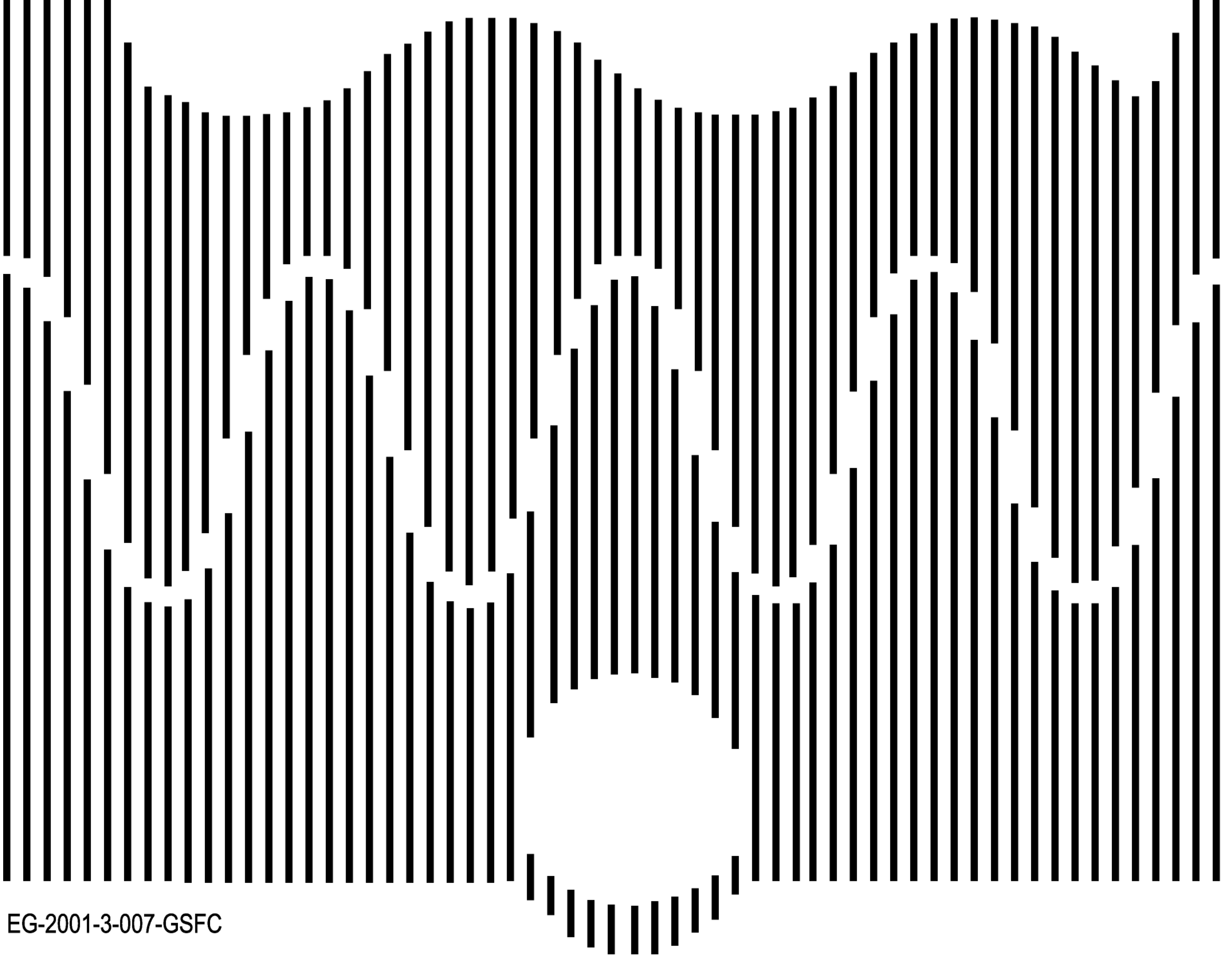
# Waves Light Up The Universe!

A Teacher's Guide
to the
Science and Mathematics of Waves

Grades 9 - 12



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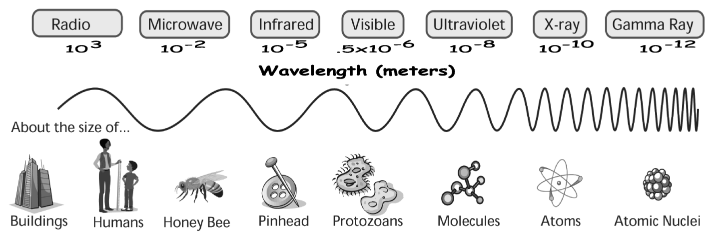
# Waves Light Up the Universe!

This booklet contains a discussion of the basics of waves and wave motions, which is then followed by two classroom lessons. **"Classroom Activity #1: Understanding Waves" is written for the science teacher** trying to introduce waves and wave motion to students. **"Classroom Activity #2: Do the Wave! Exploring Direct and Indirect Relationships" is for the teacher** looking for a fun new way for students to investigate functional relationships.



