Chap. 14 – Slow Neutron Detection

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All neutron detection relies on observing a neutron-induced nuclear reaction.

The nuclear cross sections have a characteristic variation with energy:
•Charged particle reactions are dominated by the coulomb energy since both reaction partners have a positive charge: $\sigma(E) \sim \pi r^2 (1 - V/E)$ where "V" is the coulomb barrier.

•Neutron-induced reactions also have a characteristic shape .. The interaction is always attractive and the cross section for l=0 capture reactions always grows with 1/v at (very) low energies. The form is derived from the Breit-Wigner lineshape:

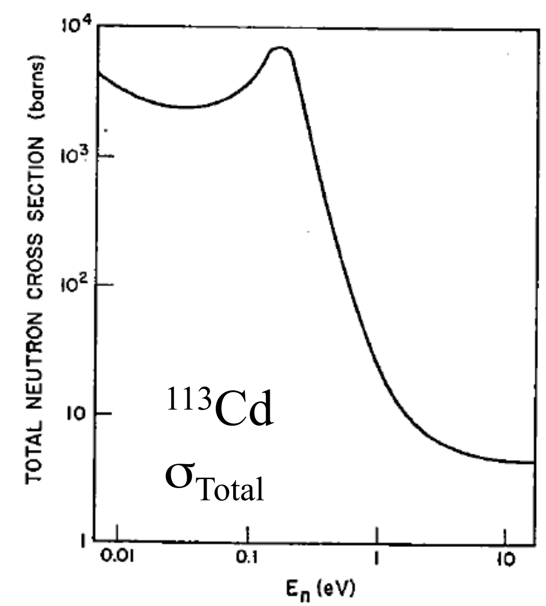
$$\sigma_{Cap} = \pi\lambda\!\!\!^{-2} \frac{\Gamma_n \Gamma_\gamma}{(\mathbf{E} - E_0)^2 + (\Gamma/2)^2}$$

$$\sigma_0 = \pi\lambda\!\!\!^{-2} \frac{4\Gamma_n \Gamma_\gamma}{\Gamma^2} \qquad \mathbf{E} = E_0; \Gamma = \Gamma_n + \Gamma_\gamma + \cdots \cong \Gamma_\gamma$$

$$\sigma_0 = 4\pi\lambda\!\!\!^{-2} \frac{\Gamma_n}{\Gamma_\gamma} \qquad \lambda\!\!\!^{-} = \frac{\hbar}{mv} \qquad \Gamma_n \sim v$$

$$\sigma_0 \sim \frac{1}{v}$$

$^{113}Cd + n \rightarrow {}^{114}Cd + \gamma$



‘Popular’ Slow Neutron Reactions

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n + ^{3}He → (^{4}He)* → p + ^{3}H , Q=0.765 MeV, target abundance = 1.4x10^{-4} %	(n,p)
n + ^{6}Li → (^{7}Li)* → ^{4}He + ^{3}H , Q=4.78 MeV, target abundance = 7.5%	(n,α)
n + ^{10}B → (^{11}B)* → ^{7}Li* + ^{4}He , Q=2.31 MeV, Branch=94%, target abundance = 19.9% → ^{7}Li + ^{4}He , Q=2.79 MeV, Branch=6%	(n,α)
n + ^{113}Cd → (^{114}Cd)* → ^{114}Cd + γ , Q~8 MeV , target abundance = 12.2% (21k barns)	(n,γ)
n + ^{157}Gd → (^{158}Gd)* → ^{158}Gd + γ , Q~8 MeV , target abundance = 15.6% (255k barns)	(n,γ)
n + ^{235}U → (^{236}U)* → (fission frags) Q~200MeV, TKE~160MeV, abundance = 0.72%	(n,f)

Check :

$$y = ax + b$$

$$Log\sigma = \left(\frac{\Delta x}{\Delta y}\right) Log E + b$$

$$\frac{\Delta x}{\Delta y} = -0.485 \quad \rightarrow \quad \sigma = E^{-0.485} \sim 1/\sqrt{E}$$

