Topic 11: Nuclear Radiation

1.1 Specification notice:

In order to develop their practical skills, students should be encouraged to carry out a range of practical experiments related to this topic. Possible experiments include measuring the half-life of a radioactive material. Mathematical skills that could be developed in this topic include applying the concepts underlying calculus (but without requiring the explicit use of derivatives or integrals) by solving equations involving rates of change, for example. $\Delta x / \Delta t = -\lambda x$ using a graphical method or spreadsheet modelling and understanding probability in the context of radioactive decay.
This topic may be studied using applications that relate to nuclear radiation, for example nuclear power stations and medical physics.

11.Q Exam questions

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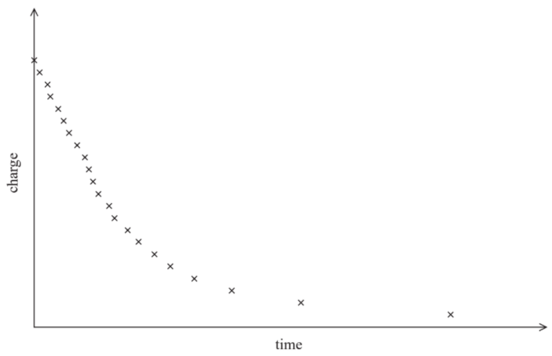
<td>
How would you prove this curve is exponential?
(b) For one sheet of zinc, the charge at different times was measured.
The following graph was obtained.


A student suggests that this is an exponential decay curve.
Explain how this suggestion could be tested.
(3)
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<td>
• would be of form $Q = Q_0 e^{-kt}$ (1)
• plot ln charge against time (1)
• if straight line with negative gradient it's exponential (1)
Or
• would be of form $Q = Q_0 e^{-kt}$ (1)
• Calculate Q/Q_0 for pairs of values with same time interval t **Or** calculates $t_{1/2}$ at least twice (1)
• If equal, then it's exponential (1)
MP3 accept some indication that gradient is negative
For both MS options MP3 is dependent on MP2
● Form $Q=Q_0 e^{-kt}$
● Plot ln charge against time
● If straight line with negative gradient its exponential
OR
● Form $Q=Q_0e^{-kt}$
● Calc Q/Q_0 for pairs of values with same time interval t OR calc $t_{1/2}$ at least twice
● If equal then it's exponential
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<td>
(c) The science department also has a sample of strontium-90. This undergoes beta decay with a half-life of 29 years.
State why the half-life of potassium-40 makes the potassium chloride a more suitable material than strontium-90 for the test.
(1)
Show that the activity of this sample is about 5 Bq.
half-life of potassium-40 = 1.25×10^9 years
State why the half life of potassium-40 make the potassium chloride a more suitable
</td>
<td>
• so the proportion of unstable nuclei does not change significantly over time
Or activity does not change significantly over time (1)
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material than strontium-90 for the test?	
13 A fusion research centre was opened in Rotherham in 2021. The centre has a device which tests materials in the extreme conditions found inside a fusion reactor. (a) Describe the extreme conditions inside a fusion reactor. (3) Describe the extreme conditions inside a fusion reactor? (3)	**Max** three from: • Very high temperatures (1) — Accept T~10^7 K -10^8 K for MP1 • High magnetic flux density (1) — Accept conditions for stars: High density, High pressure • Bombardment by neutrons (1) • Material is a plasma or material is fully ionised (1) ● Very high temperatures (1) ● Very high densities (1) ● High magnetic flux density (1) ● Bombardment by neutrons (1) ● Material is a plasma (or material is fully ionised) (1)

11.164 understand the concept of nuclear binding energy and be able to use the equation ΔE = c^2Δm in calculations of nuclear mass (including mass deficit) and energy

