Subatomic Particles

Lesson 10

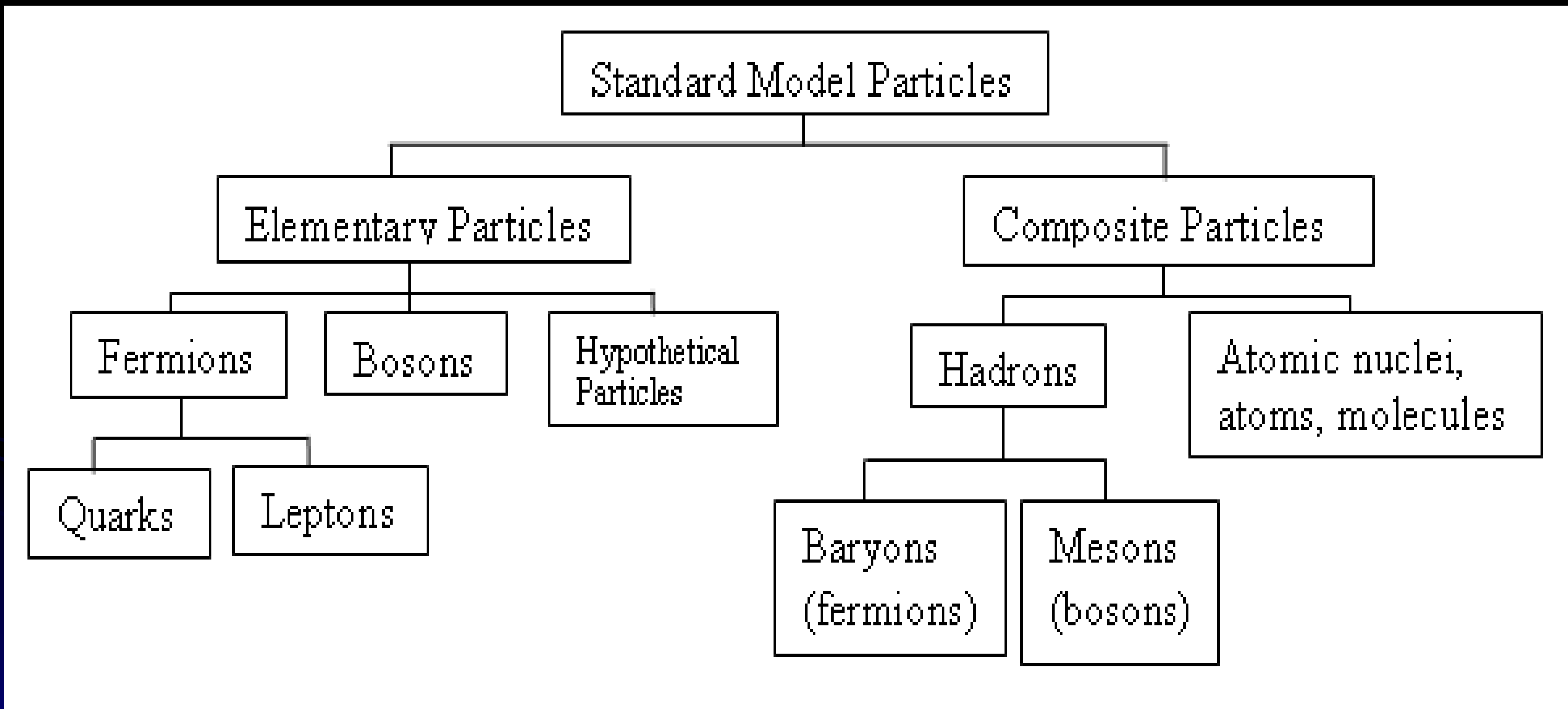
Objectives

- describe the modern model of the proton and neutron as being composed of quarks.
- compare and contrast the up quark, the down quark, the electron and the electron neutrino, and their antiparticles, in terms of charge and energy (mass-energy).
- describe beta-positive ($\beta+$) and beta-negative ($\beta-$) decay, using first-generation elementary fermions and the principle of charge conservation.

