McGraw-Hill Ryerson

BC Science Connections 8

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UNIT 3

Energy can be transferred as both a particle and a wave

TOPIC 3.2

How can models explain the properties of electromagnetic radiation?

Topic 3.2: How can models explain the properties of electromagnetic radiation?

- Scientists use models to represent ideas and concepts.
  - Visible light is often used as a model to study other types of electromagnetic radiation

The game plan shown here is a type of model.

Concept 1: Visible light can be used to model all types of electromagnetic radiation.

Properties of electromagnetic radiation:

- Invisible as it travels
- Involves the transfer of energy from one place to another
- Can travel through empty space
- Travels through empty space at the speed of light (3.00×10^8 m/s)
- Has both electrical and magnetic properties

Figure 3.7: Visible light and other electromagnetic radiation from the Sun travels 150 million km to reach Earth. The brighter object is Earth; the smaller object is our Moon.

Concept 1: Visible light can be used to model all types of electromagnetic radiation.

The seven types of electromagnetic radiation have a lot in common.

- Studying one type can tell you a lot about the others
- Visible light is used as a model to study electromagnetic radiation
  - Easy and safe to study
  - Becomes visible when it interacts with matter

Discussion Questions

- Why is visible light used as a model for other types of electromagnetic radiation?
- Explain one way that visible light is different from other types of electromagnetic radiation and one way it is similar to them.

Concept 2: The ray model of light explains that light travels in straight lines.

- Euclid: Greek mathematician that suggested that light travels in straight lines
  - Led to the development of the **ray model of light**

The Sun is a source of all types of electromagnetic radiation.

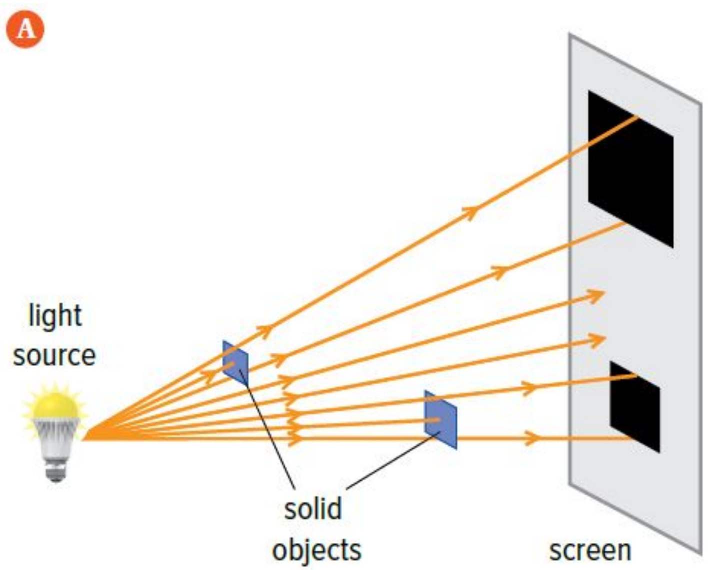
Understanding the Ray Model of Light

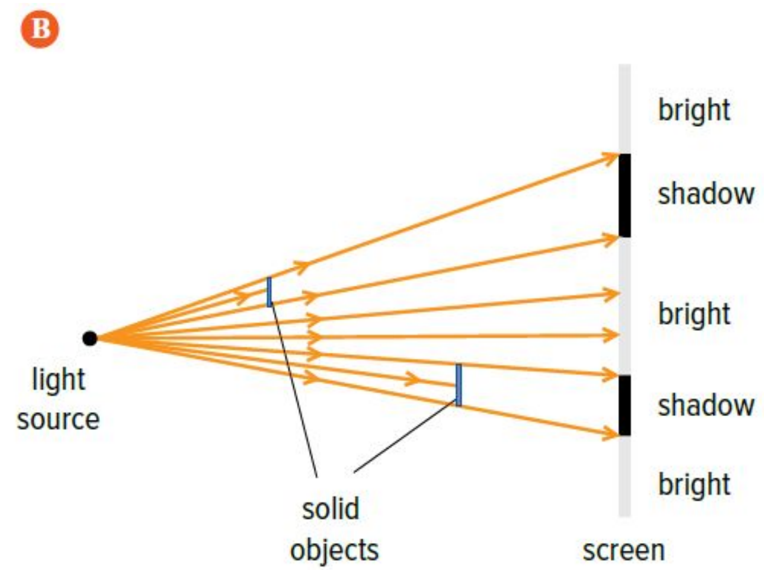
- The **ray model of light**:
  - The idea that light travels in straight lines
  - Ray: an arrow that is used to show the direction of the straight-line path of light

Figure 3.8: Light from the light source cannot bend around the person’s hand. The hands block light and cast a shadow on the wall. Therefore, light must travel in straight lines.

Using Ray Diagrams to Model Visible Light

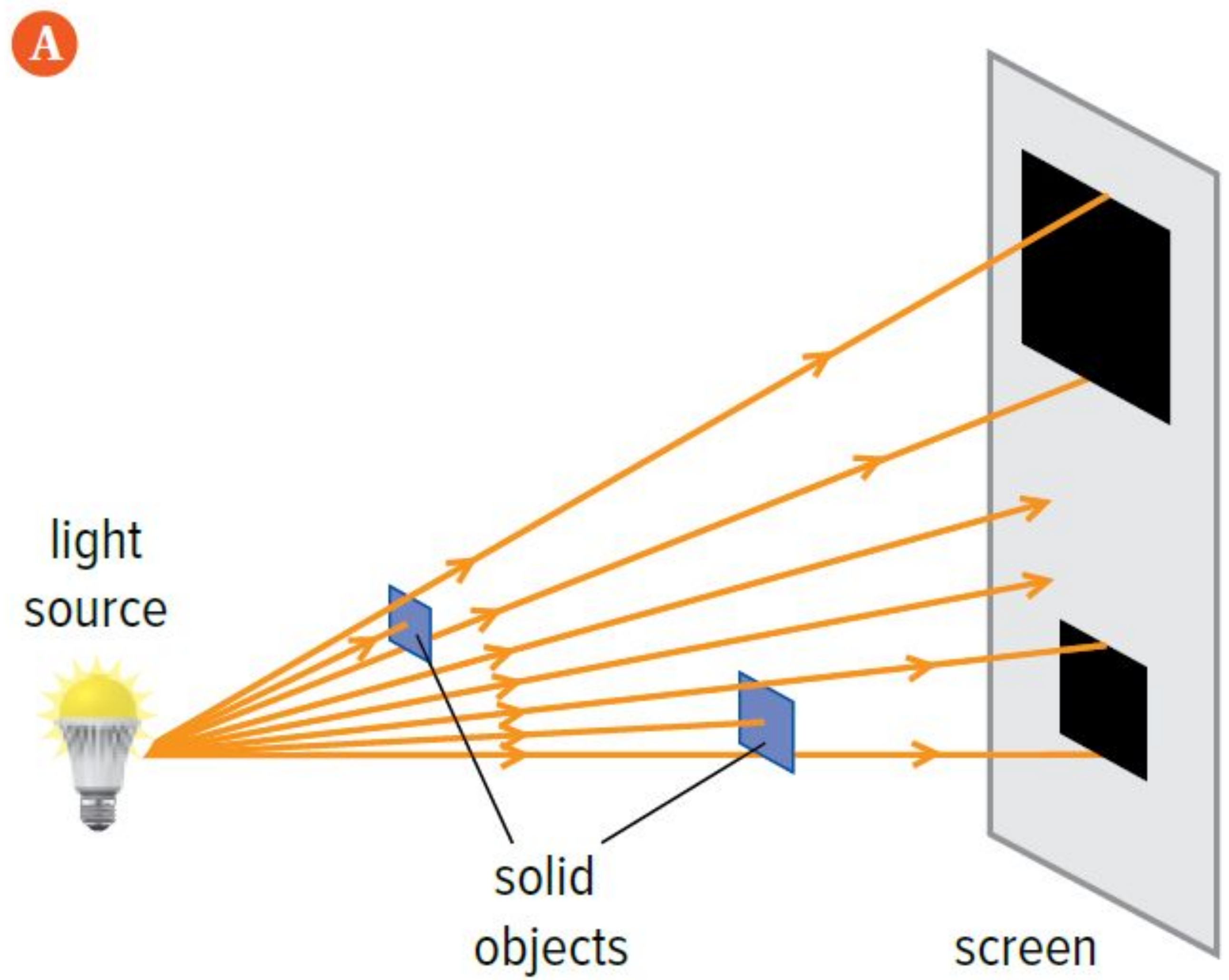
- Ray diagrams:
  - Used to study and predict how light behaves
  - Rays can be used to predict the location, size, and shape of shadows





