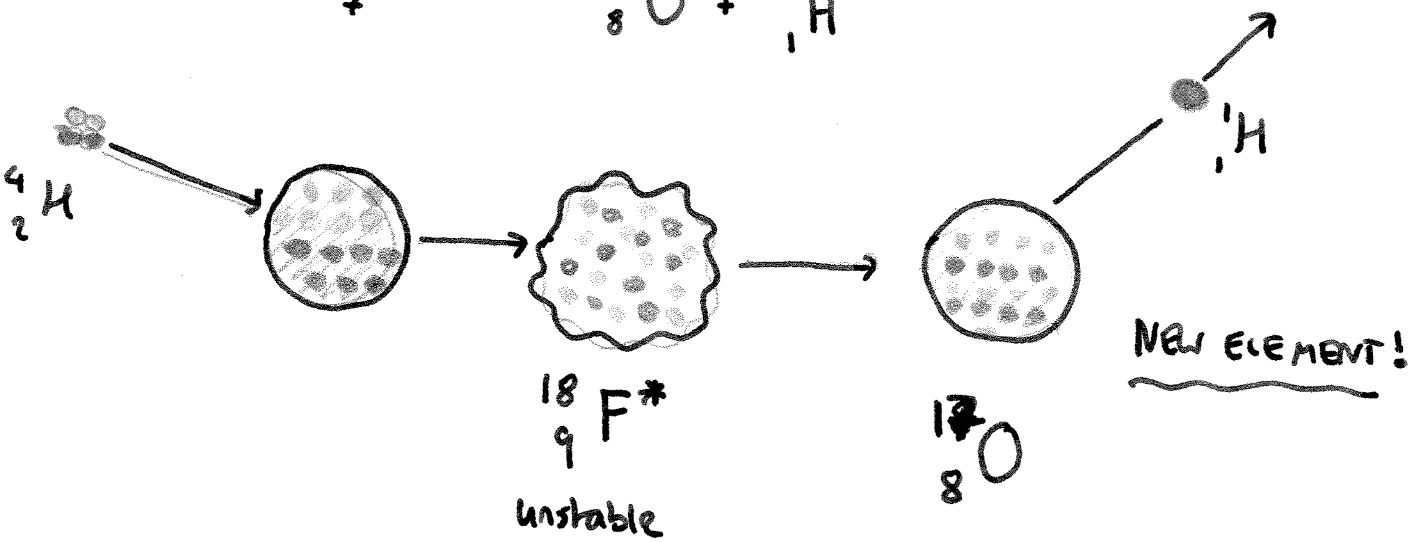
L21 NUCLEAR REACTIONS ; FISSION

For centuries chemists, magicians and scientists dreamt of converting lead into gold – this was the great quest of "alchemy". Nuclear reactions are the modern form of alchemy — and it is even possible to convert lead into gold via nuclear reactions. It is said that in 1972 Russian scientists found the shielding of their reactor in Lake Baikal in Siberia had turned to gold. How?

Nuclear Reactions

By colliding high energy particles into nucleii one can produce a nuclear reaction. e.g

$$^{4}_{2}He + ^{14}_{7}N \longrightarrow ^{17}_{8}O + ^{1}_{1}H$$



- $A_1 + A_2 = A_3 + A_4$ $\quad (4 + 14 = 17 + 1)$
- $Z_1 + Z_2 = Z_3 + Z_4$ $\quad (2 + 7 = 8 + 1)$
- $Q = (m_1 + m_2 - m_3 - m_4)c^2$ (reaction energy)

$Q > 0$ K.E increases — EXOTHERMAL

$Q < 0$ K.E decreases. — ENDOTHERMAL.

