Today’s topics

- Powers of Ten
- Scientific Notation
- Properties of Light
- Beer’s Law

Why Do We Need Powers of Ten?

- Some properties of visible light are extremely large:
  - Speed of light is $3\times10^{8}\ \frac{\text{meters}}{\text{sec}}$
  - A typical frequency for visible light: $10^{14}\,\text{Hz}$
- Some properties of visible light are extremely small:
  - A typical wavelength for visible light:

$$600\text{nm} = 600\times10^{-9}\,\text{meters}$$

Powers of Ten

- Example (powers of ten):

$$100 = 10^2$$

$$1,000 = 10^3$$

$$10,000 = 10^4$$

$$\frac{1}{10} = 10^{-1}$$

$$\frac{1}{100} = 10^{-2}$$

$$\frac{1}{1,000} = 10^{-3}$$

Simplifying Power of Ten Expressions

- Moving a factor from numerator to denominator changes the sign of the exponent

Examples (moving power of ten factors):

$$\frac{10^5}{1} = \frac{1}{10^{-5}} \qquad \frac{1}{10^3} = \frac{10^3}{1}$$

$$\frac{10^4 \cdot 10^{-5}}{10^7} = \frac{10^{-7}}{10^{-4} \cdot 10^5}$$

Simplifying Power of Ten Expressions

- When multiplying factors, exponents add
- When dividing factors, exponents subtract

Examples (Multiplying power of ten factors):

$$10^{7} \cdot 10^{2} = 10^{9} \qquad 10^{-5} \cdot 10^{3} = 10^{-2}$$

$$\frac{10^{5}}{10^{3}} = \frac{10^{2}}{1} \qquad \frac{10^{8}}{10^{17}} = \frac{10^{-9}}{1}$$

Scientific Notation

Examples (scientific notation):

$$8.37 \times 10^{7}$$

number between 1 and 10

power of 10

$$1.01 \times 10^{-14}$$

Convert to Scientific Notation

Example (converting to scientific notation):

$$230 = 2.3 \times 10^{?}$$

$$2\underset{\leftarrow}{3}\underset{\leftarrow}{0}.$$

$$46,500 = 4.65 \times 10^{?}$$

$$4\underset{\leftarrow}{6}\underset{\leftarrow}{5}\underset{\leftarrow}{0}\underset{\leftarrow}{0}.$$

$$.02 = 2 \times 10^{?}$$

$$.\underset{\rightarrow}{0}\underset{\rightarrow}{2}$$

$$.0051 = 5.1 \times 10^{?}$$

$$.\underset{\rightarrow}{0}\underset{\rightarrow}{0}\underset{\rightarrow}{5}1$$

Convert to Scientific Notation

Example (converting to scientific notation):

$$230 = 2.3 \times 10^{2} \qquad 2\underline{3}\underline{0}.$$

$$46{,}500 = 4.65 \times 10^{4} \qquad 4\underline{6}\underline{5}\underline{0}\underline{0}.$$

$$.02 = 2 \times 10^{-2} \qquad .\underline{0}\underline{2}$$

$$.0051 = 5.1 \times 10^{-3} \qquad .\underline{0}\underline{0}\underline{5}1$$

Convert from Scientific Notation

Example (converting from scientific notation):

$$6.5\times10^{2}=?$$ $$6.50$$

$$4.6\times10^{-1}=?$$ $$4.6$$

$$3.01\times10^{-4}=?$$ $$0003.01$$

$$6\times10^{7}=?$$ $$6.0000000$$

Convert from Scientific Notation

- Example (converting from scientific notation):

$$6.5 \times 10^{2} = 650 \qquad 6.50$$

$$4.6 \times 10^{-1} = .46 \qquad 4.6$$

$$3.01 \times 10^{-4} = .000301 \qquad 0003.01$$

$$6 \times 10^{7} = 60,000,000 \qquad 6.0000000$$

Simplifying With Powers of Ten

- Example (simplify):

$$\frac{.01 \cdot 6000}{.03} = \frac{1\times 10^{-2} \cdot 6\times 10^{3}}{3\times 10^{-2}} = 2\times 10^{3}$$

