1 **(a)** State, with a reason, whether or not protons and neutrons are fundamental particles.

....

.... **[1]**

(b) State **two** fundamental particles that can be classified as leptons.

.... **[1]**

(c) Some fruits, such as bananas, are naturally radioactive because they contain the unstable isotope of potassium-40 ($^{40}_{19}\text{K}$).

(i) The isotope of potassium-40 is a beta-minus emitter.

Complete the following decay equation for $^{40}_{19}\text{K}$.

$$^{40}_{19}\text{K} \rightarrow {}^{\dots\dots\dots}_{\dots\dots\dots}\text{Ca} \quad + \quad \dots\dots\dots \quad + \quad \dots\dots\dots$$ **[2]**

(ii) Explain why energy is released when a single nucleus of potassium-40 decays.

....

....

....

....

.... **[2]**

(iii) A banana contains 4.5×10^{-4} kg of potassium. About 0.012 % of the mass of potassium in the banana has the unstable isotope of potassium-40. This isotope of potassium-40 has a half-life of 4.2×10^{16} s. The molar mass of potassium-40 is 0.040 kg mol^{-1}.

Calculate the activity from this banana.

activity = ... Bq **[3]**

2 **(a)** Explain how the experiments on the scattering of alpha-particles by a metal foil provided evidence for the nuclear model of the atom.

In your answer, you should make clear how your conclusions link with the observations.

....

....

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.... **[3]**

(b) Fig. 5.1 shows an alpha-particle ($^{4}_{2}$He) of kinetic energy 8.0 MeV moving directly towards a nucleus of aluminium-27 ($^{27}_{13}$Al), initially at rest.

Fig. 5.1

(i) The alpha-particle comes to rest instantaneously a short distance away from the aluminium nucleus. It then reverses its direction of travel. Describe and explain the motion of the aluminium nucleus at the instant the alpha-particle is at rest.

....

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....

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.... **[2]**

(ii) Calculate the initial speed of the alpha-particle.

mass of alpha-particle = 6.6×10^{-27} kg

speed = ... $\mathrm{m\,s^{-1}}$ **[2]**

(iii) The electric force experienced by the alpha-particle when it is close to the aluminium nucleus is 270 N. Calculate the separation r between the alpha-particle and the aluminium nucleus when the alpha-particle experiences this force.

r = ... m **[3]**

(iv) Consider the situation where the alpha-particle travels much closer to the aluminium nucleus than in **(b)(iii)**.

Discuss how the strong nuclear force may affect the resultant force on the alpha-particle.

....

....

....

.... **[2]**

3 **(a)** Explain what is meant by the *binding energy* of a nucleus.

....

.... **[1]**

(b) The fusion of protons occurs in a star when the temperature within the core is greater than about 10^7 K. It takes the fusion of 4 protons to form a helium-4 ($^4_2$He) nucleus. In this process, known as the proton–proton cycle, energy is released.

The net energy released in producing a single helium-4 nucleus is 4.53×10^{-12} J. Calculate the binding energy per nucleon of the helium-4 nucleus.

binding energy per nucleon = ... J **[1]**

(c) The fusion of helium nuclei to make heavier elements occurs in red giants at temperatures above 10^8 K.

Explain why fusion of helium requires higher temperatures than the fusion of hydrogen (protons).

....

....

.... **[2]**

(d) Estimate the mean speed of helium nuclei at a temperature of 10^8 K.

mass of helium nucleus = 6.6×10^{-27} kg

speed = ... m s^{-1} **[2]**

4 **(a)** Deuterium ($^{2}_{1}H$) and tritium ($^{3}_{1}H$) are isotopes of hydrogen.

(i) State **two** features common to all isotopes of hydrogen.

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....

.... **[1]**

(ii) Explain why the total mass of the individual nucleons of a deuterium nucleus is different from the mass of the deuterium nucleus.

....

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.... **[3]**

(b) A fusion reaction between two nuclei is shown below.

$$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n$$

A neutron inside a nucleus is stable. However, a ‘free’ neutron, when outside the nucleus, undergoes beta decay with a half-life of about 11 minutes.

(i) Complete the decay equation below for a free neutron.

$$^{1}_{0}n \rightarrow \text{................} + ^{0}_{-1}e + \text{................}$$ **[2]**

(ii) Explain what is meant by the *half-life* of a free neutron.

....

....

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.... **[1]**

(c) For the fusion reaction to occur the separation between the deuterium and tritium nuclei must be less than 10^{-14} m. This means that the average kinetic energy of these hydrogen nuclei needs to be about 70 keV. The energy released by the fusion reaction is 18 MeV.

(i) Calculate the repulsive electrical force between the deuterium and tritium nuclei at a separation of 10^{-14} m.

force = ... N **[2]**

(ii) Assume that a mixture of these hydrogen nuclei behaves as an ideal gas.

Estimate the temperature of the mixture of nuclei required for this fusion reaction.

temperature = ... K **[3]**

(iii) In practice, fusion occurs at a much lower temperature. Suggest a reason why.

....

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....

.... **[1]**

(iv) Calculate the change in mass in a single fusion reaction.

change in mass = ... kg **[2]**

(v) Fig. 3.1 shows the variation of probability of fusion reaction with temperature *T* for deuterium and tritium and for deuterium and helium.

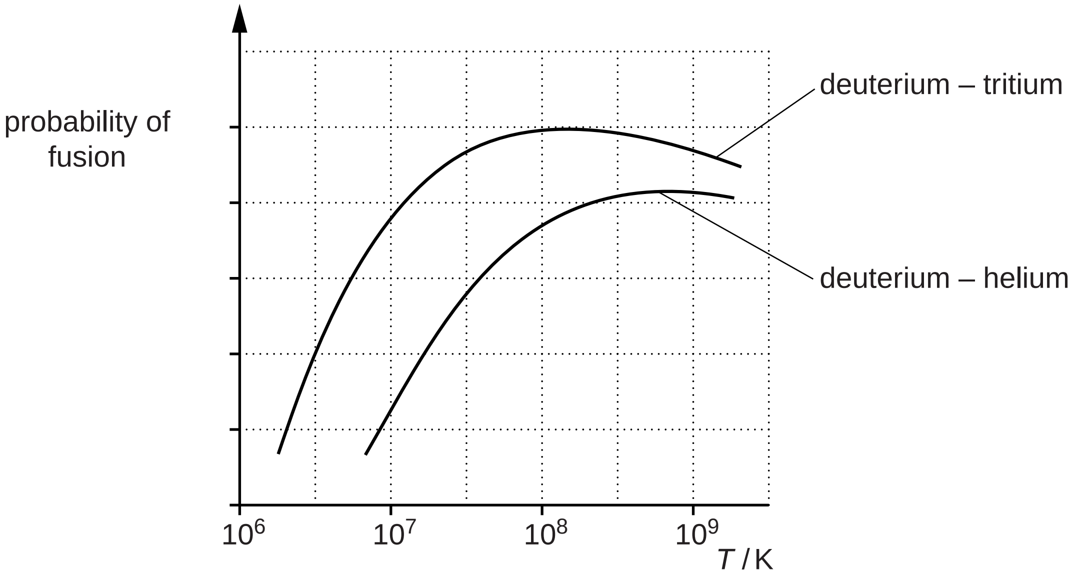

Fig. 3.1

Suggest why the probability of reaction at a given temperature is smaller for deuterium and helium.

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....

.... **[2]**

[Total: 17]