IB · DP · Physics

3 hours 14 questions

Structured Questions

7.1 Discrete Energy & Radioactivity

7.1.1 Discrete Energy Levels / 7.1.2 Calculating Discrete Energies / 7.1.3 Emission & Absorption Spectrum / 7.1.4 Isotopes & Radioactive Decay / 7.1.5 Background Radiation / 7.1.6 Alpha, Beta & Gamma Particles / 7.1.7 Decay Equations / 7.1.8 Half-Life / 7.1.9 Investigating Half-Life

Easy (5 questions)	/75
Medium (5 questions)	/62
Hard (4 questions)	/40
Total Marks	**/177**

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Easy Questions

1 (a) Match, by drawing a line, the words with their correct definitions.

Ionisation	Fundamental particles that make up all forms of electromagnetic radiation
Photon	A group of atoms containing the same number of protons and neutrons
Nuclide	The electron has gained enough energy to be removed from the atom entirely
Isotope	An atom of the same element that has an equal number of protons but a different number of neutrons

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(4 marks)

(b) The energy of a photon can be calculated using the equation

$$E = \frac{hc}{\lambda}$$

Define the following terms and give the unit:

(i) h

[2]

(ii) c

[2]

(iii) λ

[2]

(6 marks)

(c) Calculate the wavelength of a photon with an energy of 1.44×10^{-19} J.

(2 marks)

(d) (i) Complete the gaps in the following paragraph by writing the correct words on the line.

Electrons in an atom can only have specific energies. These energies are called ________ ________ ______ .

Normally, electrons occupy the ______ energy level available. This is known as the _________ _________.

Electrons can gain energy and move up the energy levels by ____________ energy.

[4]

(ii) Underline the processes that allow an electron to move up an energy level.

Collisions with other atoms or electrons   Releasing a photon   Radioactive decay   Absorbing a photon   Changing colour   Emitting a neutrino

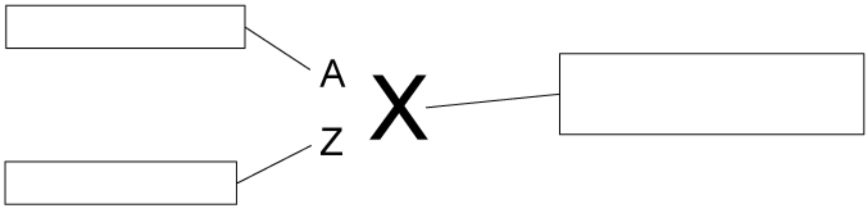
A physical source, such as heat

[3]

(7 marks)

2 (a) Nuclides can be written in symbol form.

Complete the labels on the general nuclide symbol using the words below:



- Chemical symbol for the element
- Proton number
- Nucleon number

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(3 marks)

(b) Define radioactive decay.

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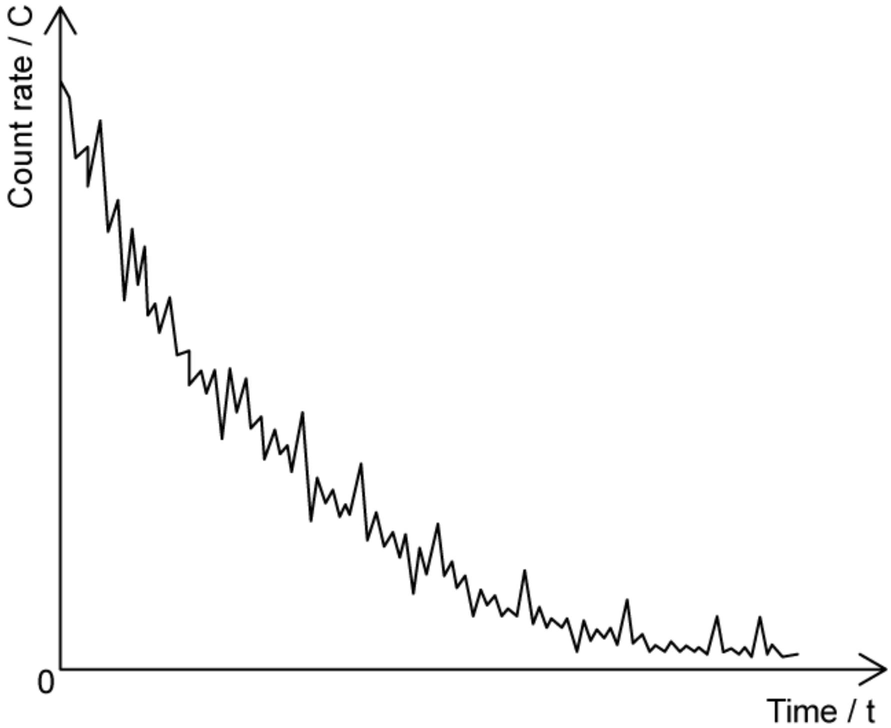
(4 marks)

