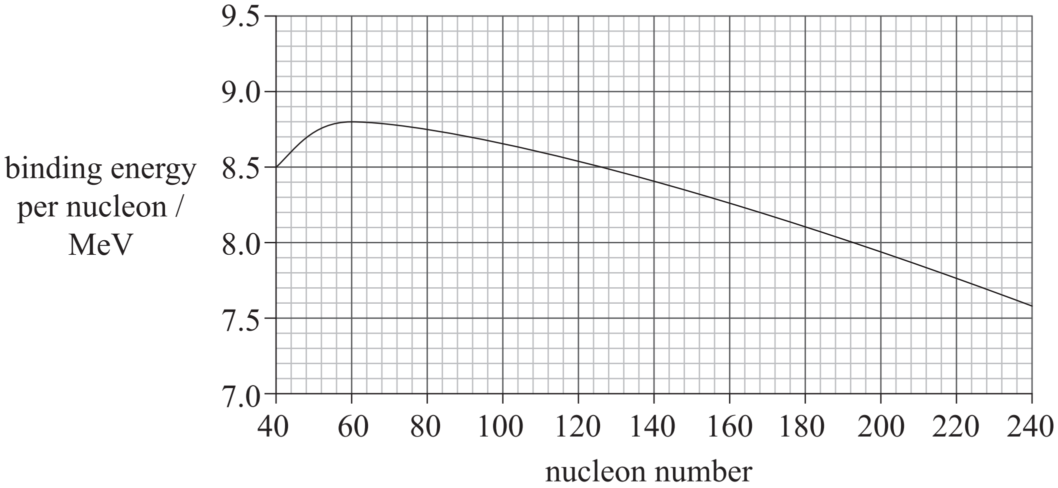
B2. This question is in **two** parts. **Part 1** is about nuclear fission and fusion. **Part 2** is about charge-coupled devices (CCD).

Part 1 Nuclear fission and fusion

(a) The graph shows the variation of binding energy per nucleon for nuclides with a nucleon number greater than 40.



(i) Define *binding energy*. *[1]*

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(ii) On the graph, label with the letter S the position of the most stable nuclide. *[1]*

(iii) State why the nuclide you have labelled is the most stable. *[1]*

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(This question continues on the following page)

(Question B2, part 1 continued)

(b) In a nuclear reactor, a nucleus of uranium(U)-235 fissions into barium(Ba)-141 and krypton(Kr)-92. The equation for this fission is

$$^{235}_{92}\text{U} \rightarrow {}^{141}_{56}\text{Ba} + {}^{92}_{36}\text{Kr} + x\,{}^{1}_{0}\text{n}.$$

(i) Use the graph to show that the fission of one nucleus of uranium-235 will release about 200 MeV of energy. *[4]*

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(ii) State the value of x in the equation. *[1]*

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(iii) The mass defect in this reaction is 3.1×10^{-28} kg. Calculate the number of uranium-235 nuclei that must fission in order to release 1.0 kJ of energy. *[2]*

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(iv) Outline how this fission reaction can lead to a chain reaction. *[2]*

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(This question continues on the following page)

(Question B2, part 1 continued)

(c) Intensive scientific effort is devoted to developing nuclear fusion as a future energy source. Discuss what could be the social and environmental benefits of using nuclear fusion as compared with nuclear fission as an energy source. *[3]*

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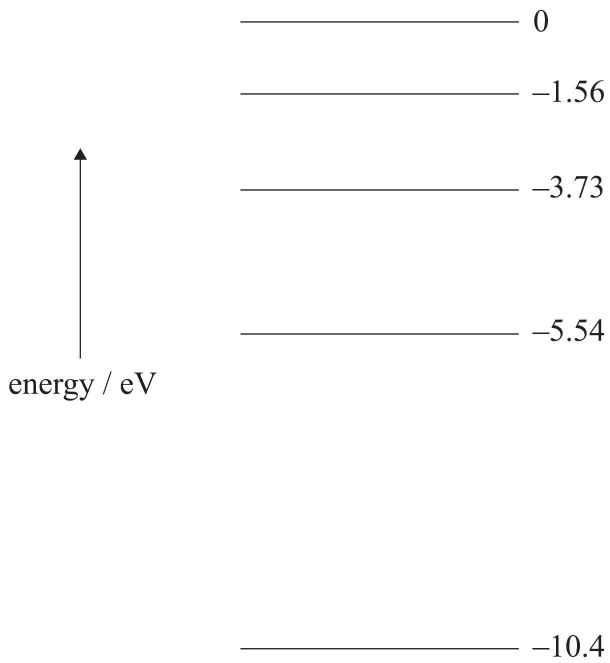
(This question continues on the following page)