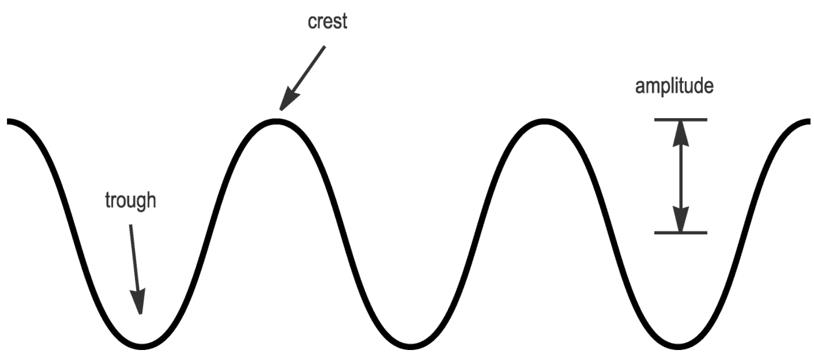

Why is the subject of waves important to understanding the Universe? All objects in our Universe emit, reflect, and absorb electromagnetic waves in their own distinctive ways. The way an object does this provides scientists with a probe they can use to reveal an object's composition, temperature, density, age, motion, distance, and other chemical and physical quantities. While the night sky has always served as a source of wonder and mystery, it has only been in the past few decades that we have had the tools to look at the Universe over the entire electromagnetic (EM) spectrum and see it in all of its glory. Once we were able to use space-based instruments to examine infrared, ultraviolet, X-ray, and gamma-ray emissions, we found objects which were otherwise invisible to us (e.g., black holes and neutron stars). A "view from space" is critical since radiation in these ranges cannot penetrate the Earth's atmosphere. Many objects in the heavens "light up" with wavelengths too short or too long for the human eye to see, and most objects can only be fully understood by combining observations of behavior and appearance in different regions of the EM spectrum.

We can think of electromagnetic radiation in terms of a stream of photons (massless packets of energy), each traveling in a wave-like pattern, moving at the speed of light. The only difference between radio waves, visible light, and gamma-rays is the amount of energy in the photons. Radio waves have photons with low energies, microwaves have a little more energy than radio waves, infrared has still more, then visible, ultraviolet, X-rays, and gamma-rays.

The importance of the EM radiation we receive from the Universe can be realized by considering the following: Temperatures in the Universe today range from $10^{10}$ Kelvin to 2.7 Kelvin (in the cores of stars going supernova and in intergalactic space, respectively). Densities range over 45 orders of magnitude between the centers of neutron stars to the virtual emptiness of intergalactic space. Magnetic field strengths can range from the $10^{12}$ Gauss fields around neutron stars to the 1 Gauss fields of planets such as Earth to the $10^{-9}$ Gauss fields of intergalactic space. It is not possible to reproduce these enormous ranges in a laboratory on Earth and study the results of controlled experiments; we must use the Universe as our laboratory in order to see how matter and energy behave in the most extreme conditions. Understanding this behavior is central to our ability to take our current models and extrapolate them successfully into "what will become of our Universe?" Electromagnetic radiation, across its full spectrum, provides us with almost all of the information we have about our amazing Universe, its structure, and its ultimate fate. Truly, waves light up our Universe!

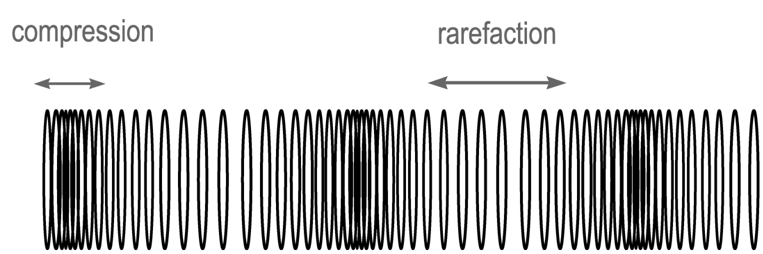
# Waves Light Up the Universe!

Just exactly what is a wave? How is it defined in science? And what do waves have to do with the Universe? A wave is defined as any disturbance from an equilibrium condition which travels (or propagates) with time from one point in space to another. We are familiar with many different types of waves in our everyday lives -- waves in the ocean, sound waves, and light, just to name a few.



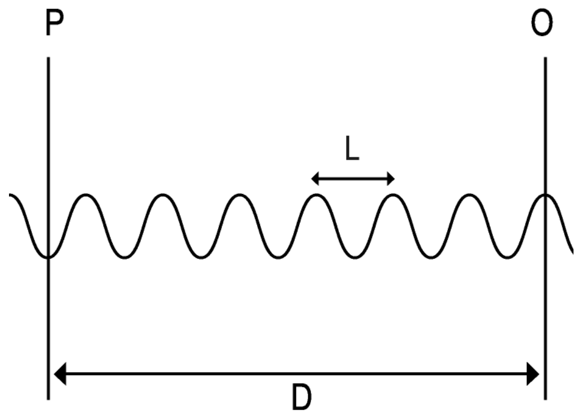

Let us think about and compare waves of light to waves in the ocean. While the waves in an ocean travel forward, the water molecules themselves are displaced only vertically. They do not travel forward with the wave. So a cork would bob up and down as the waves move along the surface of the water. (Ignore the ever-present ocean currents for this discussion.) Waves that propagate with this type of motion are called **transverse waves**. Light also propagates as a transverse wave. Two of the unique features of light are that it does not require a medium through which to travel, and that, in fact, it travels with its highest velocity through a vacuum.

Sound waves are completely different. First, sound is a physical vibration in matter. Sound cannot travel at all in a vacuum. Second, the displacements of matter that carry a sound impulse are in a **longitudinal** direction; that is, in the same direction as the wave motion (as opposed to perpendicular to it like for corks on oceans or light). Sound is a travelling wave consisting of alternating **compressions** and **rarefactions** (expansions) of the matter through which it moves.




For any kind of wave (ocean, light, or sound), however, there exists a simple relationship between **wavelength** and **frequency**. The wavelength is measured as the distance between two successive crests in a wave. The frequency is the number of wave crests that pass a a given point in space each second.

Imagine a long train of waves moving toward the right, past point O in the diagram shown below.




