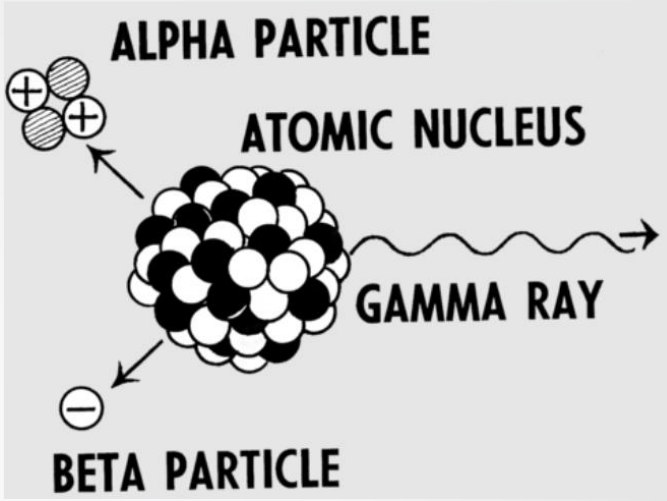


The Nucleus

Stage 1 Physics

A bit of history

- 450BC – Democritus

- Everything is made up of indivisible parts called Atoms
- In between is empty space
- At the time everyone including Aristotle said he was wrong

More history – the Electron

- 1897 – JJ Thomson https://www.youtube.com/watch?v=2xKZRpAsWL8
- suggested one of the fundamental units was more than 1,000 times smaller than an atom
- Using a cathode ray tube (modified Crooke's tube) he produced;
  - negative particles (due to their being bent in an electric field)
  - $\frac{1}{1000}$ the size of an atom; based on the energy released in impact
- Concluded that atoms contain negatively charged particles
- Plum Pudding model where the electrons were evenly spread throughout a sphere of positively charged material.

More history – the Proton

- 1909 – Rutherford https://www.youtube.com/watch?v=wzALbzTdnc8
- Gold foil leaf experiment
- Most of atom is empty space
- Solid nucleus
- Positive Proton identified
- Neutron needed to make up total mass,
  - proposed but not found

More history – Atomic model

- 1915 – Niels Bohr https://www.youtube.com/watch?v=1b9UKTbjj7I
- Demonstrated that electrons have specific energy levels associated with them
- Proposed orbital model (wrong, but good for chemistry)
- Niels' work is important, more on it later

More history – Atomic model

- 1932 – James Chadwick
- bombarded beryllium with alpha particles releasing a neutral particle with a similar mass to a Proton
- Thus, experimental evidence of the Neutron

A bit more history

- The Neutron was the hardest to find. It has no charge, is fixed within nuclei and only lasts some 14 minutes if separated from the nucleus
- Thus we have a solid nucleus of Protons and Neutrons with Electrons 'orbiting' around it
- That should all be firmly in your memory from year 10

Back to Niels Bohr

- Atoms can absorb photons of light
- Atoms can emit photos of light
- BUT the photons are discrete, distinct frequencies for each element (different for each element)

