DRAFT

Voyage: A Journey through our Solar System

Grades 9-12

Lesson 3: Earth Clocks and Viewing the Planets

On October 17, 2001, a one to ten billion scale model Solar System exhibition opened on the National Mall in Washington, DC. Created by Challenger Center for Space Science Education, the Smithsonian Institution, and NASA, the *Voyage* exhibition stretches nearly half a mile from the National Air and Space Museum to the Smithsonian's Castle Building. *Voyage* is a celebration of what we know of Earth's place in space and our ability to explore beyond the confines of this tiny world. It is a celebration worthy of the National Mall. Take the *Voyage* at www.voyageonline.org.

This lesson is one of many grade K-12 lessons developed by Challenger Center to bring the *Voyage* experience to classrooms across the nation through Challenger Center's *Journey through the Universe* program. *Journey through the Universe* takes entire communities to the space frontier. Start the *Journey* at www.challenger.org/journey.

July 2004

Lesson 3: Earth Clocks and Viewing the Planets

Lesson at a Glance

Lesson Overview

The simplicity of an Earth Clock and the precision of the *Voyage* scale model Solar System make it possible to identify times when planets are visible in Earth's nighttime sky. Whether a planet is visible in the nighttime sky depends on where the planet is in its orbit. The *Voyage* model can be animated by letting the model planets revolve on measured strings. This shows not only when a planet is visible, but also how the distances between planets change as the planets move in their orbits.

Lesson Duration

Two 45-minute class periods

Core Education Standards

National Science Education Standards

Standard E1: Abilities of technological design

- Propose designs and choose between alternative solutions: Students should demonstrate thoughtful planning for a piece of technology or technique. Students should be introduced to the roles of models and simulations in these processes.

AAAS Benchmarks for Science Literacy

Benchmark 9C1:

- Distances and angles that are inconvenient to measure directly can be found from measurable distances and angles using scale drawings or formulas.

Related Education Standards

National Science Education Standards

Standard G2: Nature of scientific knowledge

- Science distinguishes itself from other ways of knowing and from other bodies of knowledge through the use of empirical standards, logical arguments, and skepticism, as scientists strive for the best possible explanations about the natural world.

AAAS Benchmarks for Science Literacy

Benchmark 9D8:

- A physical or mathematical model can be used to estimate the probability of real-world events.

Essential Question

- How does our view of the planets change as the Earth and other planets revolve around the Sun?

Concepts

Students will learn the following concepts:

- Different planets are visible at different times of night.
- Mercury and Venus stay close to the Sun in the sky, so you can only view those planets shortly after sunset or shortly before sunrise.
- Outer planets may be visible at any time of night including midnight.

Objectives

Students will be able to do the following:

- Create an orrery of the inner Solar System.
- Determine times when various planets transit the Earth's sky.
- Determine which planets can be visible at midnight.

Science Overview

Using a Scale Model Solar System

Voyage is a scale model Solar System located in Washington, DC. It is a 1:10^{10} (one to ten billion) scale model, so all distances and linear sizes in the model are one ten-billionth the actual size of the objects they represent. The *Voyage* scale model Solar System is set up with the planets all in a line (though in reality, planets do not line up all in a row like this) so as to make it easier to compare their distances from the Sun. In the real world, the planets follow orbits that go around the Sun, all the time held on their orbits by the Sun's gravity.

Many significant things about the Solar System can be learned just from letting the model planets break out of the line and allowing them to follow circular orbits at the correct average distance from the model Sun. The planets' real orbits are elliptical, but not very far from circular. Therefore, a circular orbit on the *Voyage* scale model is an adequate model of the real orbits. All planets revolve around the Sun in the same direction: counterclockwise as seen from above the Earth's North Pole—from west to east. That is also the same direction in which the Earth and most of the other planets rotate.

Comets and asteroids (sometimes called minor planets) have orbits that are much more eccentric—ellipses that are far from circular—and only a precise model with elliptical orbits could do justice to showing how they move through space. The orbits of Mercury and Pluto are the most eccentric of the major planets, but not so eccentric that we need to model them with proper elliptical orbits in order to learn something useful.

By introducing the motions of the planets into the *Voyage* scale model, it becomes a kind of orrery. An orrery is a mechanical model of the Solar System that shows the planets in their orbits around the Sun. The name "orrery" was first used to describe these kinds of models in 1713 when one was made under the patronage of Charles Boyle (1621-1679), the Fourth Earl of Orrery in Ireland. It is difficult to depict both the distances and the sizes of the planets in an orrery at the right scale—the power of the *Voyage* scale model comes from the fact the both can be shown at the same time.

Using actual measurements within a moving model Solar System, it is possible to determine important general rules for how and when astronomical objects appear in the sky (ignoring the fact that sometimes sunlight makes the real objects hard to see), how they move through space, and how they look to observers on Earth. It is also possible to go outside and make similar observations in the real world to see how humanity observes the Earth's place within the Solar System and the Universe. For the most part, a telescope is not required to make these real-world observations; just persistence is necessary.

Apparent Motion of Objects in the Earth's Sky

An observer standing on the surface of Earth can see only half of the sky at any one time. The other half is below the horizon. Part of any other planet's orbit is above the observer's horizon, and part is below. A planet can be seen only if it is in that part of its orbit that is above the observer's horizon. Also, it generally needs to be nighttime before a planet can be seen with the naked eye. Venus is an exception; it can be seen with the naked eye during the daytime—if the observer knows exactly where to look.

