Today

- Announcements:
  - HW#5 and HW#6 are due tomorrow, October 19th.
- Energy
- The electromagnetic spectrum
- Quantum Mechanics and Atoms

Energy and Power

- Energy is the ability to do work: Work = force x distance
- Energy comes in two forms
  - Kinetic – energy of motion
  - Potential – energy of position
    - **Gravitational** GPE = m (gh); g = 9.81 m/s^2 on Earth, h height
    - **Electric** EPE = Q (V); Q is the charge, V is the volts

$$KE = \frac{1}{2}mv^2$$

- Power (measured in W = J/s) is the rate of use of energy
- Examples:
  - A charge of 0.5 C is pumped by a battery “up” 1.5 V. How much energy did this take? EPE = QV = 0.5 C x 1.5 V = 0.75 J
  - A mass of 1.0 kg is raised 1.0 m. How much work was done? W = ΔGPE = 1.0 kg x 9.81m/s^2 x 1.0 m = 9.81 J

Where are we?

- We have talked about two forces in nature
  - Gravity – General Relativity (Space and time are tied into a 4 dimensional space-time. Gravity is the result of the curvature of space.)
  - Electromagnetism – Electric and magnetic forces are the result of charge and the motion of charge.
  - Are the gravity and electricity related? Are all the forces in nature related?
- The modern picture of electromagnetism is that the electric force is carried by the photon.
- A photon is a small bundle of energy. We see photons in the range of 1.8 eV (red) to 3.1 eV (violet) [1 eV = 1.6E-19 J]

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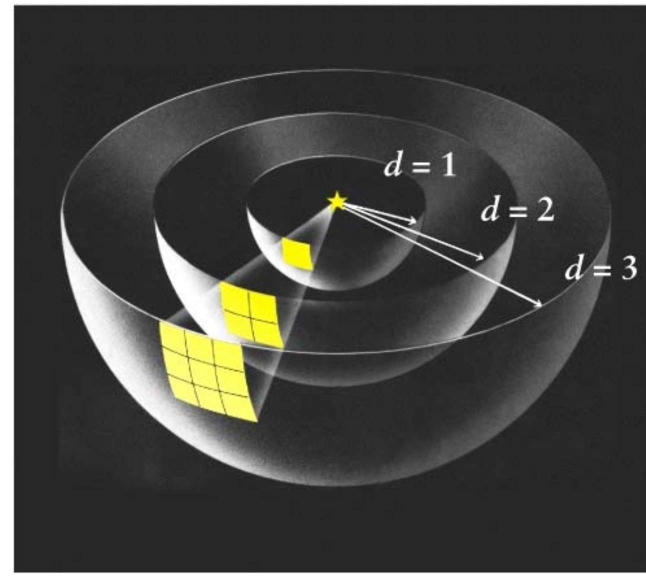
Inverse square law

