Access Tuition

A-Level Physics

Particles

Question Paper

Time available: 74 minutes
Marks available: 52 marks

1. 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.

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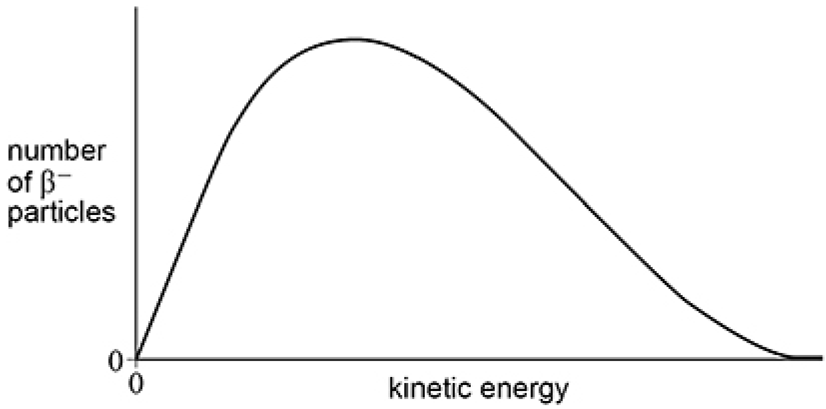
(1)

(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.

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(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**.

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(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.

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(3)

(Total 7 marks)

2. Two stable isotopes of helium are $^{4}_{2}\mathrm{He}$ and $^{3}_{2}\mathrm{He}$.

(a) An atom of $^{4}_{2}\mathrm{He}$ is produced in a rock that contains uranium. It is produced following the radioactive decay of a $^{238}_{92}\mathrm{U}$ atom. The decay also creates an atom of thorium (Th).

Write an equation for the decay of $^{238}_{92}\mathrm{U}$.

$^{238}_{92}\mathrm{U} \longrightarrow$

(2)

(b) A $^{3}_{2}He$ nucleus can be produced by the decay of a tritium nucleus $^{3}_{1}H$.

State and explain which exchange particle is responsible for this decay.

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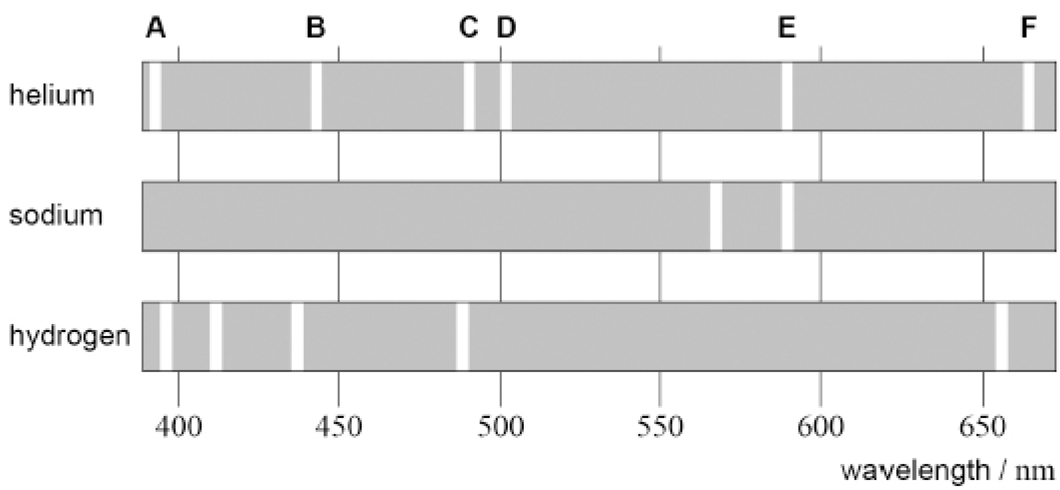
(2)

Helium was discovered by analysing the light in the **absorption** spectrum of the Sun.

The figure below shows the positions of the brightest lines, labelled **A** to **F**, in the **emission** spectrum of helium. The brightest lines in the emission spectra of sodium and hydrogen are also shown.



(c) Before helium was identified, some scientists suggested that the lines of the helium spectrum seen in the absorption spectrum of the Sun were due to the presence of sodium and hydrogen.

Discuss, with reference to the lines **A** to **F** in the figure above, the evidence for and against this suggestion.

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(2)

(d) Calculate, in eV, the change in energy level responsible for the spectral line labelled **E** in the diagram above.

change in energy level = _______________ eV

(3)

(e) Explain, with reference to the processes within an atom, the difference between an emission spectrum and an absorption spectrum.

(3)

(Total 12 marks)

3. 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:

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

(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.

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(3)
(Total 6 marks)

4. (a) Identify the number of neutrons in a nucleus of polonium-210 $\left({}^{210}_{84}\text{Po}\right)$.

Tick (✓) **one** box.

