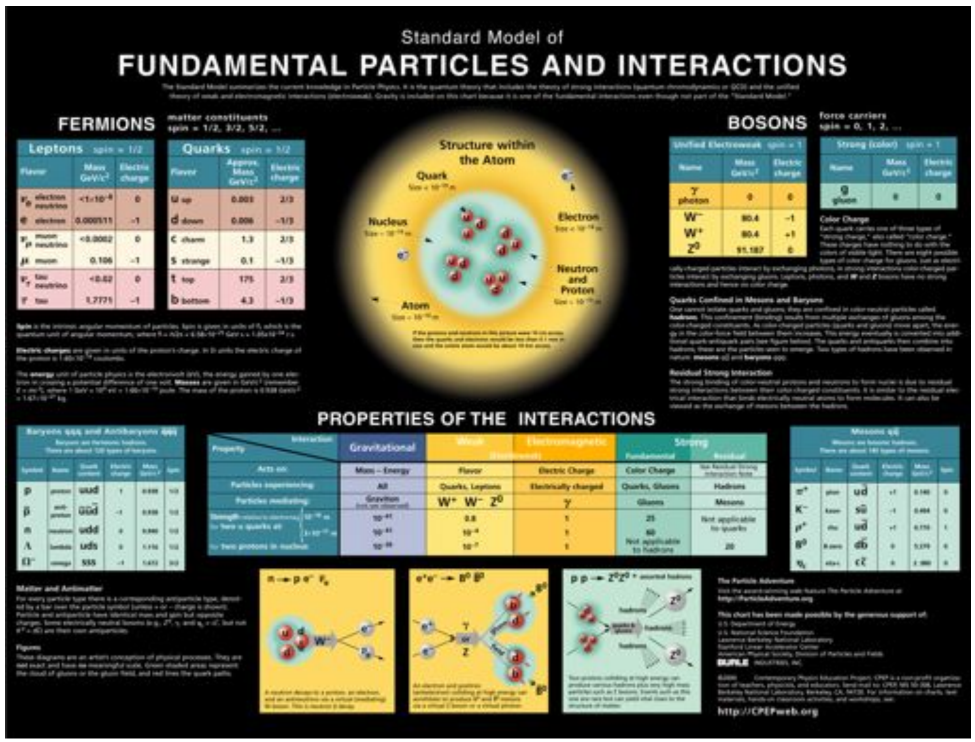
Atomic Theory

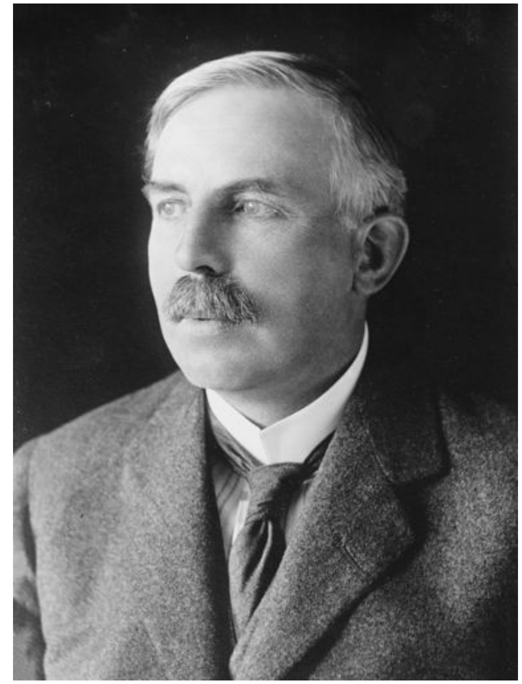
A Quick Overview . . .



. . . Well, maybe not so quick.

Ernest Rutherford

- Radiation and half-lives
- Geiger counter
- Gold foil experiment and the nucleus



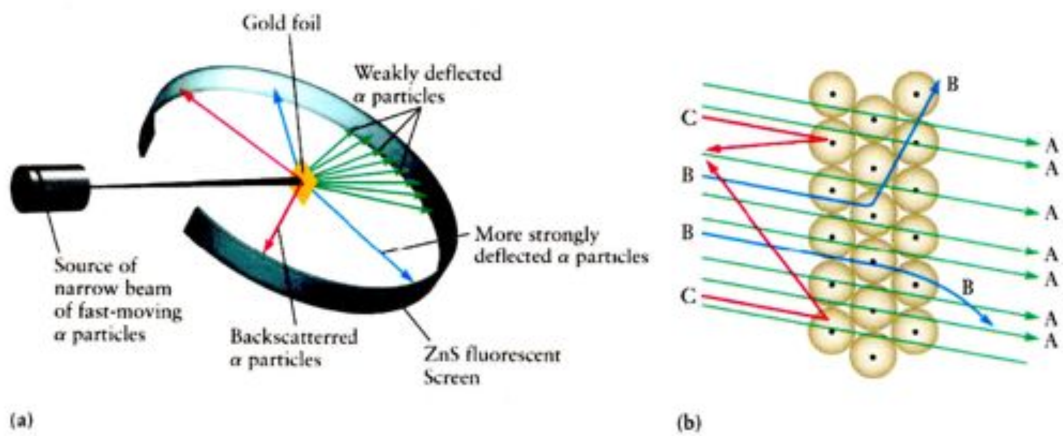


FIGURE 1.10 (a) Flashes of light mark the arrival of alpha particles at the detector screen. In the Rutherford experiment, the rate of hits on the screen varied from about 20 per minute at high angles to nearly 132,000 per minute at low angles. (b) Interpretation of the Rutherford experiment. Most of the alpha particles pass through the space between nuclei and undergo only small deflections (A). A few pass close to a nucleus and are more strongly deflected (B). Some are even scattered backward (C). The nucleus is far smaller proportionately than the dots suggest. (1911)

Robert Millikan

- Worked with Harvey Fletcher
- Oil-drop experiment determined the charge of a single electron

