A-Level Physics

Mass and Energy

Question Paper

Time available: 75 minutes
Marks available: 55 marks

1. Fission and fusion are two processes that can result in the transfer of binding energy from nuclei.

(a) State what is meant by the binding energy of a nucleus.

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(2)

(b) Calculate, in MeV, the binding energy for a nucleus of iron $^{56}_{26}\mathrm{Fe}$.

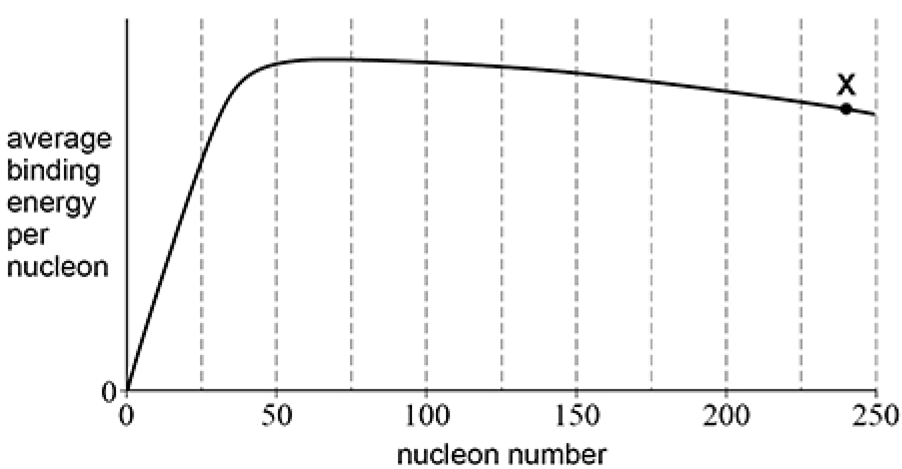
mass of $^{56}_{26}\mathrm{Fe}$ nucleus = 9.288×10^{-26} kg

binding energy = ____________________ MeV

(3)

Figure 1 shows a graph of average binding energy per nucleon against nucleon number for common nuclides.

Figure 1



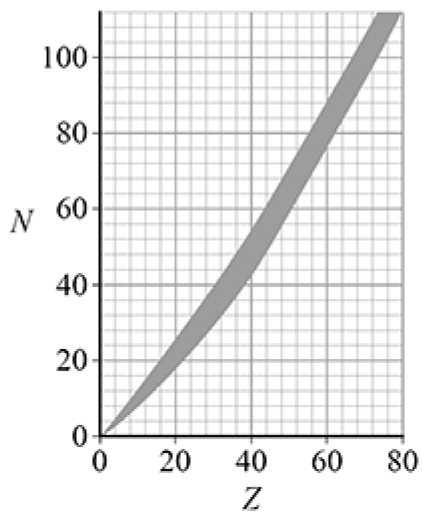
(c) The nuclide labelled **X** in **Figure 1** undergoes fission.

Annotate **Figure 1** with $\mathbf{F_1}$ and $\mathbf{F_2}$ to show **one** possible pair of nuclides resulting from the fission of **X**.

(2)

(d) **Figure 2** shows a graph of N against Z for stable nuclides.

Figure 2



Deduce the likely initial mode of decay of $\mathbf{F_1}$ and $\mathbf{F_2}$.
Refer to **Figure 2** in your answer.

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(3)
(Total 10 marks)

2. (a) Explain, in terms of binding energy, why energy can be released when two nuclei undergo nuclear fusion.

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(2)

(b) During the collapse of a supermassive star, helium-3 and oxygen-17 fuse to release energy. The equation for this reaction is

$$^{3}_{2}\mathrm{He} + ^{17}_{8}\mathrm{O} \rightarrow ^{20}_{10}\mathrm{Ne}$$

The table below gives data for these nuclei.

Nucleus	**Mass / u**
$^{3}_{2}\mathrm{He}$	3.01603
$^{17}_{8}\mathrm{O}$	16.99913
$^{20}_{10}\mathrm{Ne}$	19.99244

Calculate, in J, the energy released when this reaction occurs.

