

# Vacuum and Low Temperatures

## 1. Pumping

- pressure ranges
- plumbing
- pumps

## 2. Measuring Pressure

- mechanical
- thermal conductivity
- viscosity
- ionisation

## 3. Vacuum flange

- feed throughs
- seals
- leaks
- leak detection
- diffusion
- outgasing



# Units

$$1 \text{ N/m}^2 = 1 \text{ Pa} = 10^{-5} \text{ bar}$$

$$1 \text{ Torr} = 4/3 \text{ mbar}$$

$$1 \text{ dyn/cm}^2 = 10^{-5} \text{ N/cm}^2 = 0.1 \text{ Pa}$$

$$1 \text{ atm.} = 760 \text{ Torr}$$

physical atmosphere

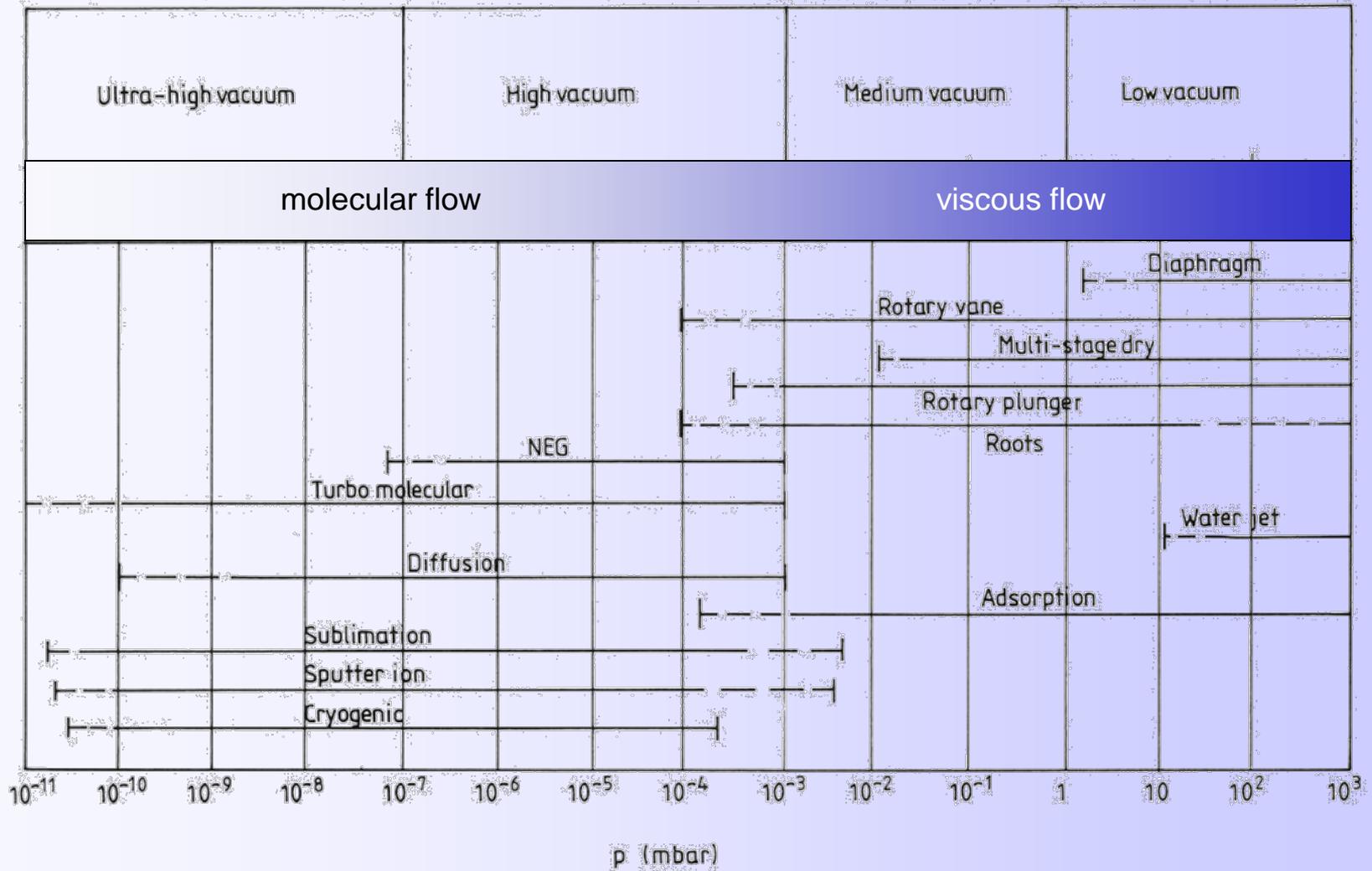
$$1 \text{ at.} = 1 \text{ kp/cm}^2 = 0.981 \text{ bar}$$

technical atmosphere

$$1 \text{ psi} = \text{lb/in}^2$$

$$1 \mu = 10^{-3} \text{ Torr}$$

# Vacuum Pumps and Pressure Ranges



# Pumping Lines

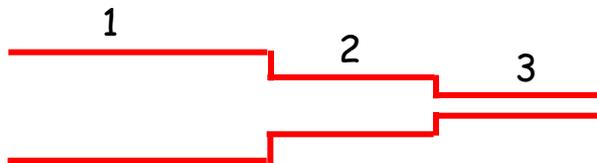


throughput

$$q = p \frac{dV}{dt} \quad \left[ \frac{\text{mbar } \ell}{\text{s}} \right]$$

Flow resistance:  $W = \frac{\Delta p}{q}$

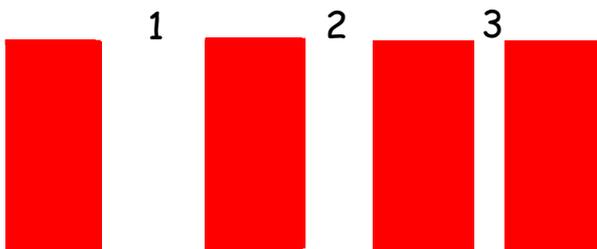
Flow conductance:  $F = \frac{1}{W} = \frac{q}{\Delta p}$



