Mass Defect and Nuclear Binding Energy

Mass Defect and Binding Energy

- Defnition : It is the amount of mass that apparently disappears when a nucleus is formed from its constituent nucleons.
- The apparent mass that is lost is all converted into binding energy, in which is energy used to hold the nucleons together in a nucleus.
- Binding Energy (per nucleon) Defnition : It is the amount of energy (per nucleon) that is released when forming a nucleus from its constituent nucleons that are separated from infinity.
- Alternative Definition : It is the energy required (per nucleon) to completely separate a nucleus into its constituent nucleons and the nucleons are separated to infinity.
- Mass defect and binding energy is related by the equation $E=mc^2$ where E = Binding Energy, m = mass defect and c = speed of light ($3 * 10^8$ ms^{-1}).

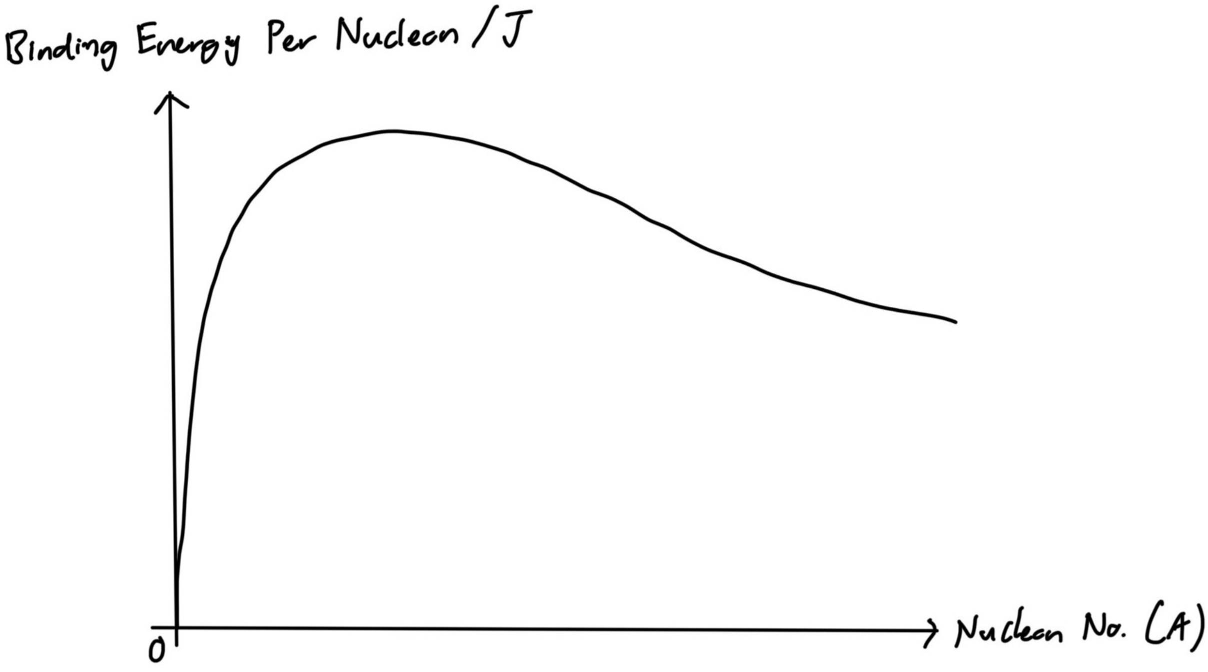

Figure 1: Sketching a Graph of Binding Energy per Nucleon against Nucleon Number.

- Binding Energy per Nucleon will increase as Nucleon Number increases until a maximum; then decreases again. The greater the Binding Energy per Nucleon, the more stable the nucleus is.
- To find Total Binding Energy of a nucleus, find the **product of Binding Energy per Nucleon and Nucleon Number of nucleus**.
- Molecules on the far left that have low nucleon number also have low binding energy and are unstable, and undergoes **nuclear fusion** to become more stable.
- Nuclear Fusion Defnition : A process where two small and light nuclei combine to form a single larger atomic nucleus with the release of energy.

- Example of a Nuclear Fusion Reaction :
  - $^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n + Q$, where Q is **energy released**.
  - **Energy is released in a nuclear fusion** as binding energy of right hand side nuclei is higher than binding energy of left hand side nuclei, hence energy is released when binding energy is formed in the nucleus (binding energy is an exothermic process).
  - Mathematically, Sum of Binding Energy on Right Hand Side – Sum of Binding Energy on Left Hand Side = Q.
- Molecules on the far right that have high nucleon number also have low binding energy and are unstable, and undergoes **nuclear fission** to become more stable.
- Nuclear Fission Definition : Nuclear reaction where a large nucleus breaks into two daughter nuclei with the release of energy.
- Example of a Nuclear Fission Reaction :
  - $^{235}_{92}U + ^{1}_{0}n \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3\,^{1}_{0}n$
  - **Energy is also released in a nuclear fission** as binding energy of right hand side nuclei is higher than binding energy of left hand side nuclei, hence energy is released when binding energy is formed in the nucleus (binding energy is an exothermic process).

Radioactive Decay

Radioactive Decay

- Defnition : A process in which an unstable nucleus undergoes spontaneous and random disintegration to become more stable by the emission of α, β or ɣ particles.
- Radioactive Decay is **random** and **spontaneous**.
- Random
  - Defnition : **We cannot tell which nucleus or when a particular nucleus will decay**; each nucleus has a constant probability of decay.
  - Evidence in a graph : **fluctuations in** count rate **reading**.
- Spontaneous
  - Definition : **Decay rate is unaffected by any other external factor** such as any physical, chemical or environmental conditions.
  - Evidence in a graph : **similar graph shape** at different conditions.

Activity, Decay Constant, Half-Life and Nature of Radioactive Decay

- Activity Definition : Number of disintegrations of its nucleus per unit time.
- Decay Constant : Probability of decay of a particular nucleus per unit time.
- Activity and Decay Constant is related by the equation $A=\lambda N$, where A = activity of nucleus, λ = decay constant and N = number of atoms.
- Radioactive Decay is an **exponential decay**, and can be written in the equation $x=x_0 e^{-\lambda t}$, where x can represent Activity, Number of Atoms, mass of atoms or count rate.
- When x drops to half of it's initial value, we take this as the **half life** of the decay, $t_{\frac{1}{2}}$. Equation will become :

$$0.5x=x_0 e^{-\lambda t_{\frac{1}{2}}}$$
$$0.5=e^{-\lambda t_{\frac{1}{2}}}$$
$$\ln 0.5=-\lambda t_{\frac{1}{2}}$$
$$\ln 2=\lambda t_{\frac{1}{2}}$$
$$t_{\frac{1}{2}}=\frac{0.693}{\lambda}.$$

- Half life Definition : Time taken for half the number of a radioactive element to decay.
- If N number of atoms exists at time t, and the change in Number of atoms is represented by -ΔN, and change in time is represented by Δt,
  - Activity is equal to $-\frac{\Delta N}{\Delta t}$.
  - Probability of Decay is equal to $\frac{\Delta N}{N}$.
  - Decay Constant is equal to $\frac{\Delta N}{N \Delta t}$.