It is moving with a velocity equal to v. If v is measured in m/sec, we can measure back to a distance of D meters to the left of O and find the point P along the wave train that will just reach point O after a length of time equal to 1 second. The frequency of the wave train, that is the number of waves to pass point O during the second is just the number of waves between points O and P. That number of waves, times the length of each wave, L, is equal to the distance D. Thus we can see that for any wave motion the speed of propagation equals the frequency times the wavelength:

$$\mathbf{v = f \bullet L\ .}$$

When we start to think about waves of light, we need to understand the concept of a photon. A photon is the quantum of electromagnetic wave energy. It is sometimes easiest to consider a photon to be a tiny packet of pure energy; quantum theory in physics then tells us that each photon of light carries a discrete amount of energy that depends only on the frequency of the radiation it comprises. Specifically,

$$\mathbf{E = h \bullet f\ ,}$$

where f is the frequency and h is a constant value known as Planck's constant (named after the German physicist Max Planck (1858-1947), who was one of the originators of quantum theory). The value of Planck's constant is $6.62 \times 10^{-34}$ Joule-sec.

We have already shown that frequency times wavelength is equal to the speed of a wave. If we combine our two equations above and apply them to a photon, we see that a photon's energy is inversely proportional to its wavelength:

$$\mathbf{E = h \bullet c / L\ .}$$

Photons of violet and blue light are thus higher energy, higher frequency, and shorter wavelength than those of red light. The highest energy photons are gamma-rays; the lowest energy are radio waves. This range of waves from radio to gamma-ray is called the electromagnetic spectrum.

**A Note on Units**

• electron volt (eV) - The change of potential energy experienced by an electron moving from a place where the potential has a value of V (volts) to a place where it has a value of (V+1) (volts). This is a convenient energy unit when dealing with the motions of electrons and ions in electric fields; the unit is also the one used to describe the energy of X-rays and gamma-rays. In terms of other units of energy, one eV is equal to 1.60 x $10^{-12}$ ergs or 1.6 x $10^{-19}$ Joules. A keV (kiloelectron volt) is equal to 1000 electron volts. An MeV (mega-electron volt) is equal to one million ($10^6$) electron volts.

• Joule/sec - A form of the metric unit for power. It is equal to 1 watt.

• Hertz (Hz) - The unit of frequency, defined as a frequency of 1 cycle per second (or the number of times the tip-tops of the waves pass a fixed point in space in 1 second of time). The unit is named in honor of Heinrich Hertz (1857 - 1894), a German physics professor who did the first experiments with generating and receiving electromagnetic waves, in particular radio waves.

# Classroom Activity #1: Understanding Waves

**Objective:** To understand transverse and longitudinal waves and the characteristics of frequency, wavelength, and interference.

**Materials:**

- Double length slinky, rope, or other type of spring
- Student Lab Sheet

The double length slinky is essential to the success of the exercise; a second type of long spring (not a slinky) such as Science Kit's Wave Demonstration Spring (#65940-00) can be linked to a "Slinky Spring" Science Kit #663700-00. Long strings or ropes will also work for the part of the experiment beginning with question 6.

**Procedure:**
Be sure to read through the lab instructions and familiarize yourslef with the procedures. Encourage students to highlight specific instructions in the procedure.

The experiments in this lab are best done in groups of 3 students: one serves as the "shaker", one as the "holder" and one as the "observer/recorder". Over the course of the experiments, students should rotate through each of the roles.

**Lab Part I. Longitudinal Waves**
Discuss the information presented to students in the Introduction. Remind them of the overall objective of the lab - it is not just to play with toys! The procedure for this part of the lab is described on the Student Lab Sheet.

***Answers to Questions:***
1. Sound waves and seismic waves travel as longitudinal pulses.
2. The energy is dissipated in overcoming the friction between the floor and the spring.

**Lab Part II. Transverse Waves**
The procedure for this part of the lab is described on the Student Lab Sheet. Suggest to the students is that they make large pulses so that they can more easily observe them.

***Answers to questions:***

3. The size of the pulse changes by becoming smaller (flatter, less round).
4. The reflected pulse returns on the opposite side of the spring because the person is holding the slinky in a fixed or rigid position so the spring has to invert to allow the pulse to reflect and continue to move.
5. As the tension in the spring increases, the speed of the pulses increases. If the tension is decreased, the speed of the pulses will decrease. This is a direct relationship.
6. When a pulse hits the boundary between the two types of material, part of the wave is reflected and part is transmitted. If the boundary is free to move the reflected pulse should be on the same side as the incident pulse, smaller than the incident pulse, the same shape as the incident pulse, and should travel with the same speed. The pulse which travels into the other medium will be on the same side of the new medium, but it will be smaller than the original pulse, and travel with a different speed.

7. When the two pulses meet in the center, they will add together to make a pulse that is as large as the sum of the two pulses. The shape should be the same, just larger. The speed of the pulses remains the same as they travel through each other. Students will often say that the pulses bounce off of each other or reflect. When this happens, suggest that the students make the pulses different sizes and that they lower the tension in the spring.

8. When pulses on opposite sides of the spring meet, they cancel out if the pulses are the same size. If they are not the same size the addition (or subtraction) of the pulses when they meet should result in a smaller pulse being formed momentarily. The shape will flatten out if the pulses are the same size, or become smaller if they are not the same size. The speed of the two pulses should stay the same.

9. There is a point where the spring does not move if the pulses start from opposite sides of the spring. This is called a node. The opposite motions of the spring cancel out so that there is no movement.

10. Pulses traveling in the same medium either add together or subtract from each other when they meet.

11. Wavelength and frequency are inversely proportional. As wavelength gets smaller, frequency gets higher. As the student moves his/her hand faster, the waves are closer together. (Either of these three sentences is an acceptable answer.)

