The STRONG nuclear force

In the nucleus:

$\oplus \longleftrightarrow \oplus$

$\ominus \longleftrightarrow \ominus$

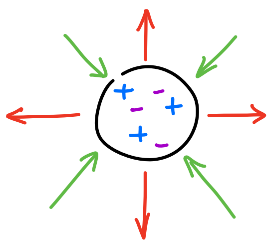
electrostatic repulsion

$\oplus$ —×— $\oplus$

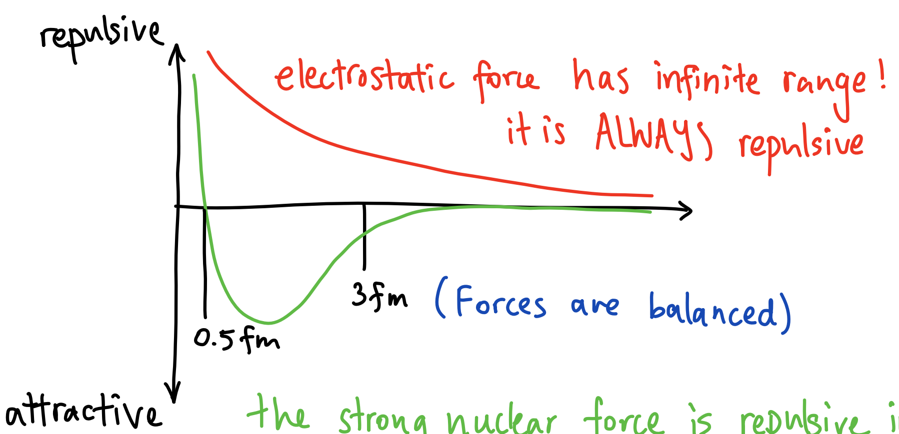
$\ominus$ —×— $\ominus$

$\oplus$ —×— $\ominus$

electrostatic attraction



Forces are balanced, stable nucleus



the strong nuclear force is repulsive in short range, attractive in long range and weakens to 0 strength at further ranges.

ALPHA (α) DECAY

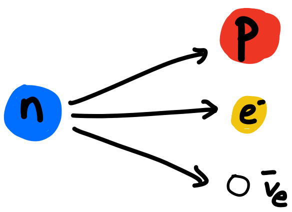
When a nucleus is too heavy, it loses 2 protons and 2 neutrons.

$$^{234}_{92}U \longrightarrow {}^{230}_{90}Th + \underbrace{{}^{4}_{2}He}_{\text{An } \alpha \text{ particle}}$$

← No electrons!

Beta (β) Decay

The proton stays in the nucleus!



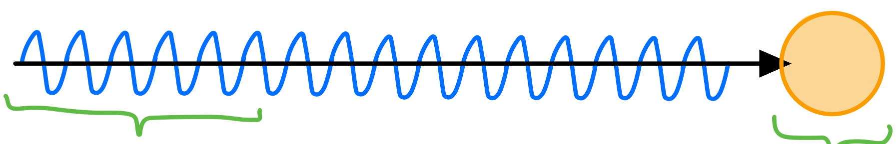
$$^{x}_{y}A \longrightarrow {}^{x}_{y+1}A^{+} + \underbrace{\beta^-}_{\substack{\text{beta particle} \\ \text{ie an electron}}} + \bar{\nu}_e$$

} antineutrino (electron antineutrino)

Neutron decays into a proton, an electron and an antineutrino.

Photons

Lights sometimes behaves like a particle.



light wave (em wave)

a "photon" (a packet of em waves)

$E = hf$

Energy of a photon = $\overbrace{\text{Planck's constant}}^{6.62607004 \times 10^{-34}}$ × frequency of the photon

$[J] = [Js^{-1}][s^{-1}]$

$E = hf = h\left(\frac{c}{\lambda}\right) = \frac{hc}{\lambda}$

AntiParticles

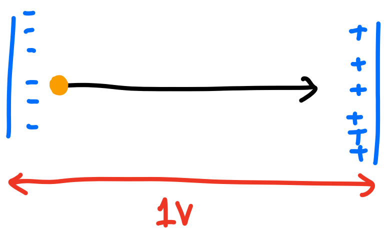
p^+	$\bar{p}$
proton	antiproton

$\Big\}$ Same rest mass and rest energy

Opposite Charge

Electron Volt

eV : Energy gained by an electron when accelerated across a P.D. of 1 volt.



$V = \frac{E}{Q}$

$E = VQ$

1 volt $\quad 1.60 \times 10^{-19}$ C (ie 1 electron)

$\therefore$ 1 eV = 1.60×10^{-19} J

1 MeV = 1.60×10^{-13} J

mega electron volts

$E = mc^2$

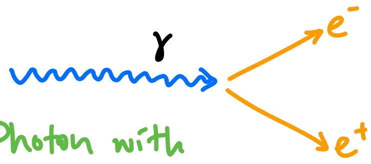
energy = mass × (speed of light)^2

Mass is energy! (Mass and energy is equivalent)

mass energy is called "rest energy".

