Thermal Neutron Detection

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PHYS 575

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Neutrons

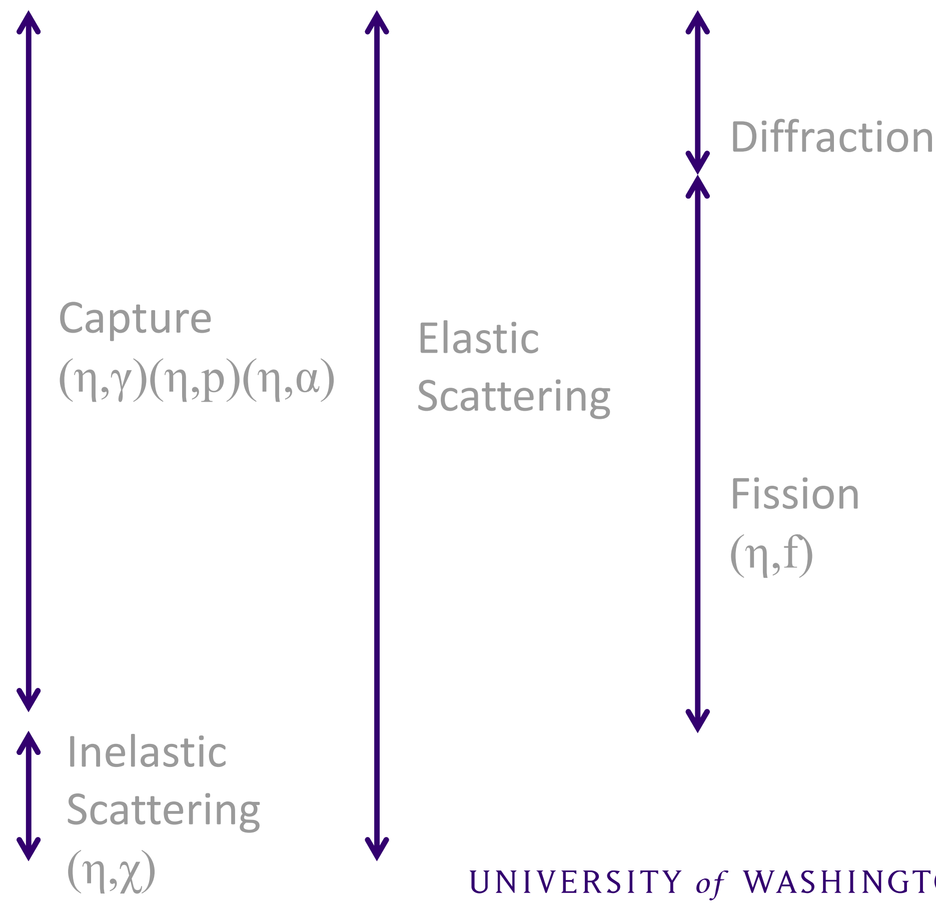
- 1932 – Chadwick discovered the neutron
- No charge, No Coulomb force, No Service!
  - Interaction with detectors
  - Interactions with nuclei
- ~10 min life time (free neutron)
- Sources
  - Nuclear Reactors, Spallation (accelerator based), Fusion sources (D-T), Radioactive decay (^{252}Cf, ^{250}Cm, ^{240}Pu)
- Applications
  - Nuclear, material science, imaging, medical physics

Fig 1. Chadwick (nobelprize.org)

Neutron Energy Ranges

< 0.005 eV	Cold
0.025 eV	Thermal
0.02 eV	Epithermal
1 – 10 eV	Slow
300 eV - 1 MeV	Intermediate
1 – 20 MeV	Fast
> 20 MeV	Ultra Fast

INTERACTIONS



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Interaction with Matter

Extremely weak electromagnetic interactions

Penetration through matter

Nuclear interactions only, low probability at that

Interaction is inversely proportional to energy

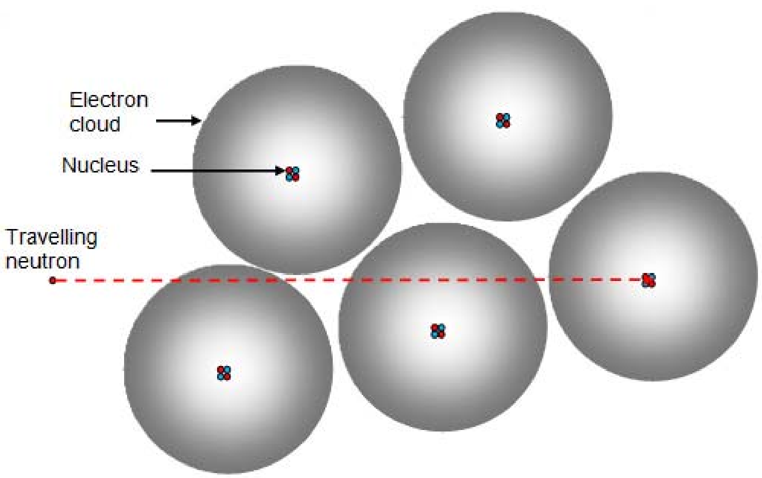

Fig 2. Neutron Interaction (explorcuriosity.org)

