An Understanding of the Positions of the Planets and the Speed of Light

Lesson #3

Lesson Plan: An Understanding of the Positions of the Planets and the Speed of Light

Objective: The students will be able to identify and understand the positions of the planets relative to Earth and Sun, then calculate distances and the time needed for radio signals to travel these distances by completing this activity.

National Standards:

1. Content Standard G: History and Nature of Science
2. Content Standard A: Science as Inquiry;
3. Content Standard B: Interactions of Energy and Matter

Course/Grade level: Earth/Space Science Course, Physics Grades: 9-12
NOTE: An understanding of scientific notation is recommended for this activity, the resource pages introduce the topic and can be included as student reference pages.

Materials:

1. Article: How to Find Your Way Around the Sky
2. Discussion Questions: Student page
3. Making a Model: Activity page
4. Teacher/student resource pages **(3)**

Estimated Time:

60 minutes for completion of the reading and student questions
30 minutes for the Making a Model activity

Procedure:

1. **Engagement**: Introduction of the activity,
    A. Engage the students in a discussion about the location and characteristics of the orbits of the planets.
    B. Ask the students to discuss or list what they know about the speed of light. Some prompting may be necessary, such as: how fast is it, what travels at the speed of light.
    C. Discussion of scientific notation may be needed, the included resource pages can be used as a guided practice.
2. **Exploration**: Have the students read the article, stopping to discuss parts as needed.
3. **Explanation**: After reading the article, have the students complete
    A. Student calculations.
    B. Activity: Making a Model (OPTIONAL).
4. **Extension**: Upon completion of the student questions, discuss any additional questions that the students might have derived from the reading, pulling out inferences that they might have made.
5. **Evaluation**: Additional questions are added for further assessment or testing.

Teacher Page 1

Possible Ideas from the Engagement activities

A. Engage the students in a discussion about the location and characteristics of the orbits of the planets.

- All planets orbit the Sun.
- The relative position and the simple ordering of the planets.
- A discussion of Nicholas Copernicus and his early ideas of a heliocentric solar system (Sun centered) that changed the way the world viewed the solar system.
- A discussion of Kepler and his plots and diagrams showing that all of the planets orbit the Sun and that the orbits are elliptical in nature.

B. Ask the students to discuss or list what they know about the speed of light. Some prompting may be necessary, such as: how fast is it, what travels at the speed of light.

- Conversions between hours, minutes and seconds.
- The importance in keeping units constant in calculations.
- Discussion that all forms of electromagnetic radiation travel at the speed of light.

C. Discussion of scientific notation may be needed; the included resource pages can be used as a guided practice.

- Review of Scientific Notation and Standard Form, tools for using large numbers (see Resource Page 3).

Teacher Page 2

Use the following table for Problems 5-8.

Planet	Radius of orbit	Mean Distance (in AU)
Mercury	57,910,000 km	.39
Venus	108,200,000 km	.72
Earth	149,600,000 km	1.0
Mars	227,940,000 km	1.5
Jupiter	778,330,000 km	5.2
Saturn	1,429,400,000 km	9.6
Uranus	2,872,320,000 km	19.2
Neptune	4,502,960,000 km	30.1
Pluto	5,909,200,000 km	39.5

In the following problems, assume that the planets are aligned on the same side of the Sun (as close to one another as possible).

