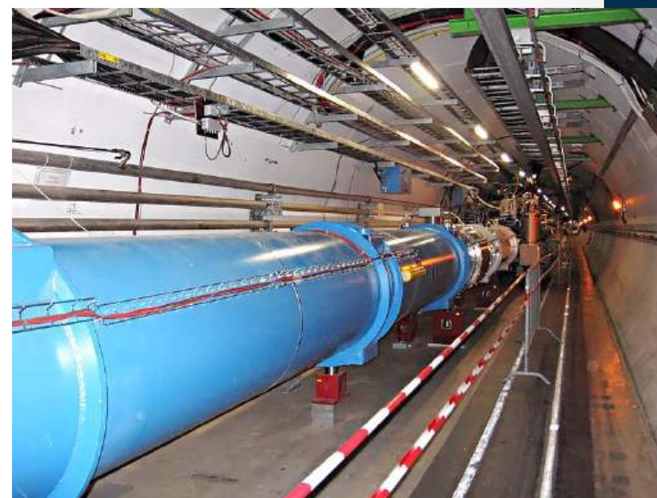
Particle Physics Summary

- Begin with the Standard Model
  - Know the different properties of fundamental particles
- What quantities are conserved?
  - Charge, spin angular momentum
  - Lepton number
  - Baryon number
- Weak interactions
  - Interacts with fermions
  - Mediates particle decay
  - Quarks can change flavor
- Interactions between particles and matter
- Other topics:
  - Additional symmetries: Parity, Charge-parity
  - Zoo of subatomic mesons and baryons
  - Interaction cross sections

Some Experimental Context

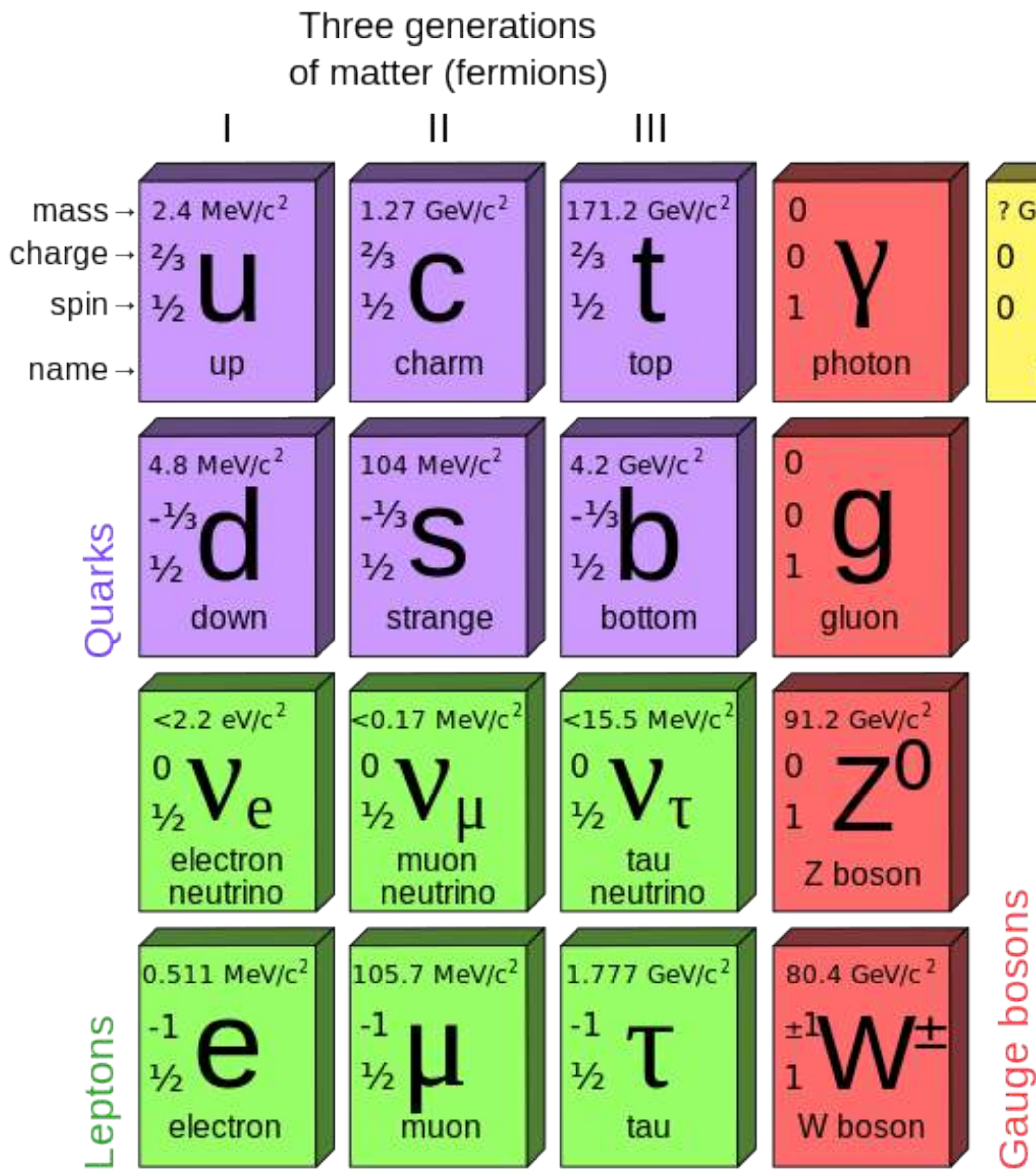
- Where do “particles” come from?
  - Radioactive decay (n, e^+, etc)
  - The environment, such as products from Cosmic Rays (muons, etc)
  - Accelerators, such as the LHC (quarks, etc)
- How do we “see” them?
  - Cloud chambers
  - Bubble chambers
  - Scintillators
- How do we measure their properties?
  - Interactions with matter
  - Indirectly through decay products



