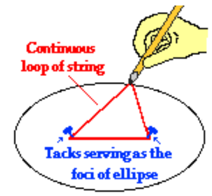
Kepler's Three Laws

In the early 1600s, Johannes Kepler proposed three laws of planetary motion. Kepler was able to summarize the carefully collected data of his mentor - Tycho Brahe - with three statements that described the motion of planets in a sun-centered solar system.

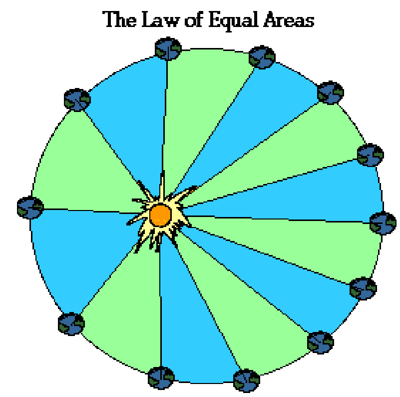


The Law of Ellipses

Kepler's first law - sometimes referred to as the law of ellipses - The path of the planets about the sun is elliptical in shape, with the center of the sun being located at one focus.

The Law of Equal Areas

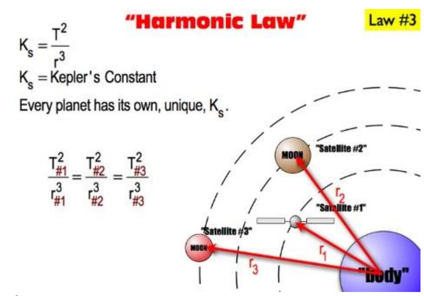
Kepler's second law - sometimes referred to as the law of equal areas - describes the speed at which any given planet will move while orbiting the sun. The speed at which any planet moves through space is constantly changing. A planet moves fastest when it is closest to the sun and slowest when it is furthest from the sun. Yet, if an imaginary line were drawn from the center of the planet to the center of the sun, that line would sweep out the same area in equal periods of time. As can be observed in the diagram, the areas formed when the earth is closest to the sun can be approximated as a wide but short triangle; whereas the areas formed when the earth is farthest from the sun can be approximated as a narrow but long triangle. These areas are the same size. Since the *base* of these triangles are shortest when the earth is farthest from the sun, the earth would have to be moving more slowly in order for this imaginary area to be the same size as when the earth is closest to the sun.



An imaginary line drawn from the sun to any planet sweeps out equal areas in equal amounts of time.

The Law of Harmonies

Kepler's third law - sometimes referred to as the **law of harmonies** - compares the orbital period and radius of orbit of a planet to those of other planets. Unlike Kepler's first and second laws that describe the motion characteristics of a single planet, the third law makes a comparison between the motion characteristics of different planets. The comparison being made is that the ratio of the squares of the periods to the cubes of their average distances from the sun is the same for every one of the planets. As an illustration, consider the orbital period and average distance from sun (orbital radius) for Earth and mars as given in the table below.



Planet	Period (s)	Average Distance (m)	T^2/R^3 (s^2/m^3)
Earth	3.156×10^7 s	1.4957×10^{11}	2.977×10^{-19}
Mars	5.93×10^7 s	2.278×10^{11}	2.975×10^{-19}

Observe that the T^2/R^3 ratio is the same for Earth as it is for mars. In fact, if the same T^2/R^3 ratio is computed for the other planets, it can be found that this ratio is nearly the same value for all the planets (see table below). Amazingly, every planet has the same T^2/R^3 ratio.

Planet	Period (yr)	Average Distance (au)	T^2/R^3 (yr^2/au^3)
Mercury	0.241	0.39	0.98
Venus	.615	0.72	1.01
Earth	1.00	1.00	1.00

(**NOTE**: The average distance value is given in astronomical units where 1 a.u. is equal to the distance from the earth to the sun - 1.4957×10^{11} m. The orbital period is given in units of earth-years where 1 earth year is the time required for the earth to orbit the sun - 3.156×10^7 seconds.)

Kepler's third law provides an accurate description of the period and distance for a planet's orbits about the sun. Additionally, the same law that describes the T^2/R^3 ratio for the planets' orbits about the sun also accurately describes the T^2/R^3 ratio for any satellite (whether a moon or a man-made satellite) about any planet. There is something much deeper to be found in this T^2/R^3 ratio - something that must relate to basic fundamental principles of motion.

Questions

1. Kepler's first law of planetary motion states that ____. Choose one.
    a. the Sun is at the center of the solar system
    b. planets orbit the Sun in elliptical orbits, with the Sun located at one focus
    c. planets orbit the Sun in circular orbits, with the Sun located at the center
    d. gravity provides the force that holds the planets in orbit about the Sun

2. Kepler's second law of planetary motion states that a line connecting a planet to the Sun ____. Choose one.
    a. is longest in winter and shortest in summer
    b. sweeps out more area during a winter month than during the summer month
    c. sweeps out the same amount of area in any two equal periods of time
    d. sweeps out the same amount of area regardless of the planet.

3. A planet would move ____.
    a. at the same speed at all times during its orbit about the Sun
    b. at faster speeds when positioned closer to the Sun during its orbit
    c. at slower speeds when positioned closer to the Sun during its orbit

4. Kepler's third law of planetary motion states that the ratio of ____.
    a. the orbital period to the orbital radius is the same for all planets
    b. the orbital periods of any two planets equals the ratio of the orbital radii
    c. all planets would orbit with the same orbital period
    d. the period squared to the radius cubed is the same ratio for all planets

5. A planet that is further from the Sun would take _____ time to orbit the Sun compared to planets that are closer to the Sun.
    a. more b. less c. the same amount of

6. Suppose a small planet is discovered that is 14 times as far from the sun as the Earth's distance is from the sun (1.5×10^{11} m). Use Kepler's law of harmonies to predict the orbital period of such a planet. GIVEN: $T^2/R^3 = 2.97 \times 10^{-19}\ s^2/m^3$ or $1\ yr^2/au^3$

7. The average orbital distance of Mars is 1.52 times the average orbital distance of the Earth. Knowing that the Earth orbits the sun in approximately 365 days, use Kepler's law of harmonies to predict the time for Mars to orbit the sun.

8. There is a belt of asteroids between Mars and Jupiter. This belt circles the “inside” of our solar system and is called the Asteroid belt. This belt has a mean radius from the Sun of 2.6 Au’s. How long does it take for 1 asteroid to in the belt to travel around the Sun once?

9. The planet Jupiter’s period is 11.8 years. What is the radius of Jupiter?

10. The planet Pluto is 39.5 Au’s from the Sun. How long does is take to go around the Sun once?