# 7.2 Nuclear Reactions

## Mark Schemes

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| Course | DP IB Physics |
| Section | 7. Atomic, Nuclear & Particle Physics |
| Topic | 7.2 Nuclear Reactions |
| Difficulty | Medium |



To be used by all students preparing for DP IB Physics SL
Students of other boards may also find this useful

1

The correct answer is **C** because:

- Point C has the greatest binding energy per nucleon; this means that the nuclei in this region are the most stable

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| **A** is incorrect as | point A has the lightest nuclei and these have a low binding energy per nucleon |
| **B** is incorrect as | point B is the point of the nuclei Helium-4, which, while particularly stable given the small size of the nucleus, is not the most stable nuclei on the binding energy curve |
| **D** is incorrect as | point D is the point on the binding energy graph where the heaviest nuclei occur; they are less stable than those that are at point C, having lower binding energy per nucleon values |

2

The correct answer is **A** because:

- Boron-11 has a proton number of 5 and a nucleon number of 11
  - Therefore, it is made up of 5 protons and 6 neutrons
- The mass of those components should be added together as a reference point for when binding energy does not occur to hold them together in a nucleus
- The actual mass of the Boron-11, $m_B$, should be subtracted to find only the mass equivalent $\Delta m$ of the binding energy
  - Therefore, $\Delta m = 5m_p + 6m_N - m_B$
- The binding energy $E = \Delta mc^2$, therefore:
  - $E = (5m_p + 6m_N - m_B)c^2$

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| **B** is incorrect as | the mass of 5 protons, 6 neutrons and Boron-11 have been added. This would not be equal to the mass equivalent of the binding energy value |

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| **C** is incorrect as | the mass of 5 protons and 11 neutrons have been added together as the reference mass. However, Boron-11 only has 6 neutrons |
| **D** is incorrect as | the mass of 6 protons and 5 neutrons should be added together as the reference mass. However, these values should be switched since Boron must have 5 protons and since it is Boron-11, this means it will have 11 – 5 = 6 neutrons |

3

The correct answer is **B** because:

- In order to separate a nucleus into its constituent nucleons, energy is required
  - In other words, work must be done
- The total amount of energy required to separate a nucleus into its constituent nucleons is the binding energy of the nucleus

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| **A** is incorrect as | the energy equivalent of the mass of the nucleus is not the same as the energy required to separate nucleons in the nucleus |
| **C** is incorrect as | the binding energy is the energy required to separate nucleons from each other in the nucleus. Therefore, it is the energy required to overcome the strong nuclear force, which is the force that binds the nucleons together in a nucleus |
| **D** is incorrect as | the average energy required to remove (separate) a single nucleon from the nucleus is called the binding energy per nucleon |

4

The correct answer is **D** because:

- The binding energy of each nucleon is 7.98 MeV per nucleon for Oxygen-16
- This can be approximated as 8 MeV for convenience
- Since there are 16 nucleons in this atom, this means that there will be about $8 \times 16 = 128$ MeV which is close to 127.7 MeV, which is the correct answer

5

The correct answer is **B** because:

- The mass-energy equivalence value comes from the data booklet in the form of unified atomic mass unit:
  - Unified atomic mass unit (*u*) = $1.661 \times 10^{-27}$ kg = 931.5 MeV $c^{-2}$
  - We can approximate this to 1000 MeV $c^{-2}$
- To determine the number of atomic mass units which make up the mass defect of helium-4, approximate as follows:
  - The mass ratio is: $\frac{5.04 \times 10^{-29}}{1.661 \times 10^{-27}} \approx \frac{5 \times 10^{-29}}{2 \times 10^{-27}} = 2.5 \times 10^{-2}$
- Therefore, since the energy equivalence can be found to be $(2.5 \times 10^{-2}) \times 1000 = (2.5 \times 10^{-2}) \times 10^{3} = 25$ MeV
  - Therefore, approximations lead us to be nearest to option B, which is correct

6

The correct answer is **D** because:

- Osmium-190 is the lightest and most stable of these isotopes, all of which are beyond the peak of stability on the binding energy per nucleon curve which occurs around Iron-56 approximately;
  - Therefore, since it is the most stable, it has the least potential to be broken into smaller, more stable components by fission and release greater amounts of energy

- Generally the more massive the isotope, the more energy it has to release in fission reactions

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| **A** is incorrect as | Uranium-235 is a large and highly fissionable isotope that is used in many nuclear reactors as fuel for their fission reactions. Since it is larger and less stable than Osmium-190, it is more readily able to release energy via fission reactions |
| **B** is incorrect as | Thorium-231 is fissionable isotope that is used in less commonly in nuclear reactors as fuel for their fission reactions. As is the case with Uranium-235, Thorium-231 is more mass and less stable than Osmium-190, it is more readily able to release energy via fission reactions |
| **C** is incorrect as | Radon-222 is fissionable isotope that occurs as a tasteless, odourless gas that contributes strongly to background radiation. While not used in nuclear reactors, it is larger and less stable than Osmium-190, it is likely to be more readily able to release energy via fission reactions |



