McAuliffe-Shepard Discovery Center

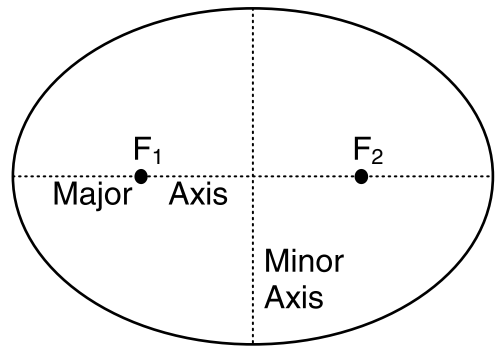
Totally Elliptical

Did you know that Earth's orbit around the Sun is not a perfect circle? Although it is close to being circular, the actual shape of Earth's orbit is described by an ellipse (similar to an oval). All of the planets, their moons, the asteroids, and comets have elliptical orbits.

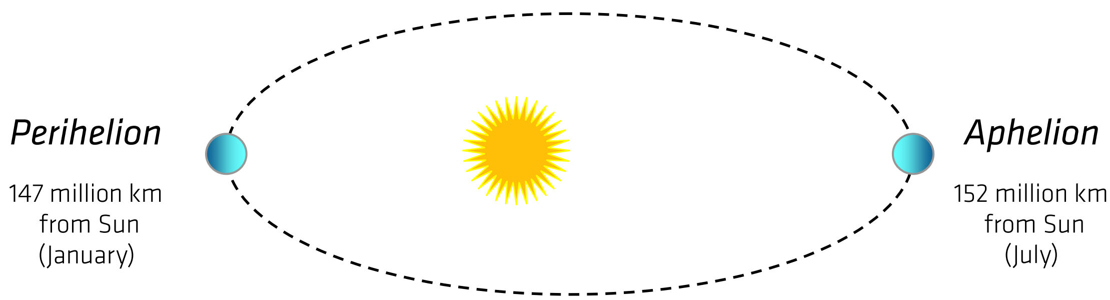
The degree of roundness or elongation of an ellipse is called eccentricity. The orbits of all the planets in our solar system are nearly circular and are therefore said to have low eccentricity. Asteroids and comets, on the other hand, may have orbits that are highly eccentric, meaning their orbits are greatly elongated (not round).

In mathematical terms, an ellipse is defined as the set of all points the sum of whose distance from two fixed points is constant. Fortunately, this definition is easy to visualize, as will be seen shortly.

The two fixed points mentioned above are called the *foci* (plural of focus), shown as F_1 and F_2 in the diagram at right. The foci are located along the major axis of the ellipse.



Because Earth traces a slightly elliptical path around the Sun, the distance from Earth to the Sun varies over the course of a year. Earth's closest approach to the Sun is called the perihelion. Its most distant point from the Sun, 180º opposite the perihelion, is called the aphelion. The Sun is positioned at one of the foci of the ellipse (the other focus being an imaginary point in space). These spatial relationships are exaggerated in the diagram below.



Many people mistakenly believe that our seasons are caused by variations in the Earth-Sun distance. But notice that aphelion occurs in the middle of winter in the Northern Hemisphere. In fact, it is the tilt of Earth's axis that is responsible for our seasons, not the shape of Earth's orbit.

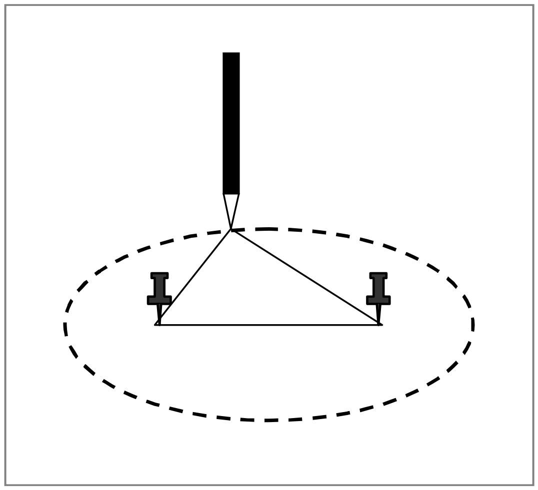
How to Draw an Ellipse

Materials: 8½" x 11" sheet of white paper, same-size piece of corrugated cardboard, 25-cm (10-inch) length of string, two push pins, ruler, pencil

Procedure:

1. With the ruler and pencil, make a faint line down the center of the paper lengthwise. This line will be the long axis of your ellipse.
2. Place the paper on the piece of cardboard. On the axis, near the middle of the paper, insert the two pushpins about 2 centimeters apart. The pushpins represent the foci of the ellipse.

