If $j \to$ current density within the fluid

$P \to$ fluid pressure

$$F = j \times B - \nabla P \quad \text{--- (1)}$$

$\hookrightarrow$ Fundamental eq^n of MHD

using $\nabla \times B = \mu_0 j$

$$F = -\frac{B}{\mu_0} \times (\nabla \times B) - \nabla P$$

$$= -\nabla\left(\frac{B^2}{2\mu_0}\right) + \frac{1}{\mu_0}(B\cdot\nabla)B - \nabla P$$

$$= \frac{1}{\mu_0}(B\cdot\nabla)B - \nabla\left(P + \frac{B^2}{2\mu_0}\right) \quad \text{--- (2)}$$

for equilibrium $F = 0$, and hence, If the first term vanishes as is the case of current sheet

$$P + \frac{B^2}{2\mu_0} = \text{constant} \quad \text{--- (3)}$$

Condition of static equilibrium

Magnetic Confinement - Pinch Effect

From eq^n (1) for equilibrium $F = 0$

$$\nabla P = j \times B \quad \text{--- (4)}$$

Scalar product with B and J

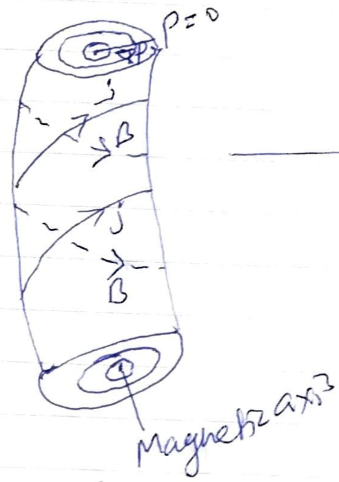
$$B \cdot \nabla P = B \cdot (j \times B) = 0 \quad \text{--- (5)}$$

and

$$j \cdot \nabla P = j \cdot (j \times B) = 0 \quad \text{--- (6)}$$

⇒ Both B and J lie on surfaces of constant pressure

If these surfaces happen to be closed, no B lines or j-lines can cross them,

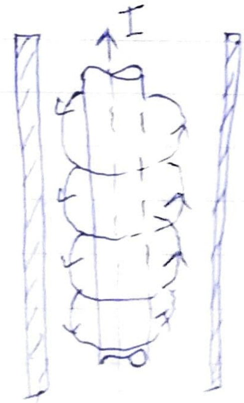


→ Surfaces made up from a winding of B lines and of j-lines

In these isobaric surfaces → pressure increases from outside towards the axis

Force j×B also points towards the axis.
Plasma is contained by the j×B forces.
↳ Magnetic confinement.

Magnetic field affect the dynamical state of a plasma



I → flowing through it axially

B → azimuthal field lines

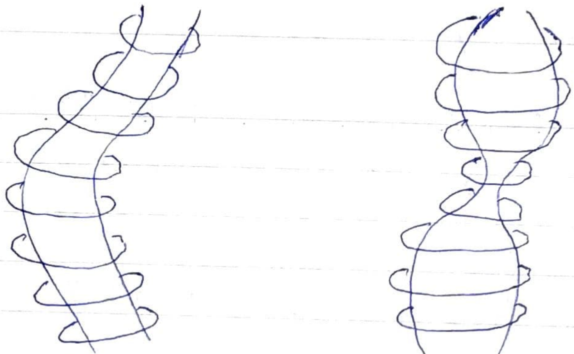
j×B → directed towards axis which tend to "pinch" or squeeze the plasma.

Under the effect of this force, the plasma contracts until the compressing electrodynamic force is compensated by the increased kinetic pressure $p = NkT$.

This phenomenon → "Pinch Effect"

Instabilities

No stable equilibrium pinch.



→ Kink instability
linear pinch is bent due to some perturbation

Sausage instability
Plasma columns are pinched by chance

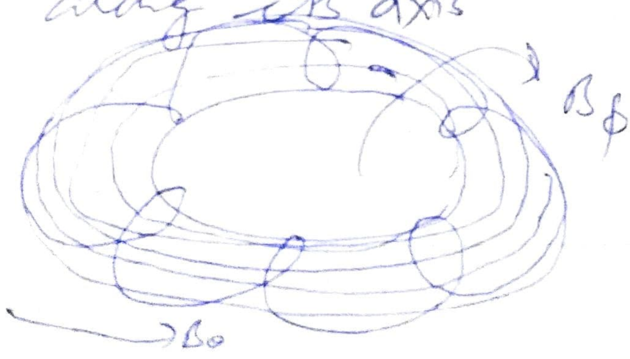
$B \propto \frac{1}{r}$, the pressure $\frac{B^2}{2\mu_0}$ is greater in the squeezed region, i.e. at the neck → further pinching → ultimately disrupting the column.

Several other kinetic instabilities → either by chance or by artificial deviation of the distribution of particles from Maxwellian distribution

To get over the difficulty of instability → various schemes for containing plasma

One such system → Tokamak

An axially symmetric toroidal system → Plasma is contained by the magnetic field of the current which flows along its axis



Tokamak → most developed magnetic confinement system

JET → Joint European Torus

* Plasma contained in a vacuum vessel.
vacuum maintained by external pumps
Plasma is created by letting a small puff of gas, which is heated by driving a current through it.
* Hot plasma → contained by a magnetic field
Combination of two sets of magnetic coils → Toroidal and poloidal field coils → creating field in both vertical and horizontal directions
→ Magnetic Cage.
* Large power supplies → to generate magnetic field and plasma current
* Additional plasma heating → Neutral beam injection (NBI) → neutral hydrogen atoms at high speed

Methods of Laboratory Plasma Production

LTE → Local Thermal Equilibrium

Three types of plasmas;
Glow discharge (GD)
Inductively coupled plasma (ICP)
Microwave-induced plasma (MIP)
Commonly used in plasma spectro-chemistry.