Pair Production

Electrons & Positrons



electron (rest energy E)

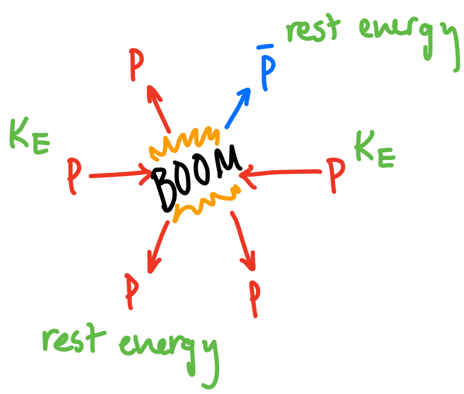
positron (rest energy E)

Photon with frequency f.
(And wavelength λ)

$$2E = hf = \frac{hc}{\lambda}$$

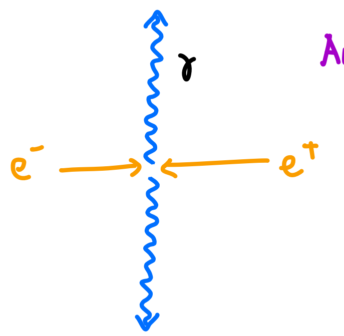
(photon created 2 particles with rest energy E)

Protons & Antiprotons



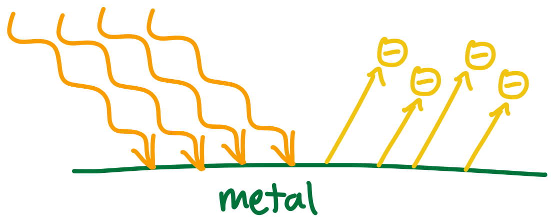
K_E from the 2 original protons is converted into rest energy of p and $\bar{p}$

Annihilation



An electron + a positron
↓
2 photons

The Photoelectric Effect



When frequency is too low, the electrons are not excited enough to escape

When frequency increases, the velocity of the electrons are higher

The energy of the photon is used to:

- Provide energy to free the electron (ie the work function ϕ)
- Give the electron velocity (ie kinetic energy E_k)

$$E = hf = \phi_{min} + E_{k\ max}$$

Work function: The minimum energy needed to remove an electron from the surface of a metal.

If E_k is 0, $\phi = hf$, $f = \frac{\phi}{h}$

threshhdd frequency (min. freq. for photoelectric effect)

$$hf = \phi + E_k$$

$$6.63\times10^{-34} \times 6.2\times10^{14} - 3.28\times10^{-20} = \phi$$

$$\phi = 3.7826\times10^{-19}\ J$$

Electron Excitation

Particle Interactions !

Interaction	Experienced By	Identified by
Electromagnetic	charged particles	photons involved
Strong	quarks (ie hadrons)	no photons, neutrinos and change of quark flavor. strangeness conserved.
Weak	everything	neutrinos involved change in quark flavor strangeness not conserved
Gravitational	everything	not significant ...

Quarks? interact via the STRONG FORCE/INTERACTION

Name	symbol	charge	strangeness	baryon #
up	u	$+\frac{2}{3}e$	0	$+\frac{1}{3}$
down	d	$-\frac{1}{3}e$	0	$+\frac{1}{3}$
strange	s	$-\frac{1}{3}e$	+1	$+\frac{1}{3}$
anti-up	$\bar{u}$	$-\frac{2}{3}e$	0	$-\frac{1}{3}$
anti-down	$\bar{d}$	$+\frac{1}{3}e$	0	$-\frac{1}{3}$
anti-strange	$\bar{s}$	$+\frac{1}{3}e$	-1	$-\frac{1}{3}$

Strangeness in conserved during formation (strong interaction)

strangeness changes by -1, 0, +1 during decay (weak interaction)

Leptons? do NOT interact via strong force/ interaction

Name	symbol	charge	L_e	L_μ
electron	e^-	-1e	+1	0
positron	e^+	+1e	-1	0
electron neutrino	ν_e	0	+1	0
antielectron neutrino	$\bar{\nu}_e$	0	-1	0
muon	μ^-	-1	0	+1
antimuon	μ^+	+1	0	-1
muon neutrino	ν_μ	0	0	+1
antimuon neutrino	$\bar{\nu}_\mu$	0	0	-1

Apart from strangeness, EVERYTHING IS CONSERVED.

tauons not included in table since they are out of syllabus.

