

# Lesson 48: The Subatomic Zoo

By the 1930's physicists blew apart any possible way of going back to a simple model of matter being made up of just three fundamental particles like electrons, protons, and neutrons.

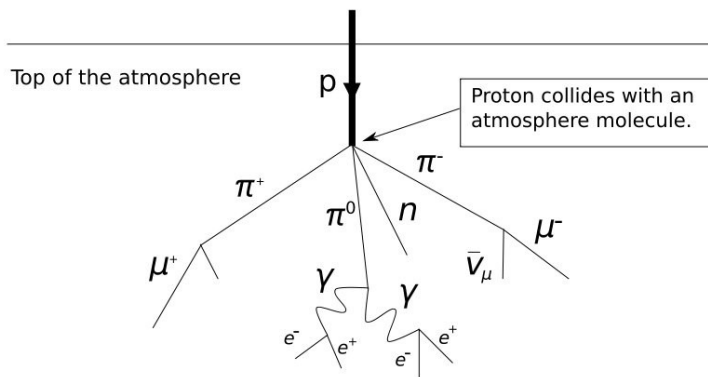
- We've already seen that we have to add in the idea of antiparticles, so, we've already doubled the number of fundamental particles.
- The discoveries that started to be made were so fantastic and almost unbelievable, that physicists started to refer to their model of subatomic particles as the **subatomic zoo**.

Over time, higher and higher energies were being used to investigate the structure of matter.

- This is necessary since as you try to probe smaller and smaller structures, the fundamental forces holding matter together get stronger and stronger.
  - At **13.6eV** you can ionize a hydrogen atom, causing an electron to be ejected.
  - At a **few hundred electron volts** you can look at various energy levels in atoms.
  - Rutherford had to use around **10 MeV** ( $10^6$  eV) to be able to look at the size of a nucleus. This was necessary to allow his alpha particles to have enough energy to get close to the nucleus, overcoming the electrostatic repulsion. He got alpha particles with about this energy from using polonium and radium isotopes.
  - By the time we reach **GeV** ( $10^9$  eV), we start to see some wacky stuff happen... the particles start to combine and break apart, momentarily creating **new fundamental particles** never seen before!
    - It would be like throwing a golf ball at a vase, and in the resulting wreckage seeing a pencil appear for a brief moment.

O.K., most of these new particles only exist for a few microseconds, but who cares! They really exist!

- Some of the first discoveries involved **cosmic rays**.
  - Although we are not certain where they come from, cosmic rays are made up of about 90% protons, 9% alpha particles, and 1% electrons. Traveling through space, these **primary cosmic rays** can have energies of  $10^{14}$  MeV! This is about seven orders of magnitude higher than anything humans can produce in particle accelerators.
  - When they hit our atmosphere they react with air molecules and create less energetic **secondary cosmic rays** that can actually reach the surface of the Earth.



*Illustration 1: Cosmic ray collision in atmosphere, causing the primary cosmic ray to split into secondary cosmic rays.*

Notice all the symbols used for the secondary cosmic ray particles in *Illustration 1*. These are some of the new fundamental particles that were discovered starting in the 1930's.

- A muon ( $\mu^-$ ) acts like an electron, but has a mass that is 207 greater. Its antiparticle is the antimuon ( $\mu^+$ ).
- Pions are unlike any other particle, and come in three types,  $\pi^-$ ,  $\pi^+$ , and  $\pi^0$ .

