National Aeronautics and Space Administration

LASER ACTIVITY BOARD

The Laser Activity Board will help strengthen understanding of the electromagnetic spectrum, with an emphasis on the application of lasers! LASER is an initialism, meaning each letter stands for a word. And in this exercise, each letter has its own activity that can be assigned together or in parts. Students should have basic prior knowledge of the parts of a wave. This activity can be a standalone assignment or used in conjunction with a unit on waves.

AGE:
11+

DURATION:
20-30 minutes

Objective

Students will learn the properties of waves, specifically lasers and their applications, through a series of math, writing, and drawing activities.

NGS Standards[1]

Performance Expectations
MS-PS4-3, MS-PS4-1

Science and Engineering Practices
- Planning and Carrying Out Investigations
- Analyzing and Interpreting Data
- Engaging in Argument from Evidence
- Obtaining, Evaluating, and Communicating Information

Disciplinary Core Ideas
- Definitions of Energy
- Relationship Between Energy and Forces
- Defining and Delimiting Engineering Problems

Cross-Cutting Concepts
- Scale, Proportion, and Quantity
- Systems and System Models
- Energy and Matter
- Scale, Proportion, and Quantity
- Structure and Function
- Influences of Science, Engineering, and Technology on Society and the Natural World
- Interdependence of Science, Engineering, and Technology

MATERIALS

- 1 copy of the handout per student
- Standard laser pointer (≤ 5 mW)

OPTIONAL

- Calculator
- Internet access for students to read linked article

ADDITIONAL RESOURCES

- What is a Laser?[2]
- Integrated LCRD Low-Earth Orbit User Modem and Amplifier Terminal (ILLUMA-T)[3]
- To the Moon and Back... in 2.5 seconds[4]
- The Apollo 15 Lunar Laser Ranging RetroReflector[5]
- Why Space Radiation Matters[6]

[1] A complete list of the NGS Standards can be found at **https://ngss.nsta.org/AccessStandardsByTopic.aspx**.
[2] **https://spaceplace.nasa.gov/laser/en/**
[3] **https://esc.gsfc.nasa.gov/projects/ILLUMA-T**
[4] **https://bit.ly/3rRDrRZ**
[5] **https://go.nasa.gov/36qokay**
[6] **https://nasa.gov/analogs/nsrl/why-space-radiation-matters**

Procedure

1. Demonstrate the use of a laser pointer. Begin class discussion by demonstrating the use of a laser pointer and asking questions such as:

   What is this?
   How does it work?
   Where have you seen other lasers?
   How are lasers different from flashlights?

2. Explain that the word LASER is an initialism, meaning each letter stands for a word. Ask students to brainstorm what each letter stands for; record their ideas, share their responses, and celebrate when they name a correct word.

3. Pass out copies of the LASER handout. Students may work independently or with a partner(s).

4. Show your students that each letter is a separate, but related, activity. Discuss how students can pick which activities they prefer to complete or assign activities to them! See below in "Differentiation" for ideas.

Expansion and Differentiation

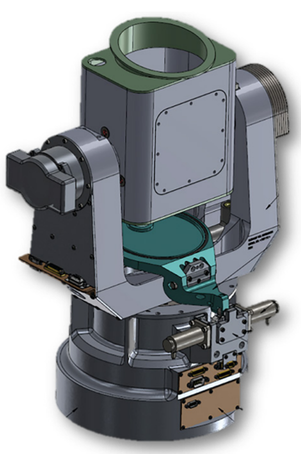
Expansion

- Suggest students read the articles linked in the resources section prior to receiving the handout.
- Provide learners with a printed copy of the NASA article "What is a Laser?" to reference while completing the activity.

Differentiation

- For larger classes, assign each letter to a different group with a time limit. Learners then share their findings with the class—or have a representative from each group communicate their work to the other groups — until the handout is complete.
- Reduce the number of activities they need to complete. For example, allow students to choose any three of the five letters to complete.
- Choose a specific letter activity that corresponds with individual learner's abilities.