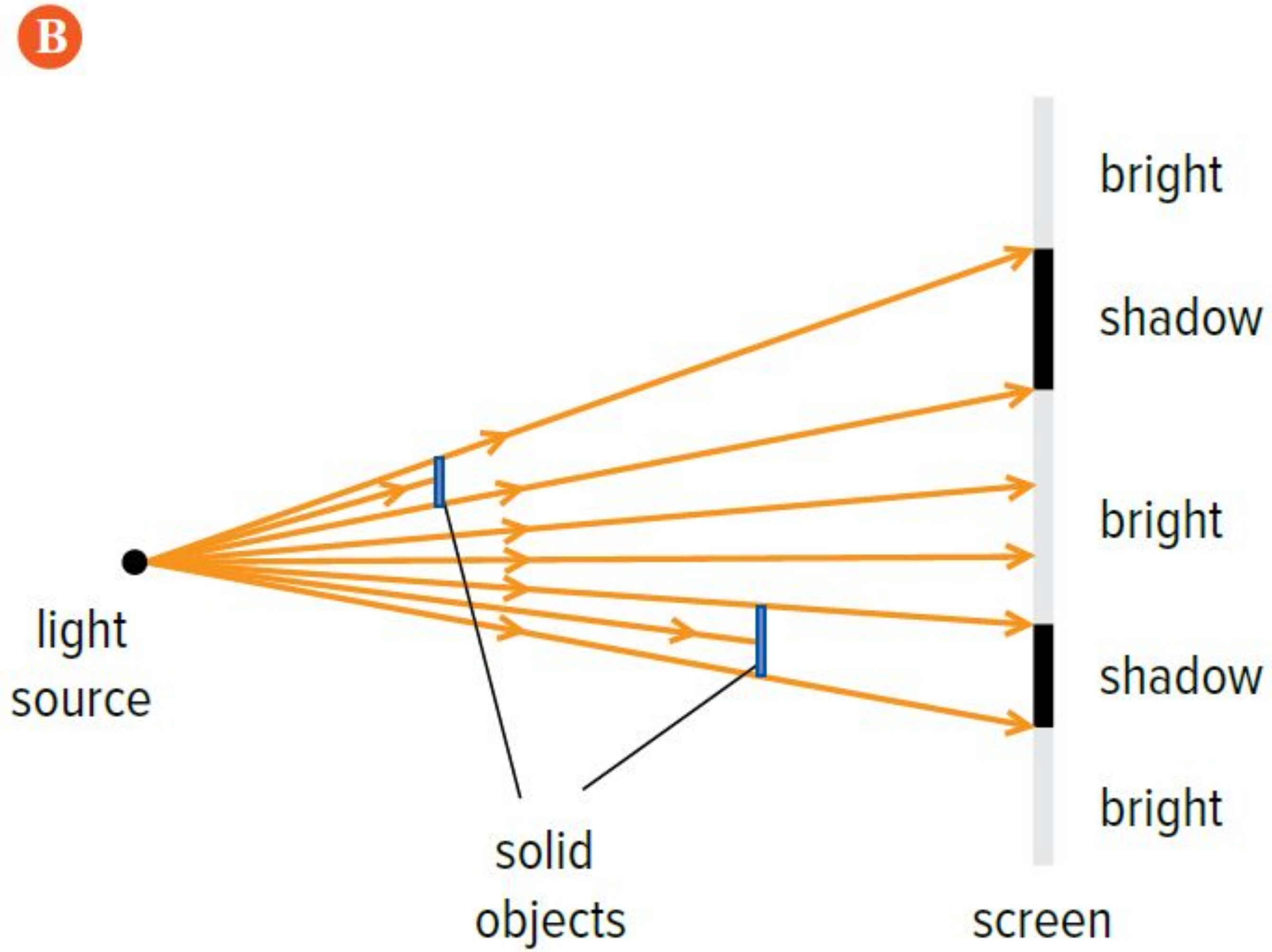
Using Ray Diagrams to Model Visible Light

Figure 3.9A: Notice that the distance between an object and the light source affects the size of the shadow.



Using Ray Diagrams to Model Visible Light

Figure 3.9B: Ray diagrams are easier to draw if you view the object from the side. The light source can be represented as a dot.



Using Ray Diagrams to Model Visible Light

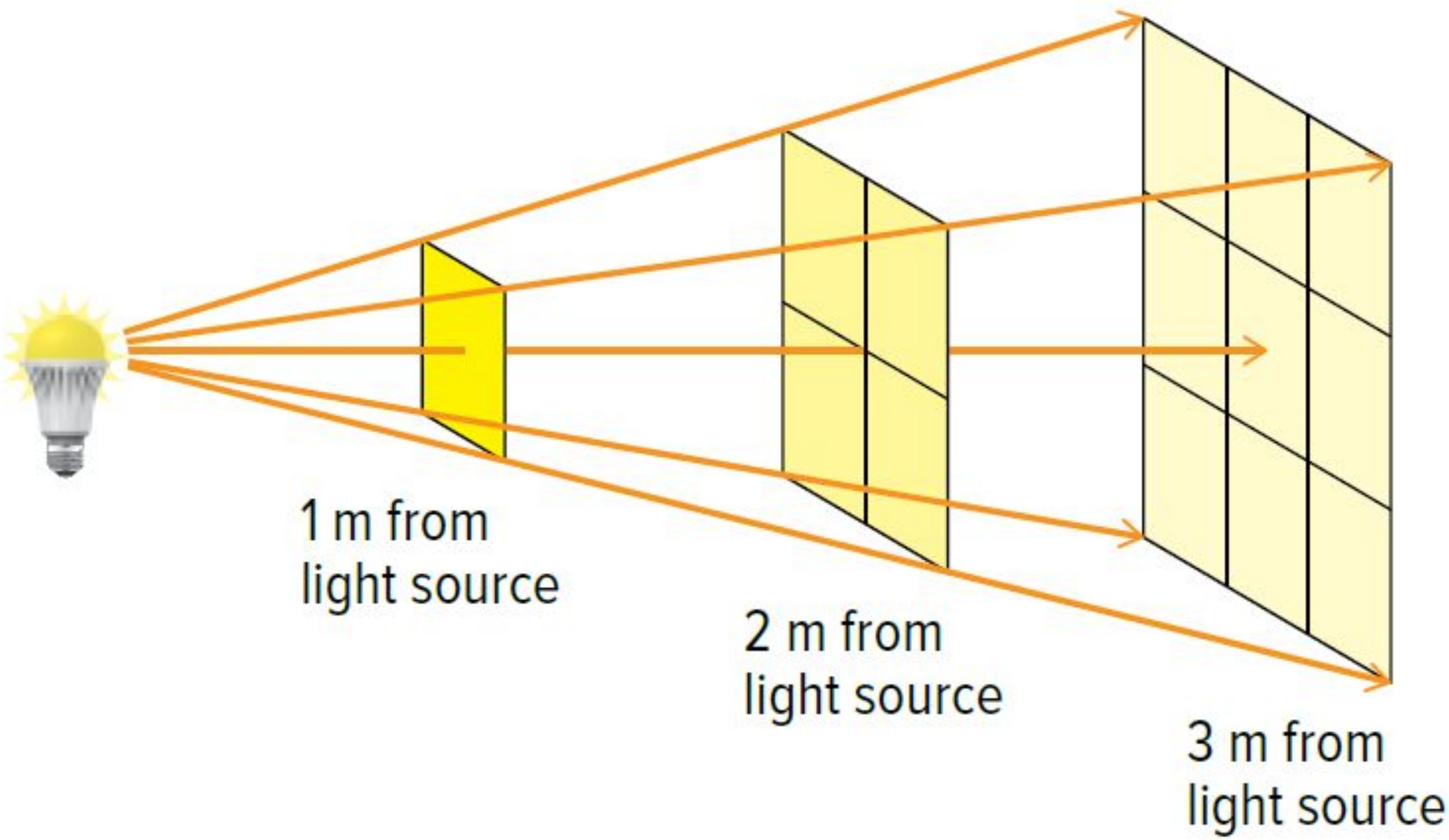
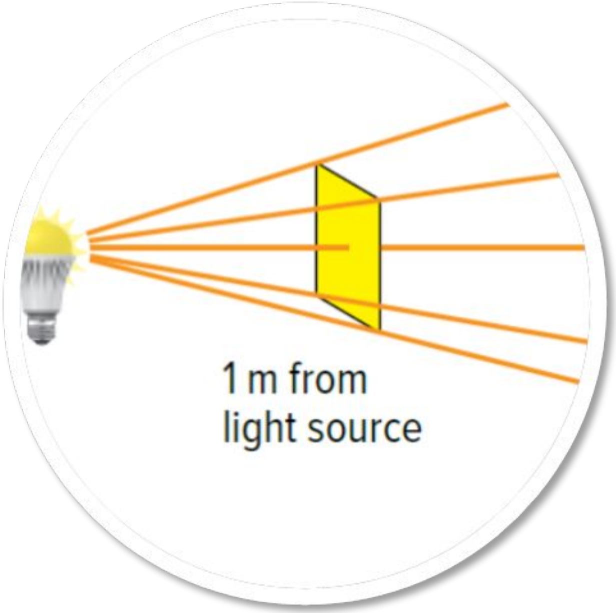


Figure 3.10: Light rays spread out as they travel from a light source and get dimmer with distance.

