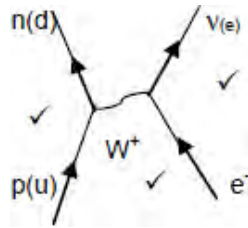


Particle Physics MS

- M1.** (a) (i) quark antiquark pair OR $\overline{q}q$ OR named quark antiquark pair ✓ 1
- (ii) 0 ✓ 1
- (iii) $\overline{u}s$ ✓ 1
- (b) (i) Weak ✓ any of the following also score 1 mark:
- weak interaction
 - weak interaction force
 - weak nuclear
 - weak nuclear interaction
 - weak decay
 - weak force
 - weak nuclear force
- (ii) conserved: baryon number, charge, lepton number, spin ✓ ✓ 1
- not conserved: strangeness ✓ 3
- (iii) $K^- \rightarrow \pi^0 + e^- + \overline{\nu}_{(e)}$ ✓ ✓ 2
- OR $K^- \rightarrow \pi^0 + \mu^- + \overline{\nu}_{(\mu)}$ 2
- [9]**

- M2.** (a)
- | | |
|-----------------|---------------------------|
| interaction | exchange particle |
| weak | W^+ OR W^- OR Z^0 ✓ |
| electromagnetic | photon OR γ ✓ |
- 2
- (b) uud ✓ 1
- (c) (i) an **atomic/orbital/shell** electron ✓
- interacts with a proton in the **nucleus** (via the weak interaction) ✓ 3

(ii) neutron formed **or** u quark changes to d quark (and neutrino released) ✓



3

[9]

M3. (a) (i) Z^0 with the weak interaction
 gluons or pions with the strong nuclear force
 γ photons with electromagnetic interaction
 gravitons with gravity
 (any exchange particle **(1)** and corresponding interaction **(1)**)

(ii) transfers energy
 transfers momentum
 transfers force
 (sometimes) transfers charge any two **(1)(1)**

4

(b) $p \bar{n} \pi^0$ **(1)**

$V_e e^+ \mu^-$ **(1)**

$\bar{n} e^+$ **(1)**

$p e^+ \mu^-$ **(1)**

4

[8]

M4. (a) baryon number $0 + 1 = 1 + 0$ **(1)**
 lepton number $0 + 0 = 0 + 0$ **(1)**
 charge $0 + 1 = 0 + 1$ **(1)**

3

(b) K^0 $\bar{s}d$ (1)

π^+ $u\bar{d}$ (1)

p udu (1)

correct number of quarks and antiquarks in each (1)

4

[7]

M5. (a)

particle	quark structure	charge	strangeness	baryon number
proton ✓	uud	+1 ✓	0	1 ✓
sigma ⁺	uus	+1	-1 ✓	1 ✓
π^+ ✓	$u\bar{d}$	+1 ✓	0	0

7

(b) (i) examples:
proton, antiquarks ✓

1

(ii) consists of 3 antiquarks ✓

1

(iii) same (rest) mass (energy) ✓
difference eg baryon number/charge ✓

2

[11]

M6. (a) (i) any two eg proton, neutron ✓✓

2

(ii) $u\bar{d}$ ✓

1

- (b) (i) contains a strange quark
or longer half life than expected
or decays by weak interaction ✓ 1
- (ii) the second one is not possible ✓
 because lepton number is not conserved ✓ 2
- (c) (i) weak (interaction) ✓ 1
- (ii) mention of charge conservation
or charge conservation demonstrated by numbers ✓ 1
- (iii) X must be a baryon ✓
 baryon number on right hand side is +1 ✓ 2
- (iv) proton/p ✓ 1

[11]

- M7.** (a) (i) positron, neutron, neutrino, positive pion **(1) (1)** (if all correct)
 (lose **(1)** for each error)
- (ii) electron, proton, negative muon **(1) (1)** (if all correct)
 (lose **(1)** for each error) 4
- (b) (i) $(\mu^-) \rightarrow e^- + \bar{\nu}_e + \nu_\mu$ **(1)**
- (ii) difference: mass or half-life or generation of lepton **(1)**
 similarity: both leptons or both negatively charged **(1)** 3

(c)



3

[10]

- M8.** (a) (i) leptons do not experience the strong interaction but hadrons do **or** hadrons not fundamental/made of quarks and leptons are not **(1)** 1
- (ii) hadron eg proton, neutron, pion **(1)**
lepton eg electron, neutrino **(1)** 2
- (iii) baryons **(1)**
mesons **(1)**
baryons made from **three quarks** (or **3 antiquarks**), mesons a **quark, antiquark** pair **or** baryons, baryon number is **+1 or -1** mesons 0 **(1)** 3
- (b) baryon number, lepton number, charge, strangeness, energy or momentum **(1)**
demonstration of conservation (before and after considered and number appropriate to particle quoted) **(1)** 2

[8]

- M9.** (a) (i) particles that experience the strong (nuclear) force/interaction **(1)** 1
- (ii) particles composed of **three quarks** **(1)** 1
- (iii) particles composed of a quark and an antiquark **(1)** 1
- (b) similarity: but the same (rest) mass **or** rest energy **(1)**
difference: **opposite** quantum states eg charge **(1)** 2

(c)

	charge/C	baryon number	quark structure
antiproton	-1.6×10^{-19}	-1	$\bar{u}\bar{u}\bar{d}$

-1 for each error 2

(d) (i) weak interaction **(1)**

strange not conserved or there is a change/decay of quark (flavour) **(1)**

2

(ii) **any two**

eg charge

baryon number

(muon) lepton number

2

[11]

M10. (a) (i) $q\bar{q}$; qqq ; $\bar{q}\bar{q}\bar{q}$

(1)(1)(1) for just two combinations)

(ii) $\pi^+ = u\bar{d}$ **(1)**

$\bar{p} = \bar{d}u\bar{u}$ **(1)**

4

(b) (i) strangeness = -3

charge = -1

baryon number = +1

lepton number = 0

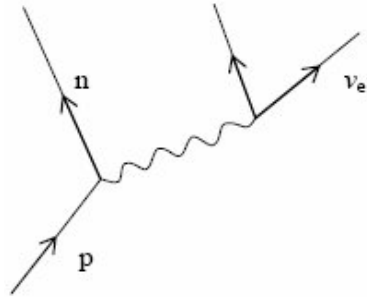
(1)(1)(1) if all correct – lose one for each error

(ii) the proton **(1)**

4

[8]

- M11.** (a) n (1)
 p (1)
 ν_e (1)



3

- (b) (i) γ photon (1)
 (ii) γ is massless
 γ has infinite range
 γ does not carry charge

(1)(1) any two

3

- (c) (i) all properties/quantum numbers (e.g. charge, strangeness) are opposite (1)

but the masses are the same (1)

- (ii) π^0 (1)

\bar{K}^0 (1)

γ (1)

5

[11]

- M12.** (a) (i) (named force) from weak (nuclear), electromagnetic or gravity (1)
 uses a mediating/exchange particle, named particle from $W^{(\pm)}$ (boson), (γ) photon or graviton (1)
 to transfer energy/momentum (1)
 when electron emits/receives exchange particle, disappearance/creation of new particle occurs (1)

QWC 1

- (ii) anti proton (1)

max 4

- (b) (i) 3 (quarks) **(1)**
- (ii) weak (nuclear) **(1)**
- (iii) proton **(1)**

3

[7]