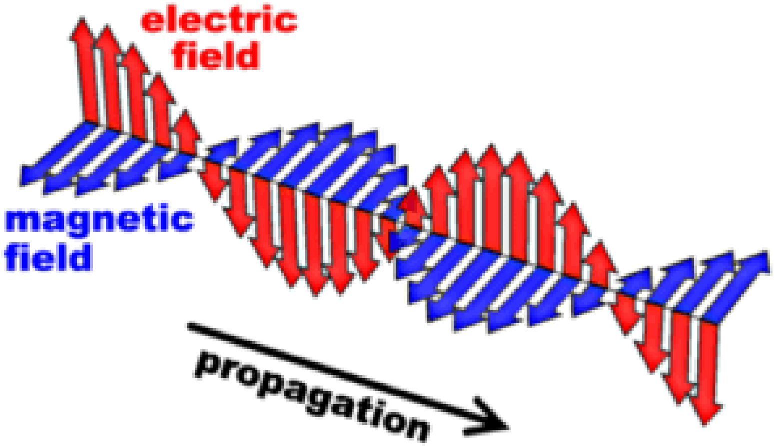
Today

- Announcements:
  - HW#7 is due after Spring Break on Wednesday March 12th
  - Exam #2 is on Thursday after Spring Break
  - The fourth extra credit project will be a "super bonus" points project. This extra credit can let your homework score go over 100%
- Light
- Wave-particle duality of nature
- Quantum Mechanics

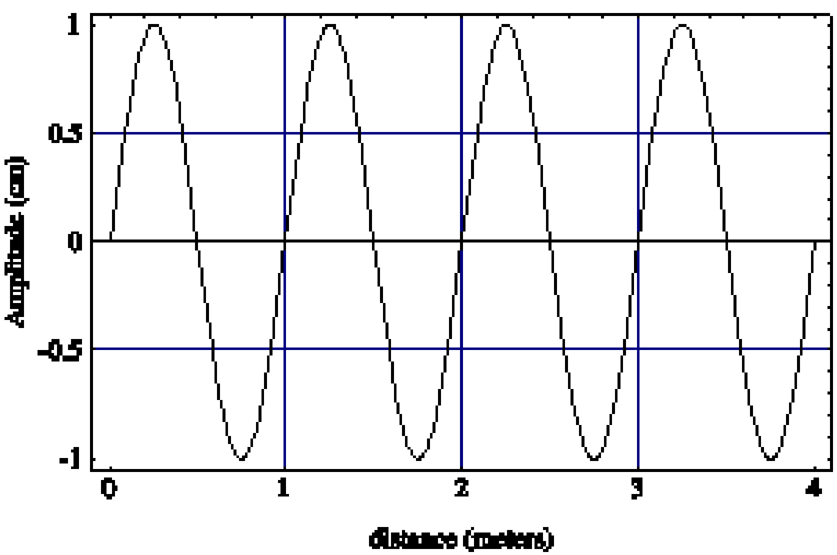
The Electromagnetic Spectrum

- Maxwell’s 4 equations describe the unity of electric and magnetic forces.
- They predict an electromagnetic wave that travels at the speed of c (3.00E+8 m/s)