**References:**


- Harvard Project Physics
- Modern Laboratory Experiments in Physics, Brinckerhoff and Taft
- Investigations in Science: Light and Sound, Phil Parratore, Creative Teaching Press,1996

# Understanding Waves Student Lab Sheet

**Objective:** To understand transverse and longitudinal waves and the characteristics of frequency, wavelength, and interference.

**Materials:** Double length slinky, rope, or other type of spring

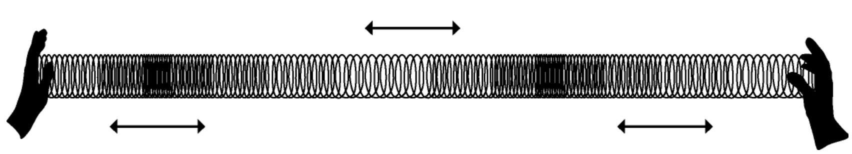
**Introduction:**
A wave is an oscillating, repetitive motion that travels through matter or space. They are all around us - water waves, sound waves, microwaves, and radio waves...just to name a few. Waves (except for light waves) need to travel through some sort of medium, such as a solid, liquid, or gas. These media transfer the wave energy. In a wave on the ocean, water is the medium. For a sound wave, air is the medium.

There are two classes of waves, transverse and longitudinal. A transverse wave is one in which the medium moves perpendicular to the wave direction. Transverse waves cause the medium to move up and down while the wave moves out from its source. An example is an ocean wave. A longitudinal wave, sometimes called a compressional wave, moves in the same direction as the medium. An example is a sound wave. Many waves move too fast or are too small to watch easily. But in a long "soft" spring, you can make big waves that move slowly.

**Procedure:**
The experiments described below are best done in groups of 3 students: one serves as the "shaker", one as the "holder" and one as the "observer/recorder". Over the course of the experiments, students should rotate through each of the roles.

**I. Longitudinal Waves**
With a partner to help you, pull the spring out on a smooth floor to a length of about 6 to 10 meters. With your free hand, grasp the stretched spring about a meter from one end. Pull the meter of spring together toward yourself and then release it, being careful not to let go of the fixed end with your other hand! Notice the single wave, called a pulse, travel along the spring. In such a longitudinal pulse, the spring coils move back and forth along the same direction as the wave travels. The wave carries energy, but the spring remains stationary after the pulse has passed through it and reflected from the other end.

Longitudinal Waves



1. What kinds of waves travel as longitudinal pulses? ________________________________________

____________________________________________________________________________

2. What happens to the energy? ______________________________________________________

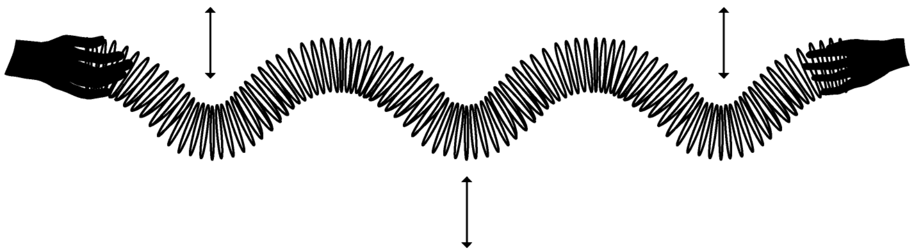
____________________________________________________________________________

Note: You can see a longitudinal wave more easily if you tie pieces of string to several of the loops of the spring and watch their motion when the spring is pulsed.

**II. Transverse Waves**

A transverse wave is easier to see. To make one, practice moving your hand very quickly back and forth at right angles to the stretched spring until you can produce a pulse that travels down only one side of the spring (that is, the bump on the spring due to the pulse is only on the right or left side of the spring). This pulse is called “transverse” because the individual coils of wire move at right angles to (transverse to) the length of the spring.

Transverse Waves



Perform experiments to answer the following questions about transverse pulses.

3. Does the size of the pulse change as it travels along the spring? If so, in what way?

_______________________________________________

_______________________________________________

_______________________________________________

4. Does the pulse reflected from the far end return to you on the same side of the spring as the original, or on the opposite side? Why?

_______________________________________________

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_______________________________________________

5. Does a change in the tension of the spring have any effect on the speed of the pulses? When you stretch the spring farther, you are changing the nature of the medium through which the pulses move.

_______________________________________________

_______________________________________________

_______________________________________________

Next observe what happens when waves go from one material into another - an effect called refraction. Attach a length of rope or rubber tubing (or a different kind of spring) to one end of your spring and have your partner hold the end of it.

6. What happens to the pulse when it reaches the boundary between the two media? Describe its size, shape, speed, and direction in BOTH media after the pulse reaches the boundary. Notice that the far end of your spring should now be free to move back and forth at the joint, which it was unable to do before because your partner was holding it. If you notice that the far end of the spring is not moving freely, be sure to make a note of it in your observations as you record the answer to this question.

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Have your partner detach the extra spring and once more grasp the far end of your original spring. Have him send a pulse on the same side at the same instant you do, so that the two pulses meet. The interaction of the two pulses is called interference.

7. What happens when the two pulses reach the center of the spring? Describe the size, shape, speed and direction of each pulse during and after the interaction. It will be easier to see what happens in the interaction if one pulse is larger than the other.

_______________________________________________

_______________________________________________

_______________________________________________

_______________________________________________

8. What happens when two pulses on opposite sides of the spring meet? That is, send one down the right side and have your partner send another down the left side at the same time. Describe as in question 7.

_______________________________________________

_______________________________________________

_______________________________________________

_______________________________________________

9. As the two pulses pass each other when they started on opposite sides of the spring, can you observe a point on the spring that does not move at all? Explain.

_______________________________________________

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_______________________________________________

_______________________________________________

10. From the observations you made in questions 7 - 9, make a general statement about the displacement caused by the addition of two pulses at the same point.