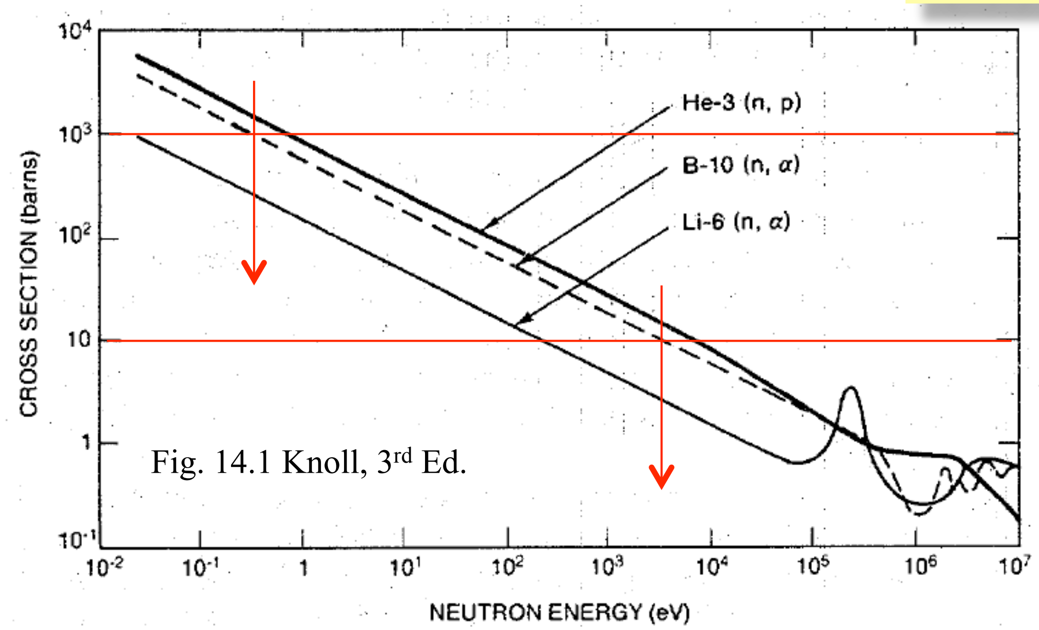
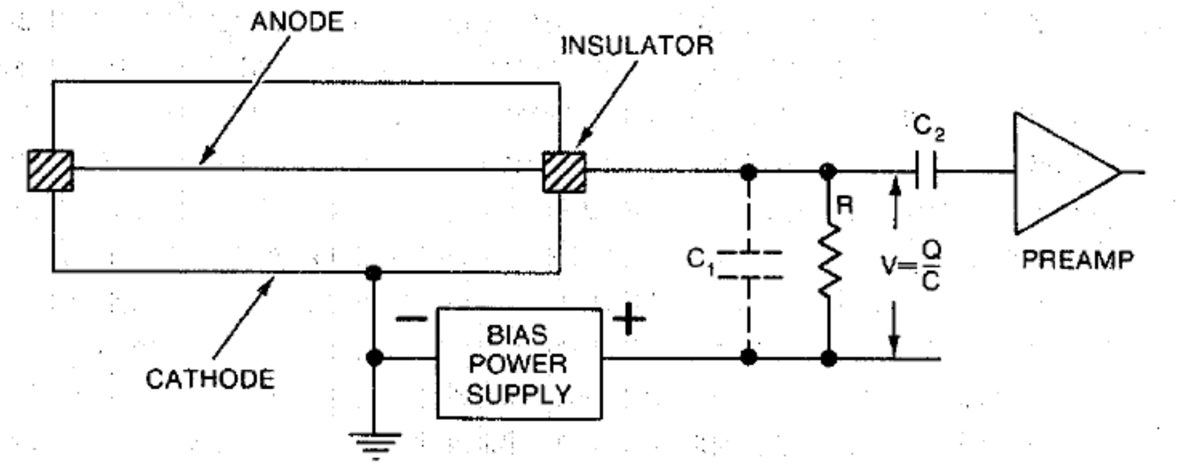


Fig. 14.1 Knoll, 3rd Ed.

Slow n Detection: Gas-filled counters

Gas-filled proportional counter .. usual gas-gain amplification on the central anode