serial

$$W = W_1 + W_2 + W_3 + \dots$$

$$\frac{1}{F} = \frac{1}{F_1} + \frac{1}{F_2} + \frac{1}{F_3} + \dots$$

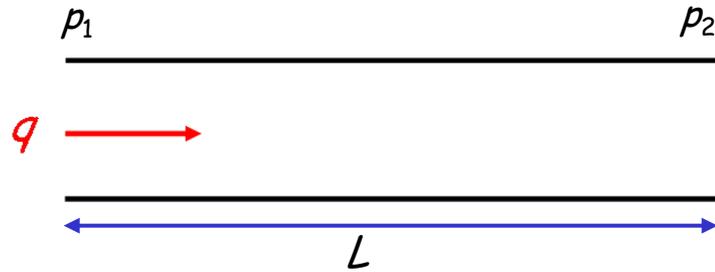


parallel

$$\frac{1}{W} = \frac{1}{W_1} + \frac{1}{W_2} + \frac{1}{W_3} + \dots$$

$$F = F_1 + F_2 + F_3 + \dots$$

# Flow conductance



Viscous regime

$$q = p_a \frac{dV}{dt} = p_a \frac{\pi r^4}{16\eta L} (p_1 - p_2)$$

average pressure

viscosity

$$F = \frac{q}{\Delta p} = p_a \frac{\pi r^4}{16\eta L}$$

Molecular flow (long tube,  $L/r > 5$ )

$$F_{\text{long}} = \frac{4r^3}{3L} \sqrt{\frac{2\pi k_B T}{m}}$$

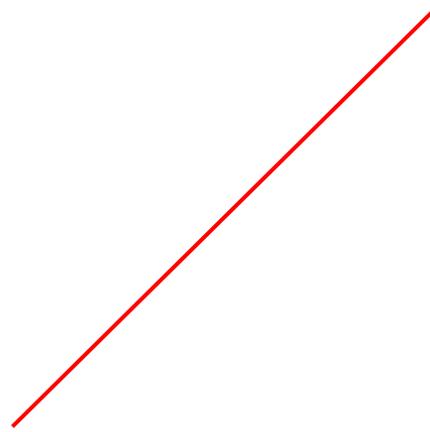
short tube,  $L/r < 5$

$$F_{\text{short}} = \frac{3L}{8r} K F_{\text{long}}$$

Clausius factor

# Flow conductance

$F/F_{\text{molecular}}$



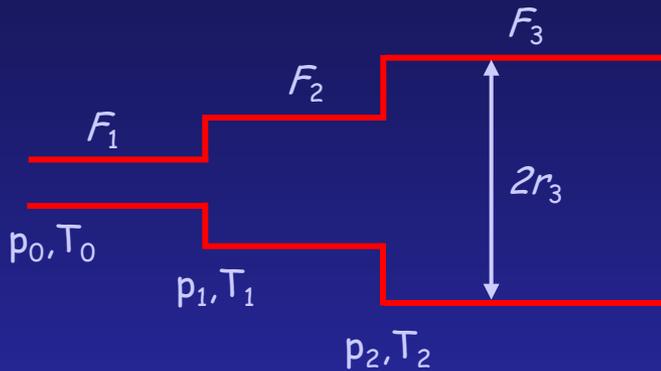
Transition region:  $F = F_{\text{viscous}} + \alpha F_{\text{molecular}}$

$$\alpha(T, p, \eta, r) = 0.81 \dots 1$$

$$\alpha \approx 1$$

# Design of Pumping Systems

most cases: molecular flow



$$\frac{p_0}{\sqrt{T_0}} - \frac{p_1}{\sqrt{T_1}} = A \frac{L_1}{r_1^3}$$

$$\frac{p_1}{\sqrt{T_1}} - \frac{p_2}{\sqrt{T_2}} = A \frac{L_2}{r_2^3}$$

$$\frac{p_{n-1}}{\sqrt{T_{n-1}}} - \frac{p_n}{\sqrt{T_n}} = A \frac{L_n}{r_n^3}$$