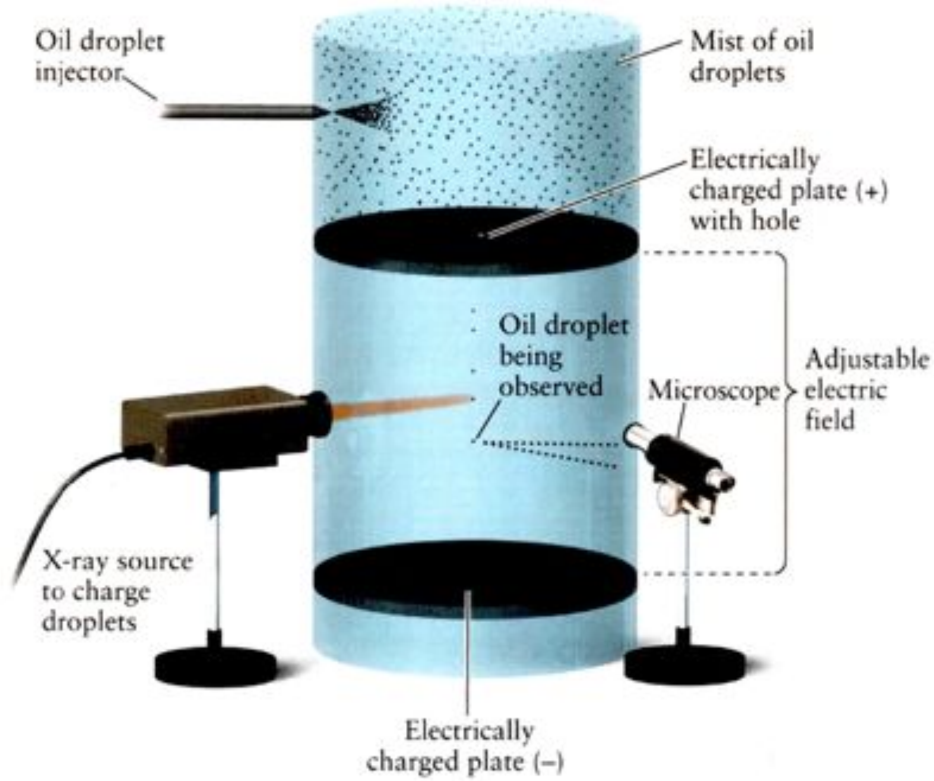


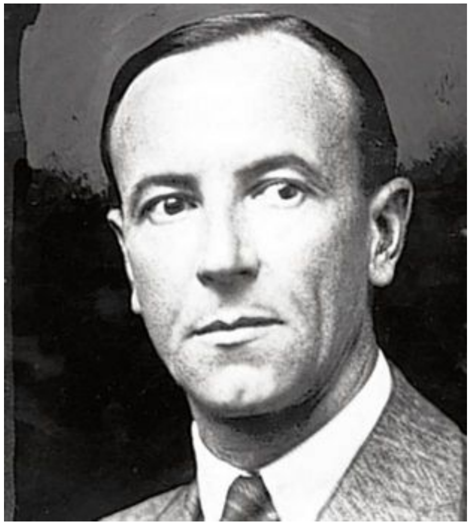
FIGURE 1.9 Millikan's apparatus to measure the charge on an electron, e. By adjusting the electric field strength between the charged plates, Millikan could halt the fall of negatively charged oil drops and determine their net charge. (1906)

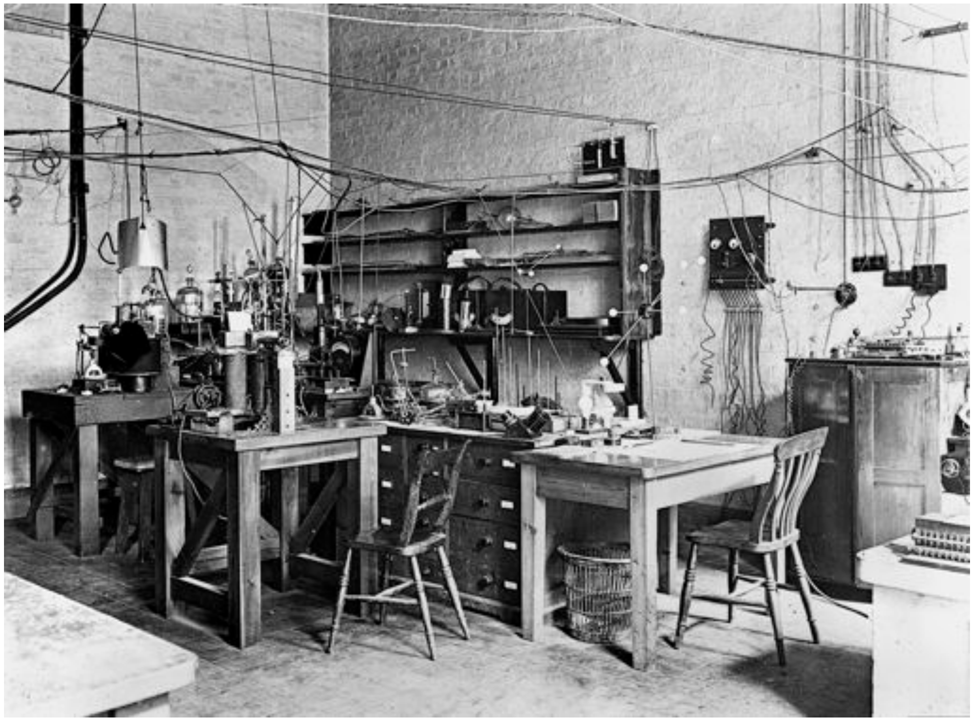
Millikan determined that the charge on an electron, e^-, is 1.60×10^{-19} C. Combined with Thomson's result for the e/m_e ratio of 1.76×10^{11} C/kg, the mass of an electron, m_e, is thus 9.11×10^{-31} kg

Actual Apparatus

James Chadwick

- Confirmed the neutron.
- Worked with Rutherford.
- Bombarded Beryllium with alpha particles.
- Trapped neutrons in paraffin wax