n + ^{3}He → p + ^{3}H , Q=0.765 MeV σ ~ 5333 λ /1.8 barns

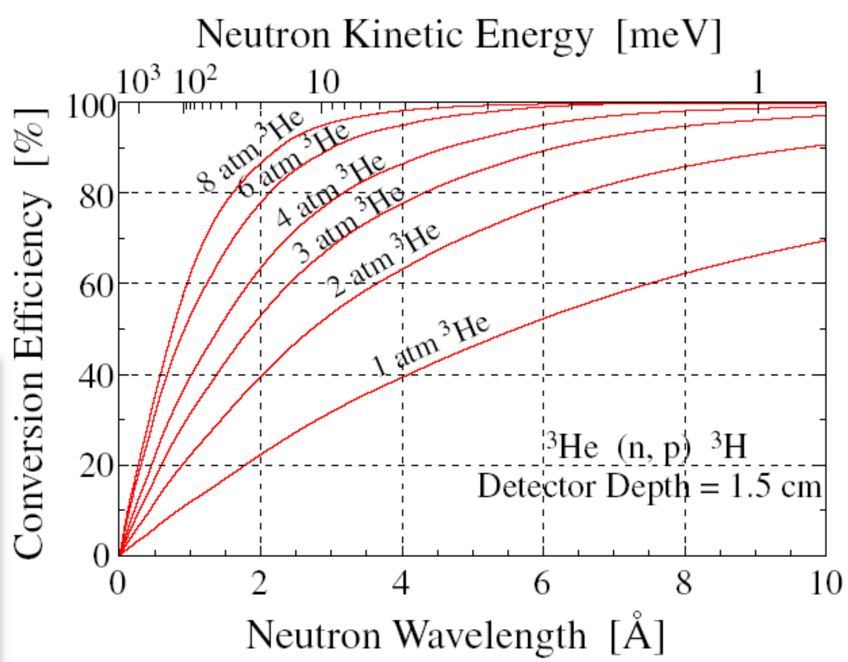
K.E. <eV ~0 → Q3/4 Q/4

0.573 0.191 MeV

Range in Si ~6μm ~5μm

Range in gas ~ 10^3 x Range in solid … few mm's

[N.B. (Rρ) ~ 0.25 mg/cm^2 for α in He gas]



What about the pulse-height distribution?

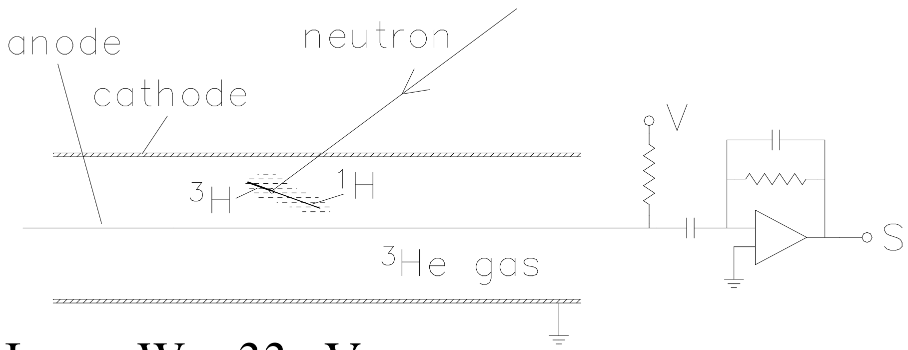
Reaction in gas volume:

→ both products range out -- full energy signal

Reaction elsewhere → ??

Slow n Detection: Gas-filled Pulse Height

n + ^{3}He → p (573 keV) + ^{3}H (191 keV)

