Physics
Unit 7: Circular Motion, Universal Gravitation, and Satellite Orbits

Planetary Motion

Geocentric Models

--Many people prior to the 1500's viewed the Earth and the solar system using a <u>geocentric model</u> with the Earth at the center of the solar system and the Sun and the planets revolving around the Earth.

--This model seemed perfectly reasonable; after all, if we observe the position of the Sun during the day, it moves across the sky as seen from Earth.

--The problem with the geocentric model is that very complex models had to be built to explain the complex motions of the planets as viewed from the Earth; for example, the <u>retrograde</u> motion of the planet Mars as viewed from the Earth.

The Heliocentric Model

--In 1543, Nicholas Copernicus (born 1473) published On the Revolution of Heavenly Bodies, in which he proposed a heliocentric model for the solar system, with the sun at the center and the Earth and planets revolving around the Sun.

--The idea was controversial and violated religious dogma of the day; Copernicus did not see a copy of the book until the day he died.

Tycho Brahe

--The Dutch astronomer Tycho Brahe (born 1546) did not accept the heliocentric model proposed by Copernicus, and he set out to prove him wrong by making accurate measurements of the positions of the planets and stars, designing many instruments he needed to make the measurements.

--Many of his measurements were so accurate they are still usable today.

Johannes Kepler

--Johannes Kepler (born 1571) was a mathematician who worked with Tycho Brahe during the last 18 months of Brahe's life.

--He took the accurate measurements of the positions of the planets and stars made by Brahe and sought a mathematical description of the orbits of the planets.

--Kepler adopted the heliocentric model of Copernicus, and derived three laws that describe the orbits of the planets around the Sun.

Kepler’s Three Laws of Planetary Motion

1) Kepler’s 1st Law states that each planet moves in an elliptical orbit with the Sun at one focus.

   (For most purposes, the elliptical orbits are so close to circles that the orbit can be treated as if it were a circle.)

2) Kepler's 2nd Law says that a line joining the Sun and the planet sweeps out equal areas in equal times.

3) Kepler’s 3rd Law says that the radius of a planets orbit cubed divided by the period of revolution squared is a constant.

$$K = \frac{R^3}{T^2}$$

--Use values of the period of revolution and radius of orbit to calculate the value of K_S for planets orbiting the sun.

Example: …K_s for Mercury:

$$K_s = \frac{R^3}{T^2}$$

$$K_s = \frac{(5.79 \times 10^{10} \text{ m})^3}{(7.60 \times 10^6 \text{ s})^2}$$

$$K_s = 3.36 \times 10^{18} \frac{\text{m}^3}{\text{s}^2}$$

Planet	K_s
Mercury	$K_s = 3.36 \times 10^{18} \frac{m^3}{s^2}$
Venus	$K_s = 3.35 \times 10^{18} \frac{m^3}{s^2}$
Earth	$K_s = 3.31 \times 10^{18} \frac{m^3}{s^2}$
Mars	$K_s = 3.36 \times 10^{18} \frac{m^3}{s^2}$
Jupiter	$K_s = 3.37 \times 10^{18} \frac{m^3}{s^2}$
Saturn	$K_s = 3.38 \times 10^{18} \frac{m^3}{s^2}$
Uranus	$K_s = 3.34 \times 10^{18} \frac{m^3}{s^2}$
Neptune	$K_s = 3.37 \times 10^{18} \frac{m^3}{s^2}$
Pluto	$K_s = 3.36 \times 10^{18} \frac{m^3}{s^2}$

--Note that the value of K_s is unique to the Sun; the equation works for other orbiting systems such as the Moon and artificial Earth satellites orbiting the Earth, but the value of K_E would be different.

$$K_E = \frac{R^3}{T^2}$$

$$K_E = \frac{(3.8 \times 10^8 \text{ m})^3}{(2.36 \times 10^6 \text{ s})^2}$$

$$K_s = 9.85 \times 10^{12} \frac{\text{m}^3}{\text{s}^2}$$

The Motion of the Moon

--The path of the Moon in our solar system is usually described in the Earth frame of reference:

The Moon follows a circular path around the Earth.

--As seen from the frame of reference of the Sun, the path of the Moon is very different, as the Moon orbits the Sun along with the Earth one time each year. This means that the Moon’s average velocity around the Sun is the same as that of Earth.

Calculate the velocity of the Earth (and Moon) around the Sun, using the data from the planetary table.

$$V = \frac{2\pi R}{T}$$

$$V = \frac{2\pi(1.49 \times 10^{11} \text{ m})}{3.16 \times 10^{7} \text{ s}}$$

$$v = 2.96 \times 10^{4} \ \frac{\text{m}}{\text{s}}$$

Calculate the velocity of the Moon around the Earth:

$$V = \frac{2\pi R}{T}$$

$$V = \frac{2\pi(3.8 \times 10^{8}\ \text{m})}{2.36 \times 10^{6}\ \text{s}}$$

$$V = 1.01 \times 10^{3}\ \frac{\text{m}}{\text{s}}$$

--The orbits of the Earth around the Sun and the Moon around the Earth are counterclockwise as seen from above the Earth's north pole.

--The velocity of the Moon around the Sun when the Moon is outside the Earth's path (full moon phase):

$$v = (2.96 \times 10^{4}\ \text{m/s}) + (1.01 \times 10^{3}\ \text{m/s})$$

$$v = 3.06 \times 10^{4}\ \text{m/s}$$

--The velocity of the Moon around the Sun when the Moon is inside the Earth's path (new moon phase):

$$v = (2.96 \times 10^4 \text{ m/s}) - (1.01 \times 10^3 \text{ m/s})$$

$$v = 2.86 \times 10^4 \text{ m/s}$$

--When the Moon is on the outside of the Earth's orbit it is traveling faster than the Earth; when it is on the inside of the Earth's orbit it is traveling slower than the Earth <u>but its velocity is still positive</u> (in the same direction as the Earth is moving).

--The moon never backs up in its orbit as seen from the Sun; its orbit is always concave towards the Sun.