HADRONS: (the heavy bois)

Particles made of QUARKS & ANTIQUARKS (doesn't matter how many)

Subcategories:

Baryon: Baryon # is always 1   Only the proton is stable

Particles made of 3 quarks

e.g. Proton: uud ⇒ +1 charge   Neutron: udd ⇒ 0 charge

Meson: Baryon # is always 0   No mesons are stable

Particles made of 1 quark & 1 anti-quark

Subcategories:

PION (π):

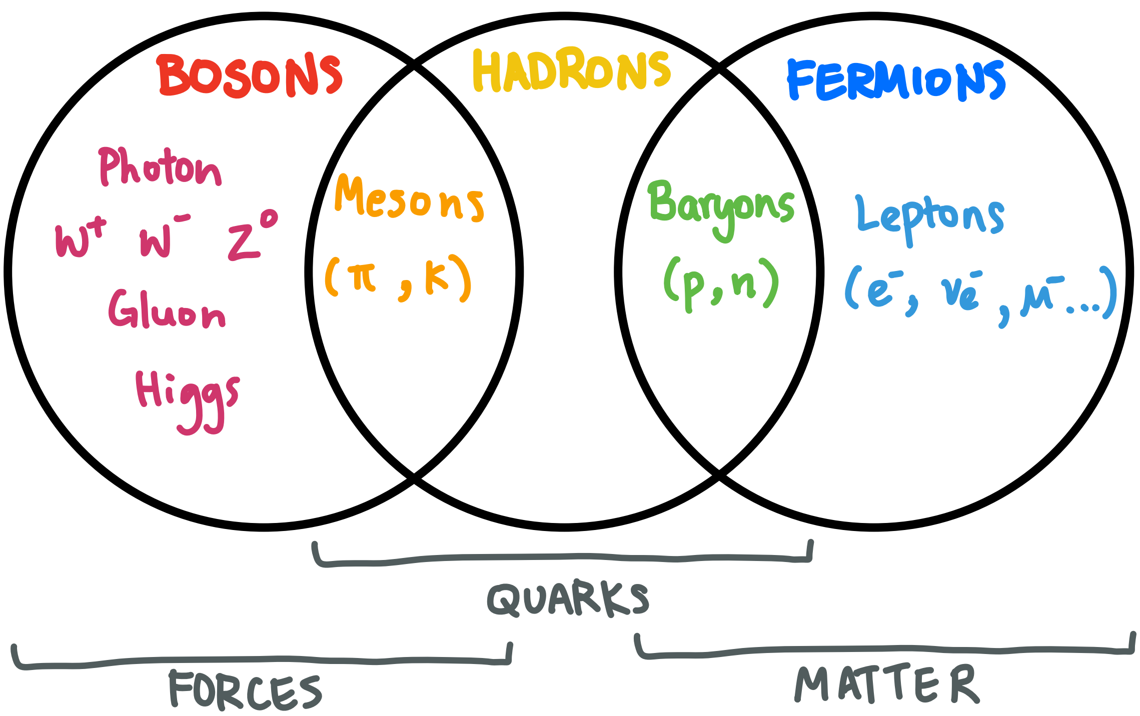
meson with NO STRANGE QUARKS

e.g. π^+ : $u\bar{d}$ π^0 : $u\bar{u}$ or $d\bar{d}$ π^- : $d\bar{u}$

KAON (K):

meson WITH STRANGE QUARKS

e.g. K^+ : $u\bar{s}$ K^0 : $d\bar{s}$ or $s\bar{d}$ K^- : $s\bar{u}$



Let's play a game called

Can this decay happen?

mesons ⟶ leptons and mesons (since all mesons decay)

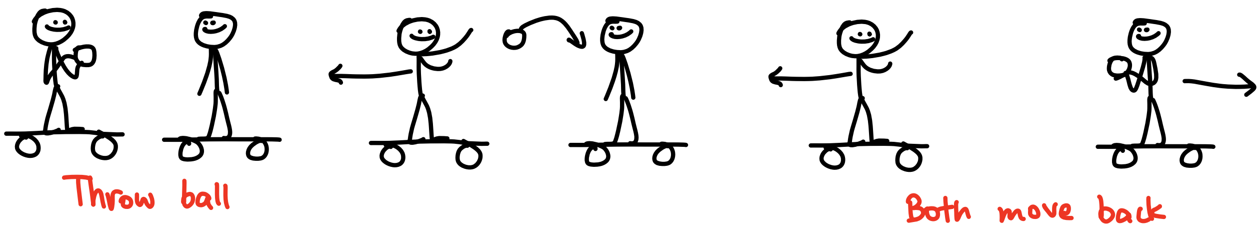
the conservation numbers: Charge, Baryon #, L_E, L_μ, (Strangeness)

