12.2 Nuclear Physics

Question Paper

Course	DP IB Physics
Section	12. Quantum & Nuclear Physics (HL only)
Topic	12.2 Nuclear Physics
Difficulty	Hard

Time allowed: 60

Score: /47

Percentage: /100

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Question 1a

In a scattering experiment, a metal foil of thickness 0.4 μm scatters 1 in 20 000 alpha particles through an angle greater than 90°.

(a)

(i)
Considering the metal foil as a number of layers of atoms, n, explain why the probability of an alpha particle being deflected by a given atom is approximately equal to

$$\frac{1}{20\,000n}$$

[2]

(ii)
Estimate the diameter of the nucleus. Consider the nuclei as cubes and the atoms in the foil as cubes of side length 0.25 nm.

[3]

[5 marks]

Question 1b

Deviations from Rutherford scattering are observed when high-energy alpha particles are incident on nuclei.

(b)
Outline the incorrect assumption used in the Rutherford scattering formula and suggest an explanation for the observed deviations.

[3]

[3 marks]

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Question 1c

In a scattering experiment, alpha particles were directed at five different thin metallic foils, as shown in the table.

Metal	Symbol
Silver	$^{108}_{47}Ag$
Aluminium	$^{27}_{13}Al$
Gold	$^{197}_{79}Au$
Tin	$^{119}_{50}Sn$
Tungsten	$^{184}_{74}W$

Initially, all alpha particles have the same energy. This energy is gradually increased.

(c)
Predict and explain the differences in deviations from Rutherford scattering that will be observed.

[3]

[3 marks]

Question 1d

(d)
Outline why the particles must be accelerated to high energies in scattering experiments.

[3]

[3 marks]

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Question 2a

(a)
Show that the decay constant is related to the half-life by the expression

$$\lambda T_{1/2} = \ln 2$$

[3]

[3 marks]

Question 2b

Uranium-238 has a half-life of 4.47×10^9 years and decays to thorium-234. The thorium decays (by a series of further nuclear processes with short half-lives) to lead.

(b)
Assuming that a rock was originally entirely uranium and that at present, 1.5% of the nuclei are now lead, calculate the age of the rock. Give your answer in years to 2 significant figures.

[3]

[3 marks]

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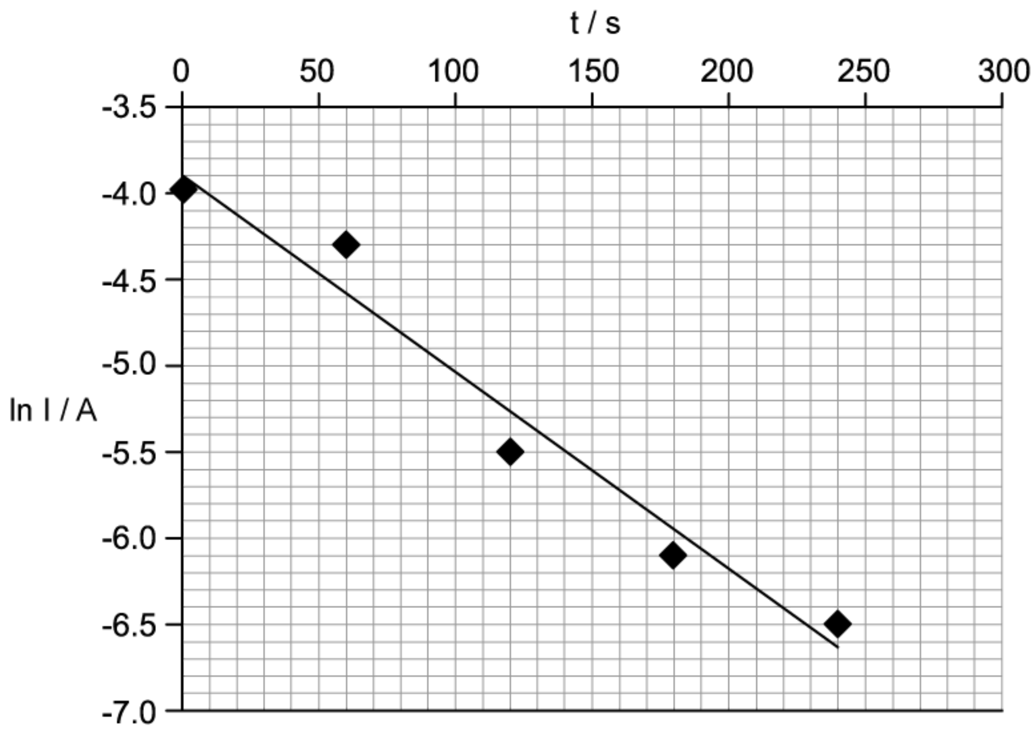
Question 2c

The ionisation current *I* produced by α-particles emitted in the decay of radon can be measured experimentally. The logarithmic graph shows how current, ln *I*, varies with time, *t*.



