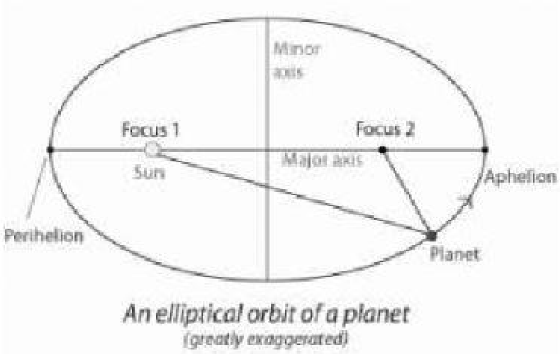
Kepler's Laws

June 11, 2013 by Brian Ventrudo

Once Kepler got his hands on Tycho's measurements, he worked diligently to make sense of the data and to develop a solid framework for the workings of the solar system. He succeeded. Working for more than a decade, crunching numbers with pen and paper, he laid out three simple mathematical laws that account for the motion of the planets. Kepler's Laws were descriptive, so they didn't explain the physical basis for celestial motion. That task fell to an even more astute mathematician: Isaac Newton. But "Kepler's Laws" are rigorous enough to account for most planetary motion, and are still taught to high-school and college students all over the world. Here's what they're all about…

Kepler's First Law

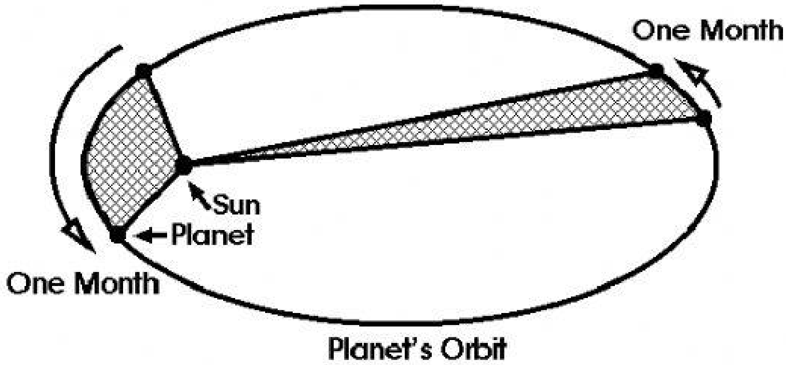
As mentioned in the short biography of Kepler, his first law was a result of a great insight: that planets did not necessarily move in perfect circular orbits, which had been long assumed. Using Tycho's measurements of the motion of Mars across the sky, Kepler discovered planets move in elliptical orbits with the Sun not at the center of the ellipse, but at one focus (the other focus is empty). It's a deceptively simple law that took astonishing insight and five years of hard work.



Kepler's First Law states that planets move around the Sun in an elliptical orbit with the Sun at one focus of the ellipse.

Kepler's Second Law

As you may have surmised, if a planet traverses an elliptical orbit, its distance from the Sun changes during an orbit. Kepler noticed, using Tycho's real-world observations, that planets seemed to speed up in their orbits when they are closer to the Sun and slow down when they're further away. The effect was subtle but unmistakable. But a verbal description was insufficient. Kepler had to quantify this motion, and did so by stating that "a line joining a planet and the Sun sweeps out equal areas during equal intervals of time." See the diagram below…



Kepler's 2nd Law: The line from the Sun to a planet sweeps out equal areas (in grey) in equal times.

"Who cares", you might ask? Well… this doesn't affect your everyday life and enjoyment of the night sky, but Kepler's 2nd Law is a) Critical for predicting where we can see planets in the sky, and b) A direct consequence of the great universal law of "conservation of energy". As a planet gets closer to the Sun, it has less "potential energy" and more "kinetic energy", and as it moves away from the Sun, it has the opposite. Without this law, we'd still be scratching our head about where and when the planets appear in the night sky.

Kepler's Third Law

Planets farther away from the Sun have larger orbits, so even if they moved at the same speed as the closer-in planets, you'd expect them to take longer to move around the Sun. And they do. But they also move at a lower rate of speed, which further lengthens the time is takes to revolve around the Sun. What Kepler discovered, to be exact, is that the square of the orbital period (P) of a planet is directly proportional to the cube of the semi-major axis of its orbit (T):

$$P^2 \sim T^3$$

Now stay with me here… this means, in plain English… that planets move slower when they're farther from the Sun, and whatever influence makes planets go around the Sun weakens with distance. It was left to the great British scientist and world-historical genius, Isaac Newton, to explain this relationship with his own law of gravity, a law upon which all of modern physical science is based.

And here's the most amazing thing of all… Kepler's three laws appear to hold not just in our own solar system, but in all circumstances where one body moves under the influence of another's gravity. They are general universal relationships.

Kepler's Laws Questions:

1. How long did Kepler work with the data to formulate the three laws of planetary motion?

2. Kepler's First Law states that the shape of a planet's orbit is ____________________.

3. The sun is not at the center of a planet's orbit; it is located at one _____________.

4. Planets ______________ in their orbits when they are ________________ to the Sun and ______________ when they are _________________________.

5. Kepler's 2nd Law states that a planet sweeps out equal _________ in equal _________.

6. What are 2 reasons why Kepler's 2nd Law is important?
   a. ____
   b. ____

7. As a planet gets closer to the sun, it has less ________________ energy and more ____________ energy. As the planet moves away from the sun, it has less ________ energy and more ______________ energy.

8. Kepler's 3rd Law explains why planets that are farther away from the sun have ________ orbits and take __________ to move around the sun.

9. Planets further away from the sun also move at a _________ speed, which further __________ the time it takes to revolve around the sun.

10. The ___________ of the orbital ______________ (P) of a planet is directly proportional to the ____________ of the ________________ axis of its orbit (T). All this means that planets move _______________ when they're __________ from the sun.

11. ______________________ explained the relationship between P and T with his own law of __________________.

12. Kepler's three laws apply to many circumstances in space, making them general _____________ relationships.