ScienceNews

Answer Key for Teachers: Lunar Orbit

Activity questions

1. The moon's orbit around Earth is elliptical. Explain what this means.

The moon doesn't travel around Earth in a perfect circle; the circle is squished a bit so it is wider than it is long.

2. The equation that follows describes the eccentricity of the moon's orbit — how much the orbit varies from being a perfect circle. In this equation for eccentricity (*e*), *a* is apogee distance and *p* is perigee distance.

$$e = 1 - \frac{2}{\frac{a}{p} + 1}$$

When *a* and *p* are approximately equal, what is the rough value of *e*? What happens to *e* as *a* becomes much larger than *p*? How does the value of *e* affect the shape of the ellipse?

When a *and* p *are approximately equal, the value of* e *is close to zero. As* a *becomes much larger than* p, *the value of* e *approaches one. The eccentricity of a perfect circle is zero and the eccentricity of an ellipse that has been squished to a flat line is one.*

3. In which month is the moon's closest approach (perigee)? In which month is its farthest approach (apogee)? What do you notice? Describe your observations.

The closest approach in 2019 is in February. The farthest approach is also in February. Because they occurred in the same month, the moon's orbit must be a bit more elliptical during this month.

4. In which month is the farthest perigee? In which month is the closest apogee? How does this compare with the closest perigee and farthest apogee?

The farthest perigee is in December. The closest apogee is in May. In the previous question, the closest perigee and farthest apogee were in the same month, indicating that the moon's orbit was probably a bit more elliptical than normal. The farthest perigee and closest apogee for 2019 did not occur in the same month, so we can't easily determine the shape of the moon's orbit from that information alone.

5. What is the average distance for perigee? What is the average distance for apogee?

perigee average distance: 362,430 km
apogee average distance: 405,504 km

6. If the moon continues moving away from Earth at the rate indicated in the article, 3.8 centimeters per year, how long will it take the moon to move one kilometer away?

3.8 cm/year → 3.8 x 10^{-5} km/year
1 km / (3.8 x 10^{-5} km/year) = 26 x 10^{3} years
At the current rate, the moon will take about 26 x 10^{3} years to move 1 kilometer farther away from Earth.

7. If the radius of the moon's orbit did increase by one kilometer but the moon still traveled along its path at the same speed, how would the length of the lunar month change?

Use the base distance of 398,304 km and the equation:

$$P^2 = \frac{4\pi^2 a^3}{G(M_1 + M_2)}$$

In this equation, *a* is the average distance of the moon in meters, *P* is measured in Earth seconds and M_1 and M_2 are measured in solar masses.

Original a = 398,304 km = 398,304,000 m

$$P = \sqrt{\frac{4\pi^2(398{,}304{,}000\,m)^3}{(6.67 \times 10^{-11}\frac{m^3}{kgs^2})(5.972 \times 10^{24}kg + 7.348 \times 10^{22}kg)}}$$

P = 248 x 10^{4} seconds = 28.7 days

New a = 398,305 km = 398,305,000 m

$$P = \sqrt{\frac{4\pi^2(398{,}305{,}000\,m)^3}{(6.67 \times 10^{-11}\frac{m^3}{kgs^2})(5.972 \times 10^{24}kg + 7.348 \times 10^{22}kg)}}$$

P = 248 x 10^{4} seconds = 28.7 days

With a one-kilometer change in distance, the time it takes the moon to complete an orbit would not change dramatically.

