# A Level AQA Physics

## 20 Nuclear energy – answers

| Question | Answers | Extra information | Mark | AO | Spec reference |
|---|---|---|---|---|---|
| **01.1** | In path **A**, the alpha particle is directed at the centre of the nucleus, so the electrostatic force is along the same line that the alpha particle is travelling, but in the opposite direction, so it stops and goes back out<br>In path B, the force and velocity are not parallel, so the electrostatic force on the alpha particle changes its direction | | 1<br>1 | 2 | 3.8.1.5 |
| **01.2** | $E = \frac{Q_1 Q_2}{4\pi\varepsilon_0 d}$<br>$5 \times 1.6\times10^{-13} = \frac{4 \times 79 \times (1.6\times10^{-19})^2}{4\pi \times 8.85\times10^{-12} \times d}$<br>$d = \frac{4 \times 79 \times (1.6\times10^{-19})^2}{4\pi \times 8.85\times10^{-12} \times 5 \times 1.6\times10^{-13}}$<br>$= 9.1\times10^{-14}$ m | Use of electric potential energy<br>Answer | 1<br>1 | 2 | 3.8.1.5 |
| **01.3** | Mass of a person = 70 kg<br>Density = $\frac{M}{V}$<br>Mass of gold nucleus = $197 \times 1.667\times10^{-27} = 3.28\times10^{-25}$ kg<br>Volume of nucleus = $\frac{4}{3}\pi r^3 = \frac{4}{3}\pi (9.1\times10^{-14})^3 = 3.16\times10^{-39}$ m$^3$<br>Nuclear density = $\frac{\text{mass}}{\text{volume}} = \frac{3.28\times10^{-25}}{3.16\times10^{-39}\text{ m}^3} = 1.04\times10^{14}$ kg m$^{-3}$<br>Volume = $\frac{\text{mass}}{\text{density}} = \frac{70}{1.04\times10^{14}} = 6.74\times10^{-13}$ m$^3$<br>Which is the volume of a cube of sides $8.8\times10^{-5}$ m | human mass estimate between 50 and 100 kg<br>Calculations of mass and volume of nucleus<br>Correct volume<br>Correct cube dimension | 1<br>1<br>1 | 3 | 3.8.1.5 |
| **01.4** | If $Z$ is half, $d$ is halved, so volume is reduced by a factor of $(0.5)^3$.<br>Mass of nucleus is halved, so density of nucleus is reduced by a factor of 4<br>Volume of person is increased by a factor of 4, and the side of a cube is increased by a factor of $4^{1/3}$ or 1.587 | Effect of $Z$ on $d$<br>Effect of $A$ on density<br>Answer | 1<br>1<br>1 | 3 | 3.8.1.5 |
| **02.1** | The neutron number decreases by 2<br>The proton number decreases by 2 | Both needed for mark | 1 | 1 | 3.8.1.4 |

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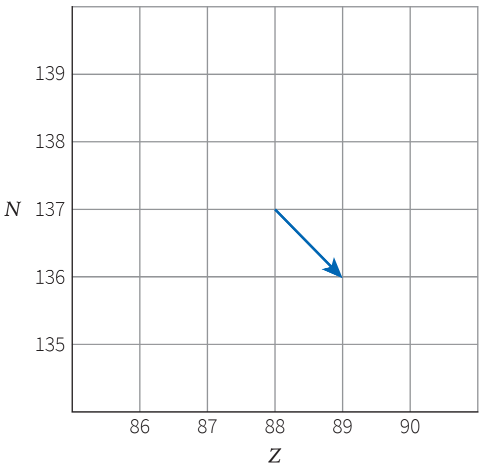
| **02.2** | Change in energy = 4.78 – 4.59 = 0.19 MeV<br>$= 0.19 \times 1.6\times10^{-13}$<br>$= 3.04\times10^{-14}$ J<br>$E = \dfrac{hc}{\lambda},\ \lambda = \dfrac{hc}{E} = \dfrac{6.63\times10^{-34} \times 3.0\times10^{8}}{3.04\times10^{-14}}$<br>$= 6.54\times10^{-12}$ m | Change in energy<br><br><br><br>Answer | 1<br><br><br><br>1 | 2 | 3.8.1.4 |
| **02.3** | In beta decay, a neutron decays to a proton, so the neutron number decreases by 1 and the proton number increases by 1<br>There are 88 protons in radium-225, and 89 protons in actinium(-226)<br>There are 137 neutrons in radium-225, and 136 neutrons in actinium(-226)<br>The arrow goes from (88, 137) to (89, 136)<br><br>Correct arrow on diagram:<br><br> | Explanation of what happens in beta decay<br><br>Changes to $N$ and $Z$<br><br>Description of arrow | 1<br><br>1<br>1<br><br>1 | 2 | 3.8.1.4 |