e.g ^{7}Li bombarded by a proton to give two α particles
What is the reaction energy

$$^{1}_{1}H + ^{7}_{3}Li \rightarrow ^{4}_{2}He + ^{4}_{2}He$$

1: $^{1}_{1}H$	1.007825 u		3: $^{4}_{2}He$	4.002603 u
2: $^{7}_{3}Li$	7.016004 u		4: $^{4}_{2}He$	4.002603 u
	8.023829 u			8.005206 u

$$M_1 + M_2 - M_3 - M_4 = 0.018623\,u$$

$$Q = (0.018623\,u) \times (931.5\,MeV/u) = 17.35\,MeV.$$

$${}^{4}_{2}He + {}^{9}_{4}Be \longrightarrow {}^{12}_{6}C + n$$

CHADWICK, 1932.
Discovery of neutron.

${}^{4}_{2}He$	4.002603	${}^{12}_{6}C$:	12.00000
${}^{9}_{4}Be$	9.012182	${}^{1}_{0}n$:	1.008665
	13.014785		13.008665

$$Q = (0.00612) \times 931.5\,\text{MeV/u} = \underline{\underline{5.7\ \text{MeV}}}$$

reverse reaction

$$n + {}^{12}_{6}C \longrightarrow {}^{4}_{2}He + {}^{9}_{4}Be$$

has $Q = -5.7\ \text{MeV}$ $\boxed{K_{cm} > 5.7\,\text{MeV}}$

$$\boxed{K_{cm} = \frac{M}{M+m} K} \qquad \therefore \quad K > \frac{13}{12} \times 5.7 = \underline{6.175\ \text{MeV}}$$