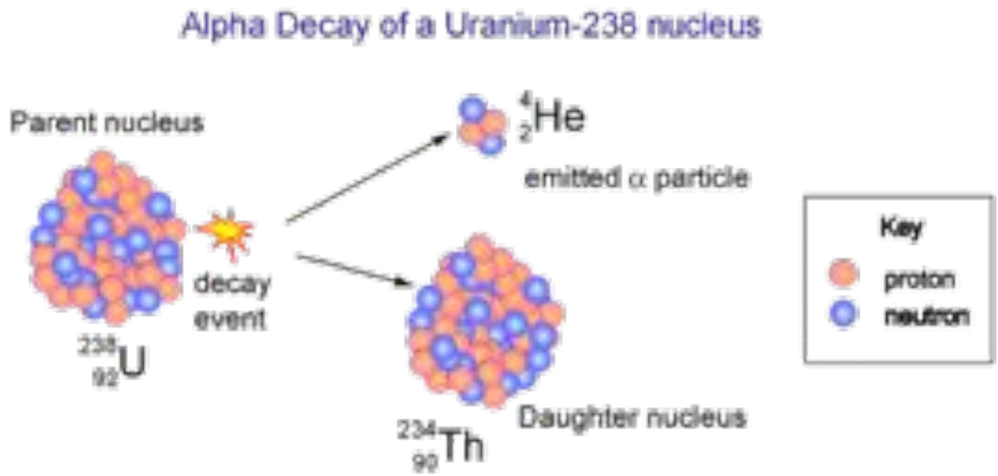
Types of Radiation

- Alpha particles: 2 n^0 and 2 p^+ (Helium nucleus)
- Beta particles: Free e^-
- Gamma radiation: very short wavelength EM radiation (size of nucleus)

α β γ

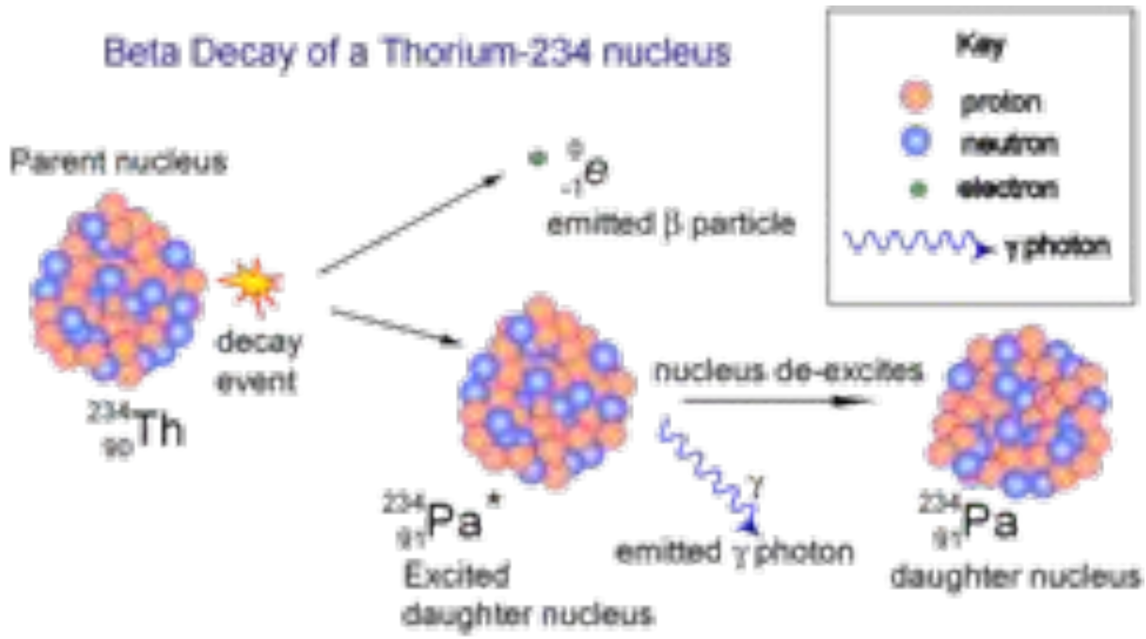
Alpha Decay

- Atom loses four AMUs (Atomic Mass Units) including two protons, so it drops down two spaces in the periodic table.
- Ex: Uranium 238 becomes Thorium 234 and produces one alpha particle.

