NUCLEAR FUSION AND NUCLEAR ENERGY

Proseminar Plasma Physics

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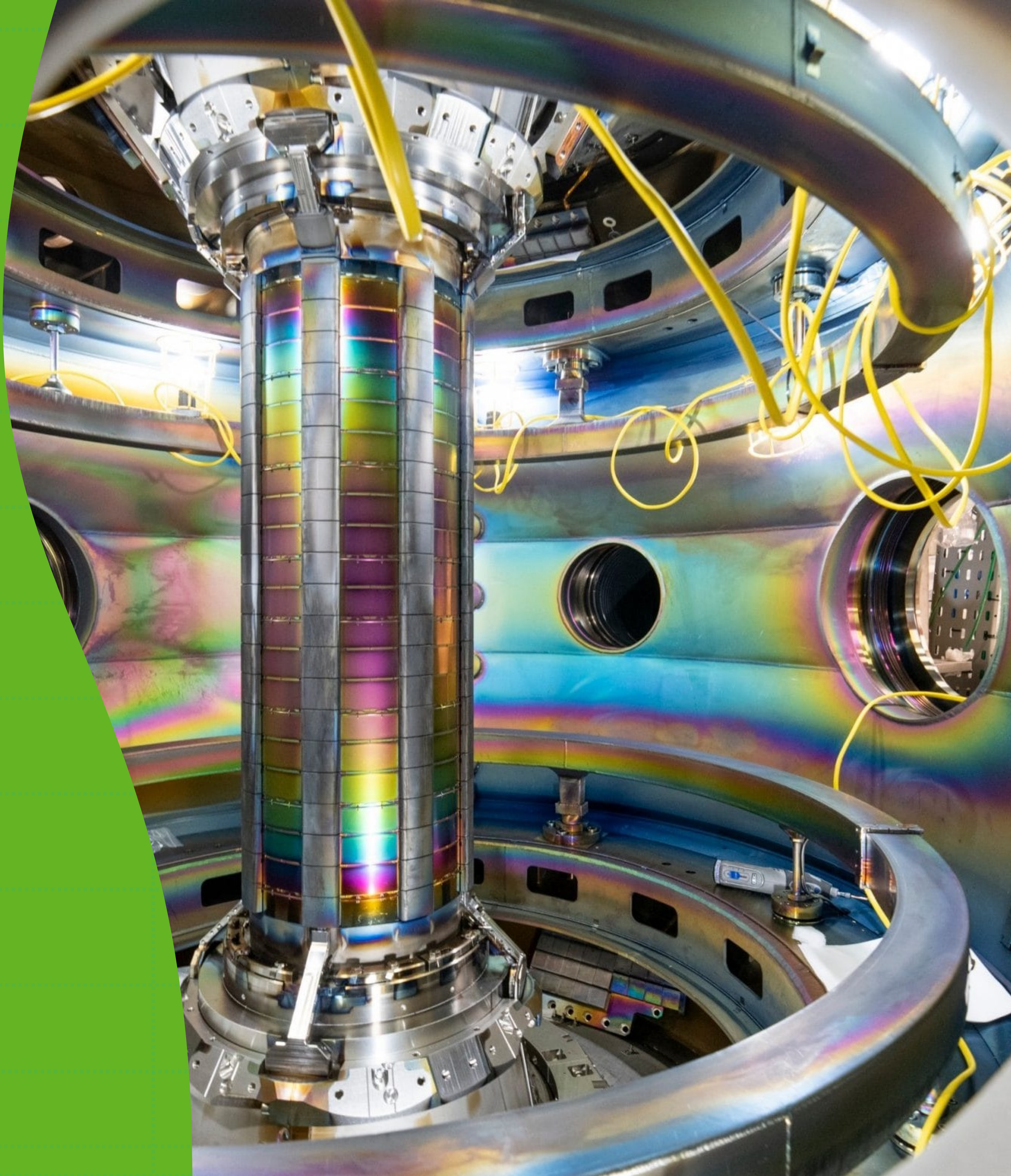

(Image source: Geoff Pugh/The Telegraph)