Standard Model

- **We know now that there are more than just protons, neutrons, and electrons that make up the atom.**
- **In all, more than 300 sub atomic particles have been discovered.**
- **To make sense of all of these particles, physicists form groups**

Classes of Particles



Descriptions of Particles

- **Elementary Particles:**
  - **particles with no internal structure (ie: are not composed of other particles)**
  - **Classified according to their spin**
    - **Fermions have half-integer spin (1/2)**
    - **Bosons have integer spin (1)**
- **Composite Particles:**
  - **are composed of other particles (can be broken down further)**

Elementary Particles: Bosons

- **These particles are said to mediate the fundamental forces of nature**

Name	Symbol	Antiparticle	Charge (e)	Spin	Mass (GeV/c^2)	Interaction mediated	Existence
Photon	γ	Self	0	1	0	Electromagnetism	Confirmed
W boson	W^-	W^+	− 1	1	80.4	Weak interaction	Confirmed
Z boson	Z	Self	0	1	91.2	Weak interaction	Confirmed
Gluon	g	Self	0	1	0	Strong interaction	Confirmed
Higgs boson	H^-	Self?	0	0	> 112	None	Unconfirmed
Graviton	G	Self	0	2	0	Gravitation	Unconfirmed

Elementary Particles: Fermions

- **These are the smallest known particles**
- **They make up all other types of matter**
- **There are 2 different types:**
  - **Quarks (6 types)**
  - **Leptons (6 types)**

Matter						
Generation	First		Second		Third	
Quarks	up	down	strange	charm	bottom	top
Leptons	electron	electron-neutrino	muon	muon-neutrino	tau	tau-neutrino
Fundamental Forces						
Force	Electromagnetic		Weak Nuclear		Strong Nuclear	
Mediating particle(s)	photon		W^+, W^-, and Z^0		gluon	

Quarks

- Quarks are involved in strong nuclear forces because quarks make up the particles of the nucleus (protons and neutrons).
- In order to obey the Law of Conservation of Charge in nuclear reactions, many of quarks have fractional charges:

Quarks

▼ **Table 17.5** Some Properties of Quarks

Generation	Name	Symbol	Mass (MeV/c^2)	Charge
First	up	u	1.5–4*	$+\frac{2}{3}e$
	down	d	4–8	$-\frac{1}{3}e$
Second	strange	s	80–130	$-\frac{1}{3}e$
	charm	c	$1.15–1.35 \times 10^3$	$+\frac{2}{3}e$
Third	bottom (or beauty)	b	$4.1–4.9 \times 10^3$	$-\frac{1}{3}e$
	top (or truth)	t	$1.7–1.9 \times 10^4$	$+\frac{2}{3}e$

*Some physicists think the up quark may be essentially massless.

Leptons

- The particles outside the nucleus (ie: electron and electron neutrino) are called leptons
- These are much smaller than nucleons
- Together, protons, neutrons and electrons, and electron neutrinos are first generation fermions.
- Other examples of leptons are the muon (μ) and the tauon (τ) particles (as well as their neutrinos)

Quick Review

- **All matter is made up of the 6 quarks and 6 leptons.**
- **Protons and neutrons are made up of quarks**
- **Electrons and neutrinos are leptons**

Composite Particles: Hadrons

- These are particles that interact (display their properties) via forces, most notably the strong nuclear force.
- These particles are made up of smaller particles called quarks and/or anti-quarks.
  - Ex: neutrons, protons
- There are 2 types:
  - Baryons (composite fermions)
  - Mesons (composite bosons)