Wavelength and Frequency

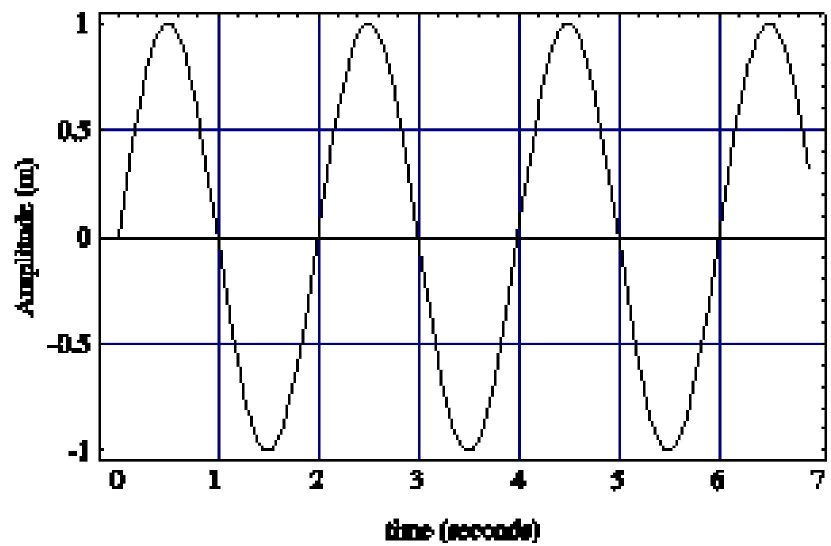
$\lambda = 1.0$ m



Wavelength

Distance over which the wave repeats

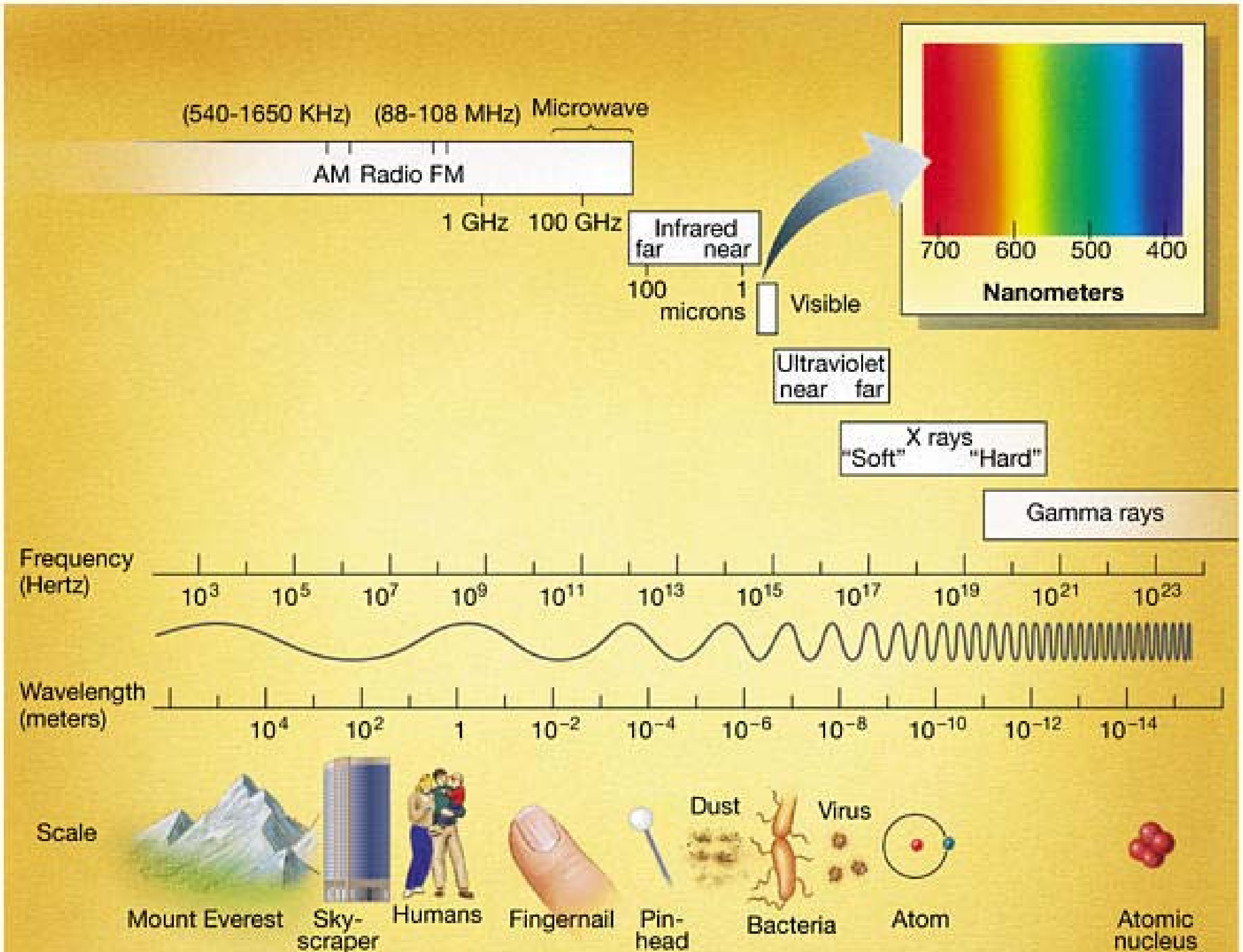
period = 2.0 s



Frequency = 1/period

Number of cycles (repeats) per second.

The Electromagnetic Spectrum