(c) Draw lines to match the phrases with the correct definitions.

A spontaneous process	A process in which the exact time of decay of a nucleus cannot be predicted
A random process	The relative amounts of different isotopes of an element found within a substance
Isotopic data	A process which cannot be influenced by environmental factors

(3 marks)

(d) The graph shows the count rate of a radioactive substance measured by a Geiger-Müller tube.



State what the fluctuations in the count rate provide evidence for.

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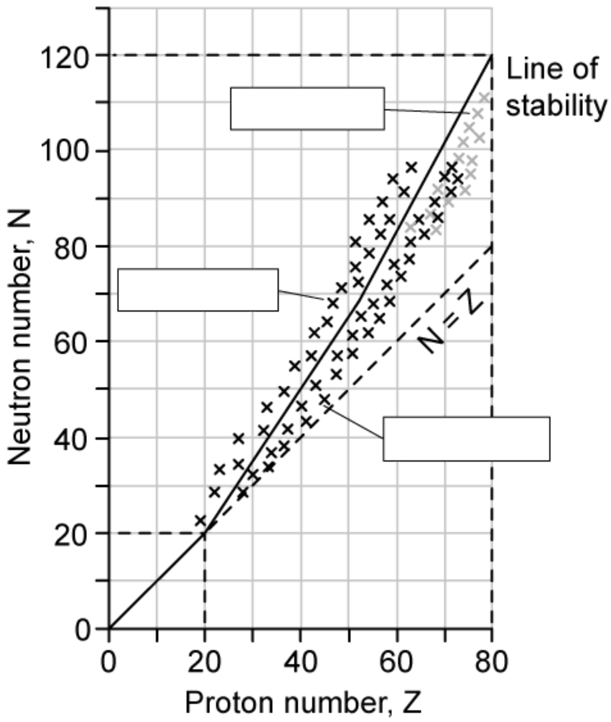
(1 mark)

3 (a) The number of neutrons and number of protons for different isotopes can be plotted on a graph called a nuclear stability curve. Different regions on the graph represent the type of decay which is expected.

The three types of radioactive particles shown are alpha emitters, beta−minus emitters and beta−positive emitters.

Label the regions of the graph to indicate which type of radioactive particle is expected to be emitted.



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(3 marks)

(b) Background radiation comes from a variety of sources, some are natural and some are man-made.

Place ticks (✔) in the correct column to indicate whether the source is man-made or natural:

	Mad-made source	Natural source
Fallout from nuclear weapons		
Cosmic rays		
Nuclear waste		
Nuclear accidents		
Carbon–14 in biological material		
Radon gas		
Medical sources		
Radioactive material in food and drink		

(8 marks)

(c) Radiation is emitted as various different types of particle.

State 4 types of radioactive particle.

(4 marks)

(d) When a beta emission occurs, a particle called a neutrino is also emitted.

Complete the gaps in the following sentences. Choose from the words below:

A neutrino has no __________ and negligable _________. Electron anti–neutrinos are produced during __________ decay. Electron neutrinos are produced during __________ decay.

mass gravity age charge beta–minus beta–positive alpha

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(4 marks)

4 (a) Complete the table with the correct properties of alpha, beta−minus, beta−positive and gamma radiation.