Problems:

1. How far does light travel in 20 seconds? **6×10^9 m**
2. How far does light travel in 30 minutes? **5.4×10^{11} m**
3. How far does light travel in 4 hours? **4.32×10^{12} m**
4. How far does light travel in 2 days? **5.18×10^{13} m**
5. How long would it take radio waves to travel from Jupiter to Mars? **1.83×10^3 s (30.6 minutes)**
6. How long would it take radio waves to travel from Jupiter to Venus? **2.23×10^3 s (37 minutes)**
7. How long would it take radio waves to travel from Jupiter to Saturn? **2.17×10^3 s (36 minutes)**
8. How long would it take radio waves to travel from Mercury to Mars? **5.6×10^2 s (9.4 minutes)**
9. Find the signal travel time (to Earth) from Neptune when at opposition. **4.0 hours**
10. Find the signal travel time (to Earth) from Mars when at conjunction. **20.8 minutes**
11. Find the signal travel time (to Earth) from Pluto when at opposition. **5.3 hours**
12. If the signal travel time is 88 minutes, from what planet did the signal come? Is the planet at conjunction or opposition? **Saturn at conjunction**
13. If the signal travel time is 2.53 hours, from what planet did the signal come? Is the planet at conjunction or opposition? **Uranus at opposition**
14. Calculate the radius of orbit for Uranus in kilometers. **2,870,000,000 km**
15. Calculate the radius of orbit for Neptune in kilometers. **4,500,000,000 km**
16. Calculate the radius of orbit for Pluto in kilometers. **5,900,000,000 km**

Teacher Page 3 QUIZ ANSWER KEY

QUIZ Name________________________________

Use the following table to answer questions 1-5.

Planet	Radius of orbit	Mean Distance (in AU)
Mercury	57,910,000 km	.39
Venus	108,200,000 km	.72
Earth	149,600,000 km	1.0
Mars	227,940,000 km	1.5
Jupiter	778,330,000 km	5.2

Speed of light = c = 300, 000, 000 meters per second = 3×10^8 m/s

1. How long does it take sunlight to travel from the Sun to Earth?

$d = 149{,}600{,}00 \text{ km} = 1.5 \times 10^8 \text{ km} = 1.5 \times 10^{11} \text{ m}$
$c = 3 \times 10^8 \text{ m/s}$

$$d = ct \qquad t = \frac{d}{c} = \frac{1.5 \times 10^{11}}{3 \times 10^8} = 5 \times 10^2 \text{ s} = 500 \text{ s} = 8 \text{ min } 20 \text{ s}$$

____________500 s__________________

2. What do we call the position of Jupiter when it is closest to Earth?

__________opposition_______________

3. What is the shortest time it could take for radio signals to travel from Jupiter to Earth?

$d = 778{,}330{,}000 \text{ km} — 149{,}600{,}00 \text{ km} = 7.78 \times 10^8 \text{ km} — 1.5 \times 10^8 \text{ km} =$
$6.28 \times 10^8 \text{ km} = 6.28 \times 10^{11} \text{ m}$

$c = 3 \times 10^8 \text{ m/s}$

$$d = ct \qquad t = \frac{d}{c} = \frac{6.28 \times 10^{11}}{3 \times 10^8} = 2.1 \times 10^3 \text{ s} = 2100 \text{ s} = 35 \text{ min}$$

_____________35 min_______________

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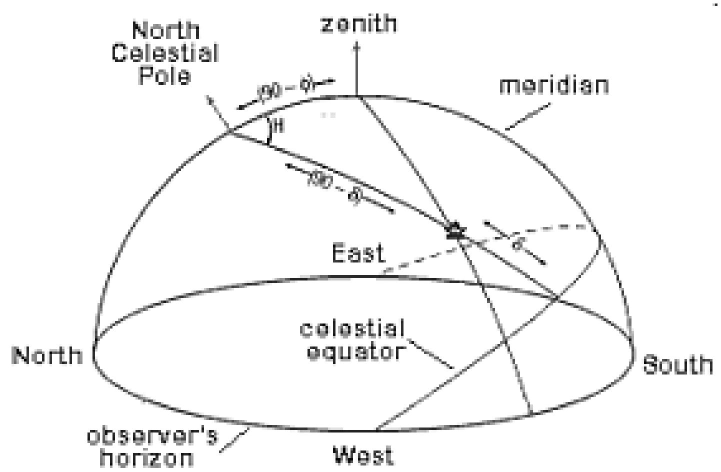
How to Find Your Way Around the Sky

by Dr. Leonard N. Garcia

Figuring out when and where to observe Jupiter from this spinning, revolving planet can be difficult. The Earth revolves around the Sun with 8 other planets plus millions of comets, asteroids, moons and other even smaller bits of rock and ice. Together they are called the Solar System. The Earth also spins on its axis. We can explain most of the motion we see in the sky overhead from these two types of motion.