The Bohr model of the Atom

The first glimpse of our current view

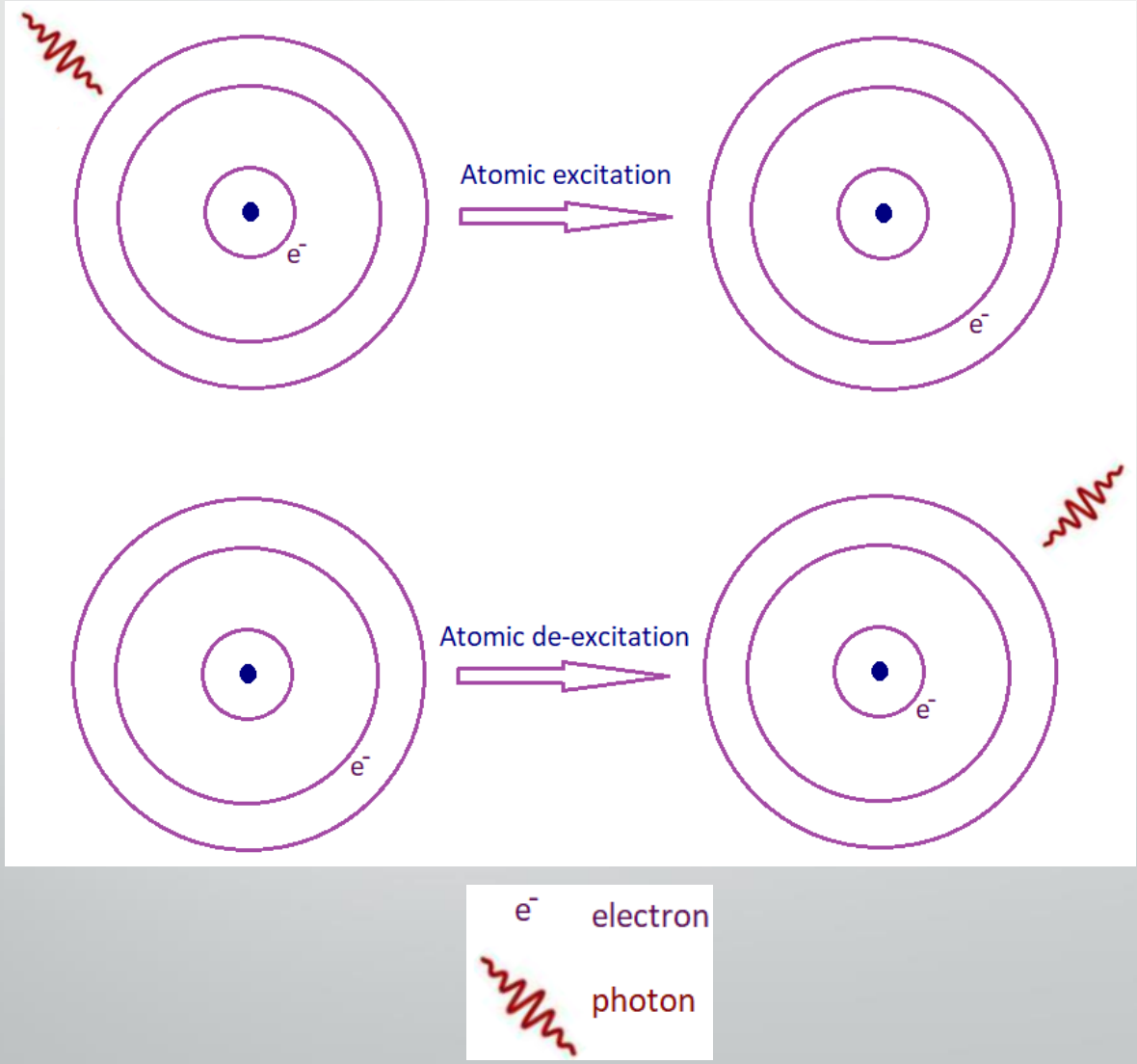
- Atoms emit discrete frequencies of light
- Niels Bohr, using the concept of the Photon (Max Planck, Albert Einstein) postulated that Electrons exist around the nucleus in discrete energy levels.
- These discrete energy levels are called shells in chemistry.

Niels Bohr

What does this mean

- If you fire Photons of light at an Atom
  - Only discrete frequencies are absorbed
  - Any other frequency simply goes through
- But then..
  - The absorbed frequencies are re-radiated as Photons of the exact same frequency that was absorbed at a later time