NASA Loves Lasers


ILLUMA-T Artist Rendition

NASA is bringing laser communications to the International Space Station! Laser communications empower exploration and science missions with higher *data rates*, meaning more information (*data*) can be sent in a single transmission. With more data, NASA can make more discoveries about our planet, outer space, and the astronaut experience.

The laser terminal aboard the space station is called the *Integrated LCRD Low-Earth Orbit User Modem and Amplifier Terminal* (ILLUMA-T). ILLUMA-T tests the power of laser communications by taking data from experiments aboard the space station and sending that data to NASA's Laser Communications Relay Demonstration (LCRD) at up to 1.2 gigabits (Gb) per second. LCRD, being a relay, sends this information down to ground stations in Hawaii and California.

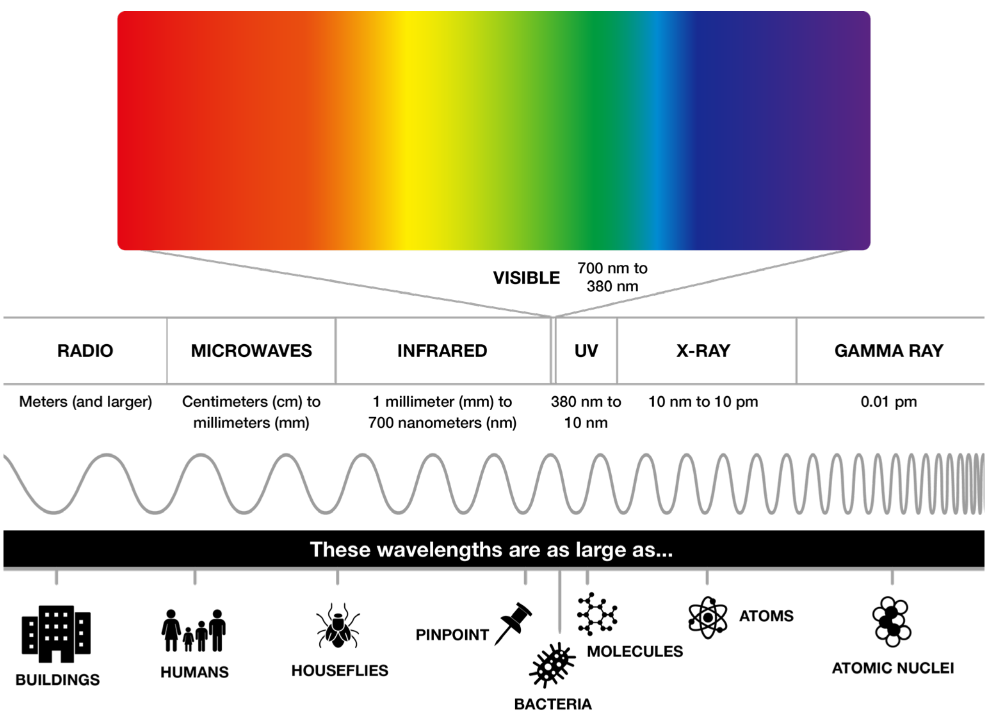
Laser communications is the use of infrared light to transmit information. Historically, NASA has relied on radio waves to send and receive information. Both radio waves and infrared light are electromagnetic radiation with wavelengths at different points on the electromagnetic spectrum.

LCRD flies in a faraway *geosynchronous orbit*: over 22,300 miles (35,890 km) from home. It moves with Earth, so it always seems to ‘hover’ over the same part of Earth. At LCRD’s altitude, it must fly almost 2 miles per second to “keep up” with the Earth as it spins beneath.

ILLUMA-T flies in a *low Earth orbit* (LEO) close to home: about 250 miles (400 km) overhead. It moves much faster relative to Earth (nearly 5 miles per second!), circling our planet 16 times every day.

