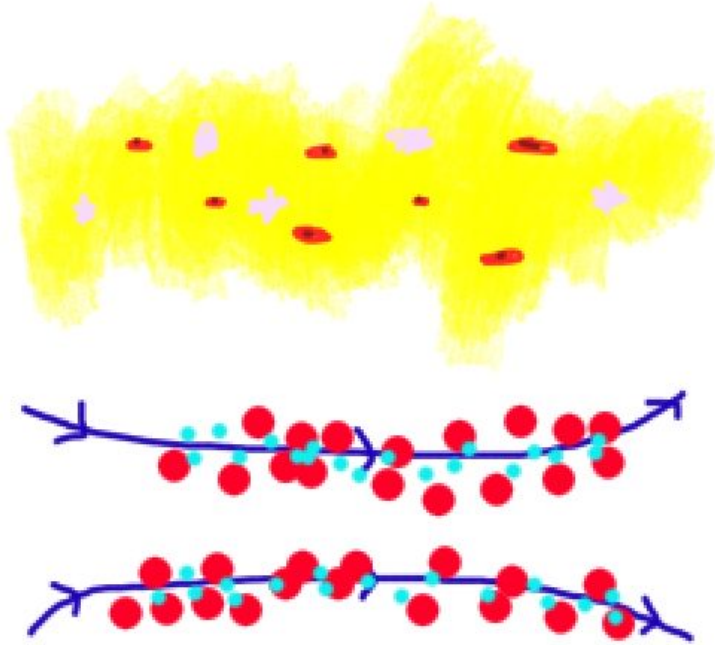
Energy and Explosions

The Fourth State of Matter

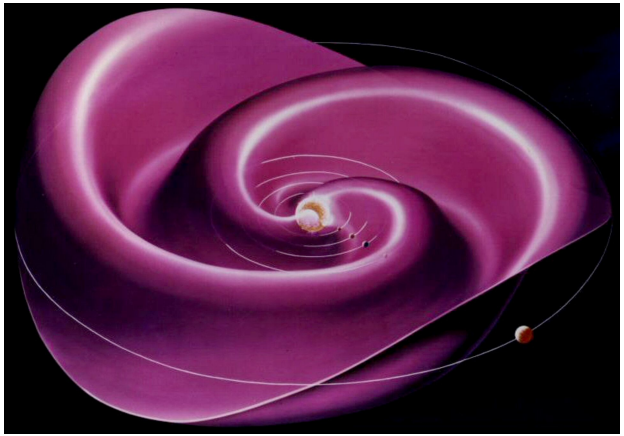
Plasmas

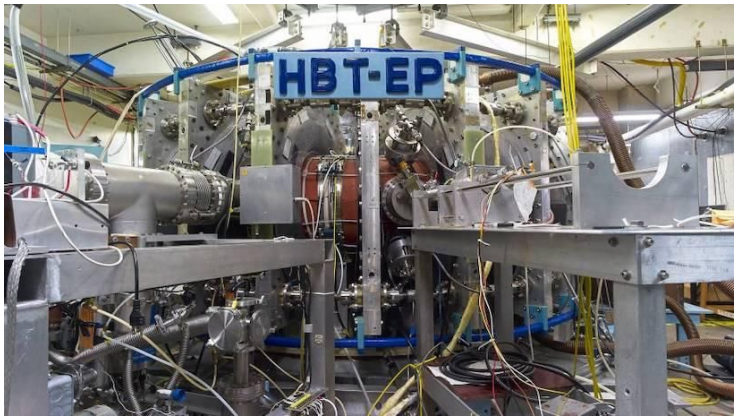
- No fixed shape or volume and has free charges (Debye length)
- Characterized by temperature, density, and ion charge
- Termed by Langmuir in 1929 due to similarities to blood plasma