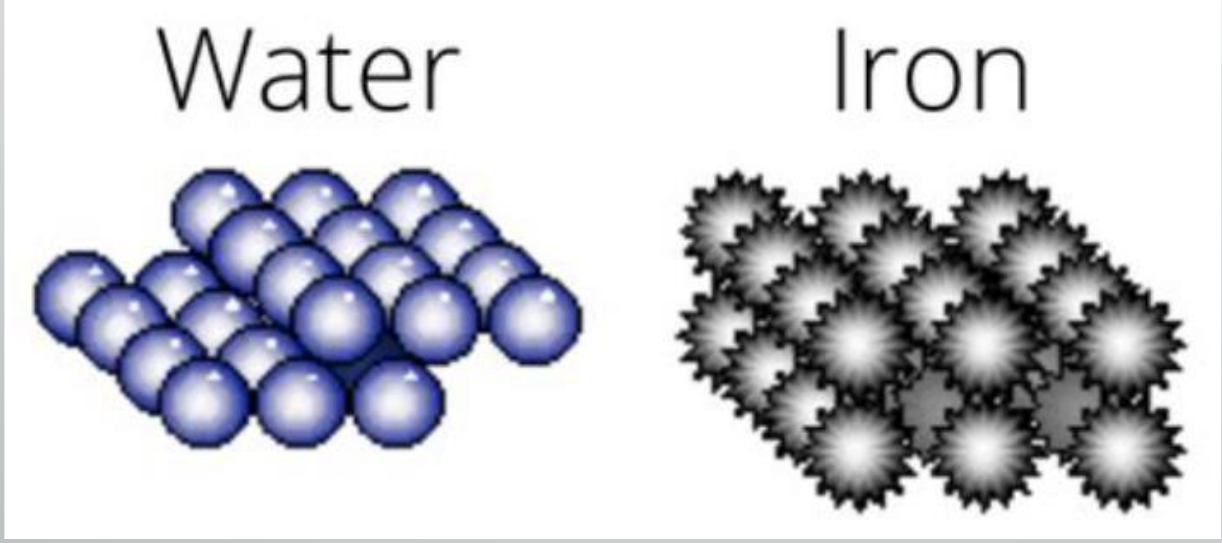
The Bohr model of the Atom



The Atom in pictures, 1

- Democritus' view of atoms

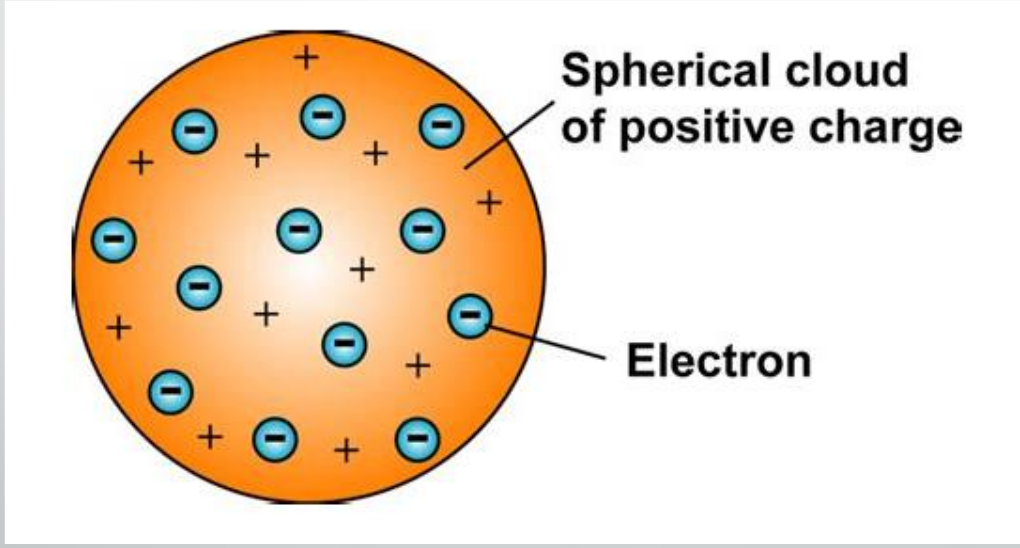
Image courtesy chemtas.com



The atom in pictures, 2

- JJ Thomson's view of the atom

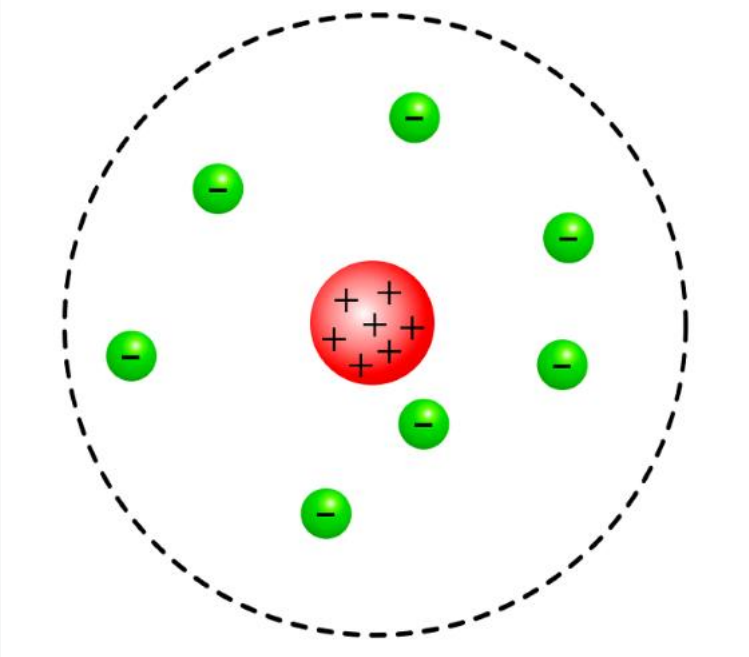
Image courtesy socratic.org



The atom in pictures, 3

- Rutherford's view of the atom

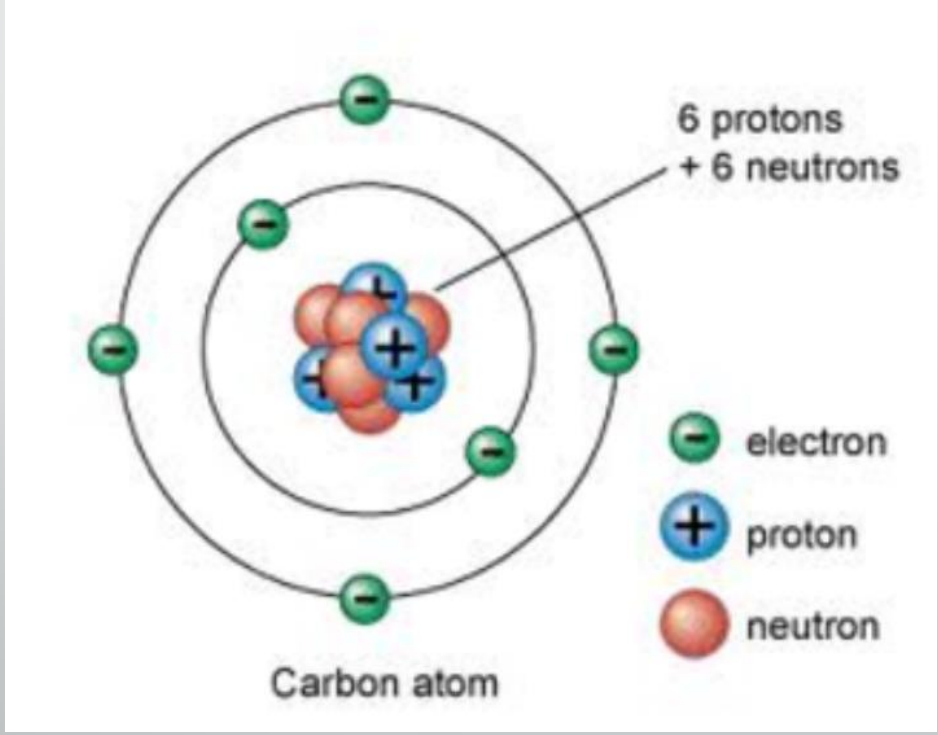
Image courtesy thestargarden.co.uk



The atom in pictures, 4

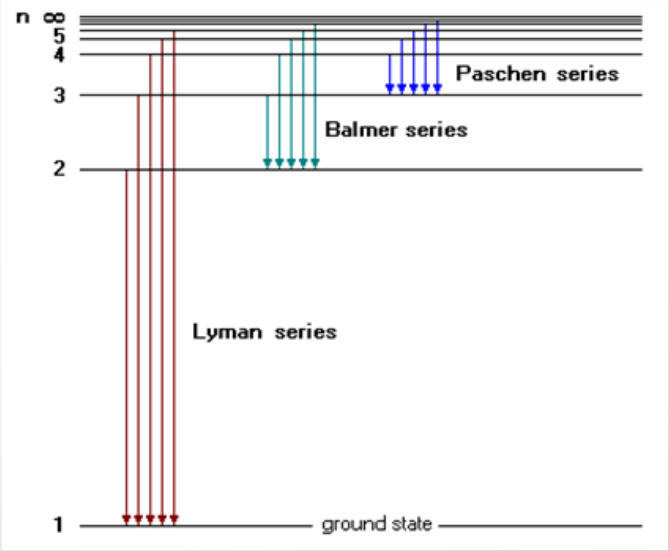
- Niels Bohr's view of the atom

Image courtesy timetoast.com



Time for a new view of the atom

- On the right is a hydrogen atom
- Somewhere a metre below the bottom is the nucleus
- Each of the levels; 1,2, ,etc are the energy levels the electrons **can** sit at (they cannot be anywhere else)
- In hydrogen the electron would naturally sit on level 1
- But if we add some energy we can push the electron up a level



Isotopes

- Isotopes are variants of a particular element which differ in Neutron number, and consequently in Nucleon number. All Isotopes of a given element have the same number of Protons but different numbers of Neutrons in each Atom.