From the space station, ILLUMA-T needs to point at LCRD fast enough to compensate for these different orbital speeds. Imagine scoring a “bullseye” on a moving target from over a mile away or taking a picture of a race car moving at 180 miles per hour from over 21 miles away. ILLUMA-T has superpowered tracking!

ILLUMA-T and LCRD will work together to show how NASA can use lasers to send data from one kind of orbit (geosynchronous) to another kind of orbit (low Earth) and, finally, to Earth.



WAVELENGTHS

The electromagnetic spectrum is a vast rainbow of colors that extends past our range of vision in both directions. This rainbow includes waves at all frequencies, including radio waves, visible light, infrared, and X-rays.

The wavelength distances shared on this chart are estimated to the nearest round number.

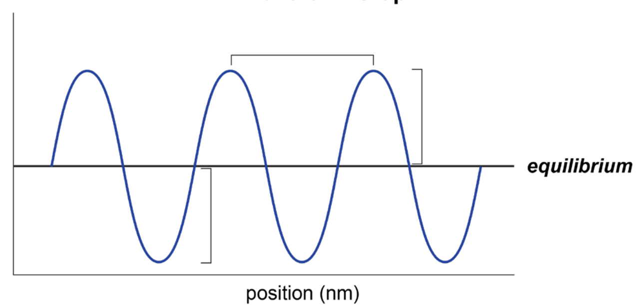
L
LIGHT

A Light Wave Diagram

Label the wave of laser light on the graph provided below:

- **Amplitude –** the largest distance from equilibrium (negative or positive) in the direction of the y-axis. Also known as **magnitude**. The **amplitude** applies to both the crests and troughs.
- **Crest –** the point in the direction of the x-axis that corresponds to the maximum amplitude. Also known as a **peak**.
- **Trough –** the point in the direction of the x-axis that corresponds to the minimum amplitude. Also known as a **valley**. Crests and troughs are always separated by exactly half a wavelength.
- **Wavelength –** the distance between each crest (or between each trough). Scientists describe this in terms of actual physical distance; for example, the wavelength of yellow light is 580 nanometers. That's very small!

Waveform Graph



A
AMPLIFICATION
(BY)

Lasers in Your Life

Read the following passage:

"Lasers have many uses. They are used in precision tools and can cut through diamonds or thick metal. They can also be used to help with delicate surgeries. In addition, lasers are used for recording and retrieving information like carrying TV and internet signals. We also find lasers in laser printers, bar code scanners, and DVD players."

What is one way that lasers have "**A**mplified" your life? Why use lasers instead of another technology (wires, a surgeon's scalpel, tape, film, etc.) in this instance?

Read the following webpage: **https://esc.gsfc.nasa.gov/projects/ILLUMA-T**. Select one of the "Quick Facts" near the bottom and copy the fact that most interests you below. Explain why you found it interesting or ask questions you have about the fact.

Lasers Go the Distance

Scientists have used lasers to measure the distance between the Moon and Earth. Navigation engineers from NASA's Goddard Space Flight Center pointed a laser at the *retroreflectors* left on the Moon by Apollo astronauts on July 21, 1969. A retroreflector is a kind of prism, or crystal, which bounces back light in the same direction from which it came. The engineers used precise clocks to measure the amount of time between sending the laser and receiving the reflected beam. You can do it too! **S**timulate your brain by calculating the distance!

$$\frac{(Rate * Time)}{2} = Distance$$

(We divide this by two because we need to account for the two parts of the laser's journey: the trip there and the trip back.)

- Speed of light = 299,792 km/s
  (Many scientists round up the speed of light to 300,000 km/s; you can decide the degree of precision you prefer to use here.)
- The time between sending and receiving the reflected laser was 2.56 seconds.