Simplifying With Powers of Ten

- Example (simplify):

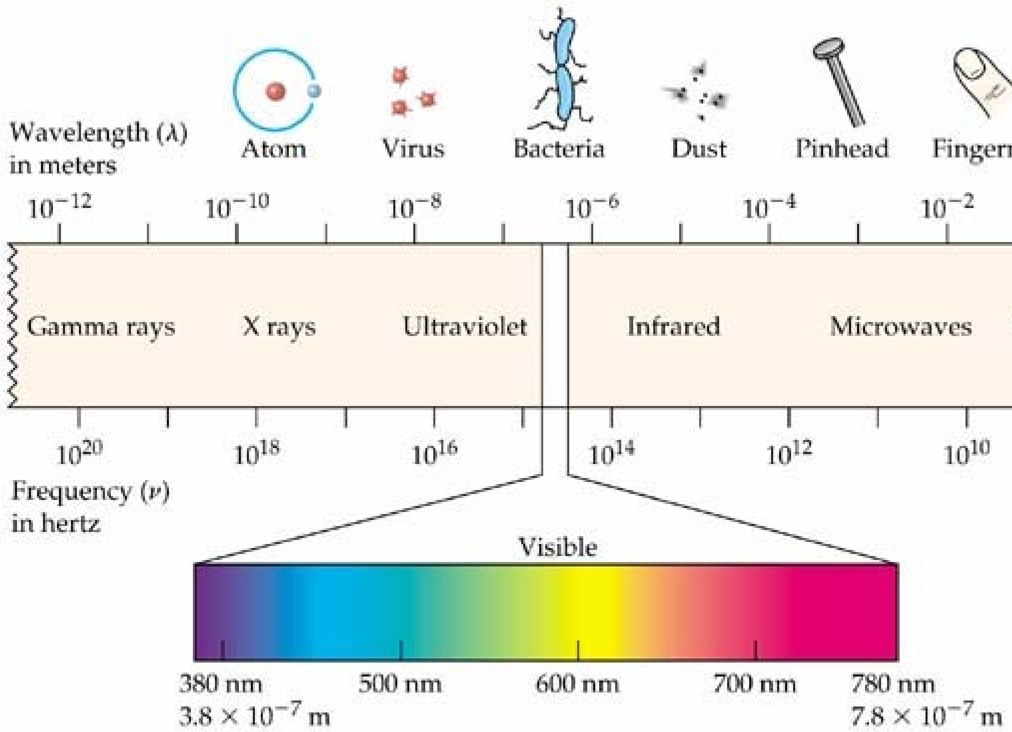
$$\frac{.004\left(300,000\right)}{2,000(.00006)} = \frac{4\times10^{-3}\cdot 3\times10^{5}}{2\times10^{3}\cdot 6\times10^{-5}}$$

$$= \frac{4\cdot 3\times10^{-6}\cdot 10^{10}}{2\cdot 6}$$

$$= 1\times10^{4}$$

What is Light?

- Form of electromagnetic radiation
  - Emission of energy in form of waves or particles