(Question B1 continued)

Part 2 Atomic and nuclear spectra

Atomic spectra

(a) The diagram represents some of the energy levels of the mercury atom.



Photons are emitted by electron transitions between the levels. On the diagram draw arrows to represent the transition, for those energy levels that gives rise to,

(i) the longest wavelength photon (label this L). *[1]*

(ii) the shortest wavelength photon (label this S). *[1]*

(b) Determine the wavelength associated with the arrow you have labelled S. *[3]*

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(This question continues on the following page)

(Question B1, part 2 continued)

Nuclear spectra

(c) A nucleus of the isotope bismuth-212 undergoes α-decay into a nucleus of an isotope of thallium. A γ-ray photon is also emitted.

Draw a labelled nuclear energy level diagram for this decay. *[2]*

(d) The activity of a freshly prepared sample of bismuth-212 is 2.80×10^{13} Bq. After 80.0 minutes the activity is 1.13×10^{13} Bq. Determine the half-life of bismuth-212. *[4]*

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B4. This question is in **two** parts. **Part 1** is about the decay of radium-226 and **Part 2** is about diffraction and resolution.

Part 1 Decay of radium-226

(a) The nuclear reaction equation for the decay of radium-226 (Ra) may be written as

$$^{226}_{88}\text{Ra} = \text{Rn} + \alpha$$

(i) State the value of the proton number and neutron number of the isotope of radon (Rn). *[1]*

Proton number: . . . .

Neutron number: . . . .

(ii) Compare, with reference to the nuclear reaction in (a), the binding energy of Ra with that of Rn. *[2]*

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(b) The following data are available.

mass of Ra = 226.0254 u
mass of Rn = 222.0175 u
mass of α = 4.0026 u

Show that the energy released in the decay of a Ra nucleus is 4.94 MeV. *[2]*

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(This question continues on the following page)

(Question B4, part 1 continued)

(c) An α-particle of energy 4.94 MeV emitted in the decay of a Ra nucleus, travels a distance *d* in air before coming to rest.

(i) Show that the initial speed of the α-particle is $1.54\times10^{7}\,\text{m s}^{-1}$. *[3]*

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(ii) State the relationship between the magnitude of the average force *F* acting on the α-particle, the change in kinetic energy ΔE_{K} and the distance *d*. *[1]*

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(iii) Use your answer to (c)(ii) to calculate *F* given that $d = 4.20\times10^{-2}\,\text{m}$. *[2]*

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(iv) Estimate the time that it takes the α-particle to come to rest. *[4]*

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B4. This question is in **two** parts. **Part 1** is about α-particle scattering and nuclear processes. **Part 2** is about the albedo of the Earth.

Part 1 α-particle scattering and nuclear processes

Radium-226 decays with the emission of α-particles to radon (Rn).

(a) Complete the nuclear reaction equation. *[2]*

$$^{226}_{88}\text{Ra} \rightarrow \quad \text{Rn} \; + $$

(b) The decay constant of radium-226 is $1.4 \times 10^{-11}\,\text{s}^{-1}$ and each emitted α-particle has an energy of $7.6 \times 10^{-13}\,\text{J}$.

