Nuclear Physics and Astrophysics

PHY-302

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Lecture 14 - Neutron Physics

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Neutron Physics

Now switch attention to neutrons:
consider neutron applications in nuclear reactions & eg. crystallography
will help us to understand fission & fusion in next part of course

- The neutron plays special role in study of nuclear forces
- Unaffected by coulomb forces ⇒ can penetrate nucleus at low energy ~ 1eV
- Initiate nuclear reactions
- Neutrons are difficult to detect - no ionisation
- Neutrons are difficult to use in experiment - cant focus / accelerate

Understanding and controlling these aspects of neutron physics
is essential to the understanding of nuclear fission reactors

α-Beryllium source:

Major source of neutrons
^{9}Be has a loosley bound neutron
collision with 5-6 MeV α -particle can knock out neutron:

$$^{4}\mathrm{He} + {}^{9}\mathrm{Be} \rightarrow {}^{12}\mathrm{C} + n$$

neutron energy spectrum is very wide

Photoneutron Sources:

Similar to method above
produces ~ monoenergetic neutron source

$$\gamma + {}^{9}\mathrm{Be} \rightarrow {}^{8}\mathrm{Be} + n$$

Spontaneous Fission:

fission of isotopes eg. ^{252}Cf produces 4n / fission
neutrons energy range ~ 1-3 MeV

Nuclear Reactions:

Many nuclear reactions to choose from
require accelerator to produce particle beam to initiate reaction
neutrons can be tuned to be ~ monoenergetic

$$\text{e.g. } {}^{3}\mathrm{H} + d \rightarrow {}^{4}\mathrm{He} + n$$

Nuclear Reactors:

Neutron flux in fission reactor core is very high

Energy spectrum ~ 1-7 MeV

Most are reduced to thermal temps in reactor

Some fast neutrons remain

Can be extracted by cutting hole in reactor shielding into lab

Neutron Detectors

neutrons produce no ionisation

detectors must detect secondary events from neutron interactions:

- protons
- α-particles
- γ-rays
- fission products

Slow/thermal neutrons: detectors based on p^+ emission or α-emission signals

- ^{10}B often used: $^{10}B + n \rightarrow {}^{7}Li^{*} + \alpha$
- Use ionisation chamber filled with BF_3 gas or coated with B metal
- Similar devices use ^{6}Li, ^{3}He

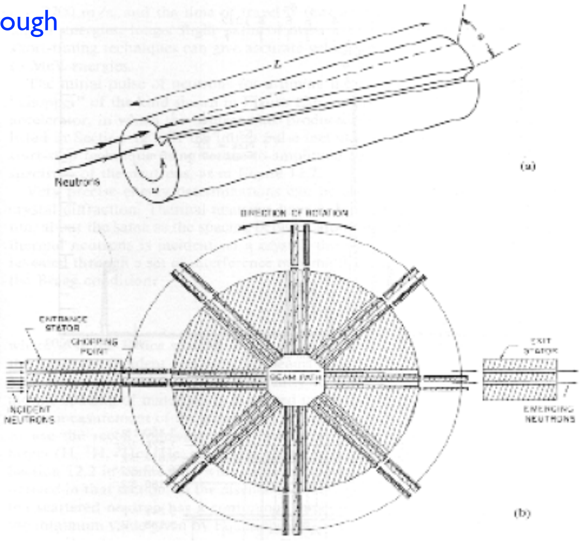
Neutron Velocity Selection

neutrons velocities can be selected by mechanical means

use rotating shutters made of Cd - high n absorption cross section

rotating shutters only allow n of specific vel to pass through

changing rotation speed, changes selection



Sources:

- neutron beams produced from variety of nuclear reactions
- impossible to accelerate them
- possible to slow them down - via collisions with atoms - **moderation**

fast	E ~ 100 keV - 10 MeV
slow	E ~ 1 keV
epithermal	E ~ 1 eV
thermal	E ~ 0.025 eV

Moderation:

As neutrons traverse matter many reactions occur

Fast neutrons react via:

- beta decay to proton	(n,p)
- α-emission in nuclear collision	(n,α)
- n-emission in nuclear collision	(n,3n)

