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| 27: Nuclear Physics  Binding Energy, Fission and Fusion | |
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| Paper 2 |  |
| 17: Thermal Physics 1  Specific Heat Capacity and Latent Heat | 1. Appreciation that applies to all energy changes, 2. Simple calculations involving mass difference and binding energy. 3. Atomic mass unit, u. 4. Conversion of units; 1 u = 931.5 MeV. 5. Fission and fusion processes. 6. Simple calculations from nuclear masses of energy released in fission and fusion reactions. 7. Graph of average binding energy per nucleon against nucleon number. 8. Students may be expected to identify, on the plot, the regions where nuclei will release energy when undergoing fission/fusion. 9. Appreciation that knowledge of the physics of nuclear energy allows society to use science to inform decision making. 10. Fission induced by thermal neutrons; possibility of a chain reaction; critical mass. 11. The functions of the moderator, control rods, and coolant in a thermal nuclear reactor. 12. Details of particular reactors are not required. 13. Students should have studied a simple mechanical model of moderation by elastic collisions. 14. Factors affecting the choice of materials for the moderator, control rods and coolant. Examples of materials used for these functions. 15. Fuel used, remote handling of fuel, shielding, emergency shut-down. 16. Production, remote handling, and storage of radioactive waste materials. 17. Appreciation of balance between risk and benefits in the development of nuclear power. |
| 18: Thermal Physics 2  Gas Laws and the MKTM |
| 19: Gravitational Fields  Field Strength and Potential |
| 20: Electric Fields  Fields Strength and Potential |
| 21: Fields Comparisons  Orbits and Comparisons |
| 22: Capacitors  Energy Stored and Exponential Decay |
| 23: Magnetic Fields 1  Magnetic Forces and Flux |
| 24: Magnetic Fields 2  Induction and Transformers |
| 25: Radioactivity 1  Nuclear Radius and Types of Radiation |
| 26: Radioactivity 2  Modes and Rate of Decay |
| 27: Nuclear Physics  Binding Energy, Fission and Fusion |
| Paper 3 |
| 28: Electron Discovery  Specific Charge and Millikan |
| 29: Wave-Particle Duality  Waves, Quantum and Microscopes |
| 30: Special Relativity  Michelson-Morley & Relativistic Speed |

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| **Monday: Binding Energy, Fission and Fusion Notes**  What is meant by the term ‘mass difference’?  ………………………………………………………………….…………….……………………………………………………….………………..  ……………………………………………………………………….……….……………………………….………………………………………..  What is the ‘binding energy’ of a nucleus?  1.………………………………………………………………………..…….………………………………………………………………………..  ………………………………………………………………….…………….……………………………………………………….………………..  2.………………………………………………………………………..…….………………………………………………………………………..  ……………………………………………………………………….……….……………………………….………………………………………..  **NEVER** use one of the terms above to define the other.  Binding energy is connected to the mass difference by the following equation:  Symbol Quantity …………………………………………………………………………………………… Units ………………………  Symbol Quantity …………………………………………………………………………………………… Units ………………………  Symbol Quantity …………………………………………………………………………………………… Units ………………………  What is meant by the ‘atomic mass unit’, u?  ………………………………………………………………….…………….……………………………………………………….………………..  ……………………………………………………………………….……….……………………………….………………………………………..  Describe how to convert from:  kg to J …………………………………………………………… J to kg ……………………………………………………………  kg to u …………………………………………………………… u to kg ……………………………………………………………  J to MeV …………………………………………………………… MeV to J ……………………………………………………………  u to MeV …………………………………………………………… MeV to u ……………………………………………………………  Calculate the binding energy of the following nuclei:   |  |  |  |  |  | | --- | --- | --- | --- | --- | | Nucleus | Mass of nucleus (u) | Mass of nucleons (u) | Mass difference (u) | Binding energy ( ) | |  | 9.00998 |  |  |  | |  | 15.99051 |  |  |  | |  | 26.97438 |  |  |  | |  | 39.95159 |  |  |  |   What is meant by the ‘binding energy per nucleon’ of a nucleus?  1.………………………………………………………………………..…….………………………………………………………………………..  ………………………………………………………………….…………….……………………………………………………….………………..  2.………………………………………………………………………..…….………………………………………………………………………..  ……………………………………………………………………….……….……………………………….………………………………………..  Calculate the binding energy per nucleon for the following nuclei:   |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | |  |  |  |  |  |  |  |  |   Sketch how the binding energy per nucleon varies with nucleon number including y-axis values and units.  https://app.doublestruck.eu/content/AA_PA/HTML/Q/QS11503_files/image001.png  How can the binding energy of a nucleus be calculated from the graph?  ………………………………………………………………….…………….……………………………………………………….………………..  ……………………………………………………………………….……….……………………………….………………………………………..  …………………………………………………………………………..…….………………………………………………………………………..  What is the significance of the peak on the graph?  ………………………………………………………………….…………….……………………………………………………….………………..  ……………………………………………………………………….……….……………………………….………………………………………..  Describe what happens in the process of nuclear fusion.  ………………………………………………………………….…………….……………………………………………………….………………..  ……………………………………………………………………….……….……………………………….………………………………………..  ………………………………………………………………………..……….………………………………………………………………………..  What conditions are needed for fusion to happen?  …………………………………………………………………………..…….………………………………………………………………………..  ………………………………………………………………………..……….………………………………………………………………………..  Explain why.  …………………………………………………………………………..…….………………………………………………………………………..  ………………………………………………………………………..……….………………………………………………………………………..  …………………………………………………………………………..…….………………………………………………………………………..  Describe what happens in the process of nuclear fission. Label the regions on the graph where fission and fusion happen.  ………………………………………………………………….…………….……………………………………………………….………………..  …………………………………………………………………………..…….………………………………………………………………………..  ………………………………………………………………………..……….………………………………………………………………………..  How can fission and fusion both release energy?  ……………………………………………………………………….……….……………………………….………………………………………..  …………………………………………………………………………..…….………………………………………………………………………..  Why does fusion release more energy than fission?  ……………………………………………………………………….……….……………………………….………………………………………..  …………………………………………………………………………..…….………………………………………………………………………..  ………………………………………………………………………..……….……………………………………………………………………….. |

