Investigating Planets Name:____Block:______ **E1:R4**

FYI: Orbits & Ellipses & FYI Kepler's Laws

Read FYI: *Orbits & Ellipses* and FYI: *Kepler's Laws* As you read answer the following questions about the readings:

1. What's the plural form of focus?

2. The closest approach for a satellite or moon orbiting the Earth or a planet is called _____________.

3. The closest approach for a planet orbiting the Sun is called _________________.

4. The farthest point in a satellite's orbit of the Earth or a planet is called _________________.

5. The farthest point in a planet's orbit of the Sun is called _________________.

6. What word is used to indicate how elliptical an orbit is?

7. What does Kepler's 1st Law of Planetary Motion say?

8. What does Kepler's 2nd Law of Planetary Motion say?

9. So, according to Kepler's 2nd Law, where in a planet's orbit is moving the fastest?

10. What does Kepler's 3rd Law of Planetary Motion say? (You can write the equation in words if you prefer.)

FYI Orbits and Ellipses

The paths that moons take around planets and planets take around stars are called orbits. Tycho Brahe was a wealthy Danish astronomer in the late 1500s who, through careful observation, gathered much of the data that were used to develop today's understandings about orbits. Johannes Kepler used Brahe's data to establish the three basic laws that describe the motion of orbiting bodies. The first of these important laws states that the orbits of planets (or moons) are ellipses, with the sun (or planet) at one focus.

In an elliptical orbit, the body being orbited occupies one of the two foci in an ellipse. Nothing occupies the other **focus**. There are two points of special interest on the ellipse. The point where the orbiting body comes closest to the central body is called **perigee** if the object is orbiting Earth, or **perihelion** if the object is orbiting the sun. The point of greatest distance is called **apogee** if the object is orbiting Earth, or **aphelion** if the object is orbiting the sun. Each ellipse has a **major axis** "a" that is the straight line through the foci connecting the aphelion and perihelion points. The **minor axis** "b" is perpendicular through the center of the ellipse. The distance between the two foci is called "c."

In a circular orbit, a planet or moon travels exactly the same speed at every point in the orbit. In an elliptical orbit, however, this is not the case. An object such as a comet, in a highly elliptical orbit around the sun, travels very fast when it is near perihelion (where the gravitational force is stronger) and very slowly when it is near aphelion (where gravitational force is weaker).

The measure of how elliptical an orbit is is called the eccentricity of the ellipse. Eccentricity is defined as the ratio of the distance between the foci (c) to the distance of the object from the sun (a). A circle has a single focus and an eccentricity of zero. Most planets and moons have eccentricities below 0.1. These would be nearly circular orbits. Objects such as Halley's comet, however, can have very eccentric, cigar-shaped orbits with eccentricities in the 0.9 range.

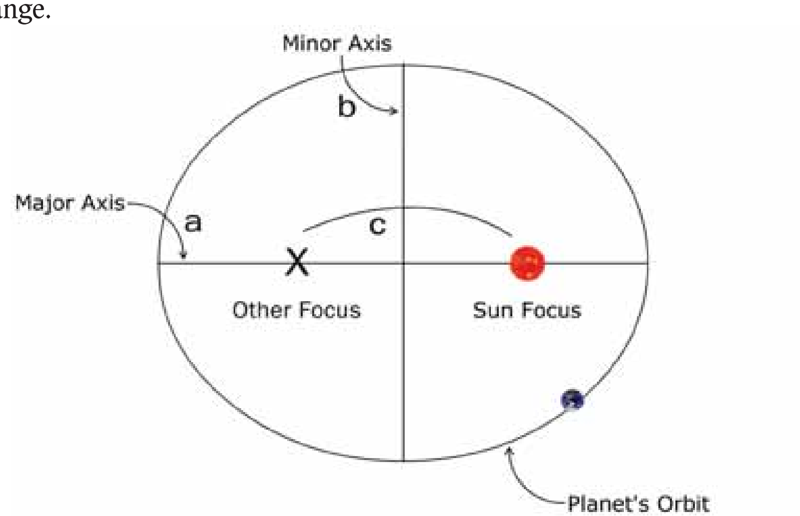

Figure 2-12: Diagram of a planet's elliptical orbit (NOT to scale)

FYI Kepler's Laws

The German mathematician Johannes Kepler (1571-1630) believed in an idea that was new in his time—that the sun, rather than Earth, was the center of the solar system. Moreover, he was convinced that the motions of the planets could be explained using simple mathematical relationships. Using data on the position of Mars, collected by the scientist Tycho Brahe, Kepler gradually worked out three laws of planetary motion. In 1609, Johannes Kepler published his first two laws in the book *New Astronomy*. A decade later (1619), his third law was published in *The Harmonies of the World*.

Kepler's first law states that the orbits of the planets around the sun are **ellipses** and that the sun is located at one focus, with nothing at the other.

LAW 1: The orbit of a planet around the sun is an ellipse, with the sun at one focus.

The planets in our solar system have relatively small but non-zero eccentricities, meaning that though their orbits are ellipses, they are more circular than not. Earth's orbit, for instance, with an eccentricity of only 0.017, would look like a perfect circle if you could view it from above the Earth-sun plane. But Mars's orbit is just eccentric enough (0.093) for Kepler to discover that all planetary orbits were elliptical in shape, not circular. This law means that the distance between the sun and each of the planets is constantly changing as the planet moves around its orbit.