7

The correct answer is **C** because:

- Since the two smaller mass nuclei with mass *m* bond together in fusion, the product will need binding energy to hold the larger single nuclei together
- Therefore, the mass of the larger nuclei must be less than the original two masses

8

The correct answer is **B** because:

- The mass of the products is less than the mass of the reactants
- Therefore energy must have been released
  - This is the kinetic energy of the daughter nuclei

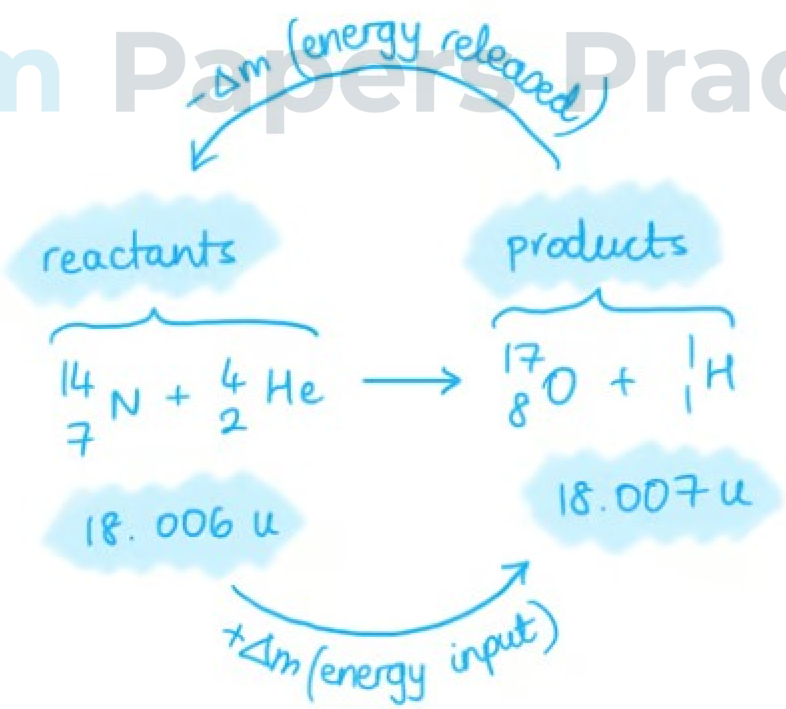
- Therefore **B** is correct

9

The correct answer is **C** because:

- The mass of the products ($^{17}_{8}O + ^{1}_{1}H$) is 0.001 u larger than the mass of the reactants ($^{14}_{7}N + ^{4}_{2}He$)
    - Therefore, the mass defect $\Delta m$ = 0.001 u
- Since 1 u is equivalent to 931.5 MeV
    - 001 u = 0.9315 MeV ≈ 1 MeV
- The law of conservation of mass-energy requires that the kinetic energy of the reactants therefore exceeds the kinetic energy of the products by about 1 MeV
    - Therefore, C is correct

Using the terms 'reactants' for the things on the left-hand side of an equation, and 'products' for the things on the right-hand side, enables you to describe the transfer of energy, using the mass defect. This is sketched out below:

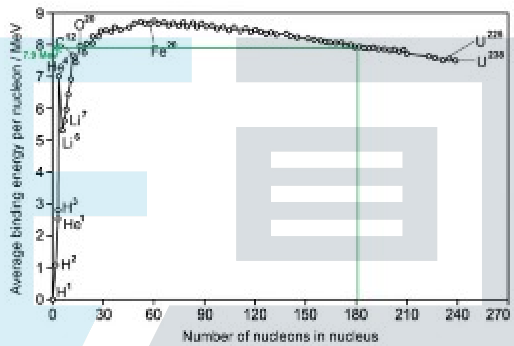


You should be able to see that there is 'extra' energy (in the form of a mass defect) on the left-hand side, with the reactants: therefore, the kinetic energy of the reactants exceeds that of the products.

10

The correct answer is **B** because:

- The mass number of the nucleus is 181
  - Therefore, there are 181 nucleons in the nucleus
- You can determine the average binding energy per nucleon of a nucleus with 181 neutrons using the graph, as shown below:




- The average binding energy per nucleon = $\frac{total\ binding\ energy}{number\ of\ nucleons}$
  - This means the total binding energy = average binding energy per nucleon × number of nucleons
- Therefore, if the average binding energy per nucleon is approximately 7.9 MeV for this nucleus, then the total binding energy = 7.9 × 181 = 1429.9 MeV
  - This means that 1429.9 MeV ≈ 1430 MeV of energy is released when the nucleus $^{181}_{70}X$ forms
- Hence B is correct

Remember to check the axis of a binding energy graph. Sometimes, the energy is given as the total binding energy (which is the energy released when nucleons fuse together, or equivalently, the energy required to separate them fully), and sometimes the energy given is the average binding energy **per nucleon**.