Interaction theory – Neutrons

Lesson FYSKJM4710

Eirik Malinen

Sources:
F. H. Attix: Introduction to radiological physics and radiation dosimetry (ISBN 0-471-01146-0
P. Rinard: Neutron interactions with matter

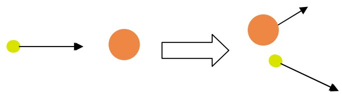
The neutron

- Uncharged particle, mass close to that of proton
- Unstable as free particle; disintegrates into a proton, an electron and an antineutrino ($t_{1/2}$=12 min)
- Do not interact with electrons
- Only nuclear interactions; complex cross sections
- Neutron attenuation similar to that for photons

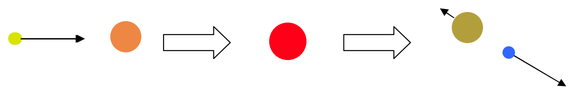
Neutron interactions

- Principally two types of interaction with matter:

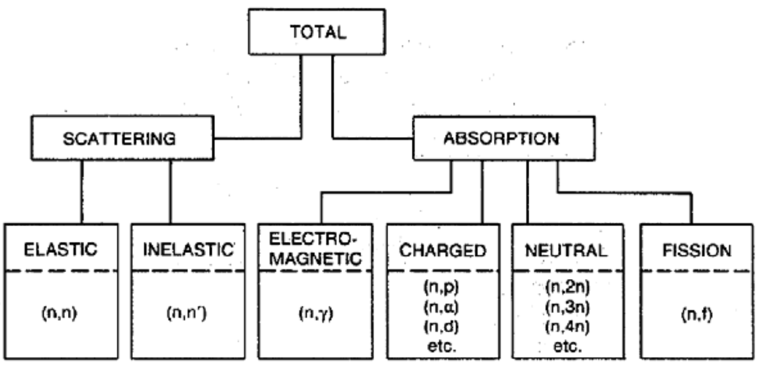
1. *Scattering*: Elastic
   Inelastic



2. *Absorption*: creation of compound nucleus, deexcitation yields p, α, fission products

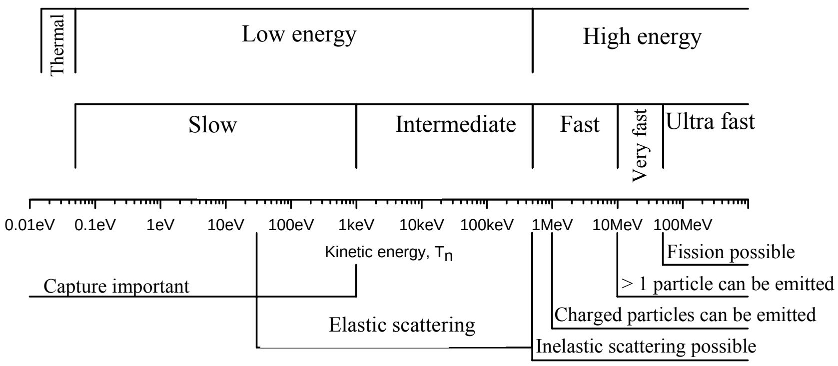


Interactions



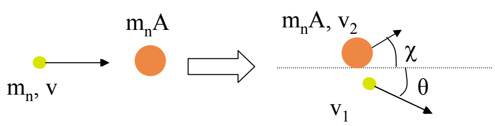
Interactions

- Cross section depends on: - Kinetic energy T_n
  - Nuclear structure



Neutron moderation 1

- Elastic scattering against nucleus – energy of neutron after scattering:



$$E_{max} = \frac{1}{2}(m_n A)v_{2,max}^2 = 4\frac{Am_n^2}{(m_n + Am_n)^2}T_0$$

$$= 4\frac{A}{(A+1)^2}T$$

- Hydrogen rich absorbers most effective

Neutron moderation 2

- It may be shown that, after *n* interactions, the *average* neutron energy is:

$$T_n = T_0\left[\frac{A^2+1}{(A+1)^2}\right]^n \qquad \Rightarrow n = \ln\left(\frac{T_n}{T_0}\right) \Big/ \ln\left[\frac{A^2+1}{(A+1)^2}\right]$$

Table 12-1. Average number of collisions required to reduce a neutron's energy from 2 MeV to 0.025 eV by elastic scattering

Element	Atomic Weight	Number of Collisions
Hydrogen	1	27
Deuterium	2	31
Helium	4	48
Beryllium	9	92
Carbon	12	119
Uranium	238	2175

Low energies, T_n < 500 keV

- "Potential" (1) and "resonance" (2) elastic scattering:

  1: Scattering on the nuclear 'surface'

