Mark schemes

Q1.

(a) MP1

To conserve charge

OR

To conserve lepton number✓

Must have some detail in support of both conservation explanation for 2 marks.

MP2

Idea of how charge is conserved:

e.g.

LHS = 0 + 17

RHS = 18 + (-1)

For charge conservation condone description of RHS only:

idea of (extra) proton on RHS having charge of +1(e) and an electron of -1(e)

(v_e + n → p + e)

AND

Idea of how lepton number is conserved:

e.g.

LHS = 1 + 0

RHS = 0 + 1 ✓

Charge conservation or lepton number can be seen in the equation.

Treat as neutral mention of conservation of:

- *momentum*
- *baryon number*

2

(b) Max 1 from: ✓

- use of specific charge = $\frac{\text{charge}}{\text{mass}}$ by substitution
- determines charge of argon nucleus = 18 × 1.6 × 10^{-19}

  Condone their charge and their mass in the use of (including POT error)

  Charge = 2.88 × 10^{-18} (C)

  Mass = 6.2 × 10^{-26} (kg)
- determines the mass of argon nucleus = 37 × 1.67 × 10^{-27}

  For the mass of the nucleus, allow for example:
  - *37 × 1.66(1) × 10^{-27}*
  - *18 × 1.673 × 10^{-27} + 19 × 1.675 × 10^{-27}*

4.6 × 10^7 to 4.7 × 10^7 (C kg^{-1}) ✓

2

(c) MP1: Exchange particle:

W^+ ✓

Do not allow W^+ meson or W.

Condone idea of W^- being emitted by electron.

MP2: Effect on baryon:

Proton changes to a neutron / charge decreases by (+)1(e) ✓

Can see proton to neutron in diagram.
Accept positive baryon changes to neutral baryon.

Max 2 from the following reasons: ✓✓

- it is the weak interaction.
- this is electron capture.
- quark changes flavour / up quark changes to a down quark / uud changes to dud
- lepton changes flavour / electron changes to a neutrino
- idea of charge conservation at a vertex

Allow weak force or weak nuclear force.

Where quark change is quoted must be correct.
Can see up to down in diagram.

Treat other conservations as neutral.

4

(d) **The mark scheme gives some guidance as to what statements are expected to be seen in a 1- or 2-mark (L1), 3- or 4-mark (L2) and 5- or 6-mark (L3) answer. Guidance provided in section 3.10 of the 'Mark Scheme Instructions' document should be used to assist marking this question.**

Mark	Criteria
6	All three areas (as outlined alongside) covered with at least two aspects covered in some detail. 6 marks can be awarded even if there is an error and/or parts of one aspect missing.
5	A fair attempt to analyse all three areas. If there are several errors or missing parts then 5 marks should be awarded.
4	Two areas successfully discussed, or one discussed and two others covered partially. Whilst there will be gaps, there should only be an occasional error.
3	One area discussed and one discussed partially, or all three covered partially. There are likely to be several errors and omissions in the discussion.
2	Only one area discussed or makes a partial attempt at two areas.
1	One of the three areas covered without significant error.
0	No relevant analysis.

The following statements are likely to be present.

Forces of repulsion and attraction that act between nucleons:

- (Repulsion =) Electromagnetic (between protons)
- (Attraction=) Gravitational force (between nucleons) or idea that gravitational is negligible
- (Both repulsive and attractive =) Strong interaction

Exchange particles associated with these forces:

- The pion is the strong interaction's exchange particle.
- Virtual photons for electromagnetic
- Treat mention of graviton for gravity as neutral

Role of these forces in keeping nucleus stable:

- Idea that strong interaction is greater in magnitude than any of the other interactions/ idea SI dominates.
- Strong interaction has short-range attraction acting on neighbouring nucleons (up to 3 to 4 fm).
- Strong interaction has very short-range repulsion at distances less than approximately 0.5 fm.
- Strong interaction acts between nucleons.

Further guidance:
Condone gluons as an alternative to pions.
Condone electrostatic force as an alternative to electromagnetic.

6

[14]

Q2.

(a) gravity, weak (nuclear), strong (nuclear), electromagnetic ✓

Any order, all four must be correct.

Condone any reference to "interaction" or "force"

Condone "gravitational"

Do not accept 'electrostatic', 'gravitational potential', 'em', 'EM'

1

(b) proton, beta minus, (electron) antineutrino all correct ✓

Allow alternative ways of writing beta minus: electron/ e / e^- / β^-

Accept p and P for proton and $\bar{\nu}_e$ *or* $\bar{\nu}$ *for antineutrino*

Condone 'anti electron neutrino'

1

(c) weak (nuclear) ✓

it involves leptons
(which do not experience strong interaction/force)
OR
there is a change in quark (flavour) ✓

Accept reference to W^- or W together with transfer of charge (from neutron)
Accept d (quark) converted to u (quark)

MP2 is conditional on award of MP1

2

(d) idea that the exchange particle is a (virtual) photon ✓

(virtual) photons/the exchange particles have momentum ✓

conservation of momentum (means that photon interchange) enables the electron momentum/path to change ✓

Accept γ for photon.

