Activity Two: Latency

Educator Notes

Learning Objectives

Students will

- Explain the relationship among frequency, wavelength, and speed with respect to electromagnetic waves.
- Calculate the latency time for signals transmitted between Earth and other locations in the solar system.
- Construct and use a model to demonstrate the ongoing change in distance, and thus signal latency, between Earth and Mars due to their differing orbital periods.

Challenge Overview

In this activity, students will derive the speed of light by observing a microwave oven and using the formula **Speed = Frequency × Wavelength**. Using the known operating frequency of microwave ovens and measuring the wavelength of the microwaves by observing the interactions between the microwaves and food within a microwave oven, students will be able to calculate the speed of light. They will then use the speed of light to calculate the latency, or signal delay time, between the Earth and other objects in the solar system. Finally, students will create a device that allows them to model the distance between Earth and Mars at different points in their orbits and determine the latency for a signal to reach Mars at different times during a Mars mission.

Suggested Pacing

60 to 90 minutes

National STEM Standards

Computer Science (CSTA)	
Standards for Students • 2-DA-09: Refine computational models based on the data they have generated.	
Science and Engineering (NGSS)	
• MS-PS4-2: Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials. • MS-ESS1.B Earth and the Solar System: The solar system consists of the Sun and a collection of objects, including planets, their moons, and asteroids that are held in orbit around the Sun by its gravitational pull on them. *Disciplinary Core Ideas* • PS4.A Wave Properties: A simple wave has a repeating pattern with a specific wavelength, frequency, and amplitude.	*Disciplinary Core Ideas (continued)* • PS4.B Electromagnetic Radiation: When light shines on an object, it is reflected, absorbed, or transmitted through the object, depending on the object's material and the frequency (color) of the light. *Crosscutting Concepts* • Structure and Function: Structures can be designed to serve particular functions by taking into account properties of different materials and how materials can be shaped and used. *Science and Engineering Practices* • Developing and Using Models: Develop and use a model to describe phenomena.
Mathematics (CCSS)	
Mathematical Practices • CCSS.MATH.CONTENT.8.EE.A.4: Perform operations with numbers expressed in scientific notation, including problems where both decimal and scientific notation are used. Use scientific notation and choose units of appropriate size for measurements of very large or very small quantities. Interpret scientific notation that has been generated by technology.	*Mathematical Practices (continued)* • CCSS.MATH.CONTENT.7.G.A: Draw, construct, and describe geometrical figures and describe the relationship between them. • CSS.MATH.CONTENT.7.EE.B.3: Solve real-life and mathematical problems using numerical and algebraic expressions and equations.

Challenge Preparation

The educator should

- Read the introduction and background information, particularly the information about latency.
- Read the Educator Notes and the Student Handout to become familiar with the activity.
- Make copies of the Student Handout and templates and gather necessary materials.
- Locate the label on the microwave oven and note the frequency. Most commercial microwaves utilize a frequency of 2,450 MHz (2.4 GHz).

Materials

- ☐ Microwave oven with removable turntable
- ☐ Microwave-safe casserole dish
- ☐ Miniature marshmallows (enough to cover the bottom of the casserole dish one layer thick). Note: Chocolate chips, shredded cheese, or other small, easily meltable food may be substituted for the marshmallows.
- ☐ Metric ruler
- ☐ Copies of Student Handout and Compass Template, Mars Orbit Template, and Earth Orbit Template
- ☐ Scissors
- ☐ Brass fasteners
- ☐ Calculator (optional)

Safety

- Use safety when operating the microwave oven. Only heat food in 5- to 10-second intervals. Contents may be hot when removed for inspection.
- Be careful of any food allergies of students who participate in the activity.
- Practice safety when using scissors and brass fasteners to avoid cut and puncture hazards.

Introduce the Challenge

Ask students a few of the following questions:

- How long does it take for your voice to travel from your phone to the phone of another person?
- How long does it take for information from the internet to travel from a wireless router in your home or school to your computer?
- How long does it take for a TV signal to travel from a satellite to your home TV?
- Why is there a delay between lightning and thunder?
- How fast do all these signals travel?

Students will likely give answers such as “instantly,” “right away,” or “less than a second.” Inform students that all these signals are sent as waves of the electromagnetic spectrum (usually microwaves or radio waves), and, like all waves of the electromagnetic spectrum, they travel at the speed of light. Even though the speed of light seems very fast, it is not instantaneous, and there is a measurable delay between when a signal is sent and when it is received. This delay is known as *latency*. On Earth, latency is a fraction of a second, but sending messages deep into our solar system can result in latency times measured in hours.

Tell students they will be

- Measuring the speed of light using common household items
- Using that measurement to calculate the latency times for signals traveling from Earth to other parts of the solar system

Share With Students

Brain Booster

Upgrades to the Deep Space Network allowed NASA to reconnect with Voyager 2, a space probe launched in 1977. The probe is currently about 18 billion kilometers from Earth, and it takes over 16 hours for signals traveling at the speed of light to make the trip each way.

