NUCLEI

NUCLEAR ENERGY

NUCLEAR FISSION:

In the process of nuclear fission, heavy nuclei with a mass number (A) exceeding 200 undergo division into two or more fragments, each possessing comparable masses. For practical energy generation through nuclear fission, uranium-235 $_{92}U^{236}$ is a particularly attractive choice as the fission material. The method involves bombarding a uranium sample with slow-moving neutrons, commonly referred to as thermal neutrons, characterized by a kinetic energy of approximately 0.04 eV.

The likelihood of a $_{92}U^{235}$ nucleus absorbing a slow neutron is substantial, leading to the formation of a $_{92}U^{236}$ nucleus. Subsequently, this nucleus undergoes fission, resulting in the production of two fragments. Numerous combinations of middle-weight nuclei may arise from the fission process, exemplified by potential outcomes such as:

$_{36}Kr^{92} + {}_{56}Ba^{141}$

Or

$_{54}Xe^{142} + {}_{38}Sr^{91}$

And various other permutations.

Several noteworthy characteristics of nuclear fission include the emission of, on average, 2.5 neutrons in each fission event, and a mass loss of 0.2 atomic mass units per reaction, and an overall increase in total binding energy with the release of excess energy. In a single fission event, approximately 200 MeV of energy is liberated, with a substantial portion manifesting as kinetic energies of the resulting fragments. Neutrons carry away about 5 MeV of this released energy.

Example.
The Q value, denoting the energy release in a nuclear reaction, can be expressed in the context of neutron-induced fission as:

$$Q = [(M_U - 92 \cdot m_e + m_n) - ((M_{Ba} - 56 \cdot m_e) + (M_{Kr} - 36 \cdot m_e) + 3 \cdot m_n)] \cdot c^2$$

Simplifying this equation yields:

$$Q = (M_U + m_n) - (M_{Ba} + M_{Kr} + 3 \cdot m_n) \cdot c^2$$

A noteworthy aspect of neutron-induced fission is the occurrence of a chain reaction, a phenomenon of significant importance and interest in the operation of nuclear reactors. Further details on this topic can be found in relevant textbooks.

NUCLEAR FUSION (THERMO NUCLEAR REACTION)

(a) Certain unstable light nuclei with a mass number (A) below 20 can undergo fusion, resulting in an increase in the binding energy per nucleon ($B.E.$) and the subsequent release of excess energy. The fusion of light nuclei is particularly feasible on Earth, and one of the more manageable thermonuclear reactions involves the fusion of two deuterons (D-D reaction) or the fusion of a deuteron with a triton (D-T reaction).

The Q value for these reactions can be expressed as follows:

$$Q = [2((M_D - m_e) - ((M_{He3} - 2m_e) + m_n))] \cdot c^2 = [2M_D - (M_{He3} + m_e)] \cdot c^2$$

$$Q = [2(M_D - m_e) - ((M_T - m_e e) + (M_H H - m_e e))] \cdot c = [2M_D D - (M_T T + M_H H)] \cdot c^2$$

$$Q = [((M_D - m_e) + (M_T - m_e)) - ((M_{He4} - 2m_e) + m_n)] \cdot c^2 = [(M_D + M_T) - (M_{He4} + m_n)] \cdot c^2$$

Note:

- In both fission and fusion, the mass defect (Δm) is equivalent to the mass defect of the atom (Δm_{atom}), which is further equal to the mass defect of the nucleus ($\Delta m_{nucleus}$).
- These reactions occur at ultra-high temperatures (approximately 10^7 to 10^8 Kelvin). At high pressure, they can also occur at low temperatures. The success of these reactions relies on bringing nuclei to a distance of 1 fermi, requiring very high kinetic energy.
- The energy released in fusion surpasses the energy liberated in the fission of heavy nuclei.