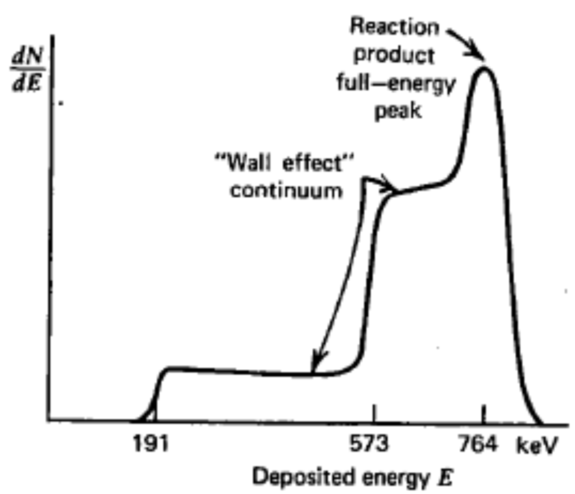


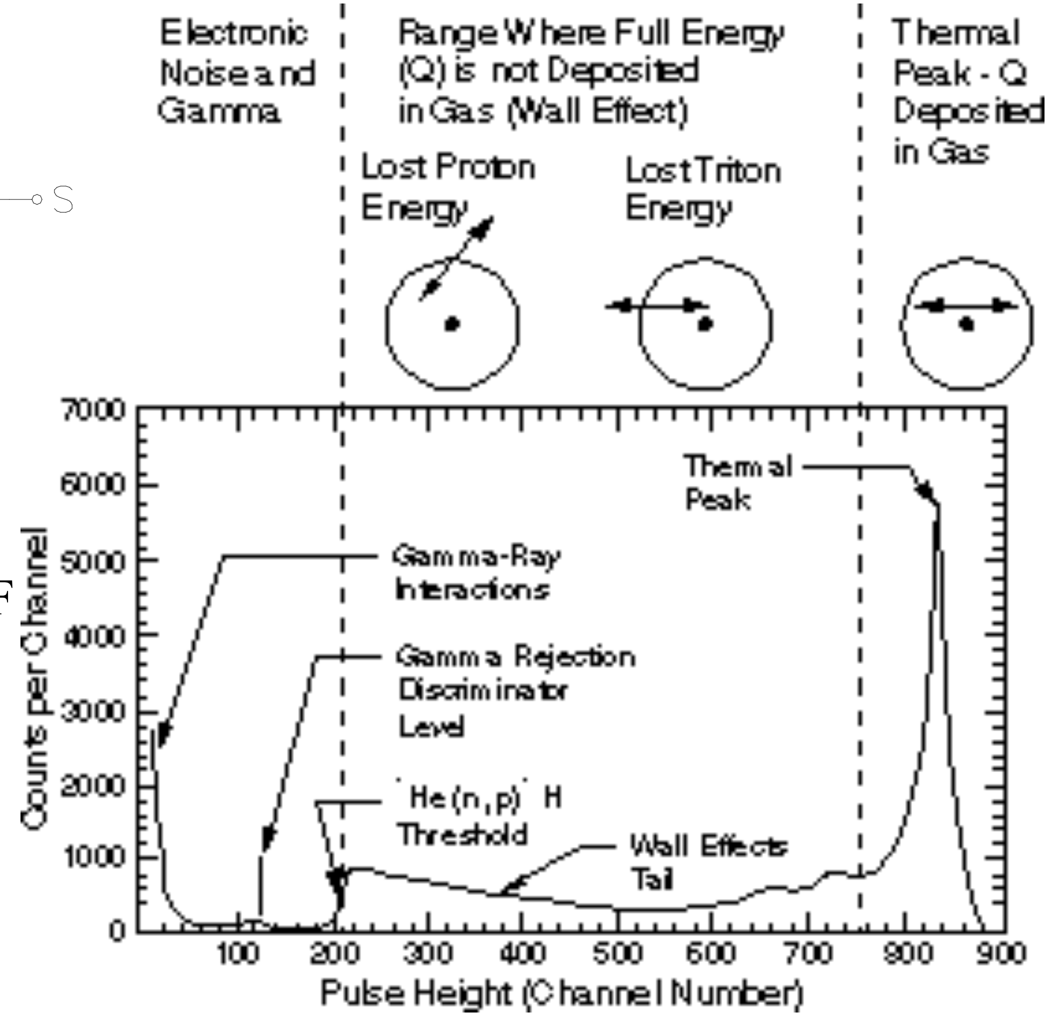
^{3}He gas W ~ 33 eV

Typical: 25mm diameter, 50μm anode

P = 5-10 bar (!)

V~ 1.5kV .. M ~ 20 .. C ~ 20pF





http://www.canberra.com/literature/936.asp

Fig. 14.5 Knoll, 3rd Ed.

Slow n Detection: BF_3

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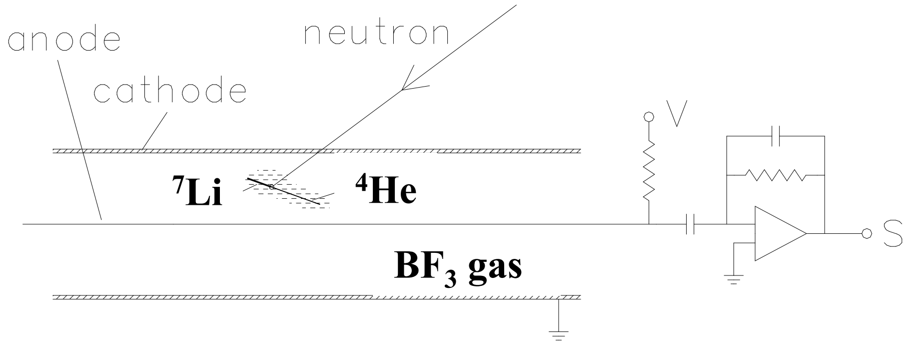


$n + {}^{10}B \rightarrow {}^{7}Li + {}^{4}He$, Q=2.8 MeV [7%]

$\rightarrow {}^{7}Li^{*} + {}^{4}He$, Q=2.3 MeV [93%]

(K.E. 0..84 1.47 MeV)

(R-air ~ 7.5mm)