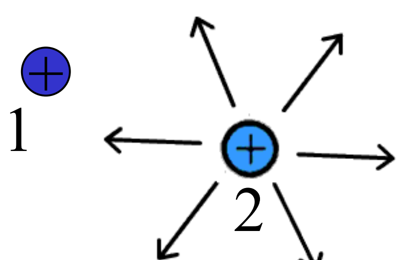


Inverse square law

$$\text{intensity} = \frac{\text{L[Watts]}}{4\pi \text{d}^2}$$

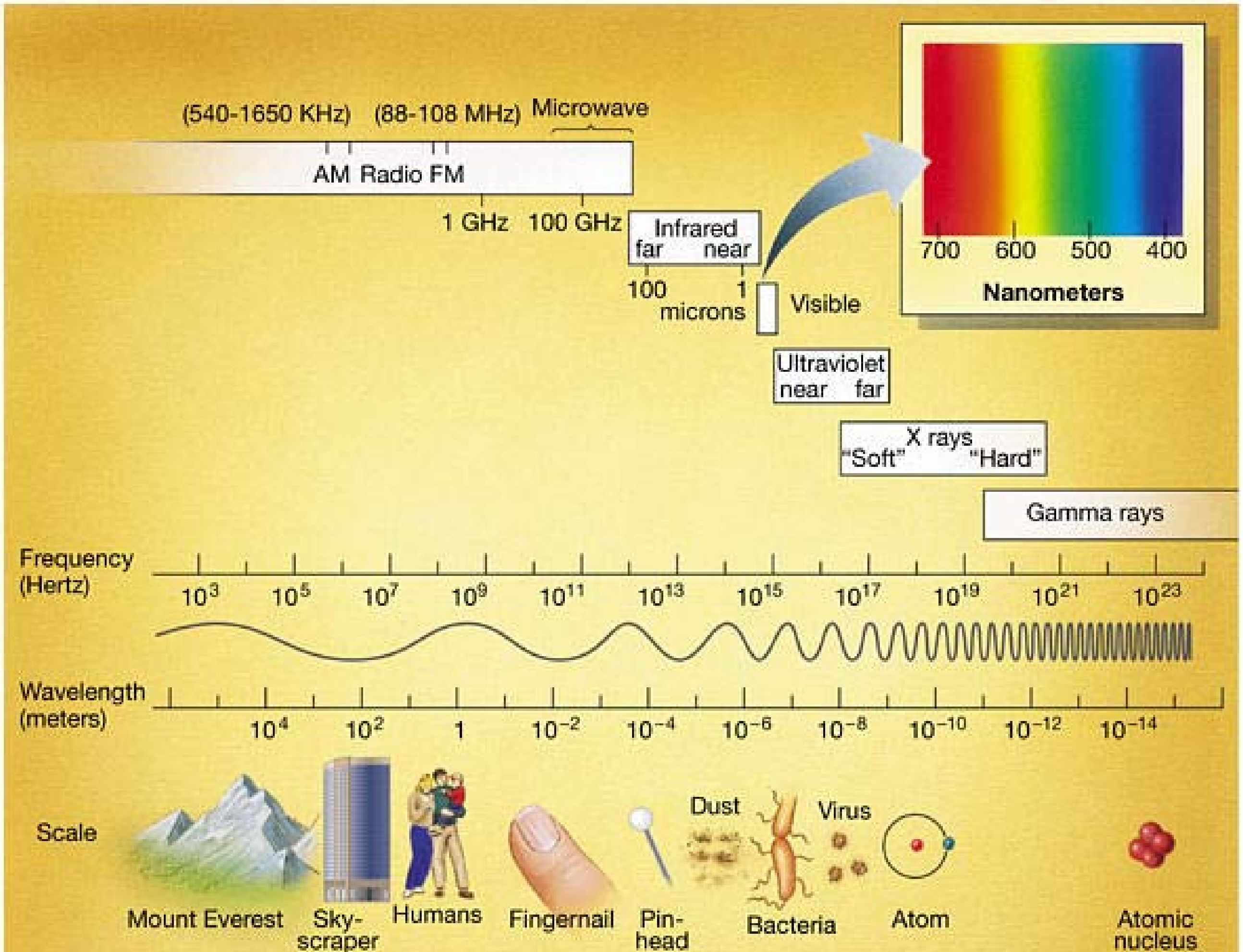
L is the luminosity, d is the distance to the source

This explains why the electric force has the form it does:



$$F = q_1 E_2 = q_1 \frac{kq_2}{r_{12}^2}; k = 8.99 \times 10^9 \frac{Nm^2}{C^2}$$