(c)
Using the graph, determine the half-life of radon.

[3]

[3 marks]

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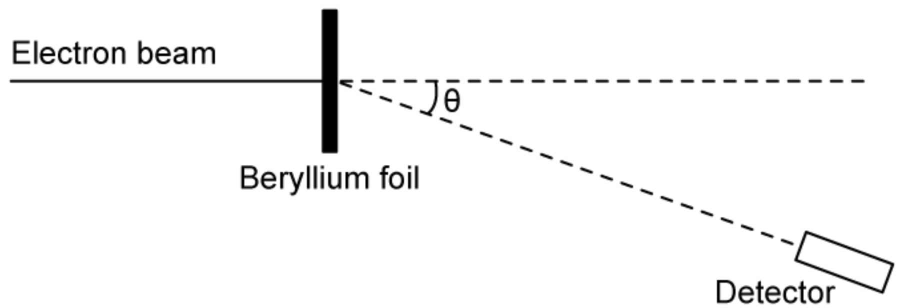
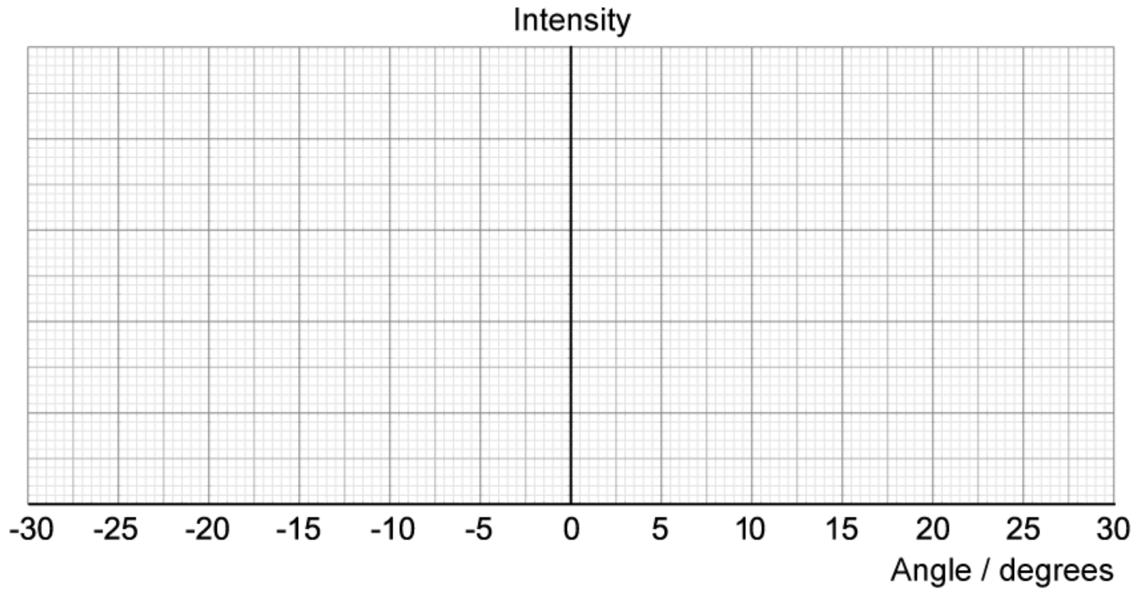
Question 3a

An electron beam of energy 1.3×10^{-10} J is used to study the nuclear radius of beryllium-9. The beam is directed from the left at a thin sample of beryllium-9. A detector is placed at an angle θ relative to the direction of the incident beam.



The radius of a beryllium-9 nucleus is 2.9×10^{-15} m. The beryllium-9 nuclei behave like a diffraction grating.

(a)
Sketch the expected variation of electron intensity against the angle from the horizontal.



[3]

[3 marks]

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Question 3b

The isotope beryllium-10 is formed when a nucleus of deuterium $\left({}_{1}^{2}\text{H}\right)$ collides with a nucleus of beryllium-9 $\left({}_{4}^{9}\text{Be}\right)$. The radius of a deuterium nucleus is 1.5 fm.

(b)

(i)
Determine the minimum initial kinetic energy, in J, that the deuterium nucleus must have in order to produce the isotope beryllium-10.

[2]

(ii)
Outline an assumption made in this calculation.

[1]

[3 marks]

Question 3c

The nucleus of beryllium-9 is replaced by a nucleus of gold-197.

(c)
Suggest the change, if any, to the following:

(i)
Distance of closest approach of a deuterium nucleus.

