A2 Level Physics

Chapter 2 – Particles and radiation

2.4.1 Particle Interactions

Notes

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Four Fundamental Interactions (or forces)

Interaction/forces can be classified into four categories:

- **Strong interaction**

The force that holds nucleons together. Hadrons are particles that interact through a strong interaction.

- **Electromagnetic interaction**

The electric force between charged particles

- **Gravitational interaction**

The forces which govern the motion of planets around stars, moons around planets, etc…

- **Weak Interaction**

While the other forces/interactions above keep things together, the weak force is more responsible for things collapsing or decaying. The weak force, also known as the weak interaction, is stronger than gravity but only works over short distances. It has an effect at the subatomic level. The two types of beta (β) decay $(\beta^{-}\ and\ \beta^{+})$ from radioactive nuclei is caused by weak interaction.

All of the above interactions occur during particle interactions and have different properties.

Exchange Particles

Particle exchange is what causes the four fundamental forces. When two particles interact and exert a force on one another, something must occur to let one particle know the presence of the other. That's the idea behind exchange particles.

Exchange particles are how forces act between two particles, and we call them virtual particles since they only exist for a short period of time - just long enough to transfer energy, momentum, and any other properties before they vanish.

Each fundamental force has its own exchange particle, which is referred to as a gauge boson.

Type of Interaction	Gauge Boson	Particles Affected
Electromagnetic	Virtual photon (γ)	Charged particles only
Weak	W^{+}, W^{-} bosons	All types
Strong	Pions $(\pi^{+}, \pi^{-}, \pi^{0})$	Hadrons only

We don't actually know the gauge boson for gravity because we never found one. We think it is graviton but there is no evidence of that so it is not included in the table above.

The range of the forces is determined by the size of the exchange particle. The range will be small if the exchange particle is large, but the force will have a higher range if the exchange particle is small.

The weak interaction has a small range because W bosons are so heavy. As a result, creating a virtual W boson requires so much energy that it can only exist for a short time and travel only a short distance.

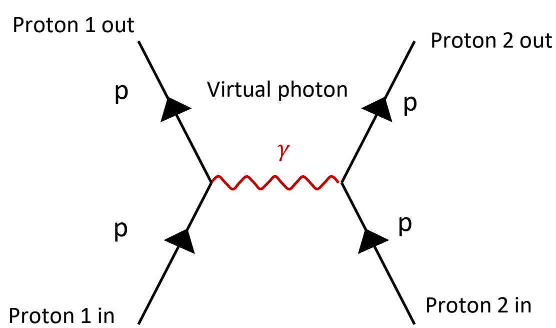
The photon, on the other hand, has no mass, hence the EM force has an infinite range.

Particle Interaction Diagrams (Feynman Diagrams)

Feynman diagrams (or particle interaction diagrams) show particle interactions, allowing us to visualise the process. There are many Feynman diagrams but they all follow the rules below:

- Exchange particles (gauge bosons) are represented as wiggly lines.
- All other particles are represented by straight lines.
- Time travels upwards, so particles enter from the bottom and exit from the top.
- Aside from neutral gauge bosons, every line must have an arrow pointing towards time.
- Baryons are on one side and leptons on the other.
- The total charge, baryon number and lepton number must be conserved at each vertex.
- Since W bosons carry charge, make sure the charges on both sides are balanced.
- Particle lines must not cross over.

The repulsion between two protons via the virtual photon is illustrated in the diagram below:



Particle Interaction Diagrams (Feynman Diagrams)

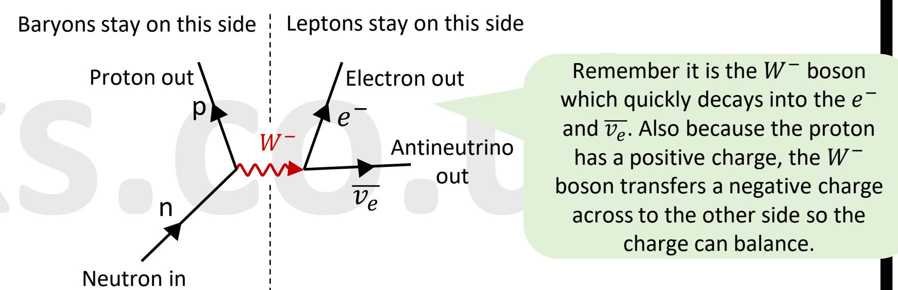
You'll need to know how to construct diagrams for a few different types of particle interactions caused by the weak interaction and electromagnetic force.

Beta-minus decay

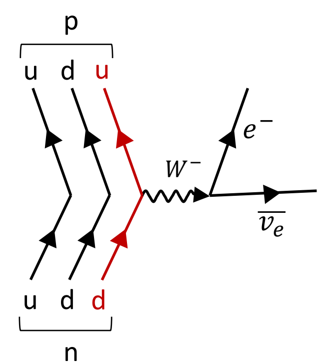
In this decay, a neutron decays into a proton, emitting an electron and an electron anti-neutrino.

$$n \rightarrow p + e^- + \overline{\nu_e}$$

Here one particle goes in and three particles come out. This means you'll need a neutron to enter the diagram from the bottom and move upwards. On the same side as the neutron, the proton will leave the diagram. On the other side of the diagram, the two leptons will leave.



