29:52 Exploration of the Solar System
Notes for February 13, 2008
Precession of the Earth's Axis, Kepler's Laws of Planetary Motion

From the beginning of the class, I have emphasized that the Earth's rotation axis points towards a place on the celestial sphere near the fairly bright star Polaris. This is true now, but was not true in the past and will not be true in the future. The Earth's rotation axis slowly *precesses.*

Precession happens when a spinning object (one which possesses angular momentum) is subject to a torque. The direction of the rotation axis moves slowly on the surface of a cone. This can be demonstrated with physics toys like tops.

The Earth acts like a large top, and it "feels" torques from the Sun and Moon. As a result, the rotation axis of the Earth moves on the surface of a cone. Right now it is pointing fairly close to Polaris, but that is gradually changing. 13,000 years from now, the rotation axis will be pointing close to the very bright star Vega. At that time, Vega will be the north star. 4500 years ago when the ancient Egyptians were building the pyramids, there was no bright pole star.

Kepler's Laws of Planetary Motion

Around 1600, Johannes Kepler deduced laws which governed the orbits of the planets around the Sun. It is remarkable that he got the answers right. We still use Kepler's Laws of planetary motion to plan space flights and calculate the positions of planets. There are three such laws. Kepler's Laws are based on the recognition, which was new in this time, that the planets move around the Sun, which is the center of the solar system.

(1) Kepler's first law says that the orbits of planets around the Sun are *ellipses* with the Sun at 1 focus. See figures 4.14 and 4.13 to see the definition of an ellipse. Be sure you understand parameters of ellipses such as *major axis, semimajor axis, eccentricity, and focus.*

(2) Kepler's 2nd Law is known as the equal area law. It says that a line from the Sun to a planet will sweep out the same area in a constant time interval (say a week), regardless of where the planet is in its orbit. Kepler's 2nd Law is illustrated in Figure 4.15.

(3) Kepler's 3rd Law is called the *harmonic law* and states a mathematical relation between the semimajor axis of a planet's orbit (A, expressed in astronomical units), and its orbital period P) expressed in years. The relation is

$$A^3 = P^2$$

Next time, we will discuss how Kepler's Laws help us understand and predict things in the solar system.

It is worth noting that, although Kepler discovered these laws *empirically,* that is, on the basis of careful observation, we now know that they are expressions or consequences of fundamental laws of physics that were unknown in Kepler's time.