Radiation Protection

- Shielding is more complicated
- It's about probability, not density
- Atypical materials: paraffin, borated materials (concrete, water, polyethylene)

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Neutron Cross Section

- Cross section is measure of the probability for a reaction between particles
    - “Barn” has area dimensions (10^{-28} m^2)
    - Microscopic – probability of **reaction** between neutron and nucleus
    - Macroscopic – probability of **interaction** between neutron and material
- Typical reactions

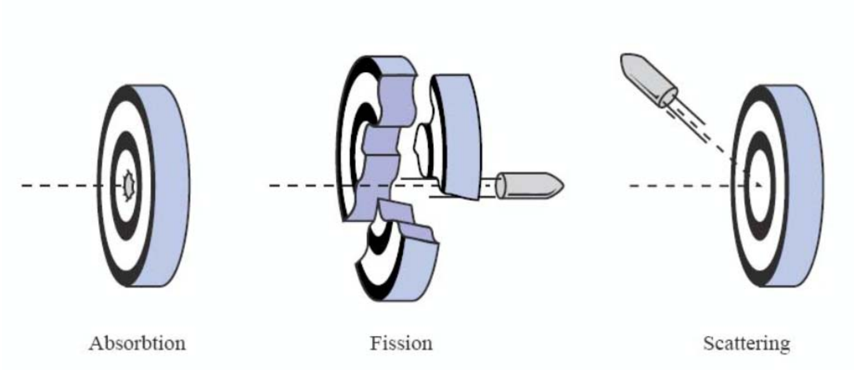

Fig 3. neutron reactions (nucleonica.net)

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Neutron Detection

Cross Section vs. Energy

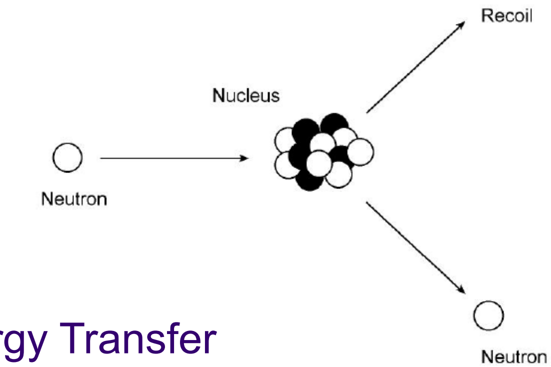
- Cross section goes down as energy increases so slow neutrons (thermal) have a vastly different detection scheme than fast neutrons
- Moderator material is used to slow neutrons down thereby generally increasing detection efficiency (to an extent…)
- Fast Neutron spectroscopy allows for detection to quantify incoming neutrons <u>and</u> deduction of incoming neutron energy.
- Thermal neutrons allow for greater chances of interaction, producing secondary (charged) particles.

Neutron Detection

Elastic Scattering

- Light nuclei scattering is most common method for fast neutron detection.
- Collision results in a recoil nucleus that (in the case of H) can transfer between 0-100% of incident neutron energy
- Recoil nucleus behaves like a proton or alpha particle for detection purposes

Fig 4. elastic scattering (www.hep.umn.edu)



Max Energy Transfer

Target Nucleus	A	E_R/E_N
^{1}H	1	1.0
^{2}H	2	0.89
^{3}He	3	0.75
^{4}He	4	0.64
^{12}C	12	0.28
^{16}O	16	0.22

Neutron Detection

Capture / Absorption

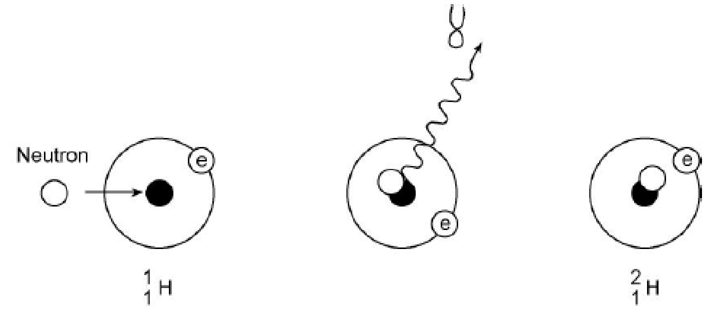


Fig 5. radiative capture (www.hep.umn.edu)

