Light

Monday, October 5
Next Planetarium Shows: Tonight, Tue, Wed 7 pm

Universe contains electrically charged particles: protons (+) and electrons (-).

Charged particles are surrounded by electric fields and magnetic fields.

Fluctuations in those fields produce **electromagnetic waves**.

**Visible light** is a form of electromagnetic wave...

...but so are radio waves, microwaves, infrared light, ultraviolet light, X rays, and gamma rays.
Light is a wave.

Wave = a periodic fluctuation traveling through a medium.

Ocean wave = fluctuation in height of water.

Sound wave = fluctuation in pressure.

Electromagnetic wave = fluctuation in electric and magnetic fields.

Describing a wave:

Wavelength (\( \lambda \)) = distance between wave crests.
Amplitude (\( a \)) = height of crests above troughs.
Frequency (\( f \)) = number of crests passing per second
The speed of a wave equals wavelength times frequency.

\[ c = \lambda \times f \]

(c for “CELERITAS”, the Latin word for “speed”)

<table>
<thead>
<tr>
<th>wavelength</th>
<th>frequency</th>
<th>speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>ocean wave</td>
<td>100 meters</td>
<td>0.1 /sec</td>
</tr>
<tr>
<td>sound wave (middle C)</td>
<td>1.2 m</td>
<td>262 /sec</td>
</tr>
<tr>
<td>light wave (red)</td>
<td>6.6×10^{-7} m</td>
<td>4.5×10^{14} /sec</td>
</tr>
</tbody>
</table>

The speed of light in a vacuum is \textbf{always} \[ c = 300,000 \text{ km/sec} \] (186,000 miles/sec).
Light is made of **particles**.

Light shows some properties of particles, such as the **photoelectric effect**.

Particles of light, called **photons**, kick electrons out of atoms.

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The **energy** of a photon is related to the **frequency** of a wave.

\[ E = h \times f \]

- \( E \) = energy of photon
- \( f \) = frequency of light wave
- \( h \) = Planck’s constant
  (a very small number indeed)

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**Wave or particle?**

Both.

Light has properties of **both** a wave and a stream of particles. Light follows the laws of **quantum mechanics**.
Light forms a spectrum from short to long wavelength.

Visible light has wavelengths from 400 to 700 nanometers. [1 nanometer (nm) = 10^{-9} meters]

The **COMPLETE** spectrum of light

- Gamma rays ($\lambda < 0.01$ nanometers)
- X rays (0.01 → 10 nm)
- Ultraviolet (10 → 400 nm)
- Visible (400 → 700 nm)
- Infrared (700 nm → 1 mm)
- Microwave (1 → 100 mm)
- Radio (> 100 mm)

Consider an atom: (highly schematic drawing)

A nucleus, consisting of protons and (usually) neutrons, is surrounded by a cloud of electrons.
**Hydrogen**: one proton, one electron.

Behavior on subatomic scales is governed by quantum mechanics.

Rule: electrons can only exist in orbits of particular energy. (Small orbit = low energy, big orbit = high energy).

Electron falls from high- to low-energy orbit: energy is carried away by a photon.

- $\lambda = 656.3 \text{ nm}$
- $\lambda = 486.1 \text{ nm}$
- $\lambda = 434.0 \text{ nm}$

Photon has a fixed energy, corresponding to fixed wavelength.

Consider a hot, low density glob of hydrogen gas.

Light emitted only at wavelengths corresponding to energy jumps between electron orbits.
Hot, low density gas produces an **emission** line spectrum.

Spectrum of hydrogen at visible wavelengths.

Carina Nebula: a cloud of hot, low density gas about 7000 light-years away.

Its reddish color comes from the 656.3 nm emission line of hydrogen.

A cool, low density glob of hydrogen gas in front of a light source.

Light absorbed **only** at wavelengths corresponding to energy jumps between electron orbits.
Cool, low density gas produces an **absorption** line spectrum.

Spectrum of hydrogen at visible wavelengths.

Each element has a unique spectrum.

- Hydrogen
- Helium
- Oxygen
- Neon
- Iron

The spectrum of the Carina Nebula:

Hydrogen line at 656.3 nanometers
The **radial velocity** of an object is found from its **Doppler shift**.

Radial velocity = how fast an object is moving toward you or away from you.

Doppler shift: If a wave source moves toward you or away from you, the wavelength changes.

Christian Doppler (1803-1853)

If a light source is moving **toward** you, wavelength is shorter (called “blueshift”).

(should be “violetshift”, more logically)

If a light source is moving **away** from you, wavelength is longer (called “redshift”).
Doppler shifts are easily detected in emission or absorption line spectra.

Size of Doppler shift is proportional to radial velocity:

\[ \frac{\Delta \lambda}{\lambda_0} = \frac{V}{c} \]

- \( \Delta \lambda \) = observed wavelength shift = \( \lambda - \lambda_0 \)
- \( \lambda_0 \) = wavelength if source isn’t moving
- \( V \) = radial velocity of moving source
- \( c \) = speed of light = 300,000 km/sec

Wednesday’s Lecture:

What is a star?

Reminders:
Have you read chapters 1 – 3?
Problem Set 1 is due Wednesday.
Planetarium shows Tonight, Tue, Wed.