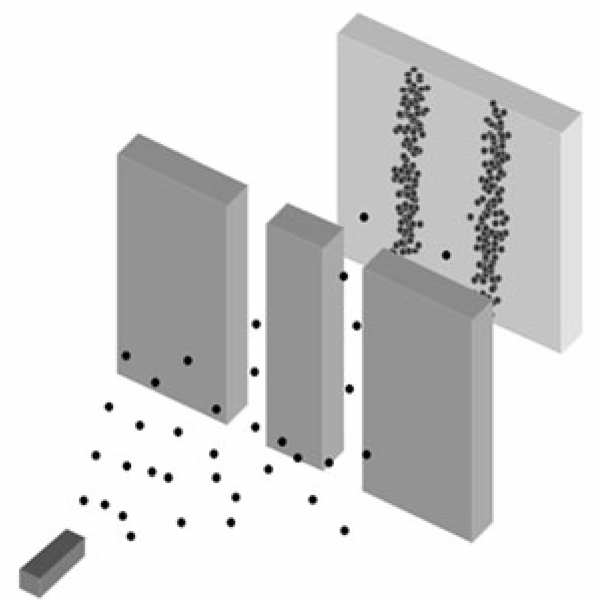


Electromagnetic Spectrum

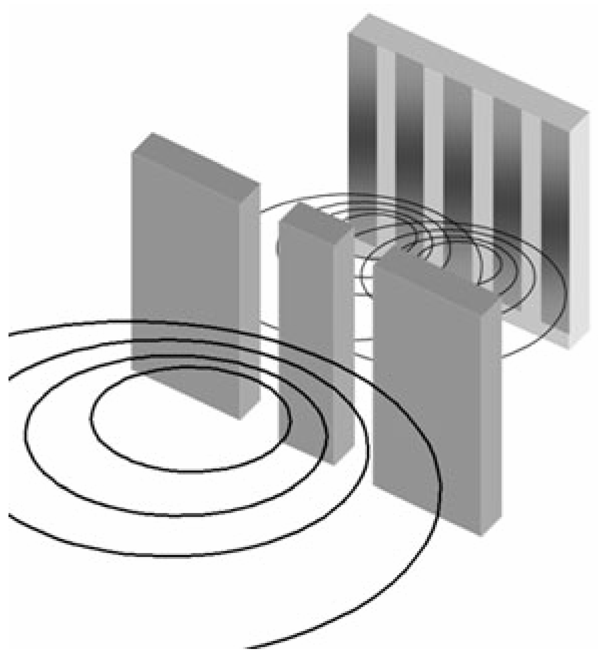
Visible Spectrum

Light – Is it waves or particles?

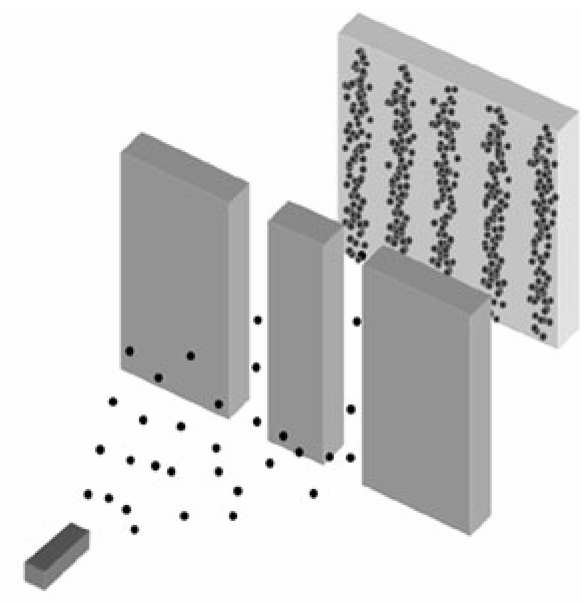
- Wave/Particle Duality – Light (and all electromagnetic radiation) has properties of both waves and particles.