$$A = \frac{3}{4} q_m \sqrt{\frac{k_B}{2\pi m}}$$

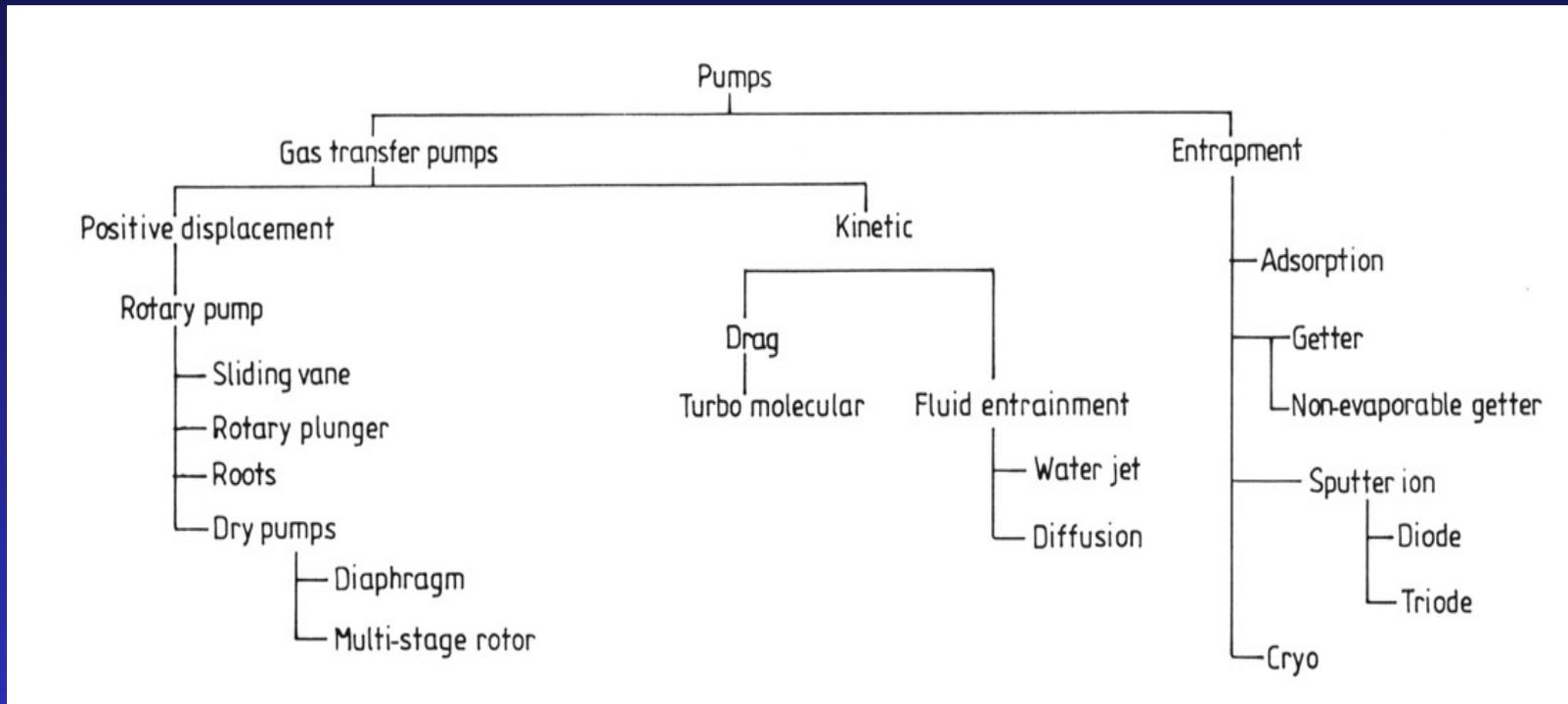
final segment at room temperature

$$\frac{p_0}{\sqrt{T_0}} - \frac{p_n}{\sqrt{T_n}} = A \sum_{i=1}^n \frac{L_i}{r_i^3}$$

$$\frac{p_0}{\sqrt{T_0}} \approx \frac{3}{4} q_m \sqrt{\frac{k_B}{2\pi m}} \sum_{i=1}^n \frac{L_i}{r_i^3}$$

if  $p_0, T_0, q_m$  are known, the design of the pumping system is straight forward

# Types of Pumps



relevant parameters:

pumping speed liters/second  $\ell/s$

throughput

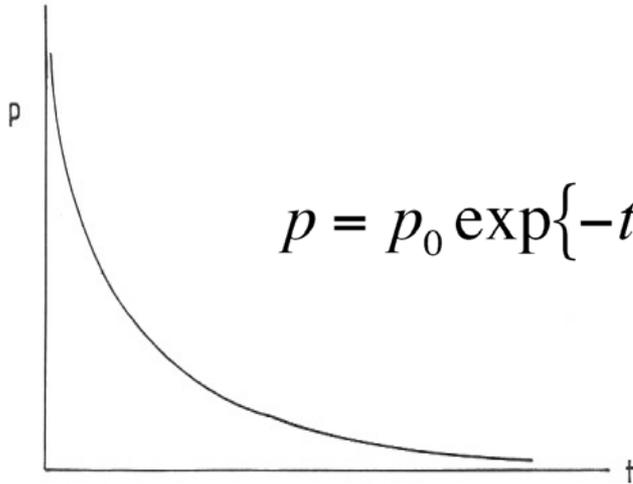
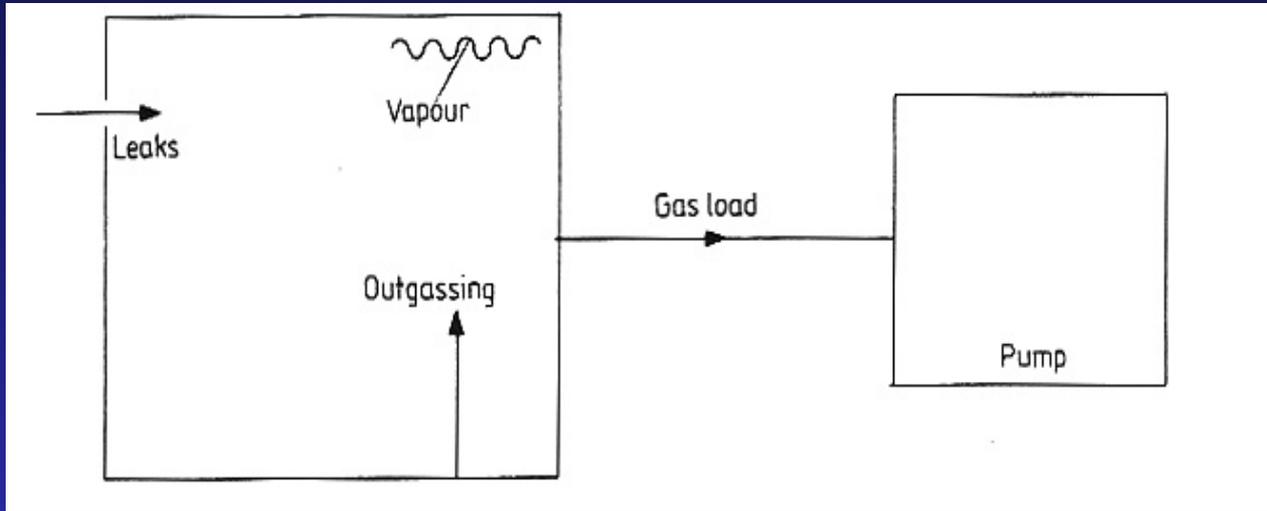
minimal pressure

