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|  | |  |  | | --- | --- | | **Physics A**  **Nuclear Physics practise questions** |  | | Please note that you may see slight differences between this paper and the original.  Candidates answer on the Question paper.  **OCR supplied materials:** Additional resources may be supplied with this paper.  **Other materials required:** •   Pencil •   Ruler (cm/mm) | **Duration:** 120 mins | |  | | |  |

## INSTRUCTIONS TO CANDIDATES

•   Write your name, centre number and candidate number in the boxes above. Please write clearly and in capital letters.  
•   Use black ink. HB pencil may be used for graphs and diagrams only.  
•   Answer **all** the questions, unless your teacher tells you otherwise.  
•   Read each question carefully. Make sure you know what you have to do before starting your answer.  
•   Where space is provided below the question, please write your answer there.  
•   You may use additional paper, or a specific Answer sheet if one is provided, but you must clearly show your candidate number, centre number  
    and question number(s).

## INFORMATION FOR CANDIDATES

•   The quality of written communication is assessed in questions marked with either a pencil or an asterisk. In History and Geography   
    a *Quality of extended response* question is marked with an asterisk, while a pencil is used for questions in which *Spelling, punctuation and  
    grammar and the use of specialist terminology* is assessed.  
•   The number of marks is given in brackets **[ ]** at the end of each question or part question.  
•   The total number of marks for this paper is **100**.  
•   The total number of marks may take into account some 'either/or' question choices.

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|  | |  |  | | --- | --- | |  |  | | **1.** | In beta-plus decay, a proton decays into three other particles.  Write a nuclear equation for this process.  **[2]** | |

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|  | |  |  | | --- | --- | |  |  | | **2.** | The mass of a proton is *m*p, the mass of a neutron is *m*n, and the mass of a hydrogen-3 nucleus is *M*. The speed of light in a vacuum is *c*. Which expression is correct for the binding energy (B.E.) of the hydrogen-3 nucleus?     |  |  | | --- | --- | | **A** | B.E. = *M* × *c*2 | | **B** | B.E. = (*m*n + *m*p − *M*) × *c*2 | | **C** | B.E. = (*m*n + 2*m*p − *M*) × *c*2 | | **D** | B.E. = (2*m*n + *m*p − *M*) × *c*2 |      |  |  |  | | --- | --- | --- | | Your answer |  | **[1]** | | |

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|  | |  |  | | --- | --- | |  |  | | **3(a).** | Some nuclear fission reactors use uranium-235 as fuel. In the future, there is possibility of using hydrogen-2 as fuel in fusion reactors.  Here is some information and data on fission and fusion reactions.     |  |  |  |  |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | | |  |  |  | | --- | --- | --- | |  | **Fission reactor** | **Fusion reactor** | | **Typical reaction** |  |  | | **Approximate energy produced in each reaction** | 200 MeV | 4 MeV | | **Molar mass of fuel material** | uranium-235: 0.235 kg mol–1 | hydrogen-2: 0.002 kg mol–1 | |      |  |  | | --- | --- | | • | Describe the similarities and the differences between fission and fusion reactions. | | • | Explain with the help of calculations, which fuel produces more energy per kilogram. |   **[6]** | |

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|  | |  |  | | --- | --- | |  |  | | **(b).** | Explain the function of the control rods and the moderator in a nuclear fission reactor.  **[2]** | |

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|  | |  |  | | --- | --- | |  |  | | **4(a).** | A researcher is doing an experiment on a radioactive solution in a thin **glass** tube. The solution has two radioactive materials **X** and **Y**. The table below shows some data on these two materials.     |  |  |  |  |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | | |  |  |  | | --- | --- | --- | |  | **Material X** | **Material Y** | | Half-life | 10 minutes | 10 hours | | Particles emitted | Alpha | Beta-minus | | Daughter nuclei | Stable | Stable | |   The solution has the same number of nuclei of **X** and **Y** at the start.   1. State and explain which material has the greatest activity at the start.   **[1]**   1. State why it is dangerous for the researcher to handle the test tube with bare hands.   **[1]** | |

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|  | |  |  | | --- | --- | |  |  | | **(b).** | Carbon-14 is produced in the upper atmosphere of the Earth by collisions between nitrogen nuclei and fast-moving neutrons. The nuclear transformation equation below shows the formation of a single carbon-14 nucleus.     |  | | --- | | **Fig. 22** |  1. State the proton number of particle X.   proton number = .......................................................... **[1]**   1. Use the data below to determine the binding energy per nucleon of the nucleus. Write your answer to **3** significant figures.      |  | | --- | | mass of neutron = 1.675 × 10–27 kg | | mass of proton = 1.673 × 10–27 kg | | mass of nucleus = 14.000 u | | 1 u = 1.66 × 10–27 kg |     binding energy per nucleon = ................................... J per nucleon **[4]** | |

