Neutrons

1911 - Rutherford Model

1920 - $n = [p^+ + e^-]$ - neutron

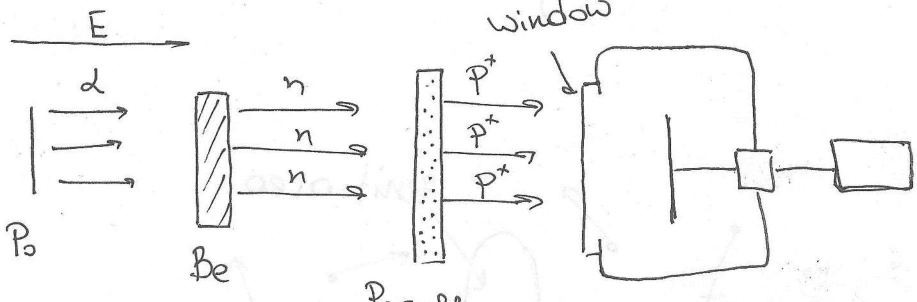
1931 - Walther Bothe + Herbert Becher:

α + Be, B, Li = ? unusually penetrating
γ ?

~~$^4_2He + ^6_3Li$~~ :

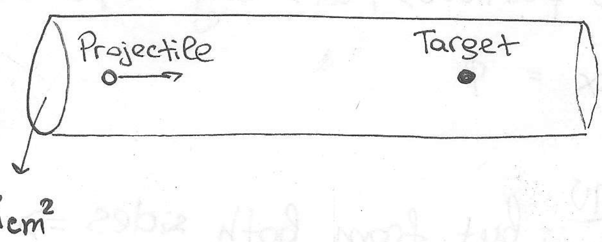
$$^9_4Be + ^4_2He \rightarrow (^{13}_6C) \rightarrow ^{12}_6C + ^1_0n$$

1932 - James Chadwick



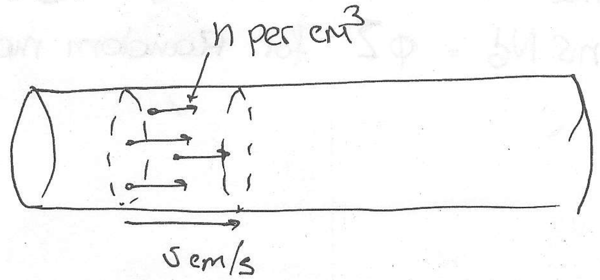
$$m(n) \approx m(p)$$

Chance of collision?

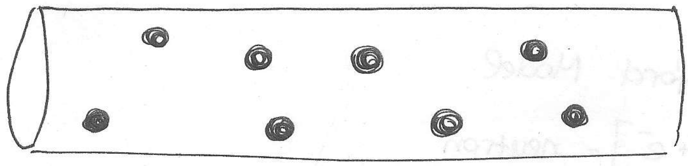


Exact trajectory is not specified...

$\sigma = \frac{S(target)}{S(tube)}$ - chace of collision/microscopic cross section



nv - number of moleculas, that cross square unit each second

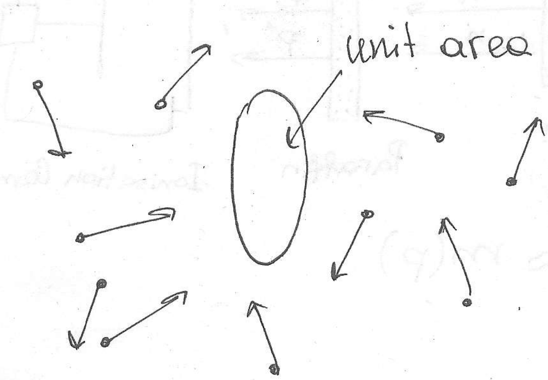


N targets σ each

$R = nvN\sigma$ - reaction rate per unit volume

Let $nv = j$ and $N\sigma = \Sigma$ (macroscopic cross section)

$$R = j\Sigma$$



Take only $\vec{v}$-particles, let's say n per volume

nv = flux = ϕ

density $= \frac{nv}{4}$, but from both sides $\Rightarrow$?

$$\frac{nv}{2}$$

Since we have many targets

$R = nvN\sigma = \phi\Sigma$ for Random motion

When a particle collides with a target nucleus, there is a certain chance of each of several reactions:

- elastic scattering (light elements)
- inelastic scattering
- absorbtion

$\sigma_s + \sigma_a = \sigma$ – total cross section (chance of collision)

$\bar{E} = 0{,}0253$ eV ⇒ calculate speed!