_______________________________________________

_______________________________________________

_______________________________________________

By vibrating your hand steadily back and forth, you can produce a train of pulses, or a periodic wave. The distance between any two neighboring crests on such a periodic wave is the wavelength. The rate at which you vibrate the spring will determine the frequency of the periodic wave. Produce various short bursts of periodic waves so that you can answer the following question.

11. How does the wavelength depend on the frequency?

_______________________________________________

_______________________________________________

_______________________________________________

References:
- Harvard Project Physics
- Modern Laboratory Experiments in Physics, Brinckerhoff and Taft
- Investigations in Science: Light and Sound, Phil Parratore, Creative Teaching Press,1996

# Classroom Activity #2: Do the Wave!

## Exploring Inverse and Direct Relationships

"The amount of money in my bank account is inversely related to the money I spend." Does this sound familiar? It's just an ordinary situation involving money, but stated in the language of mathematics. This relationship described (the more money you spend, the less you have in your account) is called an inverse relationship.

"The test grade I receive is directly related to how well I understand the material." This is a mathematical statement of the direct relationship which exists between the variables "grade" and "understanding".

These are two simple examples of direct and inverse relationships. You can find additional examples everyday in your lives, and everywhere in the world around you.

In exploring direct and indirect (or inverse) relationships, the following labs are often demonstrated or performed with students.

1. Pour a half cup of sugar from varying heights. If you measure the height of the resulting pile and compare it to the height from which it is poured, what do you notice? Is this a direct or an inverse relationship?
2. Paper cups and dry spaghetti can be used to explore mathematical relationships. Using a paperclip, hang a paper cup from near the end of the spaghetti. Let the part of the pasta supporting the paper cup hang over the edge of a table. Measure the length of the pasta from the edge of the table to the paper cup. Slowly drop pennies into the cup and make note of the number of pennies it takes to break the pasta. Get a new piece of pasta and shorten the length from the edge of the table to the paper cup. Once again, drop pennies into the cup and make note of the distance and the number of pennies it takes to break the pasta. Do this for several distances/trials. Graph the data from all of the trials in your class. Do you see a direct or an inverse relationship?

The following lesson consists of 3 parts, and teaches inverse and direct relationships. Part I is a lab in which the gathered data will be used in the later Parts. Part II examines the inverse relationship between frequency and wavelength for wave motion. Part III examines the direct relationship between frequency and energy for light waves.

**Part I**

In this activity, we investigate inverse relationships using a coiled spring.

**Teacher Notes:**

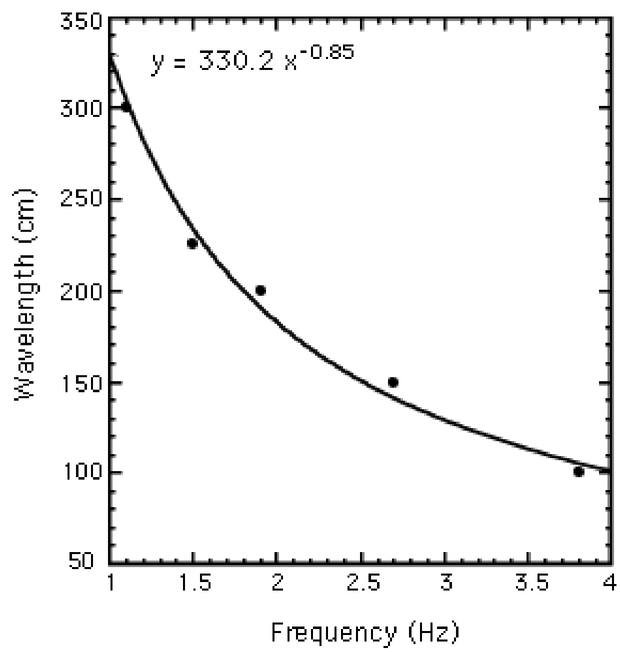
- Make sure each group has a student worksheet for this lab, a stop watch, tape measure, graph paper, double length coiled spring (or tape the end of two together), and a roll (or several strips) of masking tape.
- Steps 1-5 should be demonstrated in front of the class with a sample group of students.
- There will need to be 4 people in the lab group for this experiment.
- Each lab group will need an area of 1.5m by 6m to perform the experiment, which means that the lab may have to be conducted in the hallway or outdoors. To save time, the teacher may measure of the distances and place the tape in the lab area (step 1) before the students perform the lab.

• Make sure students are placing data in the table provided (shown below) beginning in step 5. Below we show data taken by the authors when they did the lab as a guide for values you might expect.

| Trial | Wavelength (cm) | # Crests in 10 sec | Calculated number of crests in 1 sec | Level of Effort required (Energy) |
|---|---|---|---|---|
| 1 | 300 | 11 | 1.1 | 1 |
| 2 | 225 | 15 | 1.5 | 3 |
| 3 | 200 | 19 | 1.9 | 6 |
| 4 | 150 | 27 | 2.7 | 8 |
| 5 | 100 | 38 | 3.8 | 10+ |

• Students begin plotting the data in step 10. We show a plot and the curve fit to the authors' sample data.

Frequency (Hz) vs. Wavelength (cm)




• Discuss errors in the lab with students to summarize. Ask students: "What errors can you identify in the experiment which might keep the results from being exactly what they should be?"

Tell students that first and foremost is the fact that the velocity of the waves generated in the lab are not constant as you attempt to achieve higher and higher frequencies (i.e., smaller and smaller wavelengths). Also, it is doubtful that you precisely achieve a standing wave, where every crest-to-crest is an equal distance. But still...you will undoubtedly see in the data that frequency and wavelength have an inverse relationship. The precise relationship they share, especially as it applies to light - or the electromagnetic spectrum - will be examined in Part II.