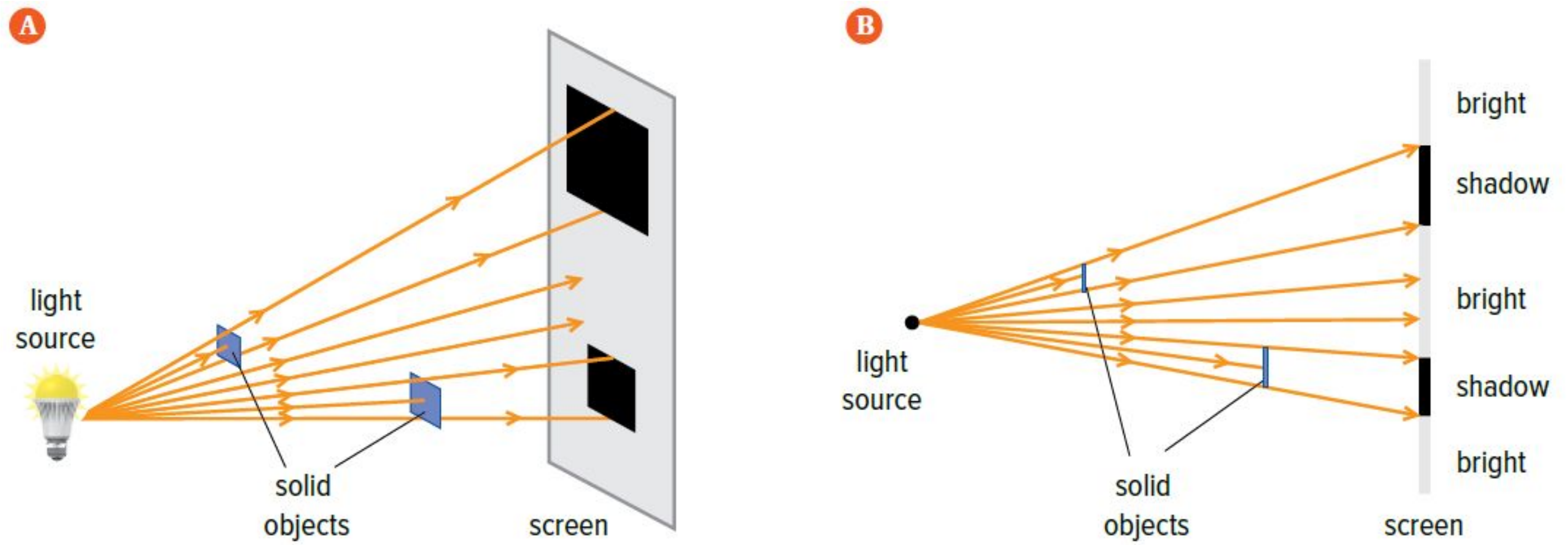
Discussion Questions

- Like visible light, microwaves spread out from a source. How might this effect cell phone use?



Discussion Questions

- In Figure 3.9 (shown here), why does the smaller object cast the bigger shadow?

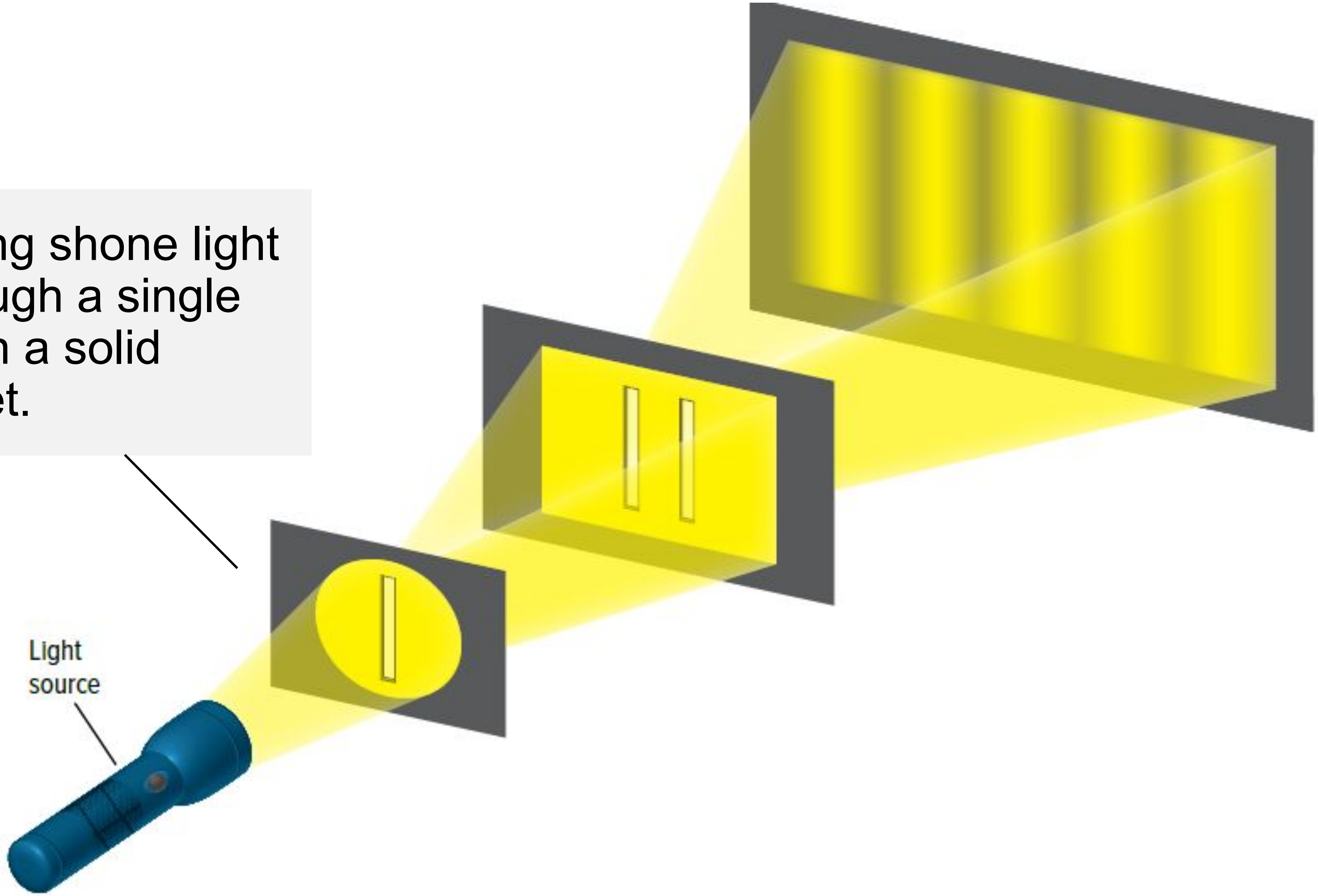


Concept 3: The wave model of light explains that light has wave-like properties.

