"Hands-on" Epicycles and Retrograde Motion

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Any model that attempts to describe the time evolution of planetary positions needs to account for retrograde motion, the apparent reversal of the planet's path against the background of the fixed stars. In discussing models of the cosmos through history, it is standard practice to present the Ptolemaic model.[1] This model, which was one of the first to successfully account for planetary motions in detail, has as its most notable geometric feature the use of epicycles and deferent circles.[2] When presented to students, it is sometimes difficult for them to envision how an epicycle and deferent combine to produce the characteristic backward motion. Textbook treatments[3] of the topic include the standard loop-the-loop picture, which is inherently static. We have developed a "hands-on" exercise, using simple supplies, which enables students to get a dynamic feel for planets executing epicyclical motion. This exercise has been used successfully by students in our "physics for poets" course and in an interdisciplinary, team-taught Science in Context course titled "Cosmological Thought."

The equipment consists of polar graph paper and a "fender" washer. The center of the polar graph paper (we use National 12-187) represents Earth and a circle drawn on the paper at a particular radius represents the deferent circle. The epicycle is represented by the outer edge of a "fender" washer of diameter 1¼ in with a hole in the center of approximate diameter ¼ in (we find these sizes work well).[4] The washer is marked with crosshairs, and the end of one of the crosshairs, at the outer rim of the washer, has an arrow that represents the planetary position (see Fig. 1). We constructed a similar washer out of clear plastic for the instructor to use on an overhead projector in conjunction with a transparency of the polar graph paper.

Using the crosshairs, students orient the center of the washer on the deferent with the planet at a particular initial position, for example with the arrow pointing down. Now they move the center of the epicycle (center of the washer) counterclockwise around the deferent circle at a constant rate, while simultaneously rotating the epicycle (washer) counterclockwise about its center at a constant, possibly different, rate. The position of the planet (arrow) exhibits epicyclical motion. Depending on the relative speeds of rotation, the resulting behavior can exhibit the retrograde motion.

To get more quantitative results, we suggest the students use specific rates of rotation. For example, 5 degrees per time step for the center of the epicycle around the deferent, and 45 degrees per time step for the rotation of the planet about the center of the epicycle. After each time step, the location of the planet (arrow) is marked on the graph paper, and the time step number is indicated. This process, moving another 5 degrees around the deferent and simultaneously another 45 degrees about the center of the epicycle, is then repeated. Several points obtained using these values are shown in Fig. 1. These points can be connected in chronological (ascending) order to represent successive planetary positions. Finally, the students draw a line from Earth (center of polar graph paper) to the extreme angular positions of the motion to indicate the retrograde arc, as shown in the figure.

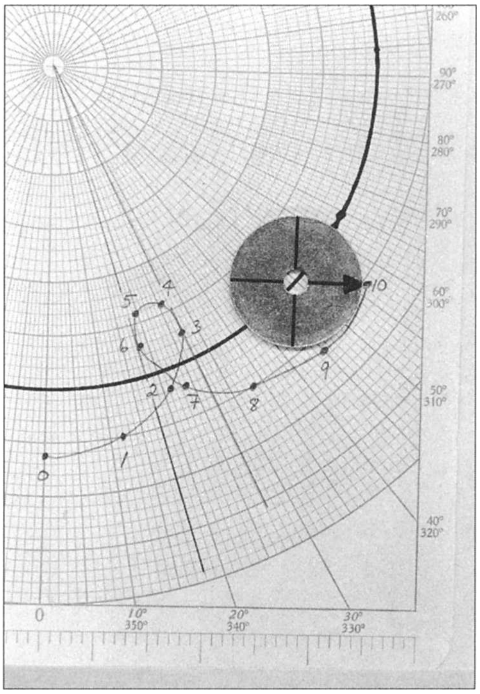

Fig. 1: Hands-on apparatus showing polar graph paper, "fender" washer with crosshairs and arrow, a labeled sequence of planetary positions, and two radial lines indicating the extent of the retrograde arc.

This exercise, using readily available and inexpensive materials, has been used successfully to give students a "feel" for the way in which an epicycle and deferent combine to produce retrograde motion.

References

1. Detailed treatments of the Ptolemaic theory are given in Michael J. Crowe, *Theories of the World from Antiquity to the Copernican Revolution* (Dover, NY, 1990), Chap. 4, and James Evans, "Ptolemy" in *Cosmology: Historical, Literary, Philosophical, Religious, and Scientific Perspectives*, edited by N. Hetherington (Garland Publishing, NY, 1993), Chap. 7.
2. Though essential to Ptolemy's final theory, the use of the eccentric deferent and an equant point will not be discussed here.
3. See for example: Michael J. Crowe, *Theories of the World from Antiquity to the Copernican Revolution* (Dover, NY, 1990), p. 37; Art Hobson, *Physics: Concepts and Connections* (Prentice-Hall, Englewood Cliffs, NJ, 1995), p. 14; John D. Fix, *Astronomy: Journey to the Cosmic Frontier* (Wm. C. Brown Publishers, Dubuque, IA, 1997), p. 49.
4. We give the relevant dimensions in inches since they are the units in most common use in American hardware stores.