• Talk about the units of frequency. To a physicist, the unit is the Hertz (Hz), which stands for 1 cycle per second. This is the same as "1/sec" when doing dimensional analysis...the "cycle" does not appear as a unit. So if you have L • f, you have units of (m) x (1/sec) or m/sec. The "cycles" don't appear. This will be important in Part II.

**Part II**

Although the spring lab performed in Part I may not produce an exact result, students should have seen that wavelengths and frequencies are inversely related. As a matter of fact, wavelength and frequency are defined by an inverse relationship, L = v/f. In this equation, v is the velocity at which the wave is travelling. Tell the students that in this investigation, this relationship will be examined closer.

**Teacher Notes:**

• Discuss with students that light is a form of waves - electromagnetic waves. Depending on the wavelength of the wave, we refer to it as radio, microwave, infrared, visible, ultraviolet, X-ray, or gamma-ray. Post the Table below on the board or on the overhead projector for the students to examine it. It is a table of values that correspond to the electromagnetic (EM) spectrum, with a representative value of wavelength (L), frequency (f), and energy (E) given for each region of the spectrum.

| | Wavelength (m) | Frequency (Hz) | Energy (eV) |
|---|---|---|---|
| Radio | 3 | $1 \times 10^{8}$ | $4.1 \times 10^{-7}$ |
| Microwave | $2 \times 10^{-2}$ | $1.5 \times 10^{10}$ | $6.2 \times 10^{-5}$ |
| Infrared | $4 \times 10^{-4}$ | $7.5 \times 10^{11}$ | $3.1 \times 10^{-3}$ |
| Visible | $5 \times 10^{-6}$ | $6 \times 10^{13}$ | 0.25 |
| Ultraviolet | $1 \times 10^{-7}$ | $3 \times 10^{15}$ | 12.4 |
| X-ray | $8 \times 10^{-11}$ | $3.75 \times 10^{18}$ | $1.5 \times 10^{4}$ |
| Gamma-ray | $2.5 \times 10^{-12}$ | $1.2 \times 10^{20}$ | $4.95 \times 10^{5}$ |

• The *Student Worksheet for Frequency and Wavelength* can then be handed out.

• Students will enter the data for Frequency and Wavelength from the Table you have shown them into their data sheets. They will then calculate velocity, v = f • L.

• Students should remember in step 2 that Hz = 1/sec, therefore producing m/sec when multiplied by m (wavelength).

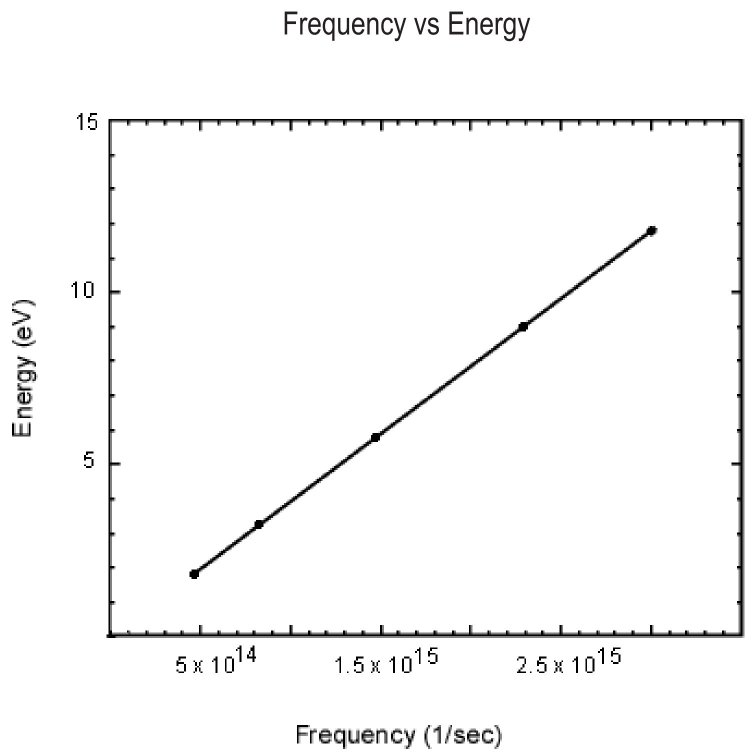
• In step 3, students should calculate approximately $3\text{x}10^{8}$ m/sec. This is an important velocity with great significance when discussing the EM spectrum; it is the speed (or velocity) of light. Students should recognize this in step 4.

• For additional practice, suggest that students go back to the data they took with the coiled springs. Using the wave velocity equation, how fast were the waves they generated travelling?

**Part III**

During the lab in Part I, the students should have noticed that to create a higher frequency wave required more energy. This implies that the relationship between frequency and energy is a direct relationship. In this Part, we will examine the exact nature of this relationship as it applies to electromagnetic waves. Students should receive a copy of the Frequency and Energy Worksheet in order to complete this final part of the lesson.

• Students will examine the graph shown below. Discuss the unit of energy, the electron-volt (eV), used in the graph. One eV is equal to 1.6 x $10^{-19}$ Joules. The unit of eV is often used by scientists because of how small the energies of individual photons are when expressed in the unit of Joules.




• The graph shows the relationship between energy and frequency - the relationship is direct and linear. Only a small part of the frequency range of the EM spectrum is shown (a subsection of the ultraviolet region). Students can use this segment to determine the equation which should apply to the whole EM spectrum, and then apply it (recall, E = h • f, where h is Planck's constant equal to 4.13x $10^{-15}$ eV-sec). In step 5, students should see that as you increase frequency by 1 x $10^{15}$ cycles/sec, the energy increases by just over 4 eV (4.13, to be exact). It is important to get them to appreciate the wide range of frequencies or energies that the EM spectrum covers....and what a very, very small part of it is occupied by the visible region that we see with our eyes.

