Pages 38–40 Exam practice questions

1 a) Hadrons are subject to the **strong force**. [1]

b) Quark, antiquark pair, $q\bar{q}$. [1]

c) Three quarks, qqq [1]

d) Similar: mass–energy. [1] Different: Opposite: charge; baryon number [1]

e) i) Q = –1e [1]

ii) B = –1 [1]

iii) $\bar{u}\bar{u}\bar{d}$ [1]

2 a) Leptons: electron OR muon [1]

Hadrons: proton OR neutron OR pion [1]

b) Hadrons are subject to the strong force (leptons are not). [1]

c) Baryons comprise three quarks (or three antiquarks) and mesons comprise a quark-antiquark pair. [1]

b) Baryons: proton OR neutron[1]

Meson: pion [1]

3 a) One mark per correct row:

Sub-atomic particle	Quark structure	Baryon OR meson	Relative charge	Baryon number	Strangeness
Pion$^+$	$u\bar{d}$	meson	**+1**	0	**0**
Neutron	udd	**baryon**	0	+1	0
Σ^+, sigma$^+$	**uus**	**baryon**	+1	**+1**	–1

b) E.g. Proton: uud and antiproton: $\bar{u}\bar{u}\bar{d}$.

c) Same: mass–energy (OR strangeness OR baryon number) [1]; Different: charge OR lepton number [1]

4 a) Electromagnetic [1]; photon [1]

b) Charge OR lepton number (OR baryon number OR strangeness) [1]

c) A: neutron [1]; B: electron-neutrino [1]; C: W^+

d) Electron capture [1]

e) Charge OR baryon number OR lepton number [any two 1]

Conservation quantity	Before interaction			After interaction			Quantity conserved?
	p	e^-	Total	n	ν_e	Total	
Q	+1	–1	0	0	0	0	✓
B	+1	0	+1	+1	0	+1	✓
L	0	+1	+1	0	+1	+1	✓

[1 mark for each row]

f) Models are used in physics to order or explain experimental observations.
Models can make predictions about (as yet) unobserved physics.
Observations confirm/disprove (or lead to further experiments) model.
A model cannot be used successfully if it predicts the existence of something that does not exist in reality. [Any 3]

5 a) Weak interaction, as it involves leptons; W^- exchange particle. [1]

b) Charge OR lepton number (OR baryon number) [2]

c) Strange particles are created by the strong interaction but decay via the weak interaction OR strange particles contain the strange quark. [1]

d) $K^+ \rightarrow \mu^+ + \overline{\nu_\mu}$ is not possible as it violates law of conservation of lepton number.

e) Weak interaction.

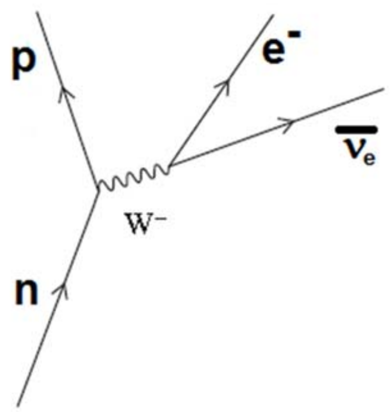
f) X must be a meson with lepton number = 0 as μ^- has L = +1 and $\bar{\nu}_\mu$ has L = –1. [1] It cannot be a baryon as that would violate baryon conservation (all the other particles have B = 0). [1]

g) Zero charge. [1]

6 a) ${}^1_0\text{n} \rightarrow {}^1_1\text{p} + {}^{\ 0}_{-1}\text{e} + \overline{\nu_e}$

b) In order for lepton number, L to be conserved [1], as the electron emitted has L = +1, the other lepton must be an antineutrino with L = –1. [1] (Neutron and proton have B = 0).

c)



Correct particle symbols [1]

Correct exchange particle [1]

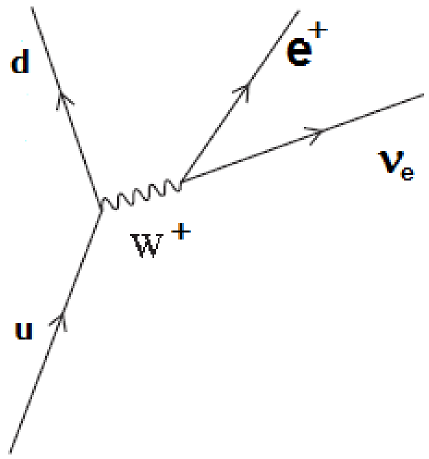
Correct connections of diagram [1]

d) Electron-neutrino [1]

e) Na-23 – baryons [1]; positron – lepton [1]; electron-neutrino – lepton [1].

f) Neutron – udd [1]; Proton – uud [1]

g)



Correct particle symbols [1]

Correct exchange particle [1]

Correct connections of diagram [1]

7 a)

Conservation quantity	Before interaction			After interaction			Quantity conserved ?
	p	e^-	Total	n	ν_e	Total	
Q	+1	−1	0	0	0	0	✓
B	+1	0	+1	+1	0	+1	✓
L	0	+1	+1	0	+1	+1	✓

b) Electron capture: ${}^{40}_{19}\mathrm{K} + {}^{0}_{-1}\mathrm{e} \rightarrow {}^{40}_{18}\mathrm{Ar} + \nu_e$ [1]