Define binding energy (2)?	The energy equal to the mass defect (1) and when the nucleons bind together to form an atomic nucleus (1) $\text{Binding Energy} = \text{Mass Defect} \cdot c^2$ *This could also be considered the energy needed to separate the nucleus into its individual separate nucleons*
What is a mass defect?	The difference between the mass of the separate nucleons added together and when all the nucleons are together in the nucleus. *The latter is less since it is more stable when it is together. When a nucleus is formed, this mass is released as energy*

11.165 use the *atomic mass unit (u)* to express small masses and convert between this and SI units

11.166 understand the processes of nuclear fusion and fission with reference to the binding energy per nucleon curve

<table>
<tr>
<td>Draw and describe the graph for ‘ Binding Energy per Nucleon’ v ‘Nucleon Number’</td>
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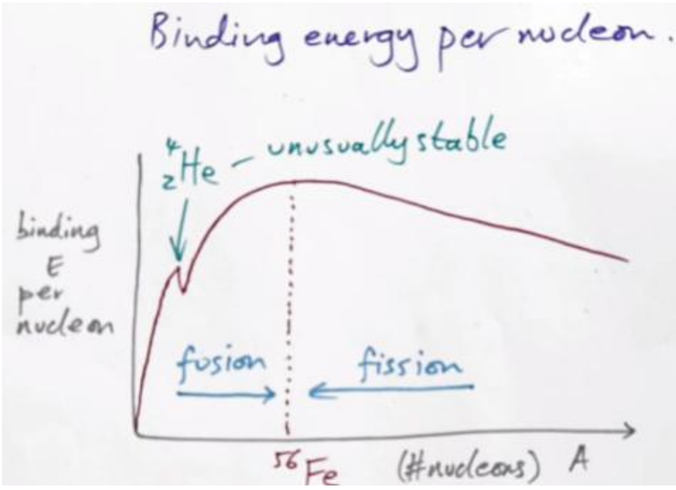
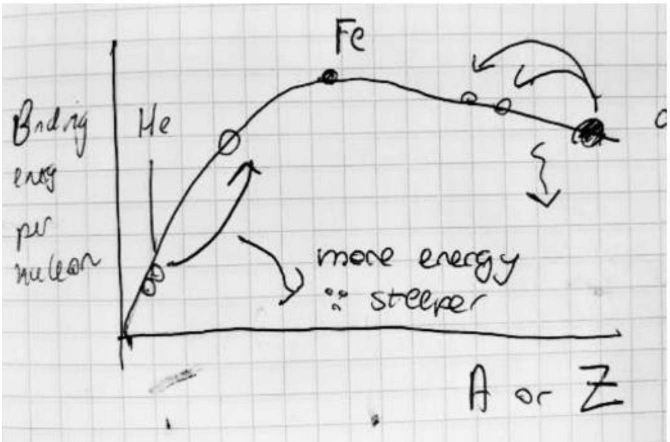


Remember that helium is unusually stable - hence why we get alpha particles during radioactive decay.

- The greater the binding energy per nucleon, the more stable a nucleus is (as show iron).
- We can get energy out by 2 ways as nuclei progress closer towards iron:
    - Fusion occurs to the left of iron as lighter nuclei fuse into heavier nuclei
    - Fissions occurs to the right of iron as heavy nuclei split into lighter nuclei.

This is shown below:



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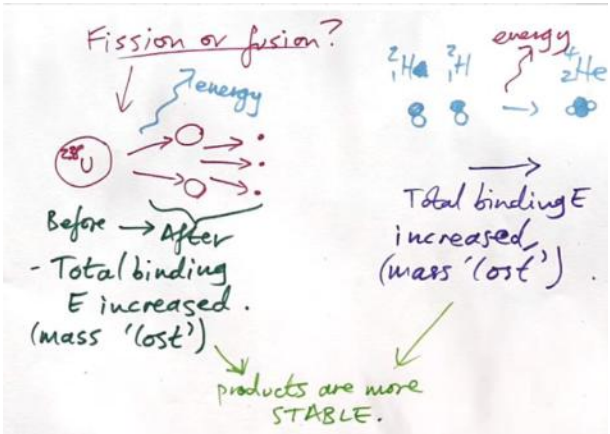
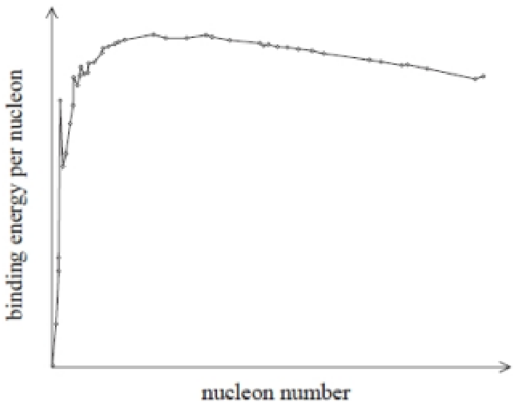
	 Where in both cases, energy is given out and products become more stable. It is less stable as you go further right as the strong nuclear force cannot hold all the neutrons together. *It gets more stable towards iron as a lot more energy is required to remove each nucleon from its nuclide. For this reason, its difficult to fuse heavy nuclei or fission light nuclei as more energy is required than you get out*
 Use the binding energy per nucleon curve to explain how fusion and fission both release energy. (3)	● Fusion involves an increase in binding energy per nucleon as the number of nucleons increases (1) ● Fission involves an increase in binding energy per nucleon as the number of nucleons decreases (1) ● If binding energy per nucleon increases energy is released in the process (1)

11.167 understand the mechanism of nuclear fusion and the need for very high densities of matter and very high temperatures to bring about and maintain nuclear fusion

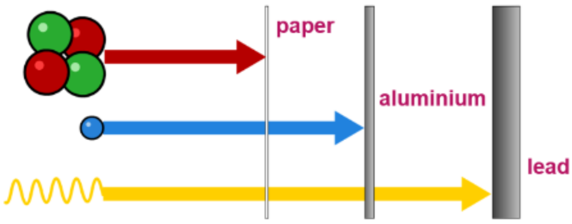
What are the conditions required for nuclear fusion and why?	● **Very high** temperature and so nuclei have high <u>**KE**</u> to overcome the large electrostatic repulsion between positively charged nuclei (1) ● **Very high** density to ensure nuclei

	are close enough together to fuse and to maintain high collision rate to maintain fusion (2) *Must say VERY HIGH* ***Some** Mark Schemes allow pressure for density but just say high density as not all of them allow pressure*

11.168 understand that there is background radiation and how to take appropriate account of it in calculations

Where does background radiation come from? (both natural and man-made)	• Natural: 1. Cosmic rays. 2. Natural radioactive material in rocks/soil 3. Radon gas 4. Food • Man-made: 1. Medical sources 2. Nuclear power stations

11.169 understand the relationships between the nature, penetration, ionising ability and range in different materials of nuclear radiations (alpha, beta and gamma)

How does α, β and γ radiation vary in penetration?	1. Alpha particles are stopped by a few cm of air / thin sheet of paper. 2. Beta particles are stopped by a few mm of aluminium 3. Gamma ray intensity is halved by 10cm of lead 

11.170 be able to write and interpret nuclear equations given the relevant particle symbols

11.171 CORE PRACTICAL 15: Investigate the absorption of gamma radiation by lead.

<table>
<tr>
<td>What MUST be measured before carrying out an experiment using radioactivity?</td>
<td>Measure BACKGROUND count rate over a course of 10 minutes then find the count rate for over 1 minute

You may have to change it into seconds/becquerels if the question requires it</td>
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<tr>
<td>How should you deal with anomalies during a radioactivity experiment?
<table>
<tr><th>Count 1</th><th>Count 2</th><th>Mean count</th></tr>
<tr><td>183</td><td>178</td><td>181</td></tr>
</table>
</td>
<td>Don’t ignore them, use them when calculating means.