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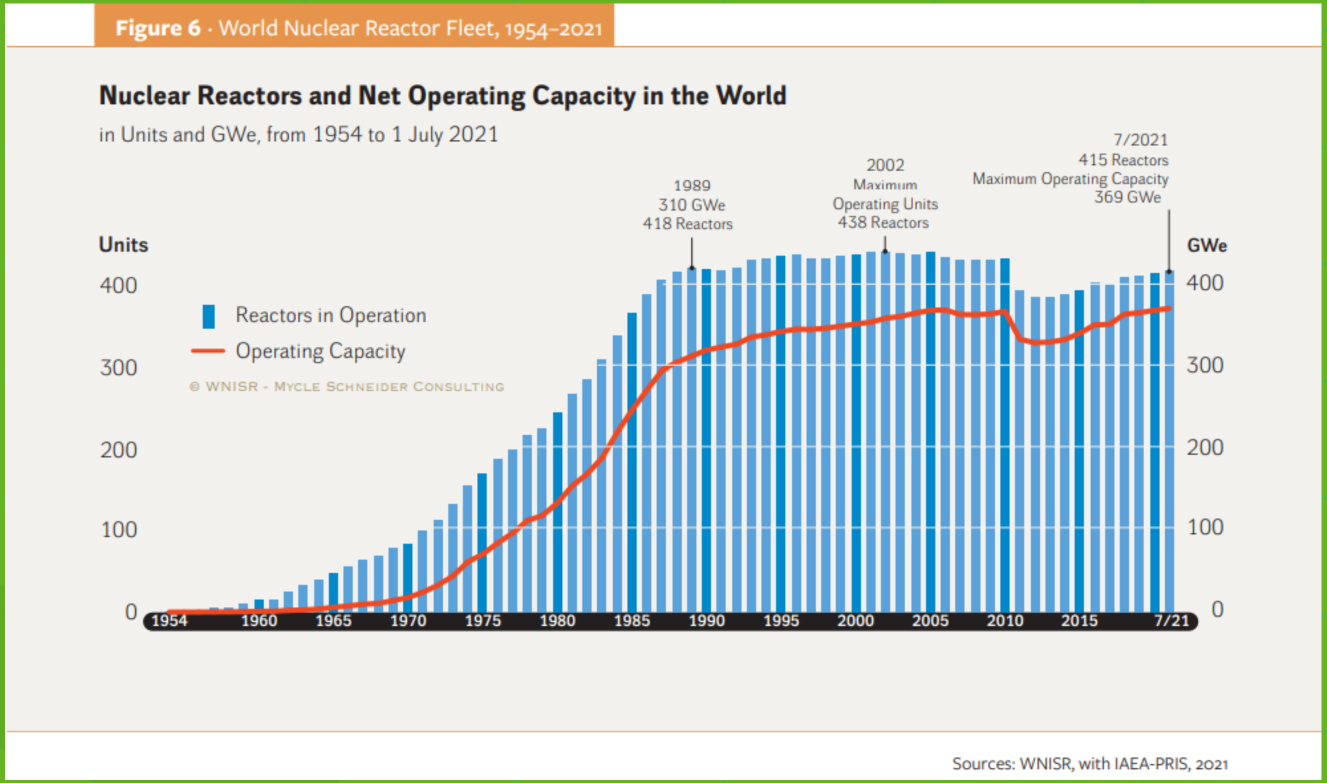
1. SITUATION OF NUCLEAR ENERGY

WORLDWIDE & GERMANY

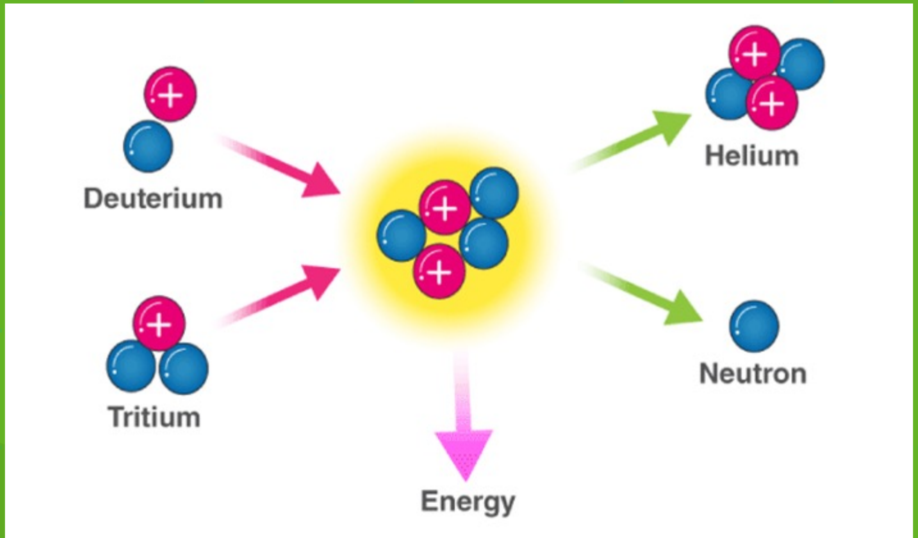


- Operation
- Investment in nuclear energy
- Development of advanced reactors
- Nuclear fusion
- Political decisions
- Safety and waste control

2. NUCLEAR FUSION

It is the process by which two light nuclei fuse to form a heavier nucleus.