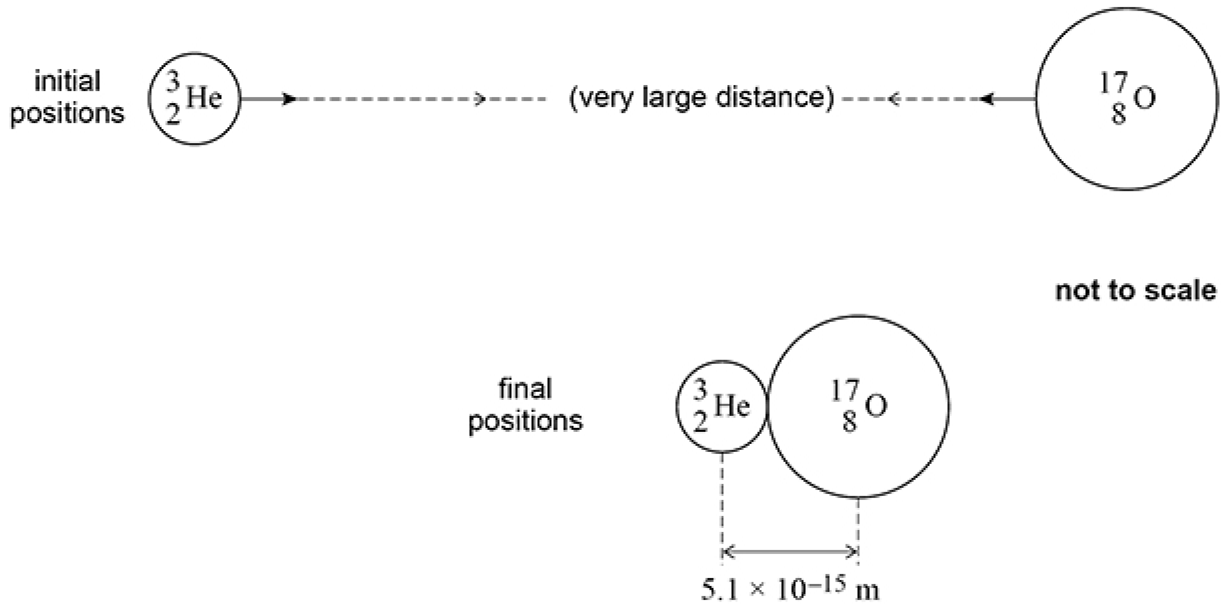
energy released = ________________ J

(2)

(c) One model of nuclear fusion suggests that fusion happens when nuclei touch.

Initially the helium nucleus and oxygen nucleus are separated so that the force between them is negligible. They move towards each other until they fuse. Fusion occurs when their centres are separated by a distance of 5.1×10^{-15} m.

The figure below shows the initial positions and final positions of the nuclei.



Calculate the total change in electrostatic potential energy between the initial positions and final positions of the nuclei.

change in electrostatic potential energy = _______________ J

(2)

(d) $^{3}_{2}He$ can undergo fusion reactions with either $^{34}_{16}S$ or $^{17}_{8}O$ at the same temperature in a star.

The nucleus has properties that depend on its proton number and its nucleon number. These properties affect the fusion reaction.

Discuss, for this star, how these properties affect the rate of fusion of $^{34}_{16}S$ with $^{3}_{2}He$ compared to the rate of fusion of $^{17}_{8}O$ with $^{3}_{2}He$.

(3)

(Total 9 marks)

3. A thermal nuclear reactor uses a moderator to lower the kinetic energy of fast-moving neutrons.

(a) Explain why the kinetic energy of neutrons must be reduced in a thermal nuclear reactor.

(1)

(b) As a result of a collision with an atom of a particular moderator, a neutron loses 63% of its kinetic energy.

A neutron has an initial kinetic energy of 2.0 MeV.

Calculate the kinetic energy of the neutron after five collisions.

kinetic energy = ____________________ eV

(2)

(c) The kinetic energy of a neutron in a thermal nuclear reactor is reduced from about 2 MeV to about 1 eV.

Explain why the number of collisions needed to do this depends on the nucleon number of the moderator atoms.

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(2)

(d) One fission process which can occur in a thermal nuclear reactor is represented by the equation

$$^{235}_{92}U + ^{1}_{0}n = ^{142}_{54}Xe + ^{90}_{38}Sr + 4^{1}_{0}n$$

Calculate in MeV the energy released in this fission process.

mass of $^{235}_{92}U$ = 235.044 u

mass of $^{142}_{54}Xe$ = 141.930 u

mass of $^{90}_{38}Sr$ = 89.908 u

mass of $^{1}_{0}n$ = 1.0087 u

energy released = ____________________ MeV

(3)

(e) Many magazine and newspaper articles focus on the risks of using nuclear power.

State **three benefits** of using nuclear power.