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

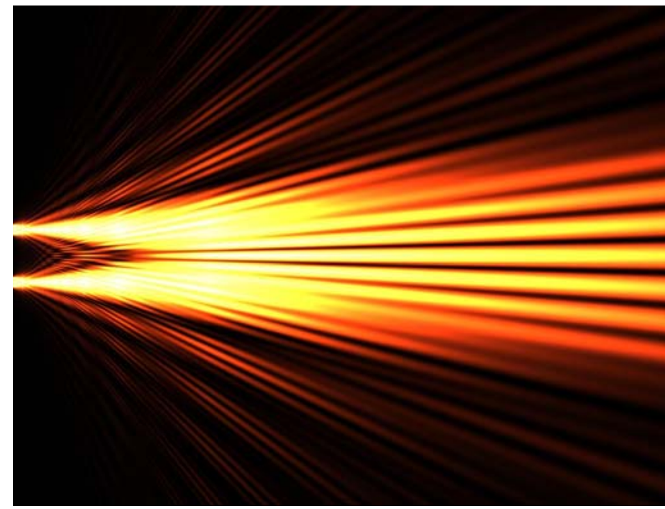
For light
Speed c = 3.0E+8m/s

Prentice-Hall 2005

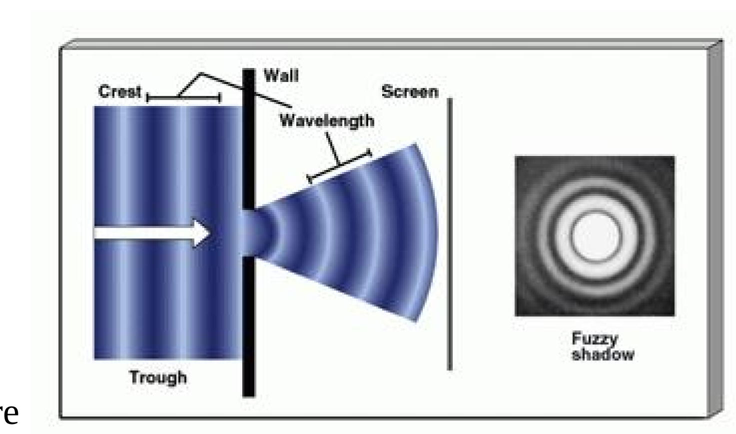
What is Light?

- Wave Picture – oscillating electric and magnetic fields
- Waves can interfere
- Examples
  - 2-slit interference
  - diffraction

