The Standard Model of Elementary Particles

Three Generations of Matter (Fermions)

	I	II	III	
Quarks	2.4 MeV, +⅔, ½, **u**, up	2.4 MeV, -⅔, ½, $\bar{u}$, anti-up	1.27 GeV, +⅔, ½, **c**, charm	1.27 GeV, -⅔, ½, $\bar{c}$, anti-charm
	171.2 GeV, +⅔, ½, **t**, top	171.2 GeV, -⅔, ½, $\bar{t}$, anti-top	0, 0, 1, **γ**, photon	
	4.8 MeV, -⅓, ½, **d**, down	4.8 MeV, +⅓, ½, $\bar{d}$, anti-down	104 MeV, -⅓, ½, **s**, strange	104 MeV, +⅓, ½, $\bar{s}$, anti-strange
	4.2 GeV, -⅓, ½, **b**, bottom	4.2 GeV, +⅓, ½, $\bar{b}$, anti-bottom	0, 0, 1, **g**, gluon	
Leptons	<2.2 MeV, 0, ½, ν_e, electron neutrino	<2.2 MeV, 0, ½, $\bar{\nu}_e$, electron-antineutrino	<0.17 MeV, 0, ½, ν_μ, muon neutrino	<0.17 MeV, 0, ½, $\bar{\nu}_\mu$, muon-antineutrino
	<15.5MeV, 0, ½, ν_τ, tau neutrino	<15.5MeV, 0, ½, $\bar{\nu}_\tau$, tau-antineutrino	91.2 GeV, 0, 1, Z^0, weak force	
	0.511 MeV, -1, ½, β^-, electron	0.511 MeV, +1, ½, β^+, positron	105.7 MeV, -1, ½, μ^-, muon	105.7 MeV, +1, ½, μ^+, anti-muon
	1.777 GeV, -1, ½, τ^-, tau	1.777 GeV, +1, ½, τ^+, anti-tau	80.4 GeV, ±1, 1, $W^\pm$, weak force	Bosons (Fores)

	Particle	Antiparticle
Mass	0.511 MeV	0.511 MeV
Charge	-1	+1
Spin	½	½
Symbol	β^-	β^+
Name	electron	positron

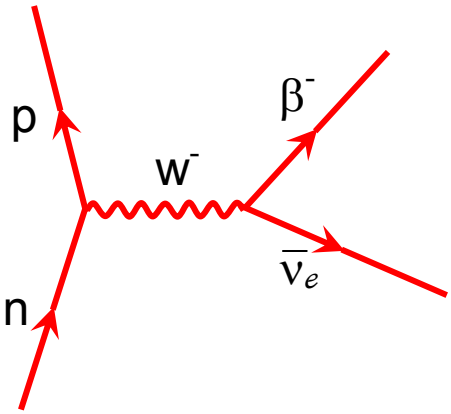
Feynman Diagrams Reference Sheet

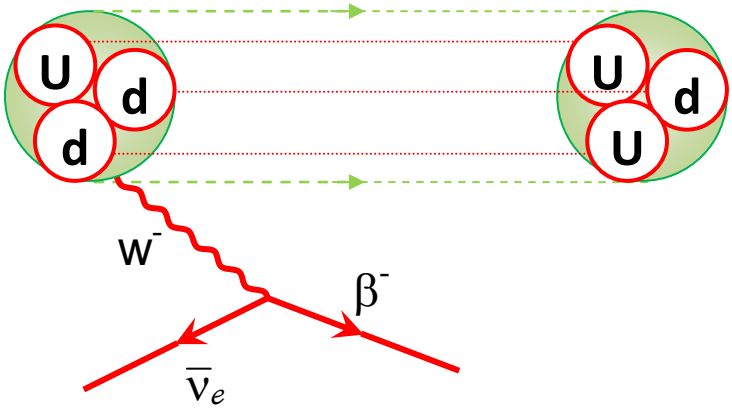
FERMIONS (Hadrons, leptons)

EXCHANGE PARTICLE (For AQA all interactions use this wavy line, institute of physics only recognizes this as a photon.)

