Demonstrations: none
Text: Mod. Phys. 2.C, 2.D
Problems: 8, 9, 10 from Ch. 2

What's important:
•classification according to interaction: hadrons, leptons, gauge bosons
•classification according to spin: fermions, bosons; baryons, mesons
•antiparticles

Particle characteristics

There are many types of elementary particles: several hundred unique particles have already been identified, and the true number might be infinite. Is there any systematic behavior to these particles, and can we classify them according to their properties? Here, we concentrate on on four characteristics:

•**mass m**: all electrons have exactly the same mass, all protons have exactly the same mass *etc*.

•**charge Q**: all the particles (except quarks, but we haven't really observed quarks yet) have a charge that is an integer multiple of **e**:

Q(electron) = -**e** **Q**(proton) = +**e** **Q**(neutron) = 0

Q(π^+) = +**e** **Q**(π^0) = 0 **Q**(π^-) = -**e**

These masses and charges are *exactly* the same for a given particle type.

•**spin angular momentum J**: For a point particle with momentum **p** travelling in a circular path of radius **r**, the magnitude of the angular momentum is **rp**, as measured around an axis through the centre of the circular path and perpendicular to the plane of the path. Spin angular momentum is quantized in units of **h**/2π, where **h** is Planck's constant and has the numerical value of 6.626×10^{-34} Joule-seconds. The spin quantum number is given the symbol **J** and is a non-negative number from the set 0, 1/2, 1, 3/2, 2, 5/2.... (The magnitude of the angular momentum is $(J[J+1])^{1/2}$ [**h**/2π].)

J(proton) = 1/2 **J**(neutron) = 1/2 **J**(pion) = 0

•**interactions**: Do all particles have the same interactions? **NO**
•some particles and charged and some are neutral -> different electromagnetic interactions
•electrons have no strong interactions, otherwise they would be captured by the nucleus, rather than orbit it.

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When a particular quantity takes on only certain discrete values, rather than a continuum of values, we say that the quantity is **quantized**. For example, **e** is called the **quantum** (or basic unit) of electric charge and the number which multiplies the quantum to give the value of the observable is referred to as the **quantum number**.

Classifications

Bosons and fermions

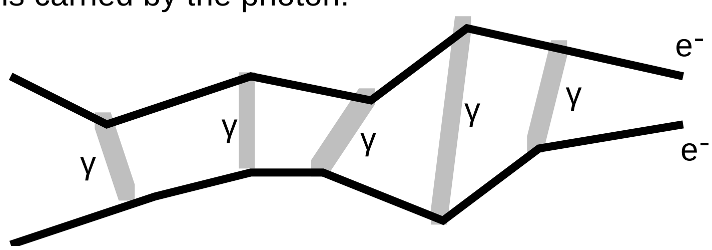
Particles can be classified into two groups according to their spin quantum numbers:

J = 1/2, 3/2, 5/2, 7/2......	**fermions**
J = 0, 1, 2, 3, ...	**bosons**.

In a group, no two fermions can have exactly the same quantum numbers; in contrast, two or more bosons are allowed to have the same quantum numbers.

Gauge bosons

Let's deal immediately with a class of particles called gauge bosons which are the carriers of the fundamental interaction. For example, the interaction between two charged electrons is carried by the photon:



As the name implies, gauge bosons have spin **J** = 1, 2.

Symbol	Name	Interaction	Mass (kg)	**J** (spin)
g	gluon	strong	cannot be isolated	1
γ	photon	electromagnetic	$< 5 \times 10^{-63}$	1
W^+, W^-	W-boson	weak	$(1.44 \pm 0.007) \times 10^{-25}$	1
Z^o	Z-boson	weak	1.63×10^{-25}	1
	graviton	gravity	predicted to exist	2

Note: gluons and gravitons are inferred from experiment, but have not been isolated.

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Leptons and lepton number

•**Leptons** are fermions with no strong interactions.
•The only leptons that we consider in this course are the electron and neutrino.
•Other leptons with non-zero mass are the muon and tao, μ and τ, and each has a distinct neutrino: ν_e, ν_μ and ν_τ.
•The leptons are said to form three groups, each with their own quantum number called a **lepton number.** Here, we are only concerned with $\mathbf{L_e}$, the lepton number associated with electrons:

Leptons: e^-, ν_e	$\mathbf{L_e}$ = 1
Hadrons, gauge bosons: p, n, π, g	$\mathbf{L_e}$ = 0.

Symbol	Mass (kg)	(proton mass)	**J** (spin)	$\mathbf{L_e}$
ν_e	$< 1 \times 10^{-35}$		1/2	1
ν_μ	$< 4.8 \times 10^{-31}$		1/2	0
ν_τ	$< 6.2 \times 10^{-29}$		1/2	0
e^-	9.11×10^{-31}	~1/1800	1/2	1
μ^-	1.884×10^{-28}	~1/9	1/2	0
τ^-	3.18×10^{-27}	1.9	1/2	0

Hadrons

•The largest family of particles is the **hadrons**, which includes all particles with strong interactions. Examples:

p, n, π (pion, 1/7 of proton mass)	hadrons
γ, e^-, ν	not hadrons

•Hadronic bosons are called **mesons**. The pion (π) is a meson.
•Hadronic fermions are called **baryons** and have a **baryon number |B|** = 1. All other particles have **B** = 0. Examples

Hadrons: p, n	**B** = 1
Hadrons: π; leptons: e^-, ν; gauge bosons: g	**B** = 0.

