AQA

A Level

A Level Physics

Nuclear Physics 2 (Answers)

Name:

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Total Marks: /30

1. The equivalence of mass and energy, quantified by Einstein's famous equation $E = mc^2$, underpins all nuclear reactions.

Total for Question 1: 13

(a) Calculate the energy equivalent of the following:

i. The mass of an electron. [2]

Solution: 8.20×10^{-14} J

ii. A human weighing 700 N. [2]

Solution: 6.42×10^{18} J

(b) Calculate the final mass when an ${}^{4}_{2}$He nucleus is taken from rest to having kinetic energy of 5.0 MeV. Will this change be an increase or a decrease? [4]

Solution: 6.7×10^{-27} Kg
An increase.

(c) Calculate the minimum photon energy required for pair production, giving your answer in units of MeV. Give an example of when pair production is useful. [5]

Solution: 1.02 MeV
It is an absorption mechanism for x-rays. Without absorption there would be no contrast in a medical x-ray image.

2. Nuclear transformations are capable of producing and consuming large quantities of energy. This is exploited in nuclear reactors. In this question you will calculate the energies associated with transformations and consider the implications of this for nuclear fusion and fission.

Total for Question 2: 7

(a) Define binding energy. [1]

> **Solution:** The binding energy of a nucleus is the minimum energy required to completely separate it into its constituent protons and neutrons.

(b) How is binding energy of a particle related to its mass defect? [1]

> **Solution:** binding energy of a nucleus = mass defect of nucleus $\times c^2$

(c) State the SI unit of mass defect and binding energy. [1]

> **Solution:** Kg and J.

(d) A ${}^{7}_{3}\mathrm{Li}$ nucleus has a mass of 7.016 u. Calculate the binding energy per nucleon, giving your answer in units of eV. [4]

> **Solution:** 5.4 MeV

3. Nuclear fission reactors now provide the majority of numerous countries' electricity. This question tackles the reactions that occur inside these facilities.

Total for Question 3: 10

(a) Sketch a graph to show the variation of the binding energy per nucleon with the nucleon number. Annotate your graph to show the position of ^{56}Fe and the directions of fusion and fission reactions. [4]

Solution: Shape: sharp increase for nucleon numbers from 1-50; gently decreasing tail slope thereafter.
Peak at 56 i.e. Fe
Scales: 0-10 MeV vs 0-250 is appropriate.

(b) Nuclear fission reactions in a reactor can only continue if the number of nuclei involved in the reaction does not decrease. This is achieved by using a particular amount of uranium fuel. Why is the arrangement of the fuel important? [2]

> **Solution:** A chain reaction is needed, which requires a critical mass. Neutrons lost from the surface of the fuel are not involved in future reactions. So, it is the surface area : volume ratio that must be minimised. For a sphere, V/A is proportional to the radius, so increasing the radius would decrease the relative loss of neutrons. However, the same mass distributed in 10 smaller spheres would have a much lower V/A and hence this arrangement would have a higher critical mass.

(c) What is the role of the control rods in a nuclear fission reactor? [1]

> **Solution:** To ensure that precisely one slow neutron survives each fission reaction.

(d) Low-level waste accounts for 90% of the waste (by volume) generated by nuclear power plants. In contrast, high-level waste represents only 3%. Give an example of each and briefly explain how each is treated and disposed of. [3]

> **Solution:**
> LLW: workers' clothing; compacted and encased in cement before being stored until decay has reduced to background levels; it is then disposed of conventionally.
> HLW: spent rods; produces heat so first needs cooling in water baths; in the long-term it is vitrified then stored in metal cylinders designed to last sufficiently long to protect the environment from the harmful radiation; these, in the future, are likely to be stored underground.