Particle	Composition	Mass / u	Charge / e
Alpha	2 protons and 2 neutrons		
Beta-minus		0.0005	-1
Beta-plus	Positron (e^+)	0.0005	
Gamma			0

(6 marks)

(b) Plutonium−239 decays to Uranium−235 through the emission of an alpha particle.

Determine the missing values in the decay equation:

$$^{239}_{94}\mathrm{Pu} \rightarrow ^{(i)}_{92}\mathrm{U} + ^{4}_{(ii)}\alpha$$

(2 marks)

(c) Strontium−90 decays through beta−minus decay to form Yttrium−90.

Determine the missing values in the decay equation.

$$^{90}_{38}\text{Sr} \rightarrow {}^{90}_{(\text{i})}\text{Y} + {}^{0}_{-1}\beta + (\text{ii})$$

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(2 marks)

(d) Fluorine−18 decays through beta−plus decay to form oxygen−18.

Determine the missing values in the decay equation.

$$^{18}_{9}\text{F} \rightarrow {}^{(\text{i})}_{8}\text{O} + {}^{0}_{(\text{ii})}\beta + \nu_e$$

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(2 marks)

5 (a) Define half–life.

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(2 marks)

(b) A student investigates the half–life of technetium with time. This list shows the variables in the experiment.

time   size of sample   distance from detector to sample

same material for the sample   radioactive activity

Using variables from the list:

(i) State the independent variable [1]

(ii) State the dependent variable [1]

(iii) State the control variables for the experiment [3]

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(5 marks)

(c) The experiment uses a variety of apparatus.

Draw a line to match the apparatus with its correct use.

Apparatus
Long tongs
Geiger-Müller tube
Secure holder for radioactive source
Stopwatch

Purpose
To detect the count rate of the radioactive source
To measure the same interval of time for each reading
To handle the radioactive source at a distance
To ensure the radioactive source remains in place. It is lined with lead to reduce unnecessary exposure

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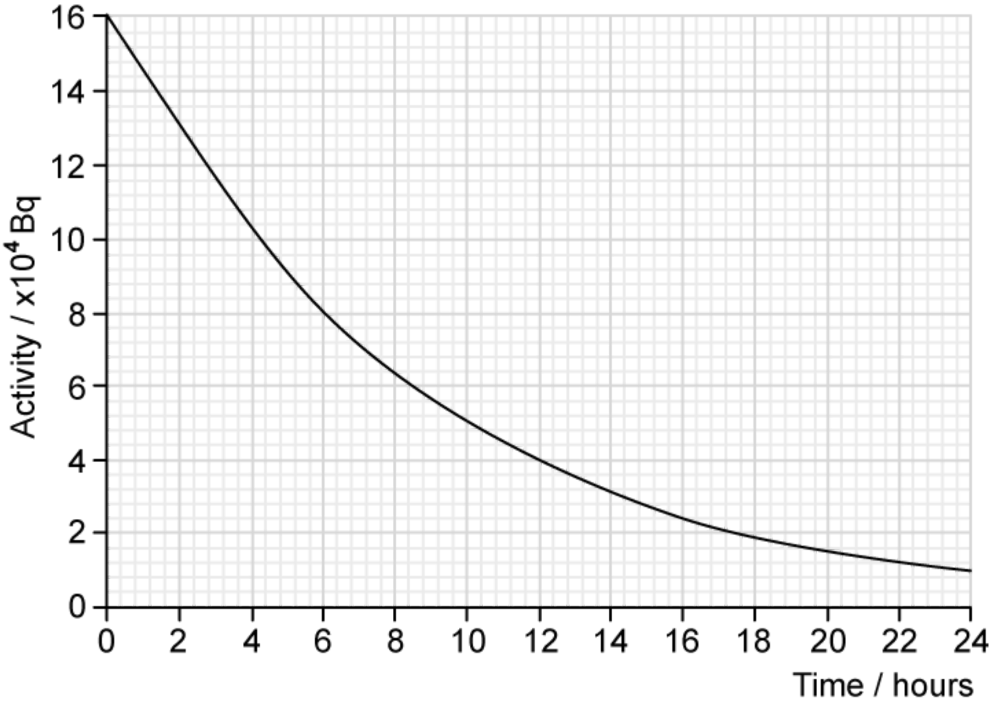
(4 marks)

(d) The student plots the following graph of their results.



