CHEM 103
Radiation and Waves

Lecture Notes
March 28, 2006
Prof. Sevian

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Announcements

- Exam #2 is this Thursday, March 30
  - Study guide, practice exam, and practice exam answer key are already posted on the course website
  - Where to take your exam:
    - Last names starting with A-H, room M-1-207
    - Last names starting with I-Z, in our regular lecture hall
- No labs this week

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Map of this chapter

- Waves
  - Light (energy)
  - Matter
  - Are matter and energy really the same thing (on some scale)?
- Wave-matter duality
  - Black body radiation and photoelectric effect
  - Quantization of energy
- The quantum mechanical model
  - Spectroscopy: a phenomenon in need of explanation
  - How to use the quantum mechanical model
  - What the model explains/predicts
  - Where the model breaks down

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Waves

- Disturbance that transfers energy from one place to another without requiring any net flow of mass
- Two kinds of waves
  - Pulse: single disturbance
  - Periodic wave: continually oscillating motion
- Two kinds of waves
  - Transverse: motion of particles at right angles to direction of wave motion
  - Longitudinal: motion of particles oscillate along direction of wave motion

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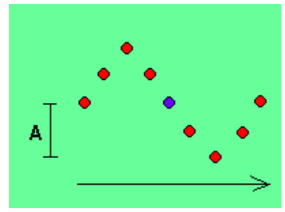
Describing Waves



- For waves requiring a medium in which to travel, wave is a manifestation of kinetic energy of particles of medium
- Particles in medium move up and down with a particular frequency (bobs per second)
- Animation at right: although the wave appears to be moving to the right, the blue particle is bobbing up and down
- Other important parameters to describe waves
  - Wavelength (λ): length (distance in meters) of one cycle
  - Amplitude (A): maximum distance a particle gets from its undisturbed position
  - Frequency (ν): number of cycles per second
  - Speed: given by frequency x wavelength

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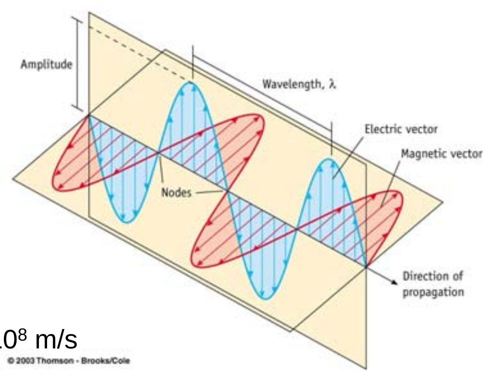
see http://www.ewart.org.uk/science/Waves/wav1.htm

Light and other electromagnetic waves



Speed of light in a vacuum

$c = 3.00 \times 10^8$ m/s

Therefore $c = \nu\,\lambda$

wavelength (m or m/cycle)

frequency (Hz or cycles/s)

How to create an electromagnetic wave:

- An oscillating electric field generates an oscillating magnetic field
- Vice versa

