Q1.

An electron neutrino interacts with a chlorine-37 nucleus to produce an argon-37 nucleus and an electron.

The interaction is represented by the equation:

$$\nu_e + {}^{37}_{17}\text{Cl} \rightarrow {}^{37}_{18}\text{Ar} + e$$

(a) Explain, with reference to appropriate conservation laws, why the electron is emitted in this interaction.

charge: $0 + 17 \longrightarrow 18 + (-1) = 17$

lepton: $1 + 0 \longrightarrow 0 + 1$

To conserve charge

To conserve lepton number

(2)

(b) Calculate the specific charge of the argon-37 nucleus.

$$\frac{18 \times 1.6 \times 10^{-19}}{37 \times 1.67 \times 10^{-27}} =$$

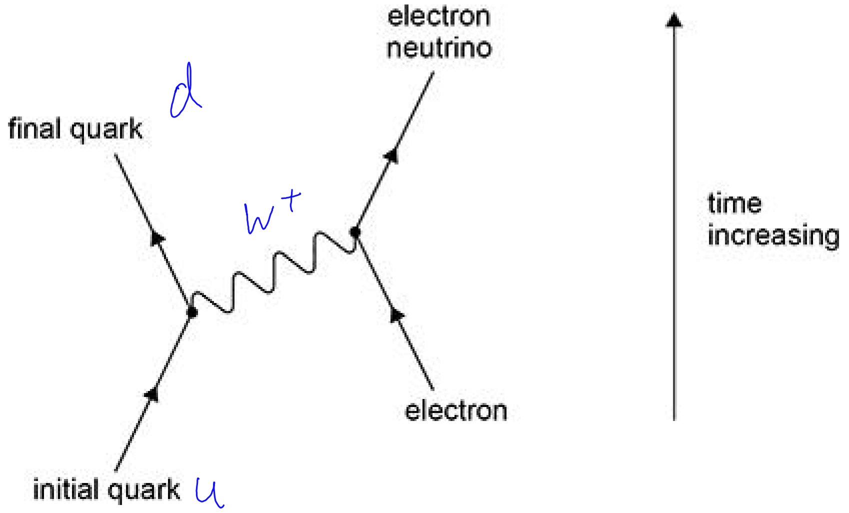
$$= 4.67 \times 10^{7} \text{ C/kg}$$

specific charge = ____________________ C kg^{-1}

(2)

(c) In a different interaction, the argon-37 nucleus interacts with an electron.

The figure below represents the interaction of a quark in a baryon of the nucleus.



Deduce the exchange particle and the effect on the baryon.
Give **one** reason to support each answer.

exchange particle W+

reason weak

effect on baryon p → n / charge decreases by +1e

reason

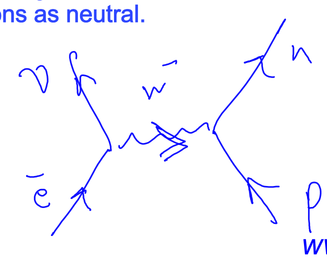
Exchange particle:
W+ ✓
Do not allow W+ meson or W.
Condone idea of W- being emitted by electron.
MP2: Effect on baryon:
Proton changes to a neutron / charge decreases by (+)1(e) ✓
Can see proton to neutron in diagram.
Accept positive baryon changes to neutral baryon.
Max 2 from the following reasons: ✓ ✓

- 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

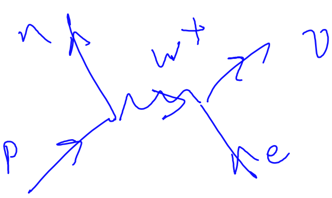
Allow weak force or weak nuclear force.
Where quark change is quoted must be correct.
Can see up to down in diagram.
Treat other conservations as neutral.

(4)

e-p collision:



electron - capture:



(d) The argon-37 nucleus decays into a stable nucleus.

Describe the nature of the forces that act between nucleons and how these forces can maintain nuclear stability.