http://en.wikipedia.org/wiki/File:CERN_LHC_Tunnel1.jpg

http://en.wikipedia.org/wiki/Cloud_chamber

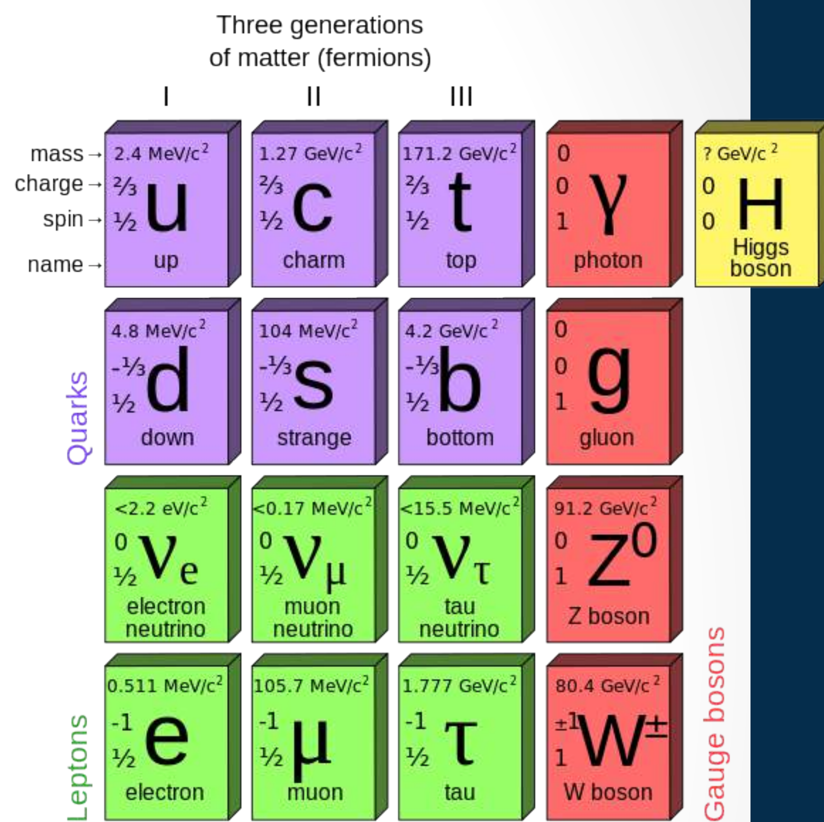
The Standard Model



http://en.wikipedia.org/wiki/File:Standard_Model_of_Elementary_Particles.svg

The Standard Model

- All elementary, non-composite particles that we know of (so far)
- Quarks
  - 6 flavors
  - Fractional charge
  - Fermions
  - Up/Down make up protons, neutrons
- Leptons
  - 3 flavors
  - Fermions
  - Electrons and heavier electrons
  - Neutrinos, chargeless and (practically) massless
- Force Carriers
  - Bosons
  - Photons – carry Electromagnetic Force
  - Gluons – carry Strong Nuclear Force
  - W/Z – carry Weak Nuclear Force
- (Probably don't need Higgs physics for test)



63. According to the Standard Model of elementary particles, which of the following is NOT a composite object?

(A) Muon
(B) Pi-meson
(C) Neutron
(D) Deuteron
(E) Alpha particle

Conserved Quantities

- Most particle physics GRE questions deal with nuclear reactions and other types of decay processes
- Typically, reactions obey **conservation laws**
- What you probably already know:
  - Momentum and Energy
  - Charge
  - Angular momentum (spin)
