# **Energy from Fusion**

Carbon-free.
Energy release ~$10^6$ times greater than chemical reaction (similar to fission).
Basic fuel: Deuterium (D), Lithium (Li)
High energy density: 100 g of D and 150 g of tritium (T) required to produce ~1 GW for 1 year (same energy content as one Tonne of oil)
Waste level much lower than fission.
D: 35 $gm^{-3}$ in seawater, cost ~£0.6/g
Li reserves ~$10^6$ Tonnes (enough for 10 TWyears for ~1000 years)

## D-T fusion

Fusion of deuterium ($D \equiv {}^2H$) and tritium ($T \equiv {}^3H$) releases 17.6 MeV:

$$\mathrm{D + T \rightarrow \; {}^4He + n + 17.6\ MeV}$$

The released energy is shared by the $^4$He ($\alpha$-particle, 3.5 MeV) and the neutron , n (14.1 MeV

Deuteron = nucleus of deuterium

Triton = nucleus of tritium

Need $10^8$ °C for deuteron and triton fusion to occur at a sufficient rate. Matter is a **plasma** (gas of charged particles with long-range collective effects) in this temperature regime.

$\alpha$-particles produced by the D-T reaction provide a source of heat to maintain $10^8$ °C in the plasma.

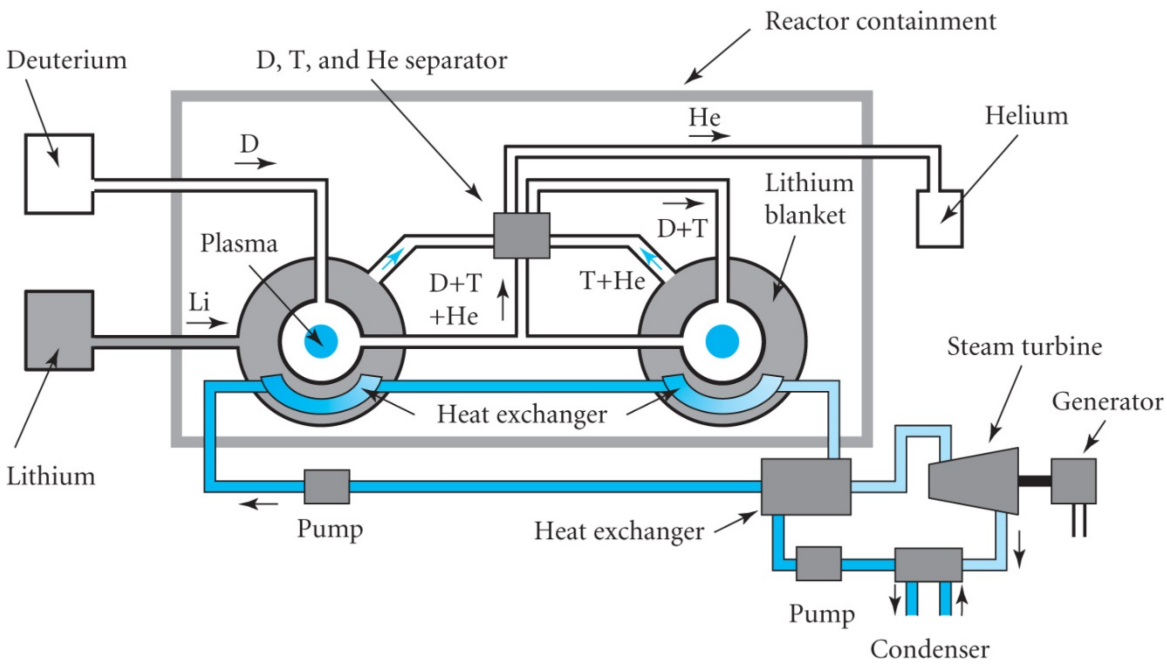
Plasma losses energy to reactor walls through radiation, particle diffusion, and heat conduction. Need **magnetic** or **inertial confinement** of plasma. P

Energetic neutrons can be stopped by lithium and used as a source of heat for thermal power a station and produce tritium:

$$\mathrm{n + \; {}^6Li \rightarrow T + \alpha + 4.78\ MeV}$$

$$\mathrm{n + \; {}^7Li \rightarrow T + \alpha + n - 2.87\ MeV}$$

Basic fusion reactor:




(From AJ Ch.9)

The 14.1 MeV neutrons pass through reactor wall and stopped by lithium blanket (tritium also produced)

Natrual lithium: 7.4% $^{6}$Li, 92.6% $^{7}$Li

Need tritium breeding ratio (TBR) > 1 for self-suffieciency.

Use the nentron from the $^{7}$Li reaction to increase T production by adding Be or Pb.