The Sun, Moon, planets, and most stars, appear to rise once a day somewhere near the eastern part of the horizon and set somewhere near the western part of the horizon. Halfway between rising and setting, these bodies cross the meridian—an imaginary circle running across the sky from north to south (see Figure 1). In the morning, the Sun has not yet reached the meridian, so we call the morning hours "a.m.," for the Latin words *ante meridiem*, meaning "before the meridian. " In the afternoon, the Sun has passed the meridian, so we call the afternoon hours "p.m.", for the Latin words *post meridiem*, meaning "after the meridian." It is when one of these celestial bodies crosses the meridian, halfway between rising and setting, that we say it is "transiting." When one of these objects is transiting, it is at its highest point in its daily arc across the sky. This highest point will usually not be at the zenith—the point directly overhead. As seen from anywhere in the continental U.S., the sun is never seen at the zenith; it is never directly overhead.

Angular Measurement

Angles measure how big something appears. An object could appear big because it really does have a large physical size or because it is close to the observer. A thumb held up at arm's length would blot out the Moon. This shows that the angular size of the thumb is larger than the angular size of the Moon. The Moon is physically larger, but because it is so far away, it has a smaller angular size.

There are 360 degrees in a circle and 90 degrees in a right angle. Thus, from the horizon to the zenith is 90 degrees. A human fist held at arm's

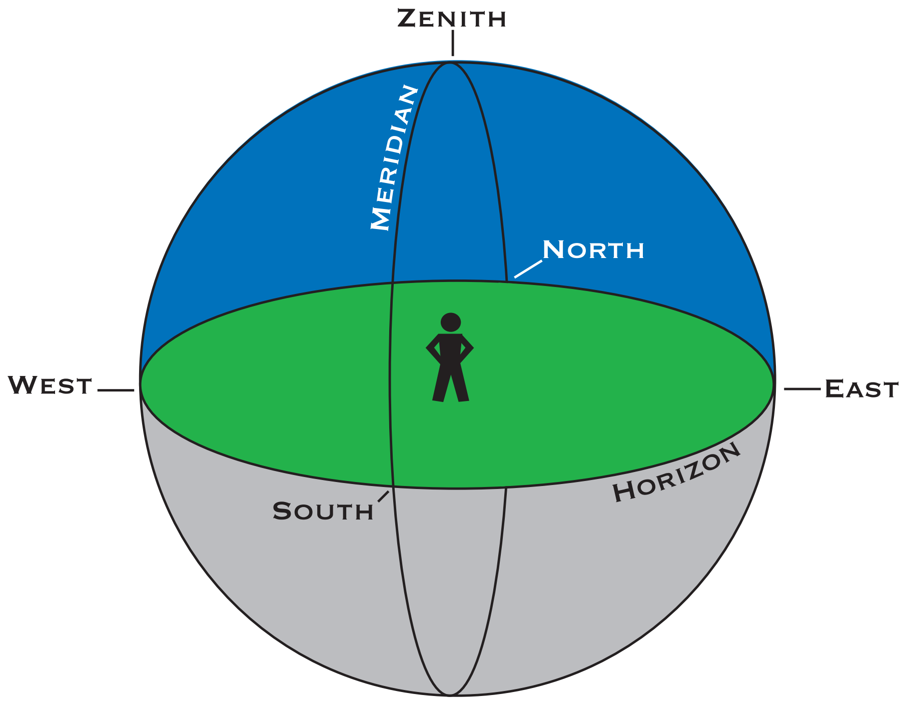

Figure 1. The orientation of the sky as seen from the surface of Earth. Horizon is the dividing line between the earth and the sky, and determines how much of the sky is visible from any location on Earth. The meridian is an imaginary line running from south to north across the sky.

length has an angular size of approximately 10 degrees. Have your students count how many fists it takes to measure the angle from the horizon—with their arms horizontal—to the zenith—with their arms vertical. (This is a good opportunity to point out the etymological connection between "horizon" and "horizontal.")

Time Zones

Because of the Earth's rotation (once around—360°—in 24 hours; or 15° per hour), the Sun appears to move across the sky at a rate of 15° per hour, and the Sun appears to rise every 24 hours. People have divided the Earth into time zones 15° wide, so the Earth rotates through one time zone every hour, and the Sun rises an hour later for each time zone farther west. Since the local time for any location on Earth is based on the position of the Sun in the sky, the local time in each time zone is set one hour earlier for each time zone farther west. When a time zone is directly under the Sun, it is noon (or 1:00 pm if daylight saving time is in effect). When a time zone is on the exact opposite side of the Earth from the Sun, it is midnight (or 1:00 am daylight saving time). At the borderline between day and night (called the "terminator"), it is sunrise or sunset, around 6:00 am or 6:00 pm, respectively. Times of sunrise and sunset vary with the time of year and the latitude, but a decent average rule of thumb is that they occur at 6:00 am and 6:00 pm, with each day having 12 hours of daytime and 12 hours of nighttime—this is most applicable during the spring and autumn equinoxes on or about March 20 and September 23, respectively.

Conducting the Lesson

Warm-Up & Pre-Assessment

Teacher Materials

- Flashlight
- Globe
- Post-it note

Preparation & Procedures

1. Choose a city in a different time zone from where you are located, and determine the time there. Sample cities in U.S. time zones:

Eastern	New York, NY
	Washington, DC
Central	Chicago, IL
	Austin, TX
Mountain	Boise, ID
	Tucson, AZ (Arizona does not go on daylight saving time.)
Pacific	Seattle, WA
	San Francisco, CA

   Greenwich Mean Time (GMT) in Greenwich, England, is the standard time to which other time zones are often compared. Eastern Standard Time (EST) is five hours earlier than GMT (that is, when it is 10:00 pm GMT, it is 5:00 pm EST); Central Standard Time (CST) is six hours earlier than GMT, etc. Use other examples as necessary.