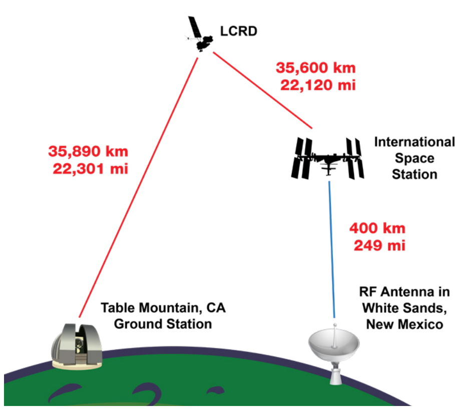
The Moon is ____________ km from Earth.

Bonus Questions

a. If the International Space Station orbits at an average altitude of 400 kilometers above Earth, how long would light from ILLUMA-T take to reach a target immediately below it?

b. ILLUMA-T transmits and receives data at 1.2 Gb per second. Excluding processing time, how much time would elapse between ILLUMA-T sending a 0.51 Gb message to Earth and getting a 0.07 Gb response back? (Assume ILLUMA-T is directly over the ground station). Normally more time is needed as modems and computers receive and decode a laser signal, then either re-transmit the same signal, or compose and transmit a reply. For this calculation, though, we will focus only on the time-of-flight and time-of-transmission.

c. NASA wants to test a new message protocol by sending a 3.0 Gb video file from the NASA White Sands Complex to the International Space Station (in low Earth orbit) to LCRD (in geosynchronous orbit) and then back down to an optical ground station in California. Unfortunately, it's cloudy over White Sands that day, so NASA sends the signal from White Sands to the space station with an older radio system at 0.02 Gb/s. On the station, the video will be transferred to ILLUMA-T for transmission to LCRD and down to Earth. How long will it take the message to travel from White Sands to ILLUMA-T to LCRD to California?



Assumptions:

- ILLUMA-T is directly over the White Sands ground station and LCRD is directly over the California ground station.
- The distance between the spacecraft is approximately 35,600 km.
- Disregard all processing and relaying times for computers on Earth, the space station, LCRD, and ILLUMA-T.

S
STIMULATED

LEARN MORE

As part of the Artemis missions, scientists and engineers continue to measure the precise distances to the Moon to prepare for landing on its surface. Using this technique and extremely precise clocks, we can calculate the distance to the Moon's surface to within 1 millimeter! You can learn more at **go.nasa.gov/36qokay**.

Note to teachers:
We have been treating the transmission time as instantaneous, but, in reality, the laser communications systems will take a few milliseconds to send a few megabytes of data, and the radio communications systems would take tens to hundreds of milliseconds to send the same data. We're leaving these out to avoid further complicating the scenario.

Remember:
Radio waves and laser waves *travel at the same speed*, so while the *transmission* rates are different, the *travel* rates are identical!

E
EMISSION
(OF)

All Together Now

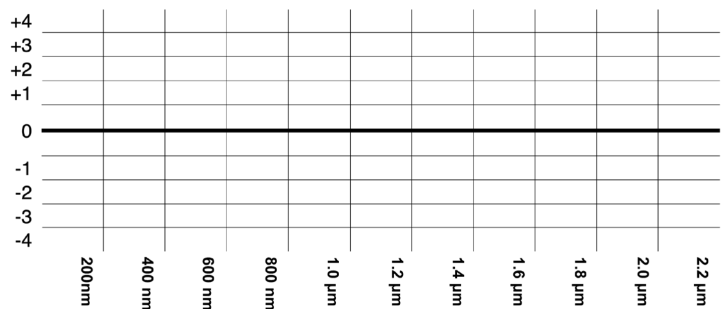
Lasers are different from regular light in a few different ways. For example, the waves being **E**mitted from lasers have their crests matched up; this is called being *in phase*.