compare LHS & RHS conservation numbers

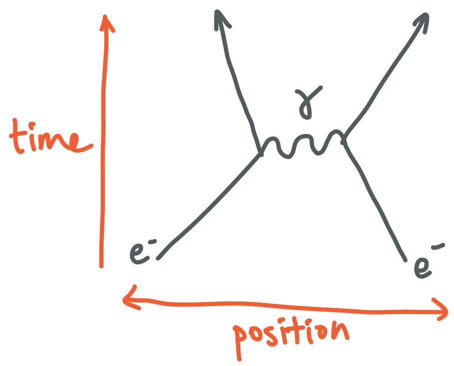
```
string CanThisDecayHappen(){
    if(charge, baryon #, L_E, L_μ, check out){
        if(strangeness checks out and no neutrinos involved){
            return "STRONG INTERACTION";
        }else{
            return "WEAK INTERACTION";
        }
    }else{

        return "THIS DECAY CANNOT HAPPEN";
    }
}
```

Gauge Bosons:

Virtual particles that cause interactions / exerts forces



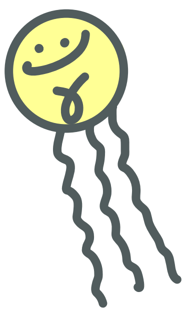
Feynman Diagrams!



electromagnetic force (electrons repel!)

Electromagnetic Force

(Virtual) Photon



AFFECTS CHARGED PARTICLES!

STRONG

Gluon

AFFECTS QUARKS!
(Out of syllabus)

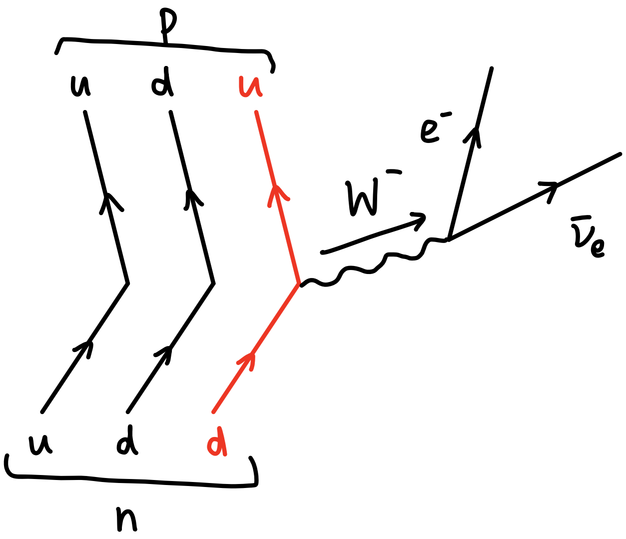
WEAK

$W^{\pm}, Z^0$ Boson

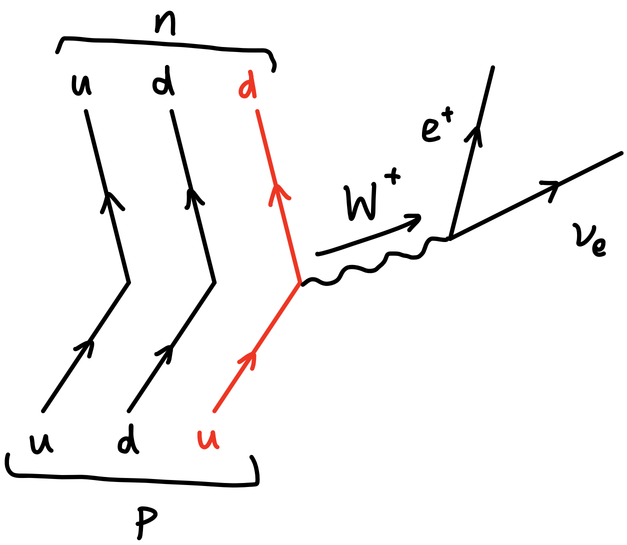
AFFECTS EVERYTHING!

THE 4 WEAK INTERACTIONS (The only 4 Feynman Diagrams you need to know)

Beta Minus (β^-)

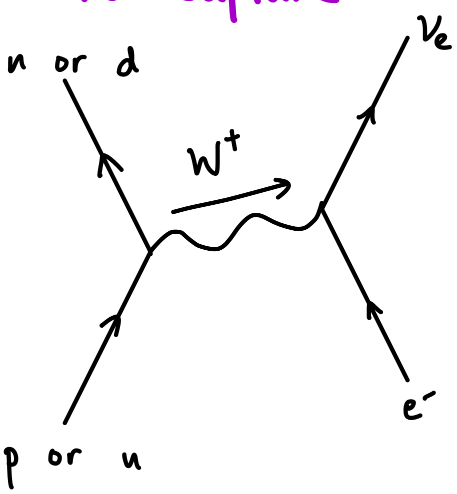


Beta Plus (β^+)



These are the same interaction, just described differently

Electron Capture



Proton Electron Collision