The weak force

These interactions involve the weak force (w^+, w^- or z^o), see your standard model.

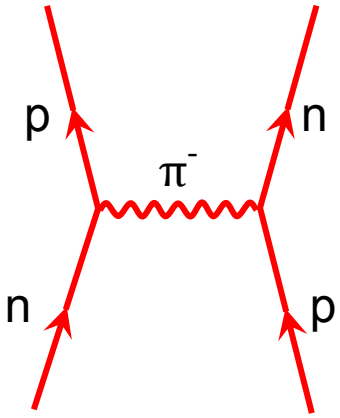




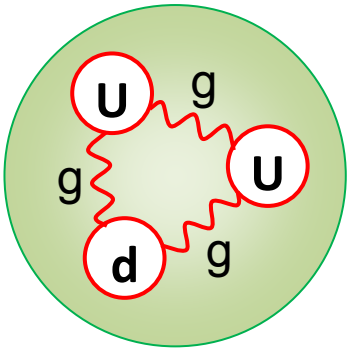
The Feynman diagram shows how a neutron can decay into a proton releasing a weak force **(intermediate vector boson).** This then releases an electron **(beta particle)** and an electron anti-neutrino. This decay changes the nature, **(or flavor)** of a quark within the nucleon as shown in the diagram on the right.

The strong force

These interactions occur between nucleons in the nucleus and quarks within nucleons

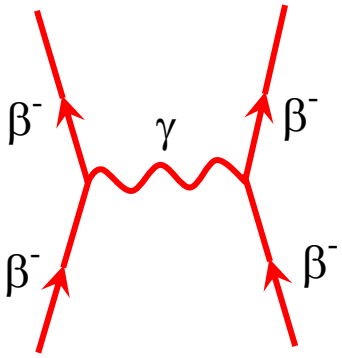


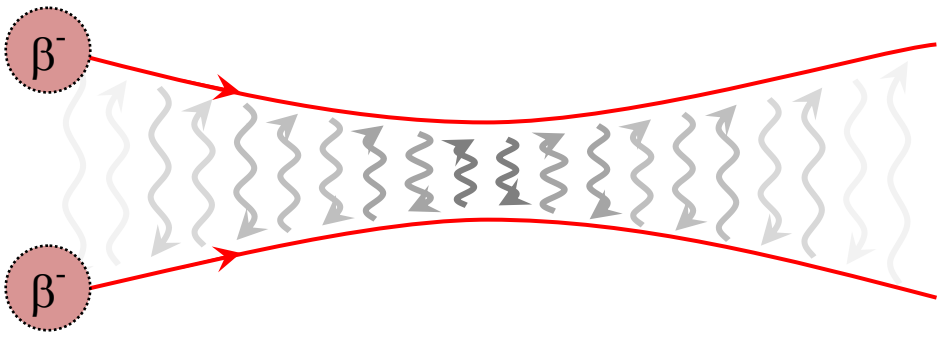
The Feynman diagram shows how a neutron can decay into a proton releasing a pion **(A Meson containing a strange quark).** This exchange of charged **pions** overcomes the repulsion between protons in the nucleus which would usually blow the nucleus to pieces. The diagram on the right shows the exchange of **gluons** which bind the quarks within a proton together. The same also happens in Neutrons



Electrical forces

These interactions occur between nucleons in the nucleus and quarks within nucleons