- **Frequency –** the number of times-per-second that our light wave *oscillates* (wiggles) between its crest and back again. For light to be organized as a laser signal, it must not only be in phase but also be the same frequency throughout.
- Calculate the frequency of orange light, which has a wavelength of 600 nanometers. Here, we can use 300,000,000 m/s (300,000 km/s) for the speed of light (c). Remember to convert to standard units before applying the formula!

$$wavelength(m) = \frac{c(\frac{m}{s})}{frequency(\frac{1}{s})}$$

$$600\ nm * \frac{1\ m}{1{,}000{,}000{,}000\ nm} = 0.0000006\ m \qquad 0.0000006\ m * \frac{300{,}000{,}000\ \frac{m}{s}}{\text{frequency}\ \frac{1}{s}}$$

Draw a wave of orange light with an amplitude of 3 on the graph below. The **wavelength** of orange light is 600 nanometers (nm). (Recall that 1,000 nanometers (nm) is equal to 1 micrometer (µm).)



Bonus Points

ILLUMA-T uses infrared light with a frequency of approximately 193.4 exahertz (EHz).

a. How many hertz (Hz) is that? Recall that some of the common prefixes for very large and very small numbers are:

Abbr.	Prefix	Multiplier	Can be described as...
p	Pico-	x0.000 000 000 001	one-trillionth
n	Nano-	x0.000 000 001	one-billionth
µ (or u)	Micro-	x0.000 001	one-millionth
m	Milli-	x0.001	one-thousandth
c	Centi-	x0.01	one-hundredth
d	Deci-	x0.1	one-tenth
k	Kilo-	x1,000	thousand
M	Mega-	x1,000,000	million
G	Giga-	x1,000,000,000	billion
T	Tera-	x1,000,000,000,000	trillion
P	Peta-	x1,000,000,000,000,000	quadrillion
E	Exa-	x1,000,000,000,000,000,000	quintillion

b. Calculate the wavelength of the infrared light used by ILLUMA-T.
c. Based on the electromagnetic spectrum chart above and the wavelength you calculated, will humans be able to see the laser light it emits? Why or why not?

A Bad Reputation

R
RADIATION

Radiation can sound scary, but there are many different types of radiation across the electromagnetic spectrum. People sometimes use 'radiation' to describe the kinds of electromagnetic energy emitted in nuclear reactors or by X-ray machines. These **high-energy waves** (also known as '*ionizing radiation*') can be dangerous for living things because it can damage the DNA in cells.

However, **all** parts of the electromagnetic spectrum are considered 'radiation,' but many kinds of electromagnetic radiation don't have enough energy to damage human beings. Of course, an extreme amount of **any** kind of light can be harmful, in the same way that an extreme amount of water can be harmful. But even 'harmful' radiation can be useful when managed carefully! For example, small doses of x-ray light can be very helpful for doctors trying to fix a broken bone, but you still wouldn't want to take a under an x-ray lamp.

Let's explore the different types of radiation and their impacts on living things.

Research the impacts of different types of radiation at **nasa.gov/analogs/nsrl/why space-radiation-matters**.

1. Fill in the **top** row with the **type of radiation**, ordering them from longest wavelength (left) to shortest wavelength (right).

Radio waves	Visible light
Gamma rays	Infrared light
Microwaves	X-rays
Ultraviolet light	

2. Fill in the **middle** row with a common way people use this type of light:

   a. Seeing the world around us
   b. Sending information through walls and buildings
   c. Vibrating water molecules to heat food
   d. Killing microorganisms to sterilize hospital equipment
   e. Sending an invisible signal to a television with a remote control
   f. Looking at a broken rib inside someone's chest
   g. Not commonly used by humans

Type of radiation							
Common use							

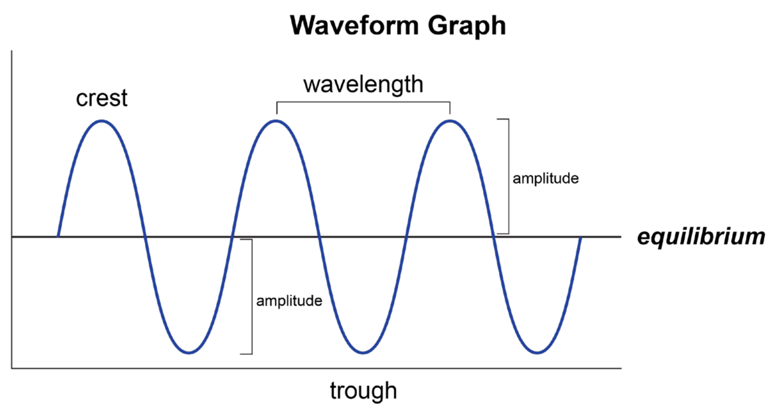
L.A.S.E.R.