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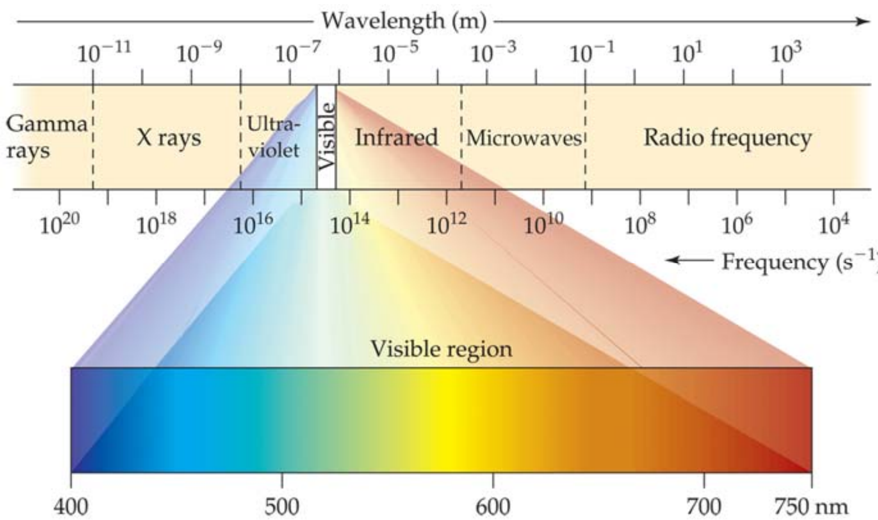
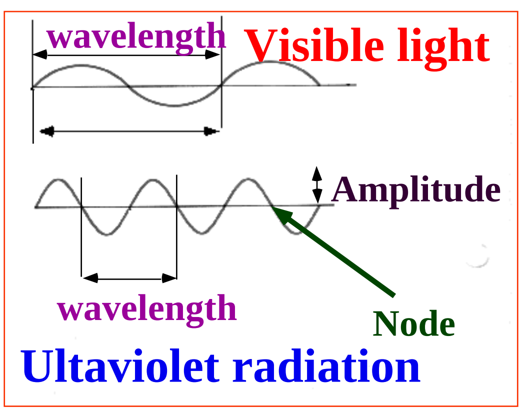
Electromagnetic spectrum divided up based on frequency



How light waves differ from each other



From Chemistry & Chemical Reactivity 5th edition by Kotz / Treichel. C 2003. Reprinted with permission of Brooks/Cole, a division of Thomson Learning: www.thomsonrights.com. Fax 800-730-2215.

Compare visible and UV light:

Both are light, so they have the same velocity (speed of light, $c = 3.0 \times 10^8$ m/s)

Wavelength

$\lambda_{visible}$ λ_{UV}

Frequency

$\nu_{visible}$ ν_{UV}

(Greater than, less than, or equal?)

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Calculation of Light Properties

Red light has λ = 690 nm. What is its frequency?

Convert wavelength to standard SI units:

Calculate frequency:

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Black Body Radiation

- Objects below ~700 K produce very little radiation in the visible range
- As the temperature increases, both the intensity and the frequency (ν) of the radiation increases
- Classical physics predicts that the energy of light depends on the its intensity

- This leads to the prediction that as the frequency increases, so does the intensity
- *Ultraviolet catastrophe*

The red glow of lava is due to its temperature of 1000 to 1200ºC

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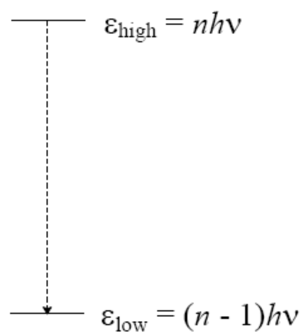
Planck's Genius

- An object contains oscillators with various individual frequencies, ν
- Each oscillator has energies restricted to quantized values,
  $\varepsilon_n = nh\nu$
  (n = 1, 2, 3, 4, …)
- Oscillators emit energy in the form of light when they transition from ε_{high} to ε_{low}



Therefore, light energy is proportional to ν not intensity

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Wave-Particle Duality of Light

- Light can be described by frequency, wavelength of various colors of visible light, and of non-visible light (*e.g.*, microwaves, IR)
- Blackbody radiation from hot objects and "ultraviolet catastrophe" solved by Planck's equation which explains that a blackbody is made of a bunch of oscillating atoms, and the energies of each oscillating atom are *quantized*
  - Planck: Energy of an oscillating atom depends on frequency of the oscillation
    $E = nh\nu$ (with n = 1, 2, 3, …)
  - Einstein: electromagnetic waves have particle nature

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Other Properties of Light

Property	Wave behavior	Particle behavior
Reflection	∿	●
Refraction	∿	●
Interference	∿	×
Diffraction	∿	×
Polarization	∿	×
Photoelectric effect	×	●