2-slit interference



diffraction



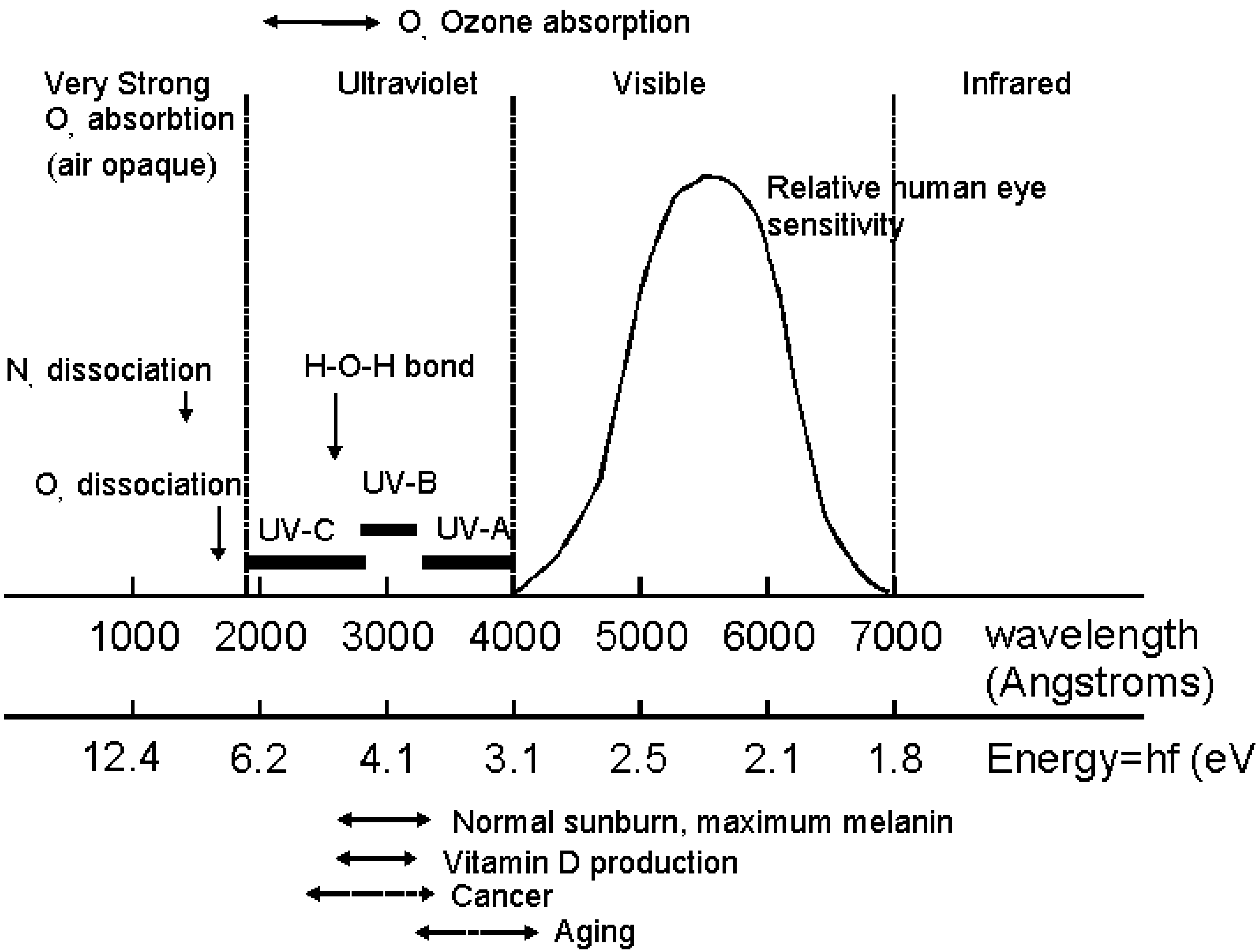
Light as a particle

- Light also behaves like a particle
- Light comes in small bundles of energy we call photons
- Energy (of a photon) = h f

h = 6.625E-34 Js

= 4.136E-15 eVs

Around Visible Electromagnetic Spectrum



Explanation of Electric Forces and Gravity

Coulomb's Law (Electric Force)

$$F = \frac{kq_1q_2}{r^2}; k = 8.99E+9 \, {Nm^2}/{C^2}$$

Coulomb force is carried by photons

Newton's Universal Law of Gravity:

$$F = \frac{Gm_1m_2}{r^2}; G = 6.673E-11 \, {Nm^2}/{kg^2}$$

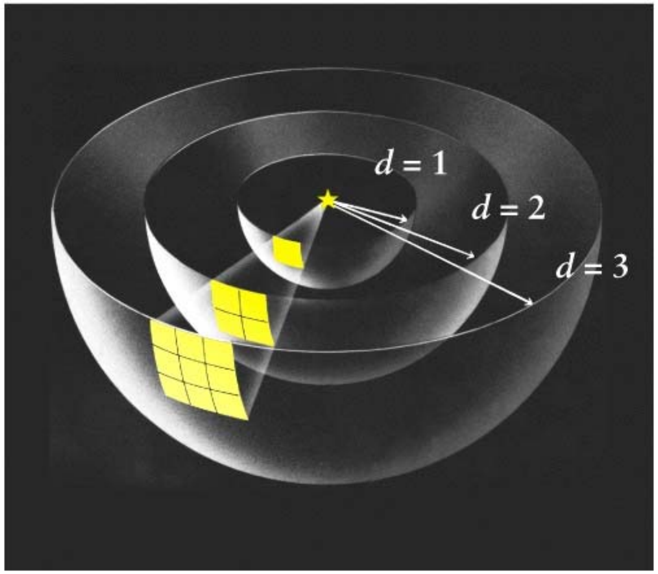
Gravity is carried by the graviton.

Why is there always r^2? I hate r^2.

Inverse square law

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

L is the luminosity(measured in watts), d is the distance to the source

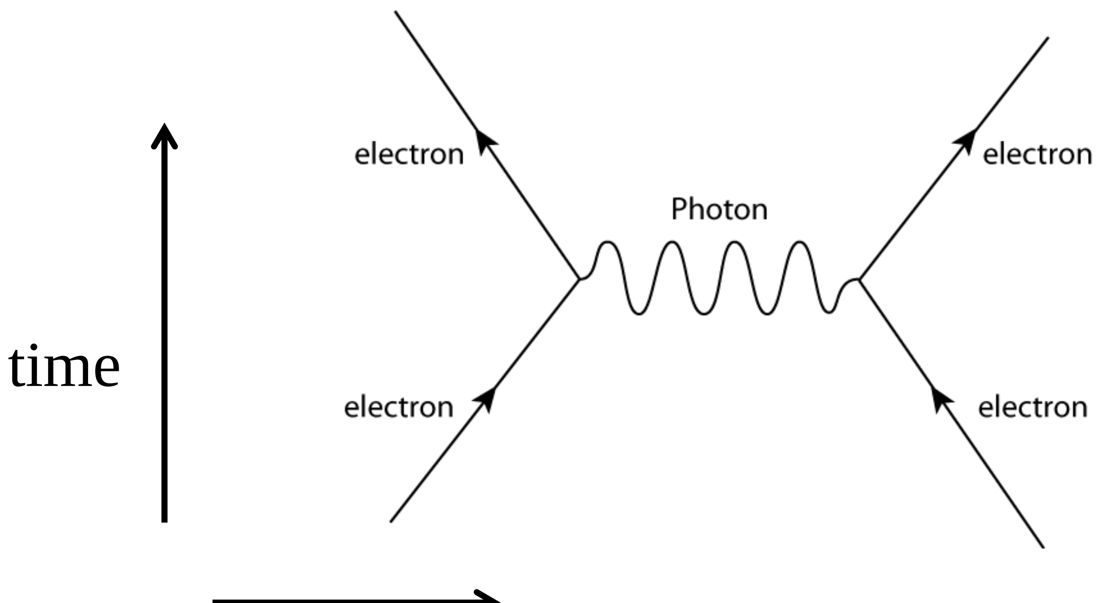


This explains why the electric force has the form it does. The strength of the force is related to the probability of being hit by a photon. That decreases as the square of the distance.