Applications

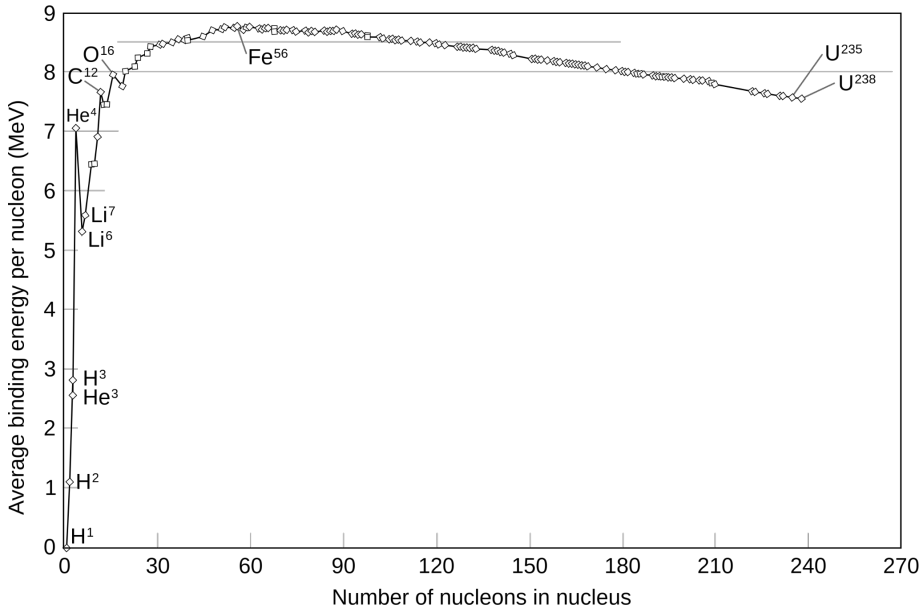
- Radios
- Astronomy
- Fusion
- Semiconductors





Fusion

- Method to harvest mass energy
- Unusually high binding energy for helium-4: good fusion product
- Often deuterium and tritium used as fuel as they have the lowest nuclear charge



Fueling up for Fusion

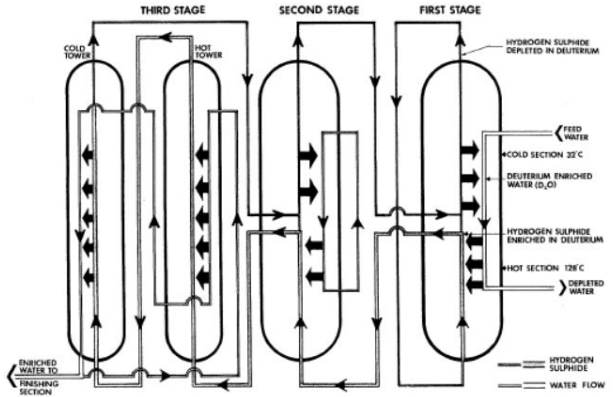
Deuterium

1) Naturally occurring in ocean water (1/6400 atoms are deuterium)

2) Refinement using the GS process and distillation can get 99% heavy water concentration (D2O)

$$H_2O + HDS \rightleftharpoons HDO + H_2S + \{\approx 1.9\ \text{kJ}\}$$

3) Electrolysis to extract the deuterium gas



Tritium

- Hard to find naturally
- Generally bread at nuclear reactors or during continuous fusion

$$ {}^{2}_{1}D + {}^{3}_{1}T \rightarrow {}^{4}_{2}He + {}^{1}_{0}n_{17.6\ \text{MeV}} $$