Direct current (d.c.) glow discharge

Sufficiently high potential difference → between two electrodes placed in a gas

Gas → breakdown into positive ions and electrons → giving rise to a gas discharge.

Few electrons are emitted from the electrode due to the omnipresent cosmic radiation.

Potential difference applied → electrons are accelerated and collide with the gas atoms

Inelastic collisions → leading to excitation and ionization

Excitation collisions → followed by de-excitation → emission of radiation → glow discharge

Ionization collisions → create new electrons and ions

Ions → accelerate towards cathode → release new electrons by ion induced secondary electron emission

Electrons → giving rise to new ionization collisions → creating new ions & electrons.

Electron emission at cathode → Ionization in plasma → glow discharge → self-sustain plasma.

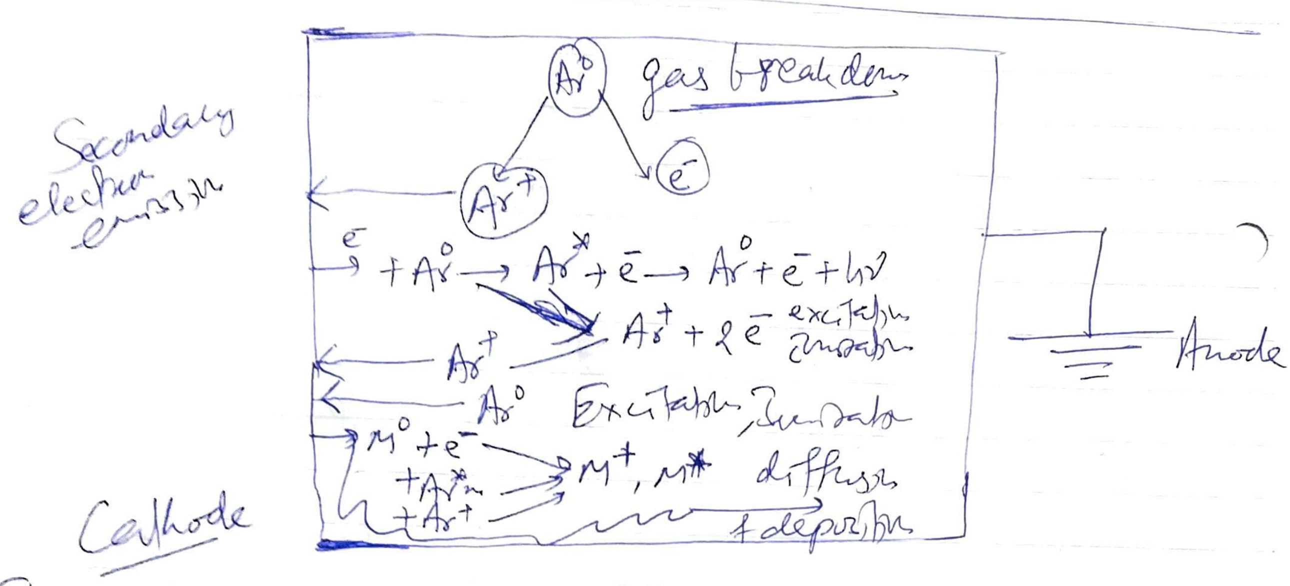
Sputtering → sufficiently high voltages

↳ Ions & fast atoms from plasma bombard cathode

↳ Release atoms of cathode material → Sputtering

↓

Useful in material technology



* Capacitively coupled (CC) radio-frequency discharges
* Pulsed glow discharges
* Atmospheric pressure glow discharges (APGDs)
* dielectric barrier discharges (DBDs)
* Corona discharges

Dielectric barrier discharge :- AC voltage from 1-100 kV with frequencies 50 Hz to 1 MHz applied between two electrodes with a dielectric barrier in between, operating pressure range of 0.1 - 1 atm.

RF discharges → Plasma breakdown is induced by RF range of frequencies generally from 1–100 MHz.

(A) Capacitively coupled :- RF power in the frequency range of 1 KHz – 100 MHz is applied on two electrodes in the pressure range of 10^{-5} – 10^{-4} atm.
Two electrodes and their sheaths form a capacitor

(B) Inductively Coupled :- This discharge is excited by an electric field generated by a transformer from an RF current in a conductor which is wound axially around a cylindrical dielectric plasma vessel. The power in the frequency range between 1 – 100 MHz is coupled in the discharge by the transformer action.

(C) Helicon Discharges :- electrodeless wave heated discharge

Dielectric cylinder surrounded by magnetic coils forms the plasma chamber → RF powered antenna launches the wave, that propagates along the tube and create plasma by wave-particle interaction

Microwave discharges

Microwave induced plasmas → all the discharges created by injection of microwave power in the frequency range of 300 MHz to 10 GHz.

Cavity Induced plasmas

Free expanding atmospheric plasma torches

Surface wave discharges (SWD)

electron-cyclotron resonance (ECR) plasmas

Wide range of conditions

Pressure range of 10^{-6} atm — few atm

Power of few W to several hundreds of kW