Lesson 49: Quarks

By 1960 physicists felt pretty much like you do right now... confused!

- **Leptons** are really small, and there are only six of them (and their antiparticles), so it seems like they are probably fundamental particles.
- The **hadrons** (**mesons** and **baryons**) are really big, and there are so many of them, that it seems like maybe they are made up of just a few *other* smaller fundamental particles.
    - In 1963 Murray Gell-Mann and George Zweig independently suggested the properties of the fundamental particles that make up the hadrons, named **quarks**.

To explain the two most important hadrons, protons and neutrons, we only need two of these quarks...

- up quark with a $+\frac{2}{3}e$ charge → symbol is u.
- down quark with a $-\frac{1}{3}e$ charge → symbol is d.

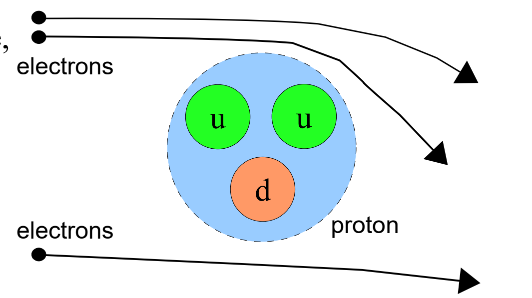

Illustration 1: The electrons are deflected around the proton because of the concentration of positively charged quarks near the top and negatively charged quarks near the bottom.

- This bothered physicists, since it involved having charges that were a *fraction* of an elementary charge, which had never been seen.
    - By 1967 the Stanford Linear Accelerator was being used to shoot high energy electrons at protons. The electrons deflected around the proton in an uneven pattern that suggested the charge of a proton was not evenly spread out, just as the quark model suggested.
- The quark model eventually built up to having six quarks and their antiparticles (wow! just like there are six leptons and their antiparticles).
    - **With these six quarks and their antiquarks we can explain all the hadrons.**
    - The six quarks were even used to predict some new hadrons that hadn't been discovered up to that point.

The following chart shows all six quarks.

- Remember that each quark also has an antiquark that only differs by having the opposite charge.
- You are only responsible to know the first generation quarks.
- All the hadrons can be built from either two or three of these quarks.
    - The exception is the theta particle (θ^+) discovered in 2003. It is made up of five quarks.

Generation	Name	Symbol	Charge
First	up	u	$+\frac{2}{3}e$
	down	d	$-\frac{1}{3}e$
Second	strange	s	$-\frac{1}{3}e$
	charm	c	$+\frac{2}{3}e$
Third	bottom (AKA beauty)	b	$-\frac{1}{3}e$
	top (AKA truth)	t	$+\frac{2}{3}e$

Example 1: Using the information from this table, explain how a proton and a neutron would be made from up and down quarks. Do not use antiparticles.

A proton needs to have a charge of +1e. The combination *uud* would give us this charge:

$$uud = \left(+\frac{2}{3}e\right) + \left(+\frac{2}{3}e\right) + \left(-\frac{1}{3}e\right) = +\frac{3}{3}e = +1e$$

A neutron needs a charge of zero. The combination *udd* would give us this charge:

$$udd = \left(+\frac{2}{3}e\right) + \left(-\frac{1}{3}e\right) + \left(-\frac{1}{3}e\right) = 0e = neutral$$

Explaining Beta Decays

We can use quarks and leptons (quarks and leptons are all fermions based on their spin) to explain beta negative and beta positive decays.

Beta Negative Decays

Keep in mind that a beta negative decay happens when a neutron decays into a proton, an electron (the beta negative particle), and an antineutrino.

$$n^o \rightarrow p^+ + e^- + \bar{\nu}$$
$$udd \rightarrow uud + e^- + \bar{\nu}$$

- Notice that one of the **down** quarks in the neutron has changed into an **up** quark to make a proton.
  - This does result in a change in charge...

$$\Delta q = q_f - q_i = \left(+\frac{2}{3}e\right) - \left(-\frac{1}{3}e\right) = \left(+\frac{2}{3}e\right) + \left(+\frac{1}{3}e\right) = +1e$$

- This is ok according to the conservation of charge, since we also see an electron with a charge of -1e produced.
  - The change in the quark caused a **+1e change**
  - The creation of an electron (beta negative particle) caused a **-1e change**
  - ***Overall the change is (+1e + -1e = 0) zero!***

Beta Positive Decays

Keep in mind that a beta negative decay happens when a proton decays into a neutron, a positron (the beta positive particle), and a neutrino.

$$p^+ \rightarrow n^o + e^+ + v$$
$$uud \rightarrow udd + e^+ + v$$

- Notice that one of the **up** quarks in the proton has changed into an **down** quark to make a neutron.
  - This does result in a change in charge...

$$\Delta q = q_f - q_i = \left(-\frac{1}{3}e\right) - \left(+\frac{2}{3}e\right) = -1e$$

  - This is ok according to the conservation of charge, since we also see a positron with a charge of +1e produced.
    - The change in the quark caused a **-1e change**
    - The creation of a positron (beta positive particle) caused a **+1e change**
    - ***Overall the change is (-1e + +1e = 0) zero!***

Where do we go from here...?

As far as Physics 30 is concerned, you're done. But that doesn't mean physics is finished.

- We've gone about as far as the late 1960's, early 1970's. There's a lot more that's been done in physics since.
- If you interested in seeing more, go on the net and check out topics like the **Standard Model**, **String Theory**, and **Grand Unified Theory**. These are the big topics in physics right now.
  - If you do check them out, be wise in your choice of sources. These theories are cutting edge, and there's a lot of kooks out there that have their own websites spreading their own "answers." Keep in mind that a wise man says "A little knowledge is a dangerous thing."

Homework

p849 #3, 7, 8, 9