ON SOME POINTS IN THE EARLY HISTORY OF ASTRONOMY.[1]

IV.

FROM what has been stated it is not too much to assume that the Egyptians observed the sun on the horizon. This being so, the chances are that at first they would observe the stars on the horizon too, both stars rising and stars setting; and that is rendered more probable by the very careful way in which early astronomers defined the various conditions under which a star can rise or set, always, be it well remembered, in relation to the sun. They spoke of a star as rising or setting achronically, heliacally, or cosmically.

The cosmic rising meant that the star rose, and the cosmic setting meant that the star set, at the same moment as the sun—that is, that along the eastern horizon we should see the star rising at the moment of sunrise, or along the western horizon a star setting at the moment of the sun setting. The achronical rising is different from the cosmic in this respect—that we have the star rising when the sun is setting and setting when the sun is rising. Finally we have the heliacal rising and setting; that is taken to be that the star appeared in the morning a little in advance of the sunrise, or set at twilight a little later than the sun. The following table from Biot[1] should make matters quite clear:—

Star at eastern horizon.	Rising.	Morning.	True or cosmic.	Sun rising.
			Apparent or heliacal.	Sun not yet risen, but depressed below horizon sufficiently to enable the star to be seen.
		Evening.	True or achronic.	Sun setting.
			Apparent or heliacal.	Sun just set, and depressed below horizon sufficiently to enable the star to be seen.
Star at western horizon.	Setting.	Evening.	True or cosmic.	Sun setting.
			Apparent or heliacal.	Sun set, and depressed below horizon sufficiently to enable the star to be seen.
		Morning.	True or achronic.	Sun rising.
			Apparent or heliacal.	Sun not yet risen, but depressed below horizon sufficiently to enable the star to be seen.

It is Ideler's opinion that, in Ptolemy's time, in the case of stars of the first magnitude, for heliacal risings and settings, if the star and sun were on the same horizon a depression of 11° was taken; if on opposite horizons a depression of 7°. For stars of the second magnitude, these values were 14° and 8½.° But if temples were employed as I have suggested, even cosmic and achronic risings and settings could be observed in the case of the brightest stars.

Before we begin to consider the question of stars at all, we must be able to describe them, to speak of them in a way that shall define exactly what star is meant. We can in these days define a star according to its constellation or its equatorial or ecliptic co-ordinates, but all these means of reference were unknown to the earliest observers; still we may assume that the Egyptians could define some of the stars in some fashion, and it is evident that we here approach a matter of the very highest importance for our subject.

So far, as we have been dealing with the sun and the observations of the sun at rising and setting, we have taken for granted that the amplitude of the sun at the solstices does not change; the amplitude of 26° at Thebes, for the solstices, is practically invariable for a thousand years; but one of the results of astronomical work is that the *stars* are known to behave quite differently. In consequence of what is called precession the stars change their place with regard to the pole of the heavens, and further, in consequence of this movement, the position of the sun among the stars at the solstices and equinoxes changes also.

In the last lecture we considered what were called the ecliptic and the equatorial co-ordinates. The ecliptic was the plane in which the earth moves round the sun, and 90° from that plane we had the pole of the heavens; celestial latitude we found reckoned from the plane of the ecliptic north and south up to the pole of the heavens, and celestial longitude we reckoned along the plane of the ecliptic from the first point of Aries. We had also declination reckoned from the equator of the earth prolonged to the stars, and right ascension reckoned along the equator from the first point of Aries. The pole of the heavens then we must regard as fixed, but the pole of the earth is not fixed, but slowly moves round it. *In consequence of that movement there is a change of declination in a star's place.*

Going back to the tables, we find that the amplitude of a body rising or setting at Thebes or anywhere else depends upon its declination, so that if from any cause the declination of a star changes, its amplitude must change at any particular place.

That is the first point where we meet with difficulty, because if the amplitude changes it is the same as saying that the place of star rising or star setting changes; that is, a star which rose in the east in a certain amplitude this year will change its amplitude at some future time.

The real cause of the precession of the stars lies in the fact that the earth is not a sphere, its equatorial diameter being longer than its polar diameter, so that there is a mass of matter round the equator in excess of what we should get if the earth were spherical. Suppose that matter to be represented by a ring. The ring is differently presented to the sun, one part being nearer than the other, the nearer part being attracted more forcibly. If we take the point where there is the greatest attraction, and draw a line to the least, we can show that the case stands in this way: that the sun's pull may be analyzed into two forces, one of them between the sun and the point in a direction parallel to the line joining the centre of the sun and the centre of the

[1] Continued from p. 60.

