Neutron capture

- Neutrons can be captured with very high probability by nuclei.
- The probability is expressed as a cross section area that the target (the nucleus) presents to the projectile (the neutron).
- A large cross section corresponds to a large area etc.
- The unit of a cross section is 1 barn (bn), which corresponds to an area of $10^{-24}$ cm$^2$. This is a large probability, like hitting a barn door.
- Boron has a huge neutron capture cross section of 3,800 bn, 35,000 times its actual size, for low-energy neutrons.
- This is due to the wave nature of the low-energy neutron $\lambda \sim 28 \times 10^4$ fm at 0.1 eV.
Neutron cross sections

- Cross section area is a pictorial expression for the probability of a projectile interacting with a target nucleus. The larger the area the higher the probability.

- A Boron nucleus has a size $R_B \sim 2.6$ fm and a nucleon has a radius $R_n \sim 1.2$ fm.

Thus we expect $A \sim \pi (R_B + R_n)^2 = 45 \times 10^{-26} \text{ cm}^2 = 0.45 \text{ bn}$

- $A = 10^{-24} \text{ cm}^2$ is called a barn (bn) because it is for neutrons like hitting a barn door.

- Boron has a neutron capture cross section at 1 eV of 3,800 bn = 35,000 times what one expects.

- This follows from the wave nature of the neutron that is important at low energies.

- If we take $R_n \sim \lambda$ the cross section can be $A = 20,000 \text{ bn}$ for very low neutron energies, like 1 eV.

\[ \lambda = \frac{1240 \text{ MeV f m}}{\sqrt{2mc^2E_n}} \approx \frac{1240 \text{ f m}}{\sqrt{2 \cdot 938 \cdot 10^{-6}}} \]

\[ \lambda = 30,000 \text{ f m} \]

\[ A = \pi \lambda^2 = 2826 \cdot 10^4 \text{ bn} \]

In reality cross sections are not quite that large.
Neutron reactions

- Neutron elastic & inelastic scattering
  
  \[ n + ^{12}C \rightarrow n + ^{12}C \]
  
  \[ n + ^{12}C \rightarrow n + ^{12}C + 4.4 \text{ MeV} \gamma \]

- Neutron capture shows distinct resonances where the n is captures into excited nuclear states.
  
  \[ n + ^{235}U \rightarrow ^{236}U \rightarrow \text{fission} \]
The initial energy of neutrons released in fission is too high to efficiently fission additional $^{235}\text{U}$ nuclei. Thus the energy must be lowered ("moderated") a factor of $\sim 10^5$.
Neutron Moderation

- In fission: neutrons are emitted with energy = 1 - 2 MeV.
- They must be “moderated” to thermal energies to be absorbed.
- Use collisions with water or graphite surrounding the Uranium.
- Light (H₂O) and heavy (D₂O) water are the best moderators.
- But H₂O absorbs neutrons → not very good, D₂O is 100 times better, Graphite is next.
- Light and heavy water can also be used as a coolant, but not graphite.
- BNL heavy water- moderated HFBR research reactor:

The prototype of all modern research reactors.