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|  | |  |  | | --- | --- | |  |  | | **5.** | A radiation detector is placed in front of a beta-emitting source. The count-rate is measured and recorded every 10 minutes. The results are shown below.     |  |  |  |  |  | | --- | --- | --- | --- | --- | | 311 s–1 | 309 s–1 | 299 s–1 | 307 s–1 | 321 s–1 |   What term can be used to describe the data shown?     |  |  | | --- | --- | | **A** | exponential | | **B** | linear | | **C** | random | | **D** | spontaneous |      |  |  |  | | --- | --- | --- | | Your answer |  | **[1]** | | |

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|  | |  |  | | --- | --- | |  |  | | **6.** | This question is about a space probe which is in orbit around the Sun.  The power source for the instrumentation on board the space probe is plutonium-238, which provides 470 W initially.  Plutonium-238 decays by α-particle emission with a half-life of 88 years. The kinetic energy of each α-particle is 8.8 × 10–13 J.   1. Calculate the number N of plutonium-238 nuclei needed to provide the power of 470 W.   N = .........................................................**[3]**   1. Calculate the power P still available from the plutonium-238 source 100 years later.   P = ..................................................... W**[3]** | |

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|  | |  |  | | --- | --- | |  |  | | **7.** | The half-life of the isotope carbon-14 is 5700 years (y).   1. Show that the decay constant λ for this isotope is about 1.2 × 10−4 y−1.      |  | | --- | | **[1]** |  1. Carbon-dating is a technique used to date an ancient wooden axe. The ratio of carbon-14 to carbon-12 in the axe material is 78% of the current ratio of carbon-14 to carbon-12 in a living tree.  Calculate the age in years of the wooden axe.      |  | | --- | | age = ....................................................... y **[3]** |  1. State **one** assumption made in the calculation in **(ii)**.     **[1]** | |

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|  | |  |  | | --- | --- | |  |  | | **8.** | The total energy released in a single fusion reaction is 4.0 MeV.  What is the change in mass in this fusion reaction?     |  |  | | --- | --- | | A | 7.1 × 10−36 kg | | B | 7.1 × 10−30 kg | | C | 2.1 × 10−21 kg | | D | 4.4 × 10−17 kg |      |  |  |  | | --- | --- | --- | | Your answer |  | **[1]** | | |

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|  | |  |  | | --- | --- | |  |  | | **9.** | Inside a nuclear reactor, fission reactions are controlled and **chain reactions** are prevented. A typical fission reaction of the uranium-235 nucleus is illustrated below.    The neutron triggering the fission reaction moves slowly. The neutrons produced in the fission reaction move fast.   1. Describe what is meant by **chain reaction**.   **[2]**   1. Explain how chain reactions are prevented inside a nuclear reactor.   **[2]**   1. The energy released in each fission reaction is equivalent to a decrease in mass of 0.19 u. A fuel rod in a nuclear reactor contains 3.0% of uranium-235 by mass.  Estimate the total energy produced from 1.0 kg of fuel rod.  molar mass of uranium-235 = 0.235 kg mol–1 1 u = 1.66 × 10–27 kg      |  | | --- | | energy = ......................................................J **[4]** | | |

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|  | |  |  | | --- | --- | |  |  | | **10.** | is produced by irradiating the stable isotope with neutrons.  Each nucleus of then decays into a nucleus of nickel (Ni) by the emission of a low energy beta-minus particle, one other particle and two gamma photons.  Students want to carry out an investigation into gamma photon absorption using a source of .  They add sheets of lead between the source **S** and a radiation detector **T**, to give a total thickness d of lead. **S** and **T** remain in fixed positions, as shown in Fig. 2.1.     |  | | --- | |  | |  |      |  |  | | --- | --- | | **Fig. 2.1** |  |  1. The source emits beta radiation as well as gamma radiation.  Explain why this would not affect the experiment.   **[1]**   1. The students record the number N of gamma photons detected by **T** in 10 minutes for each different thickness d of lead. The background count is negligible.  The results are shown in a table. The table includes values of ln N, including the absolute uncertainties.      |  |  |  | | --- | --- | --- | | **N** | **d / mm** | **ln N** | | 4300 ± 440 | 0 | 8.37 ± 0.10 | | 2500 ± 250 | 0 | 7.82 ± 0.10 | | 1400 ± 150 | 20 | 7.24 ± 0.11 | | 800 ± 90 | 30 | 6.68 ± 0.11 | | 500 ± 60 | 40 | 6.21 ± 0.12 | | 300 ± 40 | 50 |  |   N and d are related by the equation N = N0 e–µ where N 0 and µ are constants.   1. The students decide to plot a graph of ln N against d.  Show that this should give a straight line with gradient = – µ and y-intercept = ln N 0.      |  | | --- | | [1] |  1. Complete the missing value of ln N in the table, including the absolute uncertainty.  Show your calculation of the absolute uncertainty in the space below.      |  | | --- | | [2] |  1. In Fig. 2.2, five of the data points have been plotted, including error bars for ln N      |  |  | | --- | --- | | • | Plot the missing data point and error bar. | | • | Draw a straight line of best fit and one of worst fit. |      |  | | --- | | **[2]** |      |  | | --- | |  |      |  |  | | --- | --- | | **Fig. 2.2** |  |  1. Use Fig. 2.2 to determine the value of µ in m–1, including the absolute uncertainty.      |  | | --- | | µ =......................± ...................... m–1 **[4]** |      1. Determine the thickness, d½, of lead which halves the number of gamma photons reaching **T**.      |  | | --- | | d½ = ...................................................... m **[2]** | | |