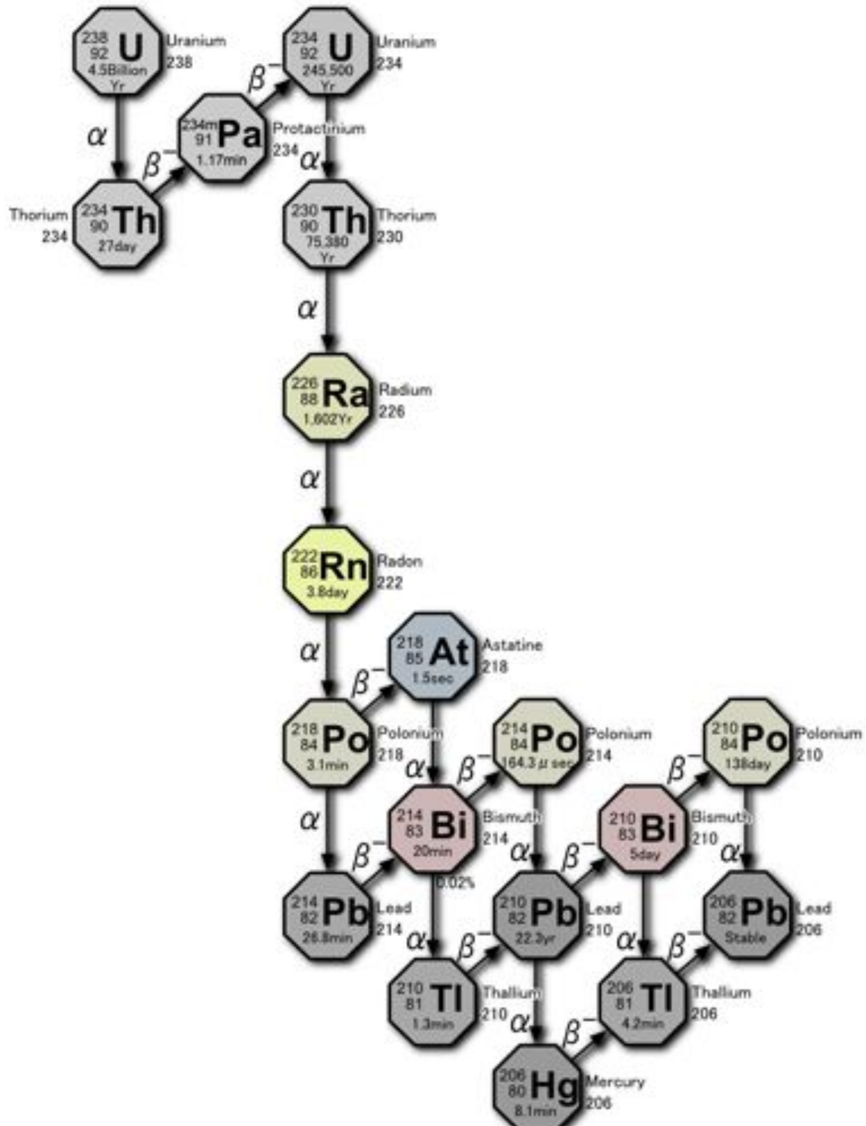


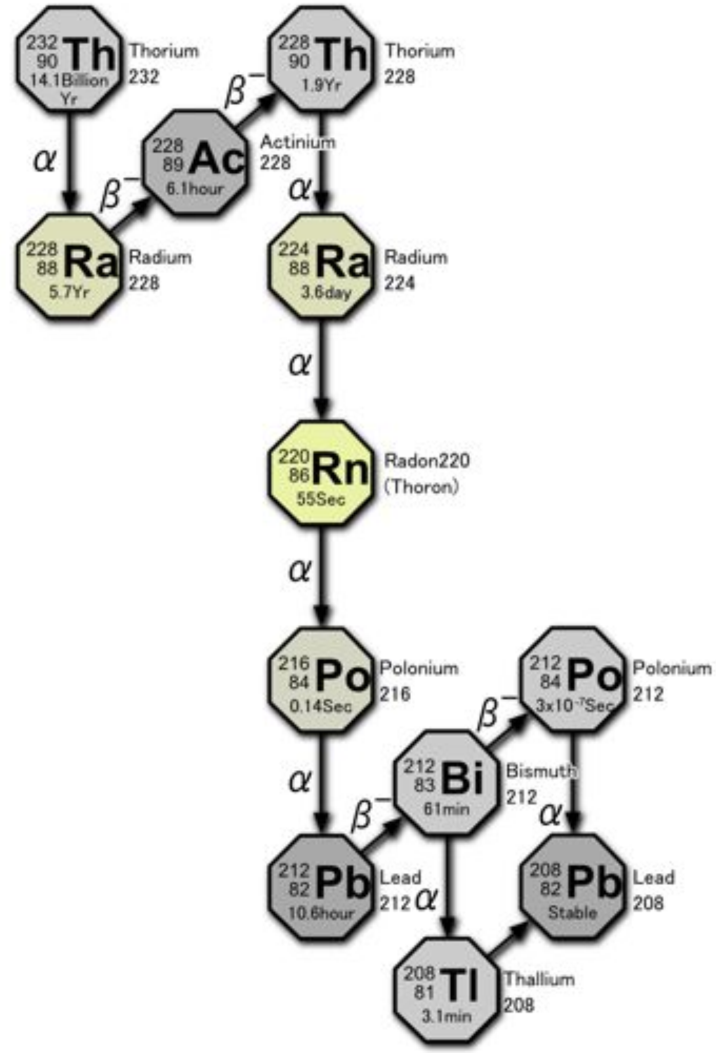
Beta Decay

- Mediated by the Weak Nuclear Force (see below). A neutron will spontaneously decay (with a W- boson) into a proton, a beta particle, an anti-electron neutrino, and gamma radiation energy.
- There are the same AMUs as before, but one more proton, so it increases one element in the periodic table.
- These decays are truly transmutation of the elements.