operating range

inlet pressure

oil or dry

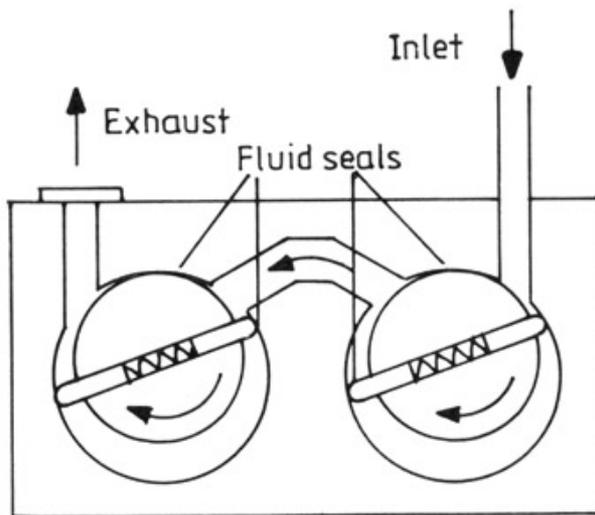
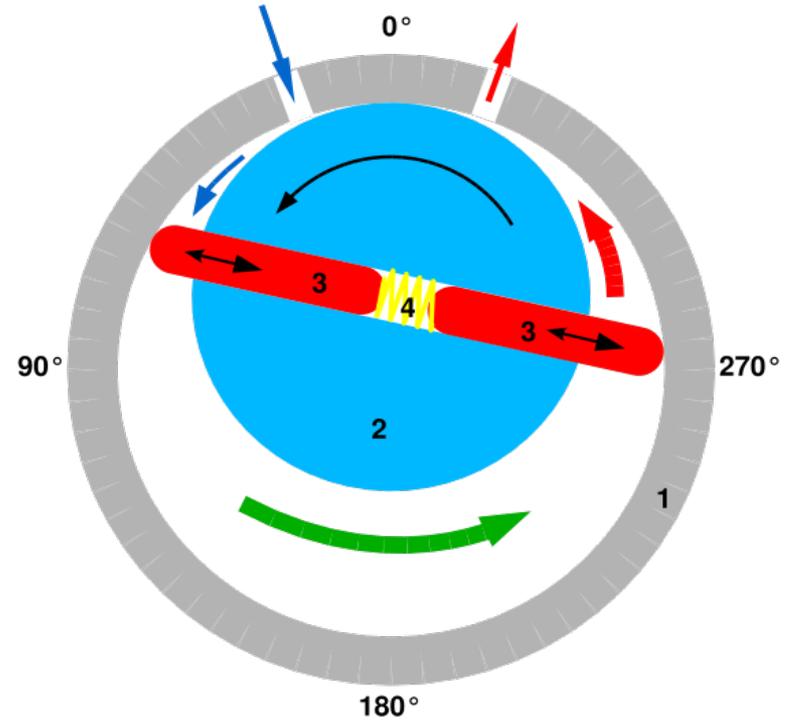
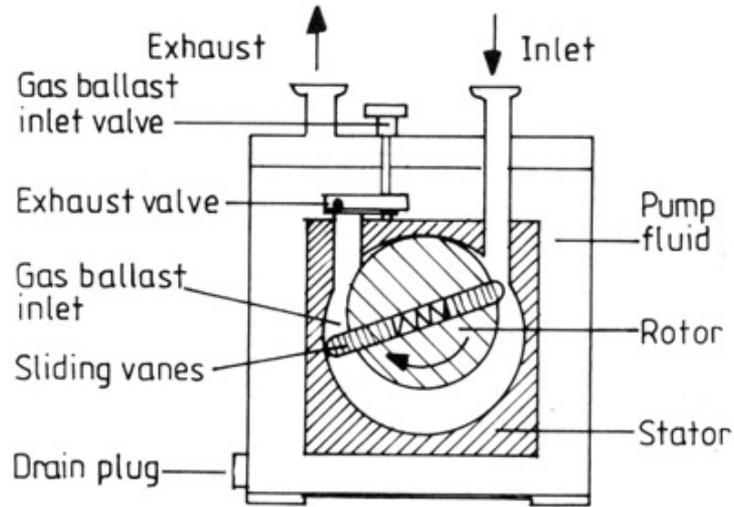
# Pumping Process