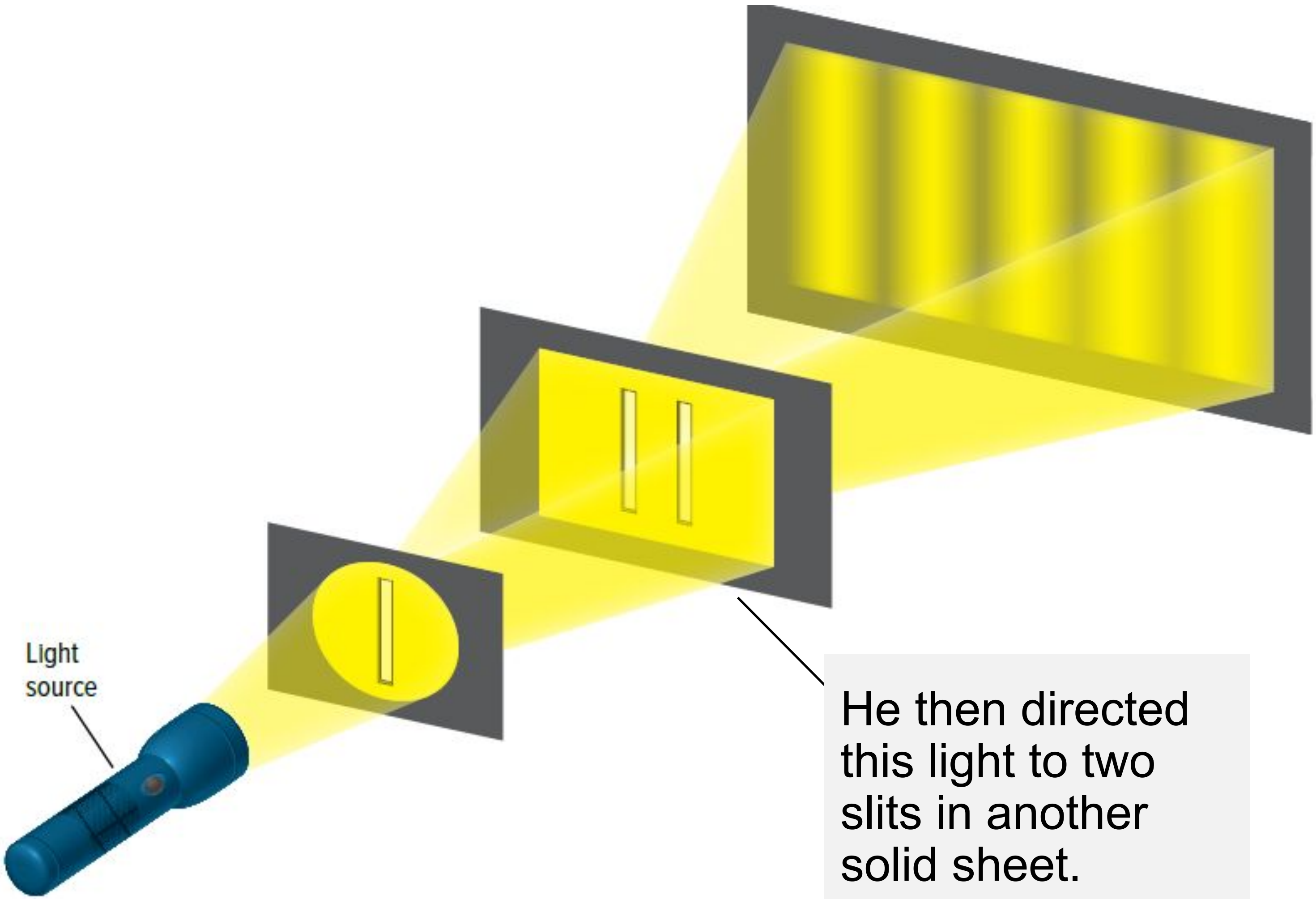
- Some scientists thought that light was a stream of particles that had particle-like properties (**particle model of light**)
- Early 1800s: Thomas Young performed an experiment that supported the idea that light has properties of a wave
  - **Wave model of light**: the idea that light has wave-like properties

Young's Experiment: Wave Model of Light

Young shone light through a single slit in a solid sheet.

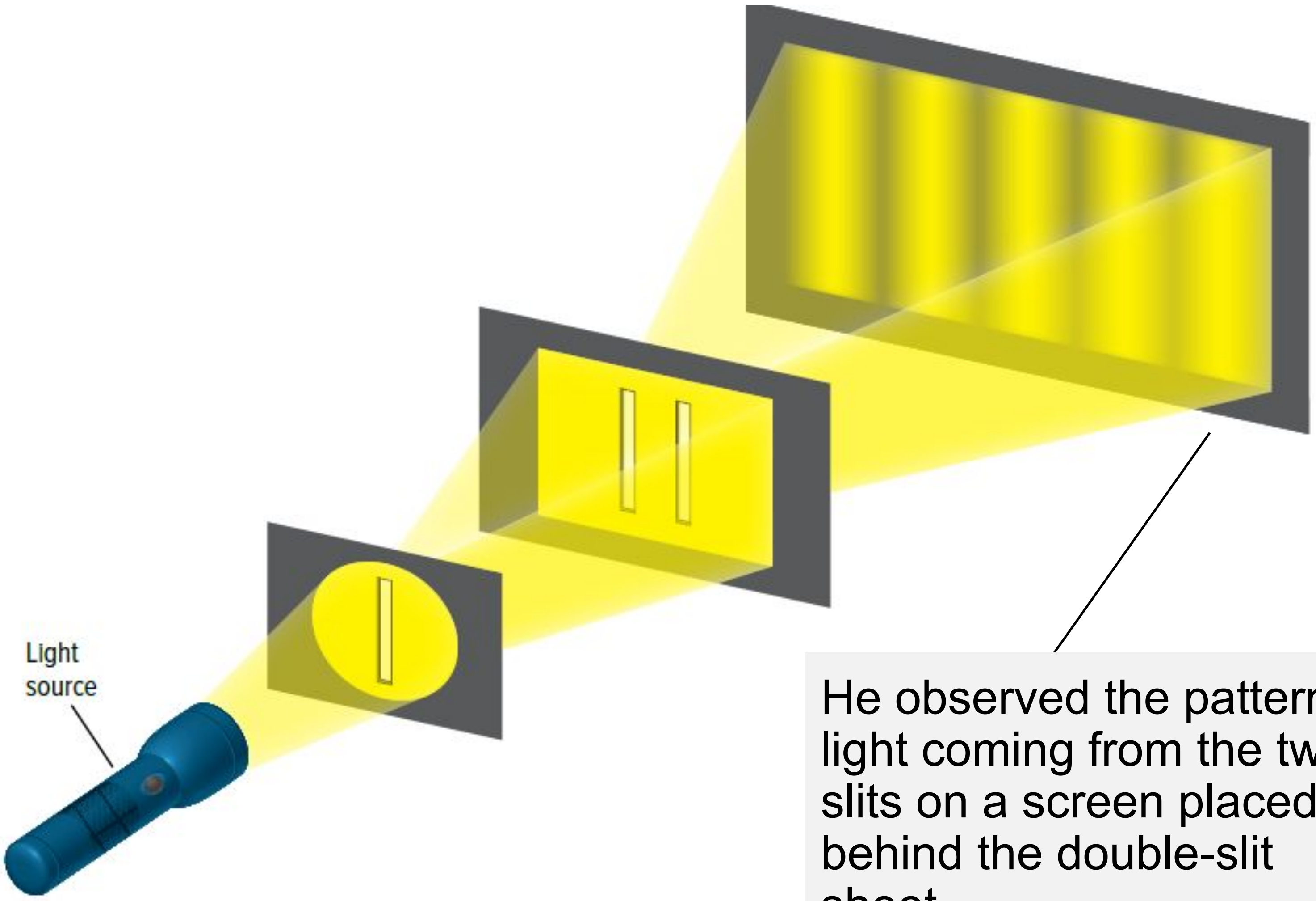


Young's Experiment: Wave Model of Light



He then directed this light to two slits in another solid sheet.