**Tuesday: Binding Energy Exam Questions**

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| **Q140(ai)**    Define the atomic mass unit.  ..................................................................................................................................................................................................  .................................................................................................................................................................................................. **(1)**  **Q140(aii)**    State and explain how the mass of a nucleus is different from the total mass of its protons and neutrons when separated.  ..................................................................................................................................................................................................  ..................................................................................................................................................................................................  ..................................................................................................................................................................................................  .................................................................................................................................................................................................. **(2)**  **Q140(b)**    Explain why nuclei in a star have to be at a high temperature for fusion to take place.  ..................................................................................................................................................................................................  ..................................................................................................................................................................................................  ..................................................................................................................................................................................................  ..................................................................................................................................................................................................  ..................................................................................................................................................................................................  .................................................................................................................................................................................................. **(3)**  **Q140(ci)**  In massive stars, nuclei of hydrogen are processed into nuclei of helium through a series of interactions involving carbon, nitrogen and oxygen called the CNO cycle.  Complete the nuclear equations below that represent the last two reactions in the series.  **(3)**  **Q140(cii)**    The whole series of reactions is summarised by the following equation.    Calculate the energy, in Me V, that is released.  nuclear mass of = 4.00150 u            energy ..................................... Me V **(3)**  **(Total 12 marks)**  **Q141(a)**    State what is meant by the binding energy of a nucleus.  ..................................................................................................................................................................................................  ..................................................................................................................................................................................................  ..................................................................................................................................................................................................  .................................................................................................................................................................................................. **(2)**  **Q141(bi)**    When a nucleus absorbs a slow-moving neutron and undergoes fission one possible pair of fission fragments is technetium and indium .  Complete the following equation to represent this fission process.  **(1)**  **Q141(bii)**   Calculate the energy released, in MeV, when a single nucleus undergoes fission in this way.      binding energy per nucleon of = 7.59 MeV binding energy per nucleon of = 8.36 MeV  binding energy per nucleon of = 8.51 MeV        energy released ..................................... MeV **(3)**  **Q141(biii)**  Calculate the loss of mass when a nucleus undergoes fission in this way.        loss of mass ......................................... kg **(2)**  **(Total 8 marks)** |

**Wednesday: Reactors Extended Writing**

In a thermal nuclear reactor, one fission reaction typically releases 2 or 3 neutrons. Describe and explain how a constant power output is maintained in a reactor by considering what events or sequence of events may happen to the released neutrons. You should not discuss the workings of a heat exchanger or beyond in terms of producing electricity. You should include:

* A description of the process of fission
* How energy is produced
* The components of the reactor and what they do
* How the output is controlled and kept constant.

