2.4 Particle interactions

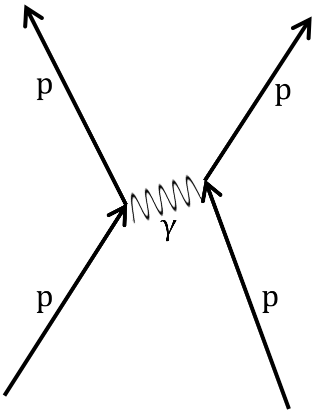
videos

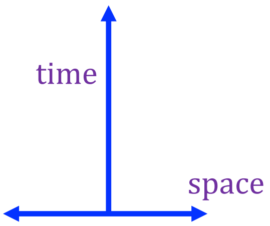
Particles interact through the four fundamental forces – the electrostatic force, the strong nuclear force, the weak nuclear force and gravitational force.

- *All particles with charge feel the electromagnetic force.*
- *All particles with mass feel the gravitational force.*
- *Only particles containing quarks experience the strong nuclear force.*
- *Both hadrons and leptons feel the weak nuclear force.*

A famous American physicist, Richard Feynman suggested that the interaction is achieved by the particles exchanging 'virtual particles'. In the case of charged particles (e.g. proton-proton), the electrostatic force experienced by the particles comes from an interaction achieved by the exchange of 'virtual photons'. Feynman came up with a visual way of describing these interactions. They are called Feynman diagrams.

Below is a Feynman diagram showing the electrostatic interaction between two protons.

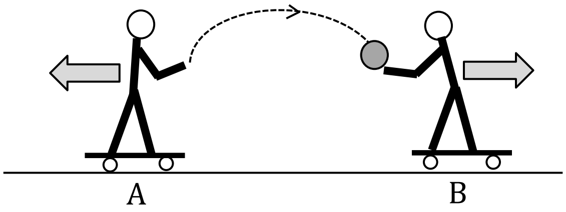




These diagrams should be read from bottom to top. This shows the events as time progresses. We can see from the example above that two protons move towards each other, exchange a virtual gamma (γ) photon and then move apart. (they repel each other). The wavy line represents the exchange of a virtual gamma photon.

A model for exchange

Below is a model to picture how exchange of virtual particles results in a force on two interacting particles.



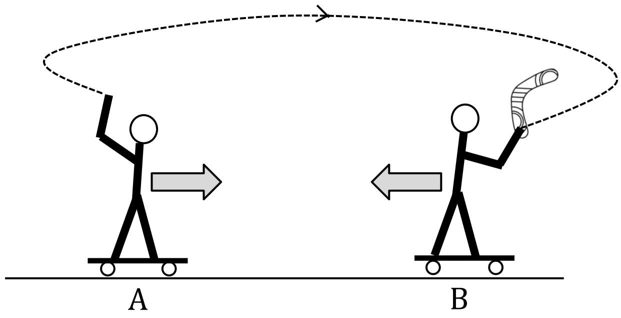
Skater A throws a heavy ball to skater B. Skater A experiences a force to the left. On catching, skater B experiences a force to the right.

(1)✏Using Newton's third law, explain why A moves to the left on throwing the ball.

(2)✏Using Newton's third law, explain why B moves to the right on catching the ball.

(3)✏Explain how the momentum of the system (containing two skaters) is conserved.

The second diagram models the effect of attraction between particles (e.g. electrostatic interaction between the electron and proton).



Person A throws a boomerang to the left, which pushes them to the right. Person B catches the boomerang, which moves them to the left. The overall effect is attractive.

The strong nuclear force

The strong nuclear force acts between all particles containing quarks, which are constituents of particles (neutrons and protons) in the nucleus. It acts over a very short range. The exchange particle acting between nucleons is the virtual pion.

(4)✏Over what range is the strong nuclear force attractive?

Gravitational force

The exchange particle for the gravitational force is the graviton. These haven't been detected yet.

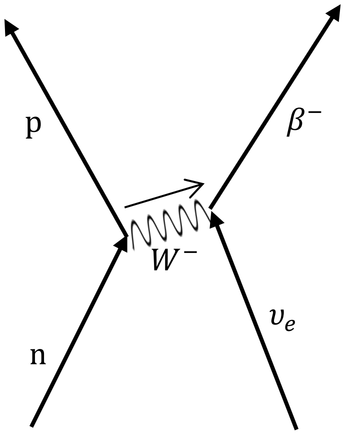
The weak nuclear force

The weak nuclear force is responsible for interactions which result in changes to the particles involved. W bosons are the exchange particles for the weak nuclear force.

Consider an interaction between an electron neutrino (v_e) and a neutron (n). (Such interactions are extremely rare.)

$$n + v_e \rightarrow p + \beta^-$$

We can see that the electron neutrino interacts with the neutron to produce a proton (p) and a beta minus particle (β^-). The Feynman diagram for this interaction is shown below:



Note: It is a good idea to draw an arrow to show the direction the exchange particle moves. In this case, we could substitute a W^+ boson moving in the opposite direction.

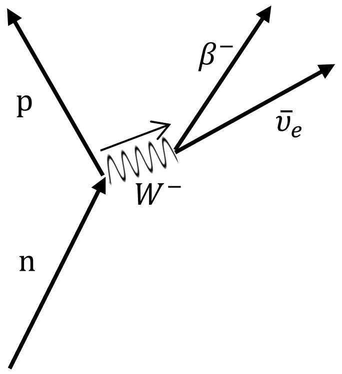
We can see the *W minus* exchange particle (W^-) is involved in changing a neutron into a proton. Note that the charge is conserved; the overall charge is zero before and after the interaction.

(5)✐An anti-electron neutrino ($\bar{v}_e$) can also (rarely) interact with a proton, producing a neutron and a beta plus (β^+)particle. A W^+ boson is the exchange particle. Draw a Feynman diagram for this interaction.

The weak nuclear force is responsible for changes which occur to nucleons during beta decay. For example, in beta minus decay, a neutron decays to a proton and emits a beta minus particle and an anti-electron neutrino:

$$n \Rightarrow p + \beta^- + \bar{v}_e$$

We can show this ‘weak interaction’ using a Feynman diagram:



In this case the exchange particle is a W^- boson.

You can see that charge is conserved as the W^- boson carries a negative charge away from the neutron to the β^-(an electron).

In beta plus decay, a proton changes to a neutron and emits a beta plus particle and an electron neutrino.

(6)✐Write a symbol equation for beta plus decay.

(7)✐Draw a Feynman diagram for beta plus decay.

Electron capture

In some cases, where a nucleus is proton rich, a proton will capture an inner shell electron and transform to a neutron.

(8)✐What other particle is produced by electron capture?

(9)✐Draw a Feynman diagram for electron capture.

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Electron-proton collision

In a collision between an electron and a proton, a neutron can be produced and another particle.

(10)✏What other particle is produced by electron-proton collision?

(11)✏Draw a Feynman diagram for electron-proton collision.