3. Tie the two ends of the string together to make a loop. Place the loop around the two pushpins and pull the loop taught with your finger to make a triangle out of the string. Rotate your finger around the pushpins while keeping the string taught. You have just traced an ellipse with your finger!
4. Notice that the lengths of the two legs of the triangle extending outward from the foci change as you rotate the string, but their sum does not. *That is the definition of an ellipse*.
5. Now use a pencil in place of your finger and make the same motion to draw a complete ellipse. Again it is necessary to keep the string taught by pulling gently with the pencil as you rotate it around the pushpins.
(Note: If the pencil extends beyond the paper, shorten the loop a little.)
6. Repeat the procedure with the foci set at 4, 6, 8, and 10 centimeters apart, so that you end up with a family of five ellipses. Try to set the pushpins in such a way that all of the ellipses have the same center – your drawing will look much better.



Answer the following questions:

- What happens to the eccentricity of an ellipse as you increase the distance between foci?

- What is the result when the foci are so close together that they become the same point (the distance between them is zero)?

- The eccentricity of Earth's orbit is a very low 0.017. If eccentricity is mathematically defined as the ratio of one-half the distance between the foci and one-half the length of the major axis,

$$\text{eccentricity} = \frac{\text{one-half the distance between } F_1 \text{ and } F_2}{\text{one-half the length of the major axis}}$$

  what is the distance between the foci of Earth's orbit? (Hint: Use the average Earth-Sun distance of 150,000,000 km (93,000,000 miles) in the denominator.)

- Astronomers have determined that the eccentricity of Earth's orbit changes over long periods of time, varying from 0 to about 0.06. This variation is believed to be a factor in global warming and cooling cycles. Why do you think the changing elliptical shape of Earth's path around the Sun could have an effect on global temperatures?

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Teachers' Notes

Objectives: Students will create ellipses and apply mathematical concepts to describe the elliptical nature of Earth's orbit around the Sun. Students will also consider the changing shape of Earth's orbit as it might apply to global temperature changes.