Learn more: https://voyager.jpl.nasa.gov/

On Location

The Hawaii Space Exploration Analog and Simulation (HI-SEAS) habitat, operated by the University of Hawaii and funded by NASA, simulates the experience of being isolated in a Mars-like environment. To enhance this experience, crews cannot communicate with the outside world in real time. All communications are delayed by 20 minutes to simulate the high-latency times one would experience on Mars.

Learn more: https://earthobservatory.nasa.gov/images/92630/living-the-mars-life-on-mauna-loa

Engage

Ask students the following questions and have them write their answers in their Student Handouts. Ask for a few volunteers to share their answers aloud and record them on the board to reference later.

- How fast is the speed of light (in km/s)?
- How long would it take (in seconds or minutes) for a beam of light to travel from the Earth to
  - The Sun?
  - A spacecraft in near Earth orbit?
  - A communications satellite in geosynchronous orbit?
  - The Moon?

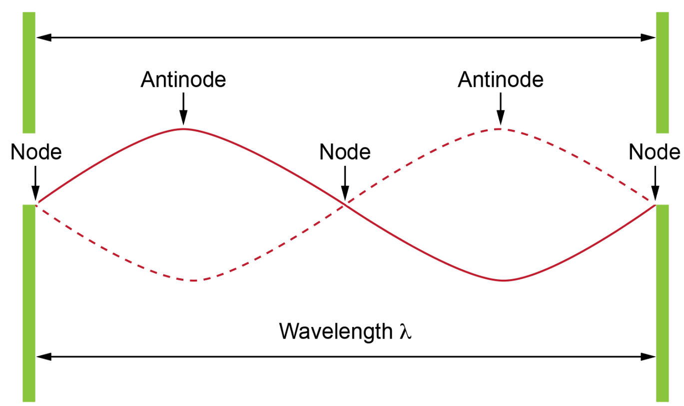
Facilitate the Challenge

Explore

Have students find the wavelengths emitted by the microwave oven by following the listed procedures:

1. Completely cover the bottom of the casserole dish with a single layer of marshmallows. The marshmallows should be packed together side by side but not piled on top of each other.
2. Remove the turntable from the microwave. The experiment will fail if the casserole dish does not remain stationary while in the microwave.
3. Place the marshmallows and dish in the microwave and power it on a low setting.
4. Observe the marshmallows, either through the front window or by opening the door at 10-second intervals. Continue to heat the marshmallows until several melted spots can be seen. Do not melt all the marshmallows, and do not move the casserole dish while inspecting.
5. Once several melted spots are visible, remove the dish from the microwave and return it to the work area.

Explain to students that microwaves heat food by sending a steady stream of microwaves into the food at a very specific frequency. This particular frequency of microwaves is absorbed by the water molecules in the food, causing them to gain kinetic energy and therefore heat up. But the energy within electromagnetic waves, such as microwaves, is not consistent throughout the wave. It is concentrated at the antinodes of the waves, or the areas where the crests and troughs of the waves oscillate (move back and forth).



As a result, the food within a microwave is heated unevenly where the antinodes collide with the food. This is why most microwaves have a turntable to help even out the heating of the food. Explain to students that eliminating the turntable concentrated the energy of the microwaves into small areas where the antinodes intersected the marshmallows and created hotspots. Now that they can see where each antinode passed through the marshmallows, they can measure the wavelength of the microwaves.

Have students perform the following procedures:

1. Using a metric ruler, carefully measure (to the nearest tenth of a centimeter) the distance between the centers of the melted spots in two of the marshmallows. The melted spots should be uniformly spaced from one another, so students may use any two adjacent melted spots to take this measurement.
2. Record this measurement (in centimeters to the first decimal place) in the Student Handout.
3. Because there are two antinodes in each wavelength, where both the crest and trough oscillate, the measurement will be for 1/2 the wavelength. Double the antinode measurement to find one full wavelength of the microwaves from the oven and record it (in centimeters) in the Student Handout.

Explain to students the formula for speed of waves**: Speed = Frequency × Wavelength**. Frequency is the measurement of how often a single wavelength is given off and is measured in cycles per second, or Hertz (Hz). Show students where the frequency is listed on the microwave oven's label (it is likely listed as 2,450 MHz or 2.45 GHz) and have them convert this to Hz and record it in their Student Handouts. Multiplying the frequency and the wavelength (measured in centimeters) will yield a very large number in cm/s. Have students convert their calculations to km/s as whole numbers and, if they are able, in scientific notation. These final calculations are the students' measured speed of light. Answers are given in bold in the table below.

Note: Many of the calculations are based on students' measurements and will therefore not be precise answers. The following answer key should be used as a guide to ensure that students are on the right track, not as a grading assessment.

