The waves that carry this girl's cell phone conversation are not visible.

What Are Electromagnetic Waves?

- **How are electromagnetic waves different from mechanical waves?**
- **Electromagnetic waves are produced when an electric charge vibrates or accelerates.**
- **Electromagnetic waves can travel through a vacuum, or empty space, as well as through matter.**

What Are Electromagnetic Waves?

Electromagnetic waves are transverse waves consisting of changing electric fields and changing magnetic fields.

- Like mechanical waves, electromagnetic waves carry energy from place to place.
- Electromagnetic waves differ from mechanical waves in how they are produced and how they travel.

What Are Electromagnetic Waves?

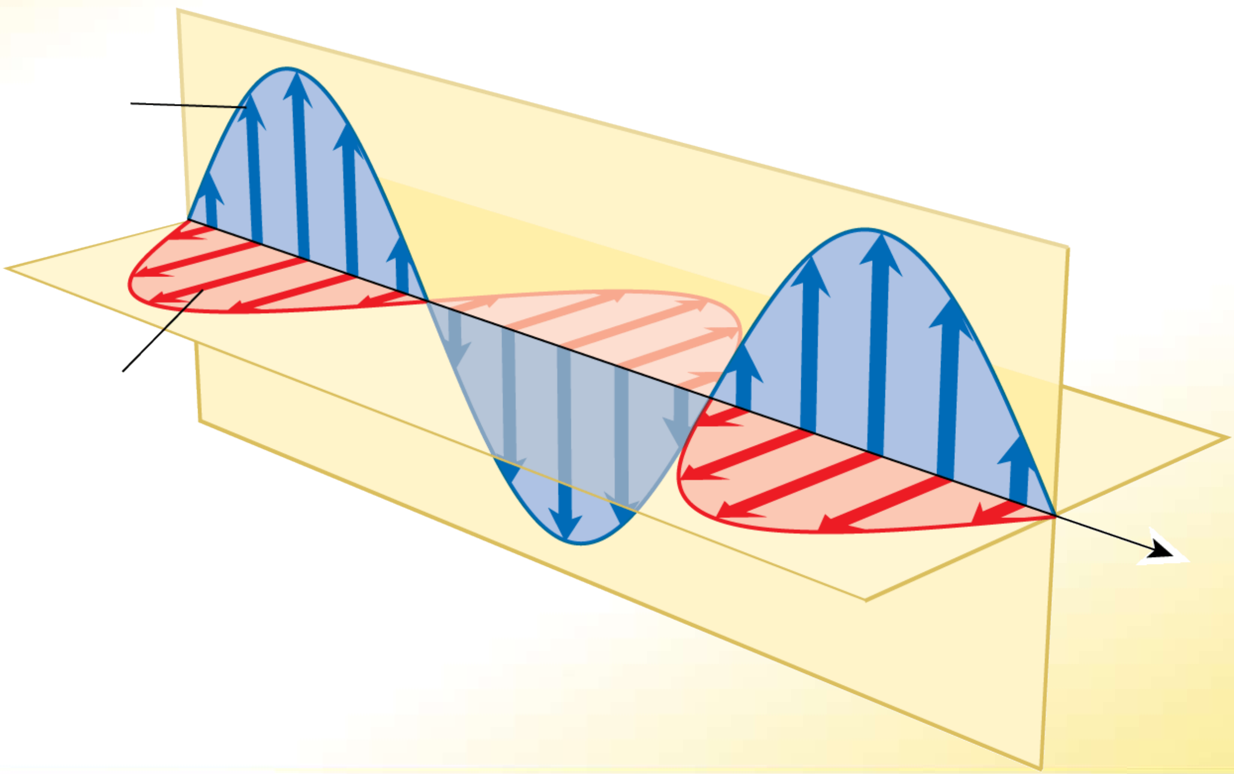
How They Are Produced

Electromagnetic waves are produced by constantly changing electric fields and magnetic fields.

