Radio Waves and the Electromagnetic Spectrum

Lesson #4

Lesson Plan: Radio Waves and the Electromagnetic Spectrum

Objective: Understand radio waves and how they relate to the electromagnetic spectrum. Determine wavelength, frequency, and speed of radio waves. Master these concepts by completing example problems.

National Standards:

1. Content Standard B: Motion and Forces, Structures and Properties of Matter
2. Content Standard D: Energy in the Earth System

Course/Grade level: Earth/Space Science Course, Physics Grade level: 9-12

Materials:

1. Reference material with sample problems
2. Student handout page with questions and problems
3. Resource page on scientific notation and standard form

Estimated Time: 30 - 45 minutes

Procedure:

1. **Engagement**: Introduction of the activity
   A. Ask the students to identify where on the electromagnetic spectrum radio waves are located.
   B. Ask the students to identify as many possible types of electromagnetic waves that they can. Can the students identify common uses of various wave types?
   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 reference material, stopping to discuss parts as needed.
3. **Explanation**: Work through the example problems with the students, then have the students complete the questions on the student page.
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 about the relationship between wavelength and frequency.
5. **Evaluation**: Additional questions to assess the students understanding of the concepts of the activity.

Teacher Page 1 Possible ideas from the engagement activities:

A. Ask the students to identify where on the electromagnetic spectrum radio waves are located
- Radio waves are located at one end of the electromagnetic spectrum.
- Near microwaves.
- Have the longest wavelengths.

B. Ask the students to identify as many possible types of Electromagnetic waves that they can. Can the students identify common uses of various wave types?
- Microwaves and their use cooking and heating food.
- Infrared waves for heat lamps.
- Ultraviolet waves and their relationship to sunburn and skin cancer.
- X-rays and their use in hospitals.
- Gamma Rays for nuclear explosions.

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).

Problems and Answers

1. Find the wavelength of a radio wave with a frequency of 650 kHz.
   4.6×10^2 m (460 m)
2. Find the wavelength of a radio wave with a frequency of 1300 kHz.
   2.3×10^2 m (230 m)
3. Find the wavelength of a radio wave with a frequency of 90 MHz. **3.3 m**
4. Find the wavelength of a radio wave with a frequency of 101.5 MHz. **2.96 m**
5. AM radio stations have frequencies from 540-1700 kHz.
   a) Find the shortest wavelength AM radio signal. **1.76×10^2 m (176 m)**
   b) Find the longest wavelength AM radio signal. **5.56×10^2 m (556 m)**
6. FM radio stations have frequencies from 88-108 MHz.
   a) Find the longest wavelength FM radio signal. **3.4 m**
   b) Find the shortest wavelength FM radio signal. **2.8 m**

The frequency range of Jupiter radio emissions that can be detected on Earth is approximately 8 MHz to 40 MHz.

7. Find the shortest wavelength Jupiter radio wave that can be detected on Earth.
   7.5 m
8. Find the longest wavelength Jupiter radio wave that can be detected on Earth.
   37.5 m
9. Find the wavelength of the Jupiter radio wave that has a frequency of 20.1 MHz.
   14.9m
10. Explain the relationship between the wavelength and the frequency of the electromagnetic spectrum. **Wavelength and frequency have an inverse relationship, meaning that as the frequency increases, the wavelength decreases, and vice versa.**

Teacher Page 2
ANSWER KEY

Quiz **Name**______________________________

Answer each question completely.

1. If you double the frequency of a wave, what happens to the wavelength of the wave?

Answer: Wavelength is one-half (1/2) its original value because frequency and wavelength are inversely proportional ($f \sim 1/\lambda$).

2. What is the frequency of a citizen's band (CB) radio which has a wavelength of 11.5 meters?

Answer: 26 MHz. (Use $c = \lambda f$)

3. What is the wavelength of electricity (power waves for buildings, lights, etc.)? The frequency of electrical waves is 60 Hz.

Answer: 5.0×10^6 meters or 5000 km!!!