Modified from http://www.opticshare.com/resource/14.asp

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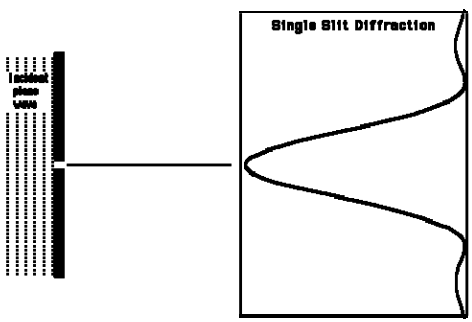
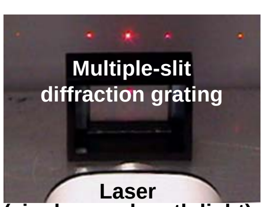
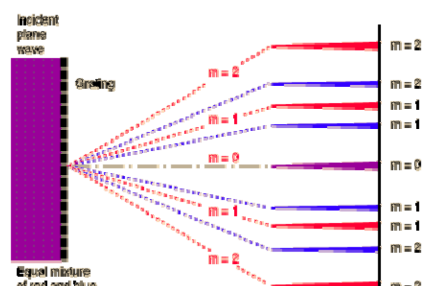
Diffraction

Property of light that can be explained only by wave behavior





(single wavelength light)

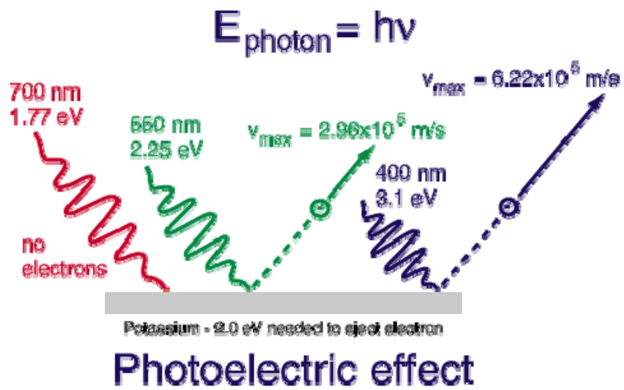


From http://hyperphysics.phy-astr.gsu.edu/hbase/phyopt/grating.html

Photoelectric Effect

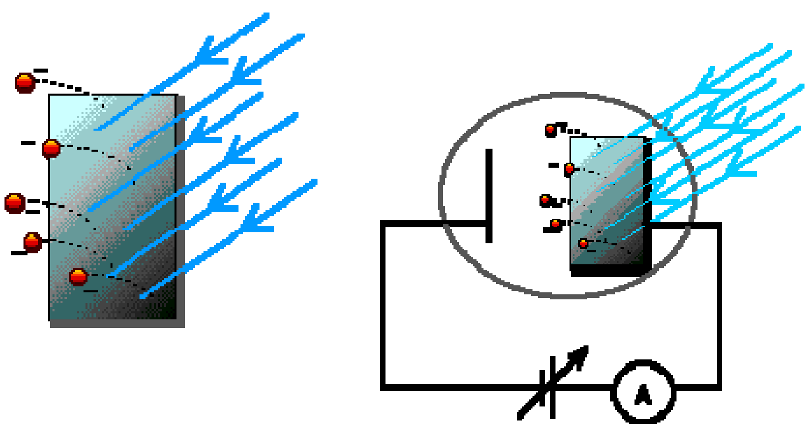
Property of light that can be explained only by particle behavior
- Shining light on a metal can free electrons from the surface
- Easy for UV light to do this, difficult for red light

- Kinetic energy (also velocity) of freed electrons depends on frequency of light
- Increasing the intensity of the light frees more electrons but doesn't change the energies of electrons freed



From http://www.opticshare.com/resource/14.asp

Photoelectric Effect is Useful



From www.ux1.eiu.edu/~cfadd/ 1160/Ch28QM/Photo.html

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Does Wave-Particle Duality Apply to Electrons?

Photoelectric effect:
- Photons (particles of light) cause electrons to be ejected from atoms

Can converse work?
- Can electrons moving cause photons to be ejected from atoms?

Light behaves as waves sometimes and particles sometimes
So…
What about electrons, which are very small particles?

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