$v = \sqrt{\frac{2E}{m}} = 2200$ m/s as a gas!

$\phi = 2 \times 10^{12}$ $cm^{-2}s^{-1}$

$n = \frac{\varphi}{v} = \frac{2 \cdot 10^{12}}{2{,}2 \cdot 10^{5}} = 9 \cdot 10^{6}$ cm^{-3}

${}^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{236}_{92}U^{*}$

$\sigma_a = 681 \cdot 10^{-24}$ cm^2

$N = 0{,}048 \cdot 10^{24}$ cm^{-3}

$(\rho = 19{,}05 ; M = 235)$

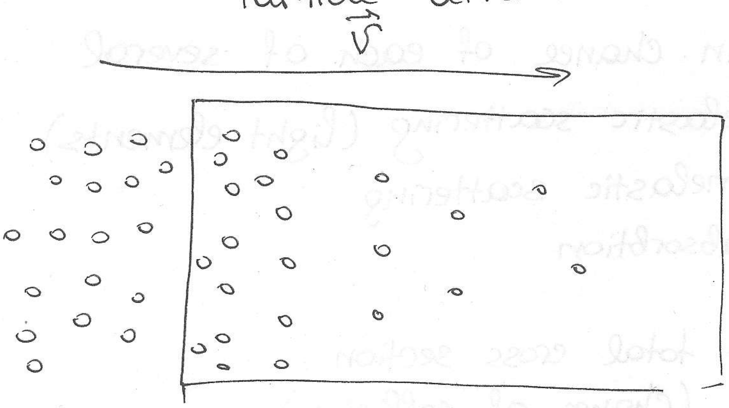
$\Sigma_a = N\sigma_a = 32{,}7$ cm^{-1}

$[barn] = 10^{-24}$ cm^2

$R = \phi \Sigma_a = 2 \cdot 10^{12} \cdot 32{,}7 = 6{,}54 \cdot 10^{13}$ $cm^{-3}s^{-1}$

The rate at which ${}^{235}U$ atoms are consumed.

Particle attenuation



z_0

density in z_0 = j_0

$j = j_0 e^{-\Sigma z}$ - not having collisions

$z_H = \frac{0{,}693}{\Sigma}$ - half-thickness

λ - free path $= \frac{1}{\Sigma}$ - averge distance before collision

$E_{(n)} = 1\ eV$

$\sigma_s = 20$ barn - dominant process

$N_H = 0{,}0668 \times 10^{24}\ cm^{-3}$ ✓ $\qquad N = \frac{\rho \cdot N_A}{M}$

$\sigma_s = 20 \cdot 10^{-24}$

$\Sigma_s =$ ~~1,342 cm~~ ? 1,2 cm^{-1} ? 1,342 $\qquad \Sigma_s = N\sigma_a$

$\lambda_s \approx 0{,}75\ cm$ $\qquad \lambda = 1/\Sigma$

Нет потока как в тот раз

Сам?

N_H не сошлось

$N = \frac{1 \cdot 6022 \cdot 10^{23}}{18} \approx 0{,}3$

$N(H) \approx 0{,}6 \cdot 10^{23}$

$\Sigma_s = N \cdot \sigma_a = 0{,}6 \cdot 20 \cdot 10^{-24} \cdot 10^{23} = 1{,}2\ cm^{-1}$

$\lambda_s = \frac{1}{\Sigma} = \frac{1}{1{,}2} \approx 0{,}83\ cm$

$z_H = \frac{0{,}693}{1{,}2} =$

May tell it earlier

?