The neutrons from the D-T cycle can produce radioactive nuclei in steel reactor walls. Use ‘low activation’ steel (recycle after ~50 years), ceramic or fibre composite material.

*Ex. F1 What is the energy produced in one year by the fusion of 100 kg of deuterium and i50 kg of tritium in a reator?*

D+$^3$He and D+D reactions:

$$\mathrm{D} + {}^3\mathrm{He} = {}^4\mathrm{He} + \mathrm{p} + 18.3\ \mathrm{MeV}$$

$$\mathrm{D} + \mathrm{D} = \mathrm{T} + \mathrm{p} + 4\ \mathrm{MeV} \rightarrow {}^3\mathrm{He}+\mathrm{n}+3.3\ \mathrm{MeV}$$

Fusion power, $P_{fusion} = P_{\alpha}(20\%)+P_{n}(80\%)$

α-particles          Neutrons

$P_{\alpha}$ heats up plasma

$P_{n}$ generates heat for heat exchanger so powers the turbine

External power $P_{ext}$ may be required in addition to $P_{\alpha}$ to compensate for losses from plasma (radiation, particle diffusion, heat conduction, bremsstrahlung, synchrotron, radiation emitted from plasma impurities) and optimise plasma conditions.

Power loss, $P_{loss}=W/\tau_E$

Where W= total plasma energy, and

**$\tau_E$=energy containment time=time for plasma energy to be lost to the walls when plasma is in its operating state but no energy input**

The quality factor $Q$ is defined as: $Q=P_{fusion}/P_{ext}$

**Break-even**: $Q=1$

**Ignition**: $Q=\infty$ (corresponds to $P_{\alpha} = P_{loss}$, i.e. $P_{ext}=0$)

The Lawson criterion (AJ Ch.9)
For a 50-50 mixture of D and T,

$$n\tau_E>12kT/\{(1+f_{\alpha})\langle v\sigma\rangle E_{fussion}\}$$

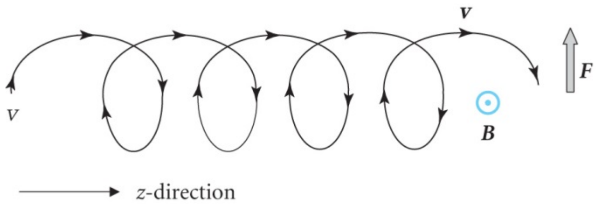
$n$=number of deuterons and tritons per unit volume
$k$=Boltzmann constant
$T$=absolute temperature
$f_a= P_{\alpha}/ P_{fusion}$
$v$=nuclear velocity
$\sigma$=fusion cross-section
$E_{fusion}$=17.6 MeV

Charged particle motion in magnetic and electric fields

Lorentz force, $\mathbf{F}=q\mathbf{E}+q\mathbf{v}\times\mathbf{B}$

**E**=electric field vector
**B**=magnetic field vector
*q*=charge
**v**=velocity

When **E**=0 and **B** is uniform, particle gyrates about a magnetic field line with angular velocity $\omega_c$ (cyclotron frequency), forming a helical path with radius $\rho$ (Larmor radius):