DEUTERIUM (^{2}H) + TRITIUM (^{3}H)



NECESSARY REQUIREMENTS:

- Extremely high temperature
- Adequate pressure and density
- Control and stability
- Sufficient time of confinement

IGNITION CONDITIONS

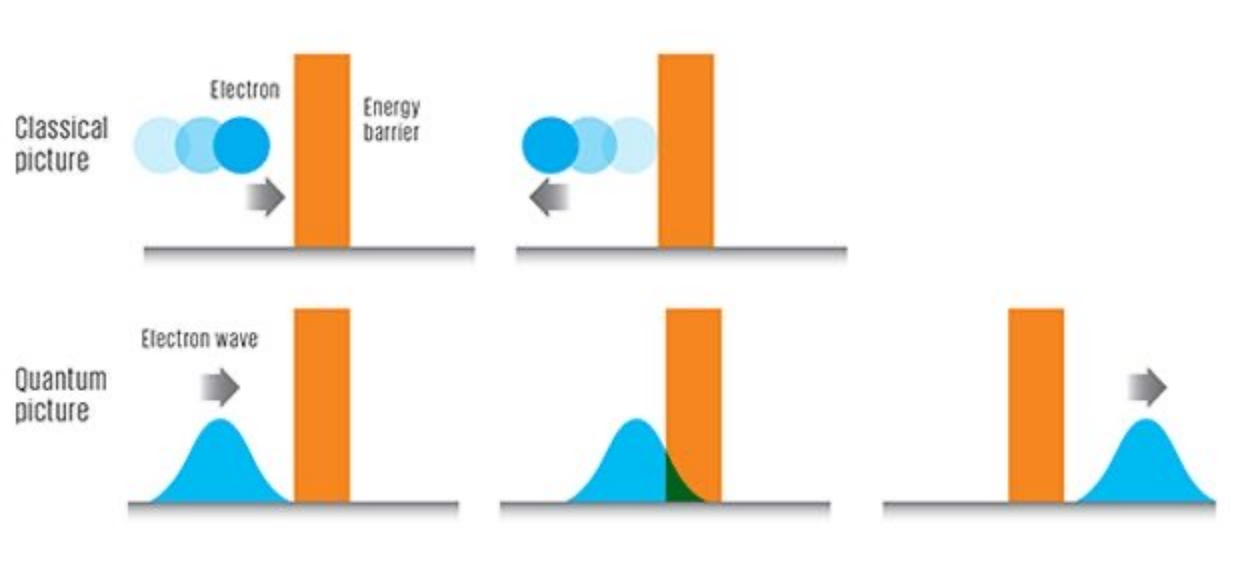
(Image source: mindthegraph.com/blog/nuclear-fusion/)

2.1 - Tunnel effect

It is a quantum phenomenon essential to understand how atomic nuclei can overcome the electrical repulsion barrier and thus be able to fuse at reasonable temperatures and not only at temperatures so extremely high that they would be unattainable in real practice.

Location and trajectory of the particles is well defined.

Particles exist in a probability cloud.