When we step outside we are aware of the sky above us and the ground beneath us. The Earth looks flat from our perspective. The sky on the other hand looks like a gigantic dome. The line where the sky appears to meet Earth we call our **horizon**. Everything that is below the horizon is blocked from view by Earth. Now imagine a line drawn from your feet through your head and pointing straight upwards. This line would point to your **zenith**, the point directly overhead.



Above: An illustration showing the horizon, local meridian and North Celestial Pole.

The rotation of Earth gives us our nights and days. It causes stars over the course of the night to appear to move across the sky and like the Sun rise in the east and set in the west. The imaginary line around which Earth spins is called the **axis**. This line points to a particular part of the sky which is very near a star called Polaris. Polaris is also known as the Pole Star since it is close to the **North Celestial Pole**. The Earth's spin axis is tilted about 23.5¡ from a perpendicular to the plane of Earth's orbit. It is Earth's revolution around the Sun in combination with the tilt of Earth's axis that gives us our seasons. It takes Earth one year to complete one orbit of the Sun. Over a few weeks we notice the constellations are setting earlier and new constellations are rising. This is all due to Earth's orbital motion.

If you now draw an arc which connects your zenith with the North Celestial Pole and extends down to the north and south points on the horizon you have drawn a line called your **local meridian**. Whenever a star or planet crosses your local meridian we say it is **transiting**. Often when we talk about the location of Jupiter we may say for example, "Jupiter is at two hours before transit" meaning that two hours from now Jupiter will cross our local meridian.

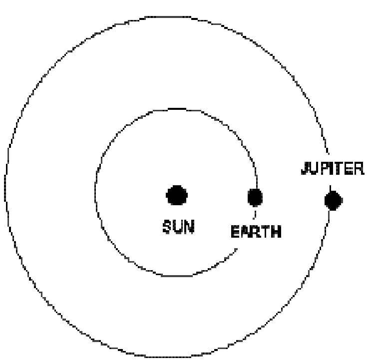
The Planets

The planets of the Solar System follow their own orbital paths around the Sun. For the planets closer to the Sun than Earth (the inner planets Mercury and Venus) it takes less than one year to orbit the Sun. For planets farther from the Sun than Earth (the outer planets) it takes more than a year. Jupiter, for example, takes 12 years to orbit the Sun once.

There are certain locations in the orbits of the planets that are important for an observer on Earth. The time when Earth is exactly between the Sun and an outer planet is called **opposition**. The time when the Sun is between Earth and an outer planet is called **conjunction**. For the inner planets conjunction occurs when the planet is between the Sun and Earth (inferior conjunction) or when the Sun is between the planet and Earth (superior conjunction).

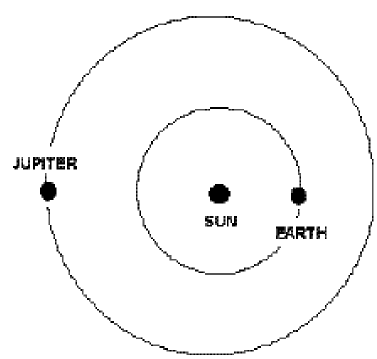
Observing Jupiter Around Opposition

The best nights to observe an outer planet is when it is at or near opposition. At this time the planet is above the horizon all night long. It is also at its shortest distance from Earth. When a planet is at opposition it transits your local meridian at midnight. When listening to Jupiter with the Radio JOVE equipment it is generally (but not always) better to observe Jupiter in the weeks prior to opposition. The reason for this is that radio interference is usually less the later in the night you observe. Therefore, you need to observe Jupiter in the night hours. The Sun and its effect on Earth's ionosphere make listening to Jupiter during daylight hours very difficult. A Jupiter observing "season" should be planned for the months before and after opposition. The farther from opposition Jupiter is, the fewer hours it will be high enough in the sky to observe with the Radio JOVE equipment while the Sun is still below the horizon.