8. How far would the moon have to move away from Earth to change the moon's orbit by one day?

$$P^2 = \frac{4\pi^2 a^3}{G(M_1+M_2)} \rightarrow a^3 = \frac{G(M_1+M_2)P^2}{4\pi^2} \rightarrow a = \sqrt[3]{\frac{G(M_1+M_2)P^2}{4\pi^2}}$$

$$a = \sqrt[3]{\frac{(6.67 \times 10^{-11}\frac{m^3}{kgs^2})(5.972 \times 10^{24}kg + 7.348 \times 10^{22}kg)(2480000s + 86400s)^2}{4\pi^2}}$$

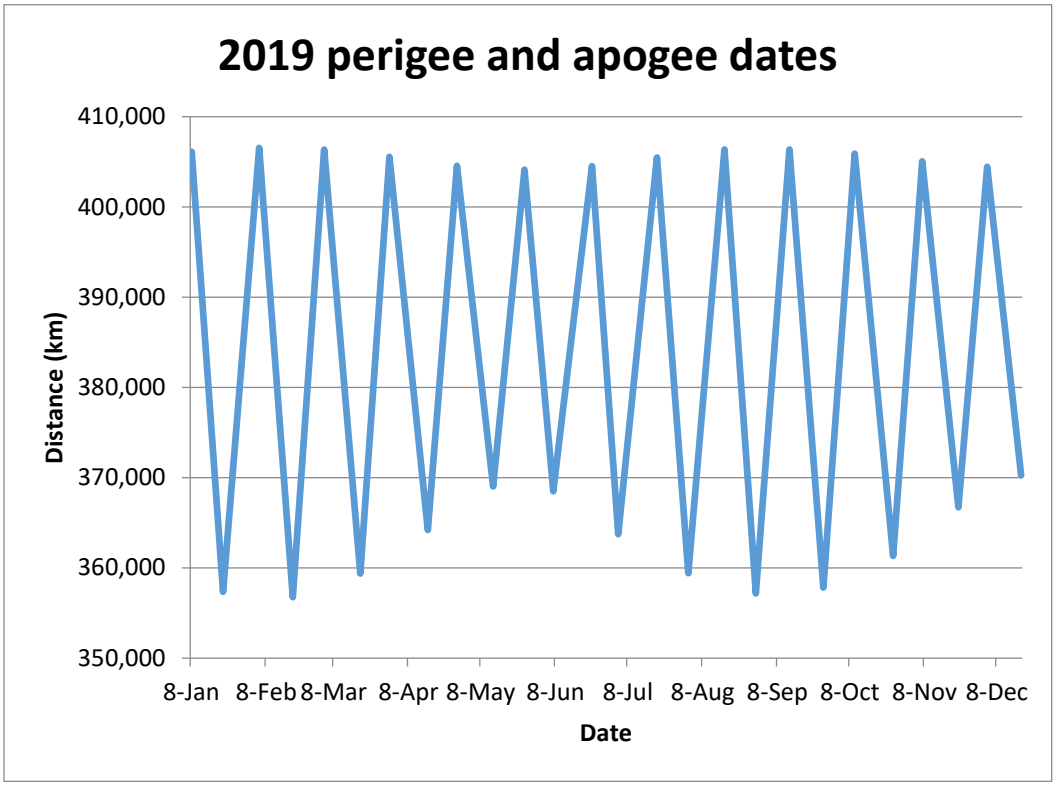
a = 407,000,000 m = 407,000 km
407,000 km - 398,304 km = 9,000 km

The moon would have to move about 9,000 km away to add a full day to its orbit, assuming it keeps the same speed along its orbit.

Data analysis and graphing

9. Use graph paper, a computer or a calculator to graph the data for both perigee and apogee on the same set of axes to trace the path of the moon's orbit. What type of graph might you use?

A linear graph (shown as an example) or scatter graph with the points connected.



10. What does the shape of the graph tell you about the moon's orbit around Earth?

Answers should include something about how one orbit is not exactly the same as the next and that the variations in distances between perigee and apogee appear to be cyclical.

11. Where on the graph is the difference between perigee and apogee distance the greatest? During what month is the difference least? Calculate the rough eccentricity for these months.

Answers may vary, but the most likely answer for the greatest distance is February:

$$e = 1 - \frac{2}{\frac{406000}{357000} + 1}$$

e = 0.0642

The most likely answer for the smallest distance is May or June:

$$e = 1 - \frac{2}{\frac{404000}{368000} + 1}$$

e = 0.0466

12. How did your calculations of the two eccentricities compare? What does that tell you about the shape of the moon's orbit?