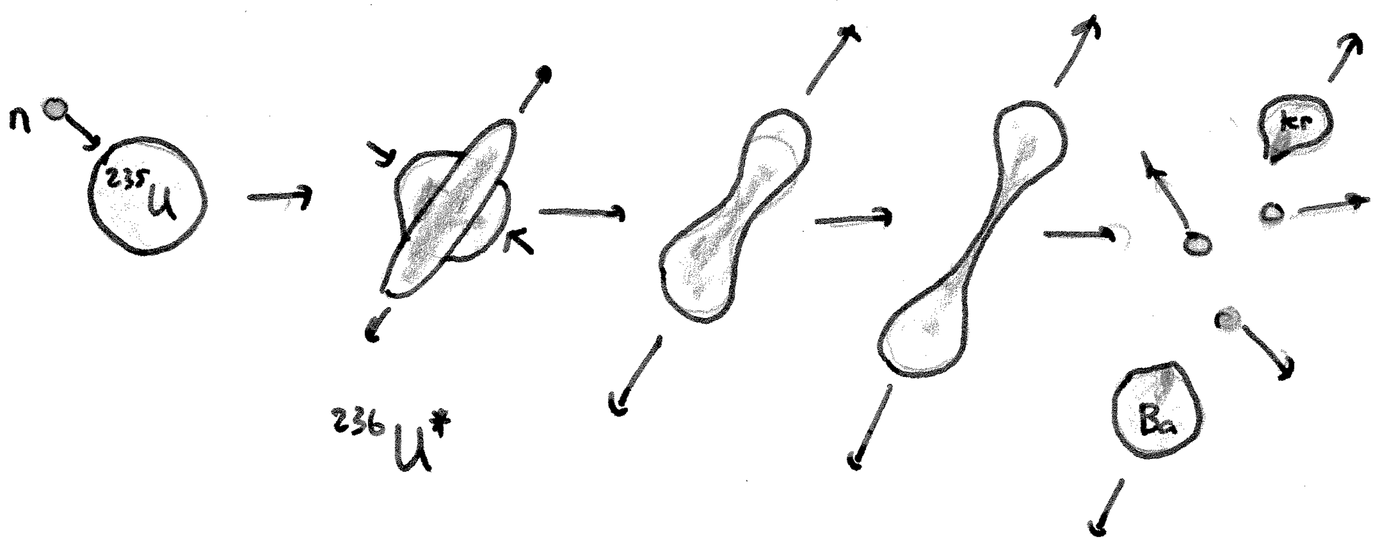
43.7 FISSION

Predicted by LISE MEITNER. Expt Otto Hahn + Fritz Strassman

1938

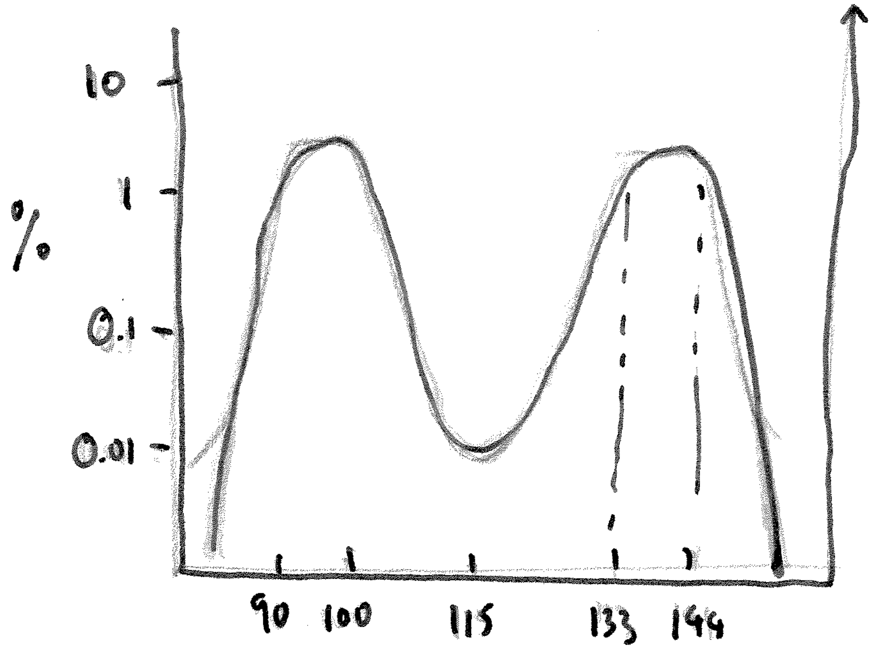
Example of neutron absorption

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{236}_{92}U^* \rightarrow \begin{cases} ^{144}_{56}Ba + ^{89}_{36}Kr + 3\,^{1}_{0}n \\ ^{140}_{54}Xe + ^{94}_{38}Sr + 2\,^{1}_{0}n \end{cases}$$