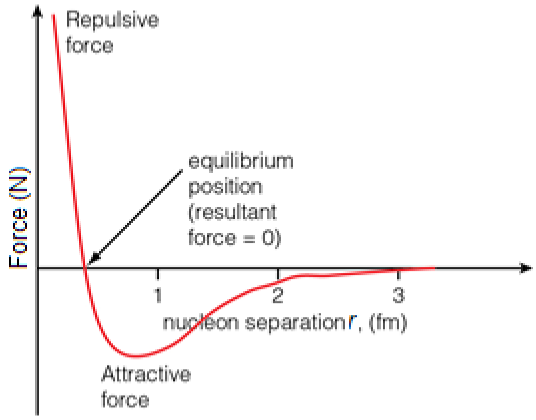
Positron emission: ${}^{40}_{19}\mathrm{K} \rightarrow {}^{40}_{18}\mathrm{Ar} + {}^{0}_{+1}\mathrm{e} + \nu_e$ [1]

Beta minus decay: ${}^{40}_{19}\mathrm{K} \rightarrow {}^{40}_{20}\mathrm{Ca} + {}^{0}_{-1}\mathrm{e} + \bar{\nu}_e$ [1]

8 a) Similarity: Same charge [1]. Differences: Protons are baryons, positrons are leptons OR different mass–energy OR protons contain quarks, positrons do not [1]

d) Gravity – graviton; strong – gluon; weak - $W^{\pm}$, Z; electromagnetic – photon [All correct = 3; 2 correct = 2; 1 correct = 1]

c) Best described by drawing the graph:



Repulsion/attraction in correct place [1]

Equilibrium position identified [1]

Values (approx.) [1]

d) Strong force [1] – exists only between quarks, positron is not a quark. [1]

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- Pions are mesons.
- Muons are leptons.
- Other mesons e.g. kaon
- Other leptons: electron; electron-neutrino; muon-neutrino; (tau and antiparticles)
- Properties in common: charge; mass–energy; zero baryon number; interact via the weak interaction
- Charged pions and the muon can interact with other charged particles via the electromagnetic interaction.
- Pions and muons can interact with other particles via the weak interaction.
- Pions and muons are attracted to each other via the gravitational force because they have mass.
- Pions can interact with other hadrons via the strong interaction.

[Any 6]

Page 41 Stretch and challenge questions

10 a) Sigma$^+$ = uus

b) π^+ = pion$^+$ = u$\bar{d}$; n = neutron = udd

c) Charge OR baryon number (OR lepton number)

d) Strangeness

e) Weak interaction.

f) ${}^{1}_{0}\text{n} \rightarrow {}^{1}_{1}\text{p} + {}^{0}_{-1}\text{e} + \overline{\nu_\text{e}}$ Correct particles; correct ${}^{A}_{Z}\text{X}$ notation

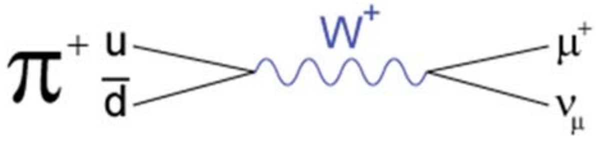
11 a) Weak interaction

b) 1. u quark; 2 or 3. Electron anti-neutrino $\bar{\nu}_e$; 3 or 2. electron e$^-$

12 a) Weak interaction [1]

b) W^+

c)



d) Multiplying both sides by *c* and squaring:

$$c^2{p_1}^2 = c^2{p_2}^2$$

And

$$E_1 + E_2 = Mc^2$$

Using

$$E^2 = c^2p^2 + {m_0}^2c^4$$

Substituting

$$c^2{p_1}^2 = {E_1}^2 - {m_1}^2c^4$$

And

$$c^2{p_2}^2 = {E_2}^2 - {m_2}^2c^4$$

Hence

$${E_1}^2 - {m_1}^2c^4 = {E_2}^2 - {m_2}^2c^4$$

Or

$${E_1}^2 - {E_2}^2 = (E_1 + E_2)(E_1 - E_2) = ({m_1}^2 - {m_2}^2)\,c^4$$

Dividing by:

$$E_1 + E_2 = Mc^2$$

$$E_1 - E_2 = \frac{({m_1}^2 - {m_2}^2)c^2}{M}$$

And adding to

$$E_1 + E_2 = Mc^2$$

$$E_1 = \frac{\left(M^2 + {m_1}^2 - {m_2}^2\right)c^2}{2M}$$

And

$$E_2 = \frac{\left(M^2 + {m_2}^2 - {m_1}^2\right)c^2}{2M}$$

e) Using

$|p_1| = |p_2|$ and $E^2 = c^2p^2 + {m_0}^2c^4$

$$cp_1 = cp_2 = \sqrt{\left({E_1}^2 - {m_1}^2c^4\right)} = \sqrt{\left({E_2}^2 - {m_2}^2c^4\right)}$$

$$E_\mu = \frac{(139.6^2 + 105.7^2 - 0^2)}{2 \times 139.6} = 109.8\ \text{MeV}$$

Hence the kinetic energy is:

$$E_k = E_\mu - m_\mu c^2 = 109.8 - 105.7 = 4.1\ \text{MeV}$$