2.5.1 Classification of particles

Consider the following classification diagram for subatomic particles:

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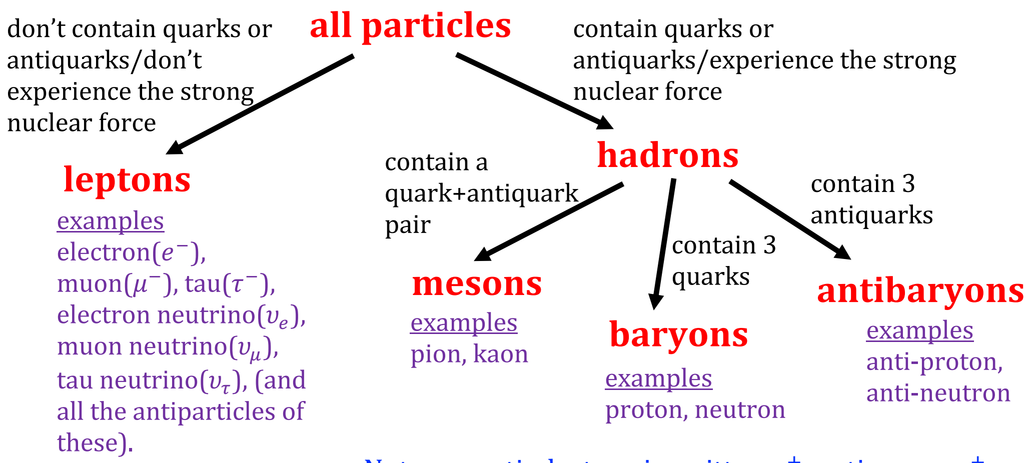

Note: an anti-electron is written e^+, anti-muon μ^+, anti-tau τ^+. All other antiparticles are written with a bar over the top – e.g. anti-electron neutrino $\overline{\upsilon_e}$, anti-proton $\bar{p}$.

We can see that we can first divide all particles into leptons and hadrons depending on whether they experience the strong nuclear force. The leptons are fundamental particles (as far as we know).

The hadrons consist of quarks/antiquarks, and are further subdivided into particles containing a quark+antiquark pair (mesons), a combination of 3 quarks (baryons), or a combination of 3 antiquarks (antibaryons).

Quarks

Quarks (and antiquarks) are the building blocks of hadrons. There are six different quarks – up(u), down(d), charm(c), strange(s), top(t), and bottom(b). You only need to be familiar with up, down and strange. Additionally, there are six antiparticles to these – anti-up($\bar{u}$), anti-down($\bar{d}$), anti-charm($\bar{c}$), anti-strange($\bar{s}$), anti-top($\bar{t}$), anti-bottom($\bar{b}$).

Examples
A proton contains 3 quarks in the combination up+up+down (uud).
A neutron contains 3 quarks in the combination up+down+down (udd).

A positive pion (π^+) contains a quark+antiquark pair in the combination up+anti-down ($u\bar{d}$).
A positive kaon (K^+) contains a quark+antiquark pair in the combination up+anti-strange ($u\bar{s}$).

(1)✐Complete the following table for hadrons (you will need to do some research):

particle	type of hadron	quark combination
positive pion π^+		$u\bar{d}$
negative pion π^-		
neutral pion π^0	meson	
positive kaon K^+		$u\bar{s}$
negative kaon K^-		
neutral kaon K^0		
neutral kaon $\overline{K^0}$		
proton (p)	baryon	uud
neutron (n)		udd
antiproton $(\bar{p})$		
antineutron $(\bar{n})$		

(2)✐List the particles which contain a strange (or anti-strange) quark.

(3)✐What do you think 'positive', 'negative' and 'neutral' indicate about the particles?

The proton is the only stable baryon. All other baryons eventually decay into a proton.

Leptons

You should be familiar with the electron as a fundamental particle. You will also be familiar with the electron neutrino and the anti-electron neutrino from section 2.4. We don't generally come across the muon and tau particles and their associated neutrinos because they are only produced by collisions in high energy environments such as particle colliders and in the Earth's upper atmosphere.

The muon and tau particles are unstable and decay very quickly into an electron (e.g. mean half-life of muon particle = 2.2×10^{-6}s).

Let us look at a muon decay:

$$\mu^- \rightarrow e^- + \nu_\mu + \overline{\nu}_e$$

A muon decays into an electron, a muon neutrino and an anti-electron neutrino.

Interestingly, the rest mass of the muon is 207 times the rest mass of the electron. Neutrinos have zero mass.

(4)✐Where do you think the missing mass has gone?

(5)✏A particle contains a quark+antiquark pair. It is negatively charged and contains a strange quark. Identify the particle.

(6)✏A particle does not feel the strong nuclear force. It is positively charged and has a rest mass ≈3500 times the mass of the electron. Identify the particle.