Since radioactivity decay is a random process, you cannot predict when an individual nucleus will decay. Yet with a large number of nuclei, you can use a statistical approach</td>
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<tr>
<td>What are the 3 ways in determining the half life of a source?</td>
<td>

You can take logs of N,A or C and draw a graph of LogN against time where gradient would be -λ then sub into $N=N0e^{-\lambda t}$ to find t
Interpolate a N,A or C against time graph for 3 pairs of half lives unless quoted otherwise to find t
If your given the decay constant you could do $\ln 2/\boldsymbol{\lambda}$ to find t

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11.172 understand the spontaneous and random nature of nuclear decay

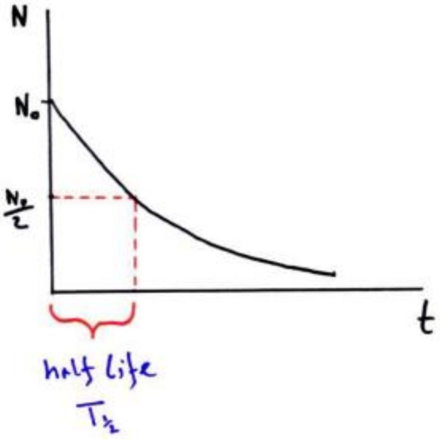
Define spontaneous decay? (1)	Decay that happens without any external stimulus (1) (or decay that is unaffected by external factors such as temperature) *Do not allow references to the randomness of the decay*

Define random decay?	A process in which the exact time of decay of a nucleus cannot be predicted

11.173 be able to determine the half-lives of radioactive isotopes graphically and be able to use the equations for radioactive decay: activity $A = \lambda N, \frac{dN}{dt} = -\lambda N, \lambda = \frac{ln2}{t_{\frac{1}{2}}}, N = N_0\, e^{-\lambda t}$ and $A = A_0 e^{-\lambda t}$ derive and use the corresponding log equations. [Personal note include $C = C_0 e^{-\lambda t}$]

Define isotopes? (1)	Isotopes are atoms (nuclides) with the same number of protons but a different number of neutrons (nucleons) in the nucleus (1)
How would you derive $Ln(A)=Ln(A_0) - \lambda t$ from $A = A_0e^{-\lambda t}$	• $A=A_0e^{-\lambda t}$ • $LnA = LnA_0 + lne^{-\lambda t}$ • $LnA = LnA_0 - \lambda t$
What is the activity of a sample defined as and was it it usually measure in?	The number of decays per second taking part in a source measured in **becquerels (Bq).** Maths skills **Exponential decay** Combining the two equations $A = \frac{dN}{dt}$ and $A = -\lambda N$ gives: $\frac{dN}{dt} = -\lambda N$ ***dN*** *= change in number of undecayed nuclei* ***dt*** *= change in time in seconds* *Also known as the average number of disintegrations per second*
What is the decay constant λ defined as?	The probability that a nucleus will decay in the next second (s^{-1})

	$$\frac{\Delta N}{\Delta t} = -\lambda N$$ So… $$A = \lambda N$$ *This makes sense if you think about it since multiplying the probability of decay per second by the number of nuclei will give you the number of decays per second.* *And using differential equations of dN/dt = -* ***λN,*** *you can derive:* $$N = N_0 e^{-\lambda t}$$

What are the 3 definitions of half life of a sample and the 3 equations	● The time it takes half the nuclei in a source to decay and $N=N_0e^{-\lambda t}$ ● The time it takes the count rate to half and $C=C_0e^{-\lambda t}$ ● The time it takes the activity to half and $A=A_0e^{-\lambda t}$  Which can also be given by the following equation: $$T_{½} = \frac{\ln 2}{\lambda}$$ Which can be derived from the following: $$N = N_0 e^{-\lambda t}$$
How does radioactive dating work?	Once a plant or animal dies, its carbon-14 content gradually decreasing and by comparing the amount found on the ancient artifact with the amount we would expect, we can date it. *We often assume the proportion of carbon-14 in the atmosphere has stayed constant which depends on whether the amount of cosmic rays penetrating the atmosphere was the same*