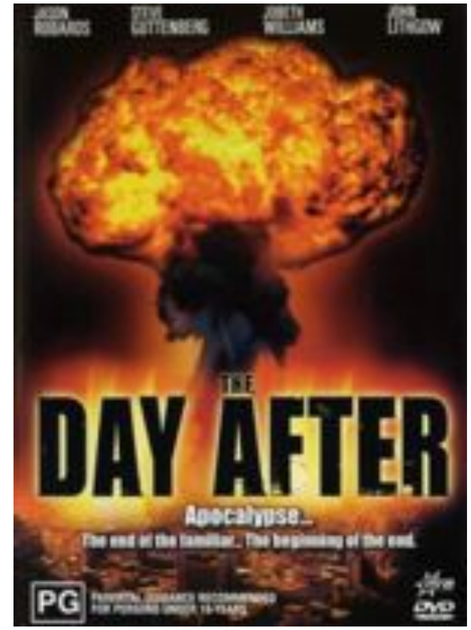
Decay Chains

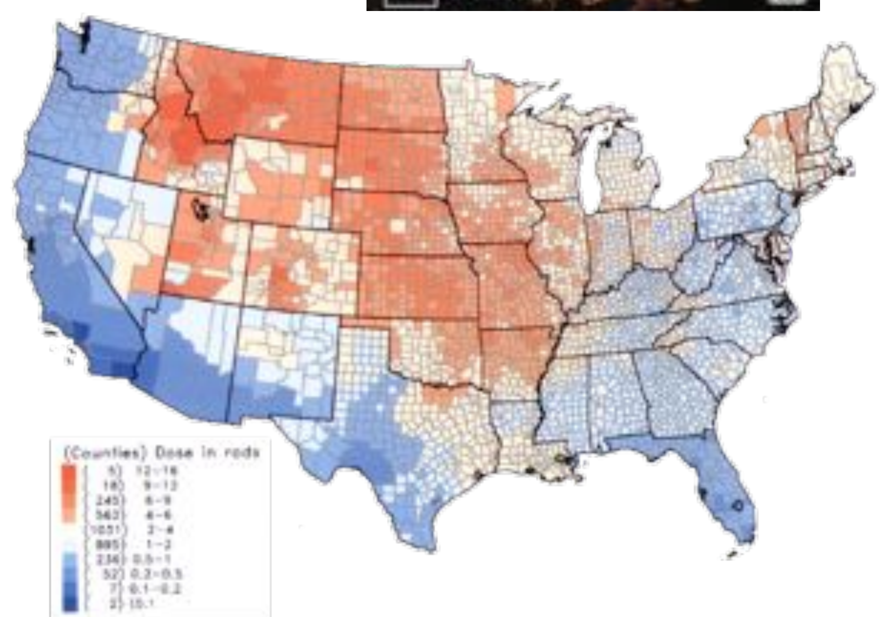




Gamma Radiation

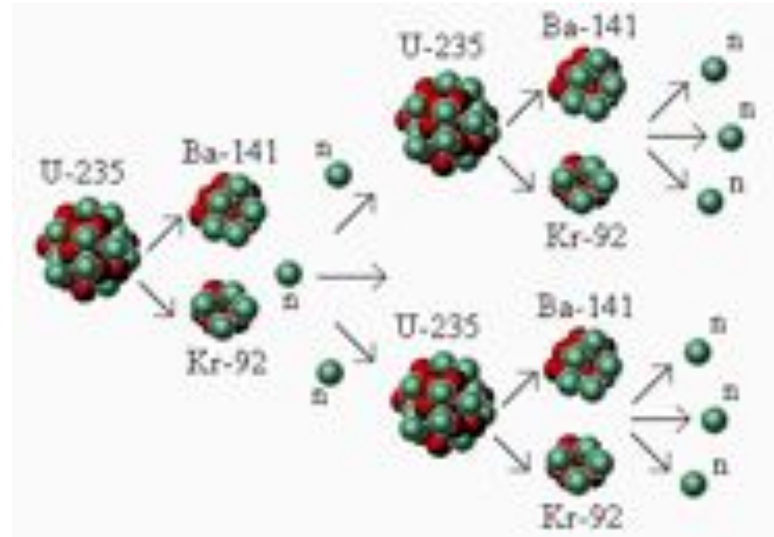
- Very short wavelength, so very high energy.
- Able to penetrate skin and bones.
- High levels will “cook” you internally.
- Lower levels will ionize your DNA and lead to cancers and mutations.
- Radioactive fallout (dust) can get in your lungs and kill you.
- “The Day After” – a grim, realistic view of the aftermath of nuclear war.
- I am a Downwinder.

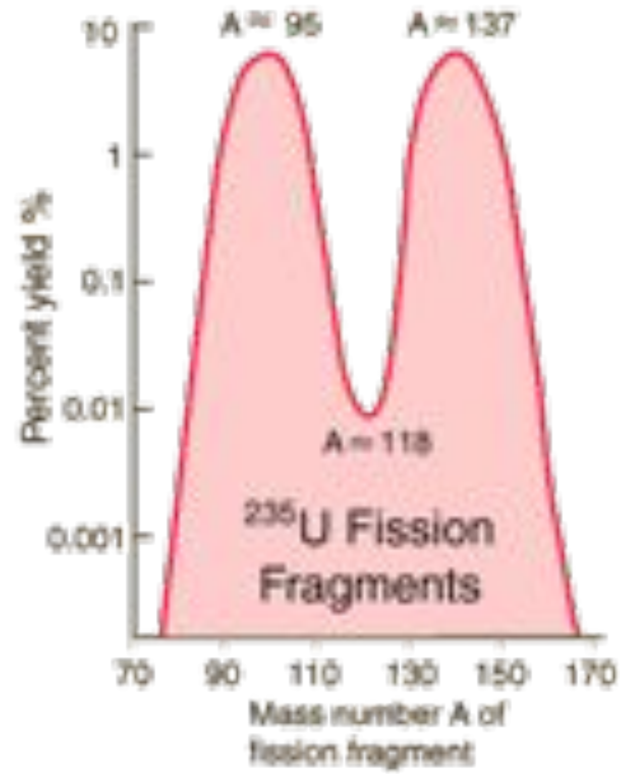




Nuclear Fission

- Fission means to split large atoms to produce smaller fragments and energy.
- Usually initiated by free neutrons.
- U-235 splits into Kr-92 and Ba-141 (or nearby isotopes).
- Chain reaction – one neutron leads to three which lead to nine, etc.
- Great amounts of energy released.

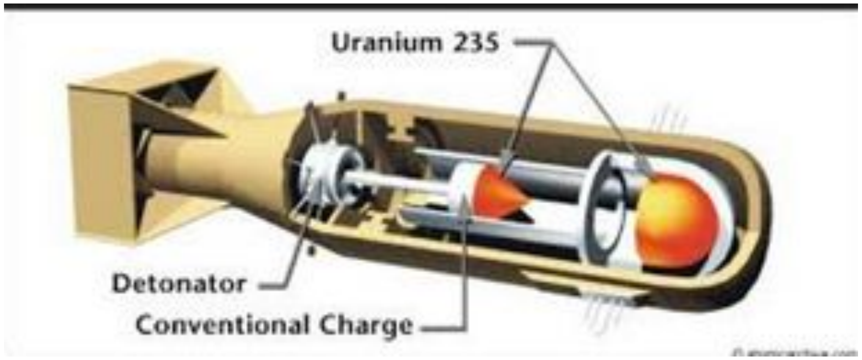




The Atom Bomb

- The Manhattan Project developed during WWII after Einstein and Szilard wrote a letter to Pres. Roosevelt.
- First nuclear reactor in Chicago by Fermi.
- Enriched U-235 and Plutonium at Oak Ridge, TN and Hanford, WA.
- Research and construction at Los Alamos, NM.
- Trinity test near Alamagordo, NM.

Fat Man and Little Boy



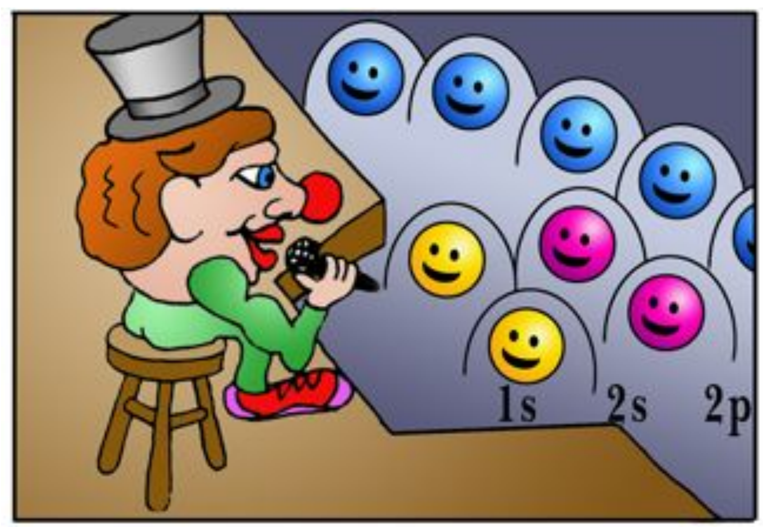
- Little Boy was a “gun” of two sub-critical masses of U-235. Slammed together, they reach critical mass.
- Fat Man was a plutonium core surrounded by shaped conventional explosives. Core implodes and reaches critical mass.
- Little Boy dropped on Hiroshima.
- Fat Man on Nagasaki.
- Above-ground testing until 1964 in Nevada.

