**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 $0 + 0 = 1 + X$ $X = -1$ ✓

*Any order*

1

(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 ✓ |
| $\pi^+$ ✓ | 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]**