Slow / thermal neutrons are mainly captured by nuclei

- neutron capture cross section usually dominated by one resonance

Consider neutron intensity loss traversing material thickness dx

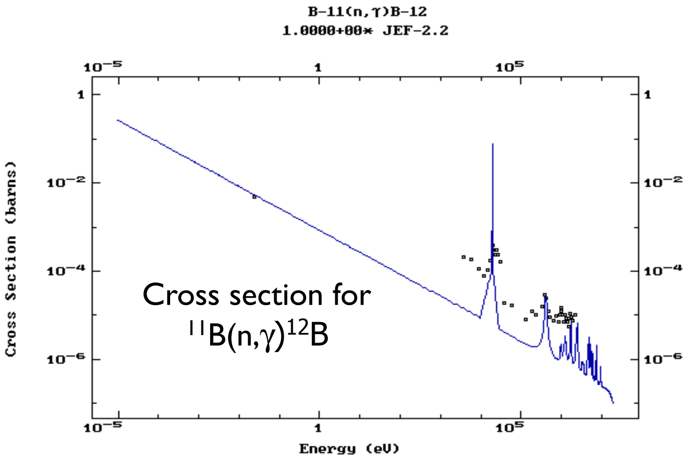
neutrons encounter ndx atoms per unit area n = #atoms per unit vol

σ_t is absorption cross section then intensity loss is

$$\mathrm{d}I = -I \cdot \sigma_t \cdot n \cdot \mathrm{d}x$$

$$I = I_0 e^{-\sigma_t n x}$$

Note: only accounts for neutrons at one energy



Cross section for ^{11}B(n,γ)^{12}B

Neutron Collisions

Elastic collision: neutron (energy E, velocity v) on atom (mass A)
E' is final neutron energy

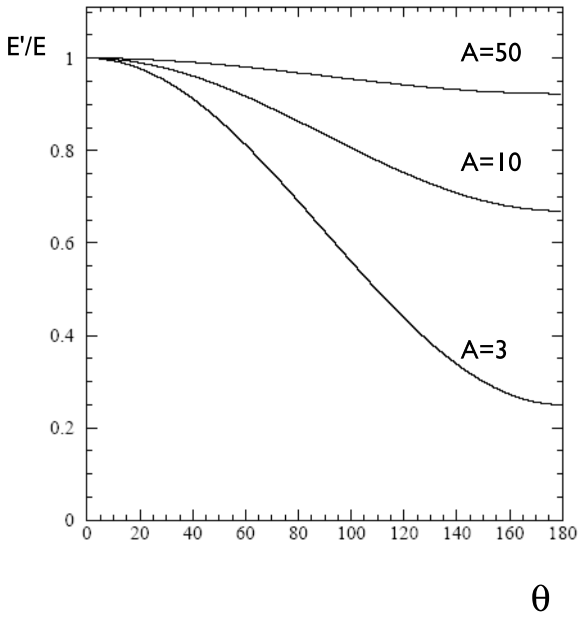
$$\frac{E'}{E} = \frac{A^2 + 1 + 2A\cos\theta}{(A+1)^2}$$

For θ=0 (no scattering) E=E' as expected
For A=1 (hydrogen target) E'=0

Maximum energy loss is for head-on collision

$$\left[\frac{E'}{E}\right]_{min} = \left(\frac{A-1}{A+1}\right)^2$$

Typically E'/E varies from 1 to min



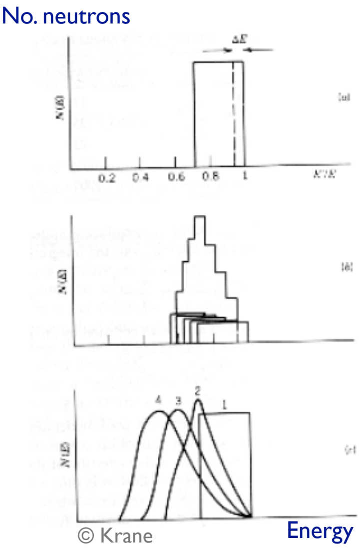
Neutron Collisions

For E < 10 MeV scattering is ~ indep of θ

For multiple collisions neutrons become increasingly less monoenergetic

In limit of infinte collisions energy spectrum of neutrons like Maxwell distribution

This is when neutron speed ~ thermal motion of atoms ⇔ thermal equilibrium !



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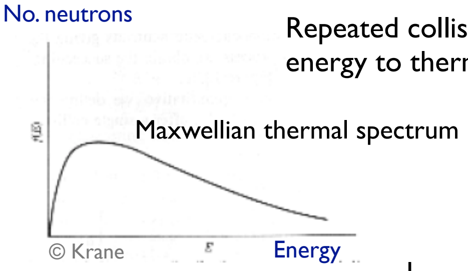

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Repeated collisions reduce neutron kinetic energy to thermal energy of medium

$$1 - \frac{E'}{E}$$

Nucleus	energy loss single collision	Collisions for thermalisation
Hydrogen-1	63%	18
Hydrogen-2	52%	25
Helium-4	35%	43
Carbon-12	15%	110
Uranium-238	0.8%	2200

Energy loss is largest for low A nuclei