Nuclear Fusion

- Light elements are fused (combined) to make heavier elements and release energy.
- Natural process in stars: nucleosynthesis.
- Hydrogen bombs use atom bomb as trigger to implode tritium (H-3).

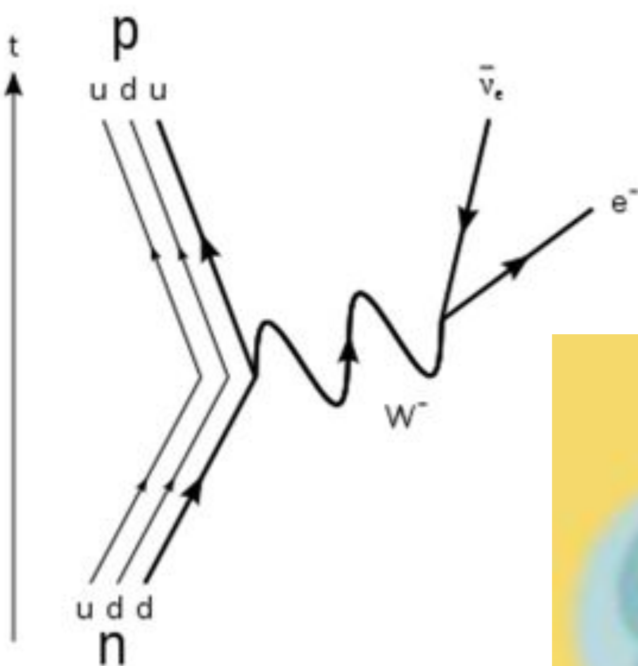
Bosons

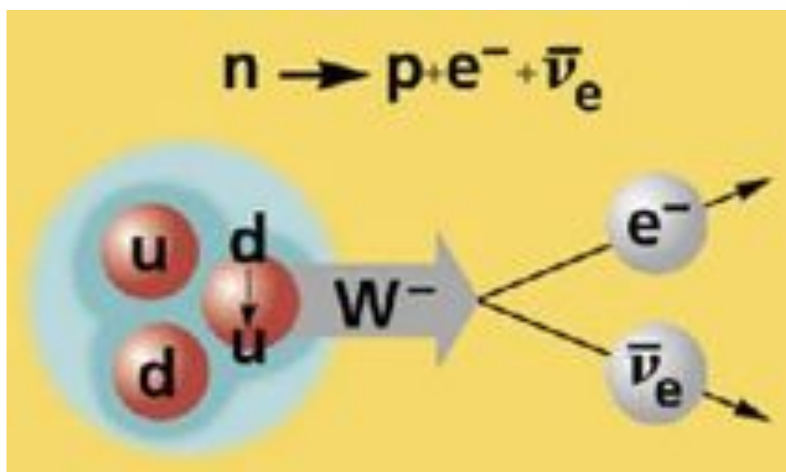
- Virtual particles that transmit forces and interact with massive particles.
- Four forces, each with bosons:
  1- Electromagnetism: carried by photons
  2- Weak nuclear force: keeps neutrons stable, beta decays. W^-, W^+, Z^0
  3- Strong nuclear force: holds hadrons together (protons, neutrons), holds nucleus together. Carried by gluons
  4- Gravity: Carried by gravitons (??)

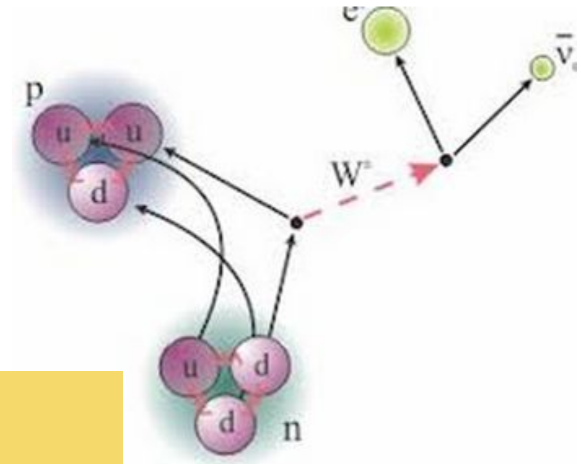


Feynman Diagrams

- Named for Richard Feynman, who first created them to explain interactions.