Frequency of microwave, Hz	2,450,000,000 Hz or 2,450 MHz or 2.45 GHz
Measured antinode, cm	Approx. 6.1 cm
Calculated wavelength, cm	Approx. 12.2 cm
Calculated speed of light, cm/s	Approx. 29,900,000,000 cm/s
Calculated speed of light, km/s (whole number)	Approx. 299,000 km/s
Calculated speed of light, km/s (scientific notation)	Approx. 2.99×10^5 km/s

After students have completed their calculations, have them look up the actual speed of light in km/s (299,800 km/s). Have students use this value as the theoretical value and their measured value as the experimental value to calculate their percent error and to find out how close they were to measuring the actual speed of light. With careful measurements, they should get within 10 percent.

$$\%\ \text{Error} \left| \frac{\text{Theoretical value} - \text{Experimental value}}{\text{Theoretical value}} \right| \times 100$$

For the remainder of this activity, have students use the actual speed of light (299,800 km/s) for all their calculations.

Explain

Have students show that they can now accurately calculate the latency of signals by completing the following table in their Student Handouts.

Object	Distance, km	Latency, s	Latency, s (scientific notation)
Spacecraft in near Earth orbit	408 (4.08×10^2)	**0.00136**	**1.36×10^{-3}**
Geosynchronous satellite	35,800 (3.58×10^4)	**0.119**	**1.19×10^{-1}**
Moon	383,000 (3.83×10^5)	**1.28**	**1.28**
Sun	150,000,000 (1.50×10^8)	(In min, s) **8 min 20 s**	**5.00×10^2**

Have students answer the following questions in their Student Handout:

- All waves in the electromagnetic spectrum travel at the same speed. Would waves that have longer wavelengths than microwaves, like radio waves, have higher or lower frequencies?
- Visible light has much higher frequencies than microwaves. Are its wavelengths longer or shorter than those of microwaves?
- If you are a spectator at a live sporting event and you are also watching the same event live on your phone while in the stands, would you expect the action that you see on your phone to happen at the same time as the action you see on the field? Is watching live sporting events from home really "live"?
- What problems could arise by trying to operate a remotely controlled rover on the lunar surface from Earth?
- What other problems could occur from a delay in communication with astronauts on a deep space mission caused by signal latency?
- The speed of light is different in different mediums (water, air, and the vacuum of space). What can you explain about light that you have observed moving from one medium to another?

Elaborate

Share with students that finding the signal latency to the International Space Station, satellites, and the Moon is fairly straightforward: because they all orbit the Earth in nearly circular orbits, their distances to Earth are constant. The same can be said for the Sun, because Earth's orbit around the Sun is also nearly circular. How can we find the signal latency between two bodies in space whose distance apart is constantly changing? Mars, for example, has an orbital period of 687 days, while Earth's is 365 days. This means that the Earth is orbiting the Sun at a faster rate than Mars, and as the Earth passes Mars, the two planets are getting farther apart until they are 180° apart from each other. At this point, Earth begins to catch up with Mars in its orbit and the two planets continue to get closer together until Earth begins to pass Mars again. Tell students they will build a scale model of the Sun–Earth–Mars system that will allow them to measure the distance between Earth and Mars at different times based on their positions in their orbits.

Have students

- Cut out the three templates located at the end of the Student Handout ("Compass," "Mars Orbit," and "Earth Orbit").
- Punch a small hole in the center dot of each of the three discs.
- Secure the three discs together using the brass fastener, with the 360° protractor on the bottom, the Mars orbit disc in the middle, and the Earth orbit disc on top.

To use their models, students must determine the scale of their models as well as the orbital period of Earth and Mars in degrees per day. Have students take the following measurements, make the necessary calculations, and record their results in the chart in their Student Handout.

Note: The measurements (listed in parentheses below and on the chart that follows) will only be accurate if the templates are printed to the correct scale. A 20-cm line is on the first page of the template to help determine if they have been printed to scale.

- Using a metric ruler, students will measure the distance between the center of Mars and the center of the Sun (brass fastener). (This distance should be 9.0 cm.)
- The average distance between Mars and the Sun is 228 million km. Students will divide this distance by the distance they measured to get the scale of their model in millions of kilometers per centimeter.
- Have students double check this scale by measuring the distance from the center of Earth to the center of the Sun (brass fastener). (This distance should be 5.9 cm).
- The average distance between the Earth and the Sun is 150 million km. Students will divide this distance by the distance they measured to get a number, in millions of kilometers per centimeter, that is very close to the scale they calculated using Mars and the Sun.

Planet	Measured distance to Sun, cm	Average distance to Sun, km	Scale, million km/cm	Are the two scales close? (Yes/No)
Mars	**Approx. 9.0 cm**	228 million km	**25.3 million km/cm**	**Yes**
Earth	**Approx. 5.9 cm**	150 million km	**25.4 million km/cm**	

Help students calculate how far, in degrees, each planet travels each day in its 360° orbit, according to its orbital period.