- An **electric field** in a region of space exerts electric forces on charged particles. Electric fields are produced by electrically charged particles and by changing magnetic fields.
- A **magnetic field** in a region of space produces magnetic forces. Magnetic fields are produced by magnets, by changing electric fields, and by vibrating charges.

What Are Electromagnetic Waves?

Electromagnetic waves are transverse waves because the fields are at right angles to the direction in which the wave travels.



What Are Electromagnetic Waves?

How They Travel

Changing electric fields produce changing magnetic fields, and changing magnetic fields produce changing electric fields, so the fields regenerate each other.

- Electromagnetic waves do not need a medium.
- The transfer of energy by electromagnetic waves traveling through matter or across space is called **electromagnetic radiation.**

The Speed of Electromagnetic Waves

- **What is the maximum speed of light?**
- **The speed of light in a vacuum, *c*, is 3.00 × 108 meters per second.**

The Speed of Electromagnetic Waves

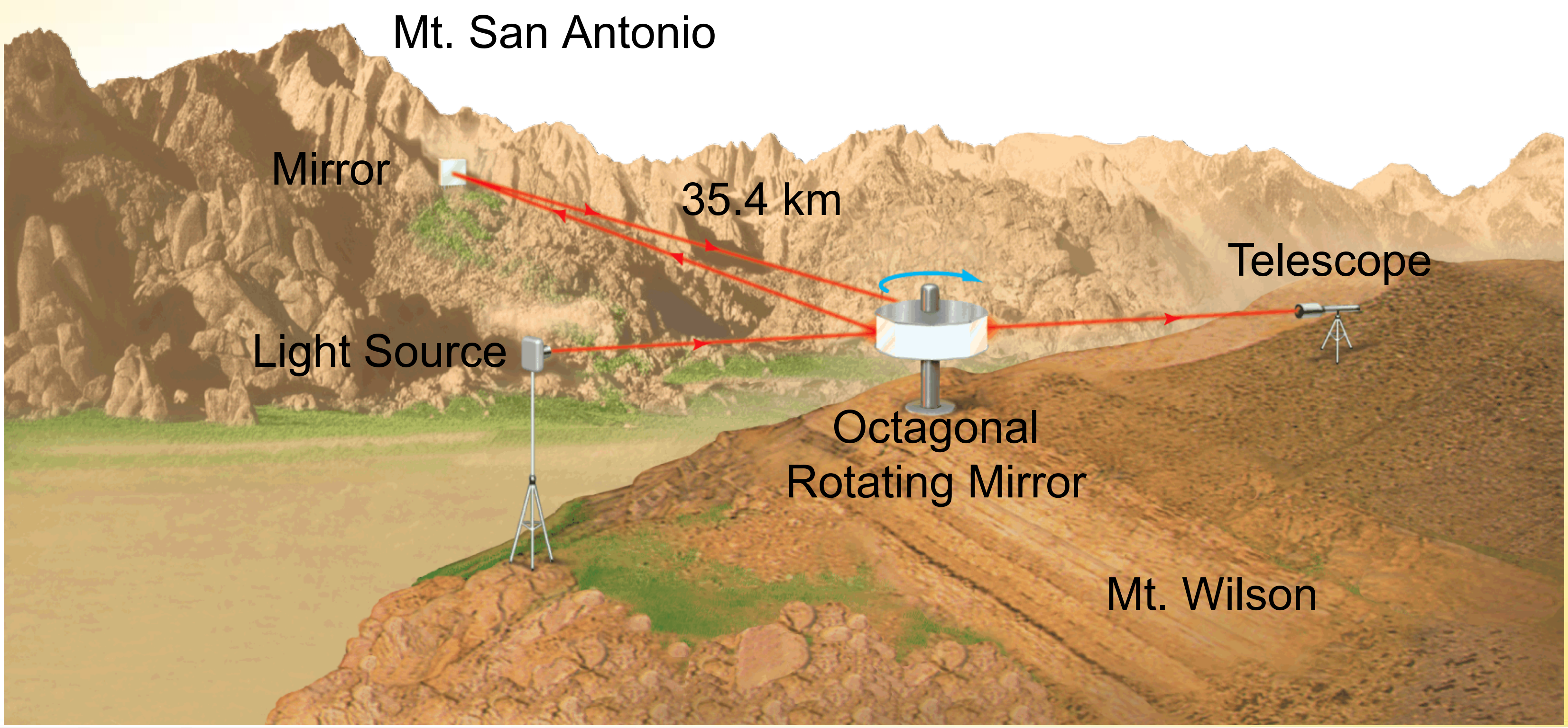
Michelson's Experiment

In 1926, the American physicist Albert Michelson measured the speed of light more accurately than ever before.

- Michelson placed an eight-sided rotating mirror and another mirror, that one stationary, about 35.4 kilometers apart.
- Knowing the rotation speed that produced an uninterruped light beam, he was able to calculate the speed of light quite accurately.

The Speed of Electromagnetic Waves

Michelson timed a light beam as it traveled from one mountain to another and back again. His experiment measured the speed of light more accurately than it had been measured before.



The Speed of Electromagnetic Waves

The Speed of Light

Since Michelson, many other scientists have measured the speed of light.

All electromagnetic waves travel at the same speed when in a vacuum, regardless of the observer's motion.

Wavelength and Frequency

- **How do electromagnetic waves differ from one another?**
- **Electromagnetic waves vary in wavelength and frequency.**

Wavelength and Frequency

The speed of an electromagnetic wave is the product of its wavelength and its frequency.