> **(Note: the velocity of the wave is NOT the same thing as the current in a wire; current travels much, much slower.)**

Resource Page

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)

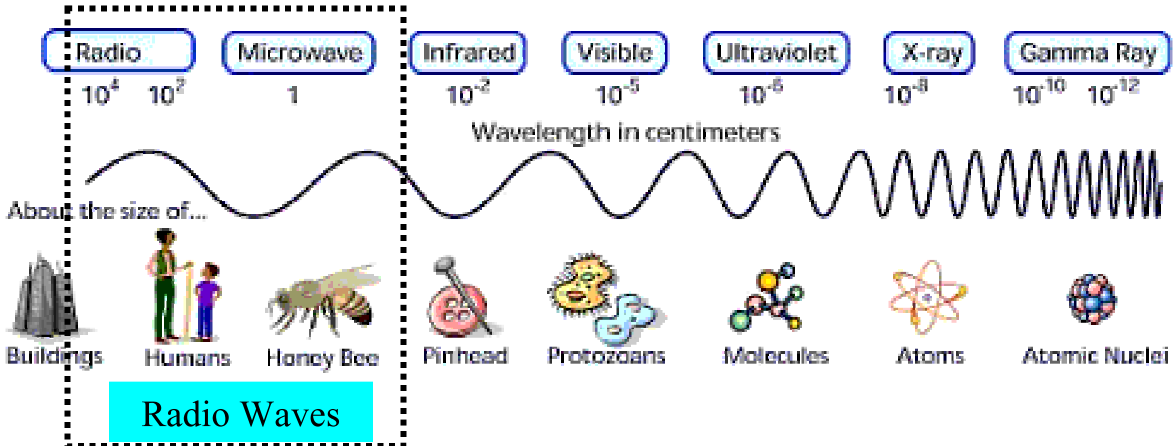
Example 4: Approximate number of stars in the Milky Way galaxy: 3×10^{11} stars.
We can write this as: 300×10^9 stars(non standard form) or 300 billion stars, then as 300,000,000,000 stars.

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

(Intentionally blank.)

Wavelength and Frequency of Radio Waves

Radio waves are one part of the complete electromagnetic spectrum. As you can see from the figure below, there are many different types of waves and these waves are different because they have different properties.



Note: the units of measurement for wavelength in the diagram is centimeters(cm)
Image credit: http://imagers.gsfc.nasa.gov

One property to compare different kinds of waves is called the **wavelength**, or length of a wave. Wavelength 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). Radio waves have the longest wavelength compared to other types of waves (see figure).

Another property used to compare waves is the **frequency** of a wave, which 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 one divided by time (1/seconds) and scientists have given this frequency unit the name of hertz (Hz). Radio waves have the lowest frequency compared to other types of waves. On your radio receivers, either in your car or at your home, the unit of measurement is also in Hz, but usually in one of two variations, kHz and MHz (kilohertz, thousands of hertz and megahertz, millions of Hertz respectively). These variations are used to help identify the length of the wave, by using simple metric prefixes.

The speed of a wave can be measured, and what scientists have discovered is that the speed of all types of electromagnetic waves is the same. Scientists call this speed the speed of light because visible light is the most familiar kind of wave to humans [that is what we see!]. The speed of light is measured to be 300,000,000 m/s, which can also be written as, 3×10^8 m/s (approximately 186,000 miles per second!).