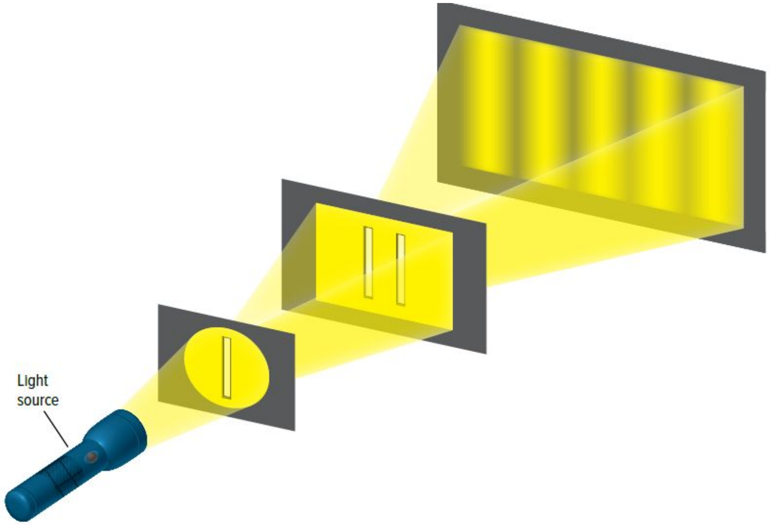
Young's Experiment: Wave Model of Light



He observed the pattern of light coming from the two slits on a screen placed behind the double-slit sheet.

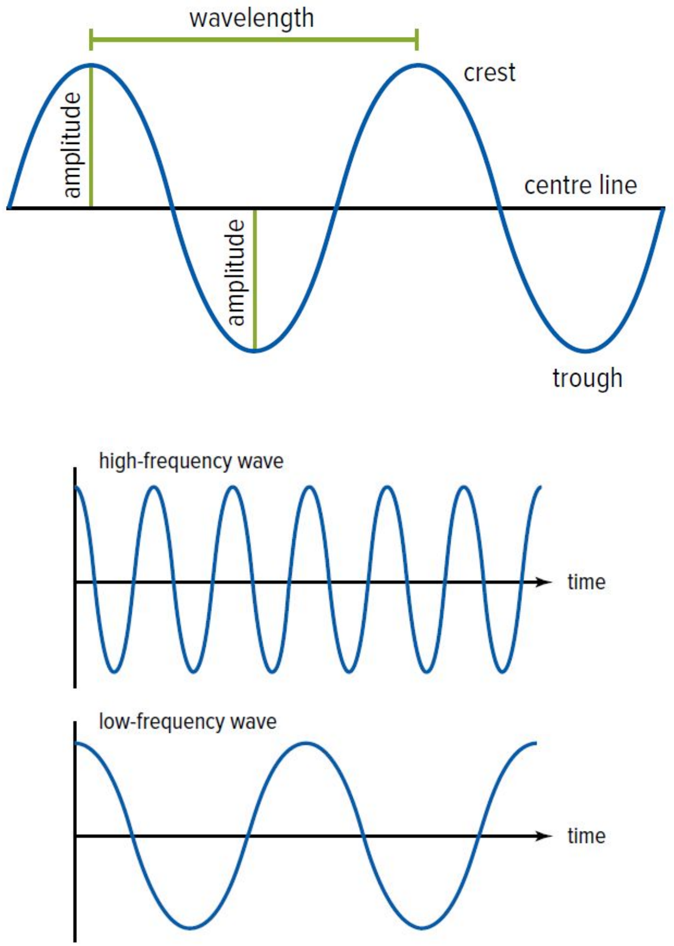
Young’s Experiment: Results and Conclusions

- If light was like a particle: pattern would be two lines.
- If light was like a wave: light would spread out into a series of lines
  - Young saw that the light spread out into a series of lines when it passed through the two narrow slits
  - Therefore, light had wave-like properties



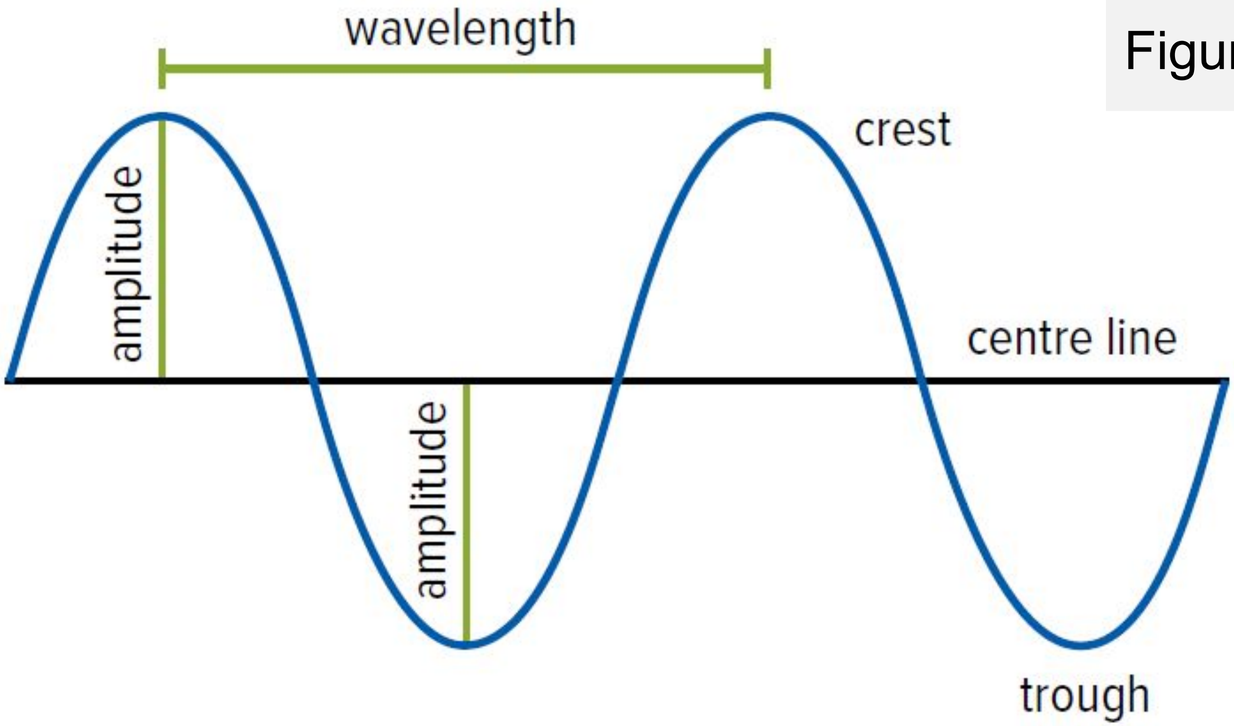
Properties of Light Waves

- Light waves have some things in common with water waves:
  - Both move energy from one place to another
  - Both have wavelength, amplitude, and frequency



Properties of Light Waves

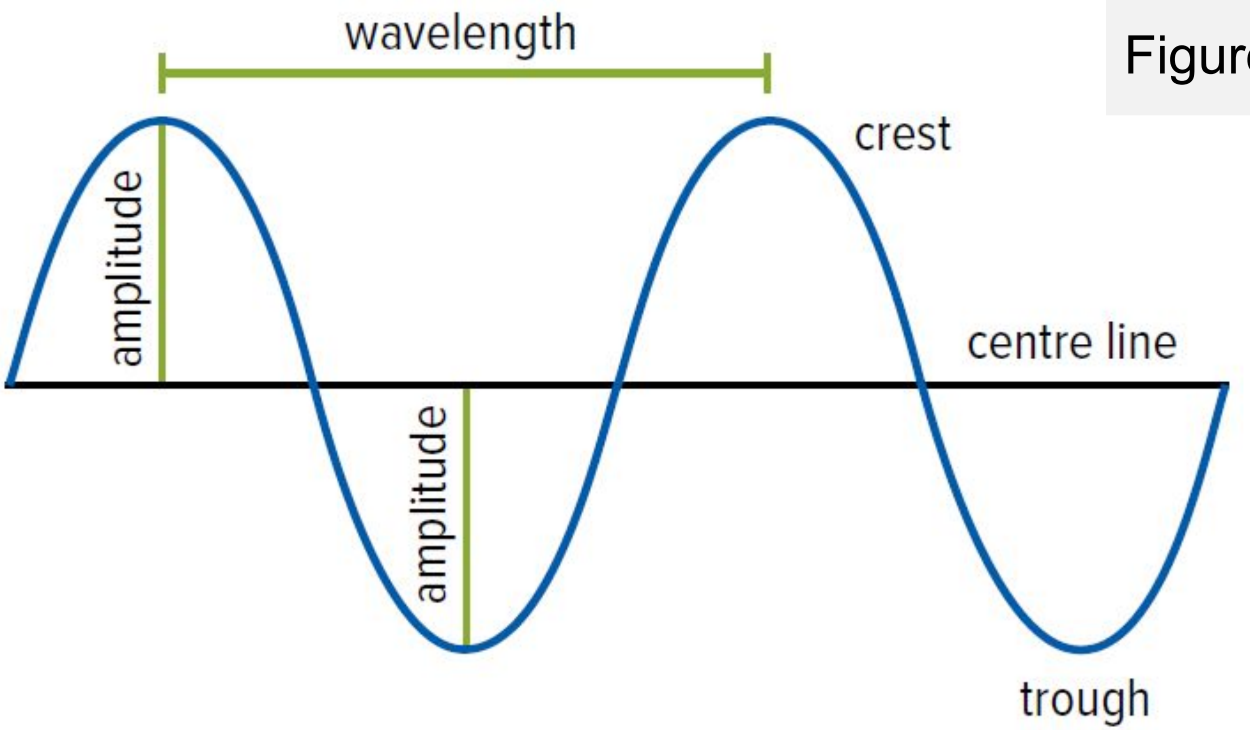
Figure 3.12



- Crest: highest point of a wave
- Trough: lowest point of a wave
- Distance from the centre line to the crest is the same as the centre line to the trough