- Note; **Nucleon** number is the number of Protons and Neutrons

Back to the Nucleus

- The Nucleus is made up of Protons and Neutrons
- Protons have a charge of $1.60 \times 10^{-19} C$
- And typical nucleus is $10^{-14} m$ in radius
- Using Coulomb's Law

$$F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$$

$$F = 0.58N$$

Let that sink in. The force between 2 protons that are less than 1/400000000000000000000000000 your mass is enough to move you

The electrostatic force between two protons is ENORMOUS

- So, something must keep it together
- This is the **Nuclear Force**, a component of the **Strong Force**

New stuff

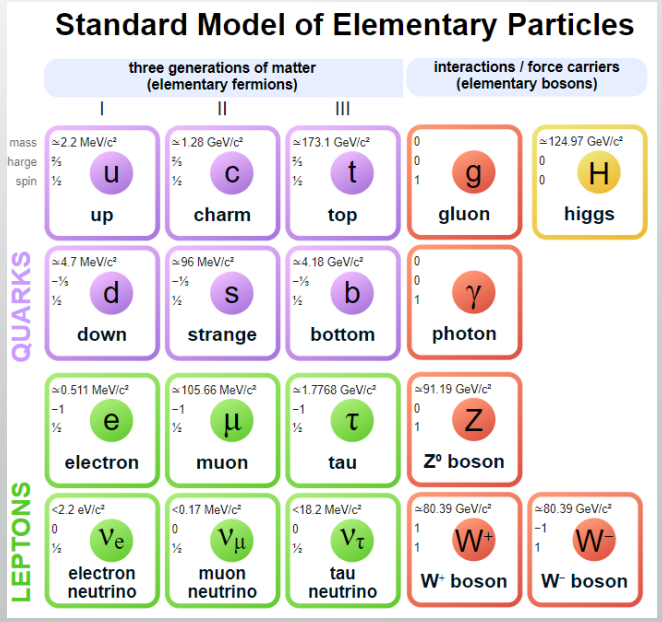
- The **Strong Force** has two components;
  - The **Strong Nuclear Force**, which is between Baryons
- What's a **Baryon**? A **Baryon** is a particle made up of 3 **Quarks**
  - Protons and Neutrons Baryons
  - Protons and Neutrons are also Hadrons (2 or more quarks, in this case 3)
- This component of the **Strong Force** is called the **Strong Nuclear Force** and is carried by **Pions**
- What's a **Pion**? We will get to that