- New concepts from particle physics:
  - Lepton Number
  - Baryon Number
  - Other quantities violated in Weak interactions only:
    - Strangeness
    - Parity
    - Charge-Parity

Lepton Number

- 3 flavors of lepton (electron, muon, tauon)
  - Note: each electron-like particle has a corresponding neutrino with the same flavor, eg muon and muon neutrino
- The number of particles belonging to each flavor of lepton is conserved
- **NB**: anti-particles contribute *negative* lepton number
  - Example: anti-electrons (e^+) have electron number -1

98. Which of the following is the principal decay mode of the positive muon μ^+ ?

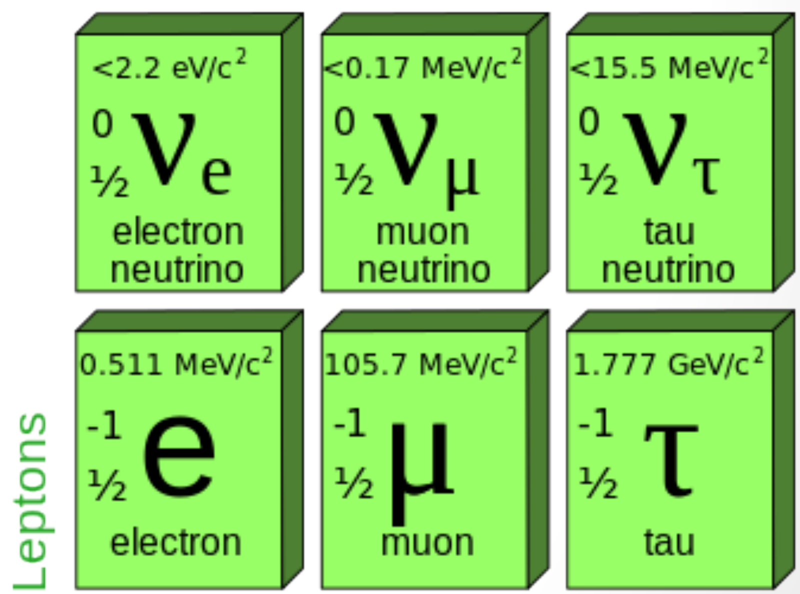
(A) $\mu^+ \rightarrow e^+ + \nu_e$

(B) $\mu^+ \rightarrow p + \nu_\mu$

(C) $\mu^+ \rightarrow n + e^+ + \nu_e$

(D) $\mu^+ \rightarrow e^+ + \nu_e + \overline{\nu}_\mu$

(E) $\mu^+ \rightarrow \pi^+ + \overline{\nu}_e + \nu_\mu$



Lepton Number Example

- Need to conserve charge (doesn't eliminate any results)
- Need to conserve muon number and electron number:
  - (A) -1 mu -> -1 e + 1 e
  - (B) -1 mu -> proton? + 1 mu
  - (C) -1 mu -> neutron? -1 e + 1 e
  - (D) -1 mu -> -1 e + 1 e -1 mu
  - (E) -1 mu -> pion? - 1 e + 1 mu