Feynman Diagrams

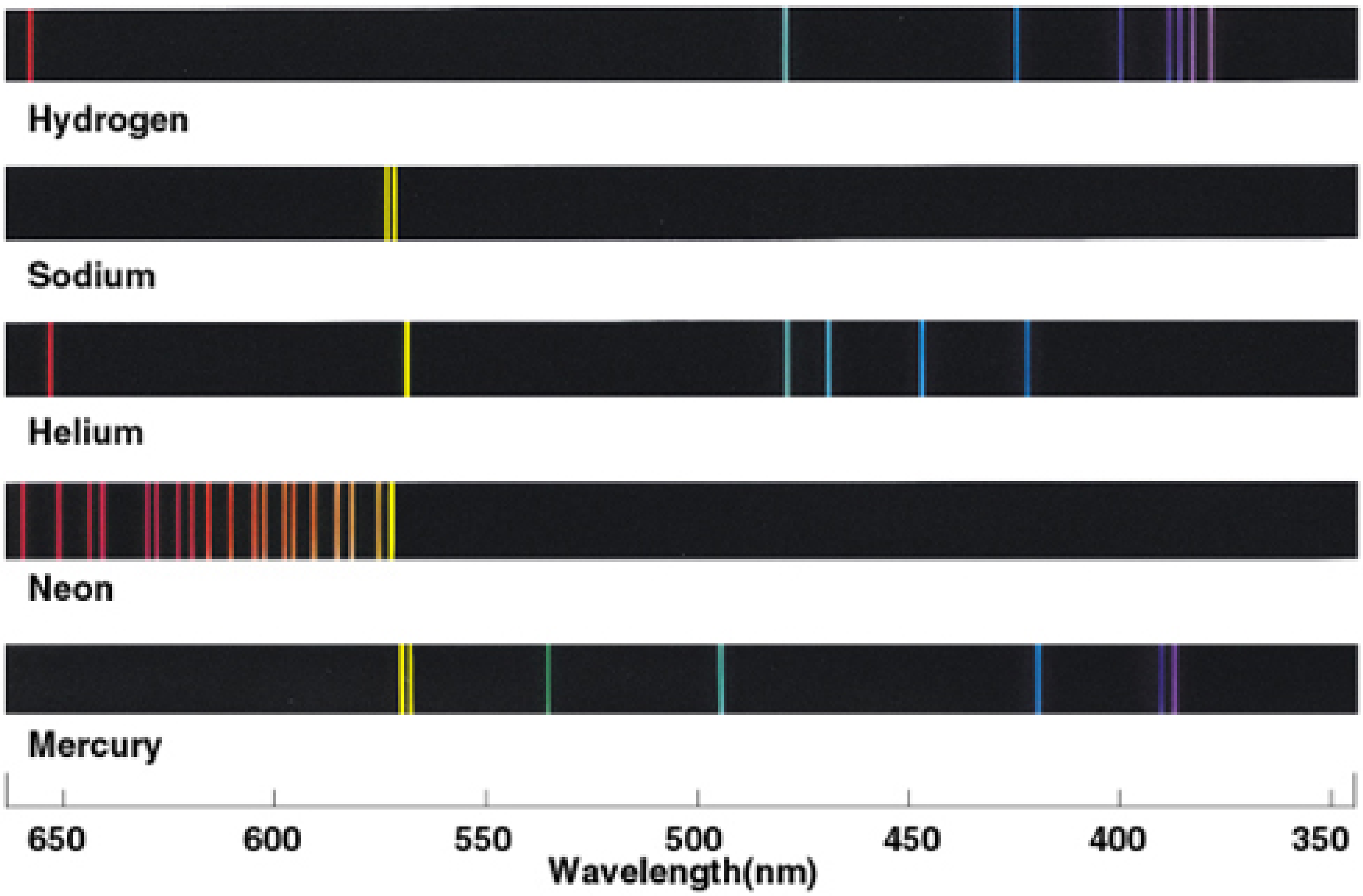
Feynman Diagrams are a pictorial way of writing the interaction between two particles.

Example: Two electrons interacting by the Coulomb force



A line that begins and ends in a diagram corresponds to a “virtual particle”. Others are “real” particles.

How do we know about photons? Atomic Spectra



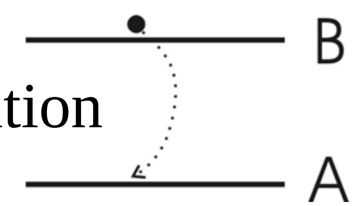
Atoms and molecules exists fixed states of energy

Excited state

3.0 eV

Emission

Transition



Absorption

0 eV

Ground state

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

If the electron is completely removed, this is called ionization.