• Unless you go to a log-log plot, it is extremely difficult to show the whole EM spectrum on a graph. This is due entirely to the enormous ranges of values encountered. Refer back to the original Table you showed with the EM spectrum data for energy, wavelength, and frequency. Pay special attention now to the ranges of the values in each column.

• If additional practice is needed in the use of scientific notation, suggest students write the ranges of the EM spectrum out in standard decimal form. You can even go through the laborious process of performing the calculations in the lab without using scientific notation. Viva scientific notation!

Group Member Names:
________________________________
________________________________
________________________________
________________________________

Date ______________
Period ______________

# Do the Wave!

*Student Labsheet*

**Materials Needed for Each Group:**

* stop watch, tape measure, graph paper, double length slinky (or tape the end of two together), and a roll (or several strips) of masking tape.

**Roles:**

There will need to be 4 people in the lab group for this experiment.

1. Length Spotter (who will "spot" the length of a wave)
2. Wave Maker (who will move the slinky from one end)
3. Frequency Reporter (who will hold the slinky at the other end and count the number of times waves pass over 10 seconds)
4. Data Recorder (who will record the data for the lab team)

**Procedure:**

1. Put strips of masking tape about 50 cm apart on the floor. Continue the process until you have a length of about 6 meters marked off. This will serve as your "measuring line". The Wave Maker and Frequency Reporter sit at the opposite ends of the measuring line (so about 6 meters apart).
2. The Length Spotter should stand beside the measuring line roughly at mid-length. These tape pieces will allow the Spotter to determine the wavelength of the waves.
3. The Wave Maker and the Frequency Reporter should hold the slinky at opposite ends and the Wave Maker should practice making waves as the Frequency Reporter Holds his/her end still.
4. The Wave Maker should move his/her arm across his/her body a constant distance for every wave made. To increase the frequency, he/she will just simply move his/her arm across that distance in a shorter period of time. Once the Wave Maker gets into a consistent motion, the Data Recorder should say "start" and the Frequency Reporter should start counting waves as they reach his/her end. You might want to practice this once or twice.

Let the Data Collecting begin! Follow the steps below and use the data table provided to record the data.

5. As the Frequency Reporter is counting the waves, the Length Spotter should be examining the length of the wave, using the pieces of masking tape as a guide. Estimations can be made between the 50 cm scale. Remember, a wavelength can be measured from "crest" to "crest".

6. Stop after the Recorder calls 10 seconds.

7. Data Recorder should record the wavelength and frequency in the table. In the column labeled "Level of Effort (Energy) Required", the Wave Maker should record a number from 1 to 10, which qualitatively evaluates the amount of energy used to create the wave for this trial. "1" would represent "very little energy" and "10" would represent "Uncle! Uncle! I can't go on a second more!"

8. Calculate the number of crests per second and enter the result in the appropriate column.

9. Repeat steps 4-8 at least 4 more times. In the beginning, produce the longest wavelength. As the steps are repeated, for each trial consistently decrease the wavelength.

| Trial | Wavelength (cm) | # Crests in 10 sec | Calculated number of crests in 1 sec | Level of Effort required (Energy) |
|---|---|---|---|---|
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |
| 4 | | | | |
| 5 | | | | |

10. Plot the frequency (in crests per second) versus the wavelength on your graph paper. Explain the relationship that you observe.

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11. Given what you know about waves, what errors can you identify in the experiment that will keep the results from being exactly what the theory predicts?

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Name ______________________________ Date ___________ Period _____

## Waves Light Up the Universe... Frequency and Wavelength

*Student Worksheet*

1. Examine the table of data the teacher just presented to you. For each range of the EM spectrum, as noted in the Table below, record the typical wavelength and frequency.

| | Wavelength (m) | Frequency (Hz) | Wvlgth * Freq (  /  ) |
|---|---|---|---|
| Radio | | | |
| Microwave | | | |
| Infrared | | | |
| Visible | | | |
| Ultraviolet | | | |
| X-ray | | | |
| Gamma-ray | | | |

2. For each of the ranges, multiply "L" by "f" and place each value in the "Wvlgth•Freq" column. Be mindful of the units. When multiplied, the units for the result become ______________, which is a measure of velocity. Enter the units into the appropriate place in the Data Table.

3. What pattern do you notice in the results of your calculations? What is the average value of velocity do you get over all of the EM spectrum ranges?

________________________________________________

________________________________________________.

4. Does this value have any special significance?

________________________________________________

________________________________________________.

Name ______________________________ Date ____________ Period ______

# Waves Light Up the Universe... Frequency and Energy

*Student Worksheet*

1. Examine your Data Table from Part I. What did you notice about the level of effort required (or the energy used) by the Wave Maker as the frequency increased? Describe what insight this provides into the mathematical relationship between energy and frequency.