[1] Biot, "Traité élémentaire d'Astronomie physique," 3rd edition, vol. iv. p. 625.

ring, and another force at right angles to it. The question is, what will that force at right angles do?

Here we have a model showing the rotation of the earth on its axis, and the concurrent revolution of the sun round the earth once a year. To represent the downward pull it is perfectly fair if I add a weight. Then the earth's axis, instead of retaining its direction to the same point as it did before, is now describing a circle round the pole of the heavens. It is now a recognized principle that there is, so to speak, a wobble of the earth's axis round the pole of the heavens in consequence of the attraction of the sun on the nearer point of this equatorial ring being greater than on the part of the equatorial ring removed from it. That precession movement is not quite so simple as it is shown by this model, because what the sun does in this way is done to a very much larger extent by the moon, the moon being so very much nearer to us.

In consequence, then, of this luni-solar precession we have a variation of the points of intersection of the planes of the earth's equator and of the ecliptic; in consequence of that we have a difference in the constellations in which the sun is at the time of the solstices and at the equinoxes; and, still more important, we have another difference, viz. that the declinations, and therefore the amplitudes, and therefore the places of setting and rising of the stars, change from century to century.

Having thus become acquainted with the physical cause of that movement of the earth's axis which gives rise to what is called the precession of the equinoxes, we have next to inquire into some of the results of the movement. The change of direction of the axis in space has a cycle of something between 25,000 and 26,000 years. As it is a question of the change of the position of the celestial equator, or rather of the pole of the celestial equator, amongst the stars in relation to the pole of the heavens, of course the declinations of stars will be changed to a very considerable extent; indeed, we easily see that the declination of a star can vary by twice the amount of the obliquity, or 47°, so that a star at one time may have zero declination—that is, it may lie on the equator—and at another it may have a declination of 47° N. or S. Or, again, a star may be the pole star at one particular time, and at another it will be distant from the pole no less than 47°. Although we get this enormous change in one equatorial co-ordinate, there would from this cause alone be practically no change with regard to the corresponding ecliptic co-ordinate—that is to say, the position of the star with reference to the earth's movement round the sun. This movement takes place quite independently of the direction of the axis, so that while we get this tremendous swirl in declination, the latitudes of the stars or their distance from the ecliptic north or south will scarcely change at all.

Among the most important results of these movements dependent upon precession we have the various changes in the pole star from period to period, due to the various positions occupied by the pole of the earth's equator. We thus see how in this period of 25,000 years or thereabouts the pole stars will change, for a pole star is merely the star near the pole of the equator for the time being. At present, as we all know, the pole star is in the constellation Ursa Minor. During the last 25,000 years the pole stars have been those lying nearest to a circle struck from the pole of the heavens with a radius of $23\frac{1}{2}°$, which is equal to the obliquity of the ecliptic; so that about 10,000 or 12,000 years ago the pole star was no longer the little star in Ursa Minor that we all know, but the big star Vega in the constellation Lyra. Of course 25,000 years ago the pole star was practically the same as it is at present.

Associated with this change of the pole star there is another matter of the highest importance to be considered, because as the axis is being drawn round in this way, the point of intersection of the two fundamental planes, the plane of the earth's rotation and the plane of the earth's revolution, will be liable to change, and the period will be the same, about 25,000 years. Where these two planes cut each other we have the equinoxes, because the intersection of the planes defines for us the vernal and the autumnal equinoxes; when the sun is highest and lowest between these points we have the solstices. In a period of 25,000 years the star which is nearest to the equinox will return to it, and that which is nearest the solstice will return to it. During the period there will be a constant change of stars marking the equinoxes and the solstices.

The chief points in the sun's yearly path then will change among the stars in consequence of this precession. It is perfectly clear that if we have a means of calculating back the old positions of stars, and if we have any very old observations, we can help matters very much, because the old observations—if they were accurately made—would tell us that such and such a star rose with the sun at the solstice or at the equinox at some special point of ancient time. If it be possible to calculate the time at which that star occupied that position with regard to the sun, we have an astronomical means of determining the time, within a few years, at which that particular observation was made.