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?

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

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

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 wave function extends over all space.
- 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.

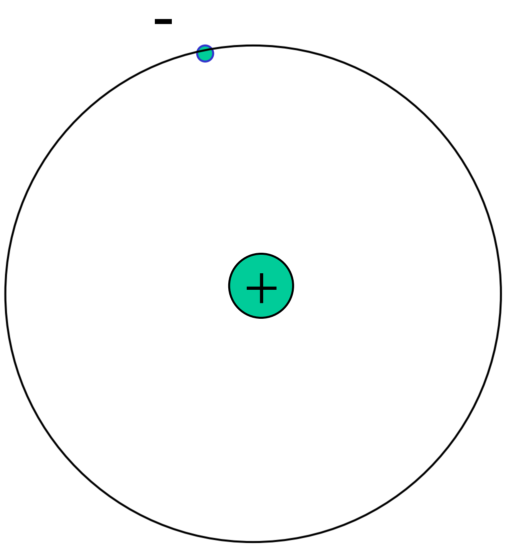
$$H\Psi = E\Psi \quad \Psi \to \text{wave function}$$

Bosons and Fermions

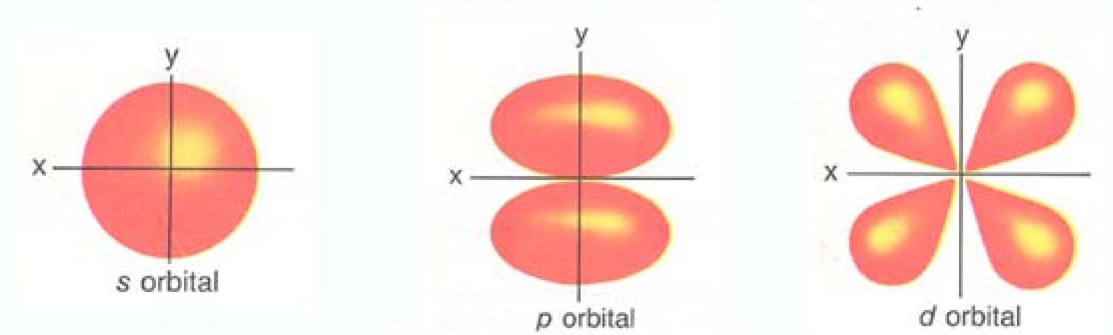
- Particles come in two types
- Bosons have the property that they can overlap. Examples are photons and certain atoms (helium)
- Fermions can not exist in the same state. Examples – electrons, protons.
- The fermion nature of elections explains atomic structure