Strong Force, Part 2

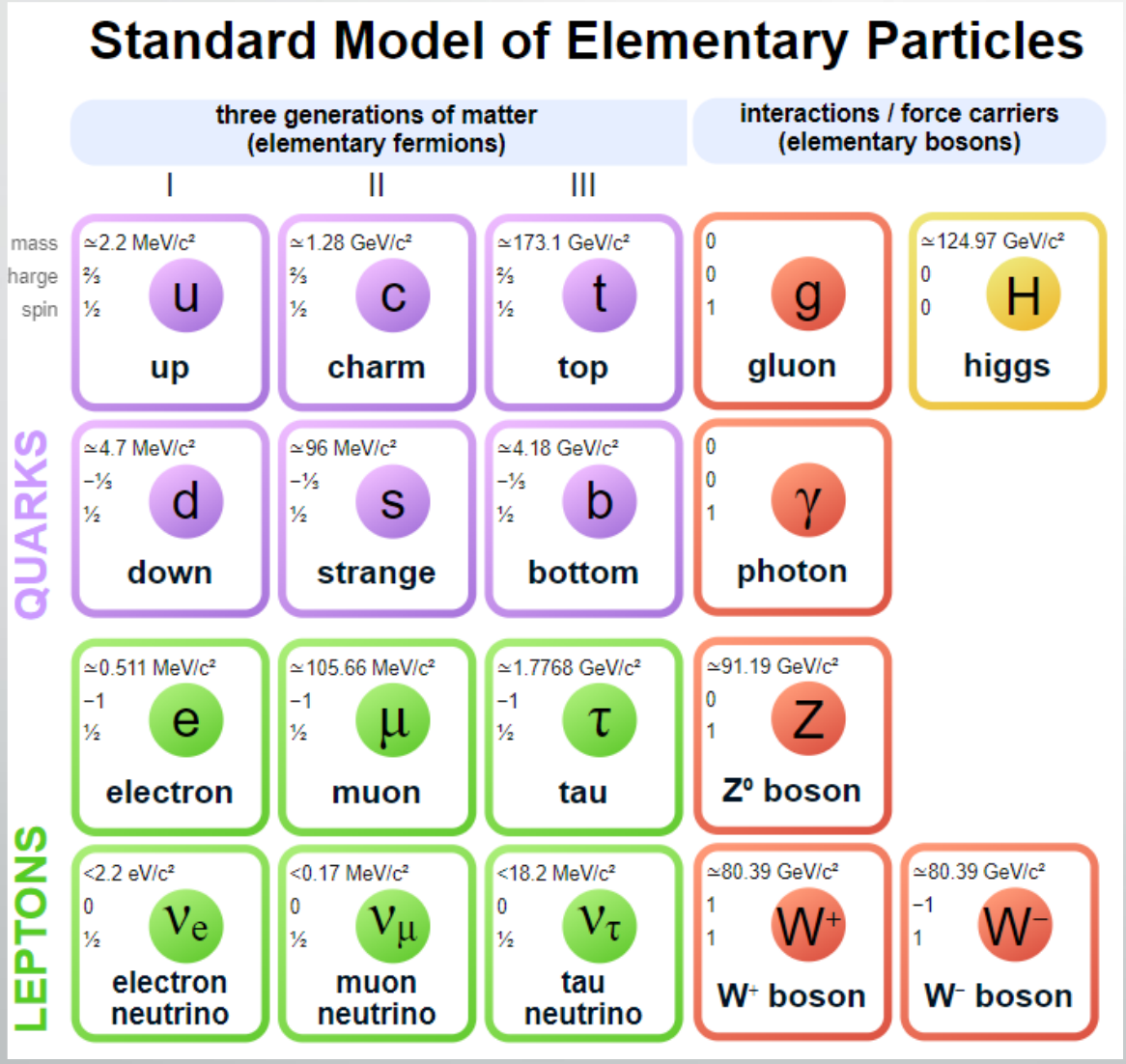
- As well as being between **Baryons** (The **Strong Nuclear Force**)
- The **Strong Force** has a component between **Quarks** called the **Color Force**
- The **Color Force** acts between the three **Quarks** holding them together to make a **Baryon**
- **Color Force** is carried by **Gluons**

Back to Pions

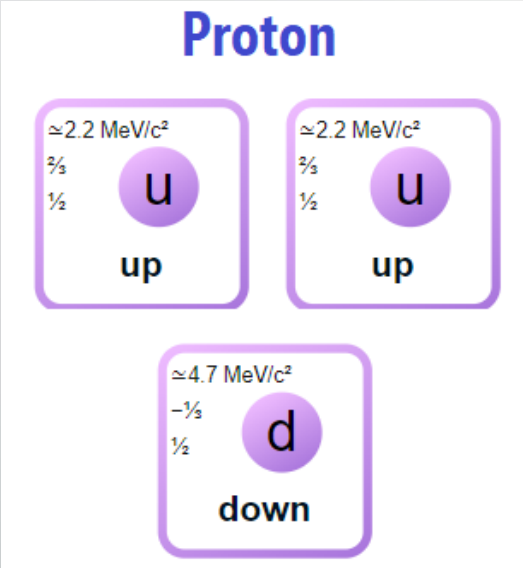
- **Pions** are made up of a **Quark** and an **Anti Quark**
- Yep, Antimatter
- Every fundamental particle has an antimatter particle
- So what's a fundamental particle?
- These are;