Light as particles



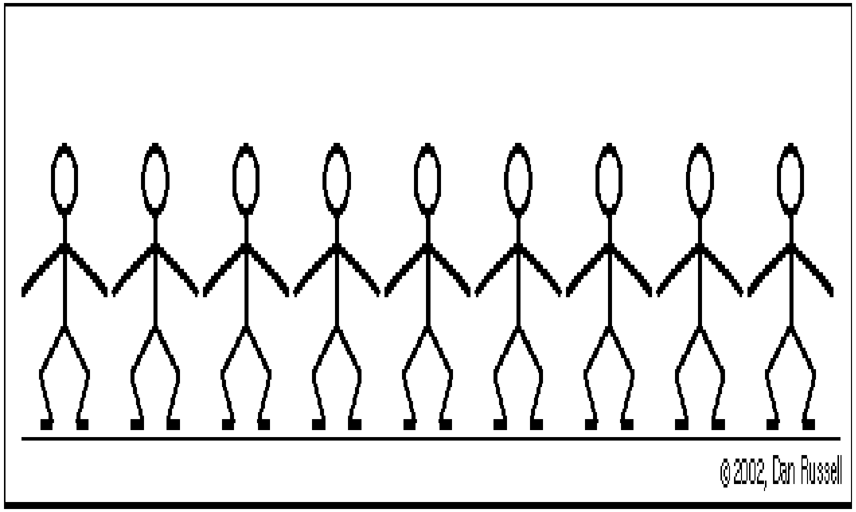
Light as waves

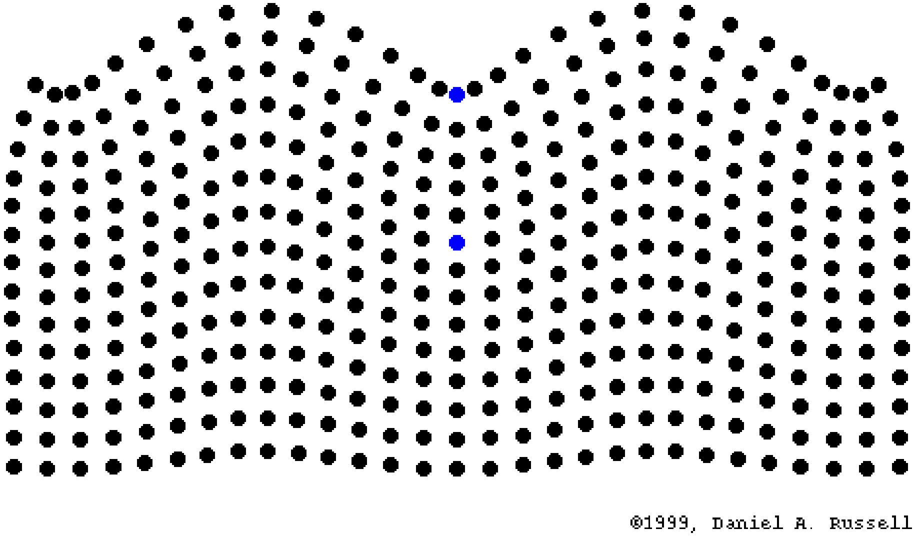


Huh?

Waves

Wave – periodic disturbance, spreading out





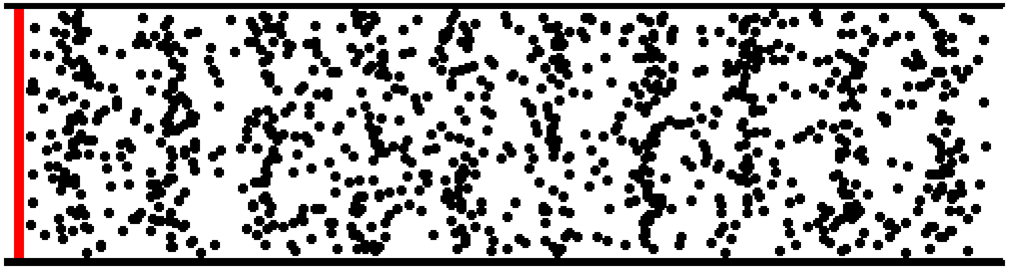
People wave

Shallow water wave

Types of Waves

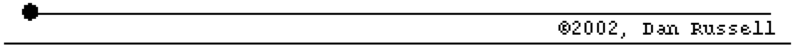
- Longitudinal – motion and disturbance same direction