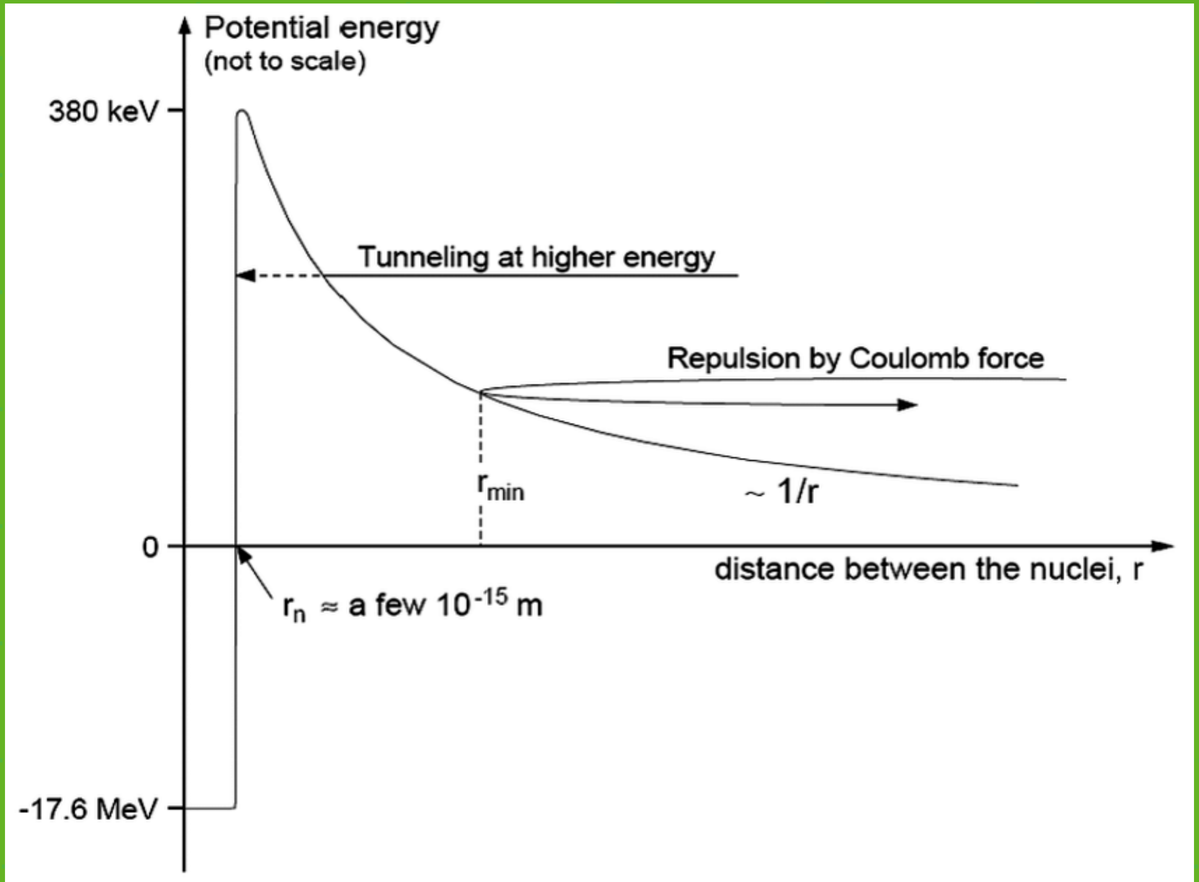


What takes place in the **CLASSICAL WORLD** is **not** the same as what happens in the **QUANTUM WORLD**.

(Image source: PhysicsOpenLab)

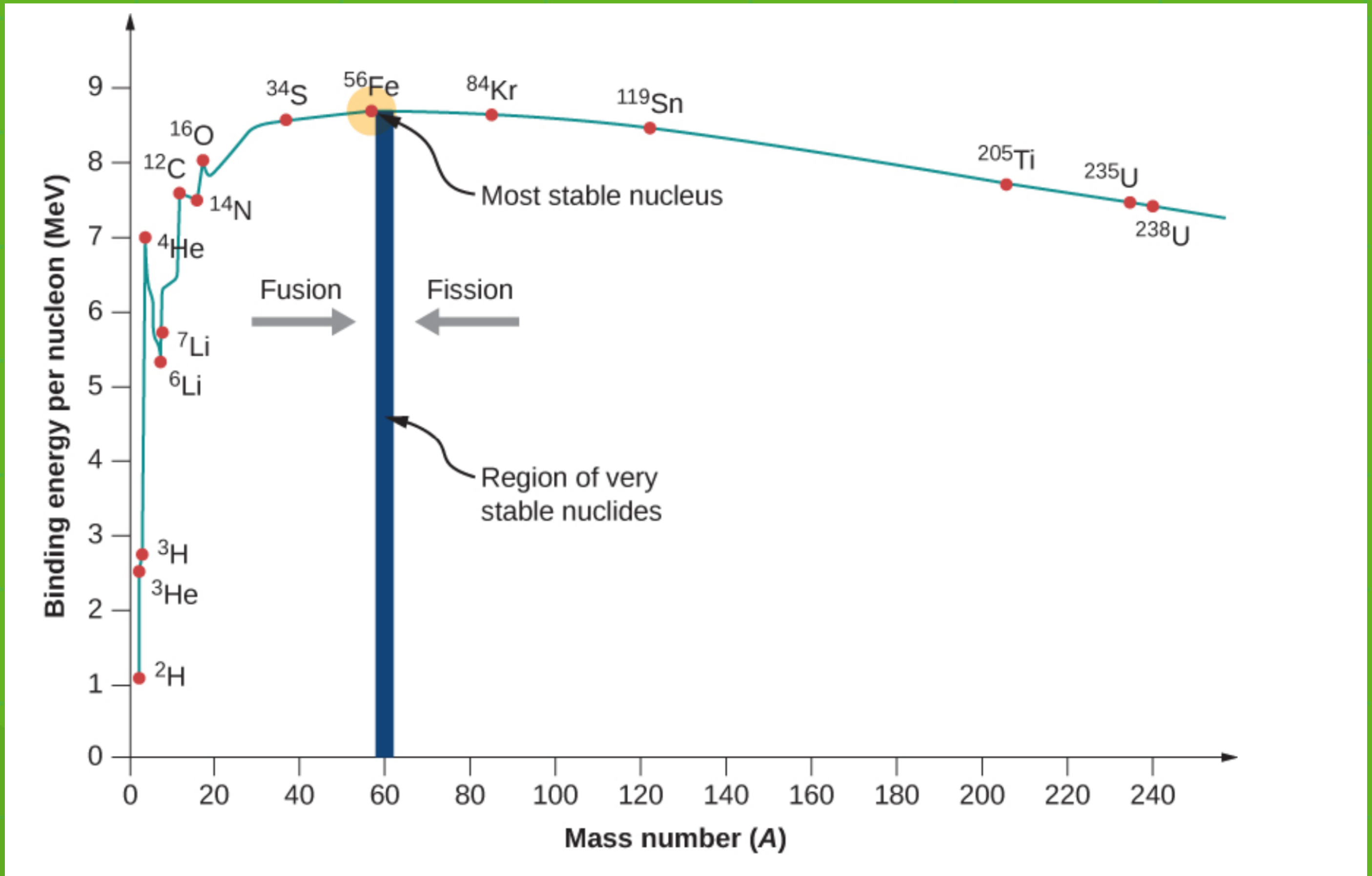
2.1 – Tunnel effect

Graphical representation of how the tunnel effect facilitates the fusion between two positively charged particles.