3

[7]

Q3.

(a) All four rows correct 1✓2✓

Any two rows correct 1✓

Particle	Baryon	Hadron	Lepton	Meson
π^+		✓		✓
n	✓	✓		
K^+		✓		✓
Σ^0	✓	✓		

Accept any reasonable notation for ✓

2

(b) Identifies strangeness as the consideration as interaction would be strong/not weak ✓
K^- and Σ^0 have same strangeness of -1✓

Demonstration that LHS and RHS strangeness not equal AND that the LHS is zero ✓

Do not award MP1 for suggestion that any other quantum number is not conserved.

Evidence for MP2 and MP3 can be seen in a correct use of strangeness values e.g.

$0 + 0 \rightarrow -1 -1$

3

(c) clear assignment of each particle to its correct rest mass including the photon ✓

idea that LHS mass > RHS mass✓

Electron AND positron rest energy = 0.510999 MeV
π^0 rest energy = 134.972 MeV
Gamma/photon rest mass = 0

Allow rounded values for rest mass.

2

(d) annihilation of the positron with an electron ✓

Do not allow answers such as 'elimination'

1

(e) Idea that international collaboration/cooperation/verification is required

OR

(investment in) expensive equipment/hardware/ infrastructure is required ✓

Accept idea that (people with) particular/specialist talents/technology/infrastructure must be in place.

Ignore references to peer review or vague statements such as 'it takes a long time' or 'it/the research is expensive'.

1

[9]

Q4.

(a) 2 rows correct ✓

3 rows correct ✓✓

	K^-	P	Ω	K^0	Y
Rest energy / MeV	493.8	938.3	1672	497.8	493.8
Baryon number	0	+1	+1	0	0
Charge	-1e	+1e	-1e	0	+1e
Strangeness	-1	0	-3	+1	+1

Y*'s charge: Allow 1 or +1 or +1e*

Y*'s strangeness: Allow +1 or 1*

2

(b) $1672 \times 10^6 \times 1.6(0) \times 10^{-19}$ **OR**

Correct conversion of:

1672 MeV to 1.672×10^9 (eV) **OR**

Correct conversion of:

1 MeV to 1.6×10^{-13} (J) ✓

MP1 allow POT error in attempted conversion of eV to J where 1672 × 1.6 is seen.

Condone correct conversion of 1672 MeV or 1 MeV seen in an otherwise incorrect expression.

2.68×10^{-10} (J) ✓

Accept answer correctly rounded to at least 2 sf.

Calculator answer 2.6752×10^{-10} (J)

2

(c) Idea that the rest energy of the products is **greater** than the rest energy of the reactants. ✓

MP1 allow:

Rest energy of reactants = 1432.1 (MeV) ***and*** *rest energy of products = 2663.6 (MeV) or 1231.5 MeV seen.*

Idea that kinetic energy of the reactants is **greater** than the kinetic energy of the products ✓

Alternative:

The rest energies of reactants + their (additional) **kinetic energy** = rest energies of the products✓✓

MP2 allow:

The additional energy (1231.5 MeV) comes from the kinetic energy of the reactants.(Allow the idea that products don't have any kinetic energy).

MP2 must relate to kinetic energy: speed / velocity / momentum is insufficient (treat as neutral).

***Max 1** for the idea that the rest energies are not equal and **kinetic energy** of the particles accounts for the difference.*

2

(d) **MP1:** Applies conservation of baryon no. correctly to at least one decay✓

MP2:

Writes first or second decay in terms of quark compositions.

OR

Identifies decay is via weak interaction

OR

Ξ^0 has a strangeness = -2 or states quark structure as ssu✓

MP3:

The Λ^0 has a strangeness = -1

OR

Writes first two decays in terms of quark compositions.✓

MP4 :

(Quark composition Λ^0 =) uds

OR

writes 3rd decay in terms of quark compositions✓

MP1

Λ^0 is a baryon or Λ^0 consists of 3 quarks (condone any 3) or Λ^0 has a baryon number = 1 ***OR***

Ξ^0 is a baryon or Ξ^0 consists of 3 quarks (condone any 3) or Ξ^0 has a baryon number = 1

***MP2**:*

Decay 1	Ω^-(sss)	Ξ^0(uss)	$\pi^-(d\bar{u})$
B	1	1	0
S	−3	−2	0
Q	−1	0	−1
Decay 2	Ξ^0 (uss)	Λ^0 (uds)	π^0 ($u\bar{u}$ or $d\bar{d}$)
B	1	1	0
S	−2	−1	0
Q	0	0	0
Decay 3	Λ^0(uds)	P(uud)	$\pi^-(d\bar{u})$
B	1	1	0
S	−1	0	0
Q	0	+1	−1

*An answer of uds scores **MP1** and **MP4**.*

*Must see **MP2** and **MP3** to award these marks.*

***Award 1 mark** if strangeness quoted as positive in both MP2 and MP3 where MP2 and MP3 otherwise not awarded.*

Working can be shown on the equations above (d).

Writes all 3 decays in terms of quarks scores all 4 marks.

