M1.(a) **The student's writing should be legible and the spelling, punctuation and grammar should be sufficiently accurate for the meaning to be clear.**

The student's answer will be assessed holistically. The answer will be assigned to one of three levels according to the following criteria.

High Level (Good to excellent): 5 or 6 marks
The information conveyed by the answer is clearly organised, logical and coherent, using appropriate specialist vocabulary correctly. The form and style of writing is appropriate to answer the question.

Student names strong, weak and electromagnetic interactions. Identifies that only hadrons experience the strong interaction but hadrons and leptons experience weak interaction. Charged particles experience electromagnetic interaction. Is able to identify all exchange particles such as gluons, W+ and W- and virtual photons. Gives examples of two of the interactions i.e. electrons repelling, electron capture, beta decay.

Intermediate Level (Modest to adequate): 3 or 4 marks
The information conveyed by the answer may be less well organised and not fully coherent. There is less use of specialist vocabulary, or specialist vocabulary may be used incorrectly. The form and style of writing is less appropriate.

Student names strong, weak and electromagnetic interactions. Identifies that only hadrons experience the strong interaction but hadrons and leptons experience weak interaction. Charged particles experience electromagnetic interaction. Is able to identify some exchange particles such as gluons, W^+ and W^- and virtual photons.

Low Level (Poor to limited): 1 or 2 marks
The information conveyed by the answer is poorly organised and may not be relevant or coherent. There is little correct use of specialist vocabulary. The form and style of writing may be only partly appropriate.

Student names strong, weak and electromagnetic interactions. Identifies that only hadrons experience the strong interaction. Identifies one exchange particle.

The explanation expected in a competent answer should include a coherent selection of the following points concerning the physical principles involved and their consequences in this case.

Names of interactions – strong, weak and electromagnetic

hadrons experience strong
hadrons and leptons experience weak
charged particles experience electromagnetic
identify exchange particles
give examples of various interactions e.g. electron capture
(either weak interaction or electromagnetic or strong interaction)
first mark conservation at left hand junction of charge, baryon and lepton number ✓
second mark conservation at right hand junction of charge, baryon and lepton number ✓
third mark for correct exchange particle ✓

ignore any reference to gravity
ignore any Feynman diagrams electrostatic not allowed as alternative for electromagnetic

Properties of interactions

- *correct exchange particle ($W^{(+/-)}$boson / Z_0 boson, (virtual) photon, gluon / pion) NB sign on W not required*
- *correct group of particles affected (strong: baryons andmesons, weak: baryons, mesons and leptons, electromagnetic: charged particles)*
- *example of the interaction*

Lower band

1 mark – two interactions OR one interaction and one property for that interaction

2 marks – two interactions and one property for one interaction

Middle band

3 marks – two interactions plus two properties

4 marks – two interactions plus minimum of four properties (e.g. 3 props plus 1 OR 2 props plus 2), if three interactions quoted then properties can be spread between the 3 e.g. one property for each (3) plus one additional

Top band

5 marks – 3 interactions plus two properties for each

6 marks – must give first two properties for all three interactions AND correctly state two examples of interactions e.g. electron capture example of weak, strong nuclear responsible for binding protons / neutrons / baryons together

A table may help:

	strong	weak	EM
property 1			
property 2			

property 3			

(b)

if exchange particle not identified but baryon and lepton numbers conserved on both sides − 1 mark
ignore orientation of line showing exchange particle or any arrows on exchange particle line when awarding first two marks

if arrows on incoming and outgoing interacting particles in wrong direction then lose mark

if lines do not meet at a junction lose 1 mark
***with third mark** orientation of exchange*
particle line must be consistent with exchange particle shown and no arrow required

if exchange particle line is horizontal (for weak) then must be a correct arrow
arrow overrides slope

3

[9]

M2.(a) (90,39)

B1

(0,-1)

B1

$\bar{\nu}^e$

B1

3

(b) d→u
or
Number of u quarks increases by 1 and number of d quarks decreases by 1

B1

1

(c) (i) Meson

Do not allow hadron

B1

1

(ii) Negative box ticked

B1

1

(iii) Characteristic of particles with strange quarks / they contain the strange quark / they have strangeness

B1

1

(iv) Gluon, W ($^{+}$ or $^{-}$) (boson) or Z^{o}

B1

1

[8]

M3.(a)

1✓

0✓ 1✓

…

ud✓ uud✓

1 mark each

5

(b) Strong nuclear circled✓

1

(c) Charge *1 + 1 = 1 + X* *X = 1*✓

1

Baryon number *0 + 1 = 0 + X* *X = 1*✓

1

Strangeness $0 + 0 = 1 + X$ $X = -1$ ✓

1

Any order

(d) Weak nuclear circled ✓

1

(e) Strangeness of X is -1,

First mark is for showing that strangeness changes

The strangeness of the pion and neutron are both zero

1

The strangeness changes from -1 to 0 ✓

This can only occur in weak interactions. ✓

Second is for stating that this can only happen if the interaction is weak.

1

(f) $\underline{\quad .}$

First mark is for the proton

1

$n \rightarrow p$ ✓ $+ \beta^- + \nu_e$ ✓

Second is for the beta minus and antineutrino.

1

(g) The only particles remaining are electrons / positrons and neutrinos / antineutrinos which are stable ✓

1

1

And a proton which is the only stable baryon ✓

1

1

[16]

M4.C

[1]

M5.C

[1]

M6.(a) (i) hadrons

B1

1

(ii) +1e

B1

1

(b) (i) (Strangeness) 1 → 0 + 0

B1

1

(ii) (Strangeness not conserved but) decay possible because it is a weak decay

B1

1

[4]

M7. (a)

particle	quark structure	charge	strangeness	baryon number
proton ✓	uud	+ 1 ✓	0	1 ✓
sigma$^+$	uus	+1	-1 ✓	1 ✓
π^+ ✓	ud	+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]