Sound moving through air

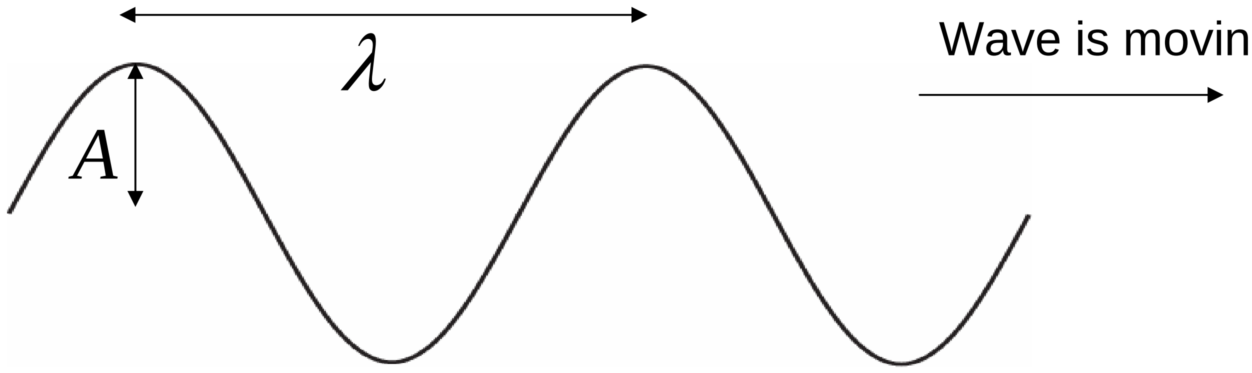


- Transverse – disturbance perpendicular to motion

Wave moving along a string



Properties of Waves



- λ is wavelength – distance between peaks
- A is amplitude – height of wave (from the middle)
- v is speed – how fast the peaks are moving
- f is frequency – number of peaks passing per second – in Hz (cycles/sec)

Typical Speeds for Waves

- Light waves –

$$186,282\,\frac{\text{miles}}{\text{second}}$$

$$671,000,000\,\frac{\text{miles}}{\text{hour}}$$

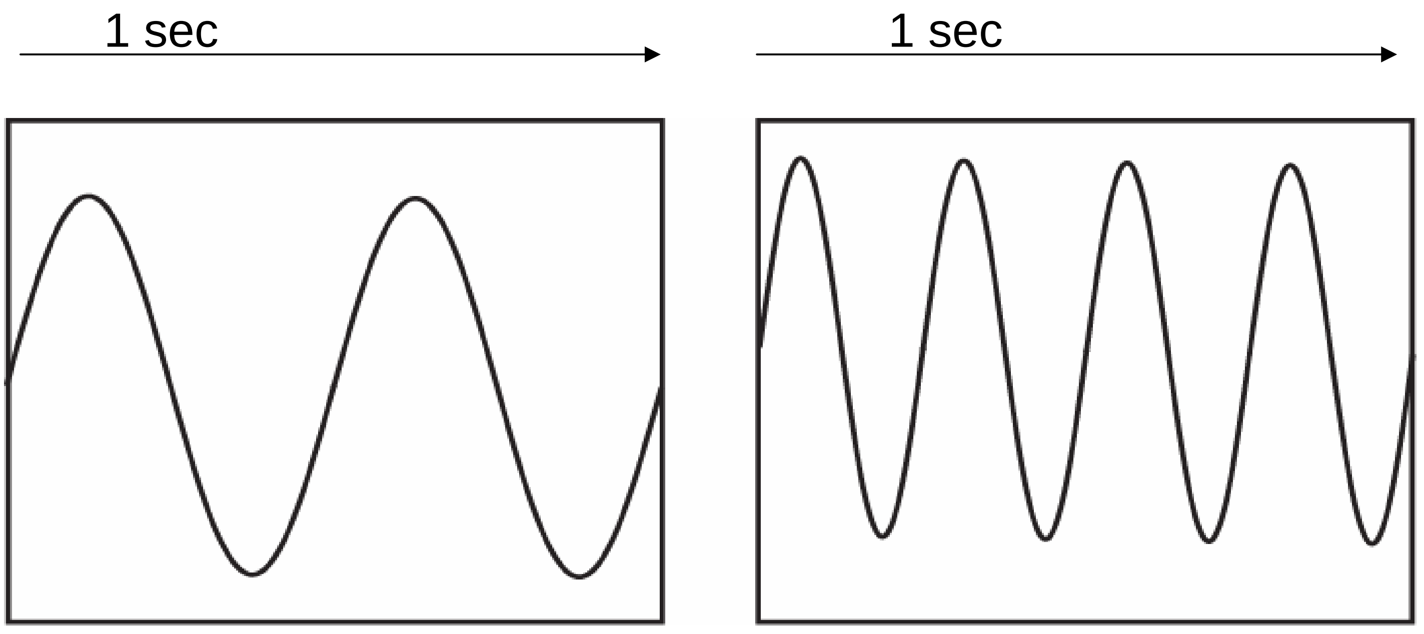
$$3\times10^{8}\,\frac{\text{meters}}{\text{second}}$$