ANSWER KEY

Answer Key

L: LIGHT

A Light Wave Diagram



The y-axis, amplitude, is measured in Volts per meter. Explaining those units (and the relationship between them) falls outside the scope of this exercise; for now, we suggest that students take it as given.

The x-axis units are length: meters or nanometers

A: AMPLIFICATION

Lasers in Your Life

Answers here will vary, but learners should provide a clear example of a modern application of lasers (e.g., video game controllers, grocery store scanners, internet connection, or LASIK surgery), and a brief explanation of *why* lasers are a positive application (e.g., no tangled wires, faster look-up of items/cost, possibility of travelling while keeping a fast connection, or the delicate, precise movement beyond human hands/handheld objects, etc.)

TYPES of applications (devices):	How we apply the laser:
Sensing (LIDAR, bar code scanners)	Shine tiny amounts of laser light at an object and measure the patterns of reflected light
Media storage (DVD players, CD players)	Shine lasers to sense tiny dimples in the discs
Medicine (Laser surgery)	Make precise cuts with focused, intense bursts of laser light
Manufacturing (Laser cutters, laser engravers)	Burn patterns into (or through) wood, metal, and plastic with intense bursts of laser light
Communications (optics)	Encode digital information into pulses of laser light
Materials science (Laser spectroscopy)	Vaporize small amounts of an object and identify its composition by studying the different colors of light it emits

S: STIMULATION

Lasers Go the Distance

$$\frac{(Rate * Time)}{2} = Distance$$

$$\frac{(299{,}792\ \frac{km}{s} * 2.56s)}{2} = Distance$$

$$\frac{(299{,}792{,}000\ \frac{m}{s} * 2.56s)}{2} = Distance$$

The Moon is <u>383,734</u> km from Earth.

Bonus Questions

a.

$$(Rate * Time) = Distance$$

$$Time = \frac{Distance}{Rate}$$

$$Time = \frac{400\ km}{299{,}792\ \frac{km}{s}}$$

$$Time = 0.0013\ s$$

b. Time for ILLUMA-T to transmit primary message at 1.2 Gb/s: $0.51\ Gb * \frac{1\ s}{1.2\ Gb} = 0.4250\ s$

Time for laser message to travel from ILLUMA-T to the ground (from bonus question a.): $0.0013\ s$

Time for ground station to transmit response at 1.2 Gb/s: $0.07\ Gb * \frac{1\ s}{1.2\ Gb} = 0.0583\ s$

Time for laser message to travel from ground back to ILLUMA-T: $0.0013\ s$

$$\mathbf{0.4250\ s + 0.0013\ s + 0.0583\ s + 0.0013\ s = 0.4859\ s}$$

c. Time to transmit radio frequency message from New Mexico: $3.0\ Gb * \frac{1\ s}{0.02\ Gb} = 150\ s$

Time for radio frequency message to travel from New Mexico to ILLUMA-T: $0.0013\ s$

Time to transmit laser message from ILLUMA-T: $3.0\ Gb * \frac{1\ s}{1.2\ Gb} = 2.5\ s$

Time for laser message to travel 35,600 km from ILLUMA-T to LCRD: $0.1187\ s$

Time to transmit laser message from LCRD: $3.0\ Gb * \frac{1\ s}{1.2\ Gb} = 2.5\ s$

Time for laser message to travel 35,890 km from to LCRD to California: $0.1197\ s$

Total message travel time: $\mathbf{155.2397\ s}$

ANSWER KEY

E: EMISSION

All Together Now

Lasers are different from regular light because all the waves being Emitted have their crests matched up; this is called being in **phase**.

