

# Lesson 49: Quarks

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

- **Leptons** are really small, and there's 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**.

In their original work they were able to show that all the hadrons known at the time could be made up of just three 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  $\rightarrow$  symbol is u.
- down quark with a  $-\frac{1}{3}e$  charge  $\rightarrow$  symbol is d.

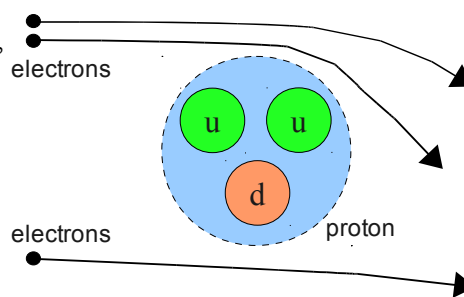
- This bothered physicists, since it involved having charges that were a *fraction* of an elementary charge, which had never been seen.

- 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.



*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.*

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.

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:

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

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

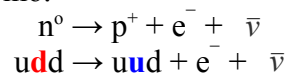
$$udd = +\frac{2}{3}e + -\frac{1}{3}e + -\frac{1}{3}e = 0e = \text{neutral}$$

## 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.



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

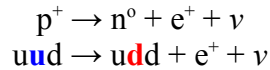
- This does result in a change in charge...

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

- 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.



- 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...

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

- 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."