- The speed of electromagnetic waves in a vacuum is constant, so the wavelength is inversely proportional to the frequency.
- As the wavelength increases, the frequency decreases.

Wavelength and Frequency

Math Skills

Calculating Wave Speed

A radio station broadcasts a radio wave with a wavelength of 3.0 meters. What is the frequency of the wave?

Wavelength and Frequency

Math Skills

1 Read and Understand

What information are you given?

Wavelength and Frequency

Math Skills

Read and Understand

What information are you given?

Speed = c = 3.00×10^8 m/s

Wavelength = 3.0 m

Wavelength and Frequency

Math Skills

2 Plan and Solve

What unknown are you trying to calculate?

What formula contains the given quantities and the unknown?

Wavelength and Frequency

Math Skills

2 Plan and Solve

What unknown are you trying to calculate?

$$\text{Frequency} = ?$$

What formula contains the given quantities and the unknown?

$$\text{Speed} = \text{Wavelength} \times \text{Frequency}$$

or, $$\text{Frequency} = \frac{\text{Speed}}{\text{Wavelength}}$$

Wavelength and Frequency

Math Skills

2 Plan and Solve

Replace each variable with its known value.

Wavelength and Frequency

Math Skills

2 Plan and Solve

Replace each variable with its known value.

$$\text{Frequency} = \frac{3.00 \times 10^8 \text{ m/s}}{3.0 \text{ m}}$$

$$= 1.0 \times 10^8 \text{ Hz}$$

Wavelength and Frequency

Math Skills

3 Look Back and Check

Is your answer reasonable?

Check that the product of wavelength and frequency gives a speed of 3.0×10^8 *m/s.*

Wavelength and Frequency

Math Skills

3 Look Back and Check

Is your answer reasonable?

Check that the product of wavelength and frequency gives a speed of 3.0×10^8 m/s.

$$\text{Speed} = 3.0\ \text{m} \times (1.0 \times 10^8\ \text{Hz}) = 3.0 \times 10^8\ \text{m/s}$$

Wavelength and Frequency

Math Practice

1. A global positioning satellite transmits a radio wave with a wavelength of 19 cm. What is the frequency of the radio wave? (*Hint:* Convert the wavelength to meters before calculating the frequency.)

Wavelength and Frequency

Math Practice

1. A global positioning satellite transmits a radio wave with a wavelength of 19 cm. What is the frequency of the radio wave? (*Hint:* Convert the wavelength to meters before calculating the frequency.)