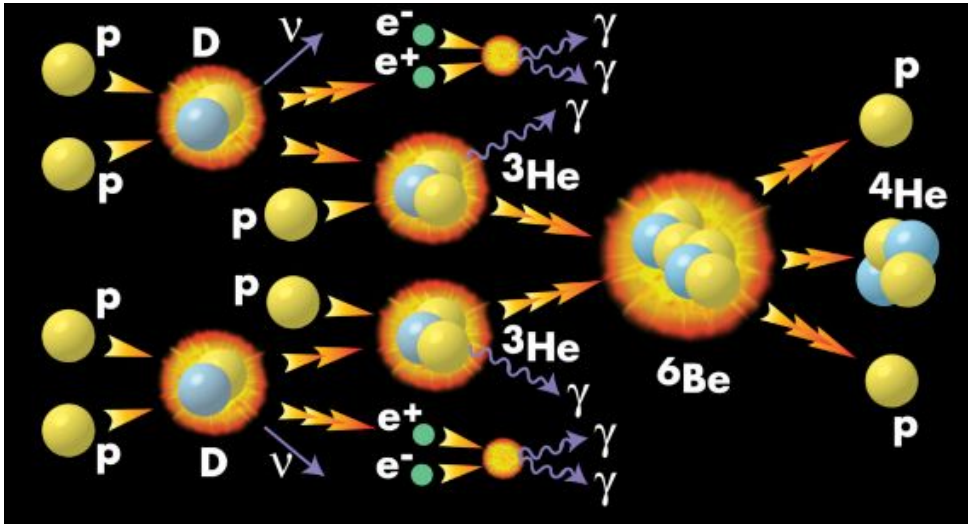
$$ {}^{6}_{3}Li + {}^{1}_{0}n \rightarrow {}^{3}_{1}T + {}^{4}_{2}He + \{4.78\ \text{MeV}\} $$

$$ {}^{7}_{3}Li + {}^{1}_{0}n \rightarrow 2 \times {}^{3}_{1}T + 2 \times {}^{1}_{0}n - \{10.3\ \text{MeV}\} $$

Harnessing the Power of the Sun

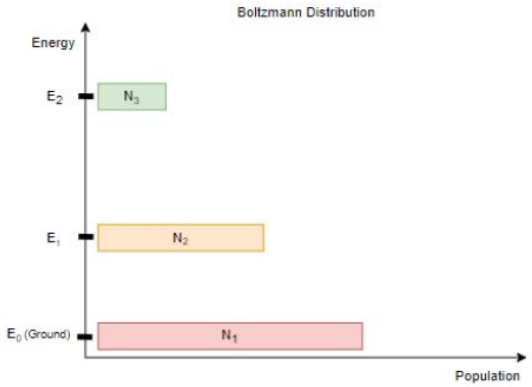
Inertial Confinement

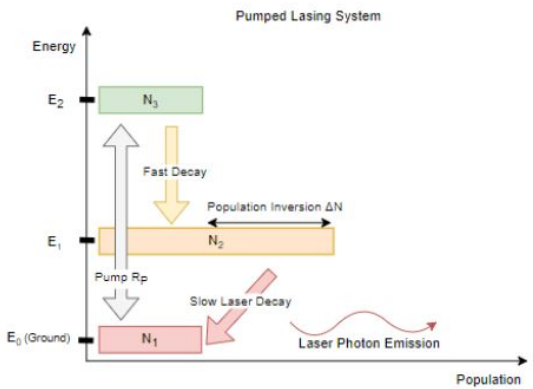
- Quick confinement of mass creates high-temperature and high-pressure environments
- Simulate the extreme fusion environments in the sun



Lasers

- Developments in ultrashort pulse lasers (including the 2023 Nobel Prize) led to their adoption in inertial confinement fusion