$\rightarrow {}^{7}Li + \gamma$, E=0.477 MeV

BF_3 gas W ~ 33 eV, enriched to ~96%

Typical: 25mm diameter, 50μm anode

P = 400 – 700 Torr,

V~ 2.5kV .. M ~ 40

http://www.centronic.co.uk/products_detectors_boron.asp

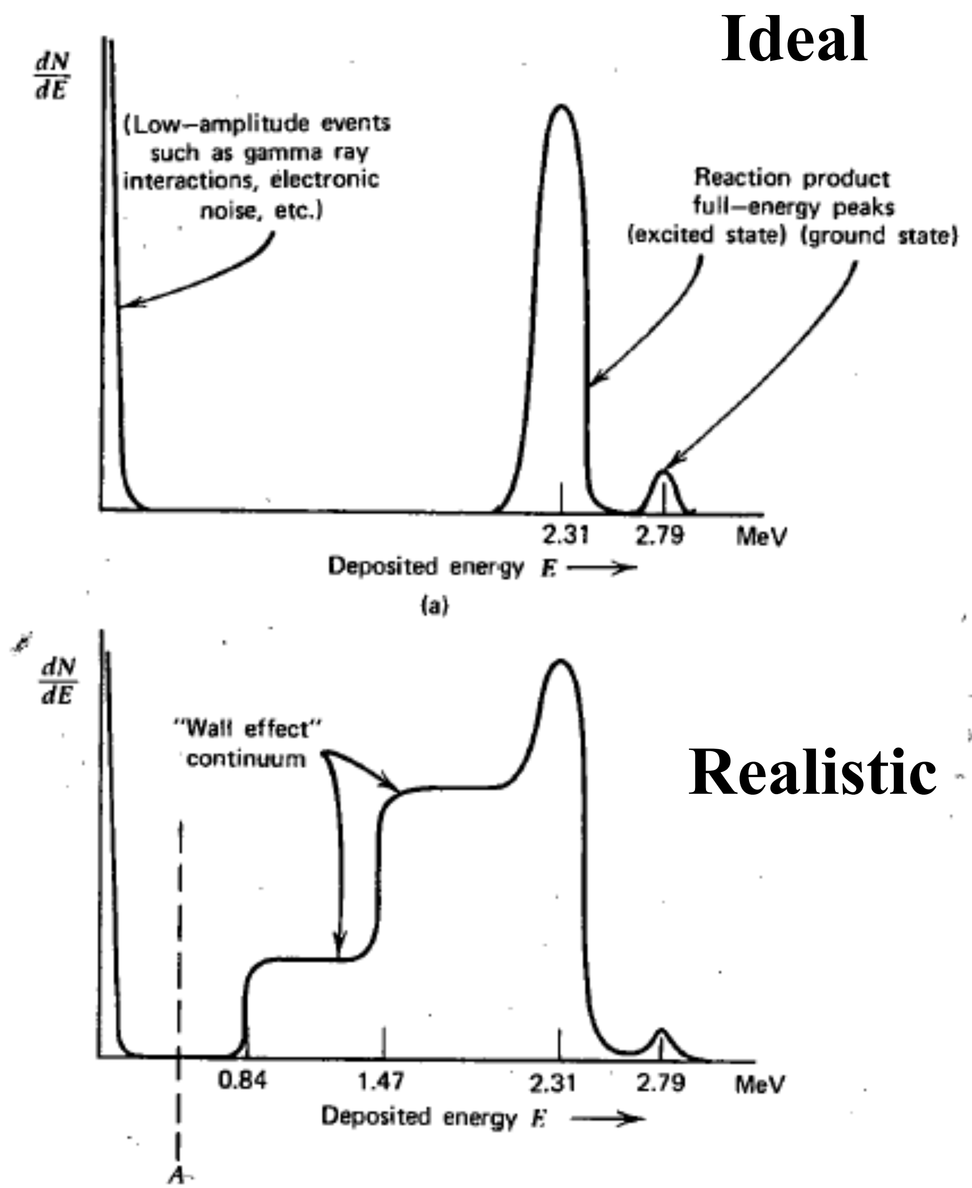
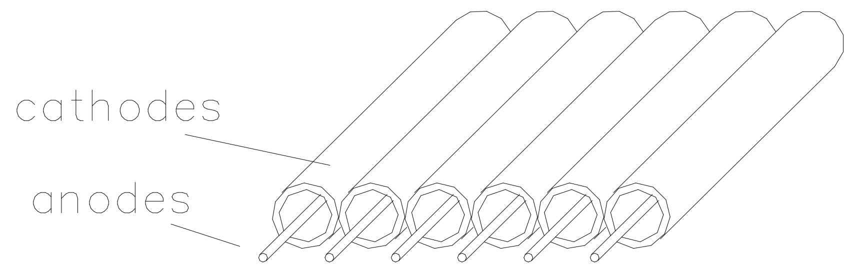
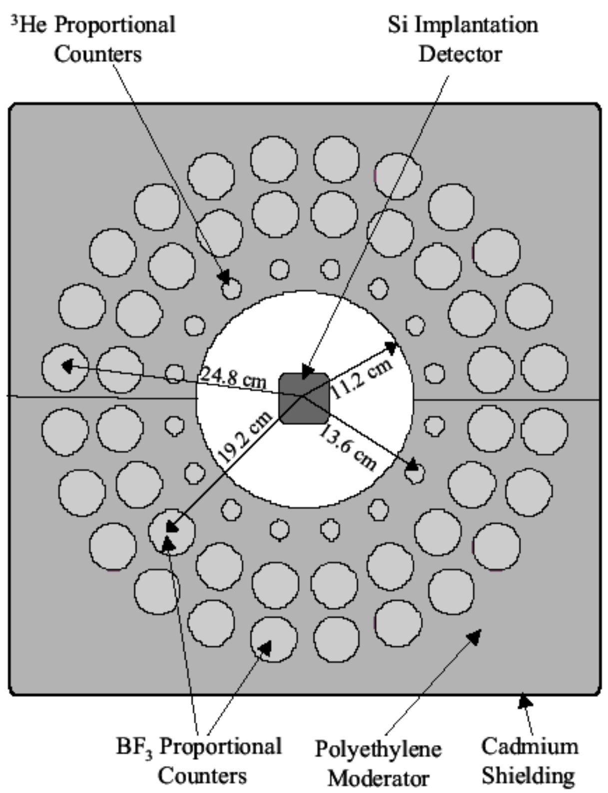


Fig. 14.3 Knoll, 3rd Ed.