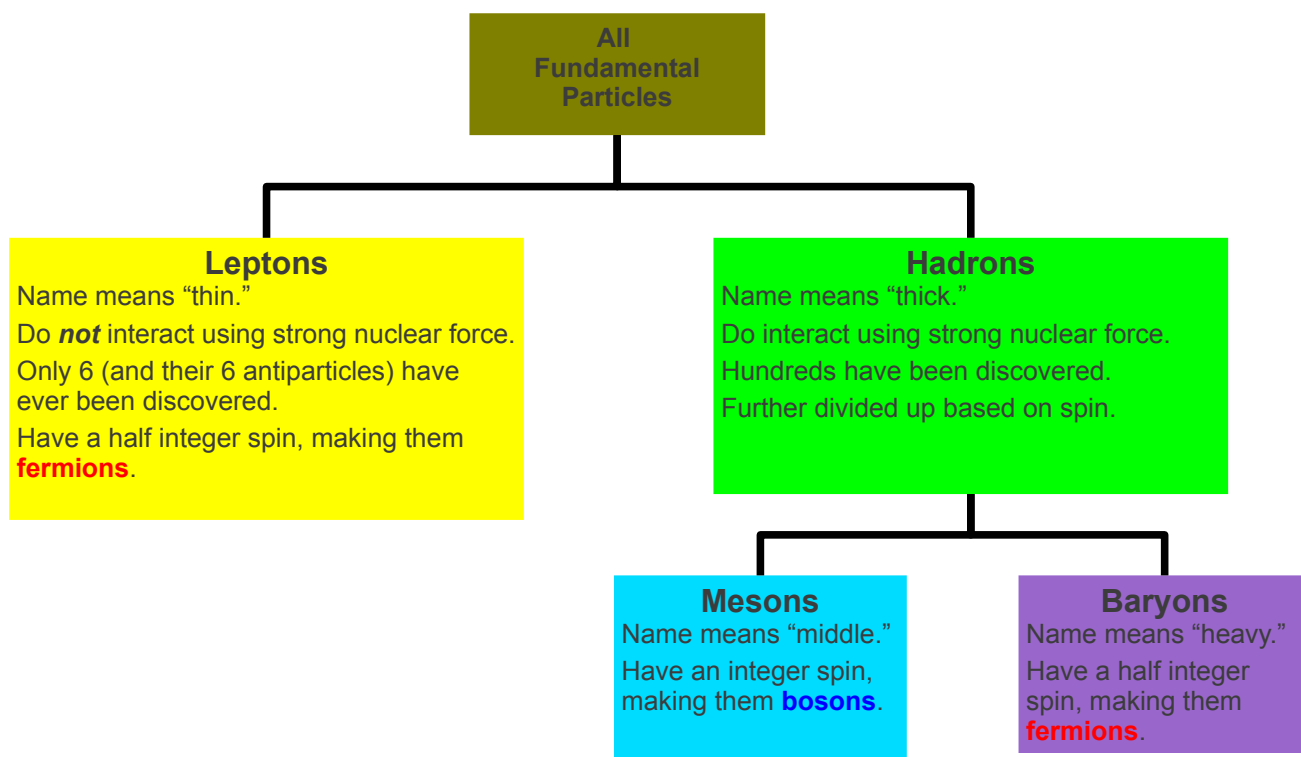
This is starting to get a bit weird, right?

- You used to think of just a little barn filled with only three critters, protons, electrons, and neutrons.
- Now we are entering the **subatomic zoo**, where the number of fundamental particles is a lot bigger. In fact, we currently know of over **300** fundamental particles.

To help keep track of everything, physicists have divided these particles into different groups, based on properties like their interactions with other particles, and spin.

- The following chart traces the relationships and main qualities of these groups.

**Spin** is a measurement of a particle similar to how we would measure the momentum of something like a spinning top. Spin always happens as a half integer (like 1/2, 3/2, 5/2, etc) called **fermions**, or whole integer (0, 1, 2, etc) called **bosons**.



When we discuss the mass of all these fundamental particles, it seems a bit silly to use kilograms.

- Although we will always use kilograms as the standard measurement of mass, it is handy to have a system that is better suited to the much smaller masses we are now dealing with.
- This is why you will often find masses listed in the units  $\text{MeV}/c^2$ .
  - This comes from rearranging the formula for mass-energy equivalence as follows...

$$E = mc^2$$
$$m = \frac{E}{c^2}$$

- To be able to do conversions with these numbers (if necessary), keep in mind two things...
  - You can always calculate the energy of a particle in Joules, then convert it into electron volts.
  - Megaelectron volts are  $10^6$ .

**Example 1:** Determine the mass of an electron in  $\text{MeV}/c^2$ .

First, figure out its mass-energy equivalence in Joules...

$$E = mc^2 = 9.11 \times 10^{-31} (3.00 \times 10^8)^2 = 8.199 \times 10^{-14} \text{ J}$$

Now figure out how many eV that is...

$$E = \frac{8.199 \times 10^{-14} \text{ J}}{1.60 \times 10^{-19} \text{ J/eV}} = 512437.5 \text{ eV}$$

Finally, determine how many MeV that is by sliding the decimal over 6 places...

$$E = 512437.5 \text{ eV} = 0.5124375 \text{ MeV} = 0.512 \text{ MeV}$$

Since this is the energy of the electron in MeV...

$$m = \frac{E}{c^2} = 0.512 \text{ MeV}/c^2$$

Although there are *many* more than shown here, this chart shows the most common fundamental particles. You do **not** have to memorize this whole table.

Family	Particle	Symbol	Mass ( $\text{MeV}/c^2$ )
Leptons	electron *	$e^-$	0.511
	electron neutrino †	$\nu_e$	< 7e-6
	muon	$\mu^-$	106
	muon neutrino	$\nu_\mu$	< 0.17
	tauon	$\tau$	1777
	tauon neutrino	$\nu_\tau$	< 24
Mesons	pions	$\pi^+$	140
		$\pi^0$	135
	kaons	$K^+$	494
		$K^0$	498
	psi	$\psi$	3097
upsilon	$Y$	9460	
Baryons	proton *	$p^+$	938.3
	neutron *	$n$	938.6
	lambda	$\Lambda^0$	1116
	sigma	$\Sigma^+$	1189
		$\Sigma^-$	1192
omega	$\Omega^-$	1672	

\* Basic fundamental particles you need to know about.

† This is the neutrino we discussed in beta positive decays in [Lesson 43](#). Remember there are also antineutrinos involved in beta negative decays.

## **Homework**

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