Kepler's second law deals with the speed at which planets travel along their orbits. Basically, the law says that a planet orbits more slowly when it is farther from the sun. The law conveys this through a very specific, mathematical statement about the orbital ellipses:

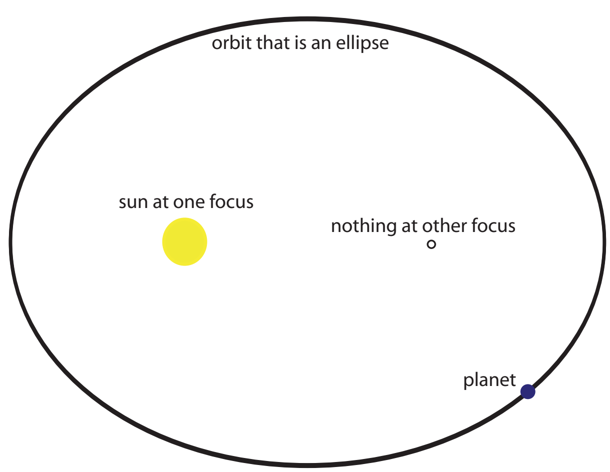

Figure 2-14: Diagram related to Kepler's first law.

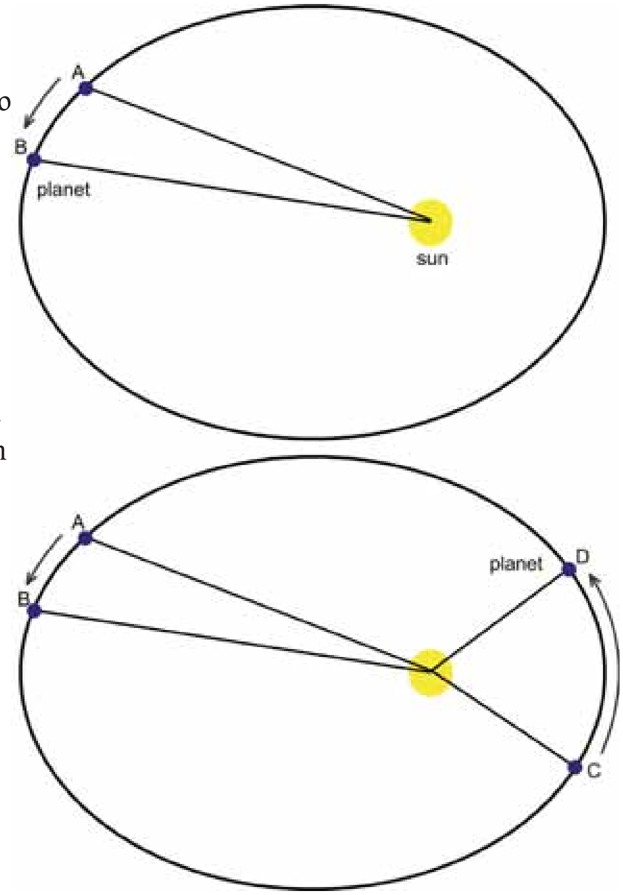

Figure 2-15: Diagrams related to Kepler's second law

LAW 2: A line joining a planet and the sun sweeps out equal areas in equal amounts of time.

As shown in Figure 2-15, as the planet moves from point A to point B along its orbit, a long, skinny area is swept.

In the same amount of time it takes the planet to get from point A to point B, the planet can move from point C to point D. According to Kepler's second law, the size of the skinny area swept from A to B is the same size as the fatter area swept from C to D.

Kepler's third law relates the length of time a planet takes to orbit the sun—the period of the planet's orbit—to the planet's average distance from the sun. Again, it conveys this through a mathematical statement related to the planet's elliptical orbit:

LAW 3: The square of a planet's period of revolution is proportional to the cube of its distance from the sun.

Kepler's third law can also be written as:
The square of the time, in Earth years, it takes a planet to orbit once is equal to the cube of the average distance, measured in astronomical units (AU), between that planet and the sun. (This works because Earth takes ONE Earth year to orbit once around the sun, and Earth's average distance from the sun is, by definition, ONE astronomical unit. These ONES drop out of the equation.)

Mathematically, this can be written:

$$(\text{Earth years it takes planet to orbit once})^2 = (\text{average distance, in AU, between planet and sun})^3$$

$$(\text{period in Earth years})^2 = (\text{distance from the sun in AU})^3$$

$$p^2 = a^3$$

Kepler generalized his three laws to all the planets (though Uranus and Neptune had not yet been discovered), and today, we know that the laws also apply to moons, comets, and other orbiting bodies. But in fact, Kepler's work was completely based on studies of one and only one orbiting body—the planet Mars. Moreover, Kepler didn't make his own observations of Mars. Instead, he used data gathered by someone else, fellow scientist Tycho Brahe, who charged Kepler with the task of making sense of his observations.

Attempts by Kepler to explain the motions of Mars using circular orbits ultimately fit the data well, but not perfectly. Even with many refinements to the model, a small error—one so small that it wouldn't have been detectable in any data gathered with less accuracy than Brahe's data—remained. Not satisfied, Kepler worked until he found a model—elliptical orbits—that fit all the data. This was an amazing accomplishment, one that depended on Kepler's trust in Brahe's meticulous data collection, on Kepler's belief that he needed to account for all the data, and on Kepler's ability to change his pre-held ideas in the face of what the data were telling him—a mark of good science.