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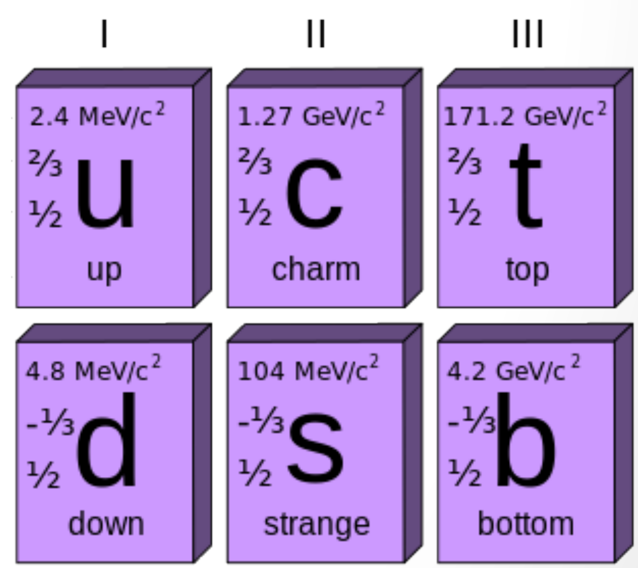
- Additional example:

78. The muon decays with a characteristic lifetime of about 10^{-6} second into an electron, a muon neutrino, and an electron antineutrino. The muon is forbidden from decaying into an electron and just a single neutrino by the law of conservation of

(A) charge
(B) mass
(C) energy and momentum
(D) baryon number
(E) lepton number

Baryons

- Composite particles made up of **3 quarks**
- Examples:
  - Proton = 2 up + 1 down
  - Neutron = 2 down + 1 up
  - Most matter consists of baryons
- All baryons are **fermions**
- Baryon number = (number of quarks – number of antiquarks)/3
  - So protons and neutrons have B = +1
  - Anti-protons have B = -1
- Other (more exotic examples)
  - Δ (3 up/down quarks)
  - Λ, Σ (2 up/down quarks)
  - Ξ (1 up/down quark)
  - Ω (0 up/down quarks)



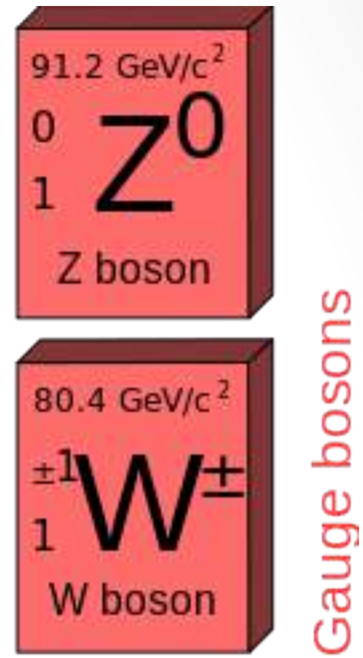
… as opposed to Mesons

- Composite particles made up of one quark and one antiquark
  - These particles appear as decay products (for example from cosmic rays)
- Examples:
  - Pions: π^+ π^- π^0, consist of up/down quarks
  - Kaons: K^+ K^- K^0 , consist of one up/down quark, one strange quark
- Baryon number is 0
- (Side note: Older literature may refer to muons as mesons, though now we know they are leptons.)

The Weak Interaction

- Interacts with all fermions
- Mediated by Z, W^+, W^- bosons
- Responsible for all decay of subatomic particles
  - Produces a whole zoo of possible interactions
- Certain symmetries are violated by Weak Interactions:
  - **Quarks change flavor**
  - Parity (also charge-parity)
- Example: Beta decay
  - Nuclear scale: n-> p^+ + e^- - ν_e
  - Sub-nuclear (quark) scale:

    d-> u + e^- - ν_e



$$^{13}\text{N} \rightarrow {}^{13}\text{C} + e^+ + \nu_e$$

63. The nuclear decay above is an example of a process induced by the

(A) Mössbauer effect
(B) Casimir effect
(C) photoelectric effect
(D) weak interaction
(E) strong interaction

