6.5: Kepler's Laws of Planetary Motion

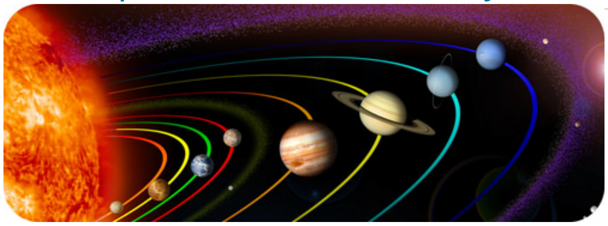


Figure 5.5.1

Though a drawing, not an accurate portrayal of the solar system, the elliptical appearance of the orbits is correct. The elliptical orbits around the sun are not limited to the planets; comets, asteroids, and other orbiting objects also follow elliptical paths.

Kepler's Laws

Fifty years before Newton proposed his three laws of motion and his law of universal gravitation, Johannes Kepler (1571 – 1630) published a number of astronomical papers with detailed descriptions of the motions of the planets. Included in those papers were the findings that we now refer to as *Kepler's Laws of Planetary Motion.* These are summarized below.

Kepler's First Law

The path of each planet around the sun is an ellipse with the sun at one focus.

Kepler's First Law states the path of the planet is an ellipse around the sun with the sun at one focus Figure 5.5.2

Though it seems at first glance that this law is incorrect (the sun appears to be in the center of our orbit), remember that a perfect circle is an ellipse with the foci in the same place. Since the Earth's orbit is nearly circular, the sun appears to stay in the center.

Kepler's Second Law

As a planet moves in its orbit, a line from the sun to the planet sweeps out equal areas in equal times.

Illustrates Kepler's Second Law Figure 5.5.3

The image above illustrates this relationship. Though the green wedges may appear significantly different in area, Kepler's Second Law states that the areas are equal if the planet travels along the perimeter of the segments in equal periods of time. From this, we can clearly see that the planet moves with greater speed when it is near the sun and slower when it is far away.

Use the simulation below to observe a planet in orbit around a star . Start by adjusting the eccentricity, which is a measure of how elliptical its orbit is. What do you notice as its eccentricity increases? Does it appear to speed up or slow down along its journey? Try to apply Kepler's first and second laws to make predictions about the planet's orbital motion before pressing play.

Kepler's Third Law

The ratio of the squares of the periods of any two planets revolving around the sun is equal to the ratio of the cubes of their average distance from the sun.

$(T_1/T_2)^2=(r_1/r_2)^3$

This is the only one of Kepler's three laws that deals with more than one planet at a time.

This equation can be reworked to reveal that the ratio between the period and the radius of the planet's orbit is always the same:

$(T_1)^2/(r_1)^3=(T_2)^2/(r_2)^3$

In truth, it has been calculated that this ratio holds for all the planets in our solar system, in addition to moons and other satellites.

Try to apply Kepler's third law in the simulation below to help you determine the right launch date to get a spacecraft to land on Mars. Then, because this law holds for all planets in our solar system, try other launches from Venus to Earth or from Mars to Venus.

Example 5.5.1

The planet Venus has a mean distance from the sun of 108.2 $\times 10^6$ km and a period of 0.615 years. The planet Mars has an average mean distance from the sun of 227.9 $\times 10^6$ km and a period of 1.88 years. Do these planets follow Kepler's third law?

Solution

The average mean distance of Venus divided by the average mean distance of Mars = 0.475. The period of Venus divided by the period of Mars = 0.327.

The square of the period ratio is 0.107 and the cube of the mean distance ratio is 0.107. It is clear that these two planets follow Kepler's third law.

Summary

- Kepler's First Law: The path of each planet around the sun is an ellipse with the sun at one focus.
- Kepler's Second Law: Each planet moves such that an imaginary line drawn from the sun to the planet sweeps out equal areas in equal periods of time.
- Kepler's Third Law: The ratio of the squares of the periods of any two planets revolving around the sun is equal to the ratio of the cubes of their average distance from the sun.

Review

1. The average mean distance of the earth from the sun is 149.6 $\times 10^6$ km and the period of the earth is 1.0 year. The average mean distance of Saturn from the sun is 1427 $\times 10^6$ km. Using Kepler's third law, calculate the period of Saturn.
2. Which of the following is one of Kepler's Laws of Planetary Motion?
    1. Planets move in elliptical orbits with the Sun at one focus.
    2. Gravitational force between two objects decreases as the distance squared.
    3. An object in motion remains in motion.
    4. Inner planets orbit in a different direction that outer ones.
3. If a planet's orbital speed is 20 km/s when it's at its average distance from the sun, which is most likely orbital speed when it is nearest the sun?
    1. 10 km/s
    2. 15 km/s
    3. 20 km/s
    4. 25 km/s

Explore More

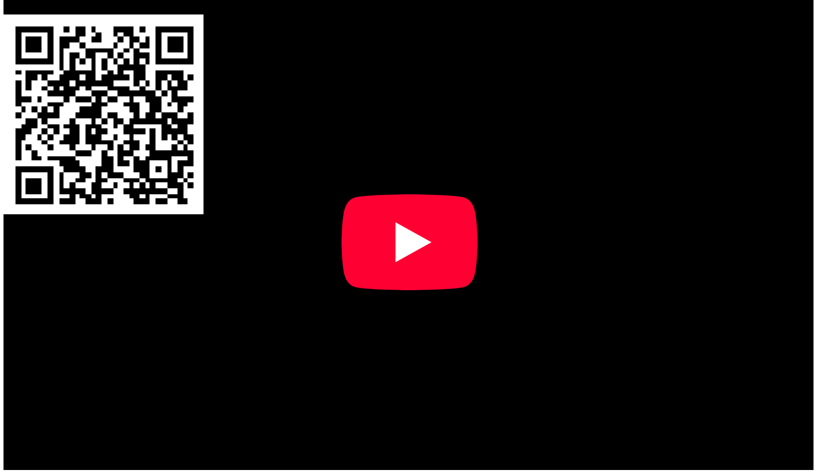
Use this resource to answer the questions that follow.

1. What is the shape of a planetary orbit?
2. How are the areas swept out by the line able to be equal, when the line is much longer at some times than others?
3. What is the T in Kepler's Third Law? What is the r?

Additional Resources

Real World Application: Perturbed Planets

Video:



Study Guide: Gravitation Study Guide