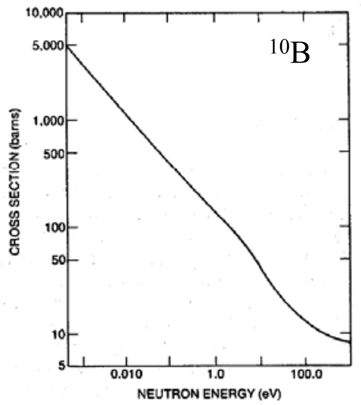
  2: Neutron absorbed, but reemitted

  For (1): virtually constant cross section

- At thermal energies, the neutron is captured and the compound nucleus deexcites via e.g. γ emission

  cross section ~ $1/v_n$

"1/v" cross section



Thermal neutrons

- For neutrons in thermal equilibrium with surroundings:

  T_n=kT=0.025 eV at T=293 K

  (k: Boltzman constant)

- ^{235}U has a high cross section for capture of thermal neutrons – gives fission

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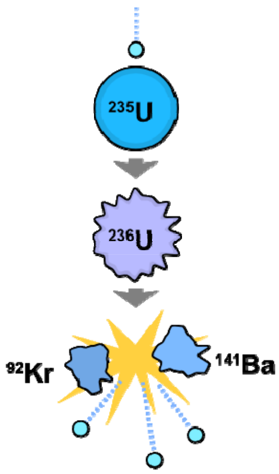
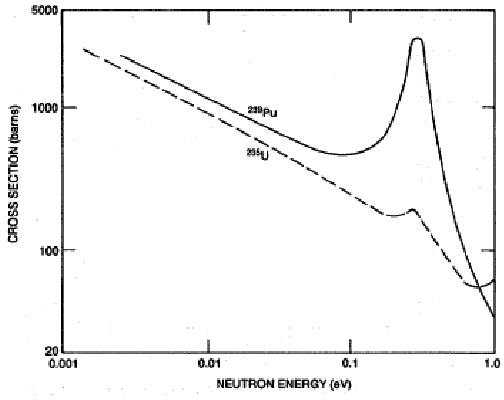
Fission



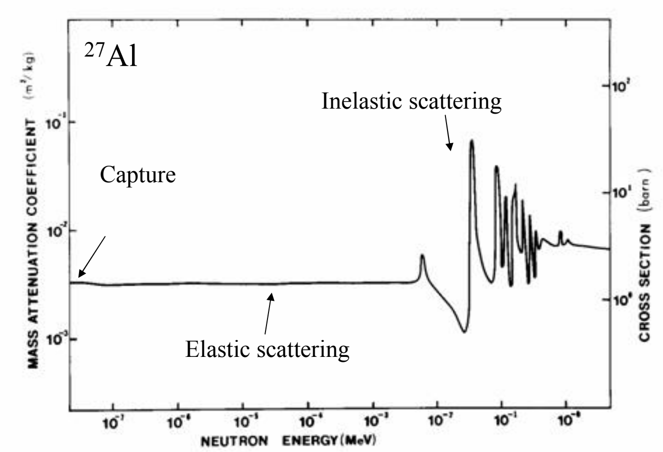


High energy neutrons, $T_n > 0.5$ MeV

- Inelastic: (n, nγ), threshold kinetic energy ~ 0.5 MeV
- Occurs at given energies: *resonances*
- Capture reacions: (n, p), (n, α)
- Emission of more than one particle:

  (n, np), (n, nα) (threshold ~ 10 MeV)
- Complicated cross sections

Cross section



Neutron attenuation

- For a thin neutron beam:

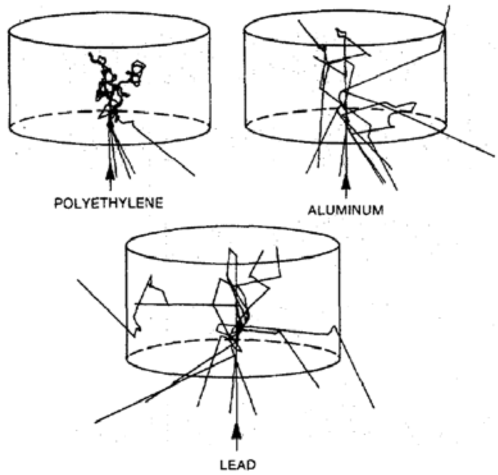
$$N = N_0 e^{-\mu x}$$

- μ is the attenuation coeffecient:

$$\mu = \rho \frac{N_A}{A} \sigma$$

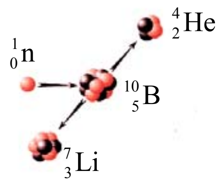
- Note: the cross section σ may show extreme variations over small energy range

Monte Carlo simulations

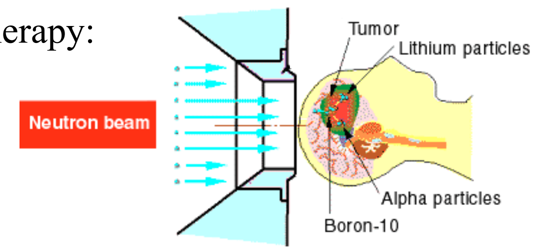


Boron neutron capture therapy

- Thermal neutrons are effeciently captured by ^{10}B
- Result is an unstable nucleus which desintegrates ^{7}Li og ^{4}He (+ kinetic energy and a photon)



- May be used for therapy:



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