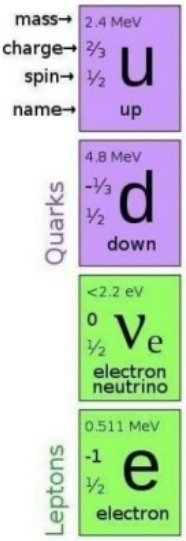
Fundamental Particles and the Standard Model by **Dr Nick Stapley**, on 10th December 2021

Dr Stapley introduced his talk by saying "Particles are the only things that exist in the Universe - except space itself (?)". They are also responsible for everything that happens in the Universe. Fundamental/Elementary particles are indivisible (although they can decay into other fundamentals). Four forces, mediated by **Bosons**, govern the way they interact:

- **Electomagnetism**, mediated by **Photons** (γ): the electromagnetic force between charged particles. It is the force that enables us to use muscles to overcome gravity.
- **Strong**, mediated by **Gluons** (g): a finite short range force, but one whose strength increases with range up to the size of a proton, and holds atoms together.
- **Weak**, mediated by $\mathbf{Z^0}$, $\mathbf{W^+}$or $\mathbf{W^-}$: a finite short range force, less than the diameter of an atomic nucleus, that relates to nuclear interactions. It enables nuclear reactors, including the Sun, to work.
- **Gravity**: the weakest of all forces, possibly mediated by the undetected **Gravititon** boson – it is not accommodated by the Standard Model.

Fermions make up all the matter in the Universe. These particles are named after Enrico Fermi, a pioneer in nuclear studies.

*Illustration of first (of three) generations of **Fermions**:*



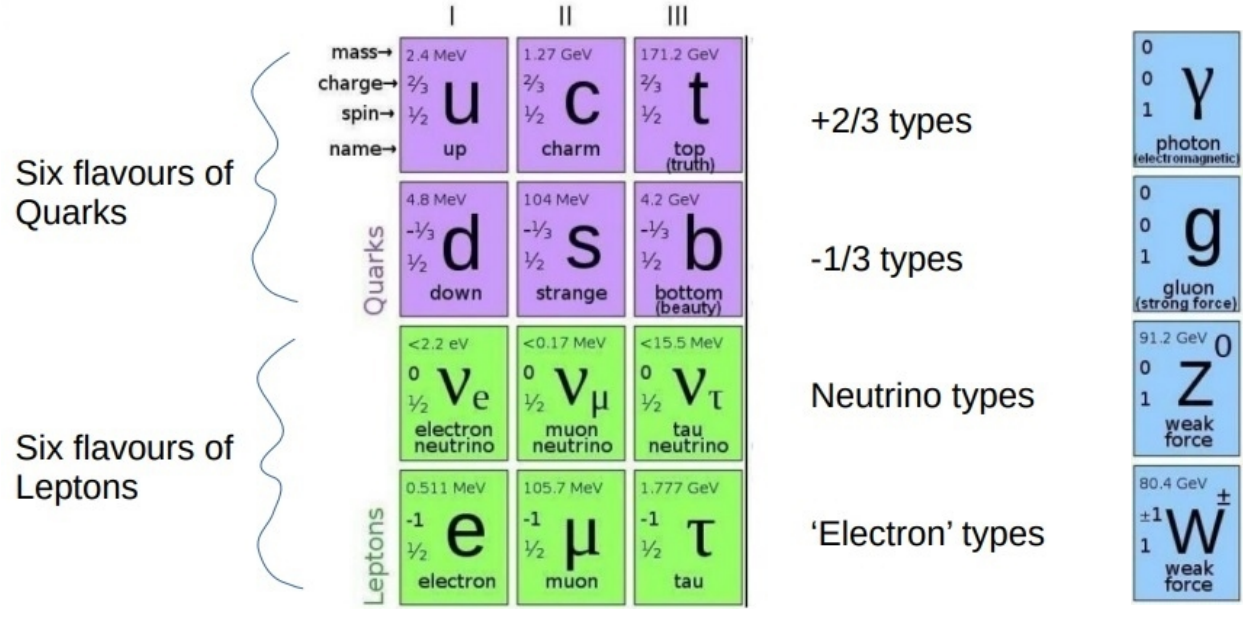
All particles have an antiparticle (with opposite charge to the particle if charged, although for bosons the antiparticle can be the same as the particle)

