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Introductory lecture

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- E.S. Kennedy (p.6)

E.S.Kennedy examining books displayed at the astronomical exhibition which was organized during the Colloquium.

1 INTRODUCTORY LECTURE

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When I undertook to serve as Chairman of the Programme Committee for this meeting, I was consoled with the reflection that,in my capacity as Chairman,I would be able to arrange that I should not make a speech and I took steps along these lines. But upon my arrival in Delhi, I was presented with a programme on which my name appeared as speaker. Well, so be it. I will attempt a survey of ancient and mediaeval astronomy.

In the programme, the title says Oriental astronomy. But if we delete (which we should not) the fundamental Hellenistic contribution, then we can forget the adjective. We can say that ancient and mediaeval astronomy was all oriental. Now, in essaying these remarks, I am subject to at least two contraints, the first being clearly that I may not speak except about the branches of the subject of which I have some personal knowledge. And the consequence is that I can say nothing about Chinese astronomy, which is a pity, and for which I apologise to the colleagues from China. And secondly, from birth I have been endowed with an extremely bad memory, and as my age increases, the ability to forget things quickly likewise increases. Therefore, the picture which I will try to paint perforce must be done with an extremely broad brush, and with the omission of practically all details. And so I begin.

In the Bible, it says, "In the beginning was the Word". For astronomy then I say, "In the beginning was the Number". By that I mean that a necessary condition for the existence of astronomy is that the prospective astronomer be in a position to carry out long and complicated computations. That is to say, it is essential for the existence of astronomy, that there exist a place-value number system. I mean, an arrangement whereby, given any real number, that number may be represented to any desired degree of precision by a series of integer multiples of integer powers of a fixed integer, the base. The invention of the first place-value number system has been said to be of equal importance with the invention of alphabetical writing, and I think justly so. Being in possession of an alphabet, the user may represent any word whatsoever by the use of a finite number of different symbols, just as with a place-value number system any number is representable by the use of a finite number of different symbols. I remind you that the thing of importance is neither the existence of the base, nor what particular integer happens to be the base, but rather the fact that in the array which represents the number, the contribution of any particular digit - any

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particular multiplier - to the value of its number is determined not only by the symbol itself, but also by its position in the array. The place-value system was invented in Mesopotamia shall we say, some 3000 years ago. The base was the number sixty, and hence this is called the sexagesimal system. Sometime after that, but, I suppose, well before the beginning of the Christian era, a second place-value number system was invented, here in India, with base ten. It has been claimed that the notion of place-value travelled from ancient Mesopotamia to India. Be that as it may, I think no one contests the fact that the decimal system came out of India. Having done so, it travelled slowly westward, penetrating the lands where the sexagesimal system was used, Western Asia, North Africa and Europe. However, at no time did the decimal system for astronomical computations replace the sexagesimals. But it should be stated that the system as used for astronomical computations was a mixed arrangement involving two bases. By and large, the numbers were small, measuring arcs on a circle, hence less than 360 degrees. So it was not inconvenient to represent the integer part of a number with a non-place-value decimal, only the fractional part being displayed as a place value sexagesimal. It should also be admitted that frequently, since computations in the decimal system are simpler than those with sexagesimals, many astronomers had the habit of converting into decimals a pair of numbers to be multiplied, performing the operation, and then turning the product back into sexagesimals.

As for astronomy proper, we can say the subject originated more or less simultaneously in two places, one of which was Mesopotamia (modern Iraq) in the fifth century B.C. The Babylonian astronomers, being long in possession of the sexagesimal system, developed extremely powerful methods for calculating the true positions of planets. Apparently behind this technique there was no geometrical model. The approach was purely numerical, and the prime tools of these astronomers were step functions and linear zig-zag functions. This extraordinary body of theory, however, soon vanished, disappearing completely until modern times, when clay tablets bearing calculations in cuneiform script were recovered with the excavation of ancient sites, and eventually deciphered.

At more or less the same time, in the eastern basin of the Mediterranean, the Greeks worked out a second variety of solutions to the same fundamental problem, the computation of planetary positions, by means of geometric models which we may put into two categories. On the one hand, the celestial body was assumed to be rotating in a circular orbit with a constant speed, but with the earth fixed not at the centre of the orbit, but displaced away from it. Hence this was called the eccentric hypothesis. The second arrangement retains the earth at the centre of the circular orbit, but the point rotating about the earth had in turn, rotating about it a satellite, as it were, the actual planet. The two rotations then proceeded simultaniously. This is known as the epicyclic hypothesis.