- Have students record the orbital periods in the table in their Student Handout. This rate, measured in degrees per day, will be used to calculate how far each planet travels in its orbit over different periods of time.
- The orbital period of Mars is 687 days. How far, in degrees, does Mars travel along in its 360° orbit each day? (Should be 0.52° per day)
- The orbital period of Earth is 365 days. How far, in degrees, does the Earth travel along in its 360° orbit each day? (Should be 0.99° per day)

Planet	Orbital period, days	Distance traveled per day, degrees
Mars	687	**0.52°**
Earth	365	**0.99°**

Have students use the following steps to calculate signal latency between Earth and Mars at different times in the planets' orbits.

1. On the model, rotate Earth and Mars so that both planets are at 0°. This point is known as opposition, because Mars and the Sun are on opposite ends of the Earth. This is the point where Earth and Mars are closest in their orbits.
2. Measure the distance between the center of Earth and the center of Mars, and record it in the table.
3. Use the scale of the model that was calculated earlier to find the actual distance, in millions of kilometers. List the actual distance in the table in both whole numbers and in scientific notation.
4. Use the speed of light to find the latency time for a signal to get from the Earth to Mars.
5. Now, on the model, keep Earth at 0° and rotate Mars to 180°. This point is known as solar conjunction, because the Sun and Mars form a straight line with Earth and would appear "conjoined" if viewed from Earth. This is the point where Earth and Mars are farthest apart in their orbits.
6. Follow steps 2 through 4 to find the latency of time for a signal to get from Earth to Mars during solar conjunction.

What if the Earth and Mars were somewhere between opposition and conjunction? Most Mars missions last several years. These missions include orbiting satellites, landers, and rovers, and will one day include crewed missions. The distance between Earth and Mars is constantly changing as time goes by and as the planets move through their orbits. Reliable communication between Earth and Mars is vital for mission success, so it is necessary for mission control to know when a message will be received as well as when to expect a message back. Can latency time be calculated at different times in their orbits? The first orbit timeframe, 100 days after opposition, is worked below. This example would be beneficial to work with your students if they are having difficulty.

- What will the latency time be 100 days after a mission begins while Mars is at opposition? To find this, start with both planets at 0° again. Use the rates that were calculated earlier to determine how far each planet will travel in its orbit, in degrees, after 100 days. At a rate of 0.52° per day, Mars will have traveled 52° after 100 days. At a rate of 0.99° per day, Earth will have traveled 99° in its orbit after 100 days. Place the planets in these positions on your model.
- Measure the distance between Mars and Earth on the model; this should be about 6.5 cm.
- Next, use the scale of the model calculated earlier (25.3 million km in the real world per 1 cm on the model) to find the distance between the planets; this should be about 164 million (1.64 × 108) km.
- Finally, calculate the latency as before, by dividing this distance by the speed of light:
  - 164,000,000 km/299,800 km/s = 547 s, or 9 min, 7 s.
- Use this same method to calculate the signal latency for the rest of the time periods listed in the table.

Time period	Earth position	Mars position	Measured distance, cm	Calculated distance, million km	Calculated distance, km (whole number)	Calculated distance, km (scientific notation)	Latency time, min, s
At opposition	0°	0°	**Approx. 3.1**	**78.4**	**78,400,000**	**7.84×10^7**	**4 min 22 s**
At solar conjunction	0°	180°	**Approx. 14.8**	**374**	**374,000,000**	**3.74×10^8**	**20 min 47 s**
100 days after opposition	**99°**	**52°**	**Approx. 6.5**	**164**	**164,000,000**	**1.64×10^8**	**9 min 7 s**
156 days after opposition	**154°**	**81°**	**Approx. 9.3**	**235**	**235,000,000**	**2.35×10^8**	**13 min 4 s**
320 days after opposition	**317°**	**166°**	**Approx. 14.4**	**364**	**364,000,000**	**3.64×10^8**	**20 min 14 s**
420 days after opposition	**56°**	**218°**	**Approx. 14.7**	**372**	**372,000,000**	**3.72×10^8**	**20 min 41 s**

- If an opposition occurred on October 6, 2020, what would the latency time be for a signal to reach Mars from Earth today? Have students choose another significant date, such as their next birthday, and calculate the latency time for that date as well.

✓ Evaluate

Wrap up the activity by leading a discussion with the following questions:

- How close were you to measuring the speed of light (their percent error)? Anyone within 5 percent, 3 percent, 1 percent?
- Record the percent error of the other groups. What are the mean, median, mode, and range for the percent errors?
- What could some of the possible sources of error be in measuring speed of light?
  - Possible answers: The melted spots were too irregular to find the centers. It was difficult to measure and be precise with a ruler.
- Look at the latency time when Mars was at solar conjunction. If it took 1 minute for someone on Mars to respond to your message, how long would you have to wait for a response after you first sent the message?
- What are some ways long latency times could make communication between deep space astronauts or spacecraft difficult or problematic for mission?
  - Possible answers: Unable to communicate in real time. Unable to control craft remotely in real time. Impossible to know the current status of mission. Slower response to emergencies.
- What are some things that mission controllers can do to mitigate the issues associated with latency?
  - Possible answers: Give more autonomy to astronauts or rovers to make decisions “on the ground.” Create detailed schedules so they can anticipate when information will arrive.

