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 $d$.

- 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 ($\theta^+$) discovered in 2003. It is made up of five quarks.
<table>
<thead>
<tr>
<th>Generation</th>
<th>Name</th>
<th>Symbol</th>
<th>Charge</th>
</tr>
</thead>
<tbody>
<tr>
<td>First</td>
<td>up</td>
<td>u</td>
<td>$\frac{+2}{3}e$</td>
</tr>
<tr>
<td></td>
<td>down</td>
<td>d</td>
<td>$\frac{-1}{3}e$</td>
</tr>
<tr>
<td>Second</td>
<td>strange</td>
<td>s</td>
<td>$\frac{1}{3}e$</td>
</tr>
<tr>
<td></td>
<td>charm</td>
<td>c</td>
<td>$\frac{+2}{3}e$</td>
</tr>
<tr>
<td>Third</td>
<td>bottom (AKA beauty)</td>
<td>b</td>
<td>$\frac{-1}{3}e$</td>
</tr>
<tr>
<td></td>
<td>top (AKA truth)</td>
<td>t</td>
<td>$\frac{+2}{3}e$</td>
</tr>
</tbody>
</table>

**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:

$$uud = \frac{+2}{3}e + \frac{+2}{3}e - \frac{1}{3}e = \frac{3}{3}e = +1e$$

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

$$udd = \frac{+2}{3}e - \frac{1}{3}e - \frac{1}{3}e = 0e = \text{neutral}$$

**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.

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

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

- 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...
    $$\Delta q = q_f - q_i = \frac{+2}{3}e - \frac{-1}{3}e = \frac{+2}{3}e + \frac{1}{3}e = +1e$$
  - 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.

\[ p^+ \rightarrow n^- + e^+ + \nu \]
\[ uud \rightarrow udd + e^+ + \nu \]

- Notice that one of the up quarks in the proton has changed into a down quark to make a neutron.
  - This does result in a change in charge...
    \[ \Delta q = q_f - q_i = -\frac{1}{3}e - \frac{2}{3}e = -1e \]
  - 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