Neutron temperature

0 - 0,025 eV	Cold neutrons
0,025 eV	Thermal neutrons
0,025 - 0,4 eV	Epithermal neutrons
0,4 - 0,6 eV	Cadmium neutrons
0,6 - 1 eV	Epicadmium
1 - 10 eV	Slow
10 - ~~300~~ 10 keV eV	Resonance
~~0,3~~ 10 keV - 1 MeV	Intermediate
1 - 20 MeV	Fast
> 20 MeV	Ultrafast

Fission

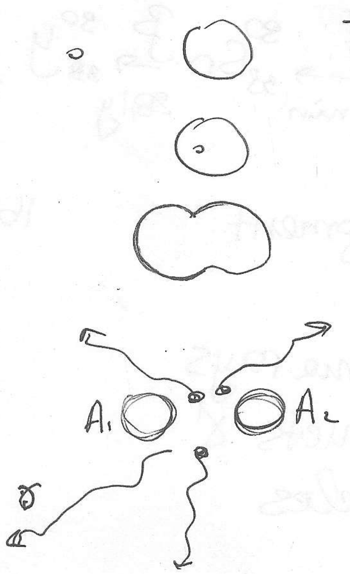
Normally $${}^{A_1}_{Z_1}M + {}^{1}_{0}n \rightarrow {}^{A+1}_{Z}M^{*} \rightarrow {}^{A+1}_{Z}M + \gamma$$

$${}^{235}_{92}U + {}^{1}_{0}n \rightarrow \left({}^{236}_{92}U\right)^{*}$$

235,04392 + 1,008665 = 236,052588 Mev

$M({}^{236}U)$ = 236,045562 Δ = 0,007026 = 6,54 MeV

~~+ Ek(n) !!!~~



ν - number of released neutrons

for ^{235}U $\nu = 2.42$

Prompt neutons - are released instantly

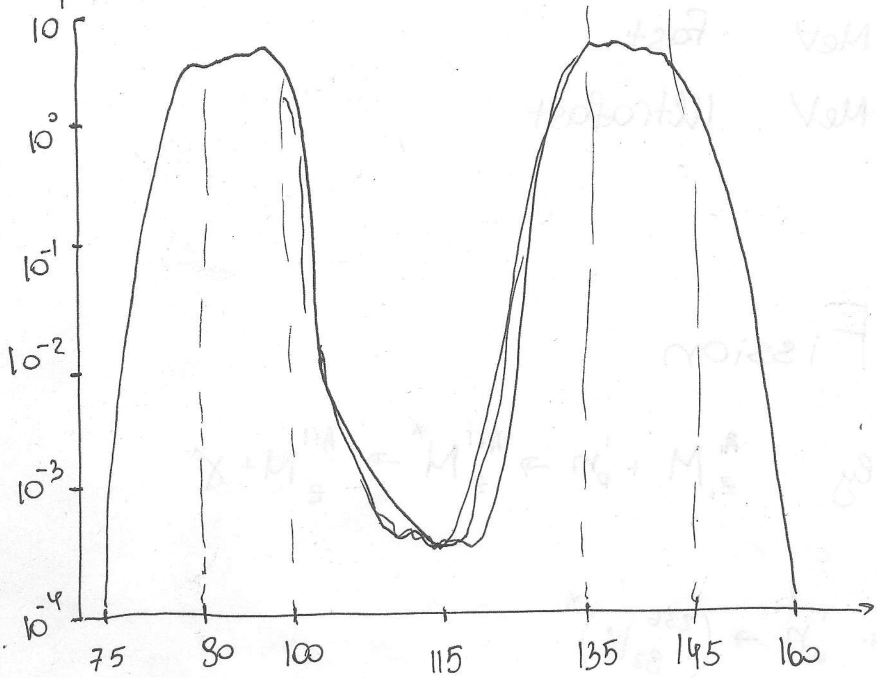
delayed neutons - released by products (0,65%)

$$^{235}_{92}U + ^1_0n = ^{A_1}_{Z_1}F_1 + ^{A_2}_{Z_2}F_2 + \nu ^1_0 n + \text{energy}$$

$$^{90}_{36}Kr + ^{144}_{56}Ba$$

75 - 160 are observed

~200 MeV



↑

fission products

$$^{90}_{36}Kr \xrightarrow[32.3s]{\beta^-} ^{90}_{37}Rb \xrightarrow[2,6min]{\beta^-} ^{90}_{38}Sr \xrightarrow[28,1y]{\beta^-} ^{90}_{39}Y \xrightarrow[2.67d]{\beta^-} ^{90}_{40}Zr$$

Fission fragment	166 MeV
Neutrons	5 MeV
Prompt gamma rays	7 MeV
Fission products γ	7 MeV
Beta particles	5 MeV
Neutrinos	10 MeV