- Sound waves –

$$761\,\frac{\text{miles}}{\text{hour}}$$

$$340\,\frac{\text{meters}}{\text{second}}$$

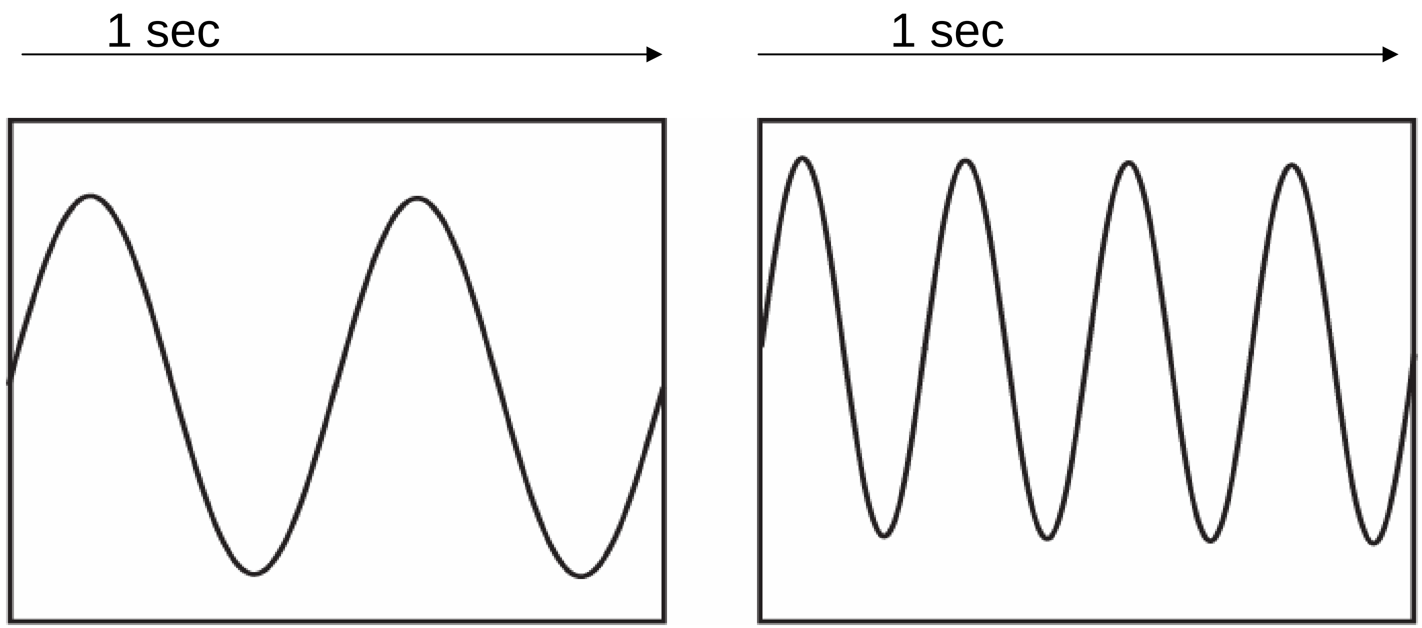
Wavelength and Frequency



Each wave moves across the box in 1 sec

What is the frequency of each wave?

Wavelength and Frequency



$f = 2$ $\qquad\qquad$ $f = 4$

High frequency $\Rightarrow$ short wavelength

Low frequency $\Rightarrow$ long wavelength

Speed, Wavelength, and Frequency

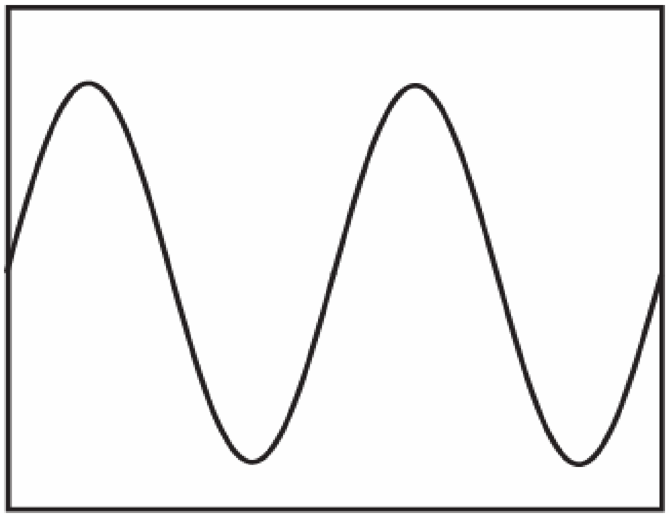
$$v = \lambda \cdot f$$

- Wavelength and frequency are inversely related
- If speed is the same (like it is for all light)
  - As frequency goes up, wavelength goes down
  - As wavelength goes up, frequency goes down