Left: An illustration of Jupiter in opposition with the Sun.

Right: An illustration of Jupiter in conjunction with the Sun.



Resource Page 1

Radio waves, like all electromagnetic waves, travel at the speed of light — 300,000,000 meters per second (3 hundred million meters per second). So the speed of light, which is 3 followed by 8 zeroes, becomes 3×10^8 meters per second. The standard symbol for the speed of light is **c**, so we can write:

$$\mathbf{c = 3 \times 10^8\ m/s}$$

Since radio waves travel at a constant speed, the distance traveled is given by:

distance = speed times time

or **d = c t**

where
d = distance in meters
t = time in seconds
c = 3×10^8 meters per second

Example Problem: How far does a radio wave travel in 5 minutes?

$t = 5\text{ min} = 5(60\text{sec/min}) = 300\text{ s} = 3 \times 10^2\text{ s}$
$c = 3 \times 10^8\text{ m/s}$
$d = ?\text{ m}$

$\mathbf{d = c\,t}$
$d = (3 \times 10^8\text{ m/s})(3 \times 10^2\text{ s})$
$d = (3 \times 3) \times 10^{8+2}\text{ m}$
$d = 9 \times 10^{10}\text{ m}$

RULE: to multiply,

MULTIPLY the numbers,
ADD the powers of ten

If you know the distance and the speed (c), you can find the time it takes for radio waves to travel that distance using:

$$\mathbf{d = c\,t} \qquad \mathbf{t = \frac{d}{c}}$$

where
d = distance in meters (m)
c = speed of light (3×10^8 m/s)
t = time in seconds (s)

Example Problem: How long does it take radio waves to travel from Earth to the moon, a distance of 400,000 kilometers?

$d = 400\,000\text{ km} = 400{,}000{,}000\text{ m} = 4 \times 10^8\text{ m}$
$c = 3 \times 10^8\text{ m/s}$
$t = ?$

$$t = \frac{d}{c}$$

$$t = \frac{4 \times 10^8\text{ m}}{3 \times 10^8\text{ m/s}}$$

$$t = \frac{4}{3} \times 10^{8-8}\text{ s}$$

$t = 1.33 \times 10^0$ s (NOTE: $10^0 = 1$)

$t = 1.33$ s

RULE: to divide,

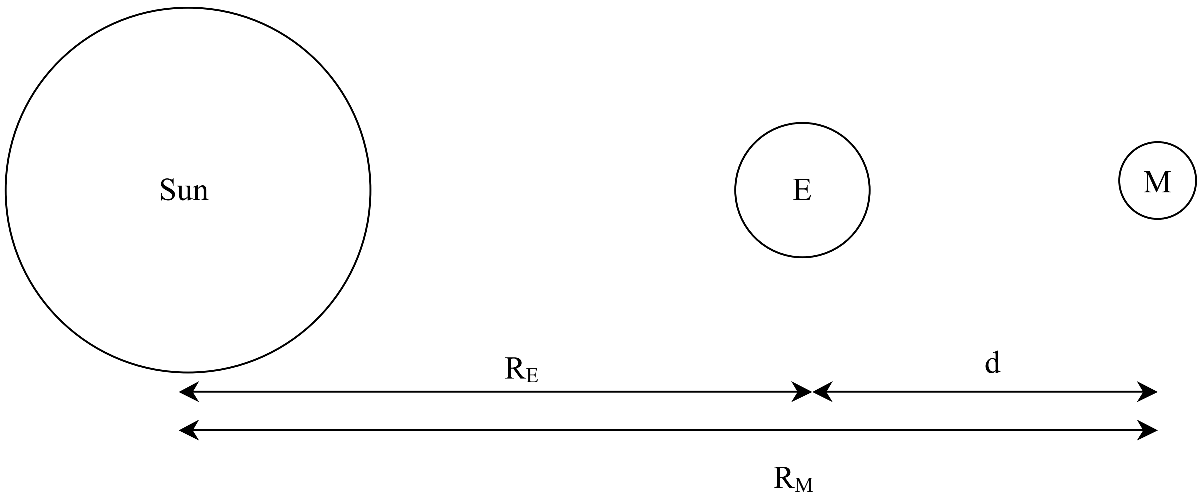
DIVIDE the numbers and SUBTRACT the powers of ten. (Subtract the bottom power from the top)