Determine the half−life of the sample.

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(3 marks)

Medium Questions

1 (a) In a HeNe laser, electrons collide with helium atoms. The ground state of a helium is labelled as 1*s* and the next energy level is labelled 2*s*.

When an electrons de-excite from 2*s* to 1*s* in helium, photons are emitted with a wavelength of 58.4 nm.

Calculate the energy difference of this transition, giving your answer in eV.

(3 marks)

(b) An electron collides with a helium in its ground state, causing an electron to transition from 1*s* to 2*s*. The electron initially has 45.0 eV of kinetic energy.

Calculate the electron's kinetic energy after the collision.

(2 marks)

(c) Explain why it is not possible for the same electron from (b) to collide with the ground state helium atom and be left with 40.0 eV of kinetic energy.

(3 marks)

(d) Helium and neon coincidentally have very similar energy gaps for certain transitions, allowing one atom to cause an excitation in the other.

The excited helium atom from part (b) then collides with a ground state neon atom. The neon atom becomes excited and subsequently emits two photons in order to return to its ground state.

(i) If the helium is left back in its ground state after the collision, determine the amount of energy transferred to the neon atom.

(ii) If one photon has an energy of 1.96 eV, calculate the wavelength of the other.

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(5 marks)

2 (a) The decay series of an isotope of thorium, $^{232}_{90}Th$, produces an isotope of radium, $^{224}_{88}Ra$. This process involves four separate decays.

The first decay involves the emission of an alpha particle.

Write the decay equation for this process, including the symbol of the daughter product.

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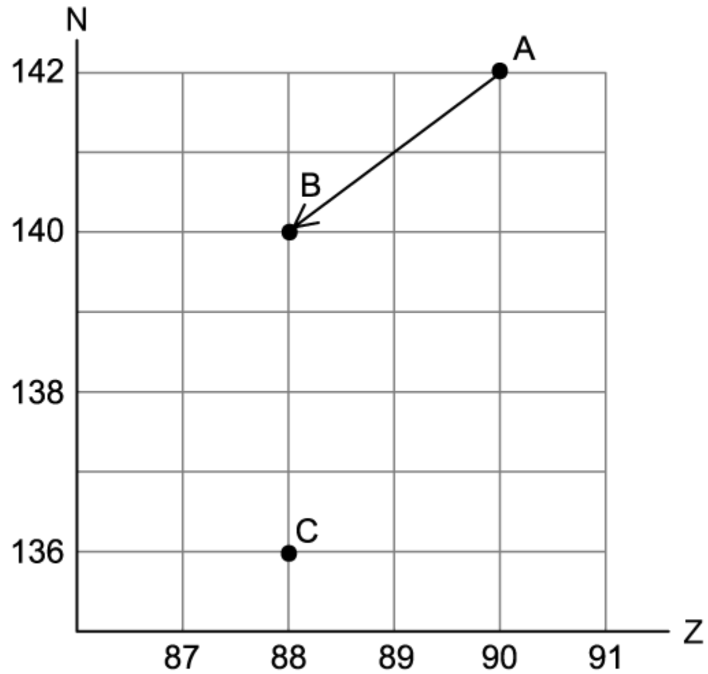
(3 marks)

(b) The first decay can be represented on an N-Z diagram as an arrow from point A to point B.



Three more decays occur before $^{224}_{88}Ra$ is produced, denoted by "C" on the N-Z diagram.

Outline the possible sequence of decays which lead from point B to C.

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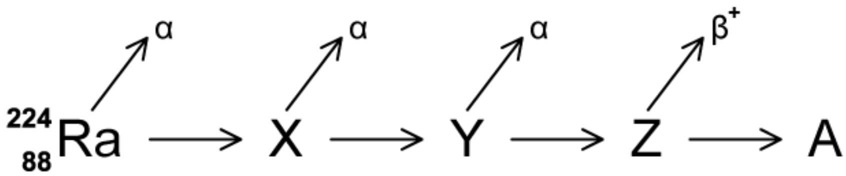
(3 marks)

(c) Nuclei can be unstable for a number of reasons.