Frequency and Wavelength

3 meters

1 sec



$$f = 2$$

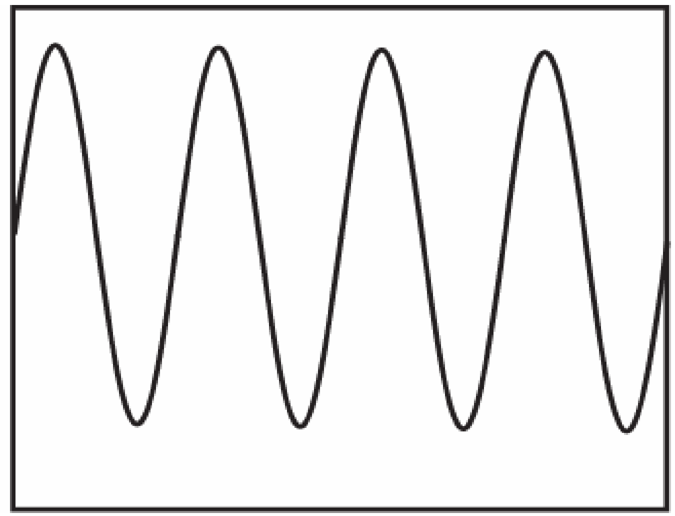
$$v = \lambda \cdot f$$

$$3 = \lambda \cdot 2$$

$$\lambda = 1.5 meters$$

3 meters

1 sec



$$f = 4$$

$$v = \lambda \cdot f$$

$$3 = \lambda \cdot 4$$

$$\lambda = .75 meters$$

Frequency and Wavelength

Example (Wavelength of cell phone radiation):

$$v = \lambda f$$

$$3 \times 10^8 = \lambda \cdot 850 \times 10^6$$

$$\frac{3 \times 10^8}{850 \times 10^6} = \lambda$$

$$.035 \times 10^2 = \lambda$$

$$3.5 \times 10^{-2} \times 10^2 = \lambda$$

$$3.5 \,\text{meters} = \lambda$$

Frequency and Wavelength

Example (Frequency of yellow spectral light):

$$v = \lambda f$$

$$3 \times 10^8 = 600 \times 10^{-9} \cdot f$$

$$\frac{3 \times 10^8}{600 \times 10^{-9}} = f$$

$$\frac{3 \times 10^8 \cdot 10^9}{600} = f$$

$$\frac{3 \times 10^{17}}{600} = f$$

$$.005 \times 10^{17} = f$$

$$5 \times 10^{-3} \cdot 10^{17} = f$$

$$5 \times 10^{14}\,\mathrm{Hz} = f$$

Intensity of Waves

$$I = A^2$$

How powerful the wave is

- Sound – intensity is loudness
- Light - intensity is brightness

Example (when the amplitude is doubled):

$I =$ original intensity

A= original amplitude

$$A_{new} = 2A$$

$$I_{new} = \left(A_{new}\right)^2 = \left(2A\right)^2 = \left(2A\right)\left(2A\right) = 4A^2 = 4I$$