Resource Page 2

Example Problem: How long does it take radio waves to travel from Mars to Earth when Earth and Mars are on the same side of the Sun?

radius of Mars' orbit R_M = 227, 940,000 km = 2.28×10^8 km = 2.28×10^{11} m

radius of Earth's orbit R_E = 149,600,000 km = 1.50×10^8 km = 1.50×10^{11} m



$$d = R_M - R_E$$
$$d = 2.28 \times 10^{11}\ \text{m} - 1.50 \times 10^{11}\ \text{m}$$
$$d = 2.28 - 1.50 \times 10^{11}\ \text{m}$$
$$d = .78 \times 10^{11}\ \text{m}$$
$$d = 7.8 \times 10^{10}\ \text{m}$$

RULE: to subtract,

IF the powers of ten are the same, SUBTRACT the numbers and the power of ten remains the SAME.

$$t = \frac{d}{c}$$

$$t = \frac{7.8 \times 10^{10}\ \text{m}}{3 \times 10^{8}\ \text{m/s}}$$

$t = 2.6 \times 10^{10-8} = 2.6 \times 10^2$ s

$t = 260$ s (4 minutes 20 seconds)

A common unit of distance in astronomy is the Astronomical Unit (**AU**), which is defined as the distance from Earth to the Sun. (1 AU = 1.5×10^8 km) It is important to be able to convert between AU and kilometers. Below is an example of how to convert the distance from Mars to the Sun from kilometers to astronomical units.

$$R_M = (2.28 \times 10^8\ \text{km}) \bullet \frac{1\ \text{AU}}{1.5 \times 10^8\ \text{km}} = 1.52\ \text{AU}$$

Resource Page 3

In scientific notation, powers of ten are used to represent the zeroes in large numbers. The following table shows how this is done.

Number	Name	Power of ten
1	one	10^0
10	ten	10^1
100	hundred	10^2
1,000	thousand	10^3
10,000	ten thousand	10^4
100,000	hundred thousand	10^5
1,000,000	million	10^6
10,000,000	ten million	10^7
100,000,000	hundred million	10^8
1,000,000,000	billion	10^9

If you examine the first and last columns, you can see that the power of ten is the same as the number of zeroes in the number. So the speed of light, which is 3 followed by 8 zeroes, becomes 3×10^8 meters per second.

Also in these activities, we will be working with large numbers that have several non-zero digits. In this case, the power of ten indicates how many places to move the decimal to the right rather than the number of zeroes to add. We will also round off the values so that there are only three nonzero digits with one digit to the left of the decimal. This is called **standard form**.

Example 1: 54311103 km becomes 5.43×10^7 km

Example 2: 923 million dollars becomes 923×10^6 dollars.
In standard form = 9.23×10^8 dollars

Example 3: 3,478 seconds becomes 3.48×10^3 seconds.
(Remember to round the numbers if necessary)

Example 4: Approximate number of stars in the Milky Way galaxy: 3×10^{11} stars.
We can write this as: 300×10^9 stars(non standard form) or 300 billion stars, then as 300,000,000,000 stars.

