

$$M_1 = \frac{1}{P^2} = \frac{1}{0.71^2} = \frac{1}{0.5} = 2$$

So the mass of the star is twice the mass of our Sun. (Remember that this way of expressing the law has units in terms of Earth and the Sun, so masses are expressed in units of the mass of our Sun.)

Check Your Learning

Suppose a star with twice the mass of our Sun had an earthlike planet that took 4 years to orbit the star. At what distance (semimajor axis) would this planet orbit its star?

Answer:

Again, we can neglect the mass of the planet. So $M_1 = 2$ and $P = 4$ years. The formula is $a^3 = M_1 \times P^2$, so $a^3 = 2 \times 4^2 = 2 \times 16 = 32$. So a is the cube root of 32. To find this, you can just ask Google, “What is the cube root of 32?” and get the answer 3.2 AU.

LINK TO LEARNING



You might like to try a [simulation \(https://openstax.org/l/30phetsimsunear\)](https://openstax.org/l/30phetsimsunear) that lets you move the Sun, Earth, Moon, and space station to see the effects of changing their distances on their gravitational forces and orbital paths. You can even turn off gravity and see what happens.

3.4 Orbits in the Solar System

Learning Objectives

By the end of this section, you will be able to:

- Compare the orbital characteristics of the planets in the solar system
- Compare the orbital characteristics of asteroids and comets in the solar system

Recall that the path of an object under the influence of gravity through space is called its orbit, whether that object is a spacecraft, planet, star, or galaxy. An orbit, once determined, allows the future positions of the object to be calculated.

Two points in any orbit in our solar system have been given special names. The place where the planet is closest to the Sun (*helios* in Greek) and moves the fastest is called the **perihelion** of its orbit, and the place where it is farthest away and moves the most slowly is the **aphelion**. For the Moon or a satellite orbiting Earth (*gee* in Greek), the corresponding terms are **perigee** and **apogee**. (In this book, we use the word *moon* for a natural object that goes around a planet and the word **satellite** to mean a human-made object that revolves around a planet.)

Orbits of the Planets

Today, Newton’s work enables us to calculate and predict the orbits of the planets with marvelous precision. We know eight planets, beginning with Mercury closest to the Sun and extending outward to Neptune. The average orbital data for the planets are summarized in [Table 3.2](#). (Ceres is the largest of the *asteroids*, now considered a dwarf planet.)

According to Kepler’s laws, Mercury must have the shortest orbital period (88 Earth-days); thus, it has the highest orbital speed, averaging 48 kilometers per second. At the opposite extreme, Neptune has a period of 165 years and an average orbital speed of just 5 kilometers per second.

All the planets have orbits of rather low eccentricity. The most eccentric orbit is that of Mercury (0.21); the rest

have eccentricities smaller than 0.1. It is fortunate that among the rest, Mars has an eccentricity greater than that of many of the other planets. Otherwise the pre-telescopic observations of Brahe would not have been sufficient for Kepler to deduce that its orbit had the shape of an ellipse rather than a circle.

The planetary orbits are also confined close to a common plane, which is near the plane of Earth's orbit (called the ecliptic). The strange orbit of the dwarf planet Pluto is inclined about 17° to the ecliptic, and that of the dwarf planet Eris (orbiting even farther away from the Sun than Pluto) by 44° , but all the major planets lie within 10° of the common plane of the solar system.

LINK TO LEARNING



JavaLab's [solar system simulator \(https://openstax.org/l/30solarsim\)](https://openstax.org/l/30solarsim) allows you to explore the size and speed of the planets' orbits, and view the orbits from different perspectives.

Orbits of Asteroids and Comets

In addition to the eight planets, there are many smaller objects in the solar system. Some of these are moons (natural satellites) that orbit all the planets except Mercury and Venus. In addition, there are two classes of smaller objects in heliocentric orbits: *asteroids* and *comets*. Both asteroids and comets are believed to be small chunks of material left over from the formation process of the solar system.

In general, asteroids have orbits with smaller semimajor axes than do comets ([Figure 3.10](#)). The majority of them lie between 2.2 and 3.3 AU, in the region known as the **asteroid belt** (see [Comets and Asteroids: Debris of the Solar System](#)). As you can see in [Table 3.2](#), the asteroid belt (represented by its largest member, Ceres) is in the middle of a gap between the orbits of Mars and Jupiter. It is because these two planets are so far apart that stable orbits of small bodies can exist in the region between them.