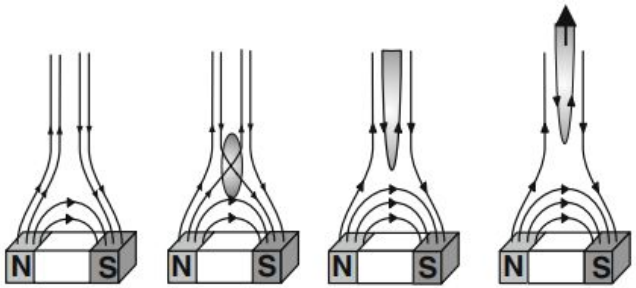


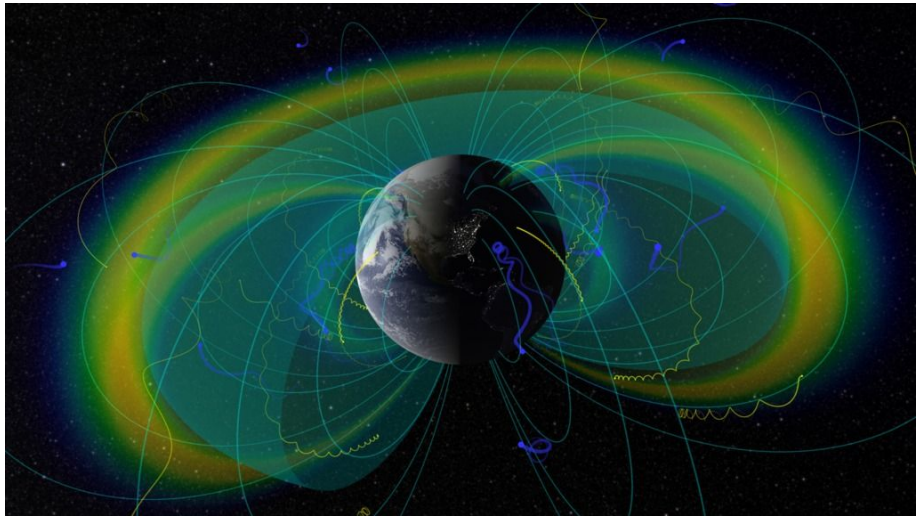


The Energy of the Future

Magnetic Confinement

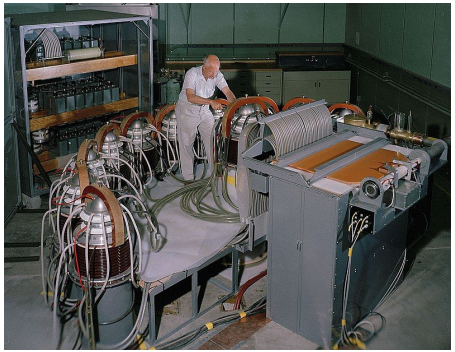
- Fuel is heated to become plasma
- Charged particles take helical paths around magnetic fields

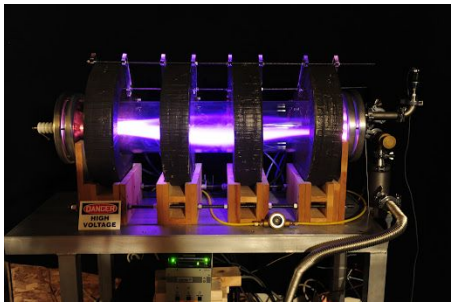




First Proposed MCF Techniques

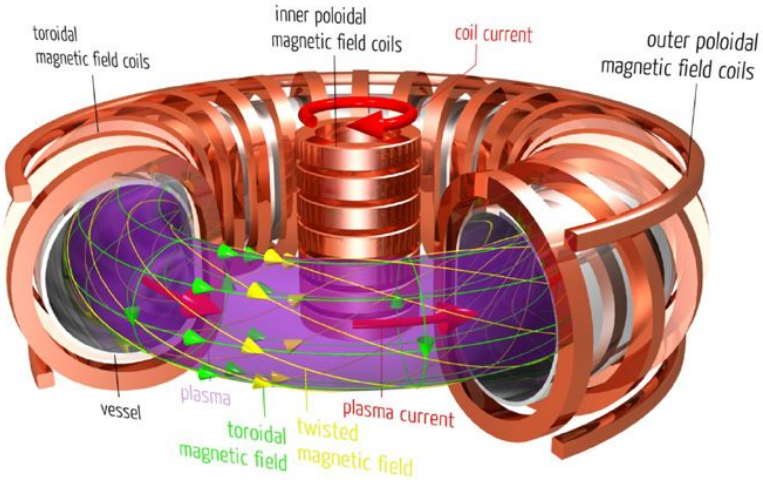
- Magnetic mirrors
- Theta-pinches
- Z-pinches