2. Ask students why there are different time zones on Earth; why it is not the same time everywhere on Earth. Using a flashlight to represent the Sun and a globe to represent the Earth, shine the flashlight on the globe so that half of the model Earth (globe) is illuminated and the half of it that is away from the model Sun (flashlight) in darkness. Ask "Where on Earth is the local time noon? 6:00 pm? Midnight? 6:00 am?"

3. Explain or review how time of day is related to where on Earth you are located relative to the direction of the Sun. Practice as needed until all students understand. Place a post-it note on one part of the globe. Slowly rotate the globe and ask students to indicate when it is noon, 6 pm, midnight, and 6 am for that location on Earth.

NOTES:

Activity: When Are the Planets Visible from Earth?

Teacher Materials

- Model Planet Cards (located at the end of the lesson)
- 150 meters of (non-stretch) string
- 5 empty paper towel roll tubes
- Scissors
- Tape
- Yellow balloon
- (Optional) Croquet wicket or tent stake

Student Materials (per student)

- Student Worksheets 1-3
- Calculator
- 1 paper fastener
- Scissors
- Field line-marker, sidewalk chalk, or some visible markers to represent planets at various places along the orbits.
- (Optional) Ruler

Preparation & Procedures

1. Prepare the model planets and the planet distance strings before class:
    a. Mark one paper towel roll each for Mercury, Venus, Earth, Mars, Jupiter.
    b. Cut strings for each planet's distance (out to Jupiter) from the Sun, using the Data Table on the next page.
    c. Tape (or staple) one end of the Mercury string to its roll. Repeat to make planet strings for Venus, Earth, Mars, and Jupiter.
    d. Cut out the Model Planet Cards and tape (or staple) each model planet to its corresponding paper towel roll. Note that the model planet cards have the planets depicted at the correct $1:10^{10}$ scale.

    You will only need to create planet distance strings for planets out to Jupiter. The other distances are provided for you in case you want to complete the scale model Solar System in the future.

Data Table	
Mercury	6 meters
Venus	11 meters
Earth	15 meters
Mars	23 meters
Jupiter	78 meters
Saturn	143 meters
Uranus	287 meters
Neptune	450 meters
Pluto	592 meters

2. Remind students how the rotation of the Earth creates the appearance of celestial objects (Sun, planets, Moon, stars) moving in the sky during the day. Discuss how the position of the planets in the sky as seen from Earth changes from one day to another depending on where the Earth and the planets are on their orbits (see *Science Overview* for more discussion.) Ask students how they could understand or predict the rising and setting of planets in the sky. (*Desired answer: they need to be able to see how the objects move on their orbits—how they are at different places in their orbits at different points in time*) Ask the students how we could demonstrate this in the classroom, or on school grounds, without actually going into space. You can give students a hint, if necessary: How can we study things that are too big or too small to study otherwise. (*Desired answer: they can create a model*) Tell students they will create a model of part of the Solar System, in order to understand when we can see planets from Earth.

Lesson Adaptations

Talented and Gifted: Divide students into groups of five, and have each group create their own orrery. You can have each group use a different color string in order to avoid confusion.

3. Distribute Student Worksheet 1, and have students follow the procedures to make the Earth Clock—a tool used to understand the times at which planets may rise or set as viewed from Earth.

4. Have students create a scale model of the Solar System:

   a. Review characteristics of the *Voyage* scale model. It is a scale model, which means that both the distances to, and sizes of, objects are all changed (reduced or enlarged) by the same factor. In the case of the *Voyage* model, the sizes and distances of the planets are all reduced from their actual values by a factor of ten billion (10^{10}). In the *Voyage* model, the Sun is the size of a grapefruit, and the Earth is the size of a pinhead.

   b. Distribute Student Worksheets 2 and 3, and remind students to bring their Worksheets, pencils, and Earth Clocks. Remember to take the planet distance strings, a yellow balloon, and tape with you.

   c. Take the students outside to a large field. Find something that will not move easily (e.g., a stake in the ground, goal post, sign post) to represent the position of the Sun. If there is no sign available, use a croquet wicket or a tent stake and drive it into the ground.

   d. Blow up the yellow balloon to a size of about 14 cm to represent the Sun. Have one of the students tie or tape the balloon to the Sun post.

   e. Designate one student to move Mercury around on its orbit, another to move Venus, and another to move Mars during step f below. In each case, the planet-mover will not be able to record the data for that particular planet. Make sure that in these cases the student gets the missing data from another student so that everyone can do the analysis on Student Worksheet 2.

Teaching Tip

You may not have a space large enough for the whole Solar System, but go out at least as far as Mars in order to see the most important phenomena. It is nice to include Jupiter in the model, so that students can begin to see how spread out are the outer planets. A standard American football field is just wide enough to contain a circle the size of Mars' orbit on the *Voyage* scale. If you place the Sun in the middle of the field, you will be able to follow the planetary orbits (up to Mars) all the way around. If you place the Sun at one end of a football field, Jupiter should be near the other end zone. In this case, you will be able to follow about half of the orbits of the planets up to Mars, and part of Jupiter's orbit, depending on how much extra space there is around the field.

Teaching Tip

If you want to make sure each student makes their own observations of all planets, you can decide to be the planet-mover for all planets yourself.

5. Have students follow directions in Student Worksheet 2 to make their observations of the planets. The students can complete Student Worksheet 2 while outside, or you can have them wait until you get back inside the classroom.