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These notions made their way to India by means, I suppose, of maritime commerce merchants plying between the southwest coast of India and the Red Sea thence by land to the Nile delta. The Indians apparently had a low opinion of the eccentric hypothesis. Rather they siezed upon the epicyclic device. It was necessary to introduce two independent perturbations to the planets' motion, the anomalistic equation and the equation of center, both periodic but of different periods. The Indian astronomers obtained these effects by introducing two epicycles per planet, each with its proper period and radius. The mutual influences of each equation on the other were obtained by sequences of complicated but ingenious numerical operations.

Meanwhile, in the Mediterranean region, astronomical activity continued. In the second century A.D. Ptolemy, the greatest astronomer of antiquity, succeeded in combining the epicyclic and and eccentric approaches to produce a set of planetary models which were extremely successful, and which maintained themselves supreme for centuries, eventually being displaced only by the elliptical orbits of Kepler and a cosmology based on the Newtonian laws of motion.

Returning to the Middle East, we note that there converged upon the scientific milieu of the Abbasid empire twin influences, from the east from India (with certain Iranian modifications about which we know very little), and from the west the Ptolemaic. There ensued a competition between the two. The Indian system was the first in the field, but eventually the Ptolemaic triumphed over the Indian, the latter curiously enough surviving for a long time in Arab Spain.

In both systems, in order to obtain numerical results from the geometric models, there was a need for some variety of trigonometry, or the equivalent thereof. In Hellenistic times the need was met by a discipline which can hardly be called trigonometry, since the basic configuration involved was not the triangle but the complete plane or spherical quadrilateral: four arbitrary straight lines or great circles. To this was applied the Menelaos theorem, and for computation a single numerical table, the table of chords, sufficed. Subsequently, the Indians discarded the chord function in favour of the much handier sine, the fundamental periodic function of modern science. Knowledge of the sine function passed westward, together with information about the tangent function, evolved perhaps simultaneously both in India and the Middle East from sets of primitive shadow tables. Then the Muslims rapidly invented the other standard trigonometric functions, and developed trigonometry proper as an independent branch of mathematics which was applied primarily to the solution of problems in astronomy.

At the same time, there occurred in the Middle East an intense and sustained burst of activity in observational astronomy, and this period, say between the eighth and the fourteenth centuries, saw the emergence

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of the astronomical observatory as a scientific institution*. Moreover, this activity was accompanied by an unprecedented development of very sophisticated computational mathematics. For instance, there was extensive application of convergent iterative algorisms. The result of this was a proliferation of numerical function tables, again practically all of them being of interest to astronomers. An example is the sine table of Ulugh Beg, produced late in the period, in which sines were calculated for every minute of every degree from zero to ninety, precise to four sexagesimal places. That is to say, to a precision of one over sixty to the fourth power, equivalent to seven decimal places.

Finally, brief mention may be made of a theoretical development not dependent upon observation, but rather in deference to an old doctrine probably first enunciated by the Pythagoreans, which one may call the principle of uniform circularity. According to this notion, any acceptable celestial motion must consist of a combination of uniform circular motions. The Ptolemaic planetary models violate this principle, and this fact had bothered people over a long period of time. There was a succession of Muslim astronomers in Iran and in Syria who succeeded in working out planetary models which on the one hand conformed to the principle of uniform circularity, but on the other hand, yielded essentially the same results as the Ptolemaic models. Curiously enough, some time later many identically the same planetary models appeared again in the work of Copernicus, the sole difference being that whereas the Muslim models were strictly geostatic, in those of Copernicus, the earth was given an orbit.

Well, I think, this will have to suffice, and I add only a general observation which is implicit in practically everything I said, and which I now make explicitly. That is to note the symbiotic relationship which has flourished throughout history between the sister disciplines of astronomy and mathematics; each of the two subjects nurtured the other. Let me close with an oversimplified geographical recapitulation. We find our subject originating a few centuries before the Christian era in two disparate cultures, Mesopotamia and the Hellenistic world. From the Mediterranean it passed to India, there to flourish. Thence the centroid of activity moved westward, residing in the lands of Islam during medieval times, more recently in Europe. Now astronomical research is carried out throughout the entire world.

* The utility of the Symposium, at least to the speaker, is demonstrated by the false statement made above. Only during the proceedings did I learn that observatories in China antedated all others.