In terms of forces within the nucleus, explain why large nuclei emit alpha radiation.

(4 marks)

(d) $^{224}_{88}Ra$ then decays four more times, shown below.



The first three decays result in the emission of an alpha particle each time. The fourth and final decay results in the emission of a beta-particle.

Calculate the nucleon number and atomic number of nuclide A.

(3 marks)

3 **(a)** A radioactive source is used to measure the thickness of paper. A Geiger counter is used to measure the count rate on the opposite side of the paper to the radioactive source. The radioactive source used must be chosen carefully.

(i) State and explain the type of radioactive source that should be used for this process.

(ii) A new type of paper is placed between the Geiger counter and the radioactive source. Explain how the equipment can be used to show if the new paper is thicker or thinner than the previous type.

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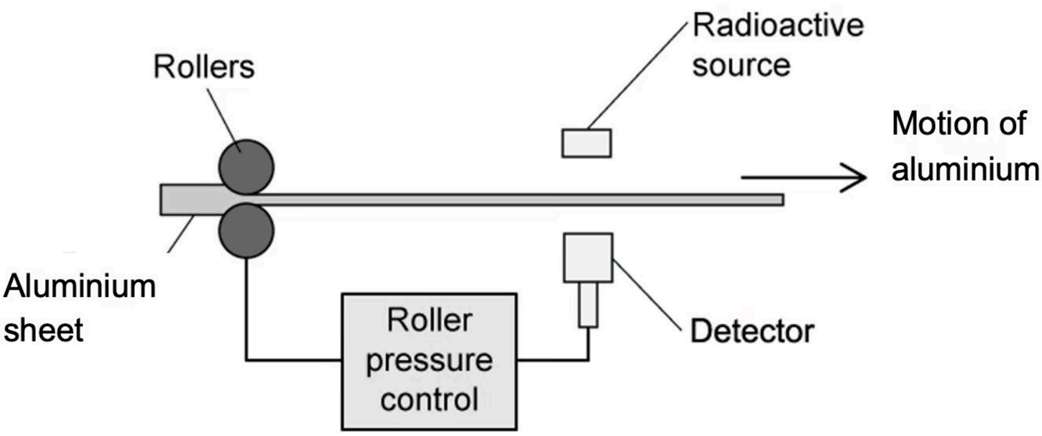
(4 marks)

(b) The arrangement below is used to maintain a constant 0.10 m thickness of aluminium sheets. Alpha, beta or gamma sources are available to be used.



Outline the most suitable radioactive source for this arrangement and explain why the other sources may not be appropriate.

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(2 marks)

(c) The source used in part (b) has a half-life of 14 days and it has an initial count rate of 240 counts per minute when first used in the apparatus.

Giving your answer in weeks, calculate the length of time it takes for the Geiger counter to detect a count rate of 0.25 s^{-1}.

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(3 marks)

(d) Once the source has reached an activity of 0.25 s^{-1}, it is replaced as the count rate of the source is comparable with that of background radiation.

State two natural sources of background radiation and two man-made sources of background radiation.

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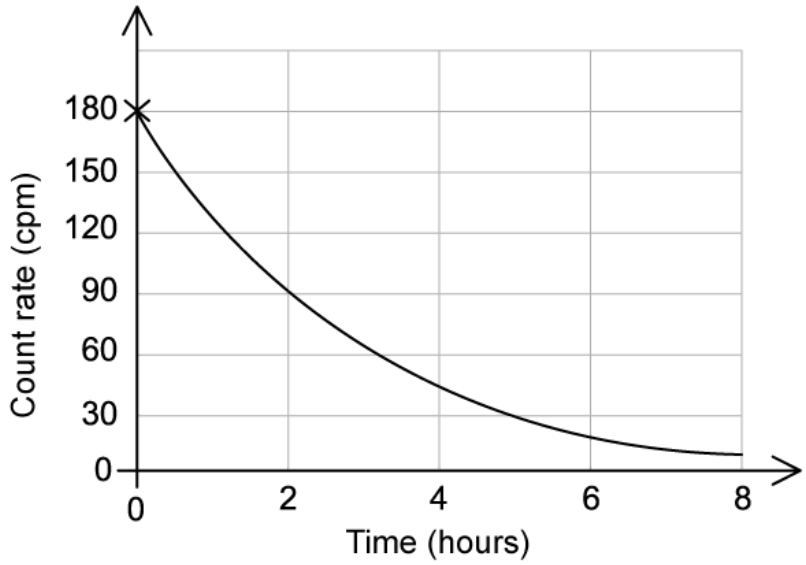
(4 marks)

4 (a) A sample's count rate in counts per minute (cpm) is measured using a ray detector. This data is plotted on a graph.