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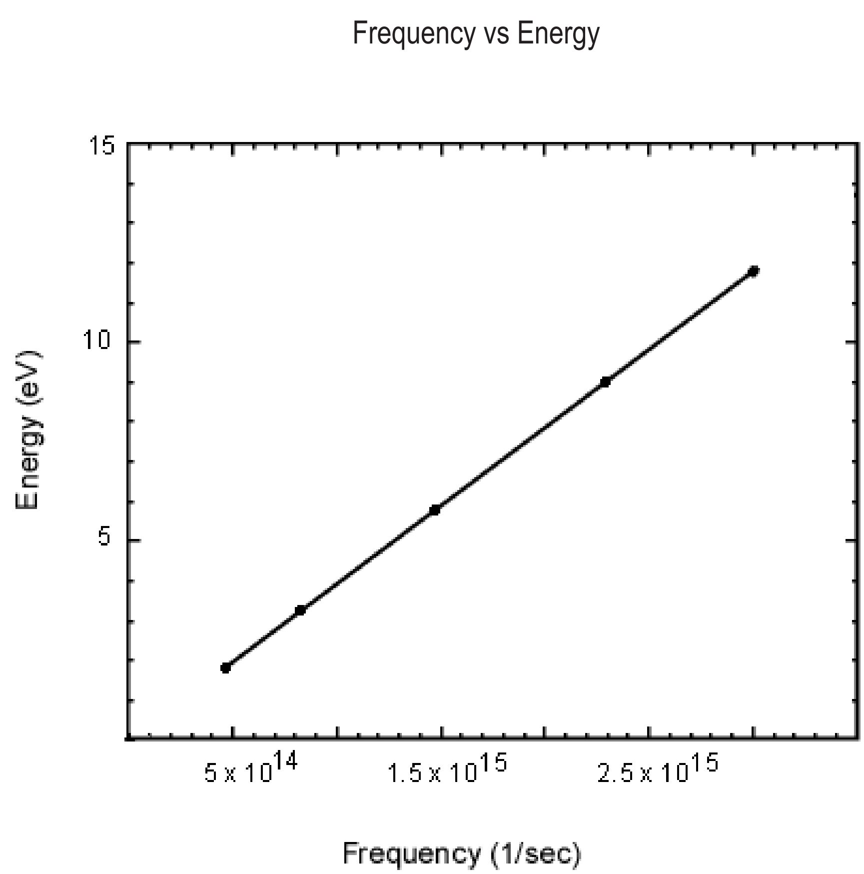
2. Examine the graph below. What sort of relationship does it show?




3. Select five separate points on the graph and determine the frequency and energy coordinates of each. Enter these data in the Table below. Calculate the ratio of E/f for all of the points you selected. Enter the ratios in decimal form in the Table.

| | Frequency (Hz) | Energy (eV) | Ratio E/f |
|---|---|---|---|
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |

4. The ratio you found is equal to the slope of the line. Explain why this is true.

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This value is called Planck's Constant. It is used in the equation that describes the relationship between energy and frequency. From what you now know, can you write this equation?

_________________________________________________________________

5. Now, let's think bigger. Let us examine the entire electromagnetic spectrum. In the Data Table given below, enter the value of the typical frequency of each region of the electromagnetic spectrum by using the Table of data given at the beginning of Part II.

| | Frequency (Hz) | Energy (eV) |
|---|---|---|
| Radio | | |
| Microwave | | |
| Infrared | | |
| Visible | | |
| Ultraviolet | | |
| X-ray | | |
| Gamma-ray | | |

6. Given the equation you have derived for energy as a function of frequency, calculate the energies which correspond to the typical frequency in each of the ranges of the electromagnetic spectrum -- from radio to gamma-ray. Enter these values in the Data Table.

7. Discuss why it would be difficult to plot the entire electromagnetic spectrum on a frequency versus energy plot of the type shown above.

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**National Science Content Standards Involved**

• Grades 9-12 Physical Science:

* Conservation of Energy and the Increase of Disorder:

"The total energy of the universe is constant. Energy can be transferred by collisions in chemical and nuclear reactions, by light waves and other radiations, and in many other ways; All energy can be considered to be either kinetic energy, which is the energy of motion; potential energy, which depends on relative position; or energy contained by a field, such as electromagnetic waves."

* Interactions of Energy and Matter:

"Waves, including sound and seismic waves, waves on water, and light waves, have energy and can transfer energy when they interact with matter; Electromagnetic waves result when a charged object is accelerated or decelerated. Electromagnetic waves include radio waves (the longest wavelength), microwaves, infrared radiation (radiant heat), visible light, ultraviolet radiation, x-rays, and gamma rays. The energy of electro magnetic waves is carried in packets whose magnitude is inversely proportional to the wavelength."

**National Mathematics Content Standards Involved**

• Grades 9-12 Algebra:

* Understand patterns, relations, and functions
  - Generalize patterns using explicitly defined and recursively defined functions;
  - Understand relations and functions and select, convert flexibly among, and use various representations for them;
  - Analyze functions of one variable by investigating rates of change, intercepts, zeros, a symptotes, and local and global behavior;
  - Understand and compare the properties of classes of functions, including exponential, polynomial, rational, logarithmic, and periodic functions;
  - Interpret representations of functions of two variables.

* Represent and analyze mathematical situations and structures using algebraic symbols
  - Use symbolic algebra to represent and explain mathematical relationships;
  - Judge the meaning, utility, and reasonableness of the results of symbol manipulations, including those carried out by technology.

* Use mathematical models to represent and understand quantitative relationships
  - Draw reasonable conclusions about a situation being modeled.

**National Mathematics Process Standards Involved**

- Reasoning
- Communication
- Connections
- Representation.

**Additional Resources**

• ***Imagine the Universe!*** Web site -- http://imagine.gsfc.nasa.gov/

• ***Swift*** Mission Web site -- http://swift.sonoma.edu/

• ***Waves*** -- a book by Gloria Skurznski. Available from the Astronomical Society of the Pacific's catalog at https://www.mailordercentral.com/aspsky/.

• ***Waves***, Bill Nye Episode #51. You can purchase a video version of this episode. Information is available at http://nyelabs.kcts.org/teach/faq/faq06.html.

• ***ExploreScience.com*** Web site -- http://www.explorescience.com/activities/activity_list.cfm?categoryID=3 has a whole list of multimedia activities teaching about waves and their various phyysical properties.

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**Credits**

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**http://swift.sonoma.edu/epo/**