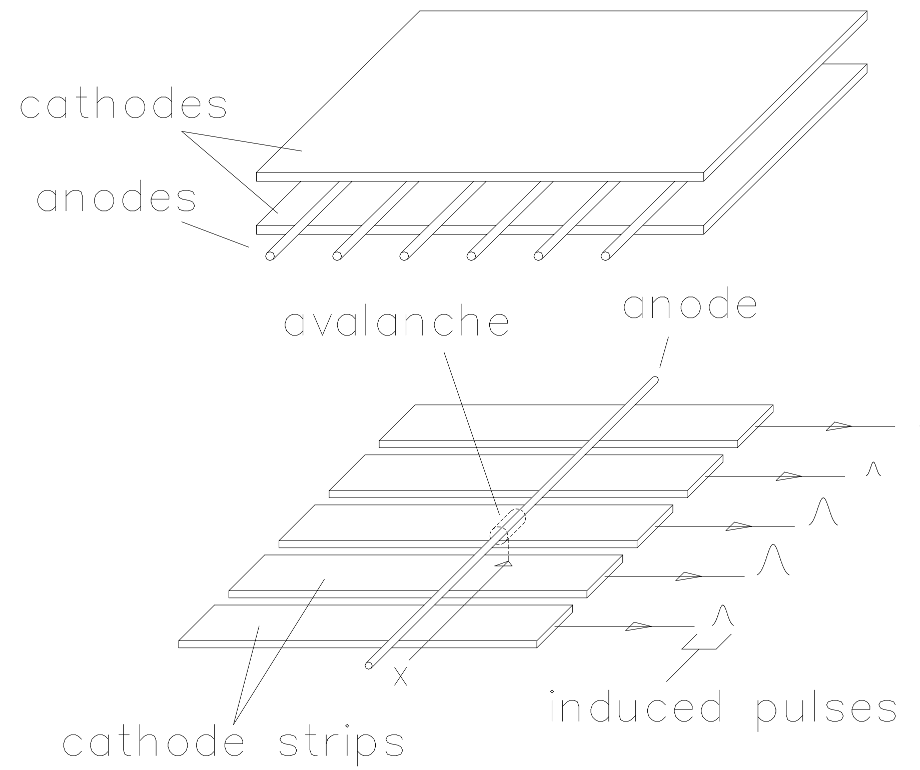
Multiple Gas Proportional Counters



High Efficiency



Position Sensitive



Slow n Detection: Fission Chambers

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n + ^{235}U → (^{236}U)* → (fission frags) Q~200MeV, TKE~160MeV, abundance = 0.72%