More than 99% of the (non-dark) matter in the Universe consists of protons, neutrons, and electrons which are, or consist of, first generation particles. Combinations of **quarks** must have integer charge - a **proton** comprises 2u + 1d; a **neutron** 2d + 1u. Note that: composite particles made of three quarks are called **baryons**, while particles made of two quarks (quark/antiquark pair) are called **mesons**. 'Hadron' is the collective term used for baryons and mesons.

A **lepton** is an elementary particle of spin ½. It does not undergo strong interactions. There are 12, of which six are quarks, 3 are **neutrinos** and 3 are '**electron** types'. The best known of all leptons is the **electron** itself.

About 10^{10} (100 billion) neutrinos pass through every cm^2 of your body per second, mainly emanating from the Sun, ca $1.5x10^{22}$ each year. There is a 25% chance you will stop one of them in your lifetime, converting a proton into a neutron or one element into another.

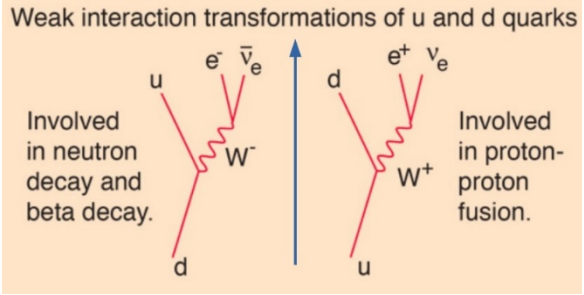
Fermions have 'Flavour'. The three generations are: together with **Bosons:**



Generations II and III decay to Generation I via weak nuclear interaction using W and Z particles – with associated flavour changes.

Colours - Baryons must have one quark of each colour: denoted Red, Green & Blue; combining to be colourless - or antiRed, antiGreen & anti/Blue; also combining to be colourless.
Mesons must consist of a quark-antiquark pair: Red/antiRed, Green antiGreen, Blue/antiBlue also colourless.

Weak Nuclear Force – this is mediated by the W^+, W^-, and the Z^0, a neutral particle - a bit like a heavy photon (ie a photon with mass). It is responsible for decay processes.



The W bosons are responsible for radioactivity by transforming a proton into a neutron, and vice-versa:

W^- is involved with neutron decay and beta decay; W^+ is involved in proton-proton fusion, allowing the sun to shine.

The Z^0 allows neutrinos to interact with each other changing one to another.

Strong Nuclear Force - Quarks have electric charge and also 'colour charge'. Colour charge is analogous to electric charge but comes in three types called red, green, and blue (+ and -). Just as electrically charged particles interact by photons, so quarks interact by **gluons** creating a colour field that binds them together. Gluons are confined to the nucleus with a range about the size of a proton. It becomes stronger the greater the distance between quarks. Since gluons have colour charge they can interact with each other - gluons have two colours.

A 'residual' nuclear force holds the protons and neutrons in a nucleus together via **pions**.

Gravity – this does not fit in with the Standard Model. **Gravitons** have not been detected – and technologically would be very difficult to detect.

However, General Relativity provides an excellent model of Gravity. General Relativity and Quantum mechanics do not play nicely together. One must be wrong.

Dark Matter (better called 'Transparent Matter') - This is real and has to exist to explain why (e.g.) galaxies don't fly apart. There must be 6 times as much dark matter as normal matter. It does not take part in nuclear fusion, nor does it interact electromagnetically neither reflecting nor absorbing em radiation, hence 'dark' (transparent) so you cannot see it. It does not mix well with 'normal' matter and is most likely (?) to be Weakly Interacting Massive Particles or WIMPs.