[Now do you see why scientific notation is so convenient?]

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Student Page 1 **Name**_________________________

Use the following table for Problems 5-8.

Planet	Radius of orbit	Mean Distance (in AU)
Mercury	57,910,000 km	.39
Venus	108,200,000 km	.72
Earth	149,600,000 km	1.0
Mars	227,940,000 km	1.5
Jupiter	778,330,000 km	5.2
Saturn	1,429,400,000 km	9.6
Uranus		19.2
Neptune		30.1
Pluto		39.5

In the following problems, assume that the planets are on the same side of the Sun (as close to one another as possible).

Problems:

Answer each of the following questions, be sure to show all work needed in the calculations and include the units in the answer

1. How far does light travel in 20 seconds?
2. How far does light travel in 30 minutes?
3. How far does light travel in 4 hours?
4. How far does light travel in 2 days?
5. How long would it take radio waves to travel from Jupiter to Mars?
6. How long would it take radio waves to travel from Jupiter to Venus?
7. How long would it take radio waves to travel from Jupiter to Saturn?
8. How long would it take radio waves to travel from Mercury to Mars?
9. Find the signal travel (to Earth) time from Neptune when at opposition.
10. Find the signal travel time (to Earth) from Mars when at conjunction.
11. Find the signal travel time (to Earth) from Pluto when at opposition.
12. If the signal travel time is 88 minutes, what planet did the signal come? Is the planet at conjunction or opposition?
13. If the signal travel time is 2.53 hours, what planet did the signal come? Is the planet at conjunction or opposition?
14. Calculate the radius of orbit for Uranus in kilometers (km).
15. Calculate the radius of orbit for Neptune in kilometers (km).
16. Calculate the radius of orbit for Pluto in kilometers (km).

Student Page 2

Making a Model
Refer to the table of opposition dates of Jupiter. Did you notice a pattern? What is it and why? Hint: It takes Jupiter 12 times as long to go once in its orbit around the Sun as it takes Earth. Draw two concentric circles and let the inner smaller circle represent the orbit of Earth. The outer larger circle represents the orbit of Jupiter. The Sun can be a dot in the center. Place a coin or a pebble representing Earth on the circle you drew for Earth's orbit. Now place another coin or pebble on Jupiter's orbit where Jupiter would have to be when it is in opposition with Earth. Where would Earth be in its orbit after 1 year? Where would Jupiter be? How much more does Earth have to travel in its orbit before Jupiter is again in opposition with Earth? Jupiter will be in conjunction on May 8, 2000. Try to make the same table for dates of Jupiter's conjunction from 1995 to 2010.

Opposition Dates of Jupiter 1995-2010			
June 1, 1995	October 23, 1999	March 4, 2004	July 9, 2008
July 4, 1996	November 28, 2000	April 3, 2005	August 14, 2009
August 9, 1997	January 1, 2002	May 4, 2006	September 21, 2010
September 16, 1998	February 2, 2003	June 6, 2007	

Information Courtesy: NASA RP 1349
Twelve-Year Planetary Ephemeris 1995-2006
by Fred Espenak NASA/GSFC

QUIZ Name___________________________________

Use the following table to answer the questions. Show all your work.

Planet	Radius of orbit	Mean Distance (in AU)
Mercury	57,910,000 km	.39
Venus	108,200,000 km	.72
Earth	149,600,000 km	1.0
Mars	227,940,000 km	1.5
Jupiter	778,330,000 km	5.2

Speed of light = c = 300, 000, 000 meters per second = 3×10^8 m/s

1. How long does it take sunlight to travel from the Sun to Earth?

____

2. What do we call the position of Jupiter when it is closest to Earth?

____

3. What is the shortest time it could take for radio signals to travel from Jupiter to Earth?

____