Particle Accelerators

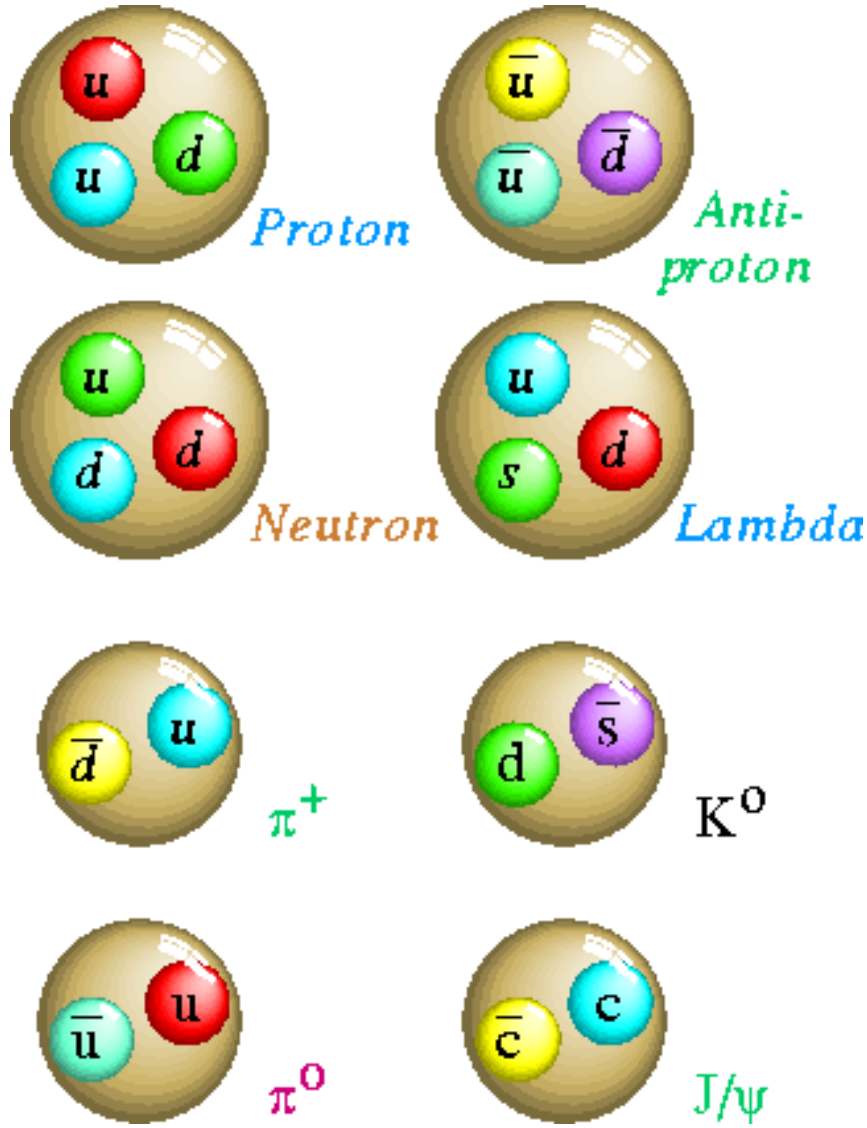
- “Atom smashers” – work by smashing subatomic particles into an atom or each other.
- Now use matter-antimatter collisions.
- SLAC: Stanford Linear Accelerator Center in Palo Alto
- Large Hadron Collider at CERN.
- Have discovered a whole zoo of particles.

Antimatter

- Mirror image particles with opposite charge.
- Electrons and positrons.
- Protons and antiprotons.
- Neutrons have no antimatter particle.
- Neutrinos and antineutrinos.
- Star Trek “warp drive” created by matter/anti-matter reactions.

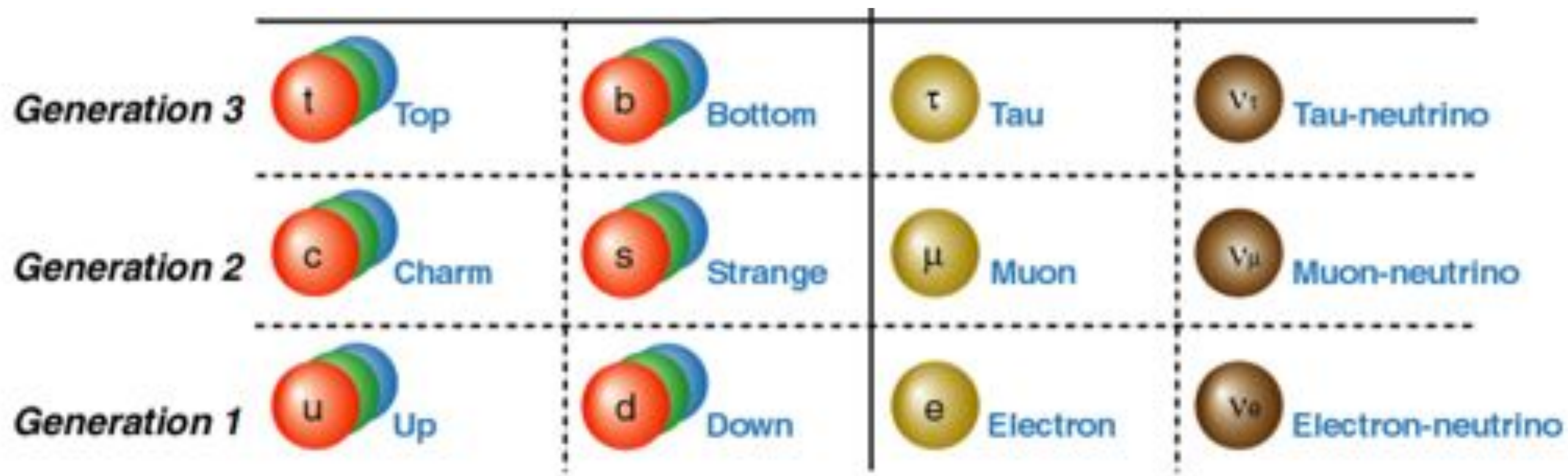
Quarks

- Murray Gell-Mann developed idea that all these particles can be explained by other, more fundamental quarks.
- Come in six flavors (up, down, charmed, strange, top, bottom) and two charges: +2/3 and -1/3.
- Protons have two up and one down. Neutrons have one up and two down.
- Muons have a quark and an anti-quark.