6. Have students use their orrery and Student Worksheet 3 to determine when planets are visible in the midnight sky.

Teaching Tip

There is room on the Student Worksheet 2 to make measurements of the planets' transit times for 12 positions of the planet, but it is not necessary that all 12 positions be used. There need be just enough so that the students can estimate the earliest and latest possible transit times. You can use the numbers in *Teacher Answer Key* for the probable number of positions required for each planet.

Reflection & Discussion

1. Ask the students what part of the Earth they are looking at in the Earth-horizon diagram. *(Desired answer: they are looking down from above the North Pole)* It may help to hold up an Earth globe so that the students are looking down at the North Pole, and then rotate it from west to east to show the direction of rotation. They will see the globe turning counterclockwise.

2. Point out that the Earth-horizon diagram shows that the Earth turns a person around from west to east. Ask students, if a planet is west of the Sun, then, as the Earth turns the person around, will that planet will be visible before or after the Sun is visible? (*Desired answer: before. That is why the transit times shown on the Earth Clock are arranged as they are—with the earlier transit times on the west side of the Sun, and the later transit times on the east side of the Sun.*)

Transfer of Knowledge

In order for students to apply what they have learned, have them answer the following question: If a planet transits at your location at 4:00 am, what time would it transit for your cousin on the opposite side of the Earth? The answer is the same—4:00 am. Our local time is based approximately on the Sun's position in the sky. That planet is in a particular place in the sky relative to the Sun. By the time the Earth turns so that the planet is in the same position—transiting—as seen by your cousin, the Sun will also be in the same position as when you saw that planet transiting. And, if the Sun is in the same position, then the local time will be the same.

Assessment Criteria for Activity

You can assess the students' understanding of the orientation of the sky as seen from the surface of Earth, and the motion of the objects in the sky by having them answer the following questions:

- Ask the students why the arrow on the Earth (on the Earth-horizon diagram) indicates a counterclockwise rotation. They should understand that the Earth rotates from west to east, and therefore, if you look at the earth from above the North Pole, it appears to rotate counterclockwise. It is this west-to-east rotation of the earth that causes celestial objects to appear to rise in the east and set in the west each day.

- Ask the students about the horizon line. Do they understand why the side labeled "eastern horizon" is toward the east (relative to the person shown standing on the earth)?

- Ask what time an object directly opposite the Sun as seen from the surface of Earth would transit. (They can use their Earth clock to answer this.) (*Answer: at midnight*)

- Ask: If a planet rises due east at 6:00 am, what time will it transit? (This should be answered without the Earth Clock, just by understanding that going from the eastern horizon to the meridian is a quarter of a circle, or six hours of Earth rotation.) What time will that same planet set? (Answer: Six hours after crossing the meridian, or 12 hours after rising.)

Extension

If time permits, have students go to the location of the Earth and look at how big other planets appear at their correct scaled distances. They will see that they do not appear very big, and they may not be visible at all! Tell the students that they would need a telescope to see any detail on them, just like with the real Solar System. (Without a telescope, the planets appear just as bright points of light in the sky.)

Lesson Adaptation

Special Education: These are abstract concepts that many students will be unable to grasp from a purely verbal presentation. It is essential to show what is happening with a rotating Earth globe.

Placing the Activity Within the Lesson

Recap the activity and what data were recorded on the Worksheets. Discuss how students used the Earth Clock to determine when planets transit and, based on transit times, when planets rise and set. Also discuss how using the Earth Clock allowed students to see which planets are visible at midnight. Note that the results from Student Worksheet 2 are consistent with the results from Student Worksheet 3 because the rise times in Student Worksheet 2 for the inner planets were never as early as midnight, and the set times were never as late as midnight.

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Lesson Wrap-Up

Lesson Closure

Discuss how, because of the location of the planets' orbits in the Solar System, different planets are visible at different times. Mercury and Venus stay close to the Sun in the sky. So, you can only view those planets shortly after sunset or shortly before sunrise. However, the outer planets are potentially visible at any time of night including midnight. Have students find out where to look for the planets that night by visiting a web site such as those listed in the *Internet Resources & References* section.

NOTES:

Resources

Internet Resources & References

Student-Friendly Web Sites:

Peter Russell's SkyWatch
http://www.peterussell.com/SkyWatch.html

Qué tal? in the Current Skies
http://www.currentsky.com/ (click on Planet Watch)

Sky and Telescope—This Week's Sky at Glance
http://skyandtelescope.com/observing/ataglance/article_110_1.asp

Voyage Online
http://www.voyageonline.org/

Teacher-Oriented Web Sites:

AAAS Benchmarks for Science Literacy
http://www.project2061.org/tools/benchol/bolintro.htm

The Busy Teacher's Web Site
http://www.ceismc.gatech.edu/busyt/astro.html

Exploring Planets in the Classroom
http://www.spacegrant.hawaii.edu/class_acts/

NASA: Planetary Photojournal
http://photojournal.jpl.nasa.gov/

NASA: Planetary Sciences at the National Space Science Data Center
http://nssdc.gsfc.nasa.gov/planetary/

NASA Quest
http://quest.arc.nasa.gov/sso/teachers/

National Science Education Standards
http://www.nap.edu/html/nses/

The Nine Planets
http://www.nineplanets.org/

Star Date
http://stardate.org/resources/ssguide/

Voyage Online
http://www.voyageonline.org/

NOTES:

Teacher Answer Key

Student Worksheet 2

The times in the following table are representative answers. Each student will have different data, but the earliest and latest times should all be about the same. Notice that it is not necessary to use all 12 positions. Students only need to make enough measurements to establish earliest and latest transit times.