- Calculate the frequency of orange light, which has a wavelength of 600 nanometers. Here, we can use 300,000,000 m/s (300,000 km/s) for the speed of light c.

$$wavelength = \frac{c}{frequency}$$

$$frequency * wavelength = \frac{c}{\cancel{frequency}} * \cancel{frequency}$$

$$\frac{frequency * \cancel{wavelength}}{\cancel{wavelength}} = \frac{c}{wavelength}$$

$$frequency = \frac{c}{wavelength}$$

$$frequency = \frac{300{,}000{,}000\ \frac{m}{s}}{600\ nm}$$

$$(600\ nm * \frac{1\ m}{1{,}000{,}000{,}000\ nm} = 0.0000006\ m)$$

$$frequency = \frac{300{,}000{,}000\ \frac{m}{s}}{0.0000006\ m}$$

$$frequency = 499{,}654{,}096{,}000{,}000\ \frac{1}{s} = 499{,}654{,}096{,}000{,}000\ s^{-1}$$

The units for frequency, 1/s, are also known as *Hertz (Hz)* when applied to periodic things like waves. This describes how many times-per-second the wave of light oscillates, or how many cycles a wave makes per second.

To make this staggeringly large number easier to use, we can apply a prefix of magnitude:

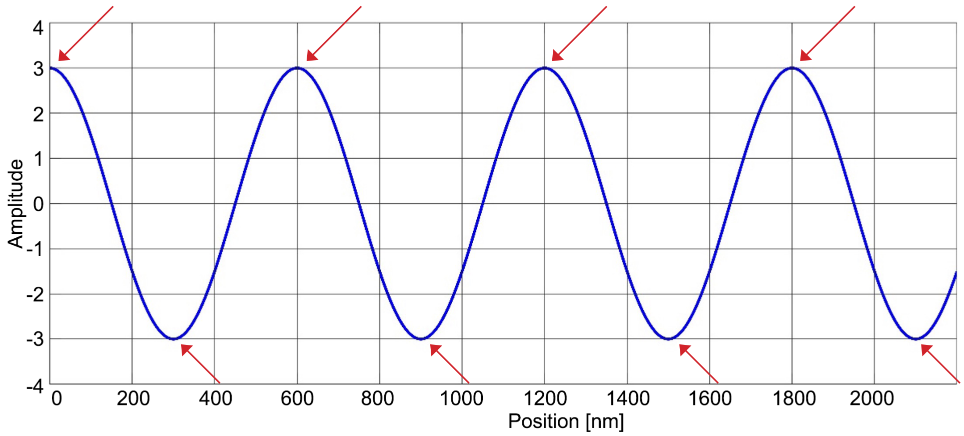
$$499{,}654{,}096{,}000{,}000\ Hz = 499\ THz$$

That’s a lot of oscillations!

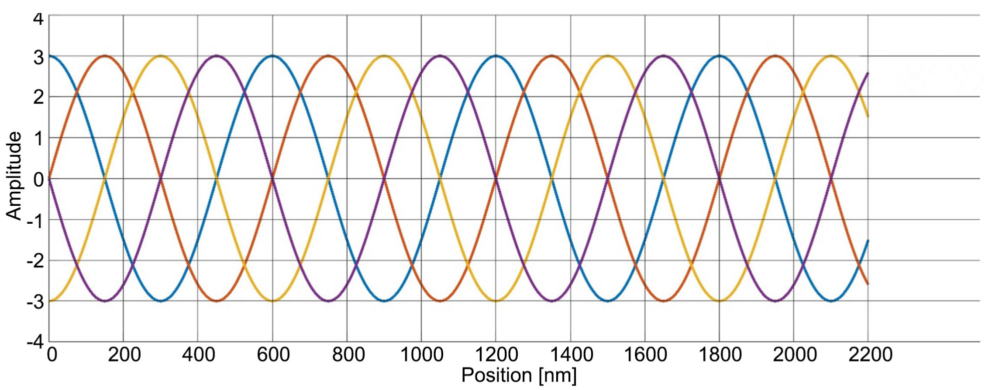
When drawing a wave of orange light with an amplitude of 3, we started by using dots to identify the crests and the troughs (marked by the red arrows.)