Properties of Light Waves

Figure 3.12



- **Wavelength**: distance from one crest (or trough) of a wave to the next crest (or trough)
- **Amplitude**: distance from the centre line to the crest of trough of the wave

Properties of Light Waves

- **Frequency**: the number of complete wavelengths that pass a point in one second as the wave goes by
- As wavelength decreases, frequency increases
- As wavelength increases, frequency decreases

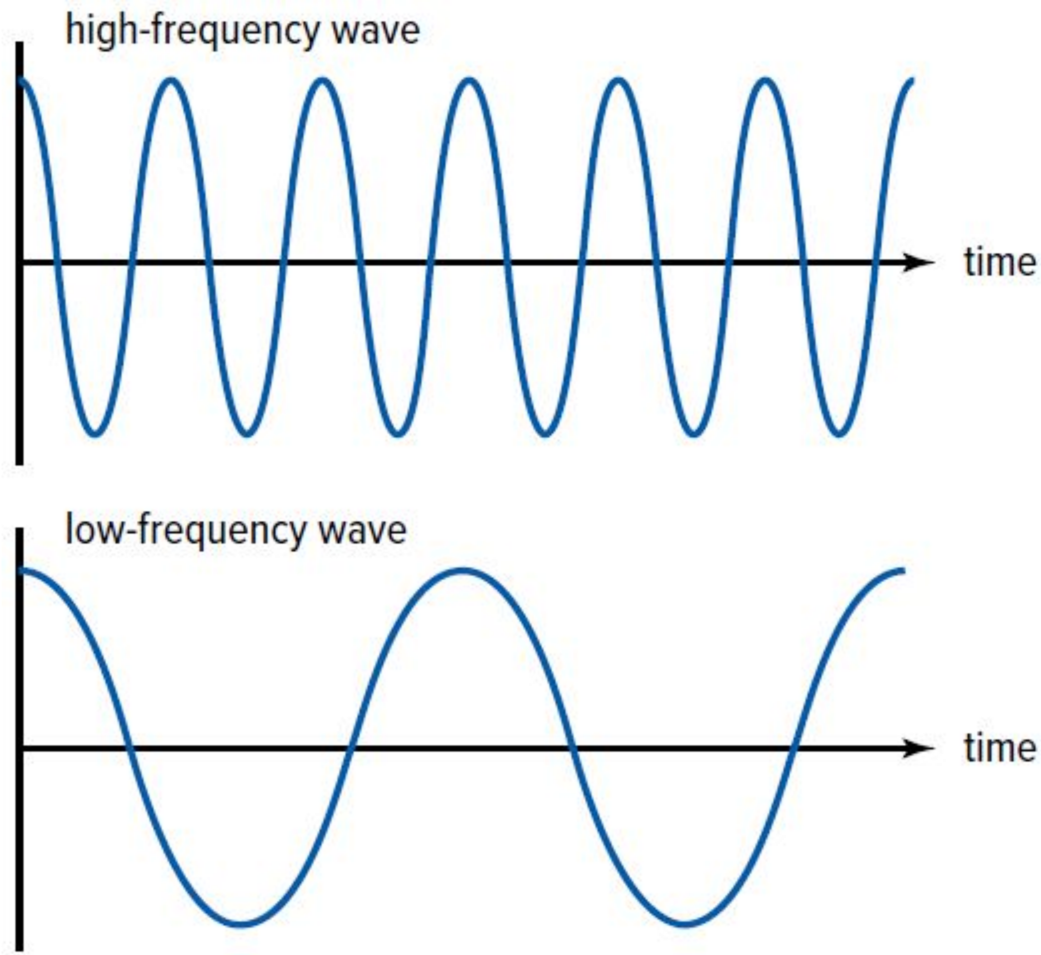


Figure 3.13

Light, Wavelength, and Colour

- 1600s: Isaac Newton used a prism to separate visible light into colours
  - Discovered that light is a mixture of colours
  - When the colours passed through another prism, the colours recombined to form white light

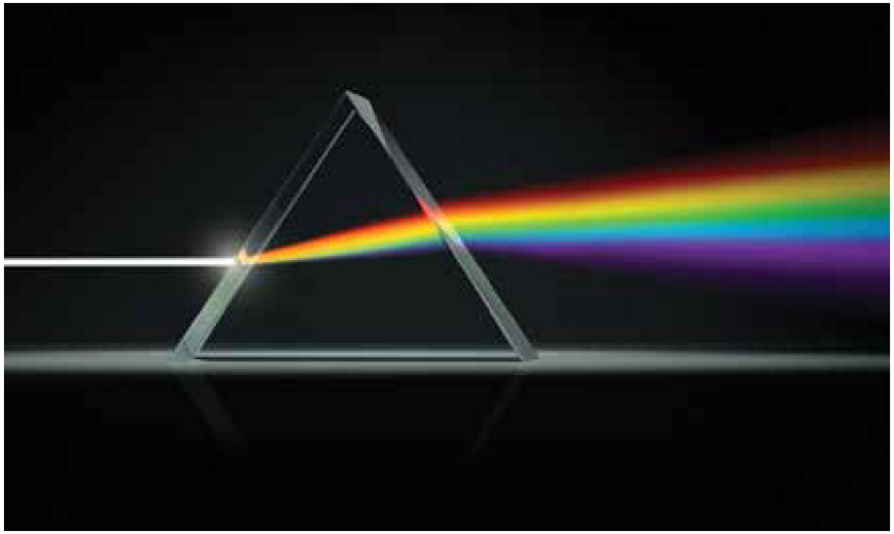


Figure 3.14: Newton separated visible light into colours.

Light, Wavelength, and Colour

Colours of light are different wavelengths of visible light (visible light spectrum)

- Colours of the spectrum are in a certain order (**ROY G BIV**)
  - **R**ed (longest wavelength)
  - **O**range
  - **Y**ellow
  - **G**reen
  - **B**lue
  - **I**ndigo
  - **V**iolet (shortest wavelength)

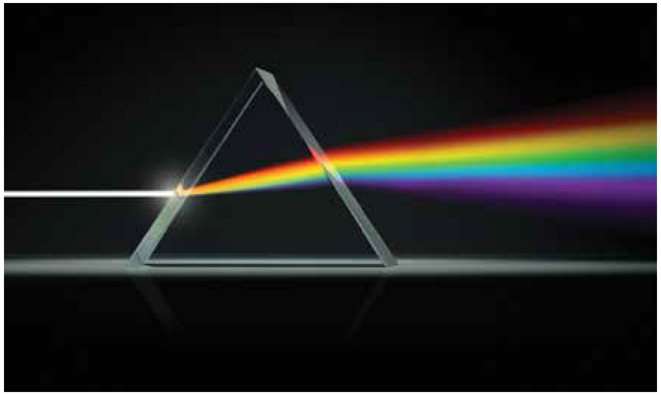
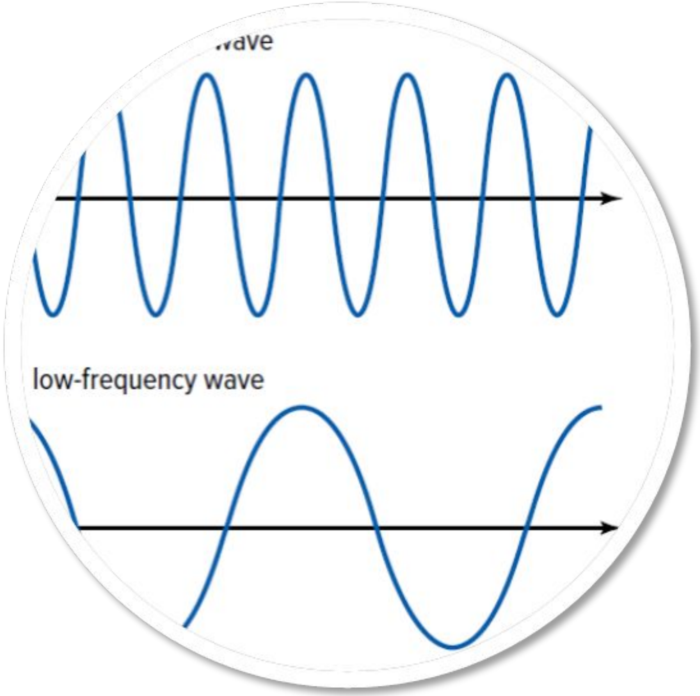


Figure 3.14: Newton separated visible light into colours.