(i) Calculate the half-life of radium-226. *[1]*

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(ii) Determine the rate, in watts, of emission of energy from 1.0 g of radium-226. *[4]*

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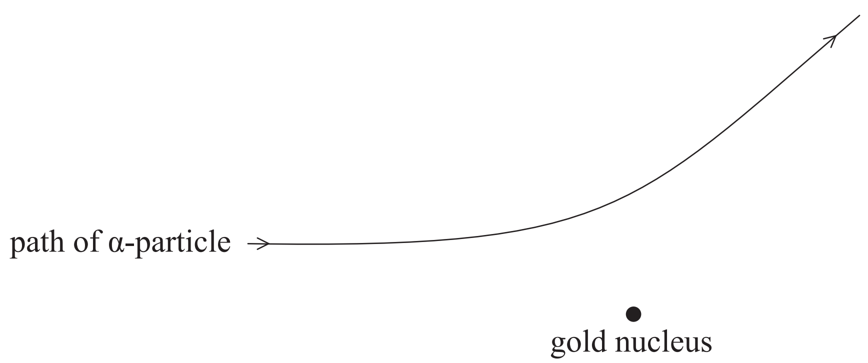
(This question continues on the following page)

(Question B4, part 1 continued)

(c) Experimental evidence that supports a nuclear model of the atom was provided by α-particle scattering. The diagram represents the path of an α-particle as it approaches and then recedes from a stationary gold nucleus.



(i) On the diagram, draw lines to show the angle of deviation of the α-particle. Label this angle *D*. *[1]*

(ii) The gold nucleus is replaced by another gold nucleus that has a larger nucleon number. Suggest and explain the change, if any, in the angle *D* of an α-particle with the same energy and following the same initial path as in (c)(i). *[2]*

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(d) Estimate the distance of closest approach to a gold nucleus ($Z=79$) of an α-particle with an initial kinetic energy of 4.0 MeV. *[3]*

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(This question continues on the following page)

B2. This question is in **two** parts. **Part 1** is about nuclear fusion. **Part 2** is about the Doppler effect.

Part 1 Nuclear fusion

(a) Define *binding energy* of a nucleus. *[1]*

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(b) Deduce, using the data below, that the binding energy per nucleon of the nucleus of tritium $\left({}^{3}_{1}\mathrm{H}\right)$ is 2.66 MeV. *[3]*

mass of tritium nucleus	3.016049 u
mass of proton	1.007276 u
mass of neutron	1.008665 u

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(c) Using the data below, calculate in MeV the energy released in the reaction

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

binding energy per nucleon, deuterium	$^{2}_{1}\mathrm{H}$	1.11 MeV
binding energy per nucleon, tritium	$^{3}_{1}\mathrm{H}$	2.66 MeV
binding energy per nucleon, helium	$^{4}_{2}\mathrm{H}$	7.20 MeV

[3]

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(This question continues on the following page)

(Question B2, part 1 continued)

(d) The diagram below shows a nucleus of deuterium $\left({}^{2}_{1}\text{H}\right)$ and a nucleus of tritium $\left({}^{3}_{1}\text{H}\right)$ that are approaching each other along a line joining their centres.

(Diagram not to scale)

The kinetic energy of each nucleus is E_K. The distance of closest approach is d.

(i) State the name of the force that prevents them from colliding. *[1]*

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(ii) At the distance of closest approach the kinetic energy of both nuclei is negligible. Deduce that the distance d is given by the expression

$$d = \frac{kq_D q_T}{2E_K}$$

where q_D is the charge of the deuterium nucleus, q_T is the charge of the tritium nucleus and k is the constant in Coulomb's law. *[3]*

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(iii) Nuclear fusion of deuterium and tritium takes place when the nuclei are separated by a distance $d = 1.2\times10^{-14}$ m or less.

Deduce that the kinetic energy E_K corresponding to a distance $d = 1.2\times10^{-14}$ m is equal to 9.6×10^{-15} J. *[2]*

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(This question continues on the following page)

(Question B2, part 1 continued)

(e) The average kinetic energy E, in joule, of nuclei is related to the absolute (kelvin) temperature T by

$$E = 2.1 \times 10^{-23}\, T.$$

(i) Determine the temperature for which the average kinetic energy of the nuclei is 9.6×10^{-15} J. *[1]*

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(ii) Nuclear fusion of deuterium and tritium occurs at temperatures that are less than the temperature calculated in (e)(i). Suggest a reason for this. *[2]*

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(iii) Explain the need for high temperatures for nuclear fusion to occur. *[2]*

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(iv) Suggest why, for large separations of the nuclei, the force between the nuclei is repulsive whilst for very small separations the force is attractive. *[2]*

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(This question continues on the following page)

A3. This question is about nuclear reactions.