Mercury			
	Transit Time	Rise Time	Set Time
Position 1	11:30 a.m.	5:30 a.m.	5:30 p.m.
Position 2	12:45 a.m.	6:45 a.m.	6:45 p.m.
Position 3	10:30 a.m.	4:30 a.m.	4:30 p.m.
Position 4	1:00 p.m.	7:00 a.m.	7:00 p.m.
Position 5	1:30 p.m.	7:30 a.m.	7:30 p.m.
Position 6	12:15 p.m.	6:15 a.m.	6:15 p.m.
Position 7			
Position 8			
Position 9			
Position 10			
Position 11			
Position 12			
Earliest Time	10:30 a.m.	4:30 a.m.	4:30 p.m.
Latest Time	1:30 p.m.	7:30 a.m.	7:30 p.m.

Venus			
	Transit Time	Rise Time	Set Time
Position 1	1:30 p.m.	7:30 a.m.	7:30 p.m.
Position 2	10:00 a.m.	4:00 a.m.	4:00 p.m.
Position 3	9:00 a.m.	3:00 a.m.	3:00 p.m.
Position 4	11:15 a.m.	5:15 a.m.	5:15 p.m.
Position 5	1:30 p.m.	7:30 a.m.	7:30 p.m.
Position 6	3:00 p.m.	9:00 a.m.	9:00 p.m.
Position 7	1:15 a.m.	8:15 a.m.	8:15 p.m.
Position 8			
Position 9			
Position 10			
Position 11			
Position 12			
Earliest Time	9:00 a.m.	3:00 a.m.	3:00 p.m.
Latest Time	3:00 p.m.	9:00 a.m.	9:00 p.m.

Mars			
	Transit Time	Rise Time	Set Time
Position 1	9:30 a.m.	3:30 a.m.	3:30 p.m.
Position 2	2:15 p.m.	8:15 p.m.	8:15 a.m.
Position 3	10:30 p.m.	4:30 p.m.	4:30 a.m.
Position 4	12:00 midnight	6:00 p.m.	6:00 a.m.
Position 5	3:30 a.m.	9:30 p.m.	9:30 a.m.
Position 6	4:00 p.m.	10:00 a.m.	10:00 p.m.
Position 7	8:30 p.m.	2:30 p.m.	2:30 a.m.
Position 8	6:00 a.m.	12:00 midnight	12:00 noon
Position 9	4:00 p.m.	10:00 a.m.	10:00 p.m.
Position 10	6:00 p.m.	12:00 noon	12:00 midnight
Position 11			
Position 12			
Earliest Time	12:00 midnight	12:00 midnight	12:00 midnight
Latest Time	12:00 midnight	12:00 midnight	12:00 midnight

Questions:

1. 12:00 noon (Since at noon the Sun is, in principle, right on the meridian, it is technically neither a.m. (before the meridian) nor p.m. (after the meridian). Consequently, 12:00 should be labeled "noon" (or, 12 hours later, "midnight").

2. 1.5

3. 15

4. 22.5

5. 47 (Based on a time difference of 3 hr, students would answer "45 degrees," which should be considered correct. You can tell them that 47 degrees is a more precise answer.)

6. 9:00 p.m.

7. Mars could be up to 180 degrees from (opposite) the Sun. In that case, it would transit at midnight. Since the orbit of Mars is outside of the Earth's orbit, it could be visible at any time of the night.

Student Worksheet 3

Questions:

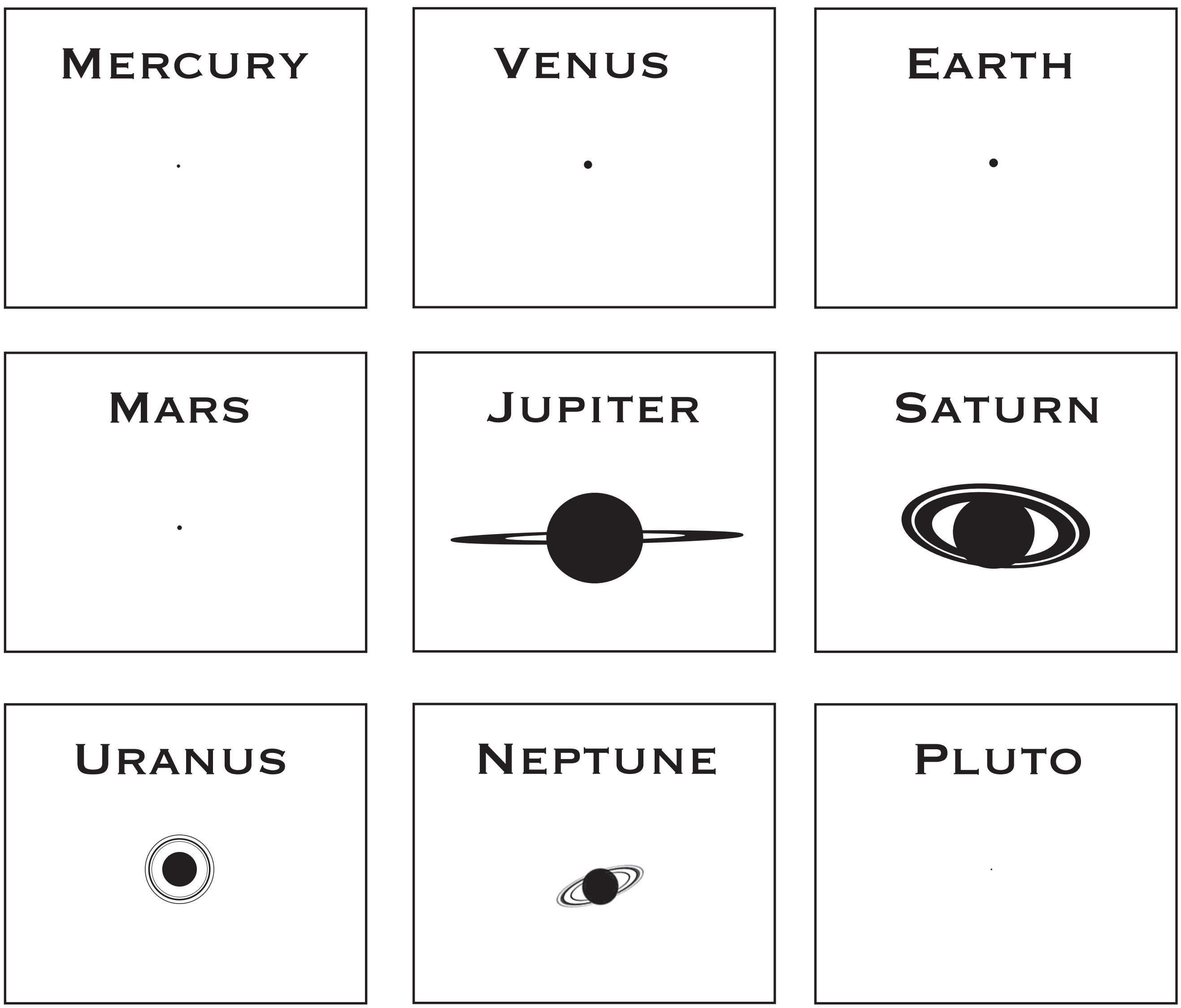
1. Only the planets with orbits outside the Earth's orbit—Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto—can be seen at some time in the Earth's sky at midnight. This can be understood by noting that the horizon line at midnight does not extend inward toward the Sun where the inner planets' orbits could be viewed above the horizon.