In your answer, describe:

- the forces of repulsion and attraction that act between nucleons
- exchange particles associated with these forces
- the role of these forces in keeping the nucleus stable.

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)
(Total 14 marks)

Q2.

(a) State the names of the four fundamental interactions.

1 ______

2 ______

3 ______

4 ______

(1)

(b) State the products of the decay of a free neutron.

proton, beta minus, (electron) antineutrino all correct

(1)

(c) Explain which of the fundamental interactions is responsible for the decay of the neutron.

weak (nuclear) ✓
it involves ~~leptons~~
OR
there is a change in quark (flavour)

(2)

(d) The forces between two moving electrons cause their paths to change.

Explain, using the concept of exchange particles, why the electron paths change.

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(3)

(Total 7 marks)

Q3.

A positive pion collides with a neutron and the following interaction is observed:

$$\pi^+ + n \rightarrow + K^+ \, \Sigma^0$$

Baryon: 0 1 0 1

Σ^0 is a neutral sigma particle with a strangeness of −1

The interaction can be used to deduce the classifications of the Σ^0.

(a) Identify the classifications of each particle in the table below.
Tick (✓) the appropriate boxes for each particle.

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

(2)

(b) A conservation rule predicts that the following interaction **cannot** occur:

$$\pi^- + n \rightarrow K^- + \Sigma^0$$

$K^- = s\bar{u}$

Strangeness: $-1 + 0 = -1$

State the conservation rule.
Go on to explain your answer.

Baryon: $0 + 1 \rightarrow 0 + 1$

Charge: $-1 + 0 \rightarrow -1 + 0$

Lepton: $0 \rightarrow 0$

Strangeness: $0 + 0 \rightarrow (-1) + (-1)$ Strong interaction

(3)

One way in which neutral pions decay is

$$\pi^0 \rightarrow e^- + e^+ + \gamma$$

(c) Compare the rest energies of the particles involved in this decay.

(2)

(d) The decay of the neutral pion leads to the production of further gamma photons.

Explain why.

(1)

(e) The Standard Model is a theory that classifies elementary particles. Evidence for the theory has been collected since about 1950. However, the term Standard Model has only been used since 1973.

Suggest why progress in particle physics is slow.

(1)
(Total 9 marks)

Q4.

A strong interaction between a negative kaon (K^-) and a proton (p) produces an omega-minus (Ω^-) particle, a neutral kaon (K^0) and an unidentified particle **Y**.

The interaction is:

$$K^- + p \rightarrow \Omega^- + K^0 + \mathbf{Y}$$

The table below contains information on the particles in this interaction.

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

(a) Complete the table above.

(2)

(b) Calculate, in J, the rest energy of the Ω^-.

rest energy = ____________________ J

(2)

(c) Suggest how energy is conserved in this interaction.
Refer to the rest energies of the particles in the table above.

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(2)

The quark structure of the Ω^- particle is sss.

The Ω^- is unstable. It decays into a proton through a series of decays:

$$\Omega^- \rightarrow \Xi^0 + \pi^-$$

followed by

$$\Xi^0 \rightarrow \Lambda^0 + \pi^0$$

followed by

$$\Lambda^0 \rightarrow p + \pi^-$$

The Ξ^0 and Λ^0 are both hadrons.

(d) Deduce the quark structure of the Λ^0 particle.

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quark structure of Λ^0 = ____________________

(4)

The products of the decay series include π^0 and π^- particles. These particles are unstable and decay.

(e) The π^0 decays into gamma photons. Each gamma photon has a wavelength of 1.25×10^{-14} m.

Calculate the energy of one of these photons.

energy of photon = ____________________ J

(2)

(f) The negative pion π^- decays.

Which row shows the particles that could be created in this decay?
Tick ✓ **one** box.

$\mu^- + \nu_\mu$	☐
$e^- + \bar{\nu}_e$	☐
$e^- + \nu_e$	☐
$e^- + e^+ + e^-$	☐

(1)
(Total 13 marks)

Q5.