Since the wavelength is 600 nm, we know that each crest must be 600 nm apart from the next crest, and each trough must be 600 nm apart from the next trough. We also know that each crest will be separated from the trough by half of the wavelength on the x-axis.

Since the amplitude is 3, the crests should have a y-value of 3 and the troughs should have a y-value of -3.



From there, we filled in the remaining curves to follow the sinusoidal wave form of light.



Note that the **phase** of the wave is unimportant. Students can stipulate any initial value they please, within the amplitude constraints. All the waves sketched to the left are just some of the examples of valid responses.

Bonus Points

ILLUMA-T uses infrared light with a frequency of approximately 193.4 exahertz (EHz).

a. $$193.4\ EHz * \frac{1{,}000{,}000{,}000{,}000\ Hz}{1\ EHz} = 193{,}400{,}000{,}000{,}000\ Hz$$

b. $$wavelength = \frac{c}{frequency}$$

$$wavelength = \frac{300{,}000{,}000\ \frac{m}{s}}{193{,}400{,}000{,}000{,}000\ \frac{1}{s}}$$

$$wavelength = 0.000001551\ m$$

$$0.000001551\ m * \ 1{,}000{,}000{,}000\ \frac{nm}{1m} = 1{,}551\ nm$$

c. Human eyes cannot detect a laser at 1,551 nm; our eyes can only detect light with wavelengths between 380 and 700 nanometers.

R: RADIATION

A Bad Reputation

For additional resources on this topic, visit:

- Tour of the Electromagnetic Spectrum[7]
- The Electromagnetic Spectrum Video Series & Companion Book[8]

	Long wavelength -- Short wavelength						
Type of radiation	Radio Waves	Microwaves	Infrared	Visible Light	Ultraviolet	X-rays	Gamma Rays
Common use	Sending information through walls and buildings	Vibrating water molecules to heat food	Sending an invisible signal to a television with a remote control	Seeing the world around us	Killing microorganisms to sterilize hospital equipment	Looking at a broken bone	Not commonly used by humans

NASA's **Integrated LCRD Low-Earth Orbit User Modem and Amplifier Terminal (ILLUMA-T)** flies aboard the International Space Station, and can offer new capabilities to the astronauts living and working there. Laser communications enable missions to transmit more data per transmission. More data from space allows NASA to make more discoveries about our planet, microgravity, and the human spaceflight experience.

ILLUMA-T sends data from the space station to the Laser Communications Relay Demonstration (LCRD) at 1.2 gigabits per second. LCRD, as a relay satellite, sends the data down to ground stations in Haleakala, Hawaii or Table Mountain, California. Together, LCRD and ILLUMA-T form the first fully operational end-to-end laser communications system.

Laser communications systems provide numerous benefits to missions, including improved size, mass, and power requirements over comparable radio systems. The smaller size makes more room on the spacecraft for other science instruments. Less mass enables cost savings. Less power drain means electric power systems last longer. These benefits are essential for missions as we explore further into space.

To learn more about ILLUMA-T:

International Space Station - https://go.nasa.gov/3qQQ7Lq
Laser Communications Relay Demonstration (LCRD) - https://go.nasa.gov/3svYnBi
NASA Laser Communication Payload Undergoing Integration and Testing - https://go.nasa.gov/40e53zU
NASA Laser Communications Innovations: A Timeline - https://go.nasa.gov/40bxQF3
Women of Space Communications & Navigation, featuring Nylse Ortiz-Collazo - https://go.nasa.gov/3ZQZ9Ur

[7] **https://bit.ly/3vHEYLv**
[8] **https://science.nasa.gov/ems**