2. Mercury and Venus are never visible at midnight. Their orbits are interior to the Earth's orbit, so they never venture to the side of the Earth opposite the Sun, where they would have to be located to be seen at midnight.

3. Mercury, Venus, and Earth would never be visible at midnight. Their orbits are interior to the orbit of Mars, so they never venture to the side of Mars opposite the Sun, where they would have to be located to be seen at midnight.

NOTES:

Model Planet Cards



Modeling Patterns and Cycles in Our Lives

Lesson at a Glance

Science Overview

Conducting the Lesson

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Internet Resources & References

Teacher Answer Key

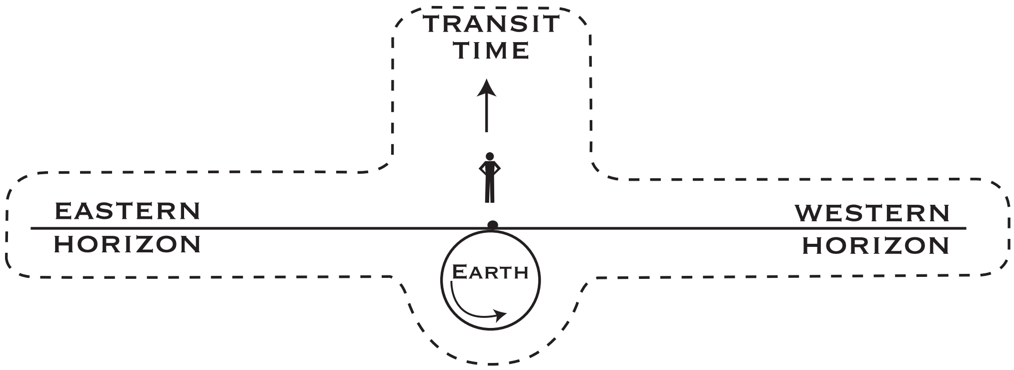
Model Planet Cards

Student Worksheet 1: Creating the Earth Clock

Name ______________________________ Date __________

1. Cut out the Earth-horizon diagram:

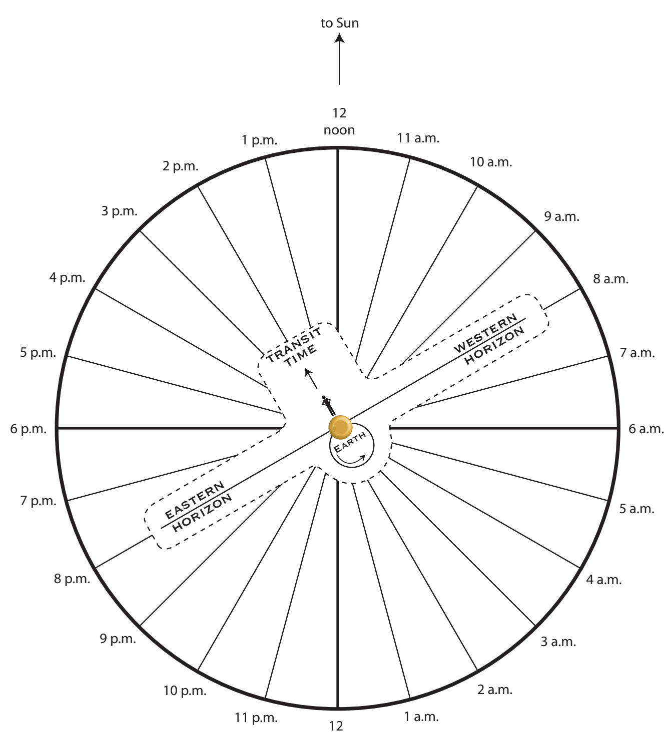
Earth-Horizon Diagram

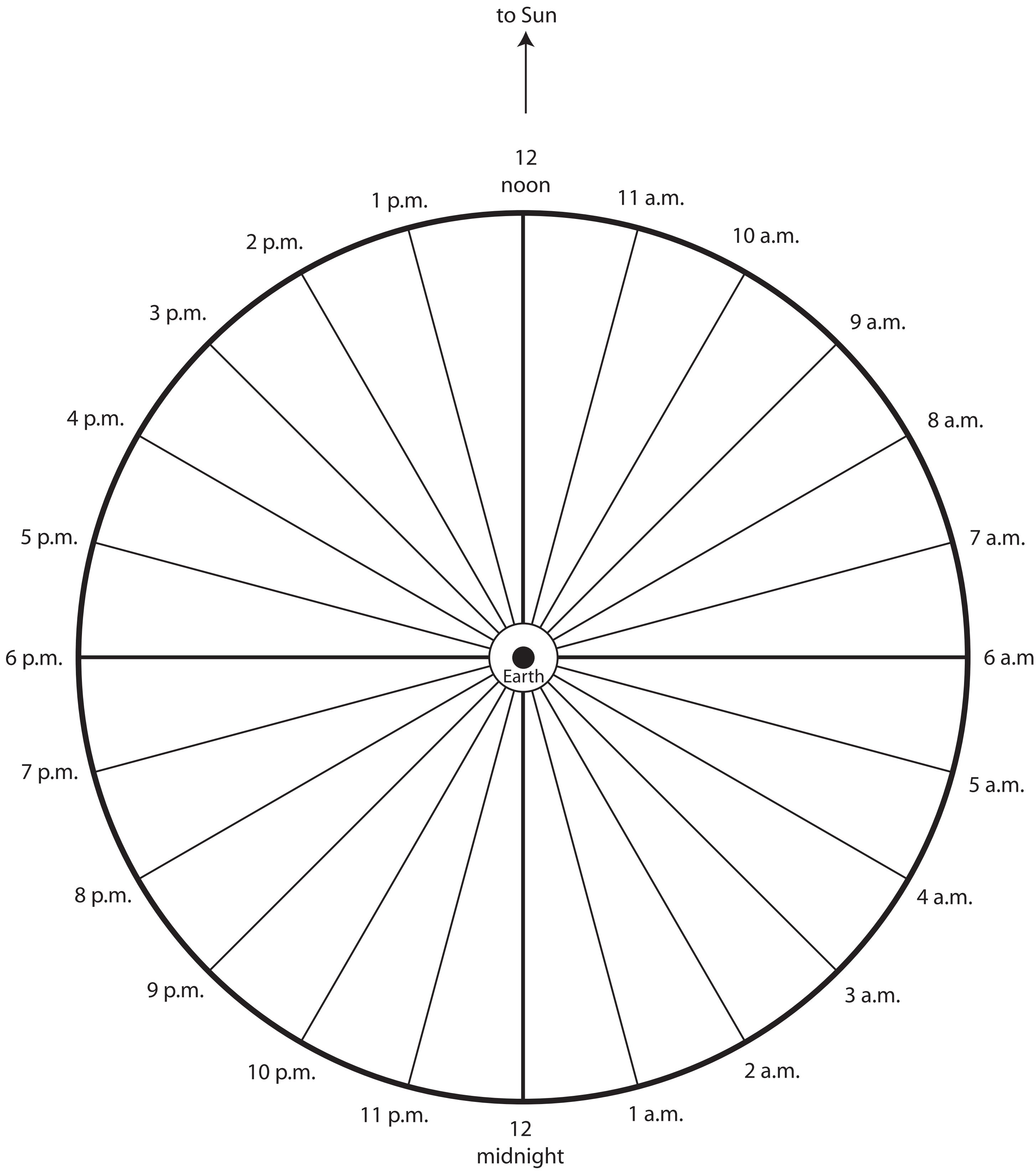


2. Take the Earth-horizon diagram and push a paper fastener through the black dot (under the person in the Earth-horizon diagram).

3. Put the Earth-horizon diagram on the Earth Clock (next page), and push the paper fastener through the black dot in the center of the Earth Clock.