You can draw particle interaction diagrams to show an interaction in terms of quarks too:



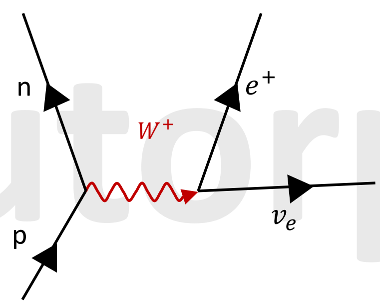
Particle Interaction Diagrams (Feynman Diagrams)

Beta-plus decay

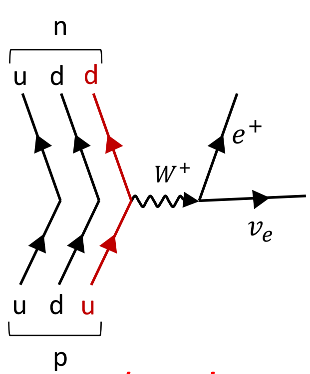
In this decay, a proton decays into a neutron emitting a positron and an electron neutrino.

$$p \rightarrow n + e^{+} + v_e$$

There is one particle that goes in and three that come out. This means you'll need a proton to enter the diagram from the bottom and move upwards. On the same side as the proton, the neutron will leave the diagram. On the other side of the diagram, the two leptons will leave.



The quark diagram is:



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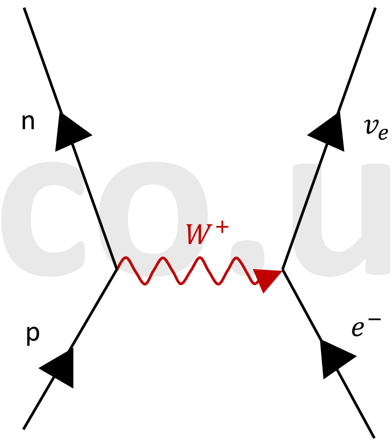
Particle Interaction Diagrams (Feynman Diagrams)

Electron Capture

This is when a proton-rich nuclei 'captures' an electron from within the atom and changes it into a neutron.

$$p + e^{-} \rightarrow n + v_e$$

The proton and electron will enter at the bottom of the diagram. The proton is then shown as decaying into a neutron, with the release of a W+ boson and the creation of a neutrino. To conserve the number of electron leptons, the electron neutrino is emitted.



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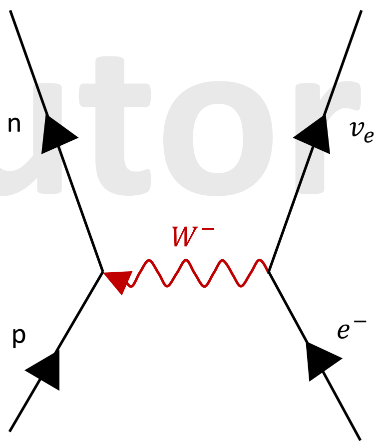
Particle Interaction Diagrams (Feynman Diagrams)

Electron-proton collisions

When a proton captures an electron from an atom, it is known as electron capture. However, an electron-proton collision is when an electron collides (at a high speed) with a proton. They practically have identical particle interaction diagrams and the exact same equation, however there is a difference.

In an electron-proton collision, the W boson is emitted from the electron.

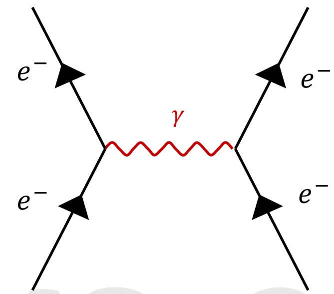
To conserve charge, it must be a W^- boson.



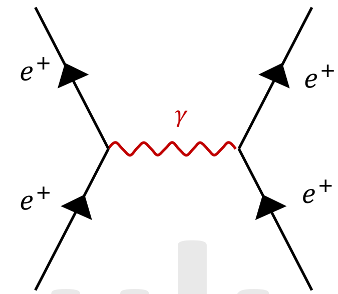
Particle Interaction Diagrams (Feynman Diagrams)

Electromagnetic repulsion

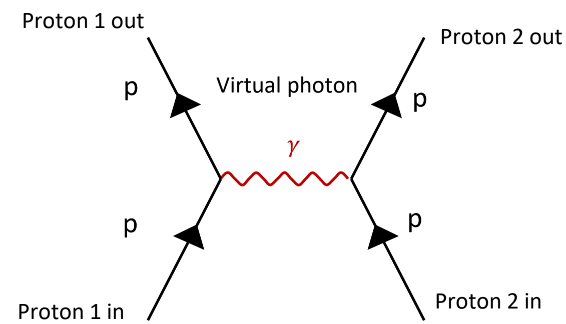
This is by far the simplest set of particle interaction diagrams. When two particles of equal charge are in close proximity, they repel one another. This is because of the electromagnetic force, which uses a virtual photon (γ) as an exchange particle.



A diagram showing two electrons repelling each other.



A diagram showing two positrons repelling each other.



A diagram showing two protons repelling each other.

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Please see '2.4.2 Particle Interactions worked examples' pack for exam style questions.

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