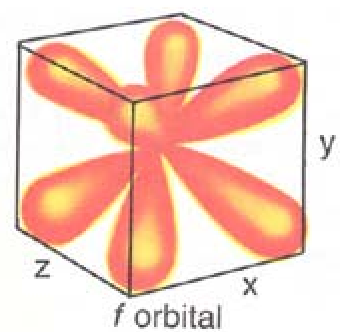
Electron Wave functions in atoms

Old picture



New Picture: *Orbitals*





Examples of wave functions

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

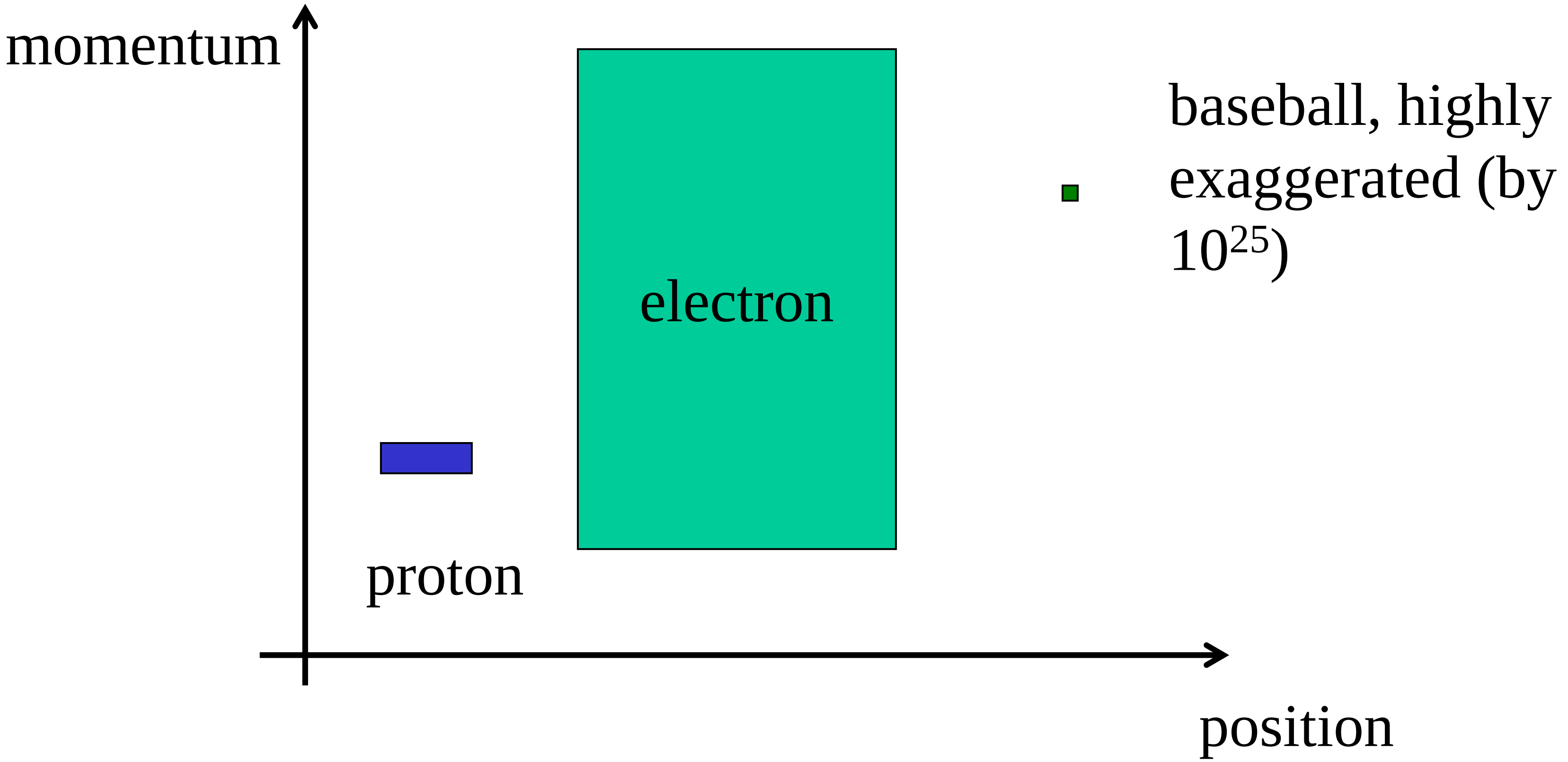
Heisenberg's Uncertainty Principle

- 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.

Uncertainty depends on mass



Sample Problem

There are two versions

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

If the position of a proton, mass 1.67E-27 kg, is known to 1E-9 m the momentum and velocity could have a range of

$$\Delta p \geq \frac{h}{4\pi\Delta x} = \frac{6.625 \cdot 10^{-34}\,Js}{4\pi 1.00 \cdot 10^{-9}\,m} = 5.27 \cdot 10^{-26}\,kg \cdot m/s$$

$$\Delta p = m\Delta \mathrm{v} = 5.27 \cdot 10^{-26}\,kg \cdot m/s$$

$$\Delta \mathrm{v} = \frac{5.27 \cdot 10^{-26}\,kg \cdot m/s}{1.67 \cdot 10^{-27}\,kg} = 31.6\,m/s$$

Summary

- Nature is governed by the rules of probability. No one can predict the exact outcome of a measurement.
- **All knowledge is imperfect.** There is no absolute knowledge of the position and velocity of objects.