The eccentricity during February of 2019 was slightly greater than the eccentricity during May/June. Answers should include that the eccentricity of the moon's orbit changes over time.

13. If the eccentricity of the moon's orbit were to double, how would the ratio of *a* to *p* be affected?

Student answers will vary slightly depending on the eccentricity they choose to use. For an average eccentricity of 0.055:

$$0.055 = 1 - \frac{2}{\frac{a}{p} + 1}$$

$$\frac{2}{\frac{a}{p} + 1} = 0.945$$

$$\frac{a}{p} + 1 = \frac{2}{0.945}$$

$$\frac{a}{p} = 1.116$$

Doubling that gives:

$$0.110 = 1 - \frac{2}{\frac{a}{p} + 1}$$

$$\frac{2}{\frac{a}{p} + 1} = 0.890$$

$$\frac{a}{p} + 1 = \frac{2}{0.890}$$

$$\frac{a}{p} = 1.247$$

Doubling the eccentricity will not dramatically change the ratio of a/p since we started with a very low eccentricity. If the eccentricity started out higher, then doubling it would show a more dramatic change.

14. What causes variations in the moon's eccentricity?

Answers should include the gravitational pull of Earth and the sun as the primary influencers for the variations in the moon's orbital parameters.

15. How do the variations in the moon's eccentricity affect Earth?

Answers should include tides: The differences in eccentricity of the moon's orbit can significantly affect the tides. The moon tugs on Earth's oceans more when it is closer, creating larger tidal ranges than when it is farther away. Greater eccentricities cause more extremes in the distance between perigee and apogee and can lead to higher high tides and lower low tides. Other effects can also include tidal braking — the slight slowing of Earth's rotation due to the tidal friction caused by the gravitational pull between Earth and the moon.

16. With the moon slowly moving away from Earth, how might the eccentricity of the moon's orbit be affected?

Answers may include that because eccentricity is calculated with the smallest and largest distances between Earth and the moon, a change in either measurement will change the eccentricity. Moving away from Earth may allow greater gravitational influence from other bodies such as the sun, which could make the orbit more eccentric.

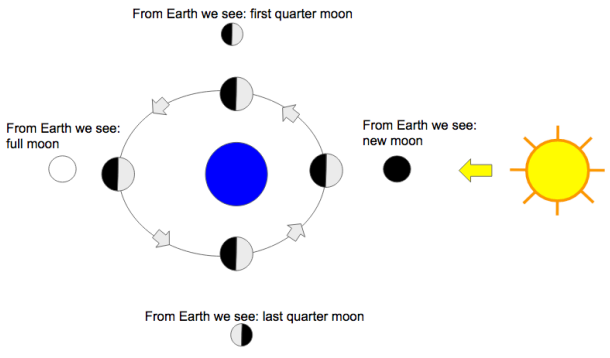
Bonus questions

17. Humans have known since ancient times that we can only see one side of the moon from Earth. Why do we only see one side of the moon?

The moon completes one full rotation in the same amount of time that it completes an orbit around Earth. As the moon turns, it rotates around the Earth so that the same side is always facing Earth.

18. The phases of the moon are caused by the orientations of Earth, the moon and the sun. Sketch and label what phases of the moon will occur at the various positions on the moon's orbit around Earth.

Answers will vary slightly but should look similar to the image shown below.



19. If a solar eclipse occurs when the moon comes between the sun and Earth, why don't eclipses occur every month? What is the difference between a total and partial eclipse?

The moon's orbital plane around Earth is tilted slightly relative to the Earth's orbital plane around the sun. In

non-eclipse months, the new moon is slightly higher or lower in the sky than the sun. A partial eclipse occurs when the moon's orbital plane brings the moon close enough to the Earth orbital plane that only part of the sun is covered by the new moon. A total eclipse occurs when the moon, Earth and sun perfectly line up.

20. Using your knowledge of the moon's orbit, can you explain what a "super moon" is?

The super moon occurs when the full moon occurs at perigee, so it appears larger and brighter because it is closer to Earth.