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| **02.4** | Any two from:<br>• the arrow starts at (88, 138)<br>• the arrow ends at (86, 136)<br>• the arrow is twice as long<br>• the arrow goes from right to left | | 2 | 3 | 3.8.1.4 |
| **03.1** | The wavelength should be about the same size as the object producing the pattern | | 1 | 1 | 3.8.1.5 |
| **03.2** | The 'target', in this case the nucleus, is not precisely defined | | 1 | 1 | 3.8.1.5 |
| **03.3** | Two correct reasons, for example:<br>Alpha particles contain nucleons that interact in terms of the strong nuclear force<br>Alpha particles are not point particles | | 2 | 2 | 3.8.1.5 |
| **03.4** | The measurements of maxima or minima from the graph are not easy to define precisely. | | 1 | 3 | 3.8.1.5 |
| **04.1** | The difference is a measure of the energy needed to separate the nucleons that are bound as a result of the strong nuclear force<br><br>Deuterium nucleus contains one proton and one neutron<br>$m_{proton}$ = 1.00728 u<br>$m_{neutron}$ = 1.00867 u<br>$m_{proton} + m_{neutron}$ = 1.007276 + 1.008665 = 2.01595 u<br>Mass difference = $2.397 \times 10^{-3}$ u<br>= $2.397 \times 10^{-3}$ u $\times 1.661 \times 10^{-27}$<br>= $3.98 \times 10^{-30}$ kg | Must mention strong nuclear force<br><br>Use of data<br><br>Sum of particle masses<br>Correct calculation of mass difference | 1<br><br>1<br><br>1<br>1 | 2 | 3.8.1.5 |

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| **04.2** | Binding energy $= mc^2$<br>$= 3.98\times10^{-30} \times (3.00\times10^{8})^2$<br>$= 3.58\times10^{-13}$ J<br>$= \dfrac{3.569\times10^{-13}}{1.06\times10^{-13}}$<br>$= 2.24$ MeV | Answer in J<br>Answer in MeV | 1<br>1 | 2 | 3.8.1.5 |
| **04.3** | The binding energy is 3 and 4 times bigger<br>The tritium nucleus has an additional neutron which is attracted to both the other two particles in the nucleus | | 1<br>1 | 3 | 3.8.1.5 |
| **04.4** | The tritium contains one proton and two neutrons, whereas the helium-3 contains one neutron and two protons<br>The strong nuclear force is charge independent, so the energy required to separate the nucleons is the same in each nucleus<br>The two protons in the helium-3 nucleus repel each other, so the energy needed to separate them is smaller | Comparison of the nuclei in terms of protons and neutrons<br>Recognition that effect of strong nuclear force is the same<br>Use of Coulomb repulsion | 1<br>1<br>1 | 3 | 3.8.1.5 |
| **05.1** | A nuclear chain reaction happens when the neutrons from one reaction trigger subsequent (fission) reactions, creating a chain<br>This will be self-sustaining if the neutrons do not escape, or if the nuclei are sufficiently close, so this will not happen if the mass of fissionable nuclei is too small | Explanation of chain reaction<br>Condition for not self-sustaining | 1<br>1 | 1 | 3.8.1.7 |
| **05.2** | Suggestion, for example:<br>The reactor did not produce enough radiation/was operating for long enough for shielding or cooling to be needed | Credit any sensible suggestion | 1 | 3 | 3.8.1.8 |

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| **05.3** | Suggestion, for example:<br>When a uranium nucleus undergoes fission, energy is released in the form of the kinetic energy of the fission fragments<br>This produces a temperature rise in the coolant, that drives a turbine and a generator<br>The fuel in the Chicago Pile-1 did not contain sufficient numbers of uranium nuclei for sufficient numbers of fission reactions to occur per second to produce a similar (or half of the) power. | Description of energy released in fission reaction<br>Description of link to power<br>Sensible suggestion for lack of energy per second | 1<br>1<br>1 | 3 | 3.8.1.8 |
| **05.4** | They absorb thermal neutrons so can be used to shut down the reactor by being lowered into the reactor | | 1 | 1 | 3.8.1.7 |
| **06.1** | Momentum/energy was not conserved | | 1 | 1 | 3.2.1.2 |
| **06.2** | $W^+$, $W^-$ bosons | | 1 | 1 | 3.2.1.4 |
| **06.3** | The half-life is (relatively) short, and the nucleus emits beta radiation, which is not very ionising, so this would be an acceptable risk if the level of sodium was potentially responsible for a serious illness | Appreciation of the balance of risk and benefit | 1 | 3 | 3.8.1.3 |
| **06.4** | When the neutron is absorbed, the atomic mass increases by one, atomic number does not change<br>When the beta particle is emitted, the atomic mass does not change, and the atomic number increases by one | Each change correct | 1<br>1 | 2 | 3.8.1.4 |
| **06.5** | The majority of the decays leave the nucleus in an excited state with 4.14 MeV<br>The nucleus can decay from this level to 1.38 MeV, emitting a gamma ray of 4.14 – 1.38 MeV = 2.76 MeV<br>It then emits a gamma ray of energy 1.38 MeV, and decays to the ground state | Both energy level correct<br>Justification | 1<br>1 | 2 | 3.8.1.5 |
| **06.6** | Exposure to a large number of neutrons could mean that fission reactions, which produce neutrons, may be too numerous; control measures such as control rods are not working<br>Geiger counters detect highly ionising radiation, but do not detect neutrons (unless modified) | Appropriate reason<br>Justification involving lack of ionisation power of neutrons | 1<br>1 | 2 | 3.8.1.7 |