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|  | |  |  | | --- | --- | |  |  | | **11(a).** | An isotope of polonium-213 () first decays into an isotope of lead-209 () and this lead isotope then decays into the stable isotope of bismuth (Bi).  Fig. 24 shows two arrows on a neutron number N against proton number Z chart to illustrate these two decays.  **Fig. 24**  Complete the nuclear decay equations for   1. the polonium isotope      |  |  |  | | --- | --- | --- | |  |  | **[1]** |      1. the lead isotope.      |  |  |  | | --- | --- | --- | |  |  | **[2]** | | |

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|  | |  |  | | --- | --- | |  |  | | **(b).** | A pure sample of polonium-213 is being produced in a research laboratory.  The half-life of is very small compared with the half-life of .  After a very short time, the ionising radiation detected from the sample is mainly from the beta-minus decay of the lead-209 nuclei.   1. Briefly describe and explain an experiment that can be carried out to confirm the beta-minus radiation emitted from the lead nuclei.   **[2]**   1. The activity of the sample of after 7.0 hours is 12 kBq.  The half-life of is 3.3 hours.  Calculate the initial number of lead-209 nuclei in this sample.      |  |  |  | | --- | --- | --- | | number of nuclei = |  | **[4]** | | |

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|  | |  |  | | --- | --- | |  |  | | **12.** | \*Fig. 5 shows a thin slice of rock mounted on the face of a lead holder. The rock contains several different radioactive elements.    Plan one or more experiments to determine the **nature** of the emissions from the sample.  A space has been left for you to draw one or more diagrams to show the arrangement of your apparatus  **[6]** | |

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|  | |  |  | | --- | --- | |  |  | | **13.** | The fusion of two nuclei produces a stable nucleus of and some fast-moving neutrons.   1. Explain why the fusion of the nuclei must produce two neutrons.   **[2]**   1. The total energy released in this fusion reaction is 11 MeV. The binding energy per nucleon of the nucleus is 7.1 MeV. Calculate in J the binding energy per nucleon of the nucleus.   binding energy per nucleon =........................................................... J **[3]** | |

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|  | |  |  | | --- | --- | |  |  | | **14.** | The space probe, Curiosity, roaming on the surface of Mars, is powered by a radioisotope thermoelectric generator (RTG). The generator transforms thermal energy into electrical energy. The thermal energy comes from the radioactive decay of plutonium-238. Fig. 5.1 shows an image of Curiosity.    The plutonium-238  isotope can be artificially produced by bombarding uranium-238 with deuterium . This produces an intermediate isotope of neptunium-238 and neutrons. The isotope of  then decays by beta-minus emission to form plutonium-238.   1. Complete the following reaction.     **[1]**   1. Complete the following decay equation for  .     **[2]** | |

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|  | |  |  | | --- | --- | |  |  | | **15(a).** | State what is meant by induced nuclear fission.  **[1]** | |

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|  | |  |  | | --- | --- | |  |  | | **(b).** | Explain the role of the moderator and the control rods in a nuclear reactor.  **[4]** | |

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|  | |  |  | | --- | --- | |  |  | | **(c).** | A possible fission reaction is    where k is the number of neutrons released in the reaction. The    nucleus is very unstable.   1. State the number k of neutrons released in this reaction.   k = ................................. **[1]**   1. State the binding energy of the released neutrons.   **[1]**   1. A nuclear reactor uses uranium-235 as fuel. The output power from the reactor is 1.0 GW. The mass of the nucleus is 236.053 u. The total mass of the fission products is 235.840 u.  Calculate the number of fission reactions per second.   number of reactions per second = .......................................... s−1 **[4]** | |

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|  | |  |  | | --- | --- | |  |  | | **16(a).** | State what is meant by the decay constant of an isotope.  **[1]** | |

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|  | |  |  | | --- | --- | |  |  | | **(b).** | A radioactive substance has 2000 nuclei. The decay constant of the isotope of the substance is 0.10 s−1.  Use the equation and Δt = 1.0 s to estimate the number of nuclei left after time t = 2.0 s.  number of nuclei left = .......................................... **[2]** | |

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|  | |  |  | | --- | --- | |  |  | | **(c).** | \* A group of students are investigating the decay of protactinium. A fresh sample of protactinium is prepared. The activity of the sample was measured at intervals of 1.0 minutes for 6.0 minutes. The table shows the activity corrected for background radiation.     |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | | time t / min | 0 | 1.0 | 2.0 | 3.0 | 4.0 | 5.0 | 6.0 | | activity A / Bq | 943 | 523 | 287 | 161 | 79 | 61 | 20 |   Fig. 20 shows the variation of ln(A) with time t.    Explain how the graph in Fig. 20 can be used to determine the half-life of protactinium. Determine the half-life of protactinium. Include an uncertainty in your value.  **[6]** | |