Answer: Speed = Wavelength × Frequency

Frequency = Speed/Wavelength =

$(3.00 \times 10^8 \text{ m/s})/(0.19 \text{ m}) = 1.6 \times 10^9 \text{ Hz}$

Wavelength and Frequency

Math Practice

2. The radio waves of a particular AM radio station vibrate 680,000 times per second. What is the wavelength of the wave?

Wavelength and Frequency

Math Practice

2. The radio waves of a particular AM radio station vibrate 680,000 times per second. What is the wavelength of the wave?

Answer: Speed = Wavelength × Frequency

Wavelength = Speed/Frequency = (3.00×10^8 m/s)/680,000 Hz = 440 m

Wavelength and Frequency

Math Practice

3. Radio waves that vibrate 160,000,000 times per second are used on some train lines for communications. If radio waves that vibrate half as many times per second were used instead, how would the wavelength change?

Wavelength and Frequency

Math Practice

3. Radio waves that vibrate 160,000,000 times per second are used on some train lines for communications. If radio waves that vibrate half as many times per second were used instead, how would the wavelength change?

Answer: At 160 MHz: Wavelength = Speed/Frequency = $(3.00 \times 10^8$ m/s)/(160,000,000 Hz) = 1.9 m

At 80 MHz: Wavelength = Speed/Frequency = $(3.00 \times 10^8$ m/s)/(80,000,000 Hz) = 3.8 m.

The wavelength would be twice as long.

Wave or Particle?

- What is the dual nature of electromagnetic radiation?
- Electromagnetic radiation behaves sometimes like a wave and sometimes like a stream of particles.

Wave or Particle?

Scientists know that electromagnetic radiation travels as a wave. Scientists also have evidence that electromagnetic radiation behaves like a stream of particles.

- So which is light, wave or particle?
- It is both.

Wave or Particle?

The fact that light casts a shadow has been used as evidence for both the wave model of light and the particle model of light.

Wave or Particle?

