed for the purpose of pointing out and correcting these differences between solar time and equal or mean time, which is the denomination given by astronomers to true time.

496. To what is it owing that the earth performs 366 revolutions in a year that has but 365 days and nights? 497. Under what circumstances should we have 366 days in the same period of time that we now have 365? 498. In what way might time be calculated so as to avoid this irregularity? 499. Why do the fixed stars appear to revolve round the earth quicker than the sun? 500. How much quicker than the sun do the fixed stars appear to go round the earth? 501. When is time called sidereal, and when solar or apparent time? 502. What illustration is given of this in the note? 503. What is the common or solar year? 504. What is the reason that the solar year is completed before the earth has made one entire revolution in its orbit? 505. What is called the precession of the equinoxes, and how is it produced? 506. How would you explain the precession of the equinoxes by the figure? 507. How can it be ascertained when the earth has performed one entire revolution in its orbit? 508. What is a sidereal year? 509. How much longer is the sidereal than the solar year? 510. What are the periods, when the sun and a perfect clock agree? 511. What is the greatest difference between solar time and true time?

Fig. 1.

Fig 2