(i) Use the graph to determine the half-life of this sample.

[2]

(ii) Explain why the distance between the detector and the source is a control variable.

[2]

(1 mark)

(b) The scientist wonders how the experiment in part (a) would have changed if the sample was twice the size.

Assuming the experiment from part (a) was repeated with a sample the exact same age but twice the mass, calculate the length of time it would have taken to reach a count rate of 22.5 cpm.

(3 marks)

(c) In reality the detector will measure a count rate of more than 5 cpm long after the length of time in part (b) has passed.

(i) Outline the reason for this larger-than-expected count rate.

[2]

(ii) Describe the measurements the scientist could take to accurately account for this additional count rate in the final data.

[2]

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(4 marks)

(d) The scientist can measure the count rate of the source but is unable to directly measure the activity of the source using their detector. Activity is the total number of particles emitted from the sample per unit time.

Explain why this is not possible.

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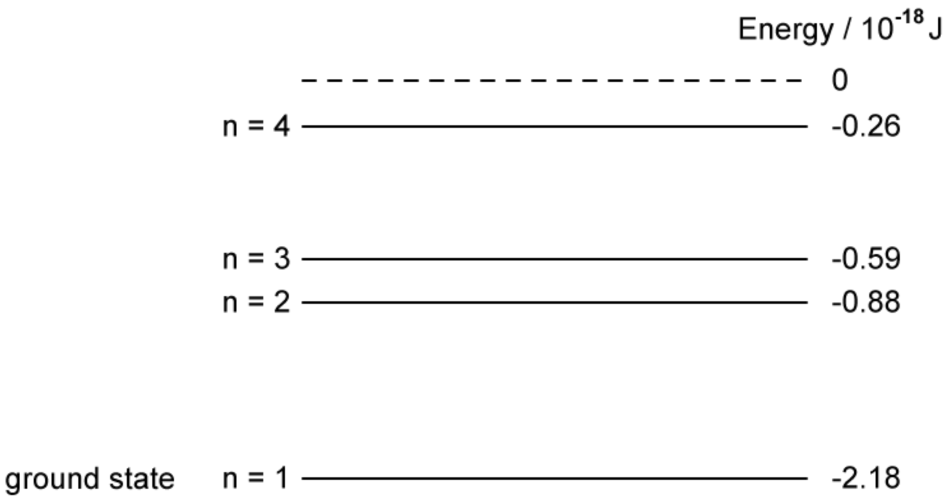
(2 marks)

5 (a) Fluorescent tubes operate by exciting the electrons of mercury atoms.

The energy levels of a mercury atom are shown below (not to scale):



An electron is excited to n = 4. On the diagram, draw all the possible de-excitation routes from n = 4 to the ground state.

(4 marks)

(b) State and explain which energy transition will emit the photon with the lowest frequency.

(2 marks)

(c) An unstable isotope of mercury, Hg-203, is tested for its radioactive emissions in a laboratory that has a background rate of 0.3 s^{-1}.

A source is placed a fixed distance from a Geiger-Muller tube. Various materials are placed in between the detector and the source while the count rate is recorded. The results are shown below.

Material	Count rate / s^{-1}
None	68
0.5 mm thick paper	69
2.0 mm thick paper	65
5 cm thick aluminium foil	15

State and explain what types of radiation are being emitted by the Hg-203 source.

(4 marks)

(d) A student notices that the count rate recorded actually increases when 0.5 mm thick paper was placed between the Geiger-Muller tube and the source.

(i) Suggest one cause of this increase.