(Image source: bosoneando.blogspot.com/2015/04/hay-luz-al-final-del-tunel.html)

2.2 - Binding Energy per Nucleon ($^{\Delta E}/_{A}$)



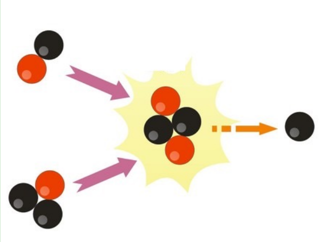
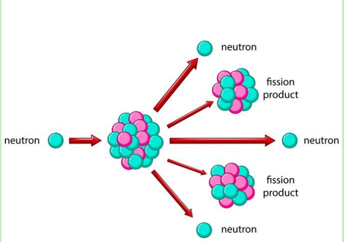
EINSTEIN EQUATION

$$E = m \cdot c^2$$

[A. Einstein et al.,PRL (1905)]

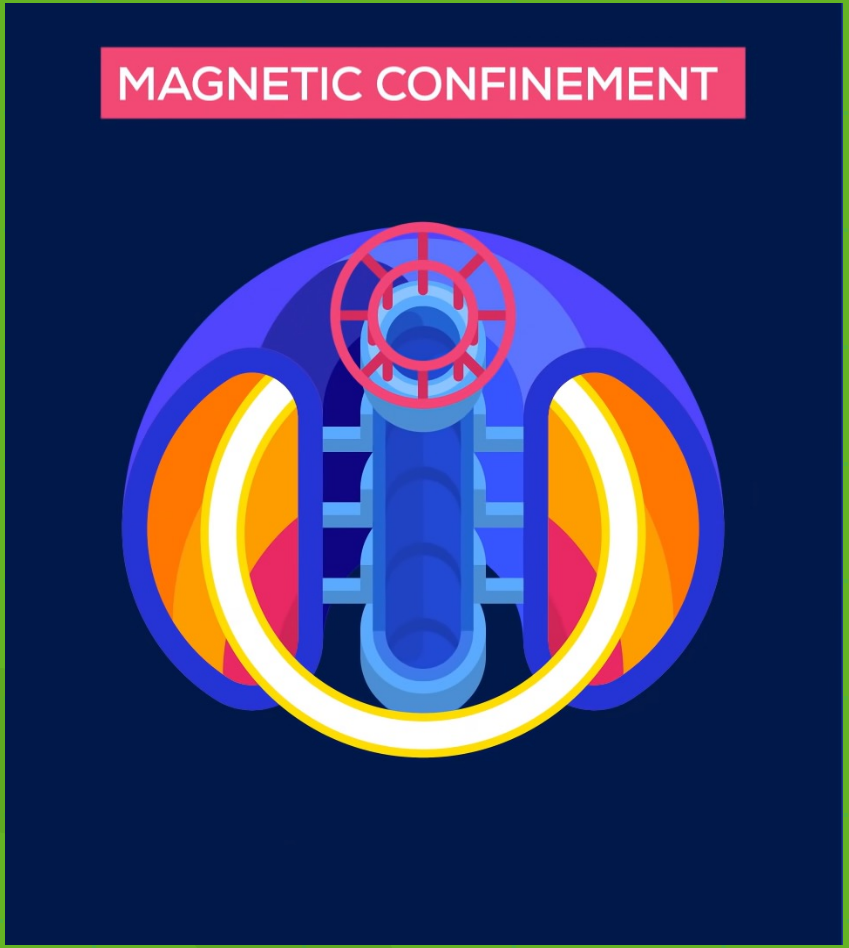
(Image source: openstax.org/books/f%C3%ADsica-universitaria-volumen-3/pages/10-2-energia-de-enlace-nuclear)

2.3 – Fusion vs Fission

	FUSION	FISSION
PROCESS		
FUEL	Light nuclei (^{2}H,^{3}H…)	Heavy nuclei (U235, Pu239)
FUEL ABUNDANCE	Abundant and easy to obtain	Less abundant and require enrichment processes
SAFETY	Stops automatically	Release of radioactive material
TEMPERATURE // PRESSURE	Critically high	Much lower and moderate
RADIOACTIVE WASTE	Short-lived waste	Long-lasting waste

(Image source: Wikipedia. Public domain)