Grade Level: Middle/High

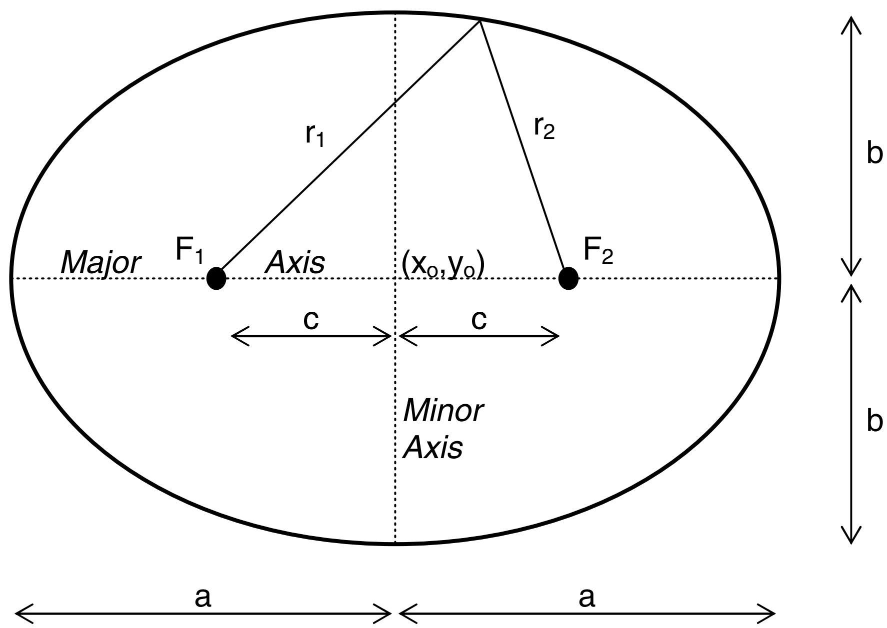
NSES: B5, B6, D6

NHSCF: 1a, 2c, 5e, 6a, 6b, 6c, 6d

Key Concepts

The orbital motions of planets, moons, asteroids, and comets are described by *ellipses*. An ellipse is defined as the set of all points the sum of whose distance from two fixed points, called *foci* (plural of focus), is constant. For any body orbiting the sun, the Sun will be located at one of the foci, while the other focus will be an imaginary point in space.

The elliptical nature of Earth's orbit means that the Earth-Sun distance varies continuously in a predictable fashion over the course of a year. However, this variation is not responsible for the seasons, which are caused by Earth's axial tilt. The following drawing and equations will be useful in understanding the concept of an ellipse.



The general form of the equation for an ellipse is $\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1$,

where a is one-half the dimension of the *major axis* and b is one-half the dimension of the *minor axis*. The *radii* r_1 and r_2 are variable in length, but the sum $r_1 + r_2$ is a constant.

Eccentricity, a measure of the roundness or elongation of an ellipse, is defined as the ratio of one-half the distance between the foci and one-half the length of the major axis, or e = c/a, where c is the distance between either focus and the center of the ellipse.

$$\text{eccentricity, } e = \frac{\text{one-half the distance between } F_1 \text{ and } F_2}{\text{one-half the length of the major axis}} = c/a$$

For any ellipse, $0 < e < 1$. The rounder the ellipse, the lower the value of e. When e is zero, the figure is a circle.

Earth's orbit is very nearly circular, so its eccentricity is low on the scale. However, astronomers have determined that the eccentricity of the Earth is not constant. The value of e varies between 0 and 0.06 over a period of approximately 100,000 years and is presently around 0.017. This variation in eccentricity is one of three factors related to Earth's orbital movements that are thought to contribute to global warming and cooling cycles. (The other orbital elements are axial inclination and precession. The three factors together form the basis for the Milankovitch Theory, which correlates well with global warming and cooling periods contained in the geologic record.)

Because they are a function of eccentricity, the minimum and maximum Earth-Sun distances (*perihelion* and *aphelion*, respectively) are changing in conformance to the 100,000-year cycle.

For additional information, visit these websites:

http://www.ncdc.noaa.gov/paleo/milankovitch.html
http://www.nasa.gov/audience/forstudents/5-8/features/orbit_feature_5-8.html
http://www.astro-tom.com/technical_data/elliptical_orbits.htm

ANSWER KEY

- What happens to the eccentricity of an ellipse as you increase the distance between foci?

  Sample Response: The ellipse becomes less like a circle and more elongated or squashed.

- What is the result when the foci are so close together that they become the same point (the distance between them is zero)?

  Sample Response: The ellipse becomes a circle.

- The eccentricity of Earth's orbit is a very low 0.017. If eccentricity is mathematically defined as the ratio of one-half the distance between the foci and one-half the length of the major axis, what is the distance between the foci of Earth's orbit? (Hint: Use the average Earth-Sun distance of 150,000,000 km (93,000,000 miles) in the denominator.)

  0.017 = one-half the distance between foci / 150,000,000 km

  distance between foci = 0.017 x 150,000,000 km x 2 = 5,100,000 km (1,580,000 miles)

- Astronomers have determined that the eccentricity of Earth's orbit changes over long periods of time, varying from 0 to about 0.06. This variation is believed to be a factor in global warming and cooling cycles. Why do you think the changing elliptical shape of Earth's path around the Sun could have an effect on global temperatures?

  Sample Response: The changing distances between the Earth and sun would change the amount of solar energy reaching Earth at different times of the year. The changing solar energy could affect climate.