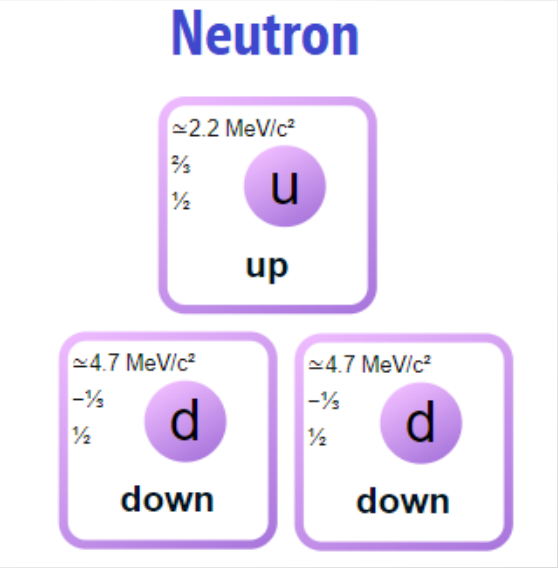


The Standard Model



So.. What are Protons and Neutrons?



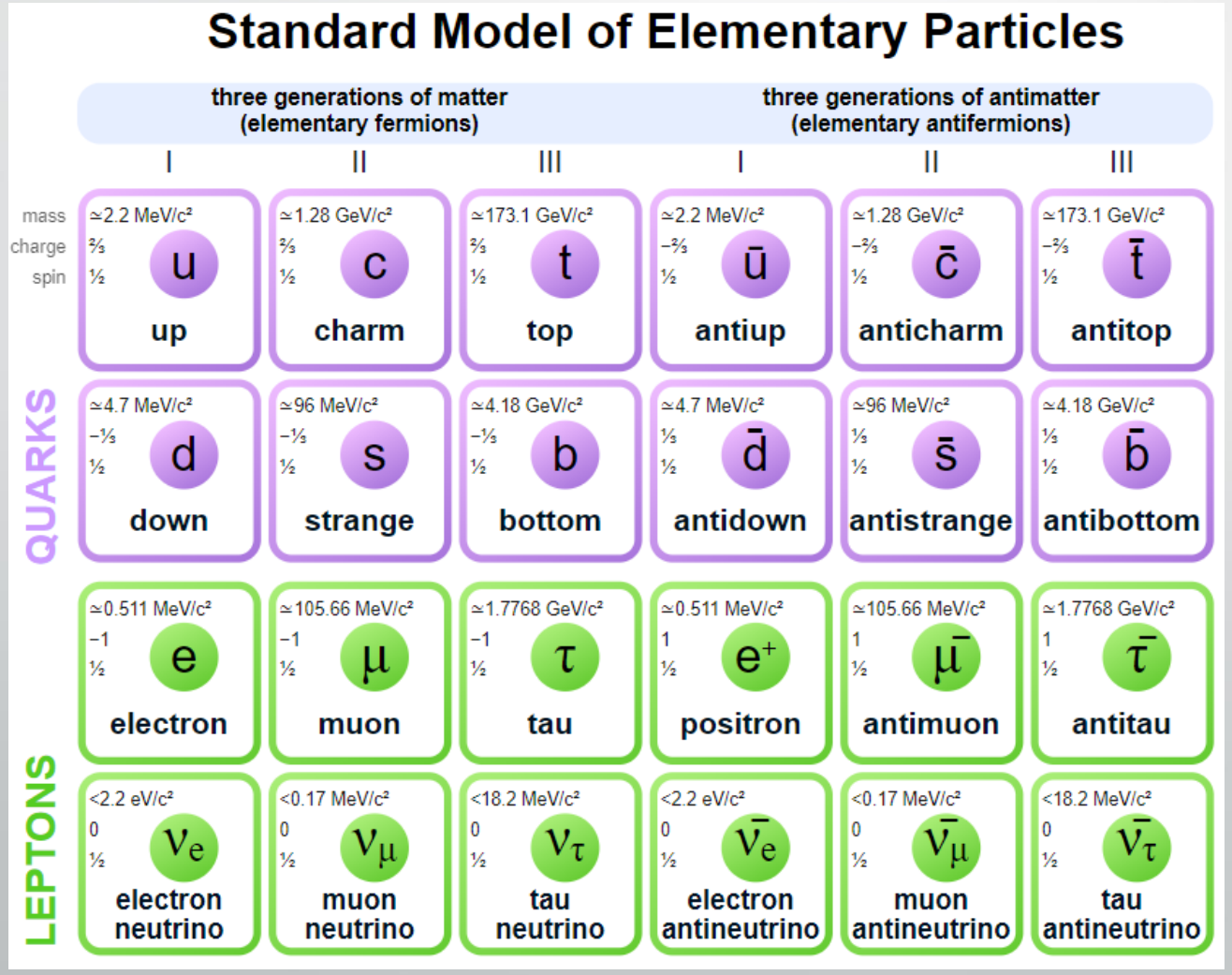


But we just use u and d

u u d

d d u

To understand Pions …. every component has an antimatter component



What makes antimatter

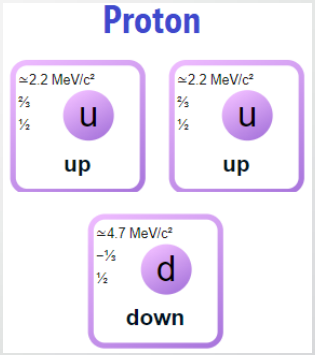
- In simple terms; it has the opposite of all of the properties of its matter equivalent, except it has the same mass
- As a result, when matter and antimatter interact, they annihilate each other becoming the energy of the combined masses
- Put another way; since all properties other than mass are opposites, when those properties "disappear", those properties have been 'conserved'. Mass becomes energy and thus is conserved
- When matter and antimatter meet they 'annihilate' each other becoming energy – lots of energy

Interesting

- Photons (the fundamental unit of light) have anti photons
- Since all properties other than energy/mass have to be conserved, the anti photon is created;
  - In the same place
  - With an identical frequency
  - Travelling the opposite direction
  - With time travelling in the opposite way
  - (note, the time conservation is a mathematical construct)

But, back to the Nuclear Force

- Remember, the **Nuclear Force** is the component of the **Strong Force** that holds **Baryons** together