The Electromagnetic Spectrum



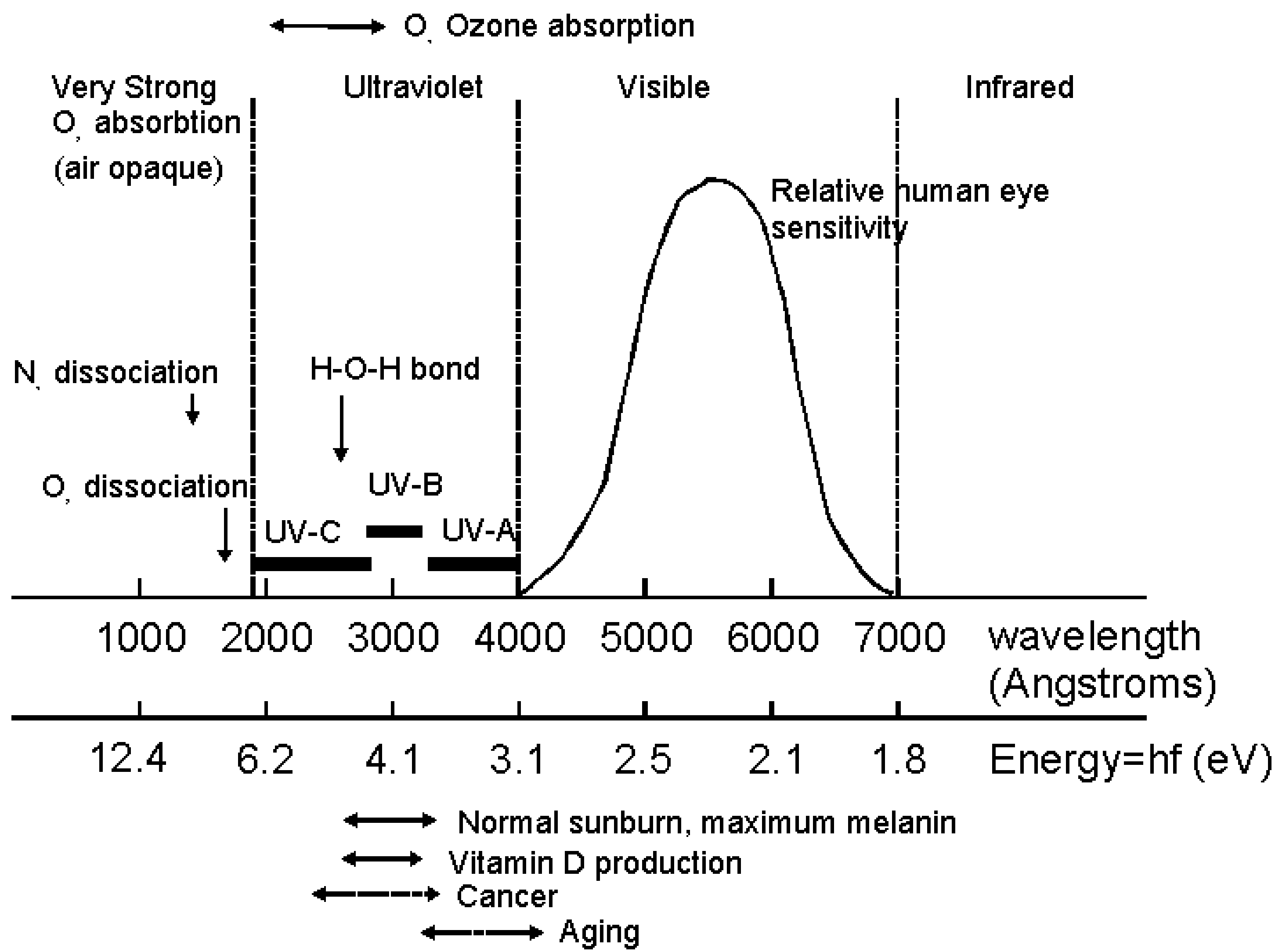
Speed = λ f
λ – wavelength
f – Frequency, Hz
(1/period)(1/s)