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**Wednesday: Nuclear Physics Definitions**

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| Shut-Down | The nuclear reaction will do this when the control rods are fully inserted. |
| Moderator | This lowers the mean kinetic energy of the neutrons released in nuclear fission. |
| Mega Electron Volt | The units of energy when converting from masses given in atomic mass units. |
| Coolant | This is used to transport the heat released from nuclear fission. |
| Critical Mass | The minimum mass of a fissionable material needed to sustain a chain reaction. |
| Required | The energy ………… when a nucleus is separated into its constituent nucleons. |
| The Most Stable | The nucleus at the peak of a BE/A against A graph would be |
| Vitrification | When radioactive waste is incorporated into a solid glassy material then stored deep underground. |
| Elastic Collisions | Neutrons have about 50 of these with the nuclei of the moderator. |
| Thermal | The name of neutrons travelling slow enough to induce another fission event. |
| Released | The energy ………… when a nucleus is formed from its separate nucleons. |
| Left | Fusion happens in nuclei to the ………… of the peak on a BE/A against A graph. |
| Graphite | A suitable material to use for a moderator. |
| Chain Reaction | When one fission event causes at least one more to happen. |
| Nuclear Fusion | When two light nuclei join to form one heavier nucleus. |
| Boron | A suitable material to use for control rods. |
| Joules | The units of energy (in E=mc2) when converting from masses given in kilograms. |
| Right | Fission happens in nuclei to the ………… of the peak on a BE/A against A graph. |
| Speed Up | The nuclear reaction will do this when the control rods are removed. |
| Mass Difference | The mass of the separate nucleons minus the mass of the nucleus they form. |
| Fuel Rods | Where the U 235 is found in a nuclear reactor. |
| Nuclear Fission | When one heavy nucleus splits into two lighter nuclei. |
| Control Rods | These absorb the neutrons in the core of a nuclear reactor. |
| Atomic Mass Unit | Equal to one twelfth of the mass of a carbon 12 atom. |
| Enriched | When the amount of U 235 has been increased beyond the percentage in natural uranium. |
| Cooling Ponds | After being removed by a robot, the spent fuel rods are stored here to lower the temperature. |

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| Atomic Mass Unit | Elastic Collisions | Mega Electron Volt | Right |
| Boron | Enriched | Moderator | Shut-Down |
| Chain Reaction | Fuel Rods | Nuclear Fission | Speed Up |
| Control Rods | Graphite | Nuclear Fusion | The Most Stable |
| Coolant | Joules | Released | Thermal |
| Cooling Ponds | Left | Required | Vitrification |
| Critical Mass | Mass Difference |  |  |
| **Thursday: Nuclear Reactors and Safety Notes**  Complete this diagram of a chain reaction.  http://content.doublestruck.eu/getPicture.asp?sub=AG_PH&CT=Q&org=b14933581456288c68995170a209fc02&folder=Q13S2H03_files&file=img01.png  The **fuel rods** in a nuclear fission reactor contain ‘enriched’ uranium, what does enriched mean in this case?  ……………………………………………………………………….……….……………………………….………………………………………..  …………………………………………………………………………..…….………………………………………………………………………..  What is the role of the **control rods**? How do they do this?  ……………………………………………………………………….……….……………………………….………………………………………..  ……………………………………………………………………….……….……………………………….………………………………………..  …………………………………………………………………………..…….………………………………………………………………………..  What are the desired properties when choosing a material for the control rods? Include an example of the material used.  ……………………………………………………………………….……….……………………………….………………………………………..  …………………………………………………………………………..…….………………………………………………………………………..  What is the role of the **moderator**? How does it do this?  ……………………………………………………………………….……….……………………………….………………………………………..  ……………………………………………………………………….……….……………………………….………………………………………..  …………………………………………………………………………..…….………………………………………………………………………..  What are the desired properties when choosing a material for the moderator? Include an example of the material used.  ……………………………………………………………………….……….……………………………….………………………………………..  …………………………………………………………………………..…….………………………………………………………………………..  What is the role of the **coolant**? How does it do this?  ……………………………………………………………………….……….……………………………….………………………………………..  ……………………………………………………………………….……….……………………………….………………………………………..  …………………………………………………………………………..…….………………………………………………………………………..  What are the desired properties when choosing a material for the coolant? Include an example of the material used.  ……………………………………………………………………….……….……………………………….………………………………………..  …………………………………………………………………………..…….………………………………………………………………………..  What could happen to the neutrons released from a fission event?  1……………………………………………………………….…………….……………………………………………………….…………………  2……………………………………………………………………….……….……………………………….………………………………………  3…………………………………………………………………………..…….………………………………………………………………………  What is meant by a ‘thermal neutron’?  ……………………………………………………………………….……….……………………………….………………………………………..  ……………………………………………………………………….……….……………………………….………………………………………..  Why is more than one fuel rod needed?  ……………………………………………………………………….……….……………………………….………………………………………..  ……………………………………………………………………….……….……………………………….………………………………………..  What is meant by the term ‘critical mass’?  ………………………………………………………………….…………….……………………………………………………….………………..  ………………………………………………………………….…………….……………………………………………………….………………..  What are the advantages of using nuclear power to generate electricity?  1………………………………………………………………………..…….………………………………………………………………………..  2……………………………………………………………………..……….………………………………………………………………………..  3…………………………………………………………………….……….……………………………….……………………………………..…  Substantial shielding around the core protects nearby workers from the most hazardous radiations. Radiation from the core includes α and β particles, γ rays, X−rays, neutrons and neutrinos. What would be a suitable material for the shielding?  ……………………………………………………………………….……….……………………………….………………………………………..  Explain why the shielding becomes radioactive.  ……………………………………………………………………….……….……………………………….………………………………………..  ……………………………………………………………………….……….……………………………….………………………………………..  ……………………………………………………………………….……….……………………………….………………………………………..  Describe how an emergency shut-down happens in a reactor.  ……………………………………………………………………….……….……………………………….………………………………………..  ……………………………………………………………………….……….……………………………….………………………………………..  ……………………………………………………………………….……….……………………………….………………………………………..  What is the main source of the most dangerous waste from a nuclear reactor?  …………………………………………………………………………..…….………………………………………………………………………..  What are the issues with storing radioactive waste that has a short half-life (e.g. 20 days)?  …………………………………………………………………………..…….………………………………………………………………………..  …………………………………………………………………………..…….………………………………………………………………………..  What are the issues with storing radioactive waste that has a long half-life (e.g. 20 years)?  …………………………………………………………………………..…….………………………………………………………………………..  …………………………………………………………………………..…….………………………………………………………………………..  Waste from a nuclear reactor is treated before it is stored; describe the processed involved in this.  …………………………………………………………………………..…….………………………………………………………………………..  …………………………………………………………………………..…….………………………………………………………………………..  …………………………………………………………………………..…….………………………………………………………………………..  …………………………………………………………………………..…….……………………………………………………………………….. | | | | |