- **Baryons** are 3 **Quark** particles
- Protons and Neutrons are **Baryons**
- And, we said, the force is carried by **Pions**
- Now it is finally time to talk about **Pions**



New terms

- Meson – a two Quark particle made up of a Quark and an Anti-Quark
- Pion – a type of Meson made up of a Down and an Anti-Down Quark
- The formal name is a Pi neutral (π^0)
- Down Quarks have the symbol d
- Anti-Down Quarks have the symbol $\bar{d}$
- Thus π^0 is $d\bar{d}$

Time to blow the mind

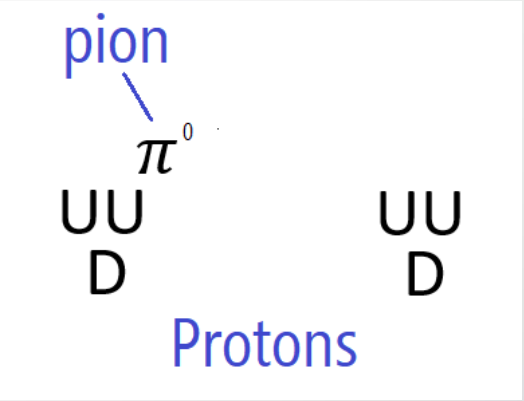
- Nothing is stable at the fundamental level
- **Baryons** spontaneously emit energy
- This energy becomes a pair of **Quarks** (one matter and one anti matter)
- A **Pion** $(d \; and \; \bar{d})$ can result
- **Pions** travel from the **Baryon** they were emitted by to another **Baryon**

Where did the energy come from?

- A Proton has a mass of $1.67 \times 10^{-27} kg$
- The 3 constituent Quarks have a total mass of less than 1/1000 of that mass
- The rest of the "mass" of the Proton is energy
- That energy is available to make Pions
- Pions are constantly being made, emitted then absorbed, annihilated so that the net energy change is zero.

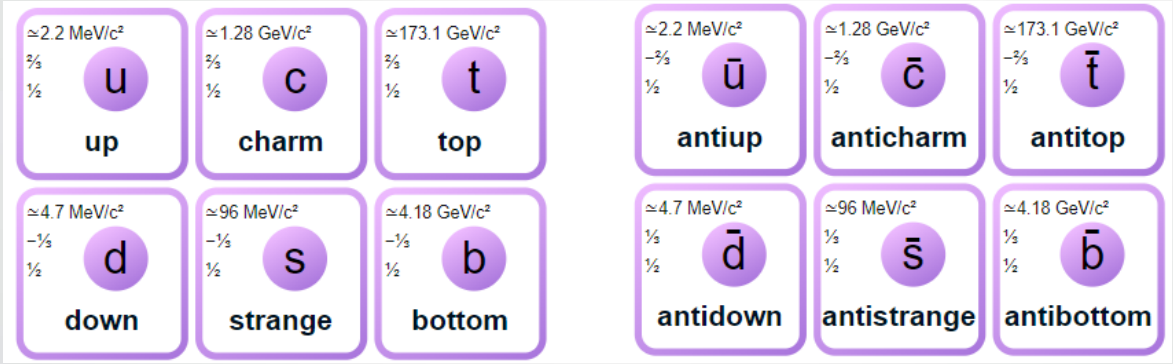
Pion life

- **Pion** is 'created' by a **Baryon** emitting a quark and an anti quark which then travel to another **Baryon**, being absorbed by the other Hadron