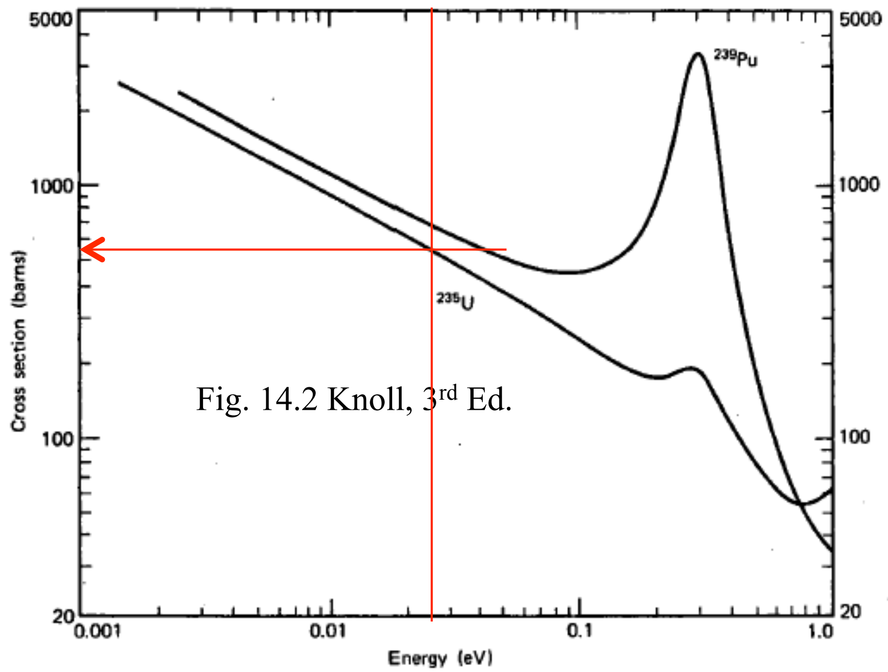
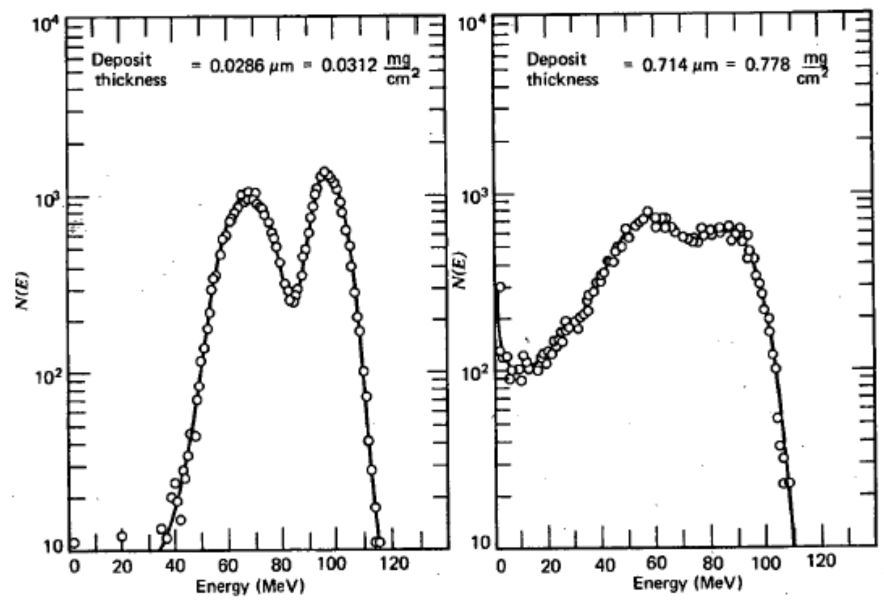


Fig. 14.2 Knoll, 3rd Ed.



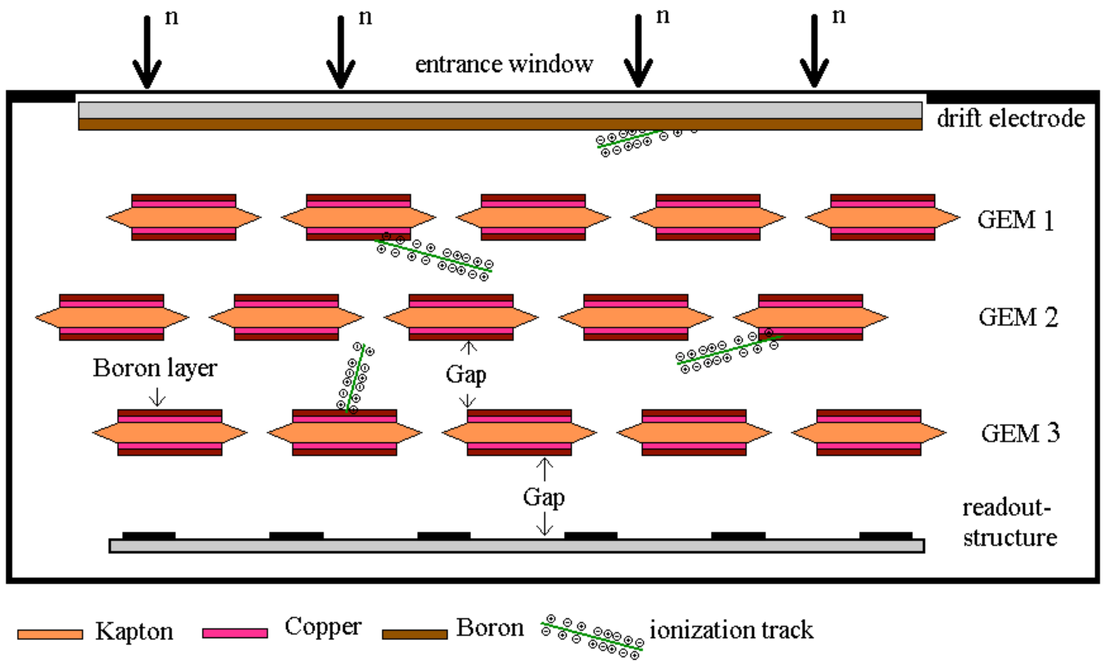
UO$_2$ deposit on wall
Fig. 14.7 Knoll, 3rd Ed.