•The hadrons have many other characteristics such as strangeness, charm, beauty *etc*.

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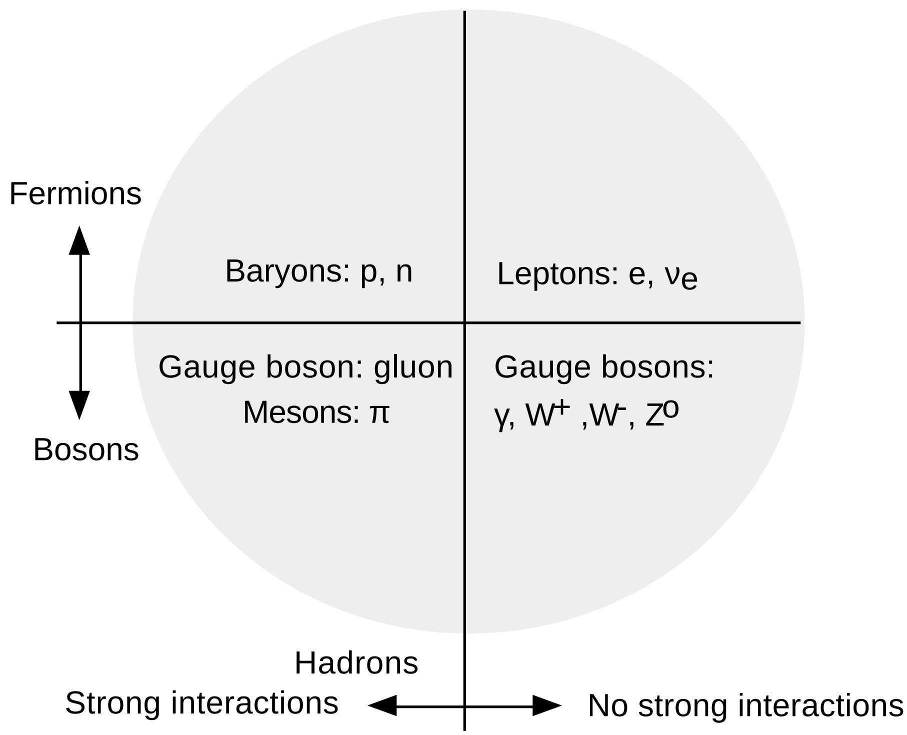
Symbol	Mass (kg)	(proton mass)	**J**	Charge states	**B**
Mesons					
π^o	2.41×10^{-28}	1/7	0	o	0
π^+, π^-	2.49×10^{-28}	1/7	0	+, -	0
η	9.79×10^{-28}	0.6	0	o	0
ρ	1.37×10^{-27}	0.8	1	+, o, - 0	
Baryons					
p, n	1.67×10^{-27}	1	1/2	+, o	1
Δ(1232)	2.20×10^{-27}	1.3	3/2	++, +, o, -	1
Λ	1.99×10^{-27}	1.2	1/2	o	1
Σ	2.12×10^{-27}	1.3	1/2	+, o, -	1

The following particles should be memorized:



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Antiparticles

Experimentally, there are many cases in which there are two particles with the same mass, but quantum numbers with opposite sign (in those situations where the quantum number can change sign). For example, both the electron and positron have the same mass but

electron = e^-	**Q** = -**e**	**J** = 1/2	$\mathbf{L_e}$ = 1
positron = e^+	**Q** = +**e**	**J** = 1/2	$\mathbf{L_e}$ = -1
neutrino = ν_e	**Q** = 0	**J** = 1/2	$\mathbf{L_e}$ = 1
antineutrino = anti-ν_e	**Q** = 0	**J** = 1/2	$\mathbf{L_e}$ = -1

Note: **J** > 0, since it is a measure of the magnitude of the angular momentum. Pairs of particles such as the electron and positron are said to be **antiparticles** of each other. The electron neutrino (ν_e) and antineutrino (anti-ν_e) are also a particle-antiparticle pair. It is arbitrary which one is the particle and which is the antiparticle. Strictly speaking, neutron decay involves an anti-ν_e:

$$n \rightarrow p + e^- + \text{anti-}\nu_e.$$

Notation: for this course, we denote the anti-particle by placing the words "anti" in front of the particle symbol: the anti-proton is anti-p.

The general rule is that for every particle there is an antiparticle with the same mass but opposite quantum numbers. However, there are cases in which the quantum numbers cannot change sign (like **J**) or are zero. For example, the neutral pion:

π^o **Q** = 0 **J** = 0 $\mathbf{L_e}$ = 0 **B** = 0.

The anti-π^o and the π^o have the same quantum numbers and are indistinguishable. In such cases, the particle is said to be its own antiparticle. But let's not be misled by the choice of words in this last sentence, the words just mean that the particle does not have a distinct antiparticle.

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