Very fortunately we have such a means of calculation, and it has been employed very extensively at different periods, chiefly by M. Biot in France, and quite recently by German astronomers, in calculating the positions of the stars from the present time to a period of 2000 years B.C. We can thus determine with a very high degree of accuracy, the latitude, longitude, right ascension, declination, and the relation of the stars to an equinox, a solstice, or a pole, as far back as 2000 years B.C. Since we have the planes of the equator and ecliptic cutting each other at different points in consequence of the cause which I have pointed out—the attraction of the sun and moon—we have a fixed equator and a variable equator depending upon that. In consequence of the attraction of the planets upon the earth, the plane of the ecliptic itself is not fixed, so that we have not only a variable equator but also a variable ecliptic. What has been done in these calculations is to determine the relations and the results of these variations.

A simpler, though not so accurate a method, consists in the use of the precessional globe, one of which I have here. In this we have two fixed points at the part of the globe representing the poles of the heavens, on which the globe may be rotated; when this is done the stars move absolutely without any reference to the earth or to the plane of the equator, but purely with reference to the ecliptic. We have, then, this globe quite independent of the earth's axis. How can we make it dependent upon the earth's axis? We have two brass circles at a distance of $23\frac{1}{2}°$ from each pole of the heavens (north and south), these represent the circle described by the pole of the earth in the period of 26,000 years. In these circles are 24 holes in which I can fix two additional clamping screws, and rotate the globe with respect to them by throwing out of gear the two points which produced the ecliptic revolution. If I use that part of the brass circle which is occupied by our present pole star, we get the apparent rotation of the heavens with the earth's axis pointing to the present pole star.

If we wish to investigate the position of things, say 8000 years ago, we bring the globe back again to its bearings, and then adjust the screws into the holes in the brass circles which are proper for that period. When we have the globe arranged to 6000 years B.C. (*i.e.* 8000 years ago), in order to determine the equator at that time all we have to do is to paint a line on the globe in some water-colour, by holding a camel's hair pencil at the east or west point. That line represents the equator 8000 years ago. Having that line, of course the intersection of the equator with the ecliptic will give us the equinoxes, so that we may affix a wafer to represent the vernal equinox. Or if we take that part of the ecliptic which is nearest to the north pole and therefore the declination of which is greatest, viz. $23\frac{1}{2}°$ N., we have there the position of the sun at the summer solstice, and $23\frac{1}{2}°$ S. will give us the position of the sun at the winter solstice. So by means of such a globe as this it is quite possible to determine the position of the equator among the stars, and note those four important points in the solar year, the two equinoxes and the two solstices. I have taken a period of 8000 years, but I might just as easily have taken a greater or a smaller number. By means of this arrangement, therefore, we can determine within a very small degree of error without any laborious calculations, the distance of any body north or south of the equator, *i.e.* its declination.

The positions thus found, say, for intervals of 1000 years, may be plotted on a curve, so that we can, with a considerable amount of accuracy, obtain the star's place for any year. Thus the globe may be made to tell us that in the year 1000 A.D. the declination of Fomalhaut was 35° S., in 1000 B.C. it was 42°, in 2000 it was about 44°, in 4000 it was a little over 42° again, but in 6000 B.C. it had got up to about 33°, and in 8000 B.C. to about 22°.

The curve of Capella falls from 41° N. at 0 A.D., to 10° at 6000 B.C., so we have in these 6000 years in the case of this star run through a large part of that variation to which I drew your attention.

Here is the curve of Sirius. This star, in 0 A.D., had a declination of 24° S.; but 5000 years B.C. it had a declination of something like $31\frac{1}{2}°$. In Sirius we have the curve plotted from the computations of Mr. Hind, who has kindly placed them at my disposal. From other computations supplied by him, I have ascertained that the globe is a very good guide indeed within something like 1° of declination, always assuming that the star has no great proper motion. Considering the difficulty of the determination of amplitudes in the case of buildings, it is clear that the globe may be utilized with advantage, at all events in the first instance.

Now that we are familiar with the effect of the precession of the equinoxes in changing the amplitudes of the rising and setting places of stars, we can return to the consideration of the temples. So far, we have considered those built in relation to the sun, in the case of which body there is, of course, no precessional movement, so that a temple once oriented to the sun would remain so for a long time. After some thousands of years, however, the change in the obliquity of the ecliptic would produce a small change in the amplitude of a solstice.

Suppose we take, as before, that region of the earth's surface in the Nile valley with a latitude of about 26° N. The temples there built to observe the sun will have an east and west aspect true if they have anything to do with the sun at the equinoxes, and will have an amplitude of about 26° N. or S. if they have anything to do with the sun at the solstices.