Discussion Questions

- Describe one way that a light wave is like a water wave. Describe one way that it is different.

- One wave has a higher frequency than another wave. Which wave would have the longer wavelength. Explain your reasoning.



Concept 4: The particle model of light explains that light has particle-like properties.

- One property of light could not be explained with the wave model of light: **the photoelectric effect**.
- The photoelectric effect:
  - When light shines on a metal surface, the surface **can** (but not always) give off electrons

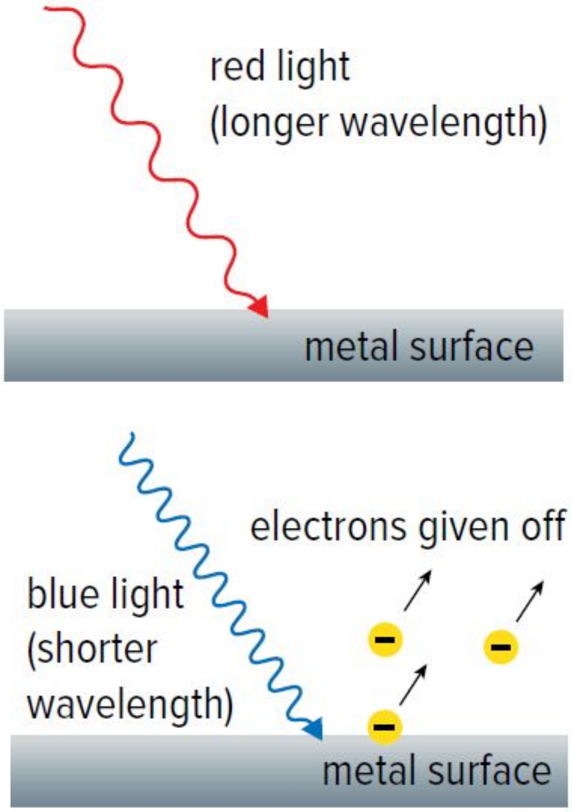
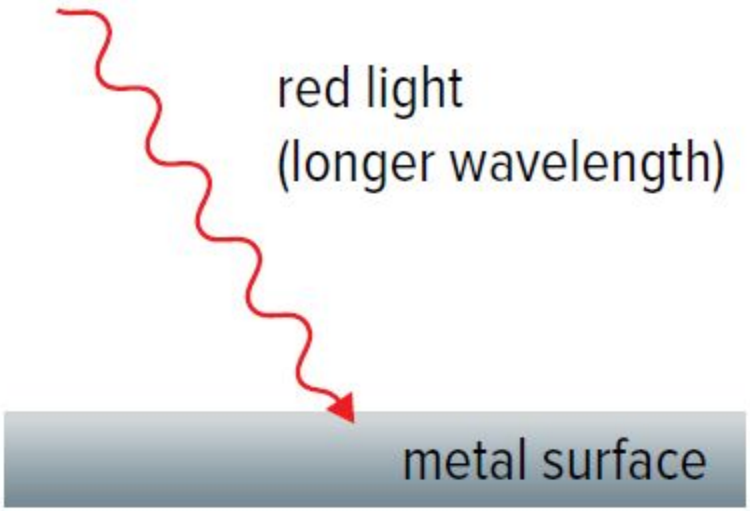


Figure 3.15: The photoelectric effect

Lenard's Experiments: The Photoelectric Effect

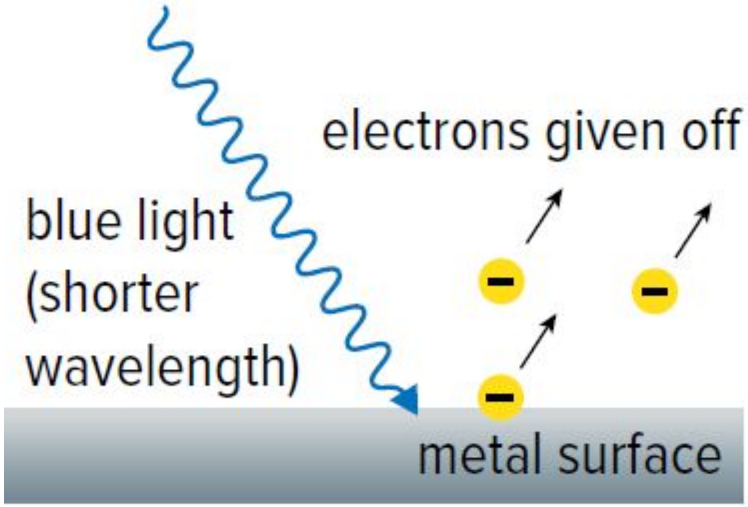
1902: Phillip Lenard performed an experiment that further studied the photoelectric effect.

- **Red light (longer wavelength) shone on metal surface**:
  - Electrons are **never** given off, no matter how bright or how long the red light shines on the metal



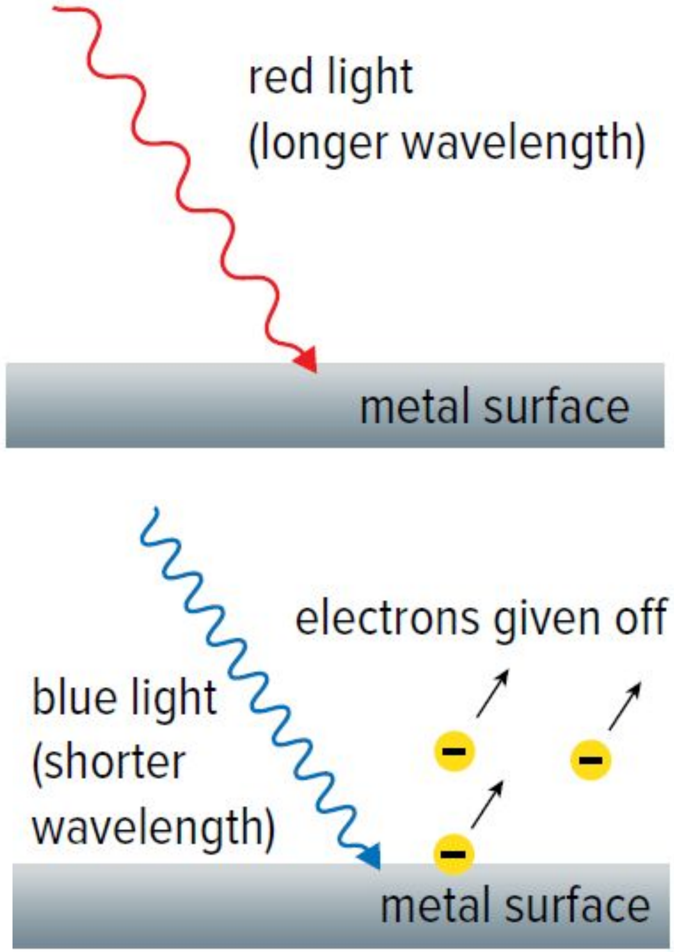
Lenard's Experiments: The Photoelectric Effect

- **Blue light (shorter wavelength) shone on metal surface:**
  - Electrons are **always** given off, no matter how dim or how briefly the blue light shines on the metal



