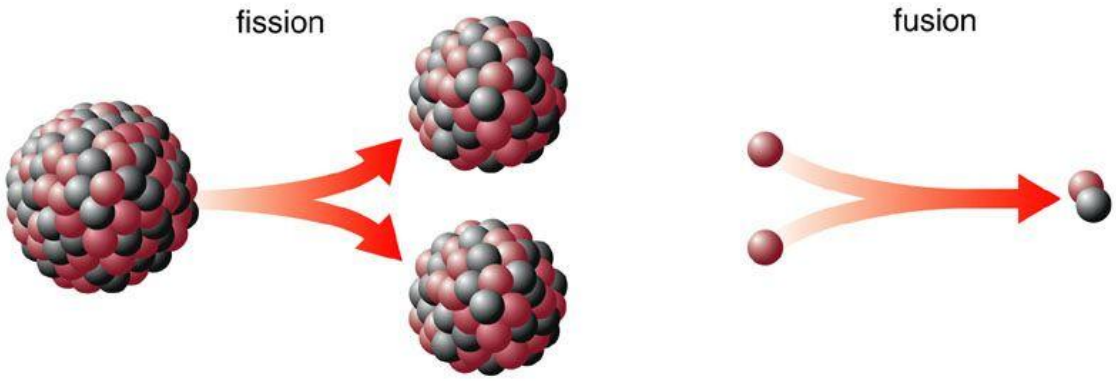

Fission and Fusion

IB PHYSICS | UNIT 7.2 | ATOMIC PHYSICS

IB Physics Data Booklet

Fundamental constants

Quantity	Symbol	Approximate value
Speed of light in vacuum	c	$3.00 \times 10^{8}\,\mathrm{m\,s^{-1}}$
Planck's constant	h	$6.63 \times 10^{-34}\,\mathrm{J\,s}$
Elementary charge	e	$1.60 \times 10^{-19}\,\mathrm{C}$
Electron rest mass	m_e	$9.110 \times 10^{-31}\,\mathrm{kg} = 0.000549\,\mathrm{u} = 0.511\,\mathrm{MeV\,c^{-2}}$
Proton rest mass	m_p	$1.673 \times 10^{-27}\,\mathrm{kg} = 1.007276\,\mathrm{u} = 938\,\mathrm{MeV\,c^{-2}}$
Neutron rest mass	m_n	$1.675 \times 10^{-27}\,\mathrm{kg} = 1.008665\,\mathrm{u} = 940\,\mathrm{MeV\,c^{-2}}$
Unified atomic mass unit	u	$1.661 \times 10^{-27}\,\mathrm{kg} = 931.5\,\mathrm{MeV\,c^{-2}}$
Solar constant	S	$1.36 \times 10^{3}\,\mathrm{W\,m^{-2}}$
Fermi radius	R_0	$1.20 \times 10^{-15}\,\mathrm{m}$

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Sample IB Questions

22. The binding energy per nucleon of a $^{3}_{1}H$ nucleus is 3 MeV. What is the minimum energy needed to completely separate the nucleons of $^{3}_{1}H$?

A. 12 MeV

B. 9 MeV

C. 6 MeV

D. 3 MeV

23. The difference between the mass of a $^{12}_{6}C$ nucleus and the sum of the masses of the individual nucleons is 0.1 u. Which of the following is approximately the binding energy of the nucleus?

A. 90 MeV

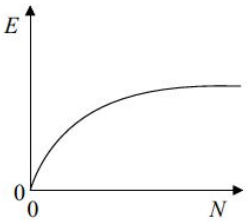
B. 90 MeV c^{-2}

C. 8 MeV

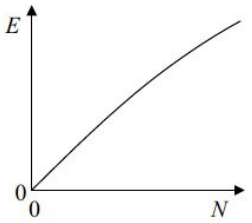
D. 8 MeV c^{-2}

24. Which of the following graphs best shows the variation with nucleon number N of the binding energy per nucleon E?

A.



B.



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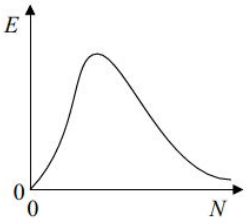
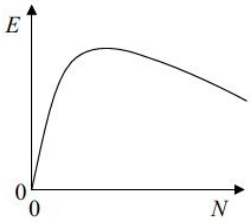


D.



Sample IB Questions

22. The binding energy per nucleon of a ${}^{3}_{1}\mathrm{H}$ nucleus is 3 MeV. What is the minimum energy needed to completely separate the nucleons of ${}^{3}_{1}\mathrm{H}$?

A. 12 MeV

B. 9 MeV

C. 6 MeV

D. 3 MeV

3 Nucleons → ${}^{3}_{1}\mathrm{H}$ (3 MeV per Nucleon) × (3 Nucleons)

= 9 MeV

23. The difference between the mass of a ${}^{12}_{6}\mathrm{C}$ nucleus and the sum of the masses of the individual nucleons is 0.1 u. Which of the following is approximately the binding energy of the nucleus?

A. 90 MeV

B. 90 $\mathrm{MeV\,c^{-2}}$

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Mass Defect

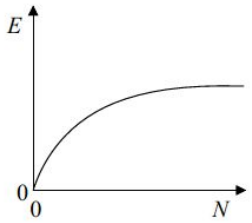
$$0.1\ u \times \frac{931.5\ MeV\ c^{-2}}{1\ u} = 93.15\ MeV\ c^{-2}$$

$$E = mc^2 = (93.15\ MeV\ c^{-2})c^2 =$$

93.15 MeV

24. Which of the following graphs best shows the variation with nucleon number N of the binding energy per nucleon E?

A.