2.4 – Plasma production

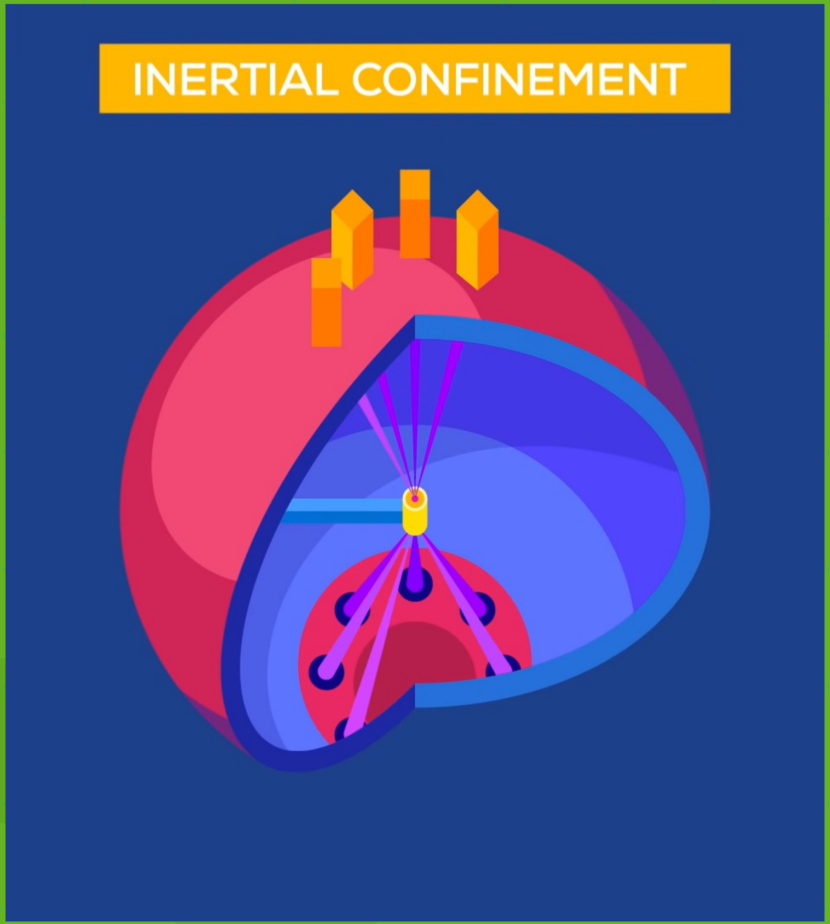


- TOKAMAKS: (ITER)
  - Toroidal and poloidal magnetic field.
  - Requires plasma current.
  - Simpler design.

- STELLARATORS: (Wendelstein 7X)
  - Complex three-dimensional magnetic field.
  - No plasma current required.
  - More complex design.

(Image source: Youtube. www.youtube.com/watch?v=mZsaaturR6E&t=164s)

2.4 – Plasma production



- LASER:
  - Uses laser pulses for compression.
  - Capsule implosion approach.
  - Requires advanced laser systems.
- Z-PINCH:
  - Generates magnetic field by current.
  - Magnetic compression approach.

(Image source: Youtube. www.youtube.com/watch?v=mZsaaturR6E&t=164s)

2.5 – Some Nuclear Fusion Reactions

P-P REACTION

- The main source of the energy radiated by small and medium stars.

- PROCESS:

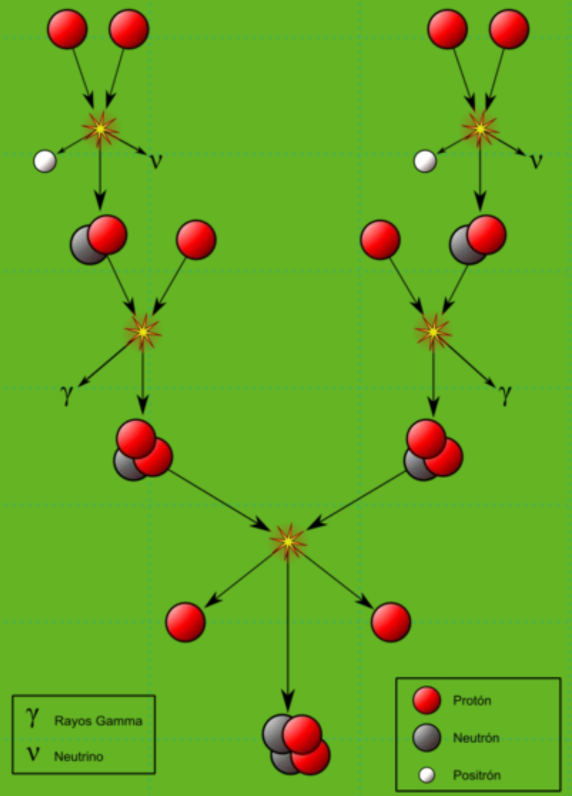
1. $$p + p \longrightarrow D + e^{+} + \nu_e$$

2. $$D + p \longrightarrow He^3 + \gamma$$

3. $$He^3 + He^3 \longrightarrow He^4 + 2p$$

- CURRENT EXPERIMENTS:

  not a common approach in current controlled fusion experiments on Earth.