4

(e) Use of $E = \frac{hc}{\lambda}$ **OR** $E = hf$ **and** $c = f\lambda$ ✓

Condone POT error in any substituted values.

1.59×10^{-11} (J) ✓

Accept any answer correctly rounded to at least 2 sf.

***Max 1** mark for otherwise correct answer with POT error.*

***Max 1** mark for an answer of 7.956×10^{-12} (J)*

(Correct use of equation but divided energy by two.)

***Max 1** mark for an answer of 2.55×10^{-30} (J)*

(Assumes that 1.59×10^{-11} is in eV and attempts to convert to J.)

Calculator display = 1.5912×10^{-11} (J)

2

(f) $e^- + \bar{\nu}_e$ ✓

Tick in 2nd box only

1

[13]

Q5.

(a) uds ✓

Do not accept D for d.

Penalise extra particles

1

(b) weak (interaction / force)✓

strangeness changes (in this decay)✓ (from -1 to 0 and strangeness can only change in a weak interaction)

MP2:

Reject negative arguments (eg 'strangeness is conserved in a strong interaction')

Reject the idea that strangeness ***always*** *changes in a weak interaction.*

General statement of strangeness conservation in the weak interaction on its own is insufficient.

Accept "strangeness is not conserved (in this decay)".

Condone "strangeness is lost".

2

(c) anti-neutron ✓

Accept $\bar{n}$

Reject ambiguous answers unless supported by other evidence.

Do not accept answer solely in terms of quarks

1

(d) $1.1(1) \times 10^3$ (MeV) ✓

Reject incorrectly rounded answers.

Accept: 1100 MeV (2sf) / 1110 MeV (3sf) / 1115 MeV (4sf) etc

Calculator value: 1114.66875 MeV

1

(e) Any **one** from ✓

(teams must be large and international) because:

- research is expensive / requires funding from many countries
- both scientists and engineers are required (because the machines used for research are complex/large pieces of civil engineering)
- research is multi-faceted / multi-disciplinary (because computation/theory/ etc. is required)
- research is round-the-clock (so teams are large to work on shift basis)
- they are needed to process the large amounts of data produced

Treat idea of peer review as neutral (this argues for independent teams).

Do not accept idea that it 'avoids bias' or 'reproducibility'.

1

[6]

Q6.

(a) 2 rows correct ✓

3 rows correct ✓✓

	π^+	p	Σ^+	Y
B	0	(+)1	(+)1	0
Q	+1	+1	+1	(+)1
S	0	0	−1	+1

2

(b) Tick 3rd box only - Σ^+ ✓

1

(c) **Y** has a greater rest energy than π^+ / **Y** has greater mass than π^+

*Treat **Y** is larger than the π^+ as neutral.*

*MP1: Condone error in mass comparisons where **Y** is identified as having a greater rest energy.*

Or

π^+ and **Y** have the same charge / or charge on both particles identified as having charge of (+)1 / π^+ and K^+ *seen* ✓

Both have a charge of +1(e)

Y is a kaon / **Y** is a k meson ✓

Accept for mp2:

***Y** contains an s or s̄ quark which is more massive than u or d quarks in the pion / **Y** contains an s or s̄ quark whereas pion does not.*

*π^+ is 1st generation (meson) while **Y** is 2nd generation (meson).*

*Loses MP2 for stating incorrect number of quarks for **Y** or stating that **Y** is a baryon.*

π^+ has a greater charge-to-mass ratio because it has the same charge as **Y** **and** less mass than **Y** / π^+ has a greater specific charge ✓

Accept converse statement

*Error carried forward for charge on **Y** from part **(a)***
***Y** will have a greater specific charge where **Y** has charge greater than +4*

3

[6]

Q7.

(a) down quark changes to up quark ✓

Allow "d⟶u"

Condone udd⟶uud

Condone U for u but not D for d.

Do not accept answers with extra particles.

1

(b) Idea that (graph shows that) beta particles (from C-14) have a range of (kinetic) energies ✓

There is a fixed/maximum/total amount of energy (released by C-14) so there must be another particle that carries the energy differences/missing energy away ✓

A mention of conservation of energy on its own is insufficient for MP2.

2

(c) neutron ✓

Condone "n" but not "N".

Do not allow "udd".

1

(d) Calculation of minimum energy produced in annihilation of positron and electron (from rest mass energy ×2)

E.g. = 2 × 0.51 MeV = 1.6×10^{-13} J ✓

Calculation of the photon energy based on one particle can get MP2.

(2 photons produced so) energy per photon = 8.2×10^{-14} J ✓

Conclusion consistent with their calculated minimum energy. ✓

The 'correct' answer would be a conclusion leading to G3 only.

ALTERNATIVE

One calculation of mass equivalence of photon energy. ✓

If no other mark awarded, award one mark for determining rest energy of positron or electron in J.

Calculation of remaining mass equivalents

OR

deduction about the other two photon energies

Only G3 has sufficient energy to have been made in annihilation. ✓

Allow mass equivalent calculations in (M)eV

Allow explanation in terms of positron and electron for annihilation in alternative MP3

3

[7]