**Friday: Fission and Fusion Exam Questions**

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| **Q142(a)**     A typical fission reaction in the reactor is represented by  **Q142(ai)**    Calculate the number of neutrons, *x*.      answer = .............................neutrons **(1)**  **Q142(aii)**    Calculate the energy released, in MeV, in the fission reaction above.  mass of neutron = 1.00867 u mass of   nucleus = 90.90368 u  mass of  nucleus = 232.98915 u mass of   nucleus = 138.87810 u              answer = ..................................MeV **(3)**  **Q142(b)**    Sketch a graph of binding energy per nucleon against nucleon number for the naturally occurring nuclides on the axes given in the figure below. Add values and a unit to the binding energy per nucleon axis.  **(4)**  **Q142(c)** Use the graph to explain how energy is released when some nuclides undergo fission and when other nuclides undergo fusion.  ..................................................................................................................................................................................................  ..................................................................................................................................................................................................  ..................................................................................................................................................................................................  ..................................................................................................................................................................................................  .................................................................................................................................................................................................. **(3)**  **(Total 11 marks)**  **Q143.**  The diagram shows how the binding energy per nucleon varies with nucleon number.    **Q143ai)**   Fission and fusion are two nuclear processes in which energy can be released. Explain why nuclei that undergo fission are restricted to a different part of the graph than those that undergo fusion.  ..................................................................................................................................................................................................  ..................................................................................................................................................................................................  ..................................................................................................................................................................................................  .................................................................................................................................................................................................. **(2)**  **Q143(aii)**   Explain, with reference to the diagram, why the energy released per nucleon from fusion is greater than that from fission.  ..................................................................................................................................................................................................  ..................................................................................................................................................................................................  ..................................................................................................................................................................................................  .................................................................................................................................................................................................. **(2)**  **Q143(bi)**   Calculate the mass difference, in kg, of the  nucleus.  mass of  nucleus = 15.991 u  mass difference = ............................................. kg **(2)**  **Q143(bii)**   Using your answer to part **(bi)**, calculate the binding energy, in MeV, of an oxygen  nucleus.  binding energy = ............................................. MeV **(1)**  **Q143(biii)**  Explain how the binding energy of an oxygen  nucleus can be calculated with information obtained from the diagram.  ..................................................................................................................................................................................................  ..................................................................................................................................................................................................  .................................................................................................................................................................................................. **(1)**  **(Total 8 marks)** |

**Saturday: Nuclear Physics Checklist**

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