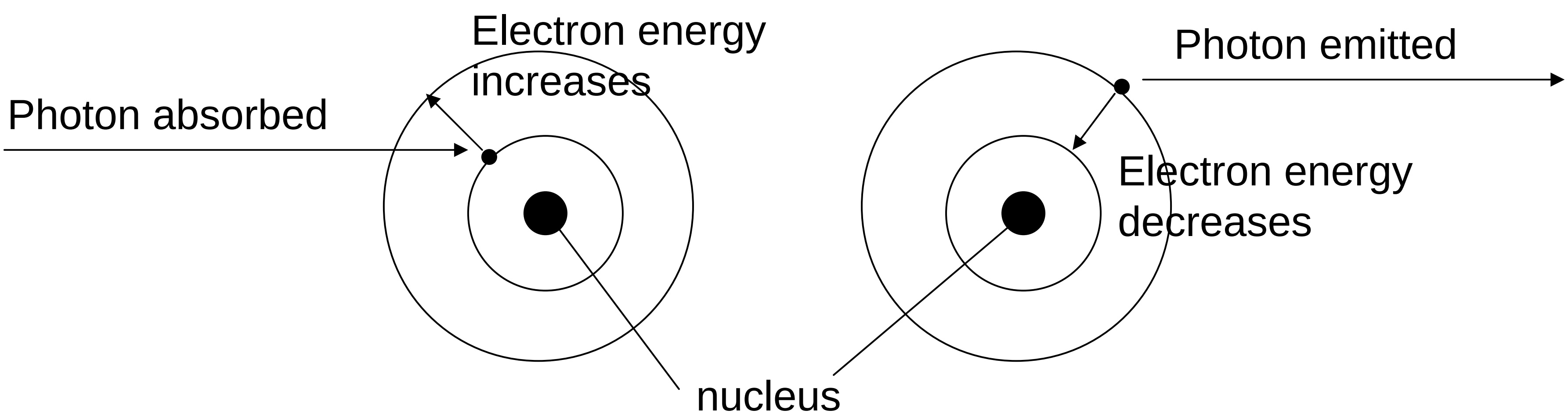
What does this mean?

What carries the Waves?

- Sound – air, water, metal
  - Sound waves need a medium to carry the sound
  - In air the air molecules bang together to move the wave
- Light – nothing
  - No medium is required
  - Electromagnetic waves can travel through a vacuum

Photons – Particles of Light

- Light is comprised of massless particles called photons which travel at the speed of light
- Photons are emitted or absorbed when electrons change energy state
  - If electron energy decreases – photon is absorbed
  - If electron energy increases – photon is emitted



Energy of a photon

$$E = h \cdot f$$

- Gives energy of photon in terms of frequency
- h is called Planck's constant – it never changes

High frequency $\Rightarrow$ high energy

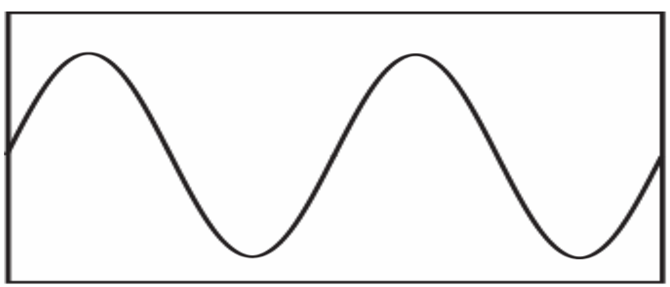
Low frequency $\Rightarrow$ low energy

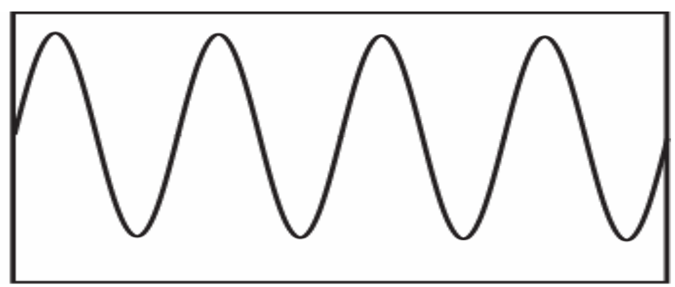
Energy, Frequency, and Wavelength

high energy $\Leftrightarrow$ high frequency $\Leftrightarrow$ short wavelength

low energy $\Leftrightarrow$ low frequency $\Leftrightarrow$ long wavelength

$$E = h \cdot f \qquad\qquad v = \lambda f$$





Which light has more energy?

Example (Ultraviolet and infrared light energy):

Is UV light of higher or lower energy than visible light? What about IR?

UV is shorter wavelength → higher energy

IR is longer wavelength → lower energy