1 ____

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2 ____

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3 ____

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(3)

(Total 11 marks)

4. (a) Calculate the binding energy, in MeV, of a nucleus of $^{59}_{27}\text{Co}$.

nuclear mass of $^{59}_{27}\text{Co}$ = 58.93320 u

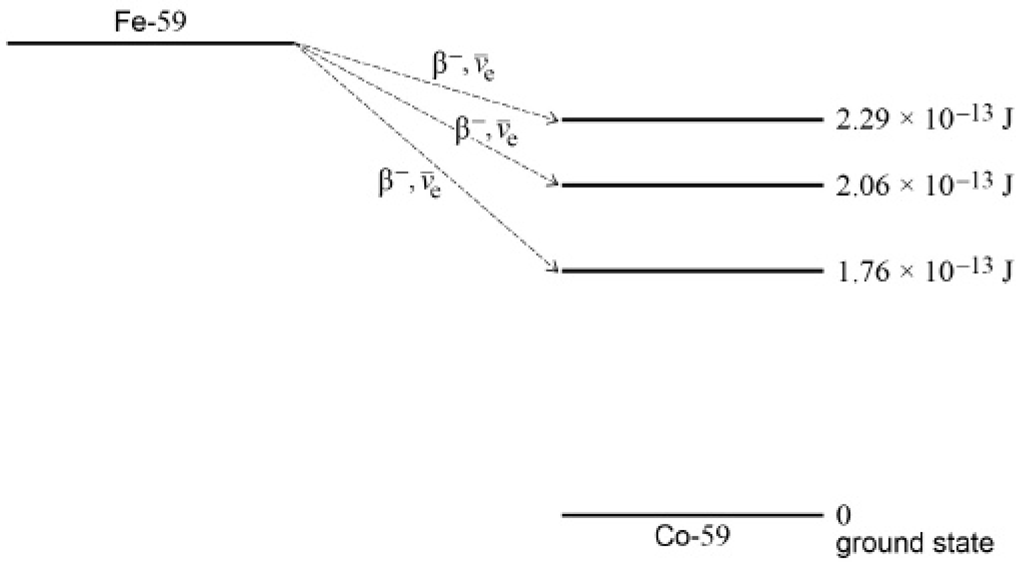
binding energy = ____________________ MeV

(3)

(b) A nucleus of iron Fe-59 decays into a stable nucleus of cobalt Co-59. It decays by β^- emission followed by the emission of γ-radiation as the Co-59 nucleus de-excites into its ground state.

The total energy released when the Fe-59 nucleus decays is 2.52×10^{-13} J.

The Fe-59 nucleus can decay to one of three excited states of the cobalt-59 nucleus as shown below. The energies of the excited states are shown relative to the ground state.



Calculate the maximum possible kinetic energy, in MeV, of the β^- particle emitted when the Fe-59 nucleus decays into an excited state that has energy above the ground state.

maximum kinetic energy = ____________________ MeV

(2)

(c) Following the production of excited states of $^{59}_{27}\text{Co}$, γ-radiation of discrete wavelengths is emitted.

State the maximum number of discrete wavelengths that could be emitted.

maximum number = ____________________

(1)

(d) Calculate the longest wavelength of the emitted γ-radiation.

Longest wavelength = ____________________ m

(3)

(Total 9 marks)

5. In stars, helium-3 and helium-4 are formed by the fusion of hydrogen nuclei. As the temperature rises, a helium-3 nucleus and a helium-4 nucleus can fuse to produce beryllium-7 with the release of energy in the form of gamma radiation.

The table below shows the masses of these nuclei.

Nucleus	**Mass / u**
Helium-3	3.01493
Helium-4	4.00151
Beryllium-7	7.01473

(a) (i) Calculate the energy released, in J, when a helium-3 nucleus fuses with a helium-4 nucleus.

energy released ____________________ J

(4)

(ii) Assume that in each interaction the energy is released as a single gamma-ray photon.

Calculate the wavelength of the gamma radiation.

wavelength ____________________ m

(3)

(b) For a helium-3 nucleus and a helium-4 nucleus to fuse they need to be separated by no more than 3.5×10^{-15} m.

(i) Calculate the minimum total kinetic energy of the nuclei required for them to reach a separation of 3.5×10^{-15} m.

total kinetic energy ____________________ J

(3)

(ii) Calculate the temperature at which two nuclei with the average kinetic energy for that temperature would be able to fuse.
Assume that the two nuclei have equal kinetic energy.

temperature ____________________ K

(3)

(c) Scientists continue to try to produce a viable fusion reactor to generate energy on Earth using reactors like the Joint European Torus (JET). The method requires a plasma that has to be raised to a suitable temperature for fusion to take place.

(i) State **two** nuclei that are most likely to be used to form the plasma of a fusion reactor.

1. ____

2. ____

(2)

(ii) State **one** method which can be used to raise the temperature of the plasma to a suitable temperature.

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(1)

(Total 16 marks)