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|  | |  |  | | --- | --- | |  |  | | **17.** | The space probe, Curiosity, roaming on the surface of Mars, is powered by a radioisotope thermoelectric generator (RTG). The generator transforms thermal energy into electrical energy. The thermal energy comes from the radioactive decay of plutonium-238. Fig. 5.1 shows an image of Curiosity.    Plutonium-238 is an alpha-emitter with a half-life of 88 years. The kinetic energy produced during each decay is 9.0 × 10−13 J. The RTG on Curiosity produces 120 W of electrical power from 2000 W of thermal power.   1. Calculate the mass of plutonium-238 on board Curiosity.  molar mass of plutonium-238 = 0.238 kg mol−1   mass = ........................................................... kg **[4]**   1. Calculate the output electrical energy in kW h from the RTG in a day.   energy = ........................................................... kW h **[2]** | |

**END OF QUESTION PAPER**

# Mark scheme

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| **Question** | | | **Answer/Indicative content** | **Marks** | **Guidance** |
| 1 |  |  | p → n **or** proton → neutron   (p → n +) e+ + v **or** positron + (electron) neutrino | M1 A1 | **Allow** u→d or uud→udd **Ignore** A/Z values for the M1 mark  **Allow** (but **not** e) for e+ **Allow** ve (but **not** ⊽) for v  **Allow**   Where A/Z values are given then they must be correct i.e.   **Examiner’s Comments**  The question did not specify what type of equation was needed, and the simple word equation proton → neutron + positron + neutrino  was sufficient for full marks.  **Common problems in 3(a)**   * using the symbol N instead of n for neutron (N is the symbol for nitrogen) * using incorrect A/Z values such as for neutron and/or for positron * using an incorrect symbol for the neutrino |
|  |  |  | **Total** | **2** |  |
| 2 |  |  | **D** | 1 | **Examiner’s Comments**  This question can correctly be answered by over three quarters of the candidates. Most appeared to be able to evaluate the composition of the nucleus correctly and then work forward from that. A was the most common incorrect response, presumably as less successful responses were able to recognise a variation of *E* = *mc*2. |
|  |  |  | **Total** | **1** |  |
| 3 | a |  | **Level 3 (5–6 marks)** Clear description and clear calculations of energy per kg  There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.  **Level 2 (3–4 marks)** Clear description **OR** Clear calculations of energy per kg **OR** Some description **and** some calculations  There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.  **Level 1 (1–2 marks)** Limited description **OR** Limited calculations  There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.  **0 marks** No response or no response worthy of credit | B1×6 | **Indicative scientific points may include:**   **Description**   * Energy is produced in both reactions * More energy produced (per reaction) in fission * The (total) binding energy of ‘products’ is greater * In fusion, nuclei repel (each other) * Fusion requires high temperatures / high KE * Fission reactions are triggered by (slow-)neutrons * Chain reaction possible in fission   **Calculations**   * 1 kg of uranium has 4.26 mols / 2.56 × 1024 nuclei * 1 kg of deuterium has 500 mol / 3.01 × 1026 nuclei / 1.50 × 1026 ‘reactions’ * 200 MeV = 3.2 × 10-11 J * 4 MeV = 6.4 × 10-13 J * Uranium: ~ 1014 (J kg-1) (actual value 8.2 × 1013) * Deuterium: ~ 1014 (J kg-1) (actual value 9.6 × 1013) * The energy per kg is roughly the same   **Examiner’s Comments**  This is the second LoR question. This is designed to assess knowledge of the two nuclear energy reactions and to calculate energy release using some given data. The differences between the fission and fusion reactions were generally well answered although many candidates explained differences in design, operation and waste more than the reactions. The similarities were often not as clear however several candidates gave excellent responses in terms of binding energies and mass differences. Candidates were also expected to complete a calculation to show which produces more energy output per kilogram. This is challenging calculation to follow through fully, but most candidates were able to make some attempt, even if it was only converting MeV to J. Only better candidates realised 2 nuclei of deuterium were used for one fusion reaction. While a small number of candidates did correctly calculate the energy per kilogram, they tended to state that fusion produced more energy rather than a feeling that they are basically equivalent. As usual with LoR questions, a holistic approach is taken to the marking and candidates can access higher levels without necessarily reaching all the marking points. Even so, relatively few candidates were able to access Level 3, generally due to poor calculations and/or descriptions. |