$$p = p_0 \exp\left\{-t / \underbrace{(V / S)}\right\}$$

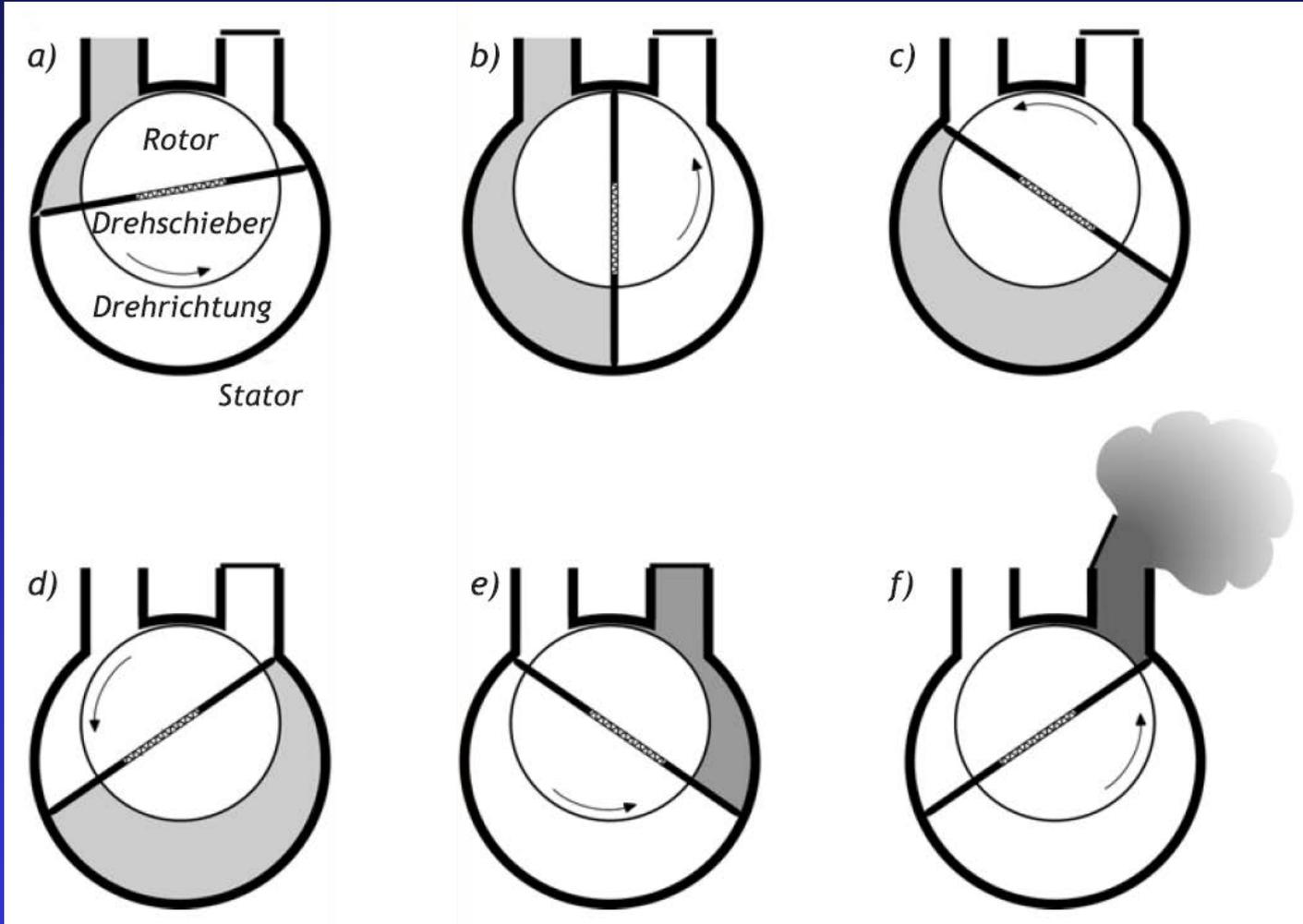
pumping time constant

# Rotary Pumps



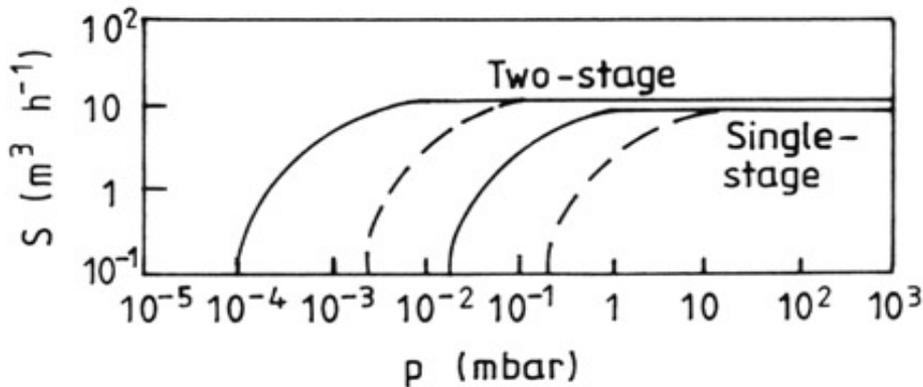
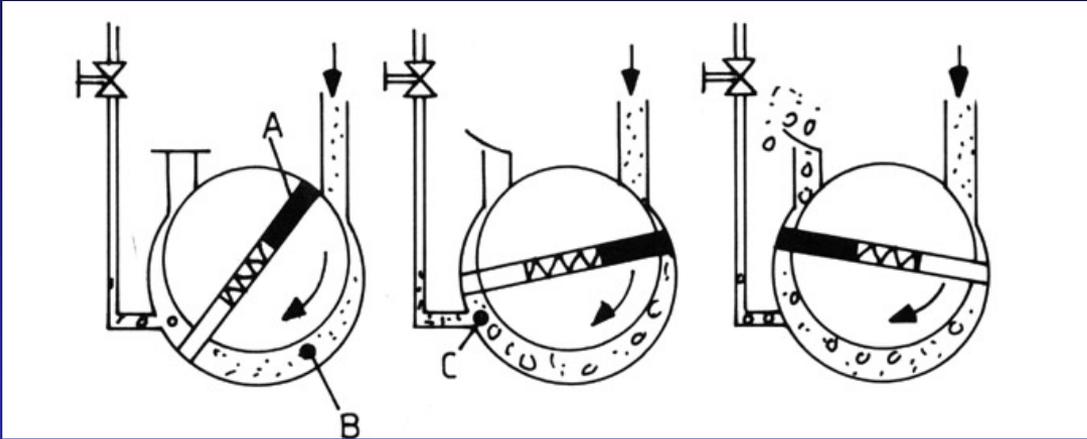
two stage rotary pump

# Operating Principle of a Rotary Pump



# Rotary Pumps With Gas Ballast

gas ballast is used when the evacuated vessel contains condensable vapours



— Without gas ballast  
- - - With gas ballast

# Root Pumps

large throughput ~ 250 torr  $\ell/s$

typical application:

$^3\text{He}/^4\text{He}$ -Kryostat

backing pump needed

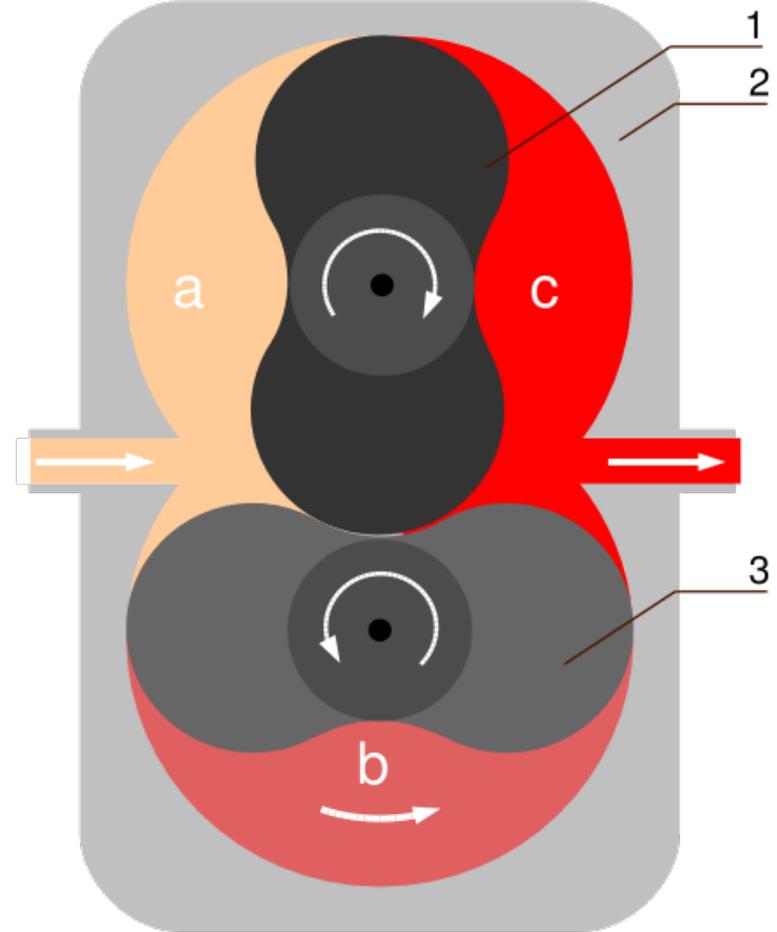
no sealing fluid  $\rightarrow$  dry

potential trouble spots:

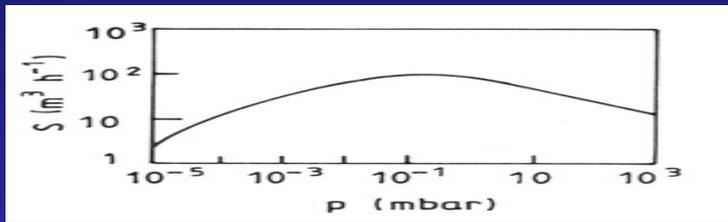
rotating seal

close mechanical tolerance 0.3 mm

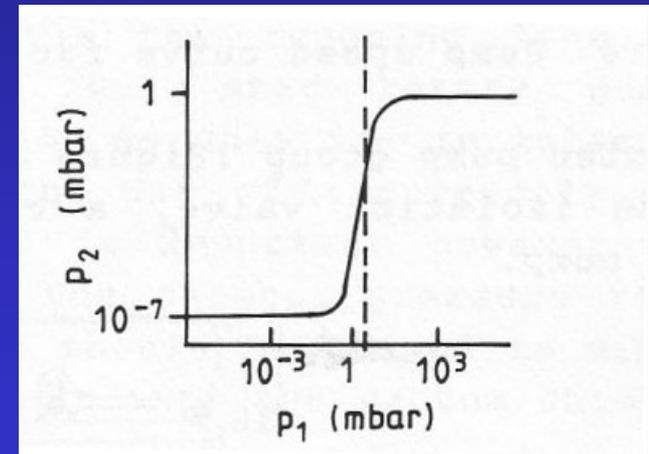
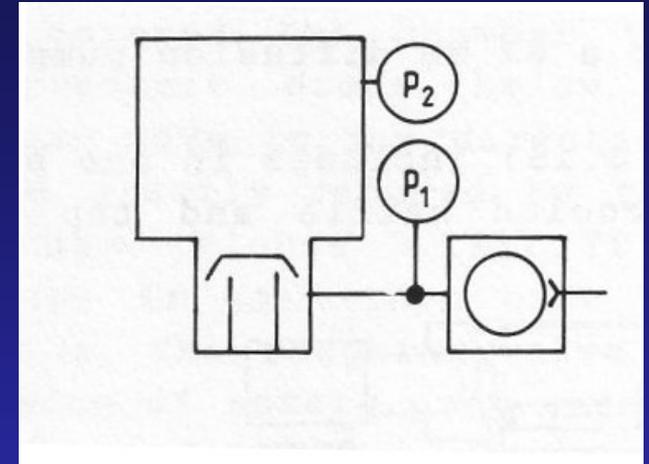
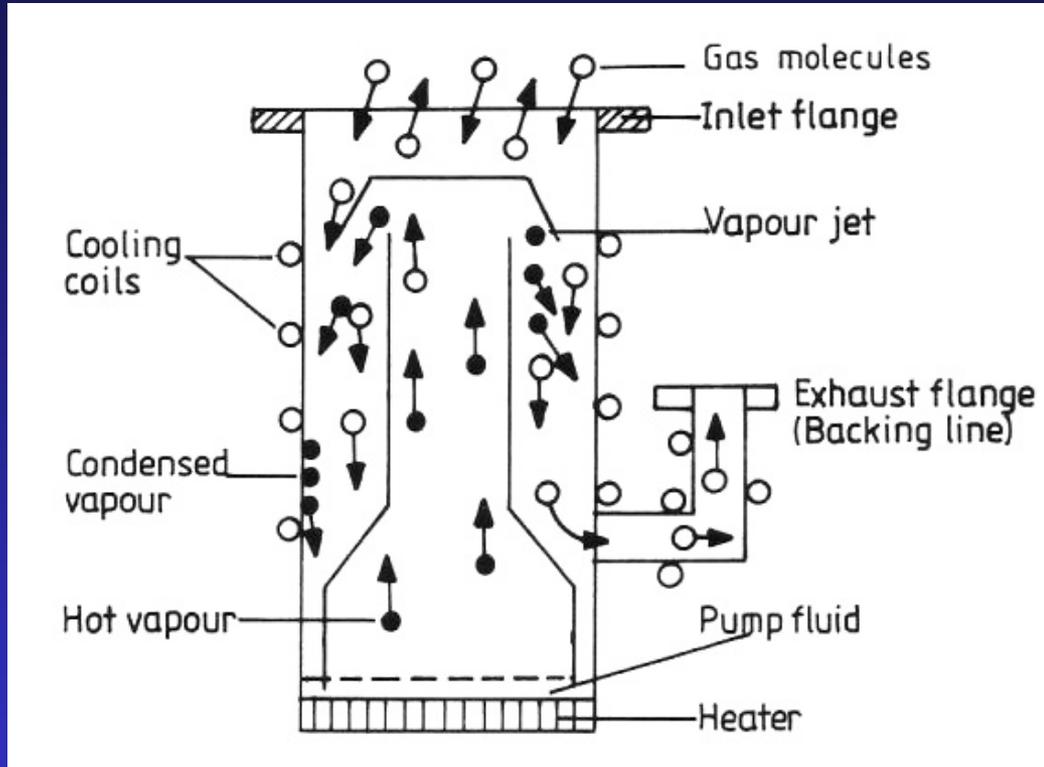
two lobed rotors interlocked and synchronised



