Grades 9-12

- Accelerating electric charges produce electromagnetic waves around them. Varieties of radiation are electromagnetic waves: radio waves, microwaves, radiant heat, visible light, ultraviolet radiation, x-rays, and gamma rays. These wavelengths vary from radio waves, the longest, to gamma waves, the shortest. In empty space, all electromagnetic waves move at the same speed—the "speed of light."

Technology for All Americans (ITEA) Standards

- Develop an understanding of the relationships among technologies and the connections between technology and other fields of study.

Technology (NET) Standards

- Select and use appropriate tools and technology resources to accomplish a variety of tasks and solve problems.

INSTRUCTIONAL OBJECTIVES:

- Students will identify radio waves on the electromagnetic spectrum.
- Students will utilize radio waves as a method of predicting the visual connection of the Sun and Earth, an aurora.

VOCABULARY:

- **Electromagnetic spectrum** consists of waves of many wavelengths ranging from very long wavelength radio waves to very short wavelength gamma rays. Visible light, consisting of short wavelength waves, is placed near the middle of this spectrum.
- **Radio waves** are energy waves produced by charged particles naturally emitted by the Sun, other stars and planets.
- **Visible light** can pass through window glass, but a solid wall will absorb a portion of the light and reflect the remaining portions. Scientists would say that glass is transparent to visible light, but a wall is opaque. Visible light is the region of the electromagnetic spectrum that can be perceived by human vision.
- **Ionosphere** is the ionized part of the Earth's atmosphere. Ultraviolet light from the Sun collides with atoms in this region knocking electrons loose.

ACTIVITIES:

ACTIVITY 1-A Scientific Notation and the Speed of Light

Radio waves, like all electromagnetic waves, travel at the speed of light–300,000,000 meters per second (3 hundred million meters per second). The speed of light is obviously a large number. In working with this number, and other large numbers, it is convenient to express it in scientific notation. In **scientific notation**, powers of ten are used to represent the zeros 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
1000	thousand	10^3
10000	ten thousand	10^4
100000	hundred thousand	10^5
1000000	million	10^6
10000000	ten million	10^7
100000000	hundred million	10^8
1000000000	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. The standard symbol for the speed of light is **c**, so we can write:

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

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
$c = 3 \times 10^8$ meters per second

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

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

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

RULE: to multiply, MULTIPLY the numbers, ADD the powers of 10

Problems:

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?

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

$$d = c\,t$$

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

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?

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

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

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

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

RULE: to divide, DIVIDE the numbers and SUBTRACT the powers of 10 (Subtract the bottom power from the top)

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

$t = 1.33 \text{ s}$

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?

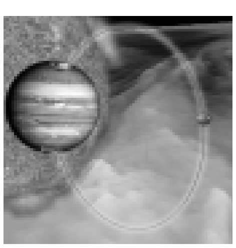
For this problem, we will be working with large numbers that have several nonzero digits. In this case, the power of ten indicates how many places to move the decimal to the right rather than the number of zeroes to add. We will also round off the values so that there are only three nonzero digits with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

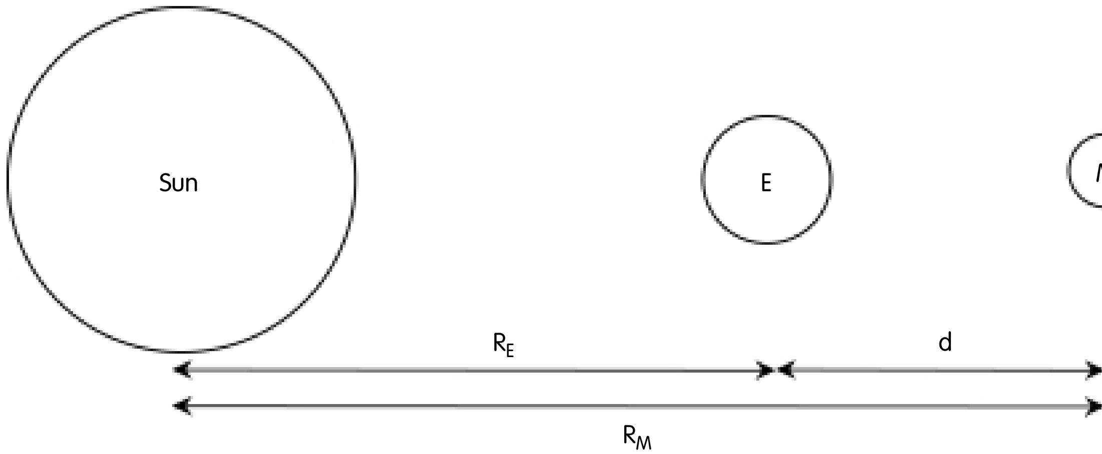
radius of Mars' orbit

$R_M = 227{,}940{,}000 \text{ km} = 2.28 \times 10^8 \text{ km} = 2.28 \times 10^{11} \text{ m}$

radius of Earth's orbit

$R_E = 149{,}600{,}000 \text{ km} = 1.50 \times 10^8 \text{ km} = 1.50 \times 10^{11} \text{ m}$