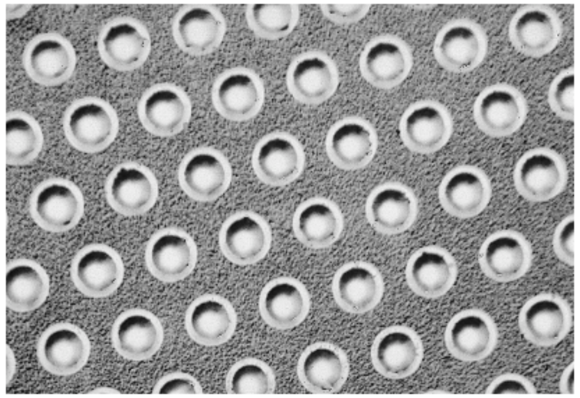
Absorption efficiency of all devices (from text):

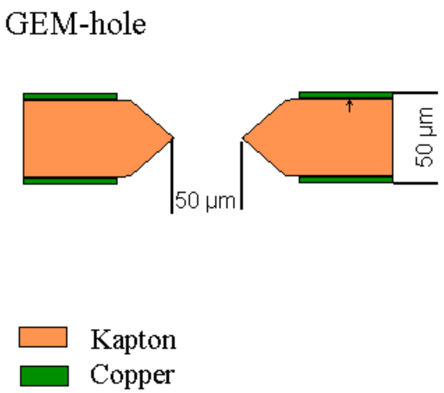
$$\varepsilon(E_n) = 1 - e^{-\Sigma(E)x} \; where \; \Sigma(E) = \rho_N \sigma(E)$$

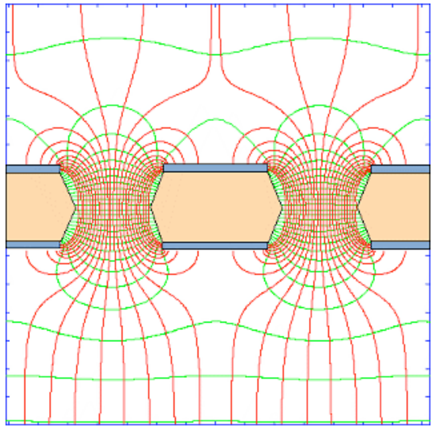
$$\varepsilon(E_n) \sim \rho_N \sigma(E) x \; f\,orsmall \; values$$

Boron-loaded GEM device









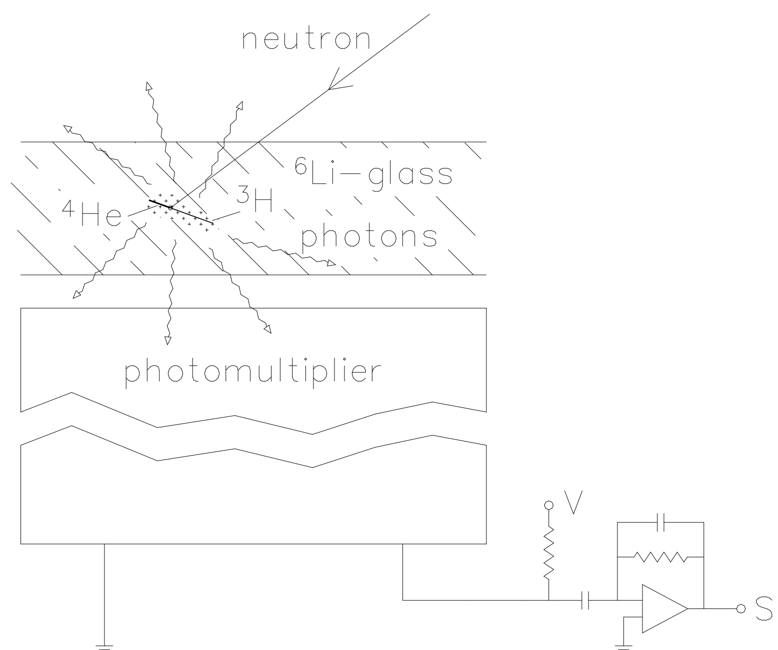
http://www.physi.uni-heidelberg.de/physi/cascade/konzept.html

Slow n Detection: lithium scintillators

Lithium loaded materials .. usual scintillation device with PMT for ToF

Li glass .. Scintillation efficiency ~ 0.45% 395nm, with ~ 7k photons/n
LiI (Eu) .. 2.8% 470 nm with ~51k photons/n

$n + {}^{6}Li \rightarrow {}^{4}He + {}^{3}H$, Q=4.79 MeV $\sigma \sim 940\ \lambda\ /1.8$ barns



Chap. 14 – Slow n Detection Question

Estimate the intrinsic efficiency and signal height from a fission chamber for thermal neutrons made up as follows: a ^{235}U coating of 1mg/cm^2 on the inside of a 1cm diameter tube with a 50μm central anode. The tube is filled with Ar/Methane (P-10) at 1 atm pressure and is operated at 1000V and has a (stray) capacitance of 50 pF.