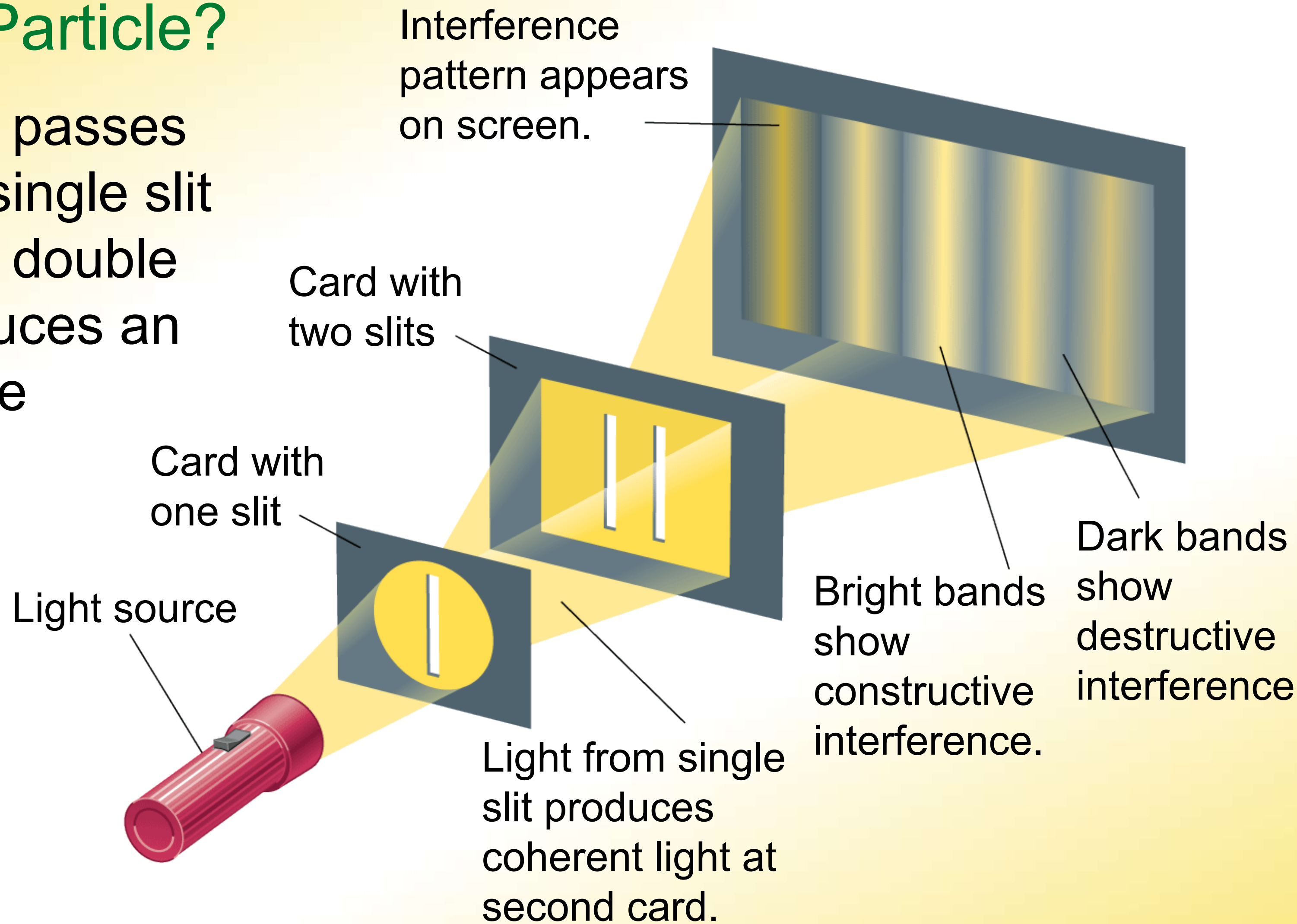
Evidence for the Wave Model

A beam of light passes first through a single slit and then through a double slit.

- Where light from the two slits reaches a darkened screen, there are alternating bright and dark bands.
- The bands are evidence that the light produces an interference pattern.
- Interference occurs only when two or more waves overlap.

Wave or Particle?

When light passes through a single slit and then a double slit, it produces an interference pattern.



Wave or Particle?

Evidence for the Particle Model

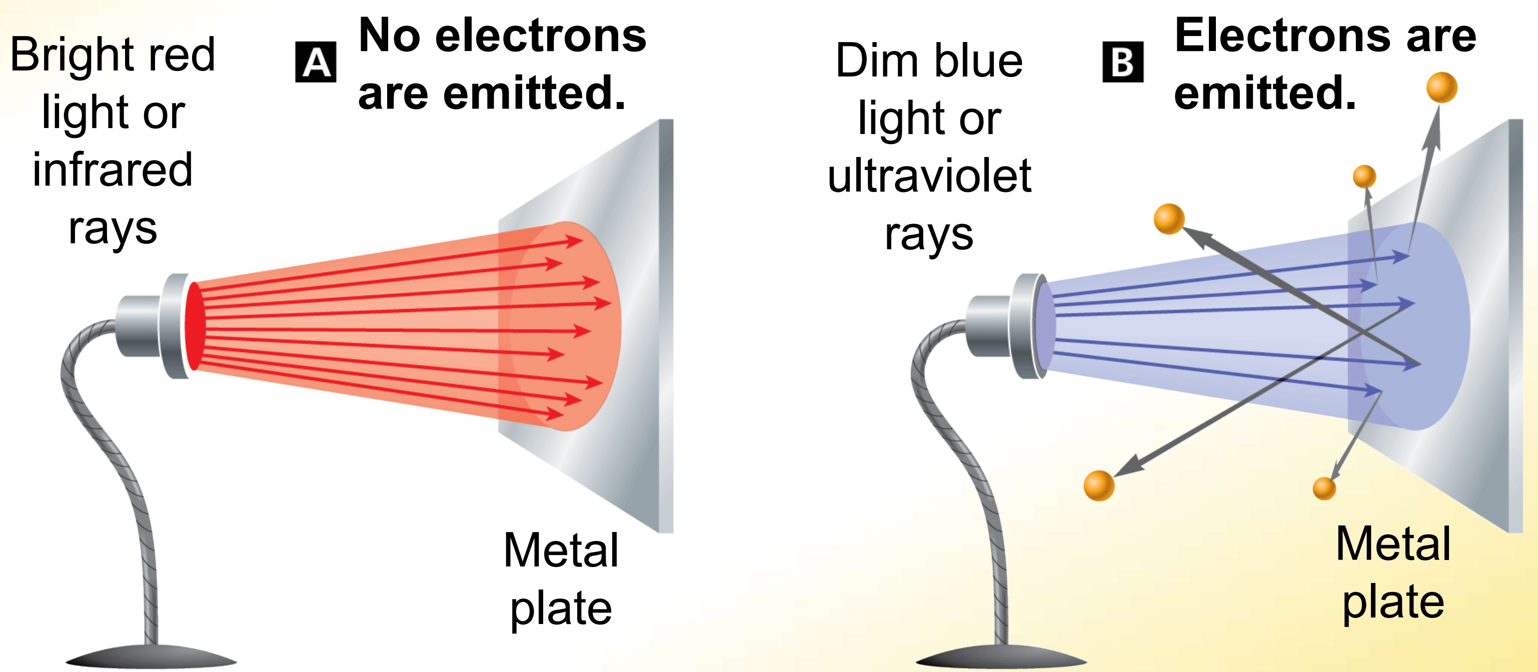
When dim blue light hits the surface of a metal such as cesium, an electron is emitted.