4. Spread apart the prongs of the fastener to attach the diagram to the dial. The Earth-horizon diagram should be free to rotate to point toward any time on the dial. The completed Earth Clock will look like this:




to Sun
12
noon
11 a.m.
10 a.m.
9 a.m.
8 a.m.
7 a.m.
6 a.m.
5 a.m.
4 a.m.
3 a.m.
2 a.m.
1 a.m.
12
midnight
11 p.m.
10 p.m.
9 p.m.
8 p.m.
7 p.m.
6 p.m.
5 p.m.
4 p.m.
3 p.m.
2 p.m.
1 p.m.
Earth

Student Worksheet 2: Determining When the Planets Are Visible

Name ____ Date __________

You will determine the time of day when planets transit—the time when a planet is highest in the sky, halfway between rising and setting.

Materials

- Earth Clock (Student Worksheet 1)
- Model planets with strings cut to show the correct distance of the model planet from the model Sun
- Field line-marker, sidewalk chalk, or some visible markers to represent planets at various places along the orbits.
- (Optional) Ruler

I. Prepare the Voyage scale model:

1. A yellow balloon is the model of the Sun; tie or tape the balloon to the post at the center of the model.

2. *The planet movers (designated by your teacher)*: tie one end of each model planet's string to the post for each planet.