Extensions

- Have students find an online resource that gives the current position of Earth and Mars in the solar system. Ask them if Earth is currently moving closer to Mars or farther away. Have students calculate the latency for a signal to get to Mars today, 2 months from now, and 6 months from now.
- Have students calculate the time between Mars opposition to the next opposition.

  Hint: How much farther (in degrees) does the Earth travel in its orbit than Mars each day? How many days would it take for Earth to catch up with Mars after an opposition?
- Have students look up the average distance from the Sun for the planets Mercury, Jupiter, and Saturn. Using the same scale they used for their model, have students calculate how large each of the orbit circles would need to be for each planet in order for students to be able to use them with their models.

Accommodations

- Scientific notation is a concept that is generally introduced as an 8th grade standard. This activity can be used to introduce scientific notation to students; however, it is not necessary for the completion of this activity. If it is above the students' ability level, the scientific notation columns in the data tables may be omitted or reserved for advanced students.
- If students are having a difficult time with the concept of the ratio calculations, try using descriptive language, such as, "One centimeter on your model is equal to 25.3 million kilometers in the real world."
- The "100 days after opposition" problem was worked out step by step in the Educator Notes. Refer to this section as well as to the answers in the key to help students who may need additional help.
- Some students may have difficulty constructing or manipulating the Sun, Earth, and Mars model. For these students, a larger, more easily manipulated model may be made ahead of time out of materials like poster board or foam board. However, a new ratio will need to be created based on the size of the model. All other concepts and calculated answers will remain the same.

Activity Two: Latency

Student Handout

Your Challenge

In this activity, you will derive the speed of light by observing a microwave oven and using the formula **Speed = Frequency × Wavelength**. Using the known operating frequency of microwave ovens and measuring the wavelength of the microwaves by observing the interactions between the microwaves and food within a microwave oven, you will be able to calculate the speed of light. You will then use the speed of light to calculate the latency, or signal delay time, between the Earth and other objects in the solar system. Finally, you will create a device that will allow you to model the distance between the Earth and Mars at different points in their orbits and determine the latency for a signal to reach Mars at different times during a Mars mission.

Engage

Record your answers to the following questions as they are read aloud.

- How fast is the speed of light (in km/s)? ______________
- How long would it take (in seconds or minutes) for a beam of light to travel from the Earth to
  - The Sun? ___________
  - A spacecraft in near Earth orbit? ___________
  - A communications satellite in geosynchronous orbit? __________
  - The Moon? ___________

Explore

Carefully follow instructions and safety guidelines to find the frequency of the microwave, measure the wavelength of the microwaves, and calculate the speed of light.

Frequency of microwave, Hz	
Measured antinode, cm	
Calculated wavelength, cm	
Calculated speed of light, cm/s	
Calculated speed of light, km/s (whole number)	
Calculated speed of light, km/s (scientific notation)	

- What is the actual speed of light? _________
- What is your percent error? __________

Explain

Now that you know the actual speed of light, use it to calculate the time delay (latency) for a signal to reach the following:

Fun Fact

Is your internet service as fast as the Moon's? In the Lunar Laser Communication Demonstration, NASA was able to transmit data from lunar orbit to Earth at a rate of 622 Mbps using a laser transmitter aboard the Lunar Atmosphere and Dust Environment Explorer (LADEE) satellite. Now, that is some serious streaming!

Learn more: https://www.nasa.gov/content/goddard/historic-demonstration-proves-laser-communication-possible

Career Corner

Interested in a career in space communications? NASA's Space Communications and Navigation (SCaN) has an internship program dedicated to providing hands-on training, and the program is open to high school students. The SCaN Internship Project (SIP) allows students to gain experience working on real missions with cutting-edge space communications systems.

Learn more: https://www.nasa.gov/directorates/heo/scan/communications/outreach/internships

Object	Distance, km	Latency, s (decimals)	Latency, s (scientific notation)
Spacecraft in near Earth orbit	408 (4.08×10^2)		
Geosynchronous satellite	35,800 (3.58×10^4)		
The Moon	383,000 (3.83×10^5)		
The Sun	150,000,000 (1.50×10^8)	(In min, s)	

Use your understanding of the relationship among frequency, wavelength, and speed regarding waves in the electromagnetic spectrum, as well as the implications of signal latency, to answer the following questions:

- All waves in the electromagnetic spectrum travel at the same speed. Would waves that have longer wavelengths than microwaves, like radio waves, have higher or lower frequencies?
- Visible light has much higher frequencies than microwaves. Are its wavelengths longer or shorter than microwaves?
- If you are a spectator at a live sporting event and you are also watching the same event live on your phone while in the stands, would you expect the action that you see on your phone happen at the same time as the action you see on the field? Is watching live sporting events from home really “live”?
- What problems could arise by trying to operate a remotely controlled rover on the lunar surface from Earth?
- What other problems could occur from a delay in communication with astronauts on a deep space mission caused by signal latency?
- The speed of light is different in different mediums (water, air, and the vacuum of space). What can you explain about light that you have observed moving from one medium to another?