Hadrons: Mesons

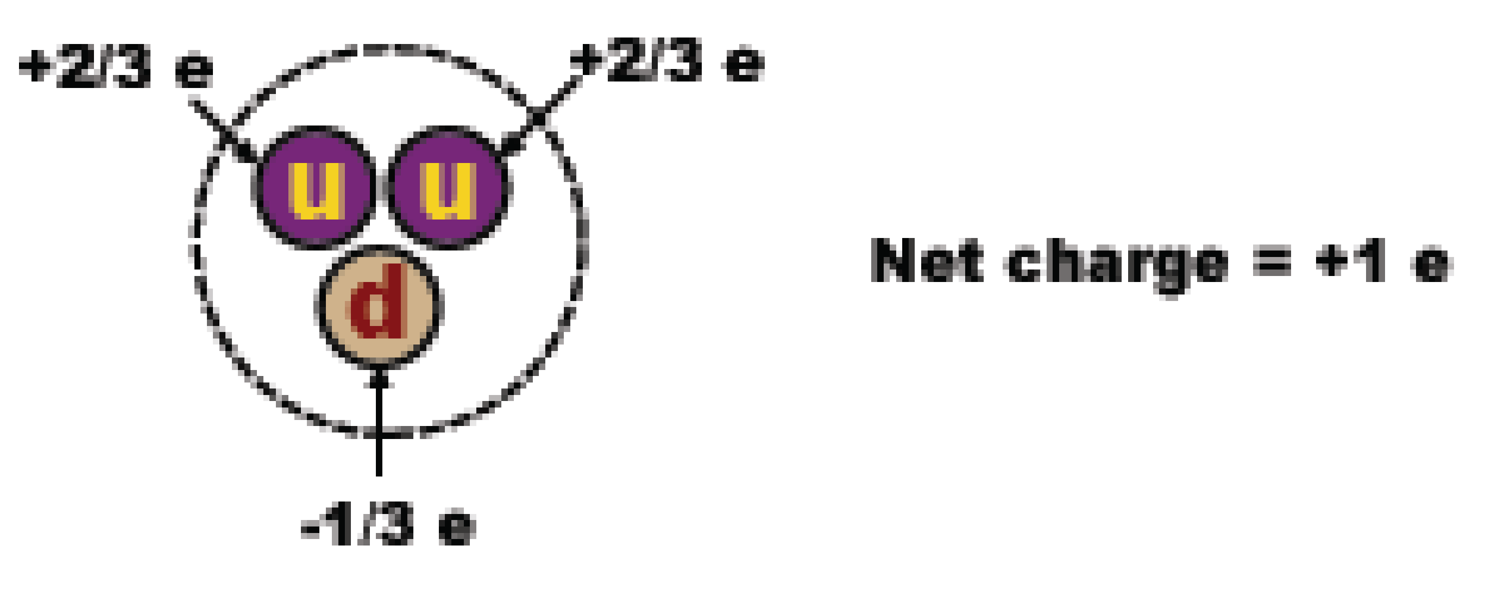
- Ordinary mesons are made up of one quark and one anti-quark
- They are classified as composite bosons because they have the same spin (integer spin) but they are not elementary particles
- Some examples include pions (π^+) and kaons (κ^+)

Hadrons: Baryons

- Baryons are composed of either three quarks or three antiquarks
- They are classified as composite fermions because they are involved in the strong forces of the nucleus.
- The most widely known baryons are the proton and the neutron
- Recall that quarks must have fractional charges in order to make the correct proton and neutron charges