A brighter blue light causes even more electrons to be emitted.

Red light, no matter how bright it is, does not cause the emission of any electrons from this particular metal.

Wave or Particle?

- Red light or infrared rays, no matter how bright, does not cause electrons to be emitted from this metal surface.
- When blue light or ultraviolet rays strike the metal surface, electrons are emitted, even if the light is dim.



Wave or Particle?

The emission of electrons from a metal caused by light striking the metal is called the **photoelectric effect.**

In 1905, Albert Einstein (1879–1955) proposed that light, and all electromagnetic radiation, consists of packets of energy.

These packets of electromagnetic energy are now called **photons.**

Wave or Particle?

Each photon's energy is proportional to the frequency of the light. Blue light has a higher frequency than red light, so photons of blue light have more energy than photons of red light.

- Blue light consists of photons that have enough energy to cause electrons to be emitted from a metal surface.
- Red light photons have too little energy to cause any electrons to be emitted from a metal surface.

Intensity

- **What happens as light travels farther from its source?**
- **The intensity of light decreases as photons travel farther from the source.**

Intensity

The closer you are to a source of light, the brighter the light appears.

- Photons travel outward from a light source in all directions.
- Near the light source, the photons spread through a small area, so the light is intense.
- Farther from the source, the photons spread over a larger area.