|  | b |  | Control rods: absorb the neutrons (without further fission)  Moderator: Slow down the neutrons / decrease KE of neutrons | B1  B1 | **Not** collide for absorb  **Examiner’s Comments**  For this question, the candidates need to explain the role of these components in terms of their interactions with neutrons and those who did not mention neutrons at all in their responses could not score any marks. Many candidates went beyond what was required and explained what effect this has on the reactor, such as controlling the rate of reaction. In general, this question was not answered well.     |  |  | | --- | --- | |  | **Misconception** |   Many candidates gave vague statements regarding the function of these components rather than an explanation. |
|  |  |  | **Total** | **8** |  |
| 4 | a | i | Material **X** because of the shorter half-life | B1 | Must be comparative **Allow** explanation in terms of decay constant  **Examiner’s Comments**  This question expects the candidates to appreciate that the activity is related to the half-life. The majority of candidates were able to successfully answer this question although a number did not make it comparative and simply said that X had a short half-life. |
|  |  | ii | (Alpha particles are stopped by the glass but) the beta-particles are not (AW) | B1 | **Allow** symbols  **Examiner’s Comments**  Not many candidates recognised that the penetrating powers of the radiations through glass were required for the response; most referred to the ionising (and so harmful to health) properties of both sources. |
|  | b | i | 1 | B1 | **Examiner’s Comments**  This question was correctly answered by the vast majority of candidates. |
|  |  | ii | Either: mass of nucleus 14.000 × 1.66 × 10-27 ( = 2.324 × 10-26 kg)  Or: mass of nucleons = 8 × 1.675 ×10-27 + 6 × 1.673 × 10-27 (= 2.3438 × 10-26 kg)  (Δm =) 2.3438 × 10-26 - 2.324 × 10-26 = (1.98 × 10-28 kg)  (ΔE =) 1.98 × 10-28 × (3.00 × 108)2  (BE per nucleon =) 1.782 × 10-11/14  binding energy per nucleon = 1.27 × 10-12 (J per nucleon) | C1  C1  C1  A1 | Δm = 1.9262 × 10-28 kg **Ignore** sign throughout   ΔE = 1.782 × 10-11 J **Allow** for any mass difference × (3.00 × 108)2   **Note** A mark for correct answer to 3sf only  **Examiner’s Comments**  This final calculation required some careful structure and several stages. An encouraging number were able to work through the solution to its conclusion. Some rounded intermediate calculations too early and so lost the final 3 significant figures mark. Several candidates also missed the division by the nucleon number, either as a slip or perhaps they did not appreciate that this was what was required. Even the weakest candidates realised the need to apply E = mc2, but would only gain credit here if they had calculated a mass difference. Some candidates also miscalculated the number of protons and neutrons in the carbon nucleus, which meant that they were limited to a maximum of 2 marks. |
|  |  |  | **Total** | **7** |  |
| 5 |  |  | C | 1 | **Examiner’s Comments**  The correct response is **C**. The responses are terms used frequently when studying data, but as around only one half of the candidates were able to get the correct response, it is clear that they are not fully understood. A little perplexingly, the most common incorrect response was **B**, as it is difficult to see how this data could be considered linear. This does show how easy it is to assume that candidates are confident in their use of terminology, just because they are frequently used. |
|  |  |  | **Total** | **1** |  |
| 6 |  | i | **A =** 470/8.8 × 10−13 = 5.3 × 1014 (Bq)  λ = ln 2/(88 × 3.16 × 107) (= 2.5 x 10−10 s−1)  (A = λN); N (= 5.3 x1014 / 2.5 x 10−10) = 2.1 x 1024 | C1  C1  A1 | Mark is for correct calculation of A (in Bq **or** decays per s)  Mark is for correct working to give λ in s−1 |
|  |  | ii | P = Po exp (− λt)  P = 470 exp (− ln 2 x 100 / 88)  P = 210 (W) | C1  C1  A1 | **Allow** formula in terms of N or A  **Allow** calculation in terms of N or A; **allow ECF** for N or A |
|  |  |  | **Total** | **6** |  |
| 7 |  | i | (decay constant =)    decay constant = 1.2(2) × 10−4 (y−1) | C1 A0 |  |
|  |  | ii | 0.78 = e−*λt*   ln0.78 = (−) 1.2 × 10−4 × *t*   age = 2100 (y) | C1 C1 A1 | **Note** 1 = 0.78e−*λt* is **XP**; answer is negative (− 2100 y)  There is no ECF from **(b)(i)**    **Note** 1.22 × 10−4 gives an answer of 2040 y or 2000 y |
|  |  | iii | The ratio (of carbon-14 to carbon-12) has remained constant | B1 |  |
|  |  |  | **Total** | **5** |  |
| 8 |  |  | B | 1 |  |
|  |  |  | **Total** | **1** |  |
| 9 |  | i | More neutrons produced (from each fission reaction)  Go on to produce further (fission) reactions / splitting (of nuclei) / energy | B1   B1 | **Examiner’s Comments**  Most candidates scored 1 mark for the general idea of a chain reaction, but the important role played by the neutrons was often omitted in the descriptions. Only a small number of candidates misunderstood fission as a reaction in which the Cs and Rb nuclei themselves were responsible for triggering subsequent reactions of the uranium nuclei. |