The archæologists who have endeavoured to investigate the orientations of these buildings have found that they practically face in all directions; the statement is that their arrangement is principally characterized by the want of it; they have been put down higgledy-piggledy; there has been a symmetrophobia, mitigated by a general desire that the temple should face the Nile. This view may be the true one, if stars were not observed as well as the sun; for at Thebes, if any temple have an amplitude more than 26° N. or S. of E. or W., it cannot by any possibility have been used, as we have seen the temples at Karnak might have been used, for observations of the sun; for since the maximum declination of the sun is almost $24\frac{1}{2}°$ (it is at present only $23\frac{1}{2}°$), represented by an amplitude of 27°, no temple oriented in a direction more northerly or more southerly could get the light of the sun along its axis.

Let us see, then, if the builders of them had any idea in their minds connected with astronomy. If they had, we may conclude that there was some purpose of utility to be served, as the solar temples were used undoubtedly, among other things, for determining the exact length of the solar year. When we come to examine these non-solar temples, the first question is, Do they resemble in construction the solar ones? Are the horizontal telescope conditions retained? The evidence on this point is overwhelming. Take the temple of Denderah. It points very far away from the sun; the sun's light could never have enfiladed it. In many others pointing well to the north or south, the axis extends from the exterior pylon to the Sanctuary or Naos which is found always at the closed end of the temple. We have the same number of pylons, gradually getting narrower and narrower as we get to the Naos, and in some there is a gradual rise from the first exterior pylon to the part which represents the section of the Naos, so that a beam of horizontal light coming through the central door might enter it over the heads of the people flocking into the temple, and pass uninterruptedly into the Sanctuary.

In these, as at Karnak, you see we have this collimating axis. We have the other end of the temple blocked; we have these various diaphragms or pylons, so that, practically, there is absolutely no question of principle of construction involved in this temple that was not involved in the great solar temple at Karnak itself.

We made out that in the case of the temples devoted to sun-worship, and to the determination of the length of the year, there was very good reason why all these attempts should be made to cut off the light, by all these diaphragms and stone ceilings, because, among other things, one wanted to find the precise point occupied by the sunbeam on the two or three days near the winter and summer solstices in order to determine the exact moment of the solstice.

But if a temple is not intended to observe the sun, why these diaphragms? Why keep the astronomer, or the priest, so much in the dark? There is a very good reason indeed; because the truer the orientation of the temple to the star, and the greater the darkness he was kept in, the sooner would he catch the rising star. In the first place, the diaphragms would indicate the true line that he had to watch; he would not have to *search* for the star which he expected; and obviously the more he was kept in the dark the sooner could he see the star.

The next point that I have to make is that in the case of some of these temples which are not directed to the sun we get exactly the same amplitudes in different localities. To show this clearly it will be convenient to bring together the chief temples near Karnak and those having the same amplitudes elsewhere.

We can do this by laying down along a circle the different amplitudes to which these various temples point. To begin with, I will draw your attention to those temples which we have already discussed with an amplitude of 27° or 26°, at Abydos, Thebes, and Karnak. Next we have non-solar amplitudes at Karnak and Thebes, associated with temples having the same amplitude at Denderah, Abydos, and other places. We have the majority of the non-solar temples removed just as far as they can be in amplitude from the solar ones, for the reason that they are as nearly as possible *at right angles* to them. We have temples with the same amplitudes high north and high south, in different places—temples, therefore, which could not have been built with reference to the sun; just as we have at different places temples with the same amplitudes which *could* have been used for solar purposes.

In connection with the possible astronomical uses of these temples, I find that when one of these temples has been built, the horizon has always been very carefully left open; there has always been a possibility of vision along the collimating axis prolonged. Lines of sphinxes have been broken to ensure this; at Medinet Abou, on the opposite side of the river to Karnak, we have outside this great temple a model of a Syrian fort. If we prolong the line of the temple from the middle of the Naos through the systems of pylons, we find that in the model of the fort an opening was left, so that the vision from the Sanctuary of the temple was left absolutely free to command the horizon.

It may be said that that cannot be true of Karnak, because we see on the general plan that one of the temples, with an azimuth of 71° N., had its collimating axis blocked by numerous buildings. That is true; but when one comes to examine into the date of these buildings, it is found that they are all very late; whereas there is evidence that the temple was one of the first, if not the very first, of the temples built at Thebes.

Mariette spent a long time in examining the temple of Karnak. His idea is that the part of the temple near the Sanctuary represents the first part of the building; and at that time the great temple of Karnak—enormous though it is now—was so small and entirely out of the way of the line of the axis of the temple of Maut that its existence might have been entirely neglected. There was first a square court like the court of the Tabernacle, and very shortly after that a very laboured system of pylons was introduced to restrict the light. The next stage shows the Sanctuary thrown back away from the court; then, after that, more complication is introduced by the addition of pylons, until finally, after two or three extensions, the length of the temple was quadrupled. So that the proof is positive that at first the horizon of the temple of Maut was left perfectly clear. Why it was subsequently blocked I shall suggest afterwards.