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## 20 Nuclear energy – answers

| Question | Answers | Extra information | Mark | AO | Spec reference |
|---|---|---|---|---|---|
| **07.1** | A chain reaction happens when the neutrons produced in a fission reaction start subsequent reactions<br>Which usually happens when a moderator slows the neutrons down<br>The water acts as a moderator, slowing down neutrons so that they can be absorbed by uranium nuclei | Allow U isotope is stable/can not absorb neutrons | 1<br><br>1<br>1 | 3 | 3.8.1.7 |
| **07.2** | Fissile means that the nucleus can split, usually when it absorbs a thermal neutron, to produce fission products and more neutrons, but non-fissile means that it cannot | Both needed for the mark | 1 | 2 | 3.8.1.6 |
| **07.3** | Before: atomic mass = 235 + 1, atomic number = 92<br>After: atomic mass = 142 + 3, atomic number = 60<br>Atomic mass = 236 – 145 = 91, atomic number = 32 | Atomic mass correct<br>Atomic number correct | 1<br>1 | 2 | 3.8.1.6 |
| **07.4** | Energy per reaction = $150 \times 1.6\times10^{-13}$ J = $2.4\times10^{-11}$ J<br>Power = 100 kW = $10^5$ J $s^{-1}$<br>Decays per second = $\dfrac{\text{power}}{\text{energy per reaction}} = \dfrac{10^5\ \text{J s}^{-1}}{2.4\times10^{-11}\ \text{J}}$<br>$= 4.2\times10^{15}$ decays $\text{second}^{-1}$ | <br>Use of power<br>Explicit or implied<br>Answer | <br>1<br>1<br>1 | 2 | 3.4.1.7 |
| **07.5** | Energy require to raise temperature of water and change state of water = $mC\Delta\theta + mL$<br>In one second: $m$[(4200 × 80) + (2260 000)] = 100 000 J<br>Mass per second = $\dfrac{100\,000}{2\,596\,000} = 3.85\times10^{-2}$ kg $s^{-1}$<br>Volume per second = $\dfrac{\text{mass per second}}{\text{density}} = \dfrac{0.0385}{0.6} = 6.4(2)\times10^{-2}\ \text{m}^3\,\text{s}^{-1}$ | Use of SHC and SLH<br><br>Correct mass per second<br>Correct volume per second | 1<br><br>1<br>1 | 2 | 3.6.2.1 |
| **08.1** | Induced fission requires the absorption of a thermal/slow-moving neutron but spontaneous fission does not | | 1 | 1 | 3.8.1.7 |

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| **08.2** | Atomic mass increases by one: 239<br>Atomic number increases by two: 94 | | 1<br>1 | 2 | 3.8.1.4 |
| **08.3** | One from:<br>• Plutonium has a higher probability of fission, so less fuel would be needed to produce the same energy as the energy per fission is about the same<br>• The half-life is less, so would become less radioactive more quickly<br>• There are fewer spontaneous fissions per kilogram, so there is less chance of the mass going critical/exploding | | 1 | 3 | 3.8.1.6 |
| **08.4** | Suggestion such as:<br>Electrons are moving faster at one end of the wire and move towards the lower temperature end and moving charge = current | | 1 | 1 | 3.5.1.1 |
| **08.5** | Plutonium-238 decays by alpha decay and it is easy to shield the patient from the radiation using a thin sheet of metal | | 1 | 3 | 3.8.1.2 |
| **08.6** | Power = $IV$<br>$= 2\times10^{-3}\,\text{A}\times1.5\,\text{V} = 3\times10^{-3}\,\text{W}$<br>Power density = $0.57\,\text{W g}^{-1}$<br>Mass required = $\dfrac{0.57}{3\times10^{-3}\,\text{W}} = 190\,\text{g}$<br>Reason: only pulses produced/continuous supply not needed | Power required<br>Answer<br>Reason | 1<br>1<br>1 | 3 | 3.5.1.4 |

**Skills box answers**

| Question | Answer |
|---|---|
| **1** | Order of magnitude values: $E_k \approx 10^{-14}\,\text{J}$; $q \approx 10^{-19}\,\text{C}$; $Q \approx 10^{-19}\,\text{C}$; $4\pi\varepsilon_0 \approx 10^{-10}\,\text{F m}^{-1}$, so $r \approx 10^{-14}\,\text{m}$. |
| **2** | Diameter of atom is $\approx 10^{-10}\,\text{m}$, thickness of foil is $0.5\times10^{-6}\,\text{m} \approx 10^{-6}$. Number of atoms in the depth of foil $= \dfrac{10^{-6}}{10^{-10}} = 10^4$. |
| **3** | Gold is an extremely malleable material and can be beaten into very thin sheets without cracking. |