|  |  | ii | Control rod(s) used   These absorb the neutrons (without fission) | B1   B1 | **Allow** boron / cadmium / indium / silver **Not** moderator  **Not** neutrons slowed down and/or stopped  **Examiner’s Comments**  The mechanism of preventing uncontrolled chain reaction within a nuclear reactor was generally well understood. Having given perfect answers with control rods absorbing the excess neutrons, a significant number of candidates confusing their answers by also mentioning the moderator. It many cases it was impossible for examiners to decide from the candidates response if the control rods, or the moderators, were responsible for preventing chain reactions. Some candidates mentioned ‘boron rods’, this was an acceptable alternative for the ‘control rods’. |
|  |  | iii | (Δm =) 0.190 × 1.66 × 10-27 **or** 3.15 × 10-28 (kg) (ΔE =) 0.190 × 1.66 × 10-27 × (3.0 × 108)2 **or** 2.84 × 10-11 (J)     |  |  | | --- | --- | |  | ×6.02×1023   **or** 2.56 × 1024 |   (energy = 0.03 × 2.56 × 1024 × 2.84 × 10-11)  energy = 2.2 × 1012 (J) | C1  C1  C1    A1 | **Note** the 3.0% can be done at any stage, allow other correct methods  **Allow** the use of 1.67 × 10-27  **Allow** ECF from 1.66 × 10-27 omitted  **Note** 7.69 × 1022 will score this C1 mark; 3.0% included   **Allow** 3 marks for 7.3 × 1013 (J); 3.0% omitted **Allow** 3 marks for 1.3 × 1039 (J); 1.66 × 10-27 omitted  **Examiner’s Comments**  This proved to be an excellent discriminator with top end candidates showing excellent skills to get to the correct answer of 2.2 × 1012 J. The majority of the candidates correctly converted the 0.19u into kilograms, and then successfully used Einstein’s mass-energy equation to calculate the equivalent energy of 2.8 × 10-11 J. The main obstacle in this question was the determination of the number of uranium nuclei in the fuel rods. Avogadro constant, given in the data booklet, was either omitted or the incorrect mass used to determine the number of uranium nuclei.     |  |  | | --- | --- | |  | **Misconception** |   There were some missed opportunities, with some candidates making the following mistakes when determining the number of uranium nuclei in the 1.0 kg fuel rod.   * Using 0.235 × NA. to calculate the number of uranium nuclei. * Using the rest masses of neutrons and protons. * Omitting the 3.0%. |
|  |  |  | **Total** | **8** |  |
| 10 |  | i | Beta radiation would not penetrate/ would be absorbed by the lead | B1 | **Not** gamma radiation would be stopped  **Ignore** reference to alpha radiation   **Examiner’s Comments**  Most candidates were obviously very familiar with this and gave a clear response. Credit was given for either  Gradient of best fit line:   * a clear comparison of ln N = – µd + lnN0 with y = mx + c * using log rules to give ln(N0e-µd) = – µd + lnN0 |
|  |  | ii | lnN = – µd + lnN0 compared to y = mx + c  (so m = - µ and c = lnN0) | B1 | **or** lnN = ln(N0e-µd) = lnN0 – µd   **Examiner’s Comments**  Candidates who gained the uncertainty mark mostly used the standard method of finding half the range i.e. (ln340– ln260)/2.  However, a very common response was to calculate the fractional uncertainty in N (i.e. 40/300) rather than the absolute uncertainty in lnN. This was not given without mathematical justification e.g. Δ(lnN) ≈ (ΔN)/N. |
|  |  | iii | 5.70  ± 0.14 | B1 B1 | Both answers must be to 2d.p.  **Allow** ± 0.13  not second B1 mark without correct working shown e.g. ln300 – ln260 or (5.83-5.56)/2 **Allow** ΔN/N (= 40/300) but only if Δ(lnN) ≈ ΔN/N is quoted   **Examiner’s Comments**  The majority of candidates had no difficulty in plotting the point (50, 5.70) correctly. Both best and worst fit lines were usually drawn well enough, although some had very thick pencil lines and a surprising number had not been extended to the lnN axis. Almost all candidates gained the mark for using a sufficiently large triangle (Δd > 25mm) for calculating the gradient of their best fit line. |
|  |  | iv | Point plotted correctly to within ½ small square  Best fit and worst fit line(s) drawn | B1 B1 | **Ignore** accuracy of length of error bar  **ECF (ii)2** for incorrect value(s) in table  **ECF (ii)2** for incorrect value(s) in table  Best fit line should have an equal scatter of points about the line  Worst fit line should be steepest/shallowest possible line that passes through all the error bars (allow ±½ small square tolerance vertically)    **Examiner’s Comments**  Most mathematically able candidates quickly obtained the result µd1/2 = ln2 and then used it with their value of µ. Other candidates used a variety of (usually correct) graphical methods with Fig. 2.2. |
|  |  | v | gradient of best fit line = (-) µ = (-) 54 (m-1)   large triangle used to determine gradient of best fit line    calculation of absolute uncertainty using their values in the formula (|wfl gradient – bfl gradient|)        uncertainty and value of μ to same number of dp | B1 B1 B1 B1 | **Allow** 51 to 56  **Allow** value of µ up to 4 SF  **ECF(ii)3** for wrongly plotted point    Δd > 25mm (seen from graph or working)  **ECF (ii)3** for worst fit line  **Ignore** any POT error in gradients  **Allow** value of absolute uncertainty up to 3 SF only  e.g. 53.4 ± 5.6 or 54 ± 6 |