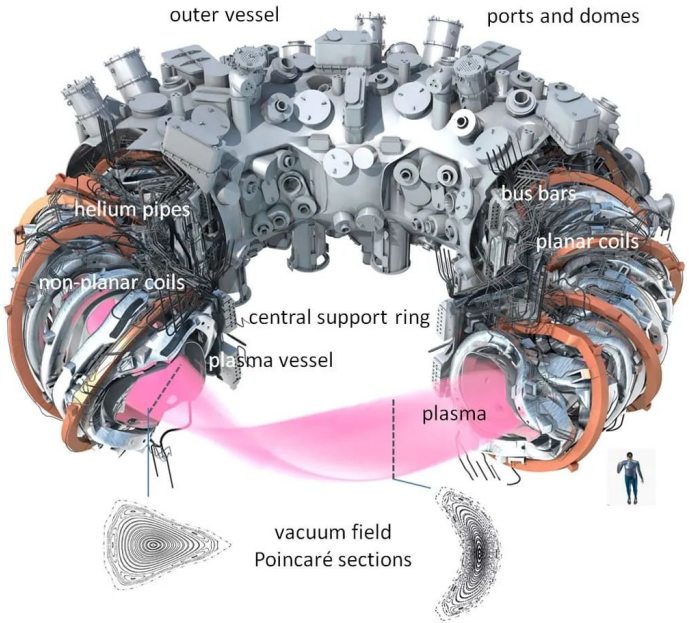




More Modern MCF Techniques

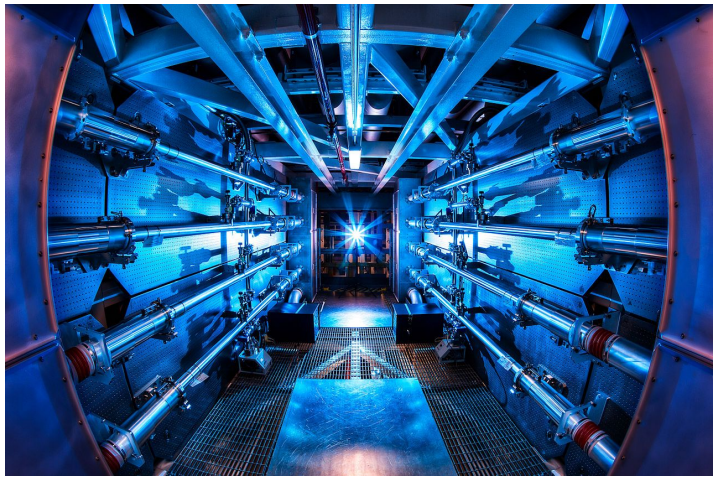
- Tokamaks and stellarators

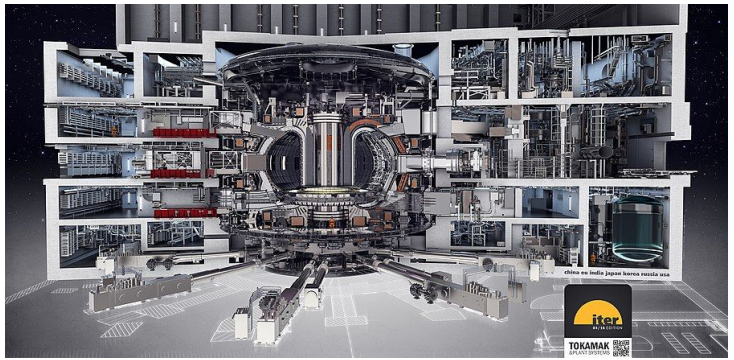




Recent Updates

- NIF ICF breakthrough: net energy gain compared to laser output energy
- ITER: international tokamak collaboration





Questions?