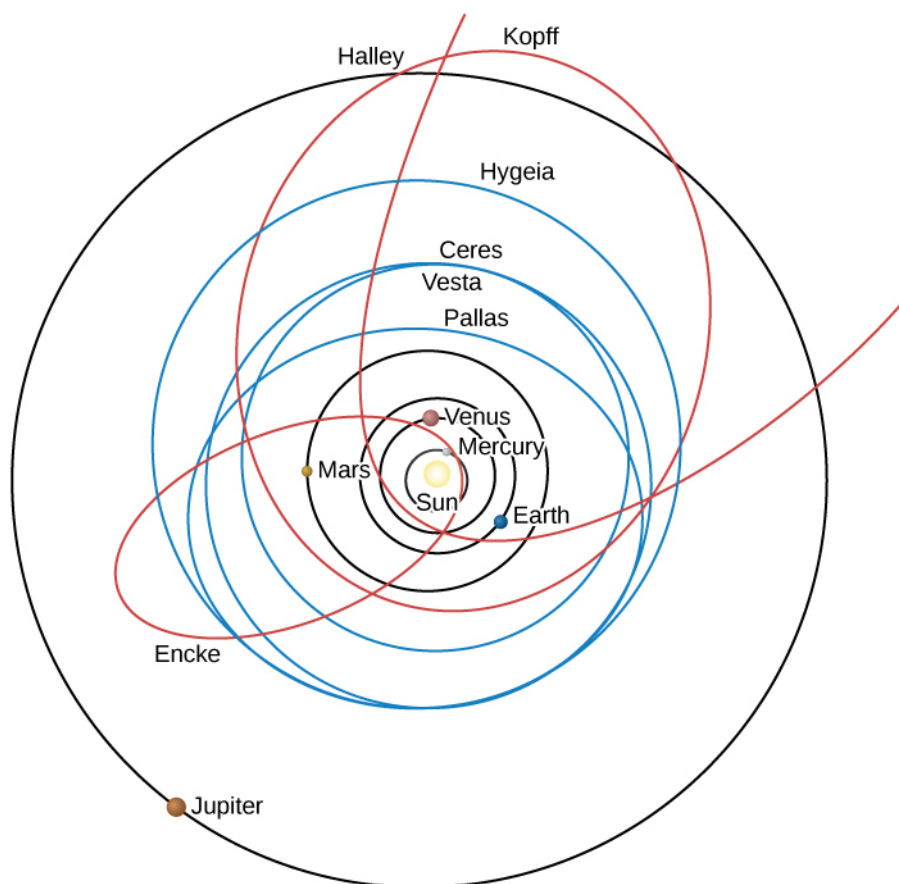


Figure 3.10 Solar System Orbits. We see the orbits of typical comets and asteroids compared with those of the planets Mercury, Venus, Earth, Mars, and Jupiter (black circles). Shown in red are three comets: Halley, Kopff, and Encke. In blue are the four largest asteroids: Ceres, Pallas, Vesta, and Hygeia.

Orbital Data for the Planets

Planet	Semimajor Axis (AU)	Period (y)	Eccentricity
Mercury	0.39	0.24	0.21
Venus	0.72	0.6	0.01
Earth	1	1.00	0.02
Mars	1.52	1.88	0.09
(Ceres)	2.77	4.6	0.08
Jupiter	5.20	11.86	0.05
Saturn	9.54	29.46	0.06
Uranus	19.19	84.01	0.05

Table 3.2

Planet	Semimajor Axis (AU)	Period (y)	Eccentricity
Neptune	30.06	164.82	0.01

Table 3.2

Comets generally have orbits of larger size and greater eccentricity than those of the asteroids. Typically, the eccentricity of their orbits is 0.8 or higher. According to Kepler's second law, therefore, they spend most of their time far from the Sun, moving very slowly. As they approach perihelion, the comets speed up and whip through the inner parts of their orbits more rapidly.

3.5 Motions of Satellites and Spacecraft

Learning Objectives

By the end of this section, you will be able to:

- Explain how an object (such as a satellite) can be put into orbit around Earth
- Explain how an object (such as a planetary probe) can escape from orbit

Newton's universal law of gravitation and Kepler's laws describe the motions of Earth satellites and interplanetary spacecraft as well as the planets. Sputnik, the first artificial Earth satellite, was launched by what was then called the Soviet Union on October 4, 1957. Since that time, thousands of satellites have been placed into orbit around Earth, and spacecraft have also orbited the Moon, Venus, Mars, Jupiter, Saturn, and a number of asteroids and comets.

Once an artificial satellite is in orbit, its behavior is no different from that of a natural satellite, such as our Moon. If the satellite is high enough to be free of atmospheric friction, it will remain in orbit forever. However, although there is no difficulty in maintaining a satellite once it is in orbit, a great deal of energy is required to lift the spacecraft off Earth and accelerate it to orbital speed.

To illustrate how a satellite is launched, imagine a gun firing a bullet horizontally from the top of a high mountain, as in [Figure 3.11](#), which has been adapted from a similar diagram by Newton. Imagine, further, that the friction of the air could be removed and that nothing gets in the bullet's way. Then the only force that acts on the bullet after it leaves the muzzle is the gravitational force between the bullet and Earth.