|  |  | vi | µd½ = ln2 (or 0.693)  d½ = 0.013 (m) | C1 A1 | **ECF (ii)4** for ½ Alternative method: ln(N0 /2) =7.67 (C1)  then use of graph to give d½ = 0.013±0.001 (m) (A1) |
|  |  |  | **Total** | **12** |  |
| 11 | a | i | alpha-particle / | **B1** |  |
|  |  | ii | nucleon number for Bi = 209  antineutrino / | **B1   B1** | **Note**: Do not allow incorrect subscript and superscript |
|  | b | i | Aluminium (sheet placed between source and detector)  The count (rate) reduces   **or**   Magnetic / electric field used  Electrons identified from correct deflection / motion in field | **M1    A1      M1   A1** | **Allow** count (rate) drop to background / zero  **Allow** 2 marks for ‘the range in air is a few m’       **Examiner’s Comments**  This turned out to be a low-scoring question from candidates across the ability spectrum. Only a quarter of the candidates gained 2 marks for identifying aluminium as the absorber for the beta-minus radiation (electrons) and providing adequate description in terms of reduction in the count-rate. A small number of candidates opted for charged parallel plates and identified the electrons curving towards the positive plate. There were some baffling descriptions involving pointing the source at ‘wires and measuring the current’. Fluorescent screens and cloud chambers were not allowed as acceptable answers because both can be used to detect the presence of gamma-photons and alpha-particles. |
|  |  | ii | (λ =) ln2/3.3 (h−1) **or** (λ =) 0.21 (h−1)  (A0 =) 12 × 103/e−(0.21 × 7.0) **or** (A0 =) 5.219 × 104 (Bq)  (N0 =) 5.219 × 104/5.835 × 10−5  number of nuclei = 8.9 × 108  **Or**  (λ =) ln2/[3.3 × 3600] (s−1) **or** (λ =) 5.835 × 10−5 (s−1)  (N =) 1.2 × 104/5.835 × 10−5 **or** 2.057 × 108  (N0 =) 2.057 × 108/e−(0.21 ×7.0)   number of nuclei = 8.9 × 108 | **C1   C1    C1   A1     C1   C1    C1   A1** | **Allow** credit for alternative methods    **Note** this is the same as 12 × 103 ÷ (0.5)7.0/3.3    **Note** 9.0 × 108 can score full marks if numbers are rounded     Possible ECF for incorrect conversion of time  Note this is the same as 2.057 × 10**8** ÷ (0.5)7.0/3.3  **Examiner’s Comments**  The question was multi-stepped calculation, requiring knowledge of radioactive decay equations, half-time and activity. The final stage of the calculation was dependent on the equation A = λN and working consistently in Bq for the activity and in s−1 for the decay constant. The number of nuclei N could not be calculated with the activity in Bq and the decay constant in either h−1 or min−1.  About half of the candidates scored full marks. Those working with inconsistent units invariably ended up with the incorrect value 2.5 × 105 nuclei, but this still earned them 2 marks for the preceding steps. |
|  |  |  | **Total** | **9** |  |
| 12 |  |  | **Level 3 (5–6 marks)** Clear set up and description of chosen experiment(s) **and** clear interpretation of observations  *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.*    **Level 2 (3–4 marks)** Limited set up and description of chosen experiment **and** limited interpretation of observations  *There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.*    **Level 1 (1–2 marks)** Very basic description of chosen experiment **and** limited interpretation of observations  *The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.*  **0 marks** No response or no response worthy of credit. | B1 × 6 | **Indicative scientific points may include:**  **1**. range/penetration/absorption/deflection experiment suggested  **2**. suitable arrangement and choice of apparatus e.g. on diagram; allow GM tube as detector for all particles  **3**. description of range/penetration/absorption experiment:  **a**. α place detector very close/ 2cm from source; measure count rate, use paper screen or move back to 10 cm or more, measure count rate, interpret result; contrast to background count level and/or other emissions from same source  **b**. β place detector e.g. 10 cm from source measure count rate, add thin sheets of Al until count drops to very low or almost constant value e.g. γ present; interpret result;  **c**. γ place detector e.g. 10 cm from source measure count rate, add thin sheets of Pb until count drops to very low/background level; interpret result  **4**. deflection experiment: needs vacuum for α experiment;source for radiation passes through region of E- or B- field; deflection or not of particles detected by detector to distinguish emissions; detail of directions; amount of curvature determines energy of emission; and nature of particle |
|  |  |  | **Total** | **6** |  |
| 13 |  | i | total nucleon number after fusion = 3 + 3 − 4 = 2 | M1 | **Allow** other correct methods |
