The Early History of the Theory of Eccentrics and Epicycles*

By Noel Sargent

BEFORE undertaking our investigation we must know clearly just what we shall mean by the terms Eccentrics and Epicycles.

An *Eccentric* circle was the orbit which the object under discussion (usually the sun and moon were the objects in eccentric theories) was supposed to describe about the earth. It was conceived *Eccentric* with the earth, that is the fixed earth is not quite at the center of the orbital circle, which is also called the deferent. The idea of *Eccentrics* was adopted to explain the unequal motions of the sun and moon.

An *Epicycle* in ancient astronomy was a little circle having its center on the circumference of a greater one; or a small orb or sphere, which being fixed on the deferent of a planet, is carried along with it, and yet, by its own peculiar motion, carries the planet fastened to it round its proper center. That is, the centers of the epicycles move around the circumference of the deferent. It was by means of epicycles that Ptolemy and his followers solved the various phenomena of the planets, but more especially their stations and retrogradations. The large circle, called the deferent, had the earth as its center. It will be noted that in both the eccentric and epicycle theories the earth is held to be fixed.

It can be easily seen that this system was in a geometrical sense defensible. It harmonized fairly well with appearances. To the ignorant it recommended itself because of its conformity to crude common sense; to the learned, by the wealth of ingenuity expended in bringing it to perfection.

A study of the early history of eccentrics and epicycles naturally involves a study of the theories which led up to the fuller developments.

So far as can be ascertained the Chinese and Chaldean astronomy held no mention of any theories regarding the revolution of the earth or planets.

The Egyptians supposed Mercury and Venus to revolve around the sun and be carried with him in his annual motion around the earth. It will be recognized that this is a forerunner of the epicyclic idea. There is no direct evidence that any of the Greek astronomers knew of the Egyptian ideas, though it is certain that Copernicus was aware of the Egyptian system.

Little of definiteness is known of Greek astronomy until the school of Pythagoras in the sixth century B. C. The exact views of Pythagoras himself do not seem to be known, as he committed nothing to writing. We find one writer (Moulton) saying that "Pythagoras believed that the earth is round, but that it is immovable and at the center of the universe." Other writers hold that, while this was what Pythagoras outwardly proclaimed, to the members of his own school he proclaimed his real views on the subject. Thus Routledge asserts: "Pythagoras taught his disciples something very like the astronomy which places the sun in the center of our system, and recognizes the fixed stars as suns which are the centers of other systems."

But it is in Philolaus that we find the first real forerunner of the heliocentric theory finally evolved in 1531 by Copernicus. Philolaus was a pupil of Pythagoras and was the first to coördinate and put in concrete form the ideas of his teacher. Though the ideas of Pythagoras himself are uncertain, the great body of the Ionian school is known to have considered the earth as the center of our system; Philolaus, on the contrary, asserted that the sun was the center of the system, though at the same time evolving a fantastic theory of Jupiter or Zeus as the real center of the universal system and of a counter-earth. There are, said Philolaus, two motions of the earth: (1) a diurnal movement on itself; and (2) an annual movement around the sun.

His theory was not based on any extensive investigation or observations; we should not expect to find it so. It was rather an astronomical hypothesis, based in large measure on a further application of the fantastic numerical system or theory of the Pythagorean school. Philolaus, for instance, held that the earth was not worthy of being the center of our universe, and that as the light came from the sun and "Fire is more worthy than earth," that, ergo, the sun was the center. Purely an imaginative theory, having little or no vogue during his period or following him, though Aristotle comments on it, we must accord to Philolaus the distinction of being the first to formulate the heliocentric theory.

Heraclides, another of Pythagoras' pupils, taught that the sun, while circulating round the earth, was the center of revolution to Venus and Mercury—exactly the Egyptian view.

Of such speculations Socrates believed, according to

Xenophon, that "the speculators on the universe and on the laws of the heavenly bodies were no better than madmen." (Lewis, *Historical Survey of the Astronomy of the Ancients*, p. 113.)

It was Plato, pupil of Socrates, who proposed the problem which occupied Greek astronomers from that time:—the problem of representing the courses of the planets by circular and uniform motions.

This was so since after the Pythagorean school Greek astronomy became less purely speculative and more scientific. Eudoxus (409–336 B. C.) presented the first mathematical theory of celestial appearances. He tried to construct a theory of celestial motions out of uniform circular motions which should agree with observations. He imagined the fixed stars to be on a vault of heaven; and the sun, moon and planets to be upon similar vaults or spheres, 26 revolving spheres in all, the motion of each planet being resolved into its components, and a separate sphere being assigned for each component motion. Callippus (330) increased the number of spheres to 33. The real existence of the spheres was not suggested, but the idea was only a mathematical conception to facilitate the construction of tables for predicting the places of the heavenly bodies.

Aristotle (384–322 B. C.) held that the earth did not move. He advanced the very conclusive argument against its revolution that there were no apparent displacements of the stars such as should result from such motion. He denied that the earth can revolve, either in the center of the world or about the center, because such a motion would necessarily be violent—that is, against the nature of the earth. "The order of the world is eternal, and therefore no violent or contra-natural motion can have a place in this order." The earth was fixed in the center of the universe. The other heavenly bodies were thought to have uniform circular motions.

THE ALEXANDRIAN SCHOOL

The last period of Greek astronomy is that of the Alexandrian school, founded at Alexandria by Alexander the Great.

Aristillus and Timocharis, early members of this school, set up instruments and fixed the positions of the zodiacal stars, near which all the planets in their orbits pass, thus facilitating the determination of planetary motions.