(a) State the meaning of the terms

(i) nuclide *[2]*

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(ii) isotope *[1]*

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(b) The isotope sodium-24 undergoes radioactive decay to the stable isotope magnesium-24.

(i) Complete the nuclear reaction equation for this decay. *[2]*

$$^{24}_{11}\text{Na} \rightarrow {}^{24}_{12}\text{Mg}$$

(ii) One of the particles emitted in the decay has zero rest-mass. Use the data below to estimate the rest mass, in atomic mass units, of the other particle emitted in the decay of $^{24}_{11}\text{Na}$. *[3]*

rest mass of $^{24}_{11}\text{Na} = 23.99096u$

rest mass of $^{24}_{12}\text{Mg} = 23.98504u$

energy released in decay $= 5.002160\text{ MeV}$

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(This question continues on the following page)

(Question A3 continued)

(c) The isotope sodium-24 is radioactive but the isotope sodium-23 is stable. Suggest which of these isotopes has the greater nuclear binding energy. *[2]*

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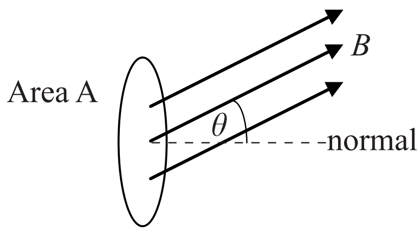
A4. This question is about induced e.m.f.

A small area A is in a region of uniform magnetic field of strength B. The field makes an angle θ to the normal to the area as shown below.



(a) With reference to the diagram, define *magnetic flux* ϕ both in words and in symbols. *[2]*

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(b) A thin copper ring encloses an area of $1.8\times10^{-3}\,\text{m}^2$. The plane of the ring is normal to a uniform magnetic field. The magnetic field strength increases at a constant rate of $5.0\times10^{-2}\,\text{T s}^{-1}$.

Calculate the e.m.f. induced in the ring. *[2]*

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A2. This question is about radioactivity.

(a) Outline a method for the measurement of the half-life of a radioactive isotope having a half-life of approximately 10^9 years. *[3]*

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(b) A radioactive isotope has a half-life $T_{\frac{1}{2}}$. Determine the fraction of this isotope that remains in a particular sample of the isotope after a time of $1.6\,T_{\frac{1}{2}}$. *[2]*

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(Question B3 continued)

Part 2 Nuclear decay

(a) Describe the phenomenon of natural radioactive decay. *[3]*

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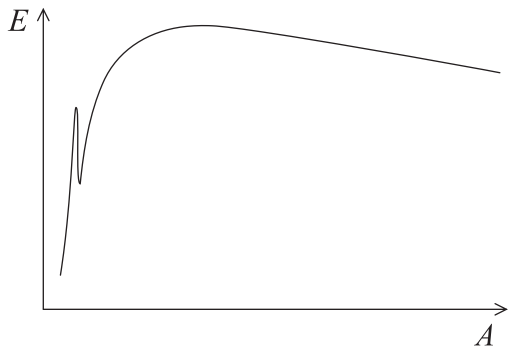
(b) The sketch graph below shows the variation with mass number (nucleon number) *A* of the binding energy per nucleon *E* of nuclei.



One possible nuclear reaction that occurs when uranium-235 is bombarded by a neutron to form xenon-142 and strontium-90 is represented as

$$^{235}_{92}\text{U} + {}^{1}_{0}\text{n} \rightarrow {}^{142}_{54}\text{Xe} + {}^{90}_{38}\text{Sr} + 4\,{}^{1}_{0}\text{n}.$$

(i) Identify the type of nuclear reaction represented above. *[1]*

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(ii) On the sketch graph above, identify with their symbols the approximate positions of the uranium (U), the xenon (Xe) and the strontium (Sr) nuclei. *[2]*

(This question continues on the following page)

(Question B3, part 2 continued)

(iii) Data for the binding energies of xenon-142 and strontium-90 are given below.

isotope	binding energy / MeV
xenon-142	1189
strontium-90	784.8

The total energy released during the reaction is 187.9 MeV. Determine the binding energy per nucleon of uranium-235. *[3]*

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(iv) State why binding energy of the neutrons formed in the reaction is not quoted. *[1]*

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