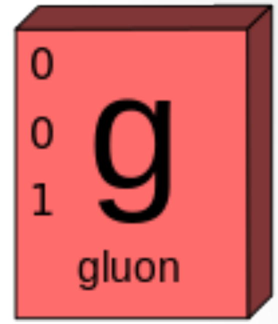
Weak Interaction Example

91. The particle decay $\Lambda \rightarrow p + \pi^-$ must be a weak interaction because

(A) the π^- is a lepton
(B) the Λ has spin zero
(C) no neutrino is produced in the decay
(D) it does not conserve angular momentum
(E) it does not conserve strangeness

- (A) Pions are mesons, not leptons
- (B) Weak interactions only affect fermions (Λ and p have spin ½)
- (C) Only need neutrinos to conserve lepton number, not necessary for every weak interaction
- (D) Looks like angular momentum *is* conserved
- (E) Strangeness counts number of strange quarks. Since quarks can change flavor under weak interactions, this could be right

Strong Interaction



- Responsible for holding quarks together
  - Hadrons: includes mesons and baryons
- Mediated by gluons
- "Massive photons" follow the Yukawa potential

$$V(r) \propto \frac{e^{-kr}}{r}$$

- (Same as charge-screened potential for electrons in matter)

How do particles interact with matter?

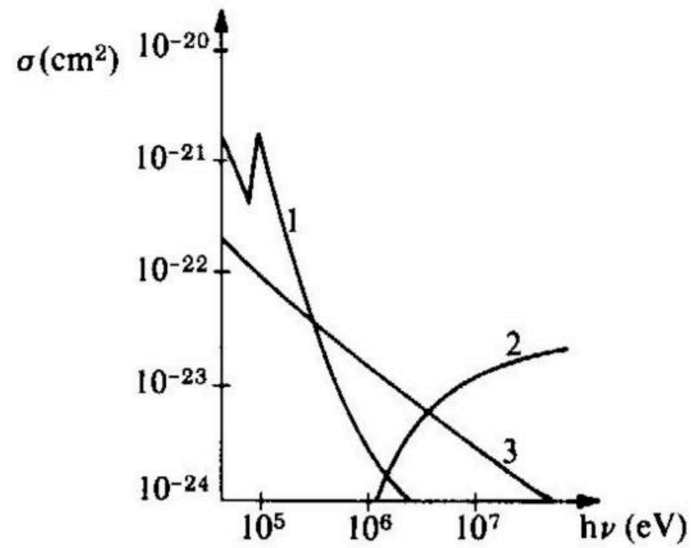
- Treat the interaction between incident particles and matter probabilistically, with some probability of scattering occurring
  - Probability: Cross sections are measured in units of **area**
- Not totally necessary to memorize rules for cross sections, but can list some rules of thumb that build on physical intuition
  - *Charged* particles interact with electrons in matter, so the higher Z of the matter, the more likely they are to interact
  - *Lighter* particle mass scatter more easily (less inertia => easier to change momentum)

25. In experiments located deep underground, the two types of cosmic rays that most commonly reach the experimental apparatus are

    (A) alpha particles and neutrons
    (B) protons and electrons
    (C) iron nuclei and carbon nuclei
    (D) muons and neutrinos
    (E) positrons and electrons

How do photons interact with matter?

- Photons primarily interact with atomic electrons
- Three primary processes (which you **need** to know for the test)
  - Compton Scattering
  - Photoelectric effect
  - Pair production
- Important to know:
  - Why does the photoelectric effect only occur with atomic electrons (as opposed to free)?
  - Why can't pair production occur in vacuum?



85. The figure above shows the photon interaction cross sections for lead in the energy range where the Compton, photoelectric, and pair production processes all play a role. What is the correct identification of these cross sections?

(A) 1 = photoelectric, 2 = Compton, 3 = pair production
(B) 1 = photoelectric, 2 = pair production, 3 = Compton
(C) 1 = Compton, 2 = pair production, 3 = photoelectric
(D) 1 = Compton, 2 = photoelectric, 3 = pair production
(E) 1 = pair production, 2 = photoelectric, 3 = Compton