(ii) Describe what the experimenter could do to check if this data point was anomalous.

(3 marks)

Hard Questions

1 (a) Transitions between three energy levels in a particular atom give rise to three spectral lines. In decreasing magnitudes, these are f_1, f_2 and f_3.

The equation which relates f_1, f_2 and f_3 is:

$$f_1 = f_2 + f_3$$

Explain, including through the use of a sketch, how this equation relates f_1, f_2 and f_3.

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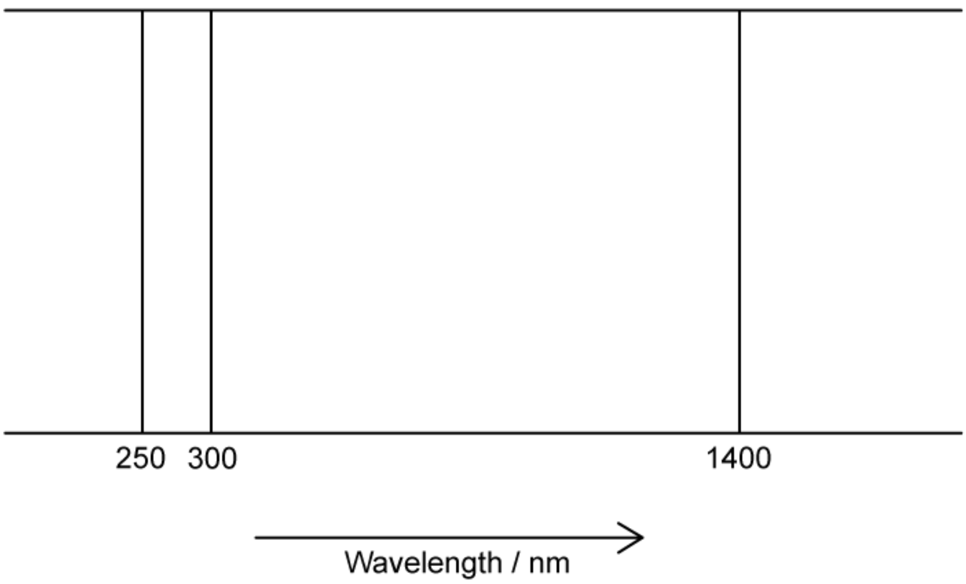
(3 marks)

(b) A different atom has a complete line emission spectra with a ground state energy of –10.0 eV. is:



Sketch and label a diagram of the possible energy levels for the atomic line spectra shown.

(5 marks)

(c) Explain the significance of an electron at an energy level of 0 eV.

(3 marks)

(d) (i) Explain the statement 'the first excitation energy of the hydrogen atom is 10.2 eV'

[1]

(ii) The ground state of hydrogen is –13.6 eV. Calculate the speed of the slowest electron that could cause this excitation of a hydrogen atom.

[2]

(3 marks)

2 (a) A radioactive nucleus $^{229}_{85}X$ undergoes a beta–minus decay followed by an alpha decay to form a daughter nucleus $^{A}_{Z}Y$.

Write a decay equation for this interaction and hence determine the values of A and Z.

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(2 marks)

(b) Thorium, $^{90}_{232}Th$ decays to an isotope of Radium (Ra) through a series of transformations. The particles emitted in successive transformations are:

$$\alpha \ \beta \ \beta \ \gamma \ \alpha$$

Determine the resulting nuclide after these successive transformations.

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(3 marks)

(c) Through a combination of successive alpha and beta decays, the isotope of any original nucleus can be formed.

Explain the simplest sequence of alpha and beta decays required to do this

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(3 marks)

(d) A nucleus of Bohrium $^{X}_{Y}Bh$ decays to Mendelevium $^{255}_{101}Md$ by a sequence of three alpha particle emissions.

Determine the number of neutrons in a nucleus of $^{X}_{Y}Bh$

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(2 marks)

3 (a) The table shows some of the isotopes of phosphorus and, where they are unstable, the type of decay.

Isotope	$^{29}_{15}P$	$^{30}_{15}P$	$^{31}_{15}P$	$^{32}_{15}P$	$^{33}_{15}P$
Type of decay	β^+	β^+	stable		β^-

State whether the isotope $^{32}_{15}P$ is stable or not. If not, determine, with a reason, the type of decay it experiences.