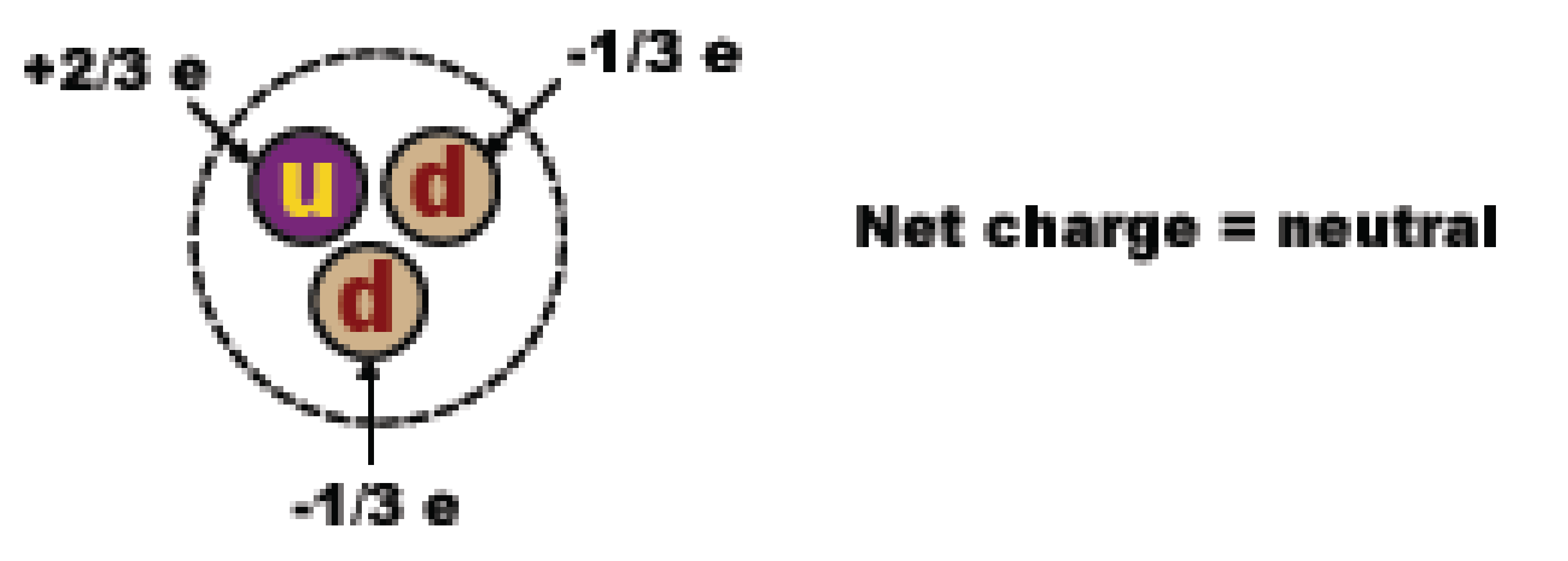
Protons

- made up of two up quarks and one down quark (uud):



Neutrons

- **made up of two down quarks and one up quark (udd):**



Beta Decay: Revisited

- These quarks can also explain the reaction seen during a beta decay:

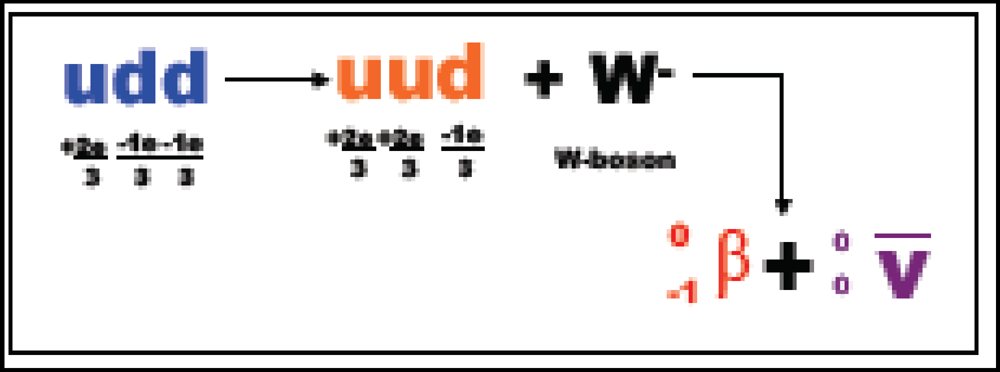
$$^{14}_{6}C \longrightarrow {}^{14}_{7}N + {}^{0}_{-1}\beta + {}^{0}_{0}\bar{\nu}$$

- In beta-negative decay, one neutron turns into a proton and an electron and an anti-neutrino:

$$^{1}_{0}n \longrightarrow {}^{1}_{1}p + {}^{0}_{-1}\beta + {}^{0}_{0}\bar{\nu}$$

Beta Decay: Revisited

- If we now include the symbols for quarks as protons/neutrons:



- In this more complete eqn. for beta-negative decay, a W-boson is produced (the mediator for the weak nuclear decay force), which decays itself into the beta particle and antineutrino.

Beta Positive Decay

- **Beta-positive decay can be described through a similar process:**

Note: Antimatter

- Each particle of matter has an antiparticle.
- As we have seen, electrons have an antiparticle, the positron.
- Protons also have an antiparticle, the antiproton (scientists have used this particle to produce antihydrogen!)
- The latest research is discovering why there is a discrepancy in the amount of matter vs. antimatter in the universe