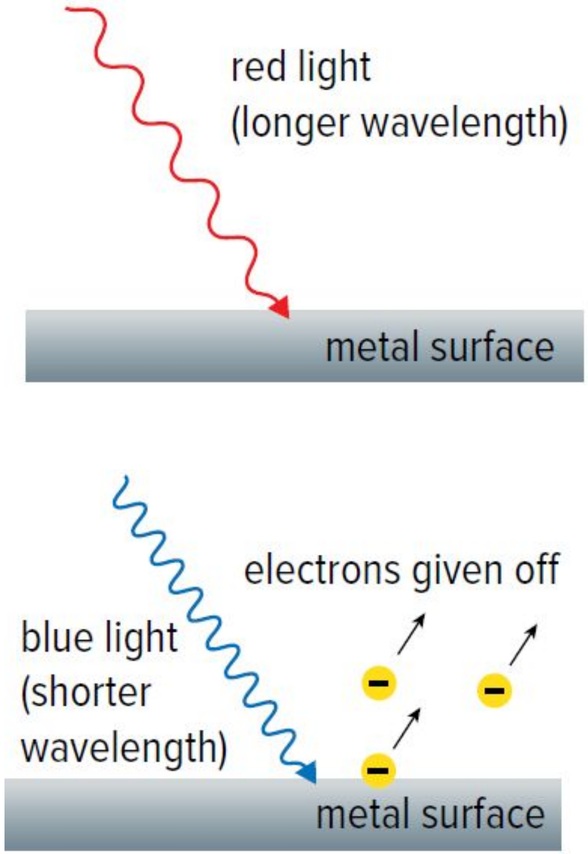
Lenard's Experiment: Conclusions

- Why did the red light not give off electrons when it hit the metal, but the blue light did?
- If light was a wave:
  - Any wavelength of light (including red) could "pile up" enough energy when it hits the metal to cause electrons to be given off by the metal
  - The wave model of light could not explain the photoelectric effect



Einstein's Thought Experiment: Explaining the photoelectric effect

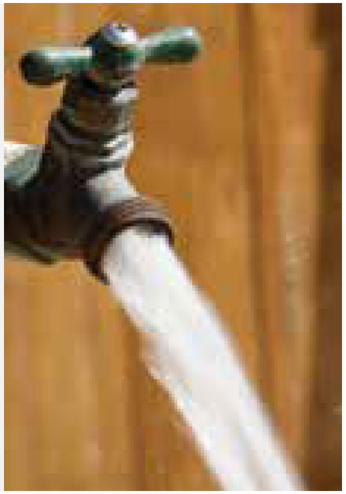
- Albert Einstein:
  - Realized that the wave model of light could not explain the photoelectric effect
  - Some difference between red and blue light must cause the effect



Einstein's Thought Experiment: Light acts as a particle when it interacts with matter

- The photoelectric effect can be explained if light acts as a particle when it interacts with matter.

Light does not interact with matter as a flowing stream, like water from a faucet.



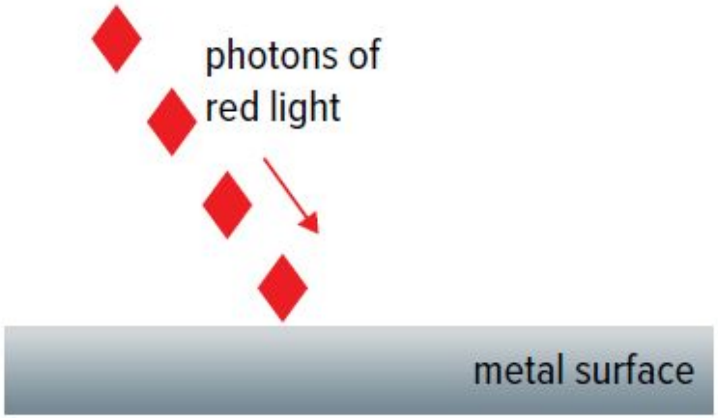
Light interacts with matter as packets or distinct particles, like water in ice cubes.

Einstein's Thought Experiment: The particles of light energy are called photons.

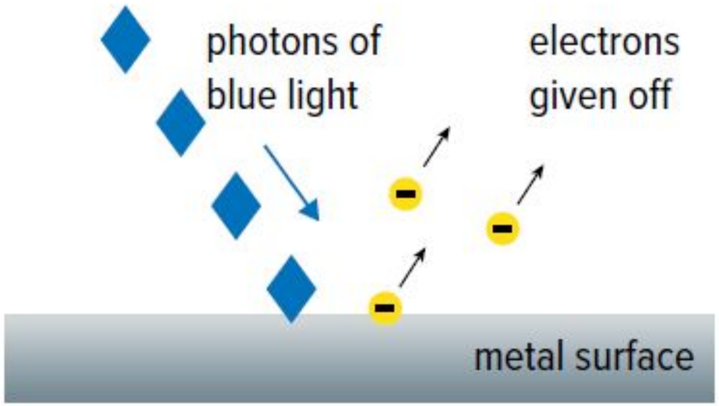
- Einstein called the particles of light energy **photons**.
  - Each photon carries an exact amount of energy that is enough to make the metal give off electrons
  - Otherwise, nothing will happen when the photon hits the metal

Einstein's Thought Experiment: The particles of light energy are called photons.

- **Red light**:
  - Photons of red light do not carry enough energy to make metal give off electrons

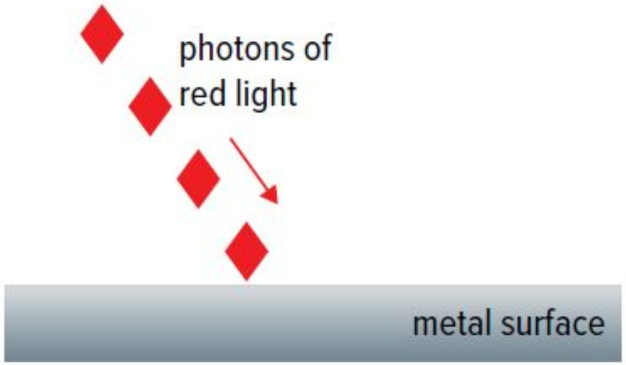


- **Blue light**:
  - Photons of blue light do carry enough energy to make the metal give off electrons

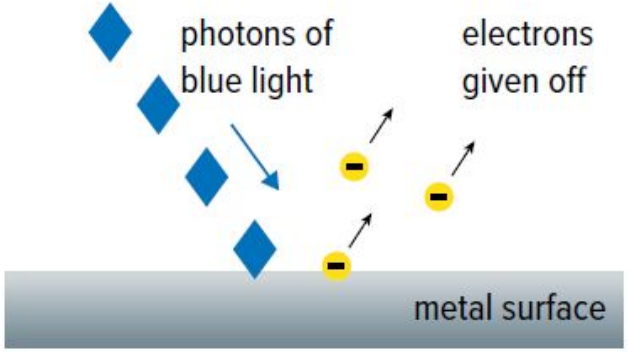


Einstein's Thought Experiment: Photons carry more energy as the frequency increases and wavelength decreases.

- **Red light**:
  - Has a lower frequency and longer wavelength
  - Photons of carry less energy



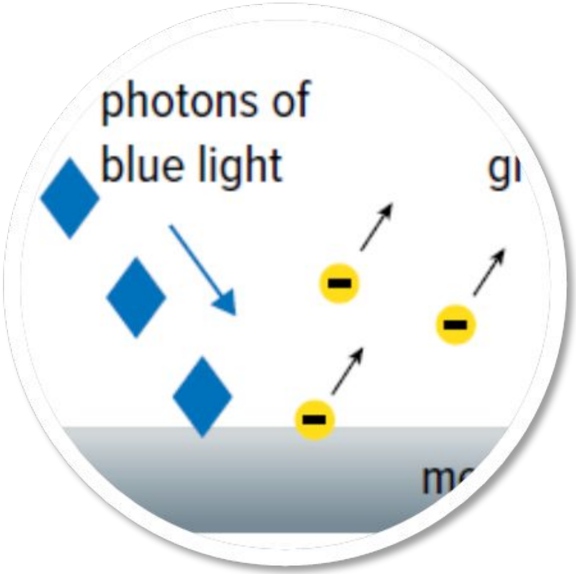
- **Blue light**:
  - Has a higher frequency and shorter wavelength
  - Photons carry more energy



Discussion Questions

- Does light have the properties of a wave, a particle, or both? Explain your reasoning.

- Scientists build on their work of other scientists. Explain how this is true of Einstein's explanation of the photoelectric effect.



Summary: How can model explain the properties of electromagnetic radiation?

- Visible light can be used to model all types of electromagnetic radiation.
- The ray model of light explains that light travels in straight lines.
- The wave model of light explains that light has wave-like properties.
- The particle model of light explains that light has particle-like properties.