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(3 marks)

(b) The isotope of phosphorus $^{30}_{15}P$ decays into an isotope of silicon, $^{A}_{Z}Si$.

Write a decay equation for this decay, finding the values of A and Z, and explain why each emission product occurs.

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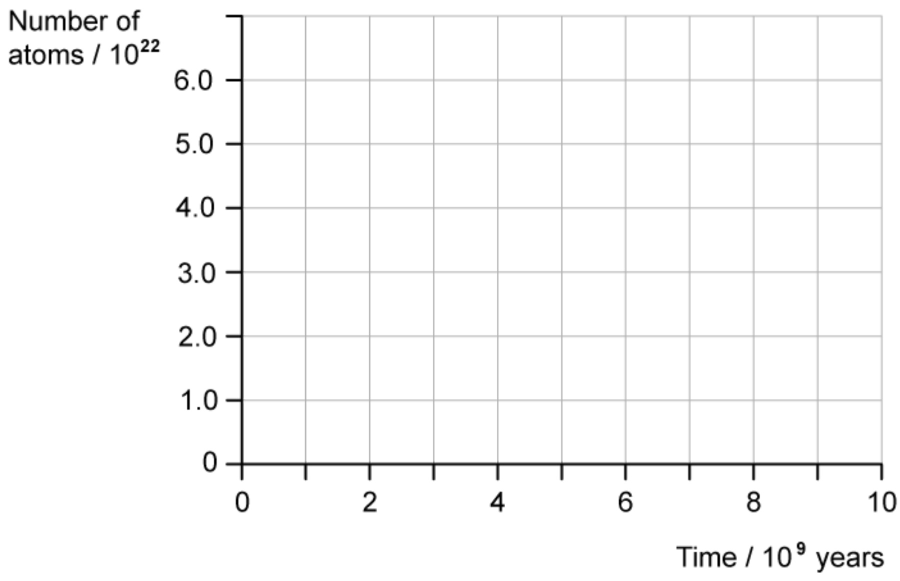
(3 marks)

4 (a) The radioactive isotope uranium−238 decays in a decay series to the stable lead−206.

The half−life of $^{238}_{92}\text{U}$ is 4.5 × 10^9 years, which is much larger than all the other half−lives of the decays in the series.

A rock sample, when formed originally, contained 6.0 × 10^{22} atoms of $^{238}_{92}\text{U}$ and no $^{206}_{82}\text{Pb}$ atoms. At any given time, most of the atoms are either $^{238}_{92}\text{U}$ or $^{206}_{82}\text{Pb}$ with a negligible number of atoms in other forms in the decay series.

Sketch on the axes below the variation of number of $^{238}_{92}\text{U}$ atoms and the number of $^{206}_{82}\text{Pb}$ atoms in the rock sample as they vary over a period of 1.0 × 10^{10} years from its formation. Label your graphs U and Pb.



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(2 marks)

(b) A certain time, *t*, after its formation, the sample contained twice as many $^{238}_{92}\text{U}$ atoms as $^{206}_{82}\text{Pb}$ atoms.

Show that the number of $^{238}_{92}\text{U}$ atoms in the rock sample at time *t* was 4.0 × 10^{22}.

(2 marks)

(c) The ratio of the number of lead nuclei N_{Pb} to the number of uranium nuclei N_U at some time *t* is given by:

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

λ is the decay constant and has a value of 1.54×10^{-10} years.

Calculate the time taken (in years) for there to be twice as many $^{238}_{92}U$ atoms as $^{206}_{82}Pb$ atoms.

(2 marks)

(d) Lead−214 is an unstable isotope of lead−206. It decays by emitting a β^- particle to form bismuth−214 (Bi)

Bismuth is also unstable and has two decay modes:

- Emitting an α particle to form thallium−210 (Tl) + energy
- Emitting a β particle to form polonium−214 (Po) + energy

Write decay equations for the decay chain of lead−214 to thallium−210 and to polonium−214. Comment on the nature of the energy released.

(4 marks)