[2]

(ii)
Angle of minimum intensity from electron scattering. Assume the electrons have the same energy as in part (a).

[2]

[4 marks]

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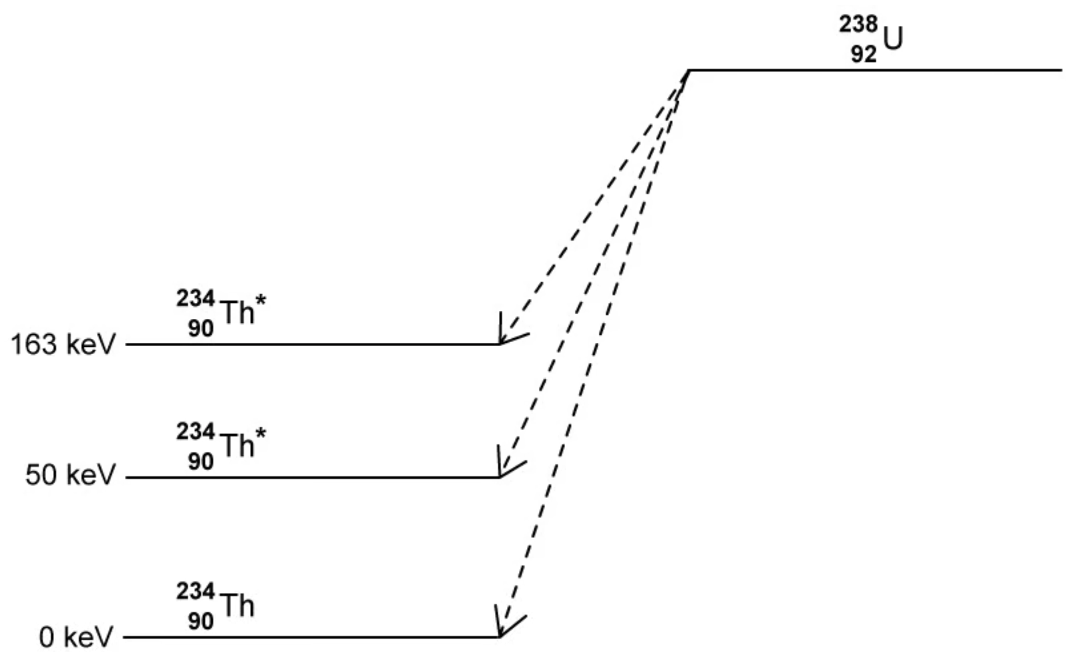
Question 4a

Unstable uranium-238 has various nuclear decay modes to become stable thorium-234. The total amount of energy released when it decays is measured to be 210 keV.



(a)
Outline, without calculation, the intermediate decay modes between the unstable uranium-238 to the stable thorium-234.

[2]

[2 marks]

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Question 4b

A possible decay chain for uranium-238 is:

$$^{238}_{92}U \rightarrow ^{234}_{90}Th^{*} + ^{4}_{2}\alpha$$

$$^{234}_{90}Th^{*} \rightarrow ^{234}_{90}Th^{*} + \gamma$$

$$^{234}_{90}Th^{*} \rightarrow ^{234}_{90}Th + \gamma$$

(b)
Calculate the total amount of energy, in joules, carried away as gamma radiation in this decay chain.

[4]

[4 marks]

Question 4c

(c)
Deduce an alternative decay chain from unstable uranium-238 to stable thorium-234 which releases the same amount of energy in the form of gamma radiation as in part (b).

Justify your answer with a calculation.

[2]

[2 marks]

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Question 5a

The half-life of uranium-238 is so long in comparison to any of the isotopes in its decay chain that we can assume the number of lead-206 nuclei, N_{Pb} at any time is equal to the number of uranium-238 that have decayed.

The number of uranium-238 nuclei N_U at time *t* is given by the equation:

$$N_U = N_0 e^{-\lambda t}$$

Where N_0 is the number of uranium-238 nuclei at *t* = 0.

(a)
Show that the ratio of N_{Pb} to N_U is given by:

$$\frac{N_{Pb}}{N_U} = e^{\lambda t} - 1$$

[3]

[3 marks]

Question 5b

Enriched uranium fuel is a mixture of the fissionable uranium-235 with the more naturally abundant uranium-238. Mixtures of radioactive nuclides such as this are very common in the nuclear power industry.

Two samples of radioactive nuclides X and Y each have an activity of A_0 at *t* = 0. They are subsequently mixed together.

The half-lives of X and Y are 16 and 8 years respectively.

(b)
Show that the total activity of the mixture at time *t* = 48 years is equal to:

$$\frac{9}{64} A_0$$

[3]

[3 marks]

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