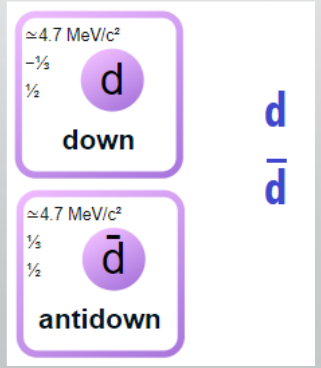


Mesons

- There are 6 different quarks and 6 anti quarks, allowing for 36 possible Mesons of which a Pion is one



- The $\pi^0 (Pi\ neutral)$ is made up of a down and an anti down Quark

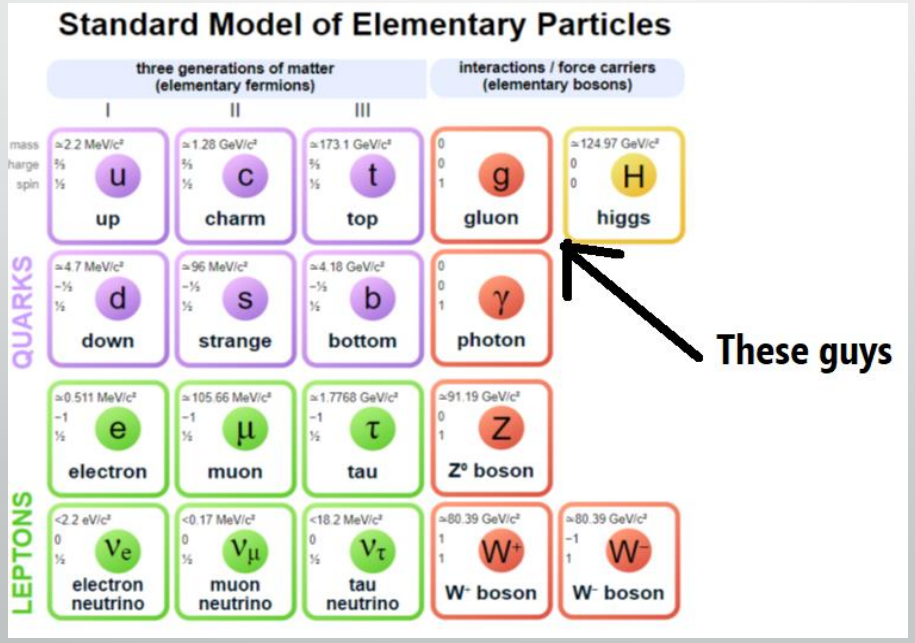


Summary time

- **Protons** have a positive charge
- Therefore **Protons** are electrostatically repelled from each other
- The **Nuclear Force** component of the **Strong Force** counteracts that repulsion and keeps the **Protons** together in the nucleus of an atom
- The **Nuclear Force** is "carried" by **Pions**
- **Pions** are emitted by one **Baryon** and absorbed by another

Back about 13 slides ago …

- Previously we mentioned that the **Strong Force** also has a component called **Color Force** that holds the **Quarks** together to create the individual **Hadrons**
- **Strong Force** is carried by **Gluons**



Gluon

- No mass
- No charge
- A momentum property called spin

- They also carry **Color** and **Anti Color**

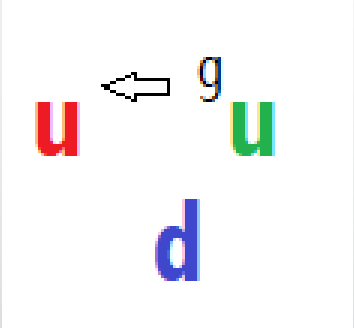
Okay … what is Color

- First, its spelt "Color" because it's a name (proper noun) like 'Charleen' and not a term like 'behaviour' that is spelt differently in different versions of English
- Sorry OCD people, I realise that this hurts; tough!

- Quarks have a property, related to energy that is called Color.
  - There are three Colors 'red', 'green', 'blue'
  - Each Quark is 'charged' with a Color
  - A Baryon must be Color neutral (have one each of RGB)

Gluons travel between Quarks

- Gluons move from one Quark to another continually changing the Color of the quark it left and the one it is absorbed by to maintain Color neutrality.



New Summary

- **Baryons** are made of 3 **Quarks**
- The **Quarks** have 1 of 3 **Colors** (red, green, blue)
- The **Baryon** must be Color neutral
- **Gluons** (a fundamental particle) travel between **Quarks** continually changing Colors to maintain Color Neutrality
- This is the **Color Force**, It is a component of the **Strong Force**
- Gluons carry both a Color and an anti Color

Full summary

- The **Strong Force** has two components;
- The **Strong Nuclear Force**, which is between Baryons
  - This component is carried by **Pions**
- The **Color Force** acts between the three **Quarks** holding them together to make a **Baryon**
  - **Color Force** is Carried by **Gluons**

The End