- Radiative capture – absorbs η, emits γ.
- Transmutation – absorbs η and emits p or
- Important for radiation protection and reactor physics
- Shielding/Attenuation/Moderation
  - Material to slow
  - Material to absorb
- E.g. Boron, Cadmium, Gadolinium

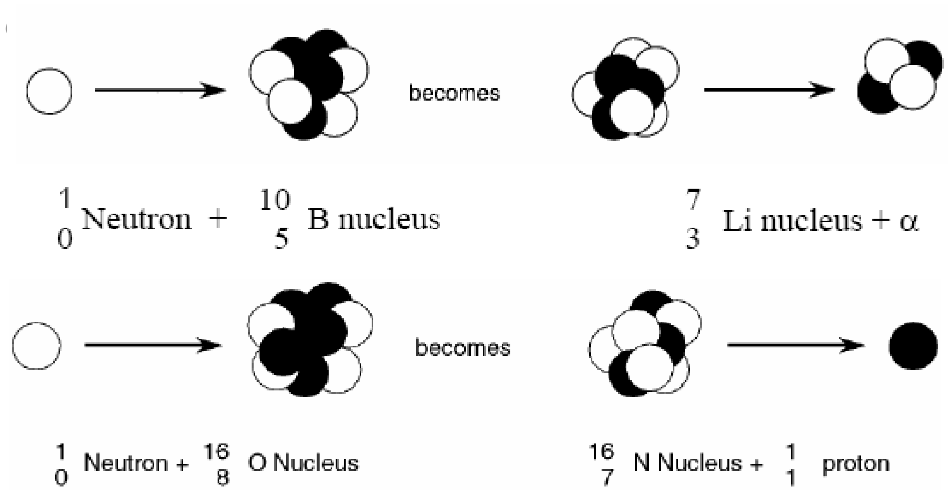


Fig 6. transmutation (www.hep.umn.edu)

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Why Thermal Neutrons?

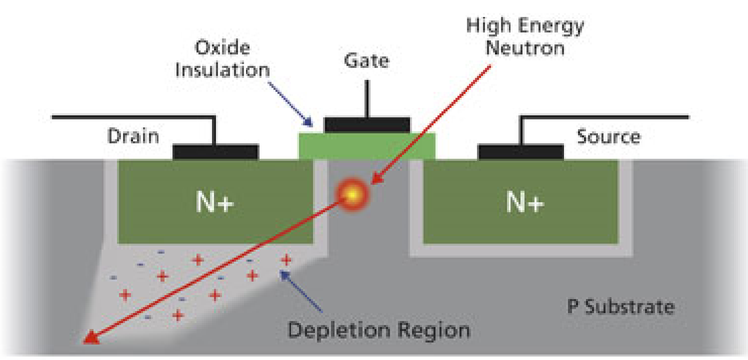


Fig 7. neutron induced upset (eetimes.com)

Single Event Effects Testing

- Cosmic and Atmospheric Neutrons
  - Primary radiation (100s of GeV for cosmic rays)
  - Spacecraft and high energy accelerator environments
  - LANSCE/WNR & TRIUMF (800 MeV & 500 MeV)

- Thermal to 14 MeV Neutrons
  - Produced by fission, fusion, and weapons
  - Borophosphosilicate glass (BPSG), SRAM FPGA

Safety First

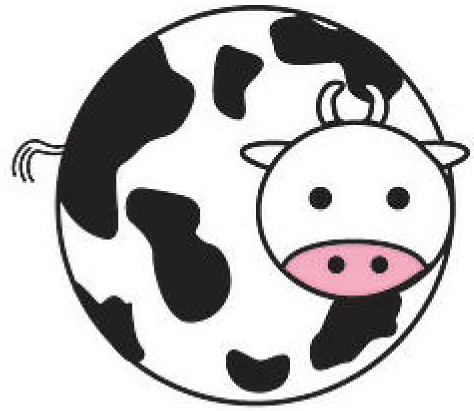
Radiation Protection

- People are excellent moderators!
  - Regulatory limits & Q factors for absorbed dose
  - Absorbed dose ➔ equivalent dose ➔effective dose