For light
Speed c = 3.0E+8m/s

Energy = h f
h = 6.625E-34 Js
= 4.136E-15 eVs

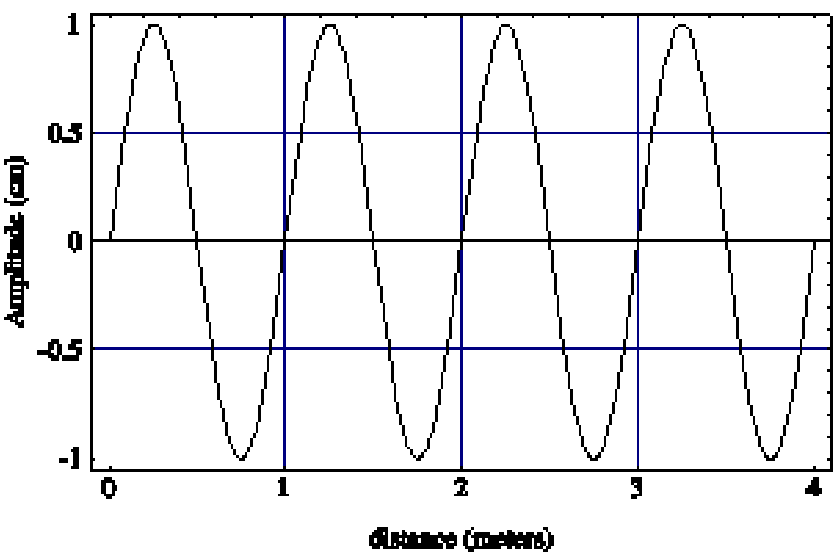
Prentice-Hall 2005

Around Visible Electromagnetic Spectrum



Wavelength and Frequency

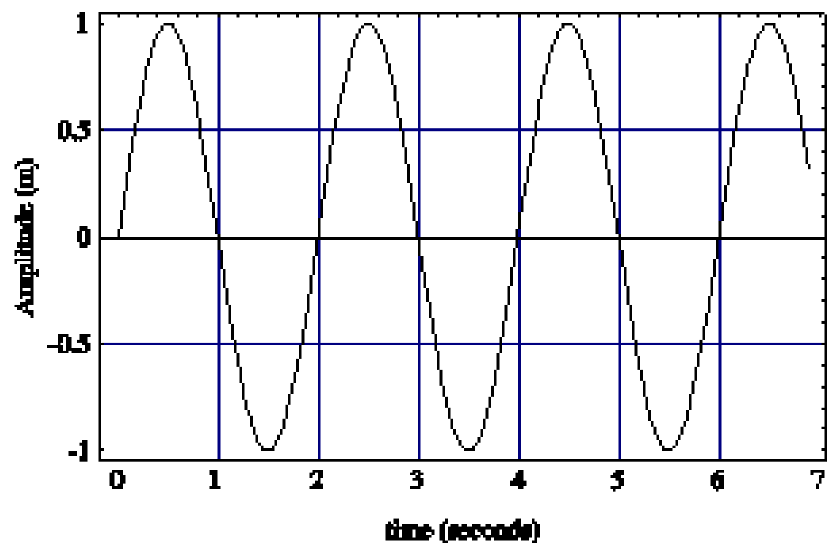
λ = 1.0 m



Wavelength

Distance over which the wave repeats

period = 2.0 s



Frequency = 1/period

Number of cycles (repeats) per second.

A mystery – The Photo Electric Effect

- Photons, if they have sufficient energy, can knock electrons out of a solid – photo electric effect
- In the wave picture of light, the height of the wave would matter (intensity). The frequency would not matter.
- In nature it is the other way around. The frequency is what matters.
- This makes sense if we consider light as little packets of energy (photons). The frequency determines the energy of the photon.
- If the energy of a photon is high enough, it can knock an electron out.
- Light behaves like a wave and like a particle. Which is it?

An even bigger surprise!

- Particles like electrons also behave like waves!
- Example Demo: electron diffraction
- de Broglie wavelength of a particle (h is Plank's constant)

$$\lambda = \frac{h}{p}; \quad h = 6.625 \times 10^{-34}\ J \cdot s$$

What is the wave length an electron with an energy of 30 keV?

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2m_e E}} = \frac{6.625 \times 10^{-34} Js}{\sqrt{2 \cdot 9.11 \times 10^{-31} kg \cdot 30 keV \cdot \frac{1000 eV}{keV} \frac{1.6 \times 10^{-19} J}{eV}}}$$

$$\lambda = 7.084 \times 10^{-12} m$$

What is waving?

- Probability – all particles are characterized by a "wave function". The square of the wave functions give the probability density of finding a particle per unit volume.
- The square of the wave function times a volume give the probability of finding the particle in that volume.
- This is the picture of Erwin Schrödinger: Matter is defined by the evolution in time of a wave function.

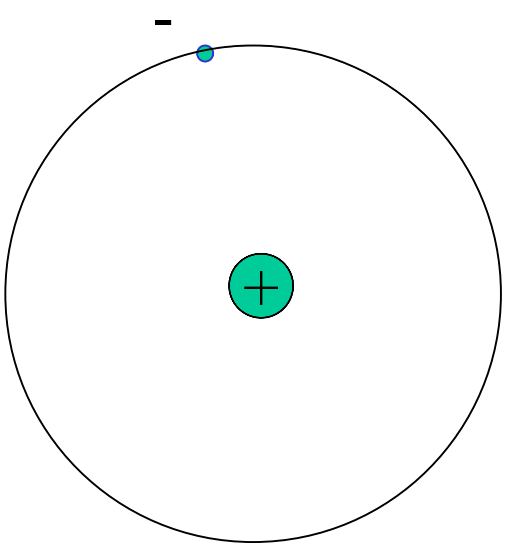
$$H\Psi = E\Psi \quad \Psi \rightarrow \text{wave function}$$