The next point to be noticed is that there is in very many cases a rectangular arrangement, so that if the sun were observed in one temple and a star in the other, there would be a difference of 90° between the position of the sun and the position of the star at that moment. This would, of course, apply also to two stars. Sometimes this rectangular arrangement is in the same temple, as at Karnak, sometimes in an adjacent one, as at Denderah.

If we look at Denderah we find that we have there a large temple inclosed in a square *temenos* wall, the sides of which are parallel to the sides of the temple; and also a little temple at right angles to the principal one.

It is hardly fair to say that a rectangular arrangement, repeated in different localities, is accidental; it is one which is used to some extent in our modern observatories.

The perpetual recurrence of these rectangular temples shows, I think, that in all the pairs of temples which are thus represented, there was some definite view in the minds of those who built them.

Another point is that, when we get some temples pointing a certain number of degrees south of east, we get other temples pointing the same number of degrees south of west, so that some temples may have been used to observe risings and others settings of stars in the same declination. It is then natural of course to conclude that these temples were arranged to observe the rising and setting of the same stars.

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(*To be continued.*)

BOTANICAL ENTERPRISE IN THE WEST INDIES.

WE have several times had occasion to mention the mission of Mr. D. Morris, the Assistant Director of the Royal Gardens, Kew, to the West Indies, in connection with the extension and organization of botanical stations in the British colonies of that region; and the *Kew Bulletin* for May and June, as we have already noted, contains his report thereon. It is a lengthy and interesting document, from which we propose to extract some particulars that may be welcome to our readers, and serve to put on record the reviving enterprise in the development of the natural resources of that part of the Empire. The primary object of Mr. Morris's visit was to settle the practical details of a scheme for establishing and administering a number of smaller botanical gardens in connection with the larger gardens of Trinidad and Jamaica. The main purpose of these gardens is to raise plants of economic value, suitable for cultivation in the various islands, "and to do all that is possible to encourage a diversified system of cultural industries, and thus relieve the planters from the results inevitable from the fluctuations of prices in the one or two staples to which they have hitherto confined their attention"; but they will also be made, as far as possible, pleasant places of public resort. Mr. Morris met with a hearty reception everywhere, and great interest was manifested in the work by the negro freeholders, in some of the islands, as well as the English colonists. The men in charge of these experimental stations, as they may be called, rather than botanical gardens, are mostly trained men from Kew; and Kew is the centre from which plants and seeds of economic plants likely to succeed in the West Indies are distributed. Mr. Morris left Kew in November last, and returned home at the end of February. Advantage was taken of his outward journey to send by the same ship, under his immediate supervision, a number of Wardian cases filled with Gambier plants. Gambier, it may be added, is the name of a substance used in tanning, obtained from *Uncaria Gambier*, Roxb.; and the plants had been raised at Kew from seeds received from the Straits Settlements, several attempts to introduce plants from the East having failed. How the plants were successfully carried to the West Indies we learn from the following passage in the report:—

"Owing to the cold weather, the cases containing the plants on board the *Atrato* were placed below in the main saloon. There was very little direct light in the daytime, but the question of warmth was for the moment of more importance than that of light. It was also hoped that they could be placed on deck in a day or two at the most. The weather during the whole of the first week, however, continued very cold, and it was impossible to expose the plants on deck. Under these circumstances it was fortunate that the electric light, with which every part of the ship was supplied, was available to try an experiment of some interest. Although the plants received very little light during the day, they had a good supply of the electric light during the night, and the plants in the cases more fully exposed to the electric light were afterwards found to be in a much better condition than the others. It is well known that plants will thrive under the influence of artificial light, but in this instance there was so little direct light available during the day, that the plants had to depend almost entirely on the light they received at night. The Gambier plants are particularly sensitive as regards a diminution of light. During the prevalence of fogs at Kew they have been known to drop their leaves within a day or two, and to remain bare during the rest of the winter. This may have been, in some measure, also due to the injurious influence of the fog itself.

"The use of electric light for the safe transit of such valuable plants as are obliged to be despatched from this country during the winter months is evidently capable of being greatly extended. It may also be utilized in the case of tropical plants arriving in this country from abroad, during the prevalence of cold weather. Such plants could be placed below directly the weather is