Type of Radiation	Quality Factor (W_R)
X-ray, gamma, beta	1
Alpha	20
Thermal neutrons (0.025 eV)	2
Fast Neutrons (1 – 20 MeV)	11-6.5

Fig 8. neutron meters (ludlums.com)

Thermal Neutron Detection



Spherical Cow

- Large cross section so the detector can be small
- Target material should be abundant and cheap
- Discriminate gamma from neutron radiation
- High Q-value
- Reaction products captured by the detector
  - Recoil nucleus, proton, alpha particle, fission fragments
- Nice clean full-energy peak

Thermal Neutron Detection

Reality

- ^{10}B (η,α) reaction
- ^{6}Li (η,α) reaction
- ^{3}He (η,p) reaction
- Neutron induced fission reactions

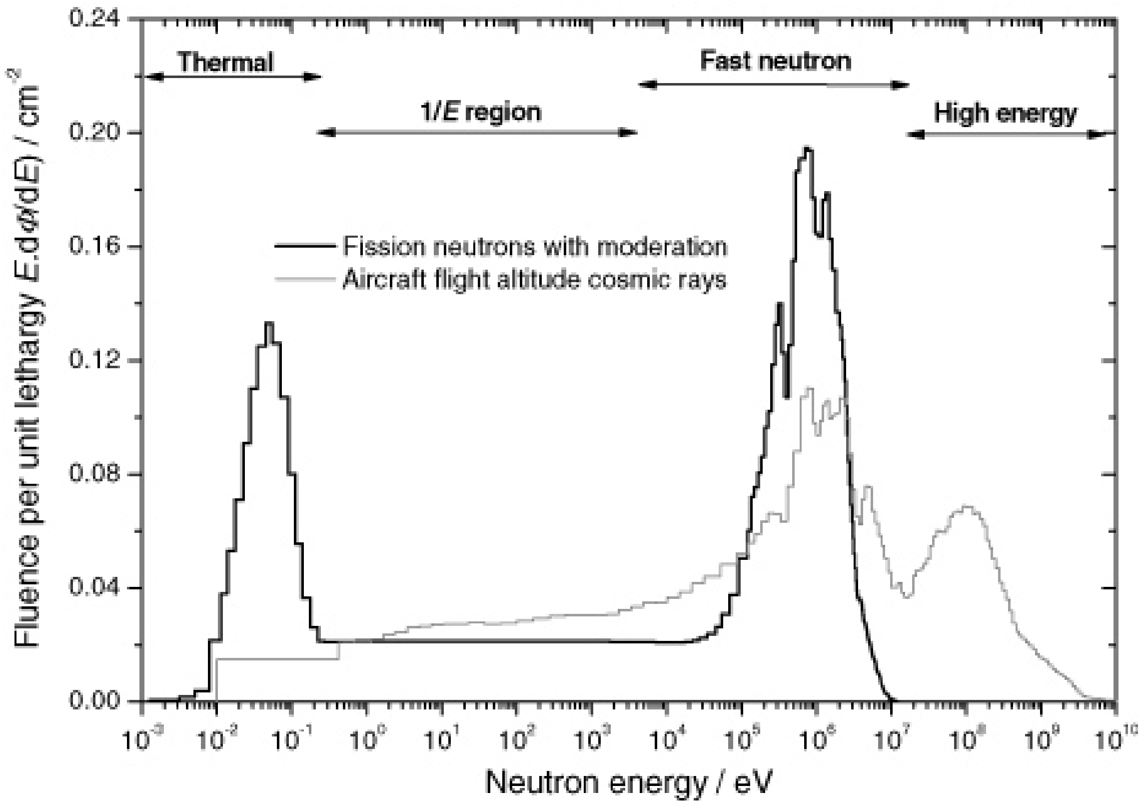


Fig 9. neutron energy (iopscience.iop.org)

References

[1] Dyer, C., Hands, A., Ford, K., Frydland, A., & Truscott, P.(2006). Neutron-Induced Single Event Effects Testing Across a Wide Range of Energies and Facilities and Implications for Standards. *IEEE Transactions on Nuclear Science*, 53(6), 3596-3601. doi:0.1109/TNS.2006.88627

[2] Knoll, G. (2010). *Radiation Detection and Measurement* (4th ed.). New York: Wiley.

[3] Shleien, B., Slaback, Jr., L., & Birky, B. K. (1998). *Handbook of Health Physics and Radiological Health* (3rd ed.). Maryland: Lippencott Williams & Wilkins

[4] Hamilton, D. (2006). Neutron Interactions with Matter. *European Commission Institute for Transuranium Elements*. Sept. 14, 2006