Aristarchus was the first great astronomer of this school (fl. 275 B. C.). He developed a genuine heliocentric system which was described by Archimedes in his "Arenarius," only to be set aside with disapproval. Aristarchus, to explain his system a little more fully, held that the earth rotates and revolves. He overcame the objection of Aristotle by supposing that the fixed stars are indefinitely remote. The earth's orbit would be a mere point in comparison. The sun was stationary and it was round it that the earth revolved.

Apollonius (latter part of third century B. C.) started a new era by proposing to consider the motions of the heavenly bodies as being purely geometrical. He used the epicycle and deferent to explain the retrograde motions of the planets. He did not, however, make much progress in applying his ideas.

Hipparchus (180–110 B. C.), perhaps the greatest astronomer of antiquity, employed a geometric scheme of eccentrics and epicycles to represent the motions of the heavenly bodies. Having measured the unequal motions of the sun and the moon, he allowed for this by supposing that the center, about which the sun moves uniformly, is situated a little distance from the fixed earth. He called this center the *excentric*. The line from the earth to the *excentric* was called the line of *apses*. A circle having this center was called the *equant*.

Ptolemy (100–170 A. D.) was the first great astronomer of note after Hipparchus and the last great astronomer of the Alexandrian period. From his time to that of Copernicus not a single important advance was made in the science of astronomy. Ptolemy's ideas were set forth in his work, "the Almagest." He put the theories of eccentrics and epicycles in their most advanced form. He adopted the *excentric* and *equant* of Hipparchus to explain the unequal motions of the sun and moon, and the epicycles and deferents of Apollonius to explain the retrograde motions of the planets. Ptolemy made improvements upon these ideas but kept their essential features. When new inequalities were brought to the attention of Ptolemy or his followers they were explained away by the addition of new epicycle—really geometrical makeshifts.

After Ptolemy astronomy was cultivated only by the Arabs until about the sixteenth century when Copernicus brought forth his system. No new discoveries were made by the Arabs, who simply kept on finding more and more accurate values for the constants involved in the Ptolemaic system.

Enlargement of the Sun at Sunset

W. F. Badgley

Most people have looked through a telescope or binoculars and need not be told that the things that they saw enlarged by the glasses were not changed in size by their looking at them, nor moved farther apart.

It is so with the enlarged sun at sunset; it only appears changed because the air magnifies it, and measured with any telescopic instrument its width is not altered.

If you have a reading glass, put it on a sheet of ruled or printed paper and you will see that it does not magnify at the middle, but does so towards the edge, and that the magnification is greater in line with the edge, and not towards the center, and that near the edge a circle becomes an oval.

The scientific explanation of the apparent enlargement of the sun is, that when it is seen high up there is nothing near it to compare it with in distance, so we believe it to be near and therefore small; but when we see it on the horizon which we know to be far away, we believe it far and therefore deceive ourselves, and believe it large.

If you are happily a dweller in the country, and get a chance of seeing the sun or moon, when near the horizon, through the branches of trees a hundred or so yards away, the orb will appear as though just at the back of the network of branches; or if you will look at the moon, when low down, through a lace window curtain, it will seem to be just beyond the lace; and whether seen through, or away from, the trees or curtain, there is not a bit of difference in the size of the orbs. This disposes of the scientific deceitful comparison idea.

The sun as it nears the horizon and appears enlarged usually becomes an oval longer in breadth than in height, because it is seen through the edge of an aerial lens. The air, to a small height, is in a condition to magnify objects and has been so all day, but looking upwards its thin layer would have little effect, where as looking through it toward the horizon, the effect would be increased about sixteen times by the increased depth of air looked through.

It is not always that the air acts to enlarge objects on the horizon, for one day it may do so and the next day not. The effect is due to some particular state of the air. It cannot be due to water vapor for the quantity in the air at any season does not change much from day to day. Neither is it due to foginess in the air, for the sun or the moon seen through fog, or thin cloud, is a pale thing not the least enlarged while if enlarged the sun is usually fiery red and the moon sometimes green.

Dust and heated air appear to be the only possible causes of the magnification. Summer and autumn are the usual times for seeing the phenomenon, because they are dusty times; we do not see it in winter, or if we do, can account for it by smoke dust. Objects seen through dusty air are enlarged and reddened. But in all these cases the air may be heated.

Objects seen through the heated air of deserts are enlarged; seen through smoke from a chimney, they are enlarged. But in both these cases the air is certainly dusty.

So there is something still left in this enquiry for clever people to find out. On one occasion, being near the western edge of the plateau three hundred feet above the plain to the west, the sun set on a clear horizon and was not enlarged; while to the east, across the plateau, the full moon rose enlarged through a reddish mist which had a height of about twenty degrees above the horizon. While in the mist the moon was of a bright green color and had a duller green halo; on leaving the mist it took on its usual size and yellowish silvery look, and had no halo. The change was sudden as the mist had a very definite edge.—*Popular Astronomy*.

Analyzing Ferrosilicon Without A Platinum Crucible

It is possible to dispense with expensive platinum crucibles in analyzing ferrosilicon, according to Dr. Herwig in an article in *Stahl und Eisen*. According to a translation in the *London Iron and Coal Trades Review* iron crucibles can be used if instead of the usual carbonate of soda and potash method sodium dioxide is used in the ignition mixture. Great care must be taken to reduce the ferrosilicon to as fine a powder as possible, to remove all coarse particles and to mix the powdered silicon thoroughly and very uniformly with the dioxide, as otherwise dangerous ebullition might take place, which would nearly empty the crucible and the spattering endanger the analyst's eyes. The author gives a comparative list of 22 analyses made, one-half of these by the sulphate, the other half by the dioxide method, of ferrosilicons, ranging in silicon content between 10.75 and 90.78 per cent. The differences in the results obtained by the two methods range only between, say, plus 0.05 and minus 0.13 per cent.—*Iron Age*.

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