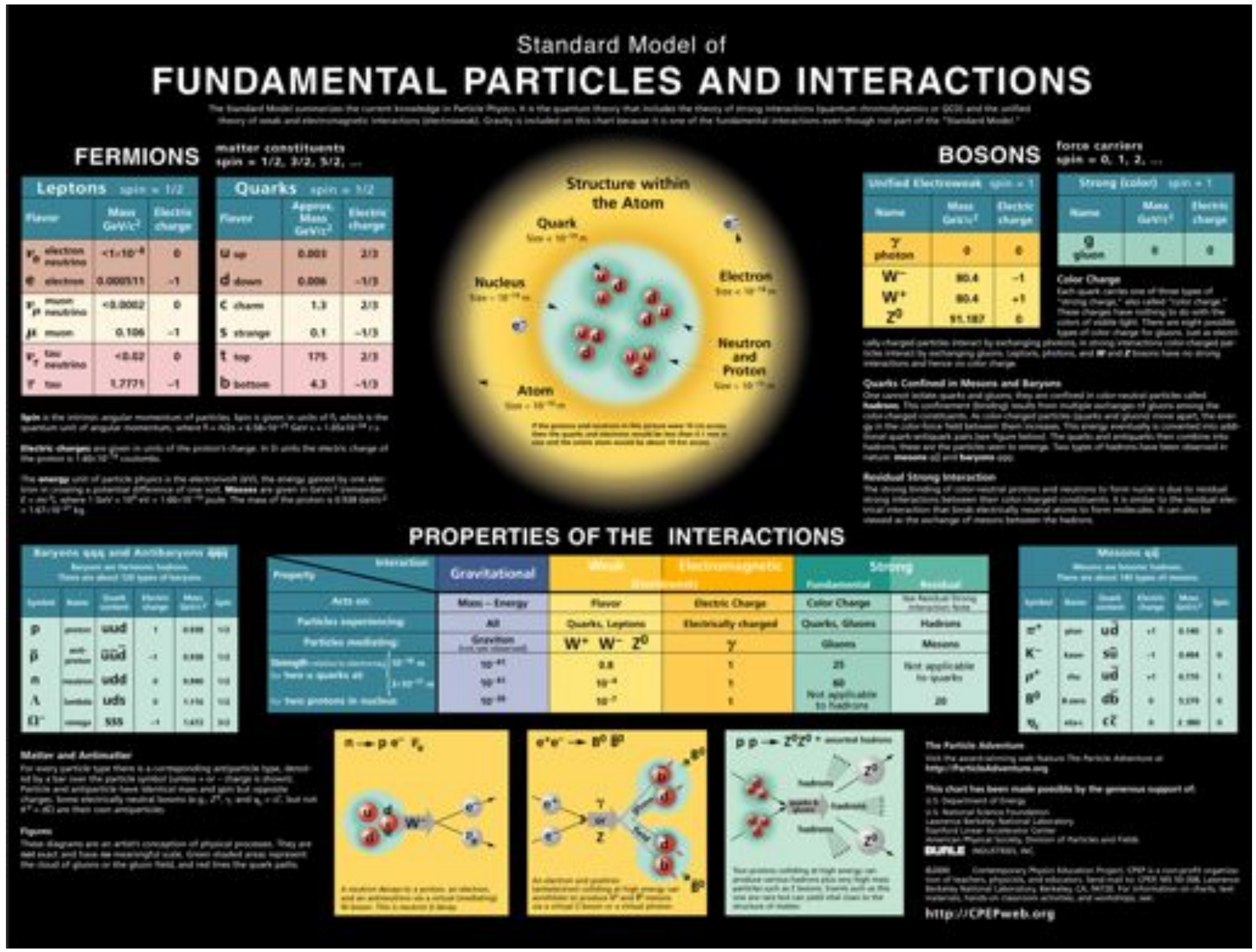
Leptons

- Six more flavors: electron, electron neutrino, muon, muon neutrino, tau, tau neutrino.
- They are fundamental.
- The six quarks and six leptons with various bosons and interactions make up the fundamental particles and forces we now call the Standard Model.



The Standard Model

- Quarks make up hadrons.
- Leptons and hadrons are grouped into fermions, combine as atoms.



Unified Theories

- Faraday discovered magnetic induction – that a magnetic field can produce an electric current and vice versa.
- Maxwell discovered they are both part of one electro-magnetic force.

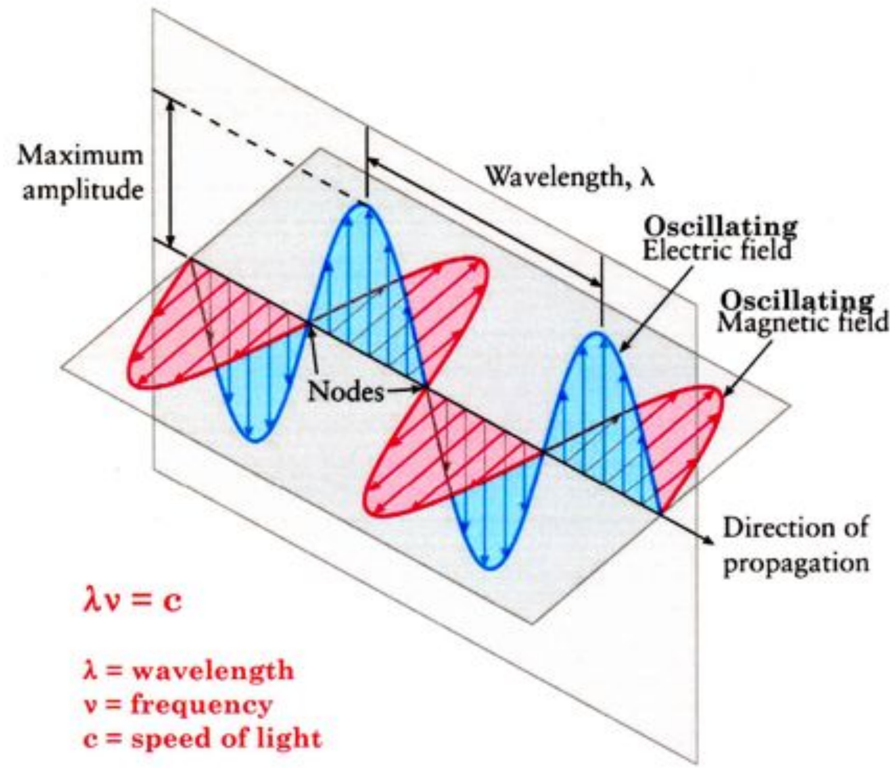


FIGURE 4.2 Light consists of waves of oscillating electric and magnetic fields that are perpendicular to each other and to the direction of propagation of the light.

Modern Theories

- The EM and weak forces combine at higher energy levels (electro-weak force).
- Super-symmetry: the strong force also combines at even higher energies.
- Quantum gravity proposes that gravity would also combine at extremely high energies, such as $< 10^{-37}$ sec ABB (Planck time).

Remaining Questions

- Quest for the graviton/gravity waves.
- No good quantum gravity or super-unified theory yet.
- What is dark matter?
- What is dark energy? Is it a fifth force?
- Are quarks and leptons really fundamental? Could there be strings or branes?
- The nature of mass: the Higgs Boson.