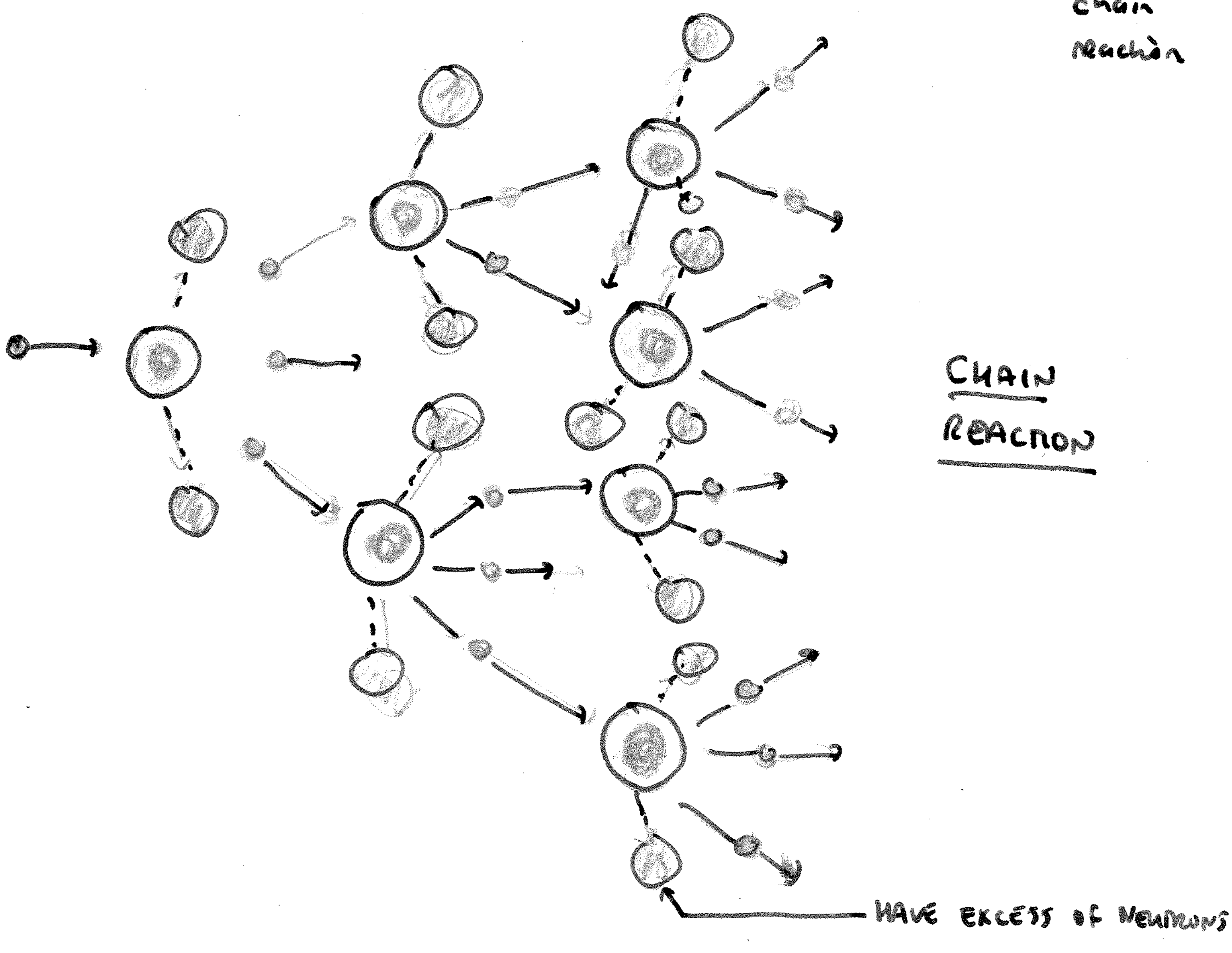


$\Delta B/\text{nucleon} \sim 8.5 - 7.6 = 0.9\,\text{MeV}$

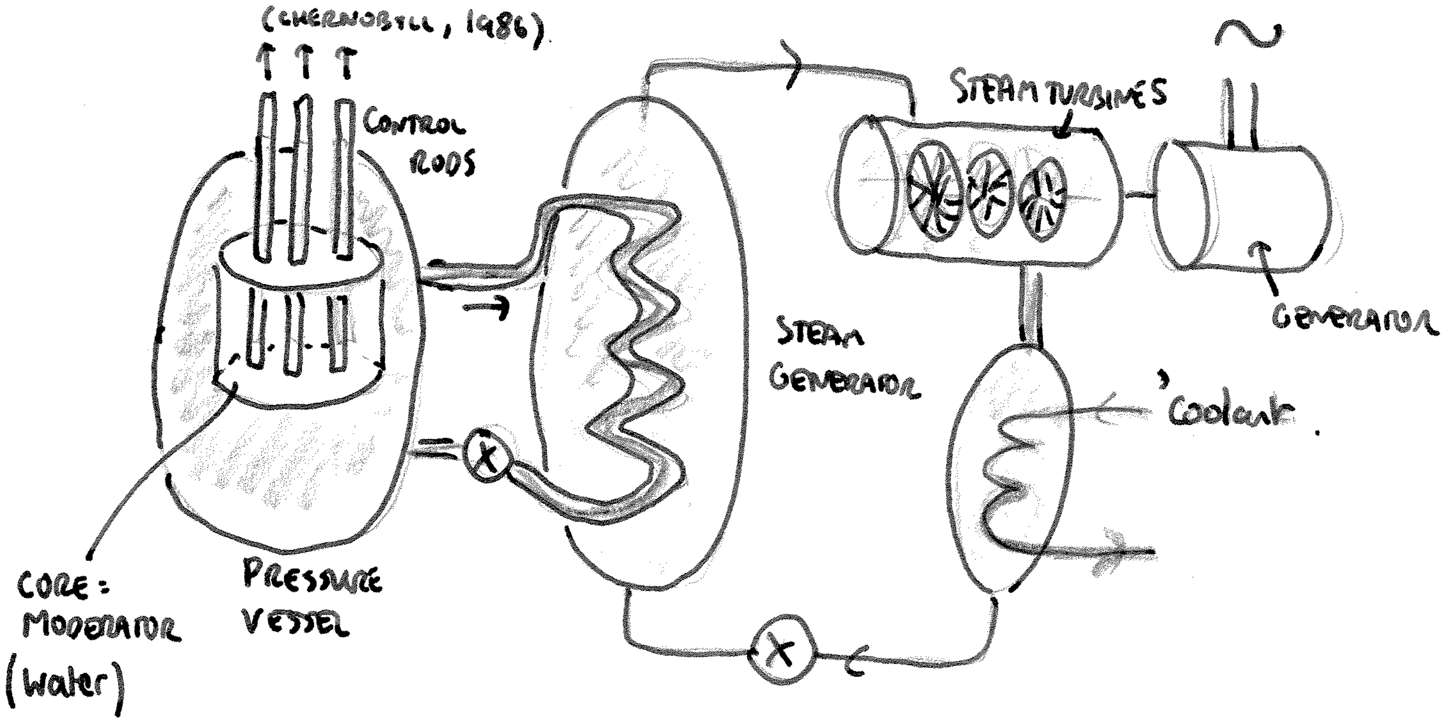
$Q \approx 235 \times 0.9 \simeq \underline{200\ \text{MeV}}$ /nucleon.



On average ~ 2.5 neutrons / decay ⟹ $40\% = \frac{1}{2.5} \times 100$ reqd for chain reaction



NUCLEAR REACTORS



Efficiency ~ 1/3rd. (Governed by efficiency $< \left(1 - \frac{T_{LOW}}{T_{HIGH}}\right)$).

Decay fragments undergo BETA DECAY.

$$^{140}_{55}Xe \xrightarrow{\beta^-} {}^{140}_{56}Cs \xrightarrow{\beta^-} {}^{140}_{56}Ba \longrightarrow {}^{140}_{57}La \longrightarrow {}^{140}_{58}Ce$$

Continues even when fission has ceased. ~ 15% power.

Without cooling water ⟶ MELT DOWN. (NEARLY OCCURRED 3 mile Island, 1979).

e.g. Calculate Mass of ^{235}U/day reqd for 3000 MW of power

200 MeV / ^{235}U atom.

$$200\,MeV \times (1.6\times10^{-13}\,J/MeV) = 3.2\times10^{-11}\,J$$

Each second, 3000 MJ $= 3\times10^{9}$ J

$$\frac{3\times10^{9}}{3.2\times10^{-11}} = 9.4\times10^{19} \text{ decays / second.}$$

$$9.4\times10^{19} \times 235 \times (1.66\times10^{-27}\,kg/u) = 3.9\times10^{-25}\,kg \times 9.4\times10^{19}$$

$$= 3.7\times10^{-5}\,kg$$

$$\equiv 37\,mg.$$

Per day

$$\#\,kg = 3.7\times10^{-5} \times 86{,}400\,s = 3.2\,kg$$