The neutral lambda particle Λ^0 is a baryon with a strangeness of −1

One possible decay for a Λ^0 is

$$\Lambda^0 \rightarrow \pi^0 + n$$

(a) Deduce the quark structure of a Λ^0.

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(1)

(b) State and explain which interaction is involved in this decay.

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(2)

(c) An antiparticle of the neutral lambda particle decays into a neutral pion and particle **X**.

Identify **X**.

____

(1)

(d) The rest energy of a Λ^0 is equal to the energy of a photon with a frequency of 2.69×10^{23} Hz.

Determine, in MeV, the rest energy of a Λ^0.

rest energy = ____________________ MeV

(1)

(e) The discovery of particles such as the Λ^0 is made by large international research teams.

Suggest **one** reason for this.

(1)

(Total 6 marks)

Q6.

A sigma-plus (Σ^+) particle and an unidentified particle **Y** are produced by the strong interaction between a positive pion (π^+) and a proton (p).

This interaction is represented by the equation:

$$\pi^+ + p \rightarrow \Sigma^+ + \mathbf{Y}$$

(a) Complete the table below to show the baryon number B, charge Q and strangeness S for the particles in this interaction.

	π^+	p	Σ^+	Y
B				0
Q	+1	+1	+1	
S				+1

(2)

(b) Which particle in the table above has the quark structure uus?

Tick (✓) **one** box.

π^+ ☐

p ☐

Σ^+ ☐

Y ☐

(1)

(c) Deduce which particle, π^+ or **Y**, has the greater charge-to-mass ratio. Justify your conclusion.

(3)

(Total 6 marks)

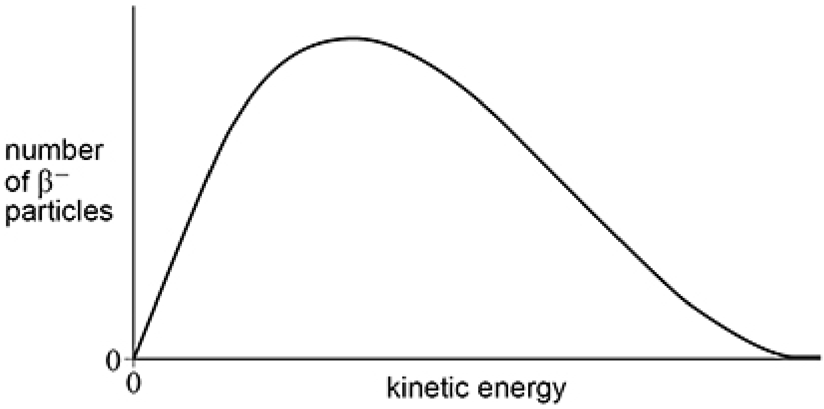
Q7.

Carbon-14 decays into nitrogen-14 with the release of a beta (β^-) particle and an antineutrino ($\bar{\nu}_e$).

(a) State the change of quark character in β^- decay.

(1)

(b) The diagram below shows the distribution of kinetic energies of β^- particles from the decay of carbon-14.



Explain how the figure above supports the existence of the antineutrino.

(2)

The existence of the antineutrino was confirmed by experiments in which antineutrinos interact with protons. The equation for this interaction is:

$$\bar{\nu}_e + p \rightarrow e^+ + \mathbf{X}$$

(c) Identify particle **X**.

(1)

(d) The positron released in this interaction is annihilated when it encounters an electron.
A pair of gamma photons is then produced.
Particle **X** can be absorbed by a nucleus. This produces another gamma ray.
The table below contains data for three gamma photons detected during an antineutrino–proton interaction experiment.

Gamma photon	**Photon energy / J**
G1	5.0×10^{-14}
G2	6.6×10^{-14}
G3	1.0×10^{-13}

Deduce which of the three gamma photons could have been produced by positron annihilation.

(3)
(Total 7 marks)