# Pumping Speed of a Roots Pump



# Diffusion Pumps

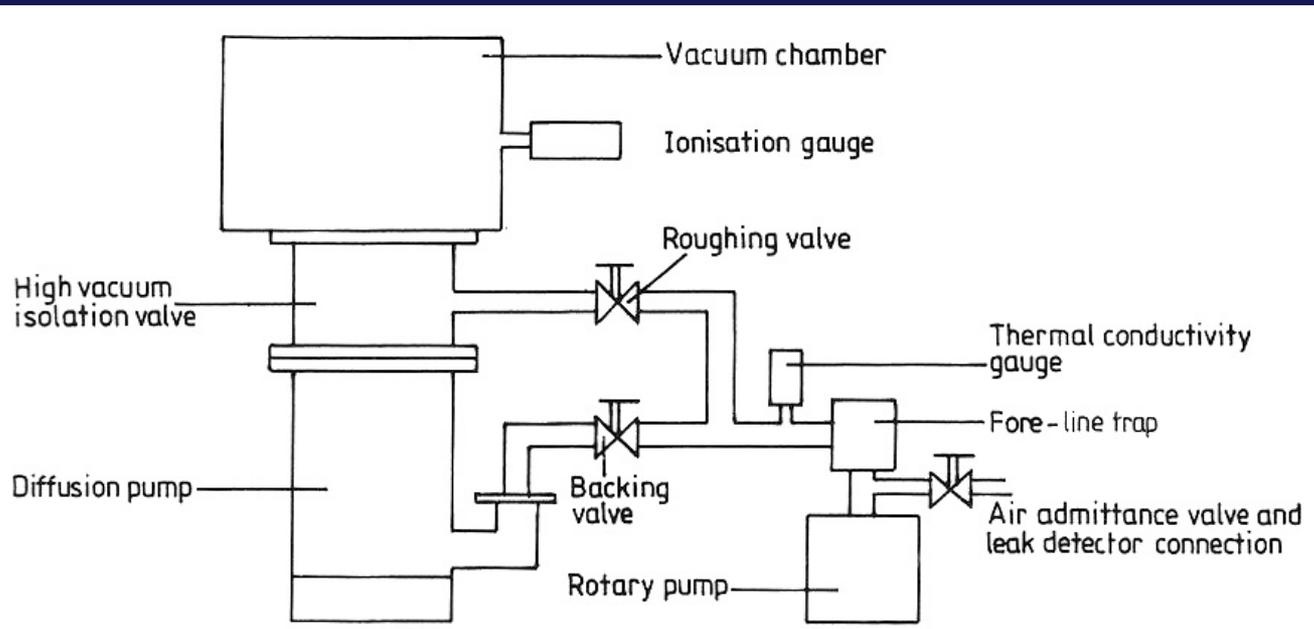


trapping the pumped gas molecules in a high velocity stream of oil

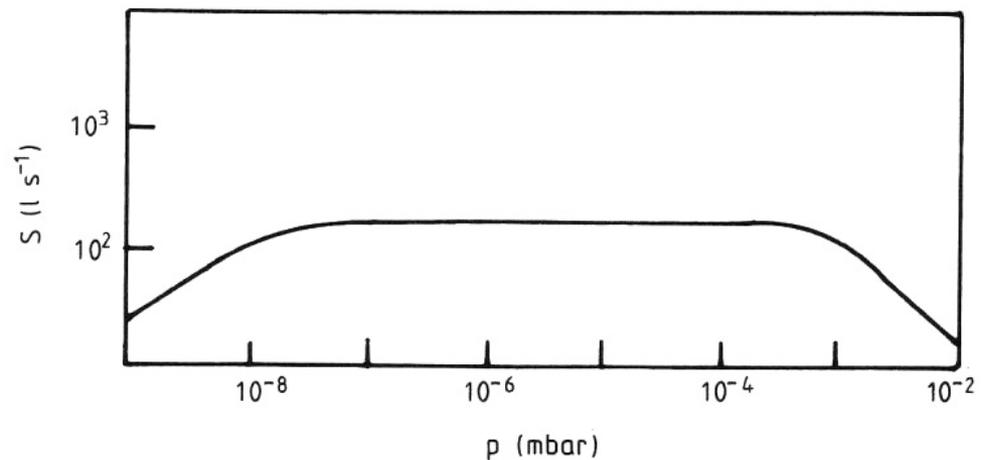
low ultimate pressure, high pumping rate, small cost