$d = R_M - R_E$

$d = 2.28 \times 10^{11} - 1.50 \times 10^{11}$

$d = 2.28 - 1.50 \times 10^{11}$

$d = .78 \times 10^{11}$

$d = 7.8 \times 10^{10}$ m (NOTE: standard form)

RULE: to subtract, IF the powers of ten are the same, SUBTRACT the numbers and the power of ten remains the SAME

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

$t = \frac{7.8 \times 10^{10}}{3 \times 10^{8}}$

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

t = 260 s (4 minutes 20 seconds)

Use the following table for Problems 5-8.

Planet	Radius of orbit
Mercury	57,910,000 km
Venus	108,200,000 km
Earth	149,600,000 km
Mars	227,940,000 km
Jupiter	778,330,000 km
Saturn	1,429,400,000 km

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

Problems:

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?

On these last two problems, be careful when you subtract the distances. They should have the same power of ten. (HINT: one distance will not be in standard form.)

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?

Answer key for Activity 1.

1. 6 x 109 m
2. 5.4×10^{11} m
3. 4.32×10^{12} m
4. 5.18×10^{13} m
5. 1.83×10^{3} s (30.6 minutes)
6. 2.23×10^{3} s (37 minutes)
7. 2.17×10^{3} s (36 minutes)
8. 5.6×10^{2} s (9.4 minutes)

ACTIVITY 1-B
Scientific Notation on the Calculator

The rules for working with numbers in scientific notation are not complicated:

- **MULTIPLICATION:** multiply the numbers and add the powers of ten
- **DIVISION:** divide the numbers and subtract the powers of ten
- **ADDITION/SUBTRACTION:** powers of ten must be the same; add/subtract the numbers; power of ten remains the same
- **STANDARD FORM:** the number part must be between 1 and 10.

The handheld scientific calculator does all of these steps automatically. The following example calculations were done using a Texas Instruments TI-30X SOLAR calculator. Steps on other calculators are similar although some key names and procedures are different. Consult the manual if you are using a different calculator.

(NOTE: When it says to "PRESS," that refers to a calculator key. If a number is being entered, simply press the digits in order.)

The following are the "Example Problems" from Activity 1.

Multiply 300 x 300,000,000

PRESS	CALCULATOR DISPLAY
[2nd] [5]	$0.^{00}$ (Scientific Notation Mode)
300 [X]	$3.^{02}$
300000000 [=]	$9.^{10}$

Divide: 4000000 / 3 x 10^8

PRESS	CALCULATOR DISPLAY
[2nd] [5]	$0.^{00}$ (Scientific Notation Mode)
400000000 [÷]	$4.^{08}$
3 [EE] 8 [=]	1.333333333^{00}

Subtract: 2.28 x 10^{11} - 1.50 x 10^{11}

PRESS	CALCULATOR DISPLAY
[2nd] [5]	$0.^{00}$ (Scientific Notation Mode)
2.28 [EE] 11 [—]	2.28^{11}
1.50 [EE] 11 [=]	7.8^{10}

Additional Examples:

Subtraction when the numbers have different powers of ten.

Subtract: 4.6 x 10^{10} - 3.9 x 10^9

PRESS	CALCULATOR DISPLAY
[2nd] [5]	$0.^{00}$ (Scientific Notation Mode)
4.6 [EE] 10 [—]	4.6^{10}
3.9 [EE] 9 [=]	4.21^{10}

Notice that all answers are given in standard form automatically. Also, in the last example there is no need to change the numbers to the same power of ten–that is done by the calculator.

ACTIVITY 2
Wavelength and Frequency

The frequency of a wave is defined as the number of waves created per second. As the waves propagate away from the source, the frequency also represents the number of waves that will pass a point per second. The unit of frequency is the hertz (Hz).

The wavelength, or length of a wave, is defined as the distance from one point on a wave to the corresponding point on the next wave. Since wavelength is a distance, the unit of wavelength is the meter (m).

Frequency, wavelength and speed are related by the equation:

$$c = \lambda f$$

where c is the speed of light (3 x 10^8 m/s),
λ (lambda) is the wavelength in meters (m),
and f is the frequency in hertz (Hz).