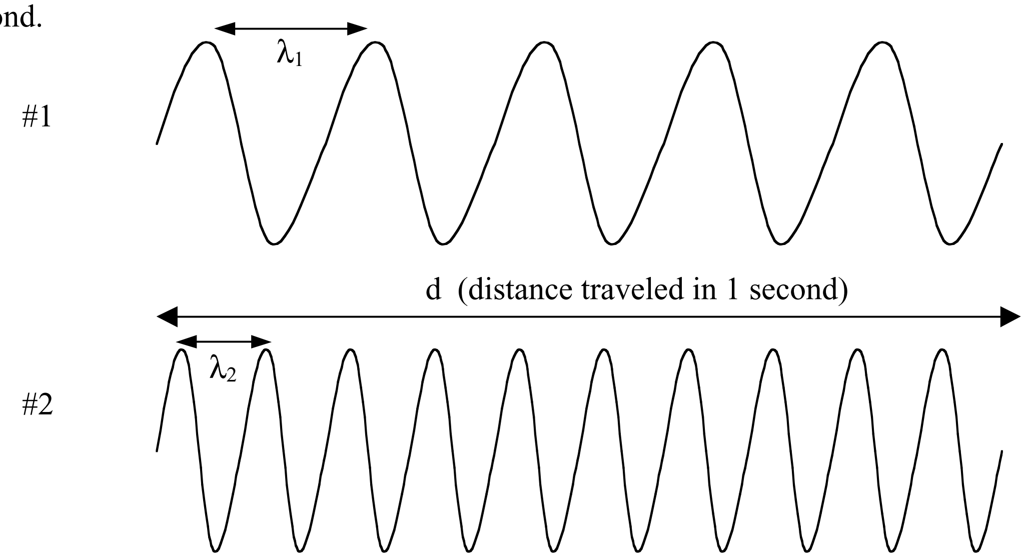
Frequency, wavelength and speed are related by the equation:

$$\mathbf{c = \lambda f}$$

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

From this equation we can see that a long wavelength will have a low frequency while a short wavelength will have a high frequency since the product of these two quantities is constant (that is, the product equals the speed of light).

In this diagram, the distance (d) indicated represents the distance the waves travel in 1 second.



Wave #1 has 5 complete waves passing by in one second, while Wave #2 has 10 waves passing by in the same time. If you were to watch Wave #1 pass a point, the frequency would be 5 waves per second or 5 Hz. Wave #2 would have a frequency of 10 hertz. Wave #1 has half the frequency of Wave #2 and two times the wavelength. For both waves, the product of the wavelength and frequency are the same.

Example problem: Find the wavelength of a radio wave with a frequency of 900 kHz.

$f = 900 \text{ kHz} = 900 \times 10^3 \text{ Hz} = 9 \times 10^5 \text{ Hz}$
$c = 3 \times 10^8 \text{ m/s}$
$\lambda = ?$
$c = \lambda f$ (Solve for λ)

1. $\frac{1}{f}\, c = \lambda f\, \frac{1}{f}$

2. $\lambda = \frac{c}{f}$

3. $\lambda = \frac{3 \times 10^8 \text{ m/s}}{9 \times 10^5 \text{ Hz}}$

4. $\lambda = .33 \times 10^3 = 3.3 \times 10^2 \text{ m (330 m)}$

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Student Page

Name_______________________
Date_______

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. Find the wavelength of a radio wave with a frequency of 650 kHz.

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2. Find the wavelength of a radio wave with a frequency of 1300 kHz.

   ____

3. Find the wavelength of a radio wave with a frequency of 90 MHz.

   ____

4. Find the wavelength of a radio wave with a frequency of 101.5 MHz.

   ____

5. AM radio stations have frequencies from 540-1700 kHz.
   a. Find the shortest wavelength AM radio signal.

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   b. Find the longest wavelength AM radio signal.

      ____

6. FM radio stations have frequencies from 88-108 MHz.
   a. Find the longest wavelength FM radio signal.

      ____

   b. Find the shortest wavelength FM radio signal.

      ____

The frequency range of Jupiter radio emissions that can be detected on Earth is 8 MHz to 40 MHz.

7. Find the shortest wavelength Jupiter radio wave that can be detected on Earth.

   ____

8. Find the longest wavelength Jupiter radio wave that can be detected on Earth.

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9. Find the wavelength of the Jupiter radio wave that has a frequency of 20.1 MHz.

   ____

10. Explain the relationship between the wavelength and the frequency of the electromagnetic spectrum.

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Quiz **Name**______________________________

Answer each question completely.

1. If you double the frequency of a wave, what happens to the wavelength of the wave?

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2. What is the frequency of a citizen's band (CB) radio which has a wavelength of 11.5 meters?

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3. What is the wavelength of electricity (power waves for buildings, lights, etc.)? The frequency of electrical waves is 60 Hz.

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