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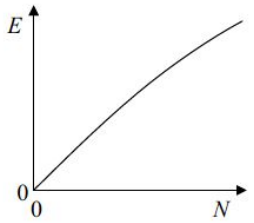
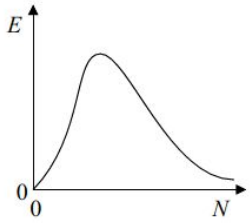
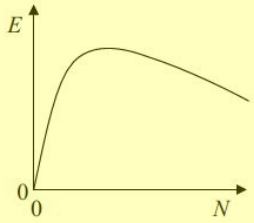


C.



D.



Intro to Fusion and Fission

Nuclear Chemistry Part 2: Fusion and Fission -
Crash Course Chemistry #39

Intro to Fusion and Fission

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Calculating the Binding Energy

Nuclide	# of p	# of n	# of e	Atomic Mass
Iron-56	26	30	26	55.934936u

m_e	0.000549u
m_p	1.007276u
m_n	1.008665u
1u	931.5 MeV c^{-2}

26×1.007276 u

30×1.008665 u

26×0.000549 u

$56.463400 \text{ u} - 55.934936 \text{ u} =$ Mass Defect **0.528454 u**

$$0.528454 \text{ u} \times \frac{931.5 \text{ MeV c}^{-2}}{1 \text{ u}} = 492.26 \text{ MeV c}^{-2}$$

$E = mc^2 = (492.26 \text{ MeV c}^{-2})(c^2) =$ **492.26 MeV** Binding Energy

Calculating the Binding Energy

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30×1.008665 u

26×0.000549 u

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Calculating the Binding Energy

$$26\,{}^{1}_{1}\mathrm{p} + 30\,{}^{1}_{0}\mathrm{n} + 26\,{}^{0}_{-1}\mathrm{e} \rightarrow {}^{56}_{26}\mathrm{Fe}$$

$26 \times 1.007276\ \mathrm{u} + 30 \times 1.008665\ \mathrm{u} + 26 \times 0.000549\ \mathrm{u} \rightarrow 55.934936\ \mathrm{u}$

$56.463400\ \mathrm{u} \rightarrow 55.934936\ \mathrm{u}$

$56.463400\ \mathrm{u} - 55.934936\ \mathrm{u}$

0.528454

u Mass Defect

$$0.528454\ \mathrm{u} \times \frac{931.5\ \mathrm{MeV\ c^{-2}}}{1\ \mathrm{u}} = 492.26\ \mathrm{MeV\ c^{-2}}$$

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Energy Released in Decay

Complete the Alpha Decay reaction for Radium-226 and calculate the energy released

$$^{226}_{88}\mathrm{Ra} \rightarrow \qquad \mathrm{Rn} +$$

Mass Defect	
Binding Energy	

Radium-226	226.0254 u
Radon-222	222.0176 u
α-particle	4.0026 u

1 u	931.5 MeV c^{-2}

Energy Released in Decay

Complete the Alpha Decay reaction for Radium-226 and calculate the energy released

$$^{226}_{88}\mathrm{Ra} \rightarrow {}^{222}_{86}\mathrm{Rn} + {}^{4}_{2}\mathrm{He}$$

226.0254 u → 222.0176 u + 4.0026 u

226.0254 u → 226.0202 u

Mass Defect = 226.0254 u - 226.0202 u = **0.0052 u**

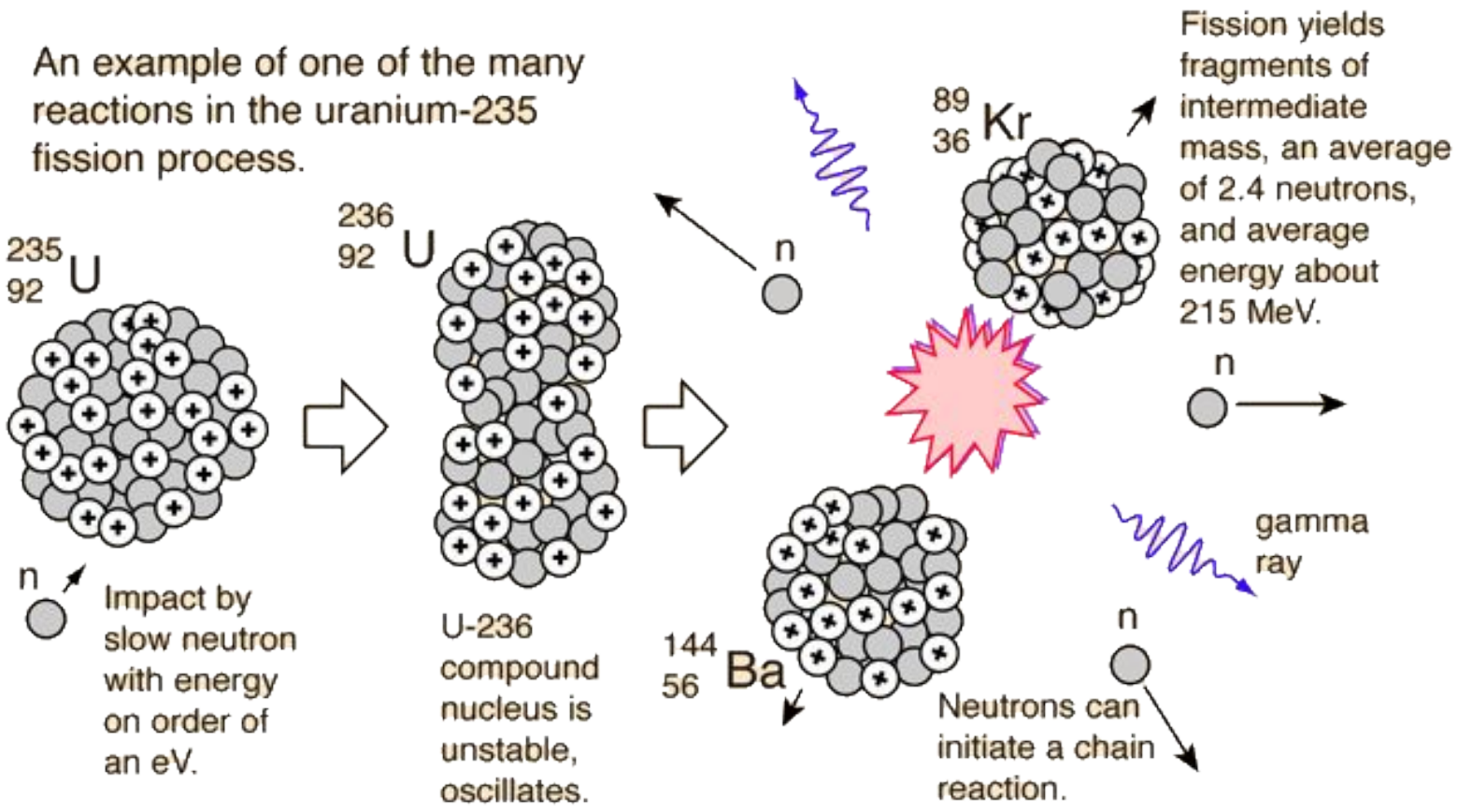
Binding Energy = 0.0052 u × 931.5 = **4.84 MeV**

Mass Defect	0.0052 u
Binding Energy	4.84 MeV

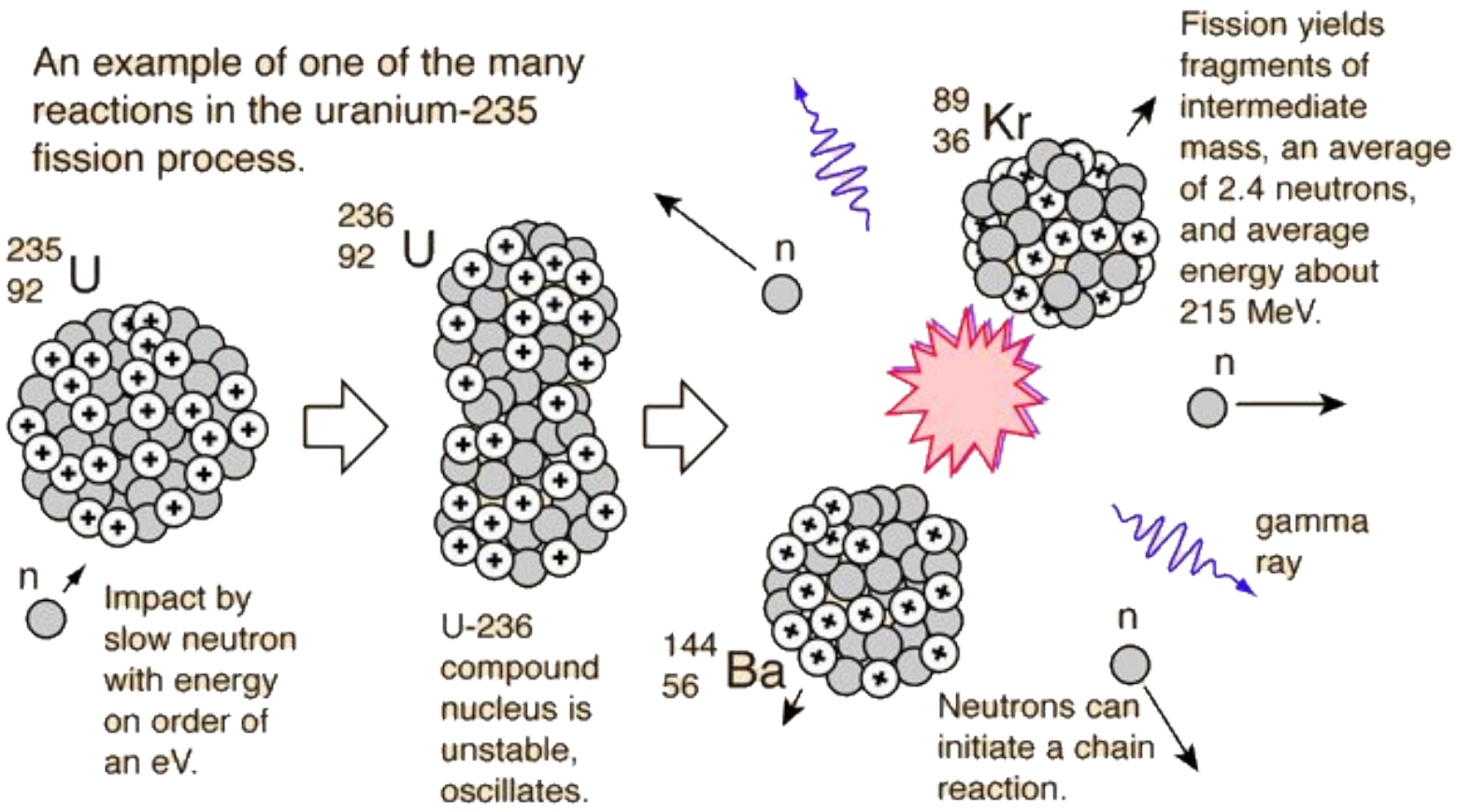
Radium-226	226.0254 u
Radon-222	222.0176 u
α-particle	4.0026 u

1 u	931.5 MeV c^{-2}

Fission


An example of one of the many reactions in the uranium-235 fission process.
235 92 U
n
Impact by slow neutron with energy on order of an eV.
236 92 U
U-236 compound nucleus is unstable, oscillates.
n
89 36 Kr
Fission yields fragments of intermediate mass, an average of 2.4 neutrons, and average energy about 215 MeV.
n
gamma ray
144 56 Ba
n
Neutrons can initiate a chain reaction.

Fission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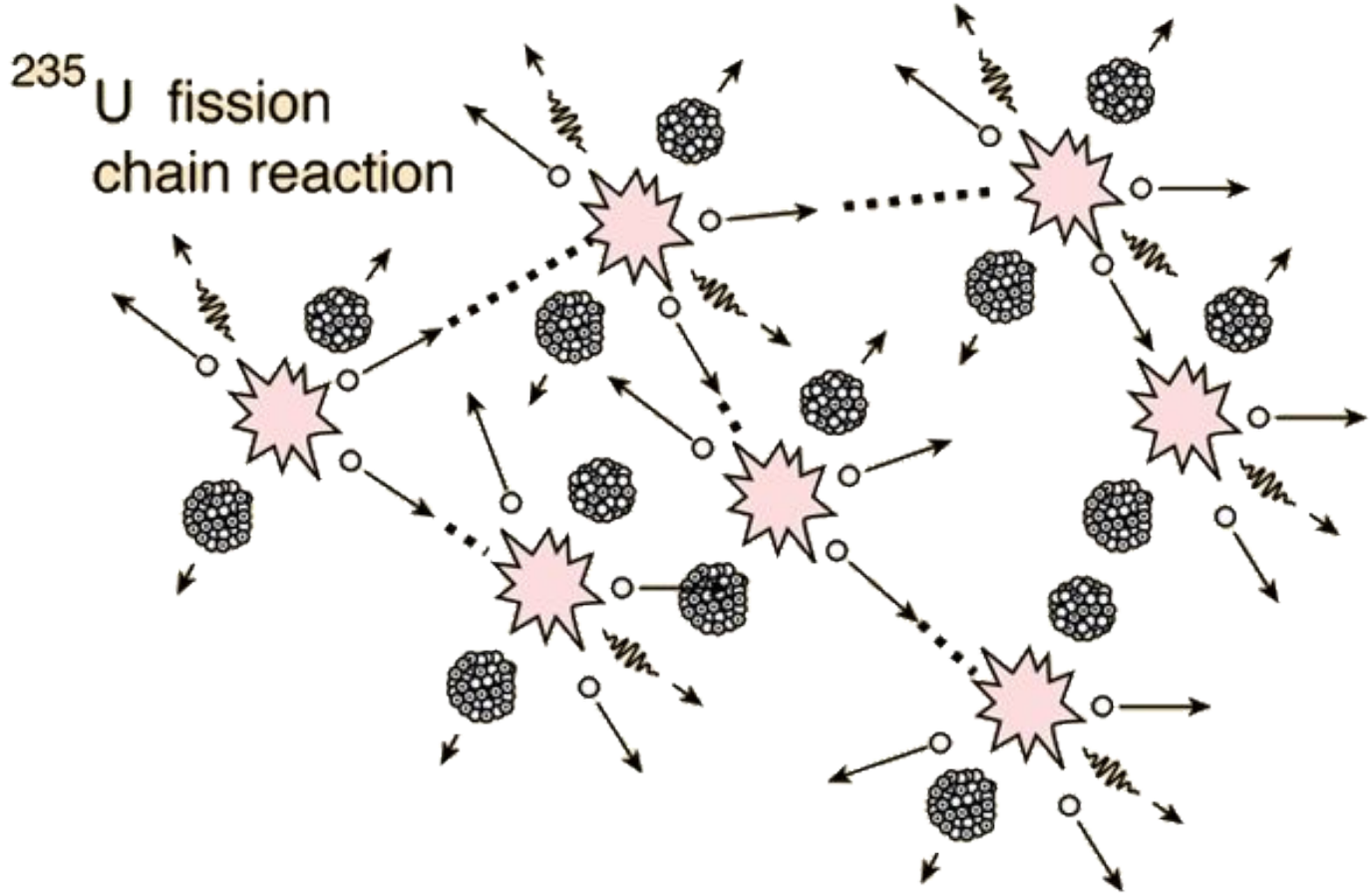
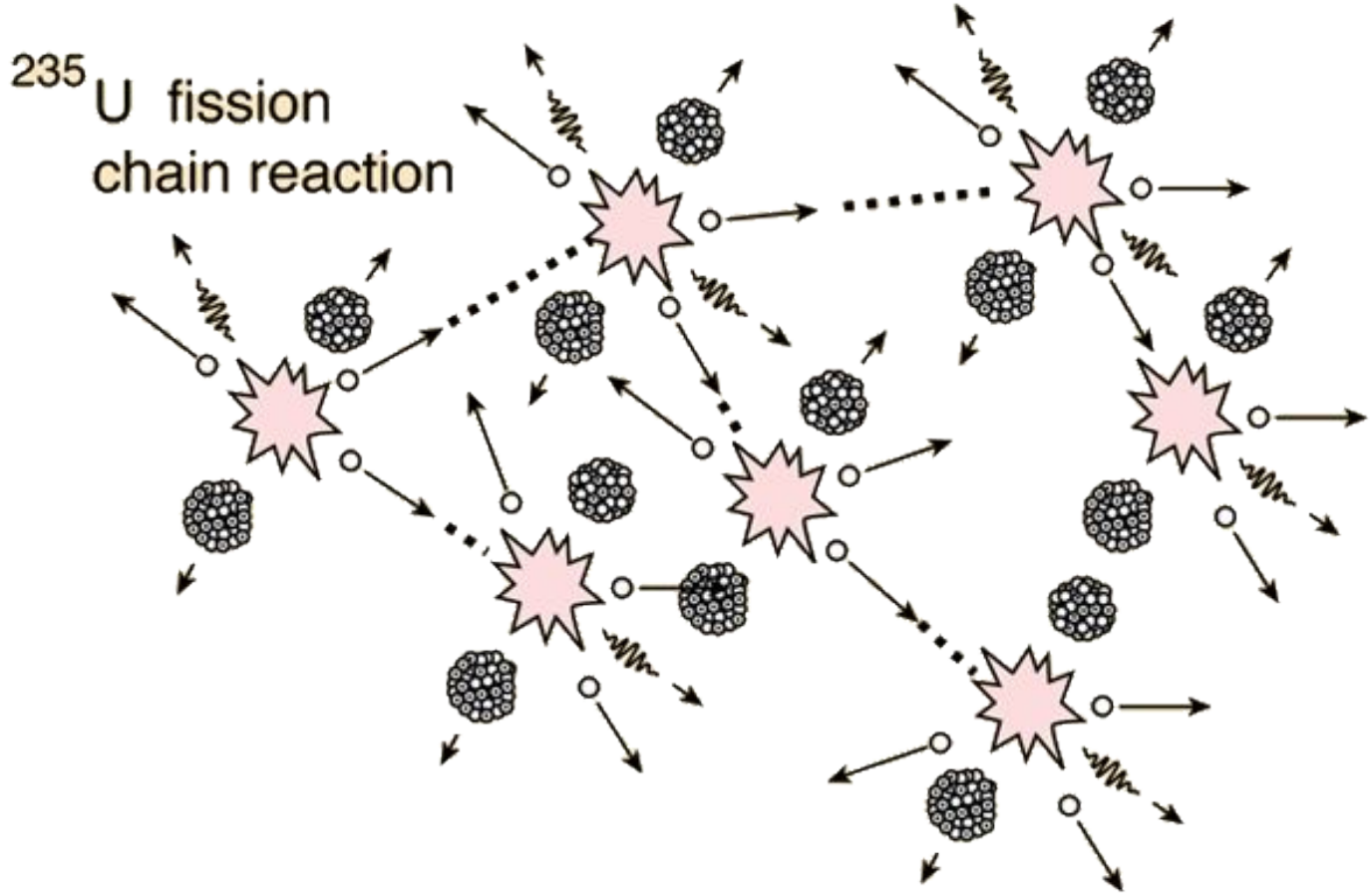
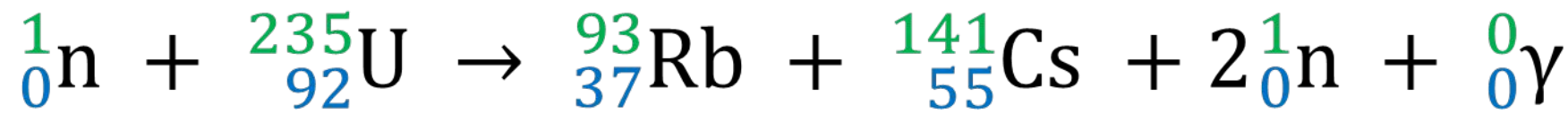
Chain Reaction



Chain Reaction



Fission



1.675 × 10^{-27} kg

390.173 × 10^{-27} kg

154.248 × 10^{-27} kg

233.927 × 10^{-27} kg

2 × 1.675 × 10^{-27} kg

391.848 × 10^{-27} kg **>** 391.525 × 10^{-27} kg

Mass Defect		Binding Energy	

Fission

$$^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{93}_{37}Rb + {}^{141}_{55}Cs + 2\,{}^{1}_{0}n + {}^{0}_{0}\gamma$$

$^{1}_{0}n$	$^{235}_{92}U$	$^{93}_{37}Rb$	$^{141}_{55}Cs$	$2\,{}^{1}_{0}n$
1.675 $\times 10^{-27}$ kg	390.173 $\times 10^{-27}$ kg	154.248 $\times 10^{-27}$ kg	233.927 $\times 10^{-27}$ kg	2 × 1.675 $\times 10^{-27}$ kg

391.848×10^{-27} kg **>** 391.525×10^{-27} kg

391.848×10^{-27} kg - 391.525×10^{-27} kg = 0.323×10^{-27} kg

$$0.323 \times 10^{-27}\ kg \times \frac{1\ u}{1.661 \times 10^{-27}\ kg} = \mathbf{0.19446\ u}$$

$$0.19446\ u \times 931.5 = \mathbf{181.14\ MeV}$$

Mass Defect	0.19446 u	Binding Energy	181.14 MeV

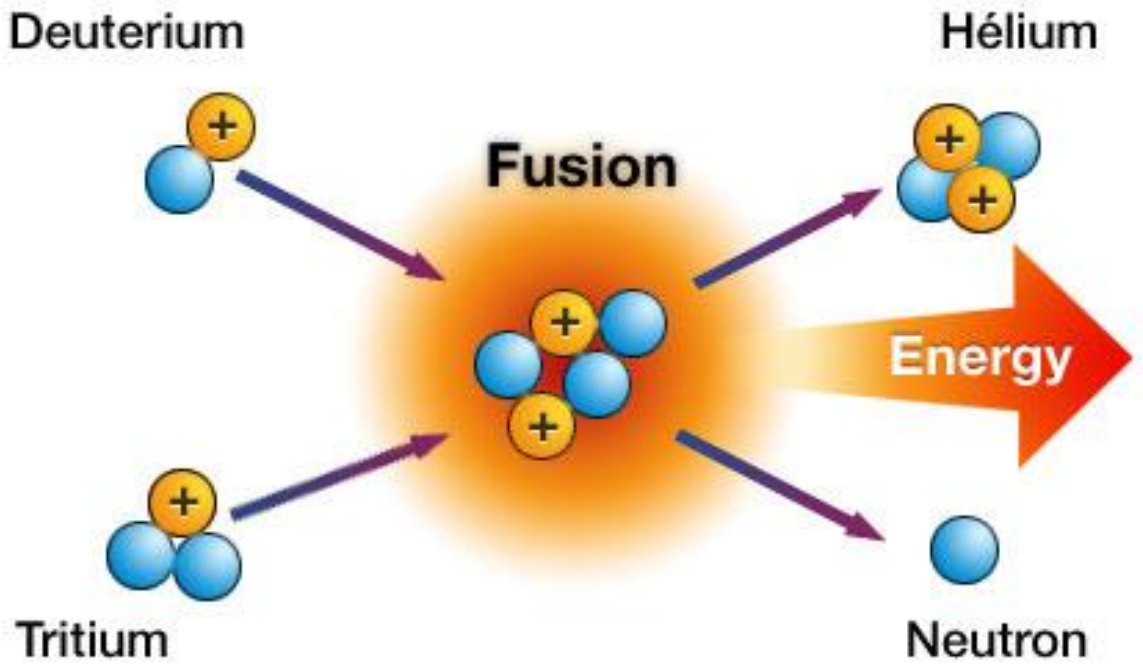
Fusion

Hydrogen-2	2.0141 u
Helium-3	3.0161 u
Neutron	1.0087 u

$$^{2}_{1}\mathrm{H} + {}^{2}_{1}\mathrm{H} \rightarrow {}^{3}_{2}\mathrm{He} + {}^{1}_{0}\mathrm{n}$$

Mass Defect		Binding Energy	

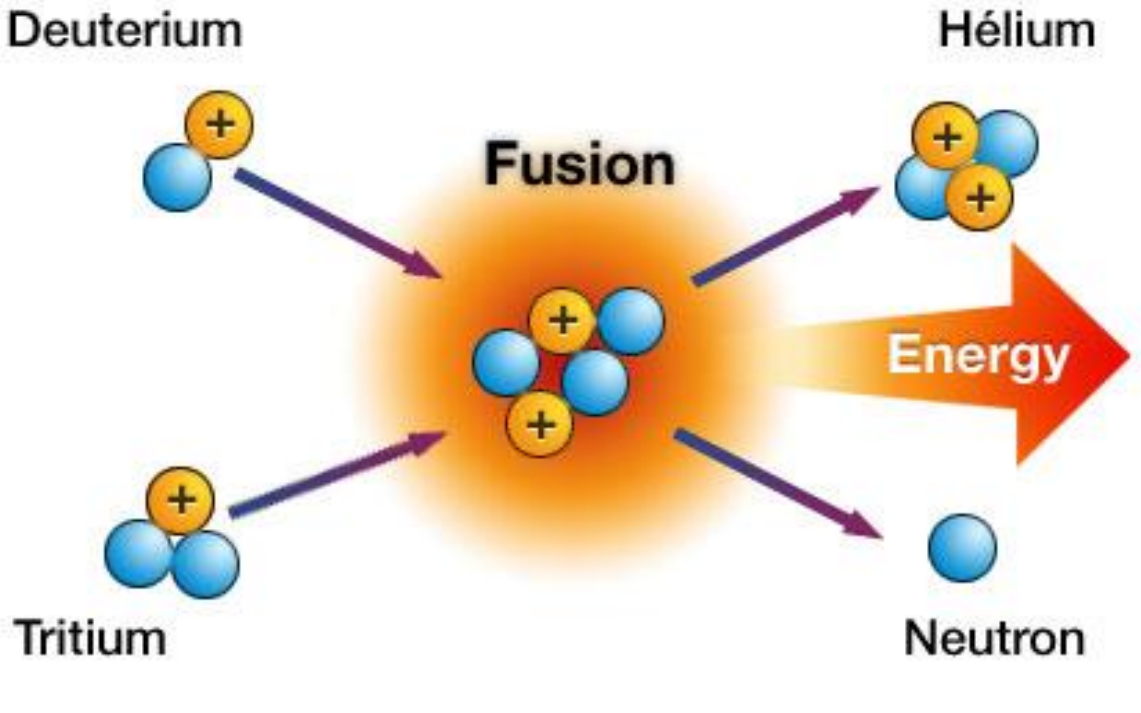
Fusion



Fusion

$^{2}_{1}H$

$^{3}_{1}H$



$^{4}_{2}He$

$^{1}_{0}n$

Fusion

Hydrogen-2	2.0141 u
Helium-3	3.0161 u
Neutron	1.0087 u

$$^{2}_{1}\mathrm{H} + {}^{2}_{1}\mathrm{H} \rightarrow {}^{3}_{2}\mathrm{He} + {}^{1}_{0}\mathrm{n}$$

(2.0141 u + 2.0141 u) – (3.0161 u + 1.0087 u) = 0.0034 u

4.0282 u

4.0248 u

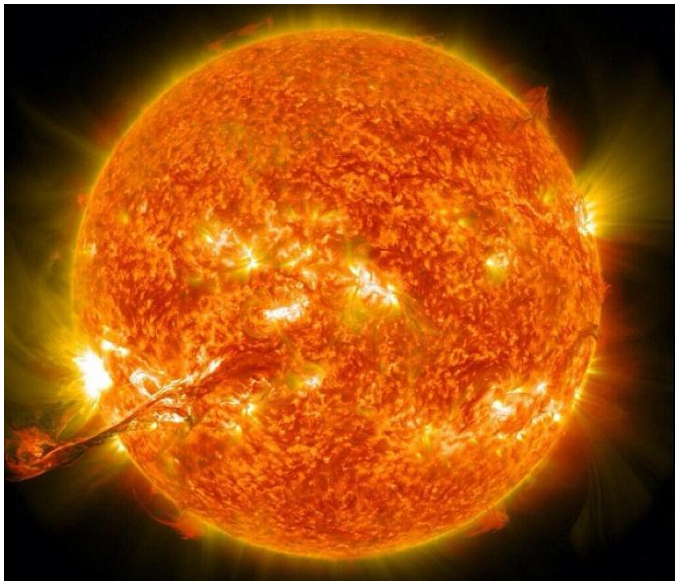
0.0034 u × 931.5 = 3.1671 MeV

Mass Defect	0.0034 u

Binding Energy	3.1671 MeV

Conditions for Fusion

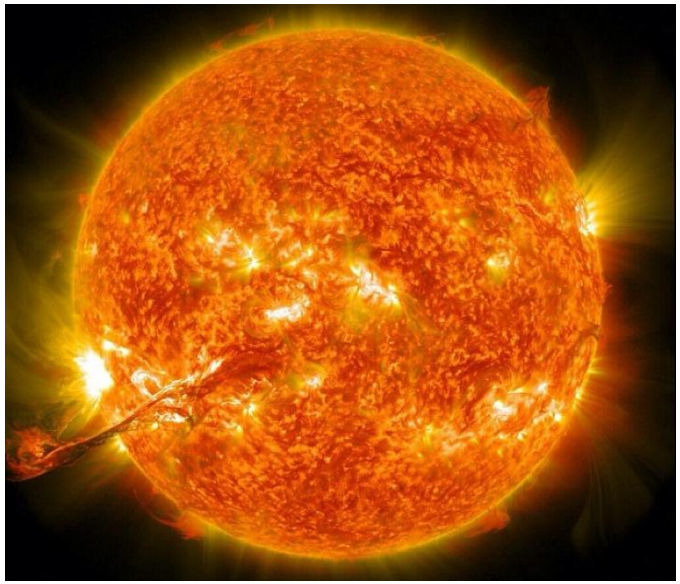
It’s significantly more difficult to create fusion reactions here on earth



Conditions for Fusion

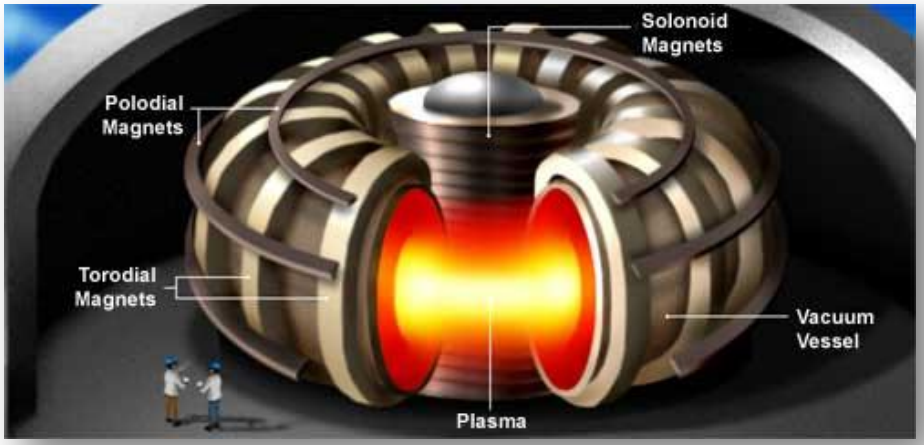
It's significantly more difficult to create fusion reactions here on earth

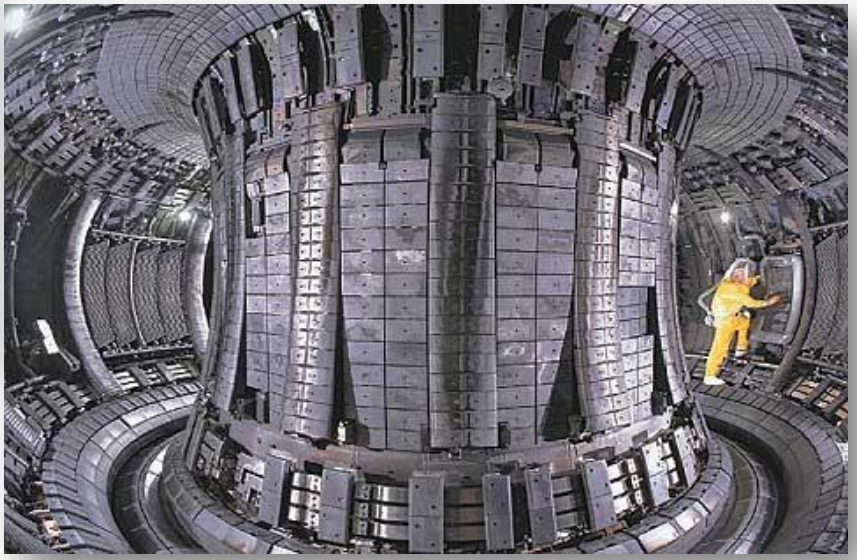
- High Pressure
- High Temperature



Fusion as a Power Source

Fusion reactions have been successfully controlled using strong magnetic fields but the energy used to run the magnets exceeds the energy released in the reaction…





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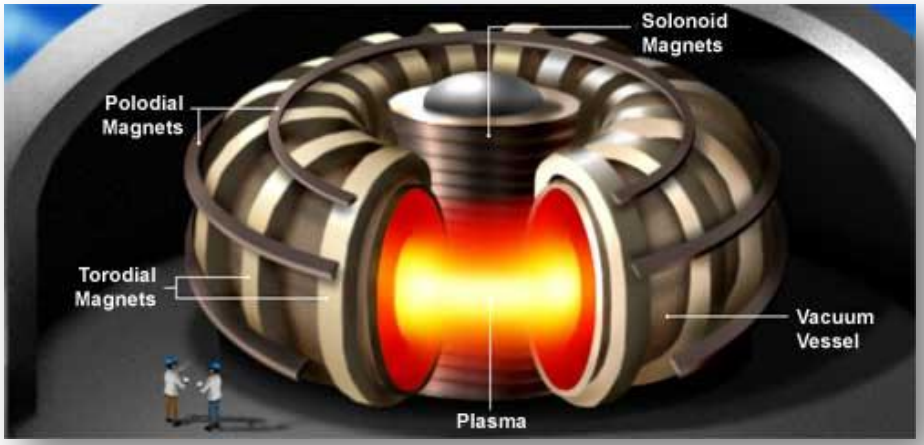
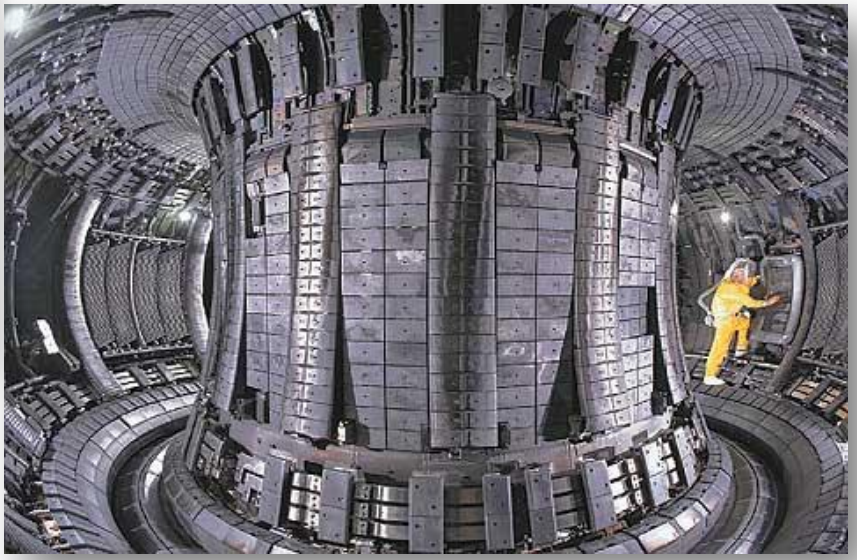
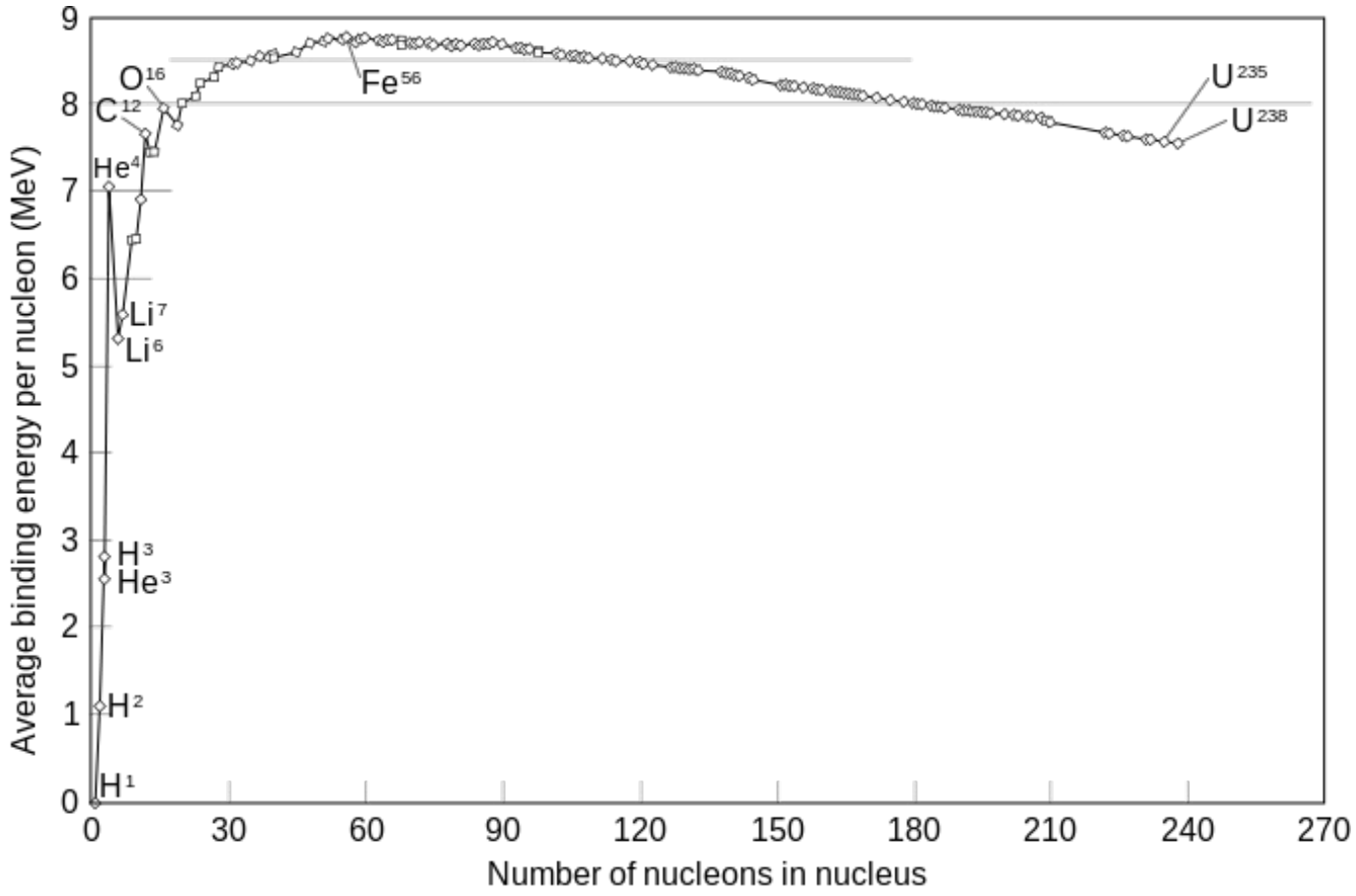




Fusion vs. Fission



Fusion vs. Fission