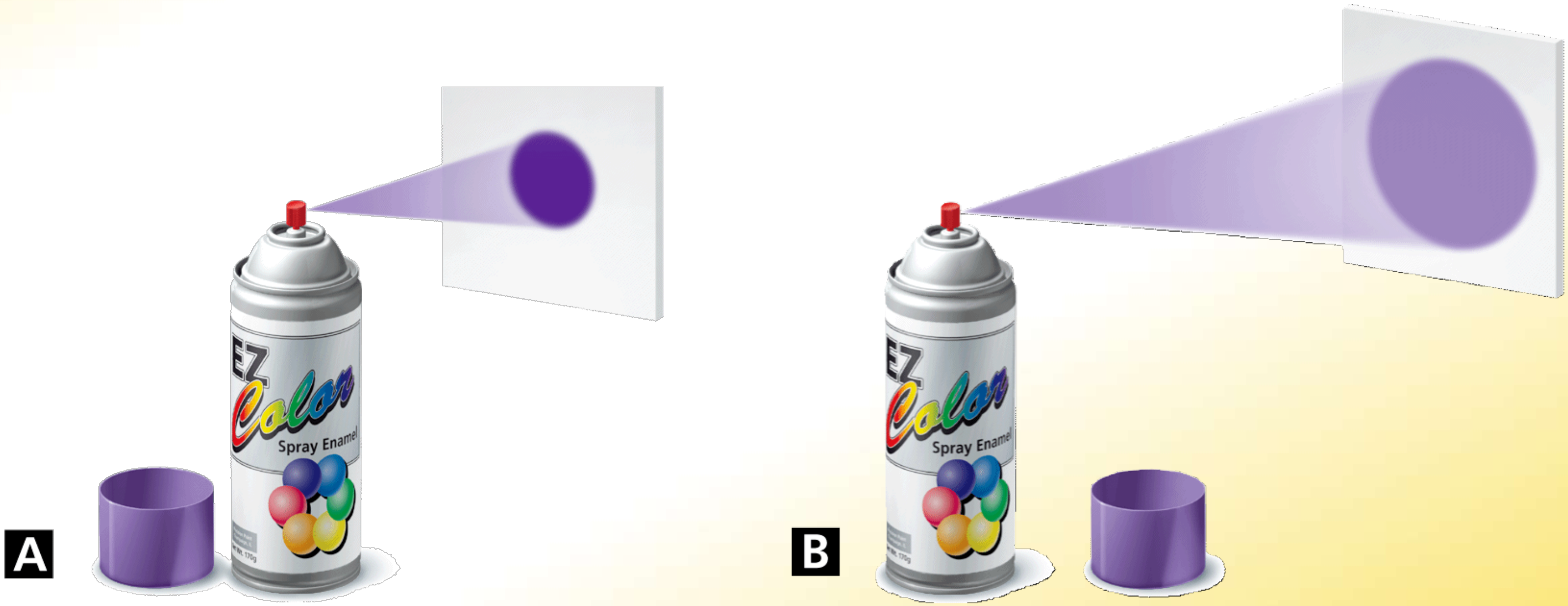
Intensity

Intensity is the rate at which a wave's energy flows through a given unit of area. A wave model also explains how intensity decreases.

- As waves travel away from the source, they pass through a larger and larger area.
- The total energy does not change, so the wave's intensity decreases.

Intensity

The closer you are to a surface when you spray paint it, the smaller the area the paint covers, and the more intense the paint color looks.



Assessment Questions

- How are electromagnetic waves different from all mechanical waves?
    - Electromagnetic waves don’t carry energy.
    - Electromagnetic waves are invisible.
    - Electromagnetic waves are longitudinal waves.
    - Electromagnetic waves can travel through a vacuum.

Assessment Questions

- How are electromagnetic waves different from all mechanical waves?
  - Electromagnetic waves don’t carry energy.
  - Electromagnetic waves are invisible.
  - Electromagnetic waves are longitudinal waves.
  - Electromagnetic waves can travel through a vacuum.

ANS:D

Assessment Questions

- What is the wavelength of a radio wave that has a frequency of 1.5×10^6 Hz? ($c = 3.0 \times 10^8$ m/s)
    - 45 m
    - 200 m
    - 450 m
    - 2 km

Assessment Questions

- What is the wavelength of a radio wave that has a frequency of 1.5×10^6 Hz? ($c = 3.0 \times 10^8$ m/s)
  - 45 m
  - 200 m
  - 450 m
  - 2 km

ANS:B

Assessment Questions

- The photoelectric effect is evidence that light behaves like
  - a wave.
  - a particle.
  - both a wave and a particle.
  - neither a wave nor a particle.

Assessment Questions

- The photoelectric effect is evidence that light behaves like
  - a wave.
  - a particle.
  - both a wave and a particle.
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ANS:B

Assessment Questions

- As photons travel farther from a light source, the intensity of light stays the same.

  True
  False

-

Assessment Questions

- As photons travel farther from a light source, the intensity of light stays the same.

  True
  False

- ANS:F, decreases