Elaborate

Follow your instructor’s instructions to build a scale model of the orbits of the Earth and Mars around the Sun. Determine the scale of the model and fill in the table below.

Planet	Measured distance to Sun, km	Average distance to Sun	Scale, million km/cm	Are the two scales close? Yes/No
Mars		228 million km		
Earth		150 million km		

With the help of your instructor, determine how far, in degrees, each planet travels along its 360° orbit each day and fill in the table below. This rate, measured in degrees per day, will be used to calculate how far each planet travels in its orbit over different periods of time.

Planet	Orbital period, days	Distance traveled per day, degrees
Mars	687	
Earth	365	

Use the following steps to calculate signal latency between Earth and Mars at different times in the planets’ orbits.

1. On your model, rotate Earth and Mars so that both planets are at 0°. This point is known as opposition, because Mars and the Sun are on opposite ends of the Earth. This is the point where Earth and Mars are closest in their orbits.
2. Measure the distance between the center of Earth and the center of Mars, and record it in the table.
3. Use the scale of the model that you calculated earlier to find the actual distance, in millions of kilometers, and list it in the table in both whole numbers and in scientific notation.

4. Use the speed of light to find the latency time for a signal to get from the Earth to Mars.
5. Now, on your model, keep Earth at 0° and rotate Mars to 180°.This point is known as solar conjunction, because the Sun and Mars form a straight line with Earth and would appear "conjoined" if viewed from Earth. This is the point where Earth and Mars a farthest apart in their orbits.
6. Follow steps 2 through 4 to find the latency of time for a signal to get from Earth to Mars during solar conjunction.

What if the Earth and Mars here somewhere between opposition and conjunction? Most Mars missions last several years. These include orbiting satellites, landers, rovers, and one day will include manned missions. The distance between Earth and Mars is constantly changing as time goes by and the planets move through their orbits. Reliable communication between Earth and Mars is vital for mission success, so it is necessary for mission control to know when a message will be received as well as when to expect a message back. Can we calculate the latency time at different times in their orbits?

- What will the latency time be 100 days after a mission begins while Mars is at opposition? To find this, start with both planets at 0° again. Use the rates that you calculated earlier to determine how far each planet will travel in its orbit, in degrees, after 100 days. Place the planets in these positions on your model. You can now measure the distance between them and calculate the latency as you did before.
- Use this same method to calculate the signal latency for the rest of the time periods listed in the table.

Time period	Earth position	Mars position	Measured distance, cm	Calculated distance, millions km	Calculated distance, km (whole number)	Calculated distance, km (scientific notation)	Latency time, min, s
At opposition	0°	0°					
At solar conjunction	0°	180°					
100 days after opposition							
156 days after opposition							
320 days after opposition							
420 days after opposition							