pumping speed between 10<sup>2</sup> ... 10<sup>4</sup> ℓ/s

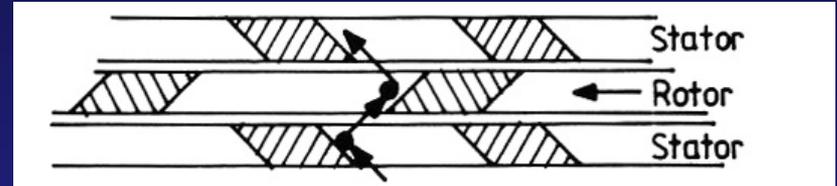
# Typical Diffusion Pump Setup



Pumping speed



# Turbomolecular Pumps



works like a high speed fan

high pumping speed 1500  $\ell/s$

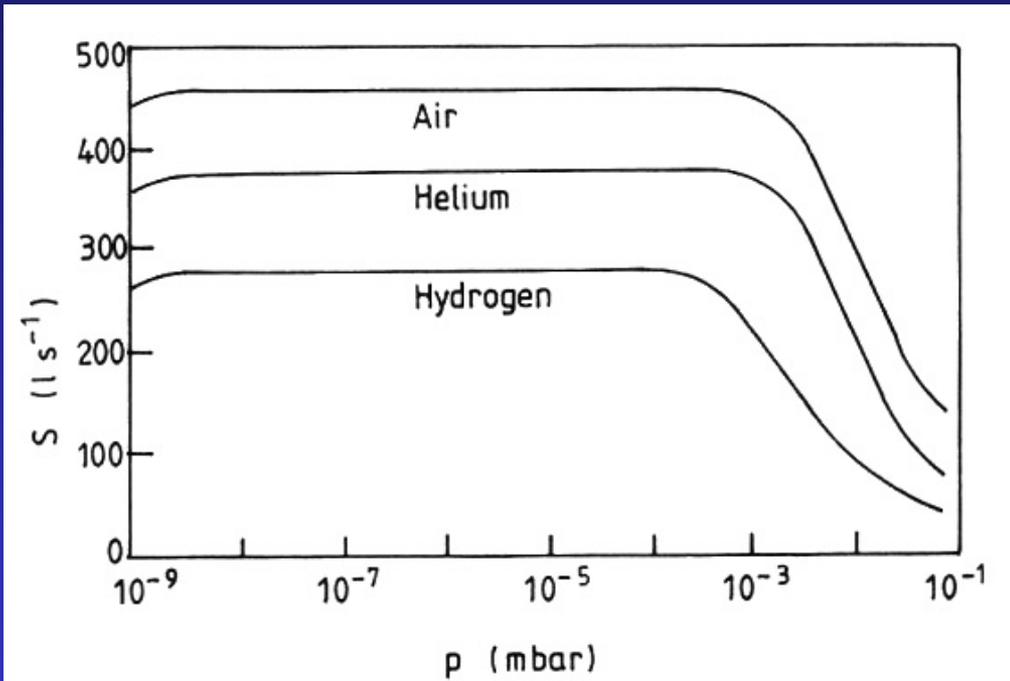
low ultimate pressure

start at ambiente pressure

expensive

# Turbomolecular Pumps

## Pumping Speed



gas	compression ratio
$\text{H}_2$	$10^3$
He	$10^4$
$\text{N}_2$	$10^9$

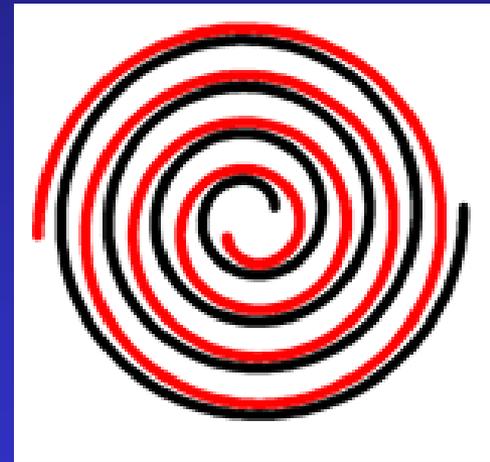
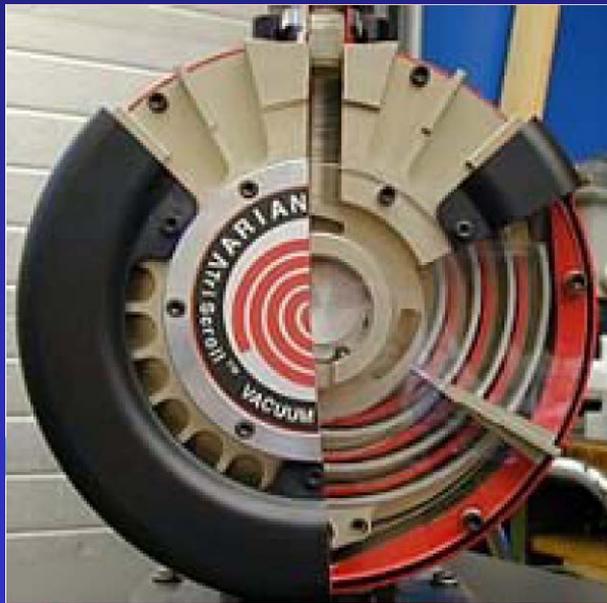
rotary backing pump is required  
producing a pressure of  $10^{-2}$  mbar

magnetically levitated  
bearings  $\rightarrow$  no oil or grease

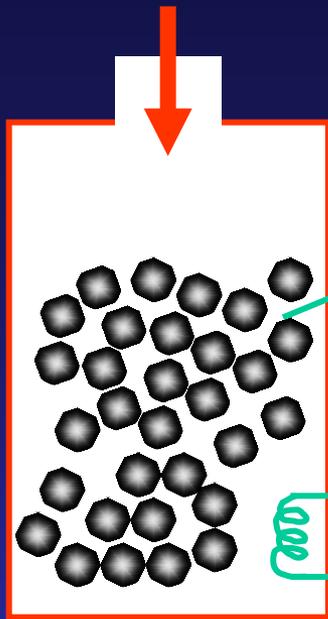
# Scroll Pumps

dry mechanical pump

used as backing pump in dry pumping systems



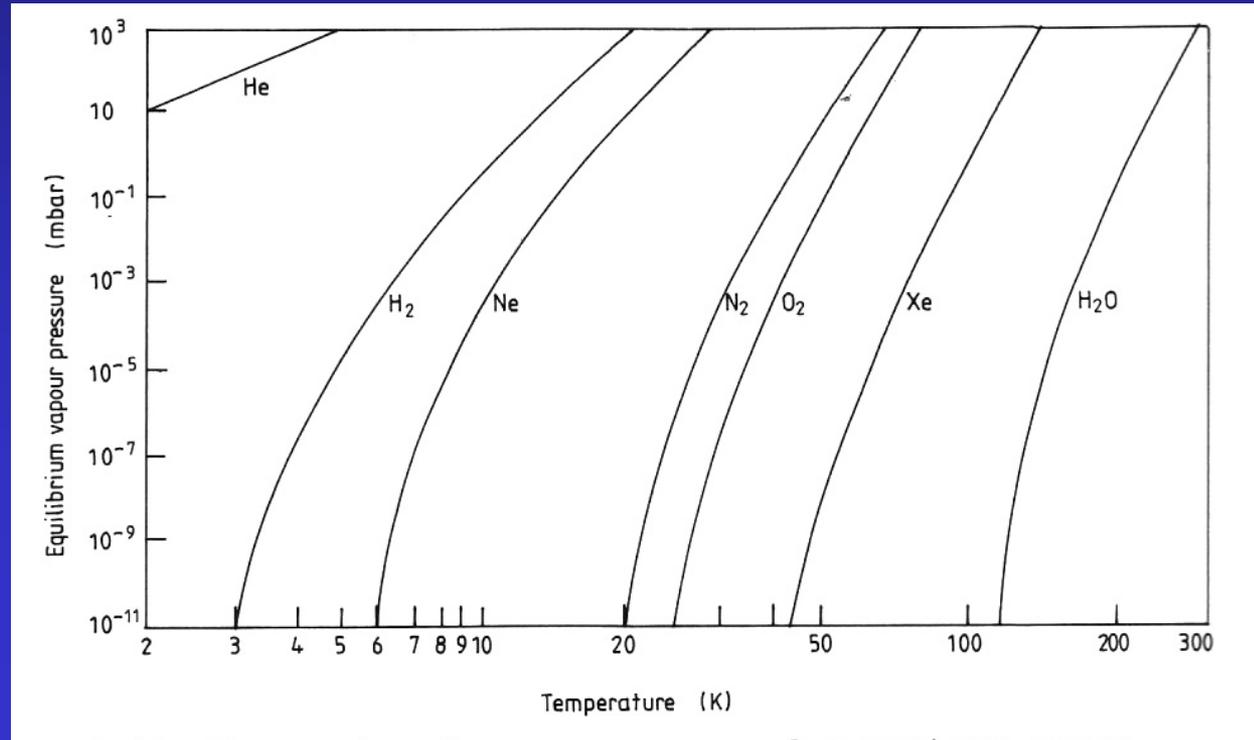
# Adsorption Pumps