|  |  | i | total proton number after fusion = 1 +1 − 2 = 0 | M1 |  |
|  |  | i | (Hence it must be 2 neutrons after the fusion reaction) | A0 |  |
|  |  | ii | (BE of neutron(s) = 0 and BE of = 28.4 MeV) BE of nucleus = ½ × (28.4 − 11) = 8.7 (MeV) | C1 |  |
|  |  | ii | BE per nucleon = 8.7/3 = 2.9 (MeV) BE per nucleon = 2.9 × 106 × 1.60 × 10−19 | C1 |  |
|  |  | ii | BE per nucleon = 4.6 × 10−13 (J) | A1 |  |
|  |  |  | **Total** | **5** |  |
| 14 |  | i |  | B1 | **Allow** answer in words, e.g. ‘two neutrons’ **Allow** 2 ×   **Examiner's Comments**  More than half of the candidates got the right answer  . The most frequent errors were and using capital N for the neutron symbol. |
|  |  | ii |  | B1 | **Not** e / e− / β / β− **Allow** electron |
|  |  | ii |  | B1 | **Allow** (electron) anti-neutrino  **Examiner's Comments**  The majority of the candidates correctly identified the electron and the antineutrino  in the decay equation. |
|  |  |  | **Total** | **3** |  |
| 15 | a |  | The splitting of a (uranium) nucleus as a neutron is absorbed (into two fragment nuclei and neutrons). | B1 |  |
|  | b |  | The moderator slows down the fast-moving neutrons. | B1 |  |
|  |  |  | The neutrons lose significant amount of their kinetic energy when colliding with moderator nuclei. or The moderator does not absorb the neutrons. | B1 |  |
|  |  |  | The control rods absorb the neutrons. | B1 |  |
|  |  |  | The rate of fission reactions is less / reduced. | B1 |  |
|  | c | i | 2 | B1 |  |
|  |  | ii | Zero | B1 |  |
|  |  | iii | Δ*m* = 236.053 − 235.840 = 0.213 u | C1 |  |
|  |  | iii | Δ*E* = [0.213 × 1.661 × 10−27] × (3.0 × 108)2 = 3.184 × 10−11 (J) | C1 |  |
|  |  | iii | number of reactions per second = 109/3.184 × 10−11 | C1 |  |
|  |  | iii | number of reactions per second = 3.1 × 1019 (s−1) | A1 |  |
|  |  |  | **Total** | **11** |  |
| 16 | a |  | The decay constant is the probability of decay of a nucleus per unit time. | B1 | **Allow**: the decay constant is the fraction of nuclei decaying per unit time. **Allow**: decay constant = activity ÷ number of nuclei left in a sample. |
|  | b |  | number decaying in 1st second = 2000 × 0.10 = 200 | C1 |  |
|  |  |  | number decaying in the 2nd second = 1800 × 0.10 = 180 number left = 1800 – 180 = 1620 | A1 |  |
|  | c |  | **Level 3 (5–6 marks)** Correct explanation Correct determination of λ and half-life Correct determination of uncertainty (Maximum 6 marks) Any point omitted or incorrect (5 marks). There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.  **Level 2 (3–4 marks)** Mostly correct explanation Mostly correct determination of λ and half-life Some attempt of determining uncertainty (Maximum 4 marks) Any point omitted or incorrect (3 marks). There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.  **Level 1 (1–2 marks)** Basic explanation Some attempt to determine λ or half-life No attempt at uncertainty. (Maximum 2 marks) The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.  **0 marks** No response or no response worthy of credit. | B1 x 6 | **Explanation**  1. A = A0e−λt  2. lnA = lnA0 − λt  3. A graph of lnA against t will be a straight line with gradient (−) λ  4. half-life = ln2/λ  **Determination**  1. Line of best fit drawn  2. Gradient determined using a large triangle  3. decay constant in the range 0.5 to 0.7 min−1  4. half-life in the range 1.0 to 1.4 min  **Uncertainty**  1. Worst line of fit drawn  2. Correct attempt to determine uncertainty |
|  |  |  | **Total** | **9** |  |
| 17 |  | i |  |  | **Allow** other correct methods |
|  |  | i | (activity =) | C1 | **Note** 2.22 × 1015 scores this C1 mark |
|  |  | i | (λ = )   (A = λN) | C1 | **Note** 2.49 × 10−10 (s−1) scores this C1 mark |
|  |  | i | 2.22 × 1015 = 2.49 × 10−10 × N (Any subject)  (mass =) × 0.238 | C1 | **Note** N = 8.91 × 1024 scores all three C1 marks Possible ECF for incorrect value(s) of activity and or λ |
|  |  | i | mass = 3.5 (kg) | A1 | **Allow** 3 marks for 0.21 (kg) if 120 W is used    **Examiner's Comments**  This was a good discriminating question with most candidates calculating the decay constant in s−1 and the activity of the source. Calculation of the mass of plutonium required knowledge of A = λN and molar mass and this is where the top-end candidates showed excellent analytical skills. A small number of candidates used 120 W instead of 200 W and got an answer of 0.21 kg; such an approach was awarded three marks. |
|  |  | ii | (energy =) 0.120 (kW) × 24 (h) | C1 |  |
|  |  | ii | energy = 2. 9 (kW h) | A1 | **Allow** 1 mark for 48 (kW h); 2 kW used instead of 0.12 kW **Allow** 1 mark for 2900; 120 used instead of 0.12  **Examiner's Comments**  The modal mark for this straight-forward question on kW h was zero. Most candidates overcomplicated the question by converting time into seconds and some even tried to link efficiency of the RTG in their answers. Only about 1 in every three candidates got the correct answer of 2.9 kW h. |
|  |  |  | **Total** | **6** |  |