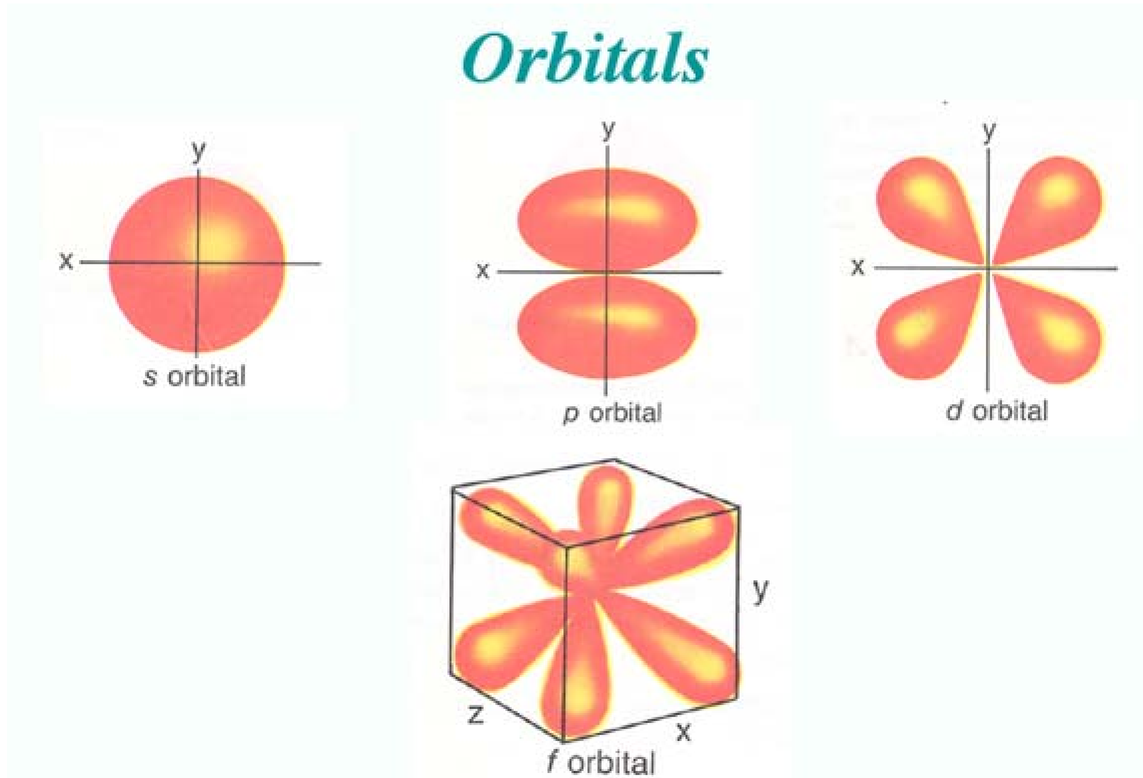
Bosons and Fermions

- Particles come in two types
- Bosons have the property that they can overlap. Examples are photons and certain atoms (helium)
- Fermions can not exist in the same state. Examples – electrons, protons.
- The fermion nature of elections explains atomic structure

Electron Wave functions in atoms

Old picture





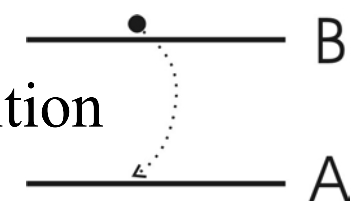
The nucleus sits at the center and these picture show possible regions were the electrons might be.

Atoms and molecules exists fixed states of energy

Excited state

3.0 eV

Transition



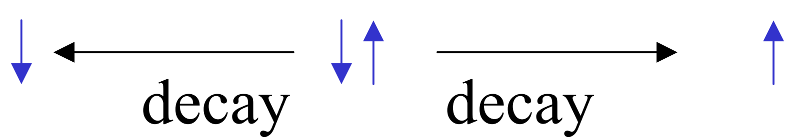
0 eV

Ground state

Energy of photon = $E_i - E_f = 3.0 - 0 = 3.0$ eV

Problems?

- How can a particle interfere with itself? This implies the particle, somehow, takes more than one path at the same time.
- Schödinger’s Cat: Is the cat alive or dead?
- Einstein, Podolsky and Rosen Effect



If we measure one, we know what the other is. Information travels faster than light.

Heisenberg's Uncertainty Principle

- If a particle has a wavelength, its position and speed are not perfectly defined.
- Uncertainty Principle: It is not possible to know exactly the position and momentum of a particle at the same time.

$$\Delta x \Delta p \geq \frac{h}{4\pi}$$

- There is no absolute knowledge. The Newtonian view of the world (if everything were known, everything could be predicted) in not attainable.