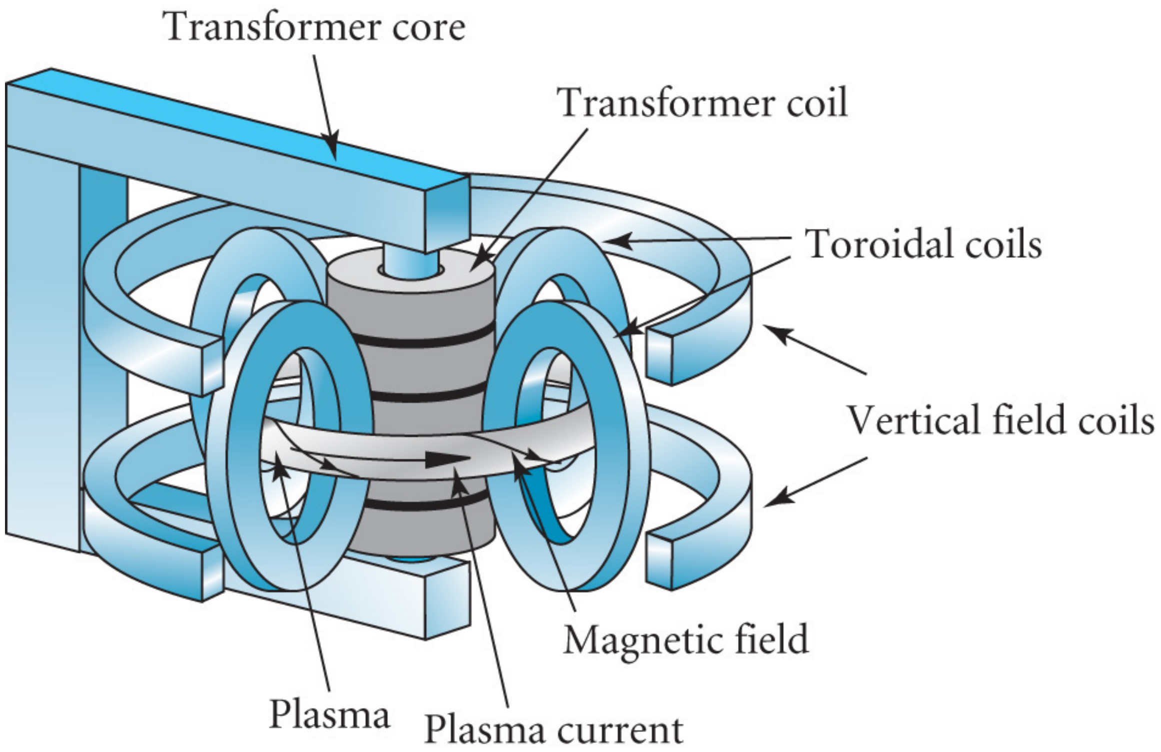


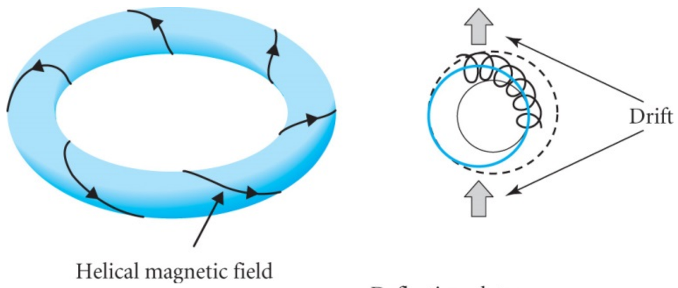

$\rho = mv_\perp/qB$,

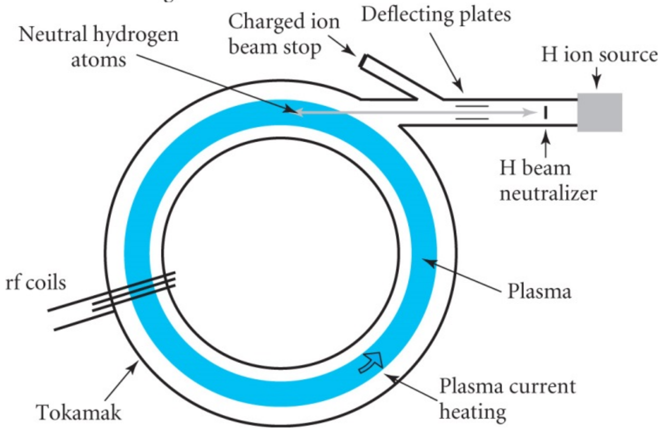
where $v_\perp$ is the component of velocity perpendicular to B, and

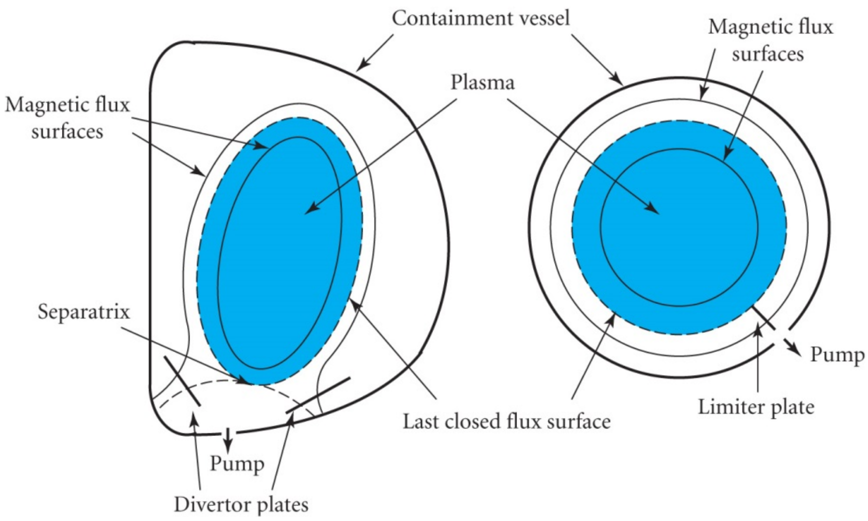
$\omega_c = qB/m$

The Tokamak






(From AJ Ch 9)

Barriers to progress:
Plasma stability
Ductile to brittle transition in steel subject to high neutron flux