3. *The planet movers*: take your model planet and walk away from the model Sun until the string is taut.

4. *Everyone*: Walk and follow a model circular orbit for the planets. Remember that the planets move counterclockwise in their orbits, as viewed from a position above the Sun's North Pole. Make sure you get to try this briefly for at least one planet.

II. Determine the times at which the planets are visible:

1. On the *Voyage* scale model, mark a circle on the ground for each of the orbits of Mercury, Venus, and Mars. Use a field line-marker on grass, sidewalk chalk on pavement, or just set down some visible markers at various places along the orbits.

2. *Everyone except Mercury planet-mover*: Choose a position along Earth's orbit and hold your Earth Clock with the "to Sun" arrow pointing to the Sun. Make sure your class covers as much of the Earth's orbit as possible.

3. *Everyone except Mercury planet-mover*: If the planets are located where they are in the model right at this point, you can measure the time of day when Mercury transits—that is, the time when Mercury is highest in the sky, halfway between rising and setting—the following way:
   a) Hold the Earth Clock stationary (with "12:00 noon" toward the Sun), while turning the Earth-horizon diagram so that the "transit time" arrow points toward Mercury (wherever it is on its orbit).
   b) Estimate the time of day on the Earth Clock that the "transit time" arrow is marking, and record it on the data table. This is the time of day on Earth at which Mercury transits: crosses the meridian and is highest in the sky. Record the transit time for Position 1 in the Mercury table.

4. a) *The Mercury planet-mover:* Move the model Mercury to various places (about 30 degrees apart) around the orbit of Mercury. Allow other students to repeat step 3 for each position before moving to the next place.
   b) *Everyone except Mercury planet-mover:* The Mercury planet-mover will move the model Mercury into different places on its model orbit. At each position of Mercury, measure the time of day on Earth that Mercury transits for that position on its orbit relative to Earth. Record the times next to Position 2, Position 3, etc. (You don't have to fill in all 12 positions; you just need enough to estimate the earliest and latest possible transit times.)

5. Determine and record the earliest and latest transit times in the table.

6. Determine and record the corresponding rise and set times. (HINT: Remember that the Earth rotates once in 24 hours. There are variations in rise and set times due to the tilt of the Earth on its axis, but for this question, you can assume that there are exactly the same number of daylight hours and nighttime hours.)

7. Repeat steps 1-6 of the procedure for Venus and Mars.

Tip

You can point the "transit time" arrow toward Mercury more accurately if you line up a ruler with the arrow and sight toward Mercury along the ruler.

Mercury			
	Transit Time	Rise Time	Set Time
Position 1			
Position 2			
Position 3			
Position 4			
Position 5			
Position 6			
Position 7			
Position 8			
Position 9			
Position 10			
Position 11			
Position 12			
Earliest Time			
Latest Time			

Venus			
	Transit Time	Rise Time	Set Time
Position 1			
Position 2			
Position 3			
Position 4			
Position 5			
Position 6			
Position 7			
Position 8			
Position 9			
Position 10			
Position 11			
Position 12			
Earliest Time			
Latest Time			

Mars			
	Transit Time	Rise Time	Set Time
Position 1			
Position 2			
Position 3			
Position 4			
Position 5			
Position 6			
Position 7			
Position 8			
Position 9			
Position 10			
Position 11			
Position 12			
Earliest Time			
Latest Time			

Questions:

1. At what time does the Sun transit? (You can use your Earth Clock to answer this question.)

2. Based on the latest transit time that you observed for Mercury, what is the greatest number of hours that Mercury could transit after the Sun transits?

   ________________ hr

3. How many degrees does the Earth rotate each hour?

   _________________ degrees

4. Knowing how many degrees of Earth's rotation each hour of time represents, what is the greatest number of degrees that Mercury can appear from the Sun in the sky?

   _______________ degrees

5. What is the greatest number of degrees that Venus can appear from the Sun in the sky?

   _______________ degrees

6. What is the latest time Venus could be visible in the evening?

   ____________ pm

7. How would the answers to the previous few questions be different for Mars? Explain.

Student Worksheet 3:
Planets Visible in the Midnight Sky

Name ______________________________ Date __________

Procedures

1. On the *Voyage* scale model, mark a circle on the ground for each of the orbits of Mercury, Venus, and Mars. Use a field line-marker on grass, sidewalk chalk on pavement, or just set down some visible markers at various places along the orbits.

2. Stand somewhere on the Earth's orbit. Look at the string running from the model Sun to the model Earth. Remember that, as the Earth rotates through the day, a spot on the surface of the Earth experiences noon as it moves across the Sun-Earth line on the side of the Earth facing the Sun. The spot experiences midnight as the Earth rotates and the spot moves across (an extension of) that same line on the far side of the Earth, the side not facing the Sun. Note that the midnight sky is not just limited to things that are very near the midnight position along the Sun-Earth line; it also includes those stars and planets that just are setting and those stars and planets that just are rising—that is, everything that is visible across the sky at midnight is part of the "midnight sky."

3. Turn the Earth Clock so that the local time is midnight. Now the eastern horizon indicates where stars and planets are rising, and the western horizon indicating where they are setting. Look at the other planets' orbits, and answer the following questions.

Questions:

1. Comparing the orbits of the planets with the horizon line, which planets are occasionally in the midnight sky, and why do you think so? What about planets farther out—Jupiter, Saturn, Uranus, Neptune, and Pluto?

2. Which planets are never in the midnight sky? Why?

3. If you lived on Mars, which planets would never be visible to you at local Martian midnight? Explain.