Topic 6: Nuclear Models and Radioactivity

Subtopic 6.1: The Nucleus

Knowledge	Application
The basic structure of an atom comprises a small central nucleus consisting of protons and neutrons (nucleons) surrounded by electrons. Atomic nuclei can be described using their chemical symbol (X), mass number (A), atomic number (Z), and number of neutrons (N). A common representation is: ${}_{Z}^{A}\mathrm{X}$. Isotopes are atoms of the same element that have different mass numbers. The nucleus is held together by a strong, attractive nuclear force.	Describe the structure of an atom, including the relative size and location of the nucleons and electrons. Describe the structure of various nuclei from their symbol and vice versa. Identify isotopes of an element based on their composition. Explain why isotopes of the same element are chemically identical but have different physical properties. Describe the properties of the strong nuclear force, including its short range. Describe the balance between the electrostatic force and the strong nuclear force in stable nuclei. Use the properties of the electrostatic force and the strong nuclear force to explain why some isotopes are unstable. Locate stable and unstable nuclei on an N vs Z graph.

Subtopic 6.2: Radioactive decay

Knowledge	Application
Unstable nuclei will undergo radioactive decay in which particles and/or electromagnetic radiation are emitted.	
In alpha decay, an unstable nucleus emits an alpha particle, ${}_{2}^{4}\alpha$. Alpha decay typically occurs for nuclei with $Z > 83$. The general equation for an alpha decay is given by: ${}_{Z}^{A}\mathrm{X} \rightarrow {}_{Z-2}^{A-4}\mathrm{Y} + {}_{2}^{4}\alpha$.	Write equations for the decay of heavy nuclei by alpha decay.
In beta minus decay, an unstable nucleus emits an electron, ${}_{-1}^{0}e$. Beta minus decay occurs when a nucleus has an excess of neutrons, and involves the decay of a neutron into a proton, electron, and antineutrino. This is shown by the equation: ${}_{0}^{1}n \rightarrow {}_{+1}^{1}p + {}_{-1}^{0}e + {}_{0}^{0}\overline{\nu}$. The general equation for beta minus decay of an unstable nucleus is shown by the equation: ${}_{Z}^{A}\mathrm{X} \rightarrow {}_{Z+1}^{A}\mathrm{Y} + {}_{-1}^{0}e + {}_{0}^{0}\overline{\nu}_e$. In beta plus decay, an unstable nucleus emits a positron, ${}_{+1}^{0}e$. Beta plus decay occurs when a nucleus has an excess of protons, and involves the decay of a proton into a neutron, positron, and neutrino. This is shown by the equation: ${}_{+1}^{1}p \rightarrow {}_{0}^{1}n + {}_{+1}^{0}e + {}_{0}^{0}\nu$. The general equation for beta plus decay of an unstable nucleus is given by: ${}_{Z}^{A}\mathrm{X} \rightarrow {}_{Z-1}^{A}\mathrm{Y} + {}_{+1}^{0}e + {}_{0}^{0}\nu_e$.	Describe the structure of unstable nuclei that causes each type of beta decay. Write the equations for the decay of nuclei by beta minus and beta plus decay. Use the conservation of charge to explain the emission of an electron in the decay of a neutron into a proton. Use the conservation of charge to explain the emission of a positron in the decay of a proton into a neutron.

Subtopics 6.2 (continued) to 6.3 on next page.

Subtopic 6.2: Radioactive decay (continued)

Knowledge	Application
In gamma decay, an unstable nucleus emits high-energy gamma rays, γ. Gamma decay occurs when a nucleus is left with excess energy after an alpha or beta decay. The general equation for a gamma decay is given by: $^{A}_{Z}\mathrm{X}^{*} \rightarrow ^{A}_{Z}\mathrm{X} + n\gamma$ where n is the number of high-energy gamma rays emitted.	Write equations for the decay of unstable nuclei involving the emission of gamma rays.
The type of decay an unstable nucleus will undergo can be predicted based on the number of protons and neutrons within the nucleus.	Use the atomic and mass numbers to predict the type of decay for an unstable nucleus. Use the location on an N vs Z graph to predict the type of decay for an unstable nucleus.
The particles emitted in radioactive decay have sufficient energy to ionise atoms. The properties of the particles and/or radiation emitted in the different types of radioactive decay result in different penetration of matter.	Describe the effects of ionising radiation on living matter. Describe methods of minimising exposure to ionising radiation. Compare and contrast the ionising ability and penetration through matter of alpha, beta, and gamma radiations.

Subtopic 6.3: Radioactive Half-life

Knowledge	Application
The number of radioactive nuclei in a sample of a given isotope decreases exponentially with time. Half-life is the time required for half of the radioactive nuclei in a sample to decay. The half-life of radioactive nuclei is independent of both the physical state and the chemical state of the material. The activity of a radioactive substance is the number of radioactive nuclei that decay per unit time. The range of products of nuclear decay, some with long half-lives, means that nuclear waste must be stored for long periods.	Relate the activity of a sample to the number of radioactive nuclei present, and hence explain how it decreases exponentially with time. Use data to estimate the half-life of radioactive nuclei. Use data to estimate the activity or number of radioactive nuclei of a sample at different times. Estimate the age of a sample based on the relative activity or the relative amounts of radioactive nuclei or their decay products. Explain the requirements for the safe storage of nuclear waste.

Subtopic 6.4 on next page.

Subtopic 6.4: Induced Nuclear Reactions

Knowledge	Application
Nuclear fission can be induced in some heavy nuclei by the capture of a neutron. The nucleus splits into two nuclei and several neutrons. The total mass of the reactants in a fission reaction is greater than that of the products, releasing energy given by $E = \Delta mc^2$, where Δm is the mass of the reactants minus the mass of the products. On average, more than one neutron is emitted in nuclear fission. This leads to the possibility that these neutrons will induce further fissions, resulting in a chain reaction. The neutrons emitted as a result of nuclear fission have high speeds. $^{235}\mathrm{U}$ undergoes fission with slow neutrons. Hence to induce fission in these nuclei the neutrons must be slowed down. Many neutrons are absorbed by surrounding nuclei, or escape and cause no further fissions.	Calculate the energy released per fission reaction, given the relevant masses (in kg). Relate the starting, normal operation, and stopping of a nuclear reactor to the nature of the chain reaction. Explain why neutrons have to be slowed down in order to produce fission in $^{235}\mathrm{U}$.
Enrichment increases the proportion of $^{235}\mathrm{U}$ in uranium fuel.	Describe how enrichment enables a chain reaction to proceed. Use a diagram of a reactor to locate and discuss the function of the principal components of a water-moderated fission power reactor.
Energy released during nuclear fission reactions can be harnessed for use in power generation.	Explain the use of nuclear fission in power production. Describe some of the risks associated with the use of nuclear energy for power production.
Nuclear fusion is the process in which two nuclei combine into a single nucleus. The energy absorbed or released is given by $E = \Delta mc^2$, where Δm is the difference in mass between the reactants and the products.	Explain why high temperatures are needed for nuclear fusion to occur. Calculate the energy released per fusion reaction, given the relevant masses (in kg).