Particle Interactions

What is a force?

- We know that when a single force acts on an object, it changes the momentum (velocity/mass/energy) of an object.
- $\boxed{\text{Momentum} = \text{mass} \times \text{velocity}}$

- Newton's Third Law: When two objects, they exert equal and opposite forces on each other.
- Momentum is transferred between the objects by these forces, if no other forces act on them.

The Four Forces in Fundamental Interactions

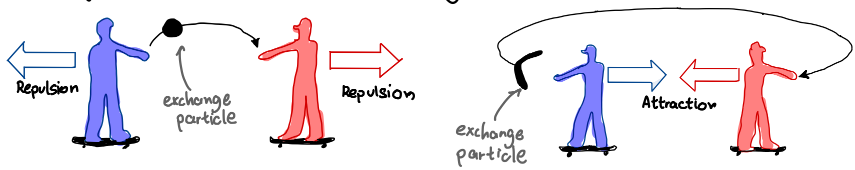
- Gravitational: Affects ALL matter - always attractive
- Strong: Holds the nucleus together. Also known as strong nuclear force / strong interaction. (Read above)
- Weak: Responsible for the radioactive decay of atoms. (Read below)
- Electromagnetic: A type of physical interaction between electrically charged particles. (Attractive / repulsion)

Why do electromagnetic forces (attraction and repulsion) happen?

- American Feynman researched that electromagnetic forces occur due to the exchange of virtual photons.

Interaction Analogy

- Repulsion: Two skaters throwing a ball to each other causes them to repel, as the ball transfers momentum from the thrower to the catcher. The people represent same-charged particles, and the ball represents an "exchange particle".
- Attraction: Two skaters throwing a boomerang to each other causes them to attract. Again, the people represent oppositely charged particles and the boomerang represents an "exchange particle".



The weak nuclear force

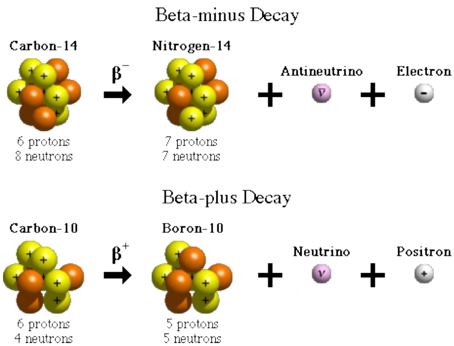
- As mentioned before, the strong nuclear force holds the neutrons and protons in a nucleus together. But it doesn't cause a neutron to change into a proton in β^- decay, or a proton to change into a neutron in β^+ decay.
- The particle conversions cannot be the electromagnetic force as neutron is uncharged.
- Gravity is not the force as well as they don't change particles.
- The strong nuclear force is also not the case for these decay as it involves particles other than hadrons (like electron and anti-neutrino)
- Hence there must be a different force at work causing these particle changes in beta plus/ minus decay.
- This is known as the weak nuclear force.

Why is the weak nuclear force weak?

- The force must be weaker than the strong nuclear force, otherwise it would affect the stable nuclei.

Neutrino / antineutrino interactions

- In both β^- decay and β^+ decay, a new particle and a new antiparticle are created in each type of decay.
- But unlike pair production, a corresponding particle-antiparticle pair is not created — as one is an electron/positron and the other is a neutrino/antineutrino.
- Neutrinos and antineutrinos hardly interact with other particles, but such interactions sometimes happen:
  - → A neutrino can interact with a neutron and make it change into a proton. A B^- particle (an electron) is created and emitted.
  - → An antineutrino can interact with a proton and make it change into a neutron. A β^+ particle (positron) is created and emitted.



Exchange Particles

- Exchange particles are how forces act between two particles. They are virtual particles.
- The electrostatic repulsion between two protons is caused by the exchange of virtual protons, which are the exchange particles of the electromagnetic force.
- Each four fundamental forces (strong, weak, gravity, electromagnetic) has its own exchange particle. These exchange particles are called gauge bosons.

How do exchange particles / Gauge bosons differ from each other?

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Fundamental Forces	Gauge bosons (exchange particles)	Particles Affected
Strong	Gluons (pions)	Hadrons only (protons, neutrons)
Electromagnetic	Virtual photon (γ)	Charged particles only
Weak	Z^0, W^+, W^- bosons	All particles
Gravitational	Graviton (not observed)	All particles

- The size of the exchange particle determines the range of the force.
- Heavier exchange particles have a SHORTER range. $\xrightarrow{\text{hence}}$ the force itself has a shorter range.
- W bosons (weak force exchange particle) have a mass of about 100 times that of a proton, which gives the weak force a very SHORT range. They could be positive (W^+) or negative (W^-) ← non-zero rest mass
- On the other hand, the photon has 0 mass, which gives the electromagnetic force an infinite range.

Feynman Diagrams for Particle Interaction

Rules for Feynman diagrams

- We only need to draw them for the weak interaction and the electromagnetic force (the proton-proton diagram to the right demonstrates the repulsive electromagnetic force.)
- Direction of time points upwards in the diagrams.
- Baryons

Proton - proton repulsion