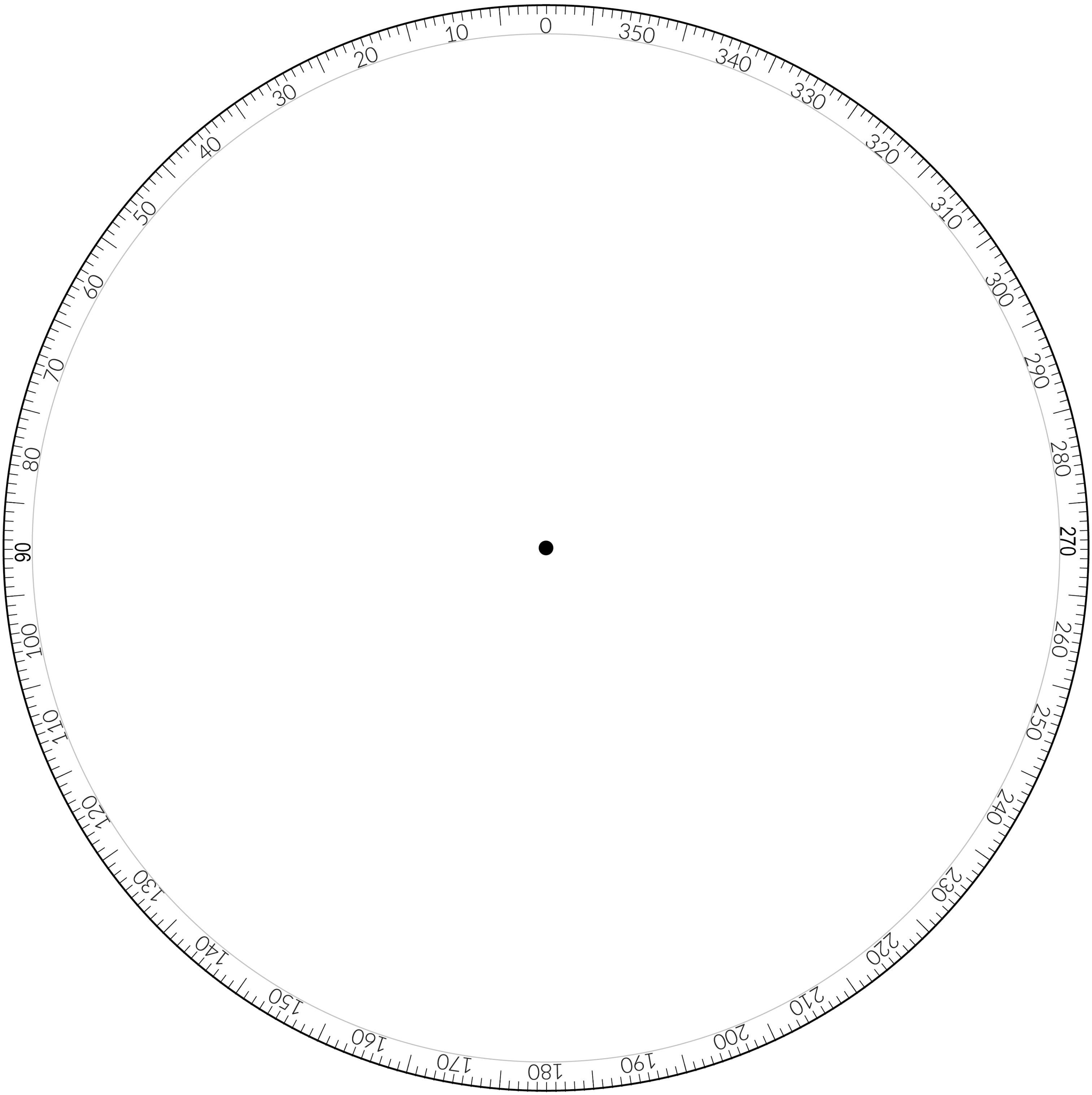
- If an opposition occurred on October 6, 2020, what would the latency time be for a signal to reach Mars from Earth today?
- Choose another significant date, such as your next birthday, and calculate the latency time for that date as well.

✓ Evaluate

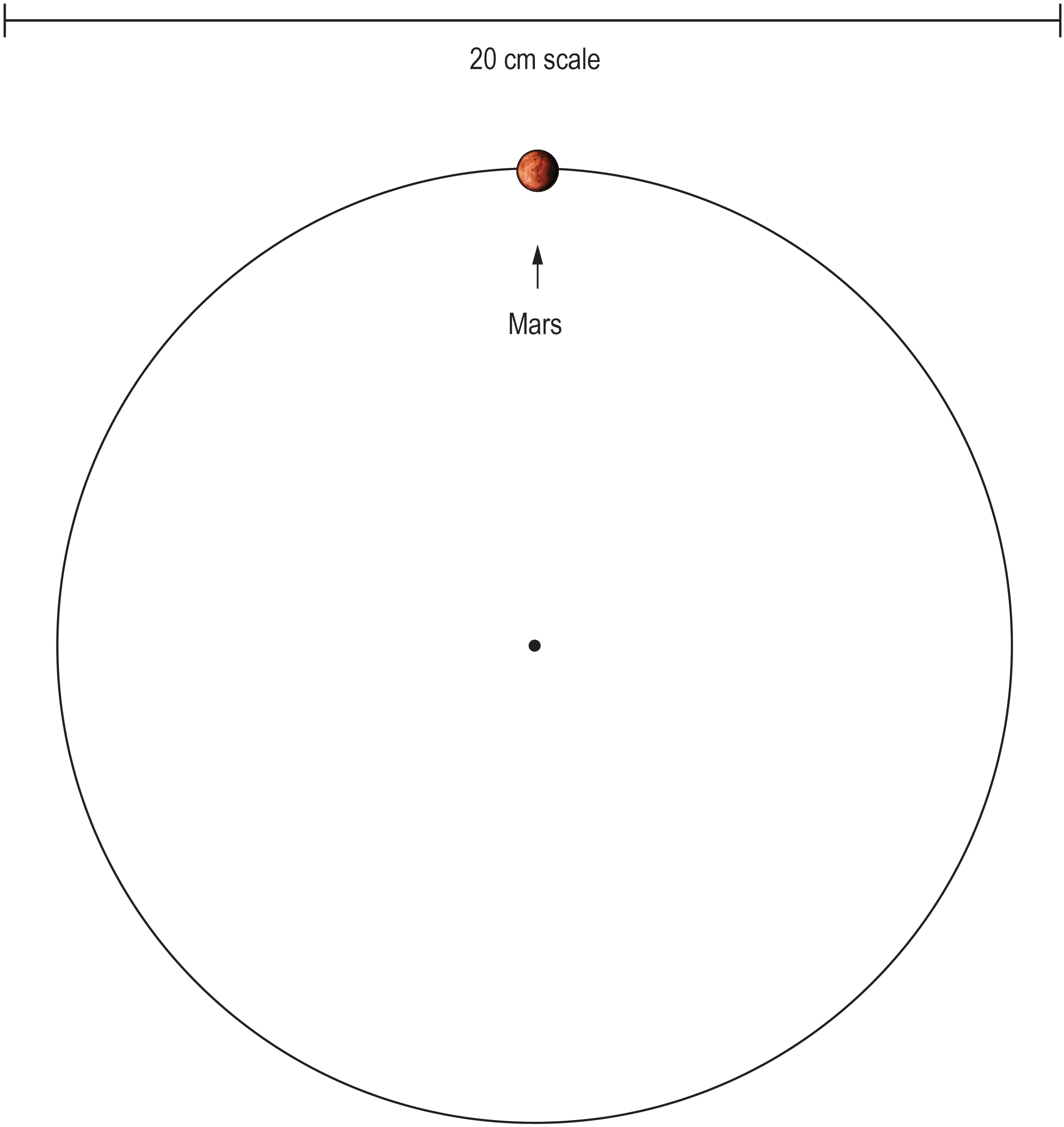
Be prepared to show your understanding of the activity by engaging in the following questions with the rest of your group:

- How close were you to measuring the speed of light (your percent error)? Was anyone within 5 percent, 3 percent, 1 percent?
- Record the percent error of the other groups. What are the mean, median, mode, and range for the percent errors?
- What could some of the possible sources of error be in measuring speed of light?
- Look at the latency time when Mars was at solar conjunction. If it took 1 minute for someone on Mars to respond to your message, how long would you have to wait for a response after you first sent the message?
- What are some ways long latency times could make communication between deep space astronauts or spacecraft difficult or problematic for missions?
- What are some things that mission controllers can do to mitigate the issues associated with latency?

Compass Template



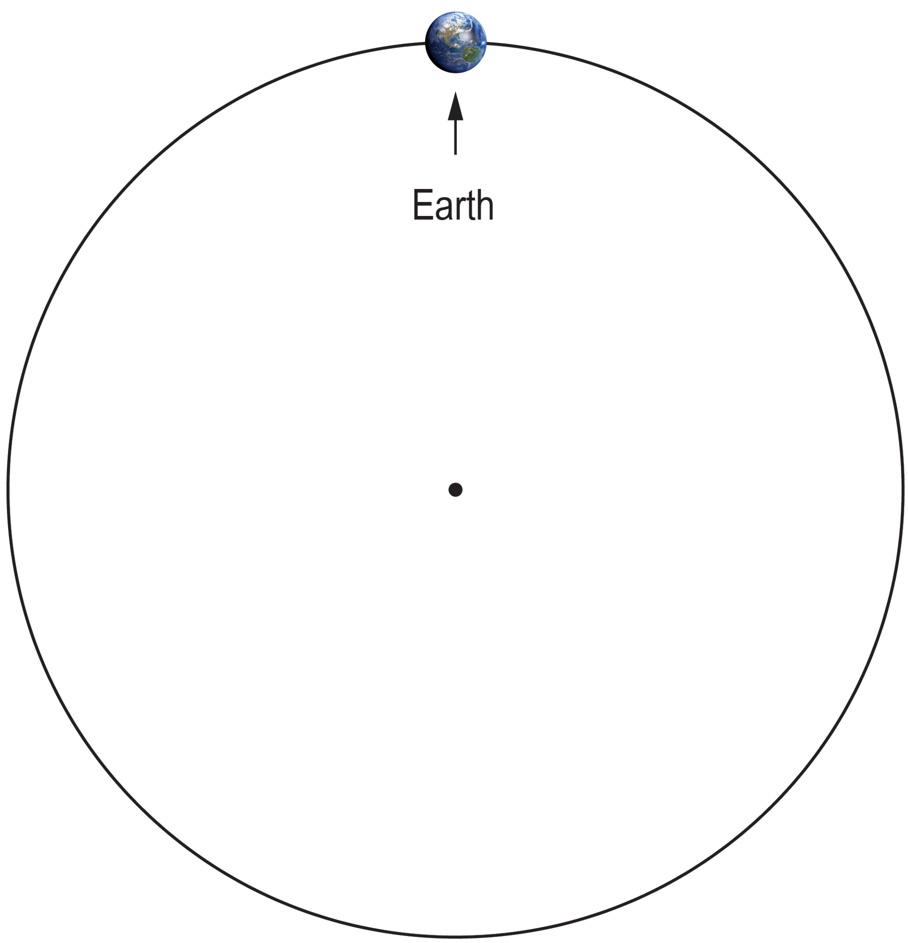
Mars Orbit Template



Mars orbit template

Earth Orbit Template

20 cm scale



Earth orbit template