84 ☐

126 ☐

210 ☐

294 ☐

(1)

(b) A polonium-210 nucleus is formed when a stationary nucleus of bismuth-210 decays. A beta-minus (β^-) particle is emitted in this decay.

Outline, with reference to β^- decay, why bismuth-210 and polonium-210 have different proton numbers.

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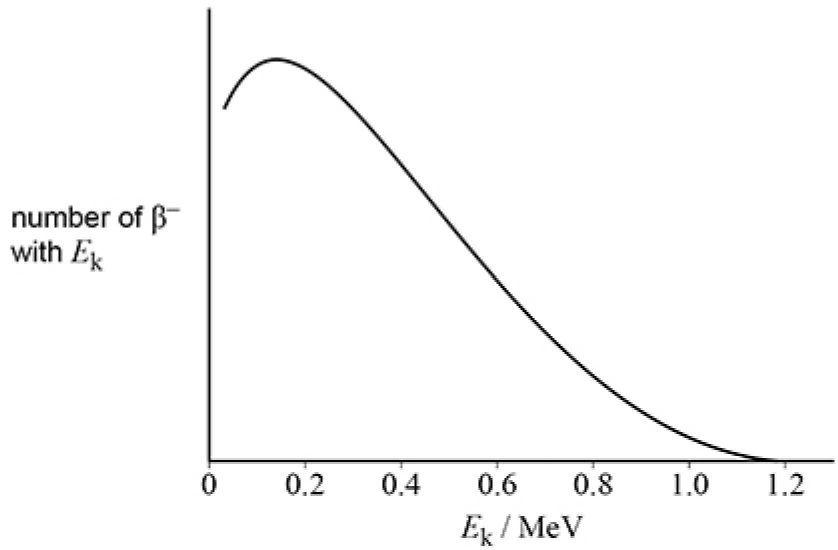
(2)

The kinetic energies of β^- particles emitted from a sample of bismuth-210 are analysed. These β^- particles have a range of kinetic energies.

The total energy released when each nucleus of bismuth-210 decays to a nucleus of polonium-210 is 1.2 MeV.

Figure 1 shows the variation with E_k of the number of β^- particles that have the kinetic energy E_k.

Figure 1



(c) Explain how the data in **Figure 1** support the hypothesis that a third particle is produced during β^- decay.

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(2)

(d) This third particle is an electron antineutrino.

Explain why an electron antineutrino, rather than an electron neutrino, is produced during β^- decay.

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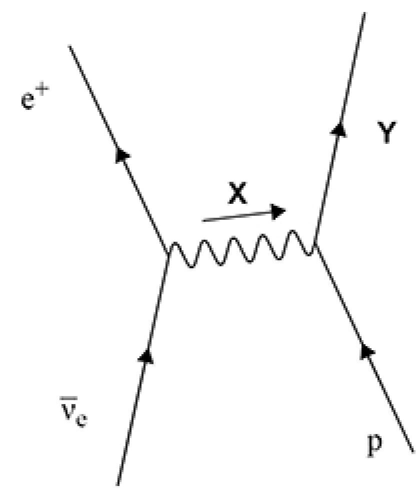
(2)

(e) A large tank of water is used as part of an electron antineutrino detector. An electron antineutrino $\bar{\nu}_e$ enters the tank and interacts with a proton (p).

Figure 2 represents this interaction.

Figure 2



Identify **X** and **Y**.

X = ________________

Y = ________________

(2)

(f) The positron produced in the interaction in **Figure 2** slows down and collides with a lepton in a molecule of water.

Describe the process that occurs when the positron collides with this lepton. In your answer you should identify the lepton in the molecule of water.

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(3)

(g) The range of the electromagnetic interaction is infinite.
The table below gives the range of the strong nuclear interaction and the range of the weak nuclear interaction.

Interaction	**Range / m**
strong nuclear	10^{-15}
weak nuclear	10^{-18}

Deduce whether the positron or the electron antineutrino is likely to travel the shorter distance in the tank of water before interacting.

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(3)
(Total 15 marks)

5. Cosmic rays are high-energy particles that come from space. Most of these particles are protons. There are other particles in cosmic rays, including atomic nuclei.

The table below gives the data for one particular nucleus **X**.

Mass / kg	8.02×10^{-26}
Specific charge / C kg^{-1}	4.39×10^{7}
Kinetic energy / MeV	215

(a) Determine the number of neutrons in nucleus **X**.

number of neutrons = ________________

(3)

(b) Calculate the speed of **X**.
Ignore relativistic effects.

speed = ________________ m s^{-1}

(3)

A pion (π^{+}) and a kaon (K^{+}) are produced when cosmic rays interact with the upper atmosphere.

(c) The π^+ decays to produce a positron and an electron neutrino.

Show how the conservation laws apply to this decay.

(2)

(d) The K^+ decays to produce an anti-muon and a muon neutrino.

Explain how strangeness applies in this decay.

(2)

(e) Write an equation for a K^+ decay that involves only hadrons.

(2)

(Total 12 marks)