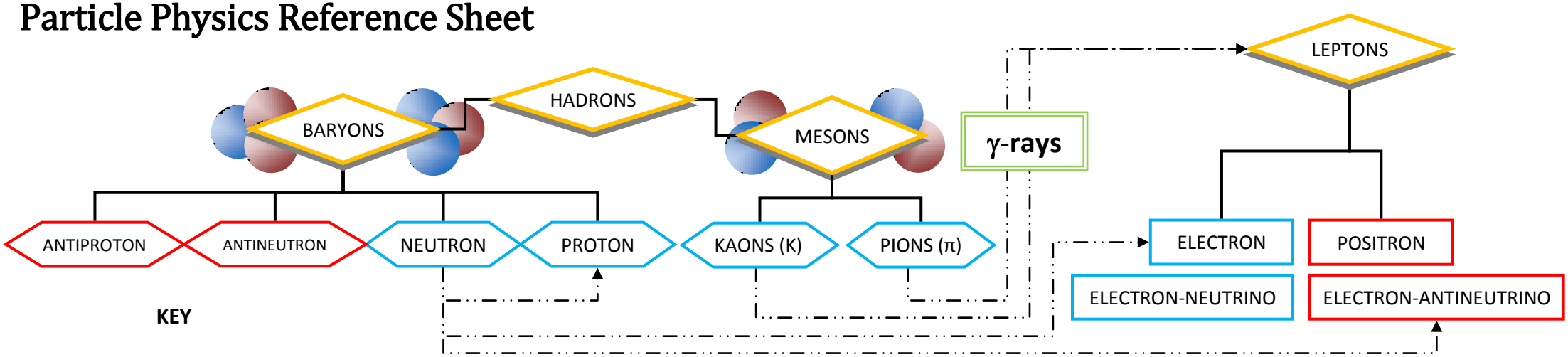
This Feynman diagram shows the exchange of a photon between two electrons resulting in the electrons moving away from each other in the same way as two ice skaters on a collision course would move away from each other if they kept throwing things at each other! The diagram above shows how the process is constant and involves many photons.

Be aware of the following notation, although it is not used in AQA exams and materials it may be used in other revision materials and physics textbooks.

GLUONS

BOSONS (w or z)

Particle Physics Reference Sheet



KEY

Rectangles indicate fundamental particles

Diamonds indicate types of particle

Pointed rectangles indicate particles made up of fundamental particles

RED = Antiparticles
BLUE = Particles

Indicates decay

HADRON	Quark constitution
Proton	u u d
Anti-proton	$\bar{u}\ \bar{u}\ \bar{d}$
Neutron	u d d
Anti-neutron	$\bar{u}\ \bar{d}\ \bar{d}$
Kaon (K^+, K^-, K^0)	$u\bar{s}$, $s\bar{u}$, $d\bar{s}$
Pion (π^+, π^-, π^0)	$u\bar{d}$, $d\bar{u}$, $d\bar{d}$ / $u\bar{u}$

Quarks	symbol	Charge/e	Baryon number	strangeness
Up	u	$+\frac{2}{3}$	$+\frac{1}{3}$	0
Anti-up	$\bar{u}$	$-\frac{2}{3}$	$-\frac{1}{3}$	0
Down	d	$-\frac{1}{3}$	$+\frac{1}{3}$	0
Anti-down	$\bar{d}$	$+\frac{1}{3}$	$-\frac{1}{3}$	0
Strange	S	$-\frac{1}{3}$	$+\frac{1}{3}$	-1
Anti-strange	$\bar{S}$	$+\frac{1}{3}$	$-\frac{1}{3}$	+1

LEPTON	Symbol	Lepton Number	Rest energy/MeV
Electron	β^-	+1	0.51
Positron	β^+	-1	0.51
Electron-neutrino	ν_e	+1	0
Electron-antineutrino	$\bar{\nu}_e$	-1	0
Negative muon	μ^-	+1	105
Positive muon	μ^+	-1	105
Muon-neutrino	ν_μ	+1	0
Muon-antineutrino	$\bar{\nu}_\mu$	-1	0
Negative tau	τ^-	+1	1780
Positive tau	τ^+	-1	1780
Tau-neutrino	ν_τ	+1	0
Tau-antineutrino	$\bar{\nu}_\tau$	-1	0