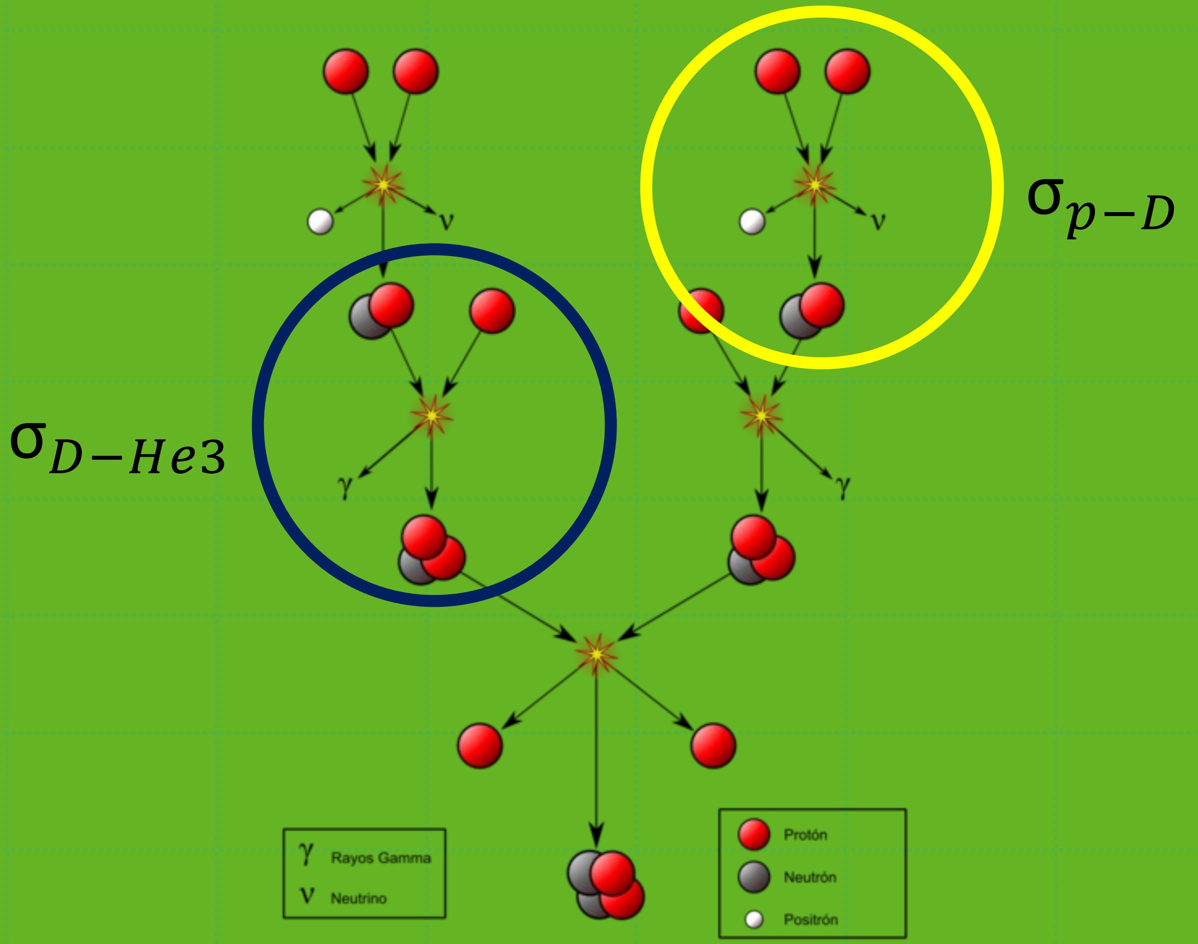
$$4\,H^1 + 2e^- \longrightarrow He^4 + 2\nu_e$$

(Image source: EnergyEducation.ca)

2.5 – Some Nuclear Fusion Reactions

CROSS-SECTION (σ):
describe the probability of certain types of interactions occurring between subatomic particles, such as neutrons, and the nuclei of atoms.

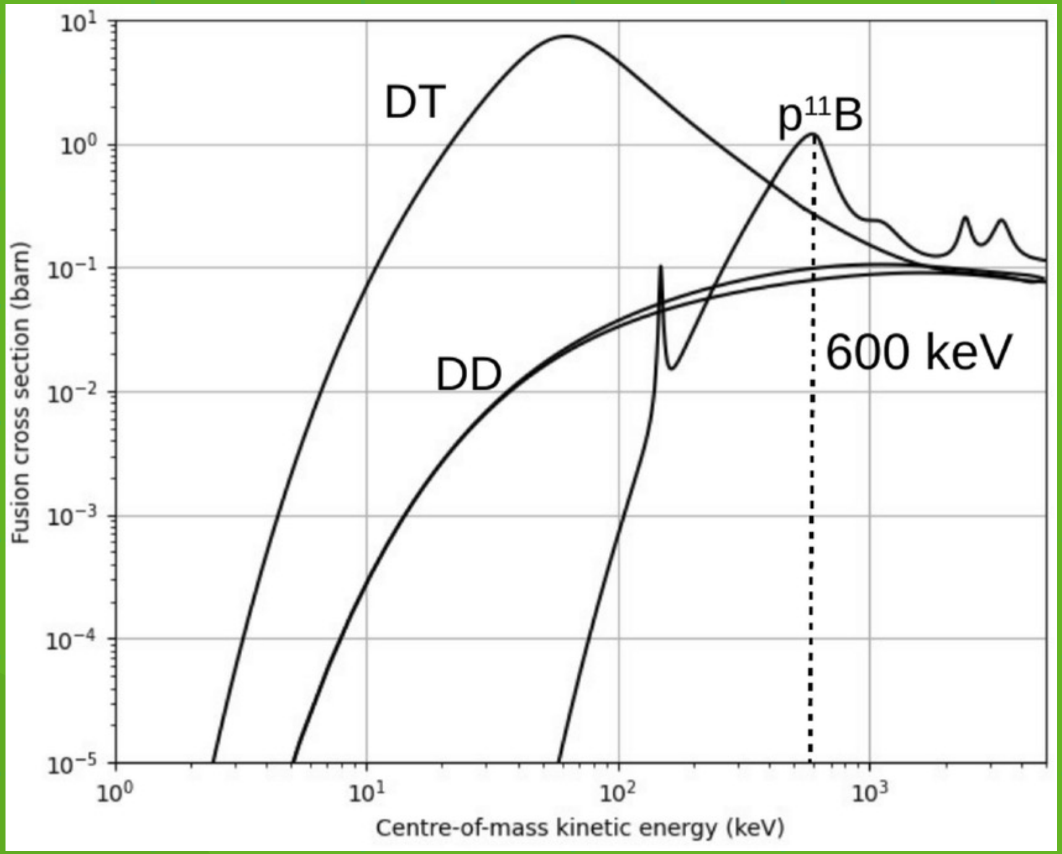
$$1\ \mathrm{b} = 10^{-28}\ \mathrm{m}^2 = 10^{-24}\ \mathrm{cm}^2$$



(Image source: EnergyEducation.ca)

2.5 – Some Nuclear Fusion Reactions

CROSS-SECTION – KINETIC ENERGY



D-T ≈ 60 keV

D-D ≈ 1000 keV

P-B ≈ 600 keV

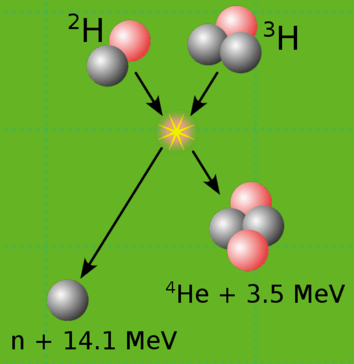
(Image source: www.nature.com/articles/s41598-022-08433-4)

2.5 – Some Nuclear Fusion Reactions

D-T

- PROCESS:

$$D + T \longrightarrow He^4 + n + 17.6\ MeV$$

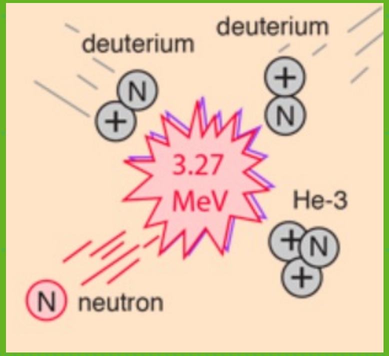


- PROS: Lower ignition conditions // Higher energy output
- CONS: Tritium is radioactive // Tritium is less abundant

D-D

- PROCESS:

$$D + D \longrightarrow He^3 + n + 4.0\ MeV$$



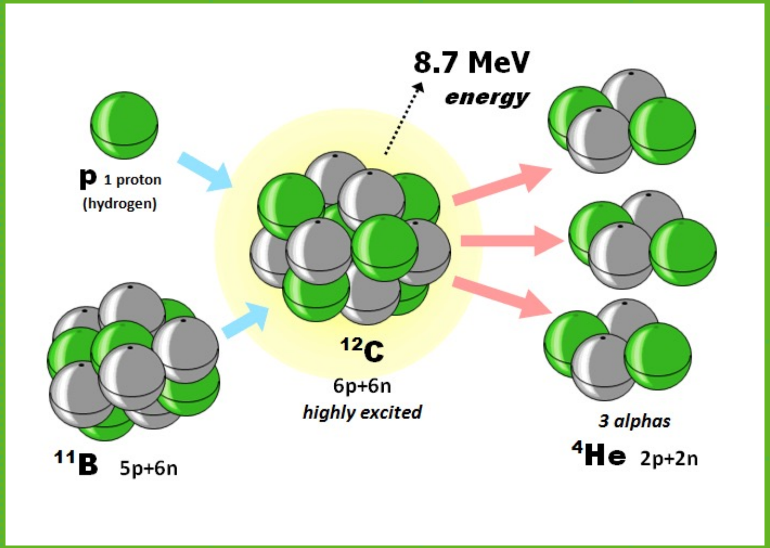
- PROS: No tritium required // Deuterium is very abundant
- CONS: Higher ignition conditions // Lower energy obtained

(Image source: Wikipedia. Public domain)

2.5 – Some Nuclear Fusion Reactions

P-B

- PROCESS:



- PROS: Less radioactivity production // Easier waste management
- CONS: Extremely high temperatures // Lower probability

(Image source: LastTechAge.wordpress.com)

3. CURRENT CHALLENGES

- IGNITION CONDITIONS
- DURABILITY OF MATERIALS
- NET ENERGY GENERATION
- FINANCIAL AND ECONOMIC IMPACT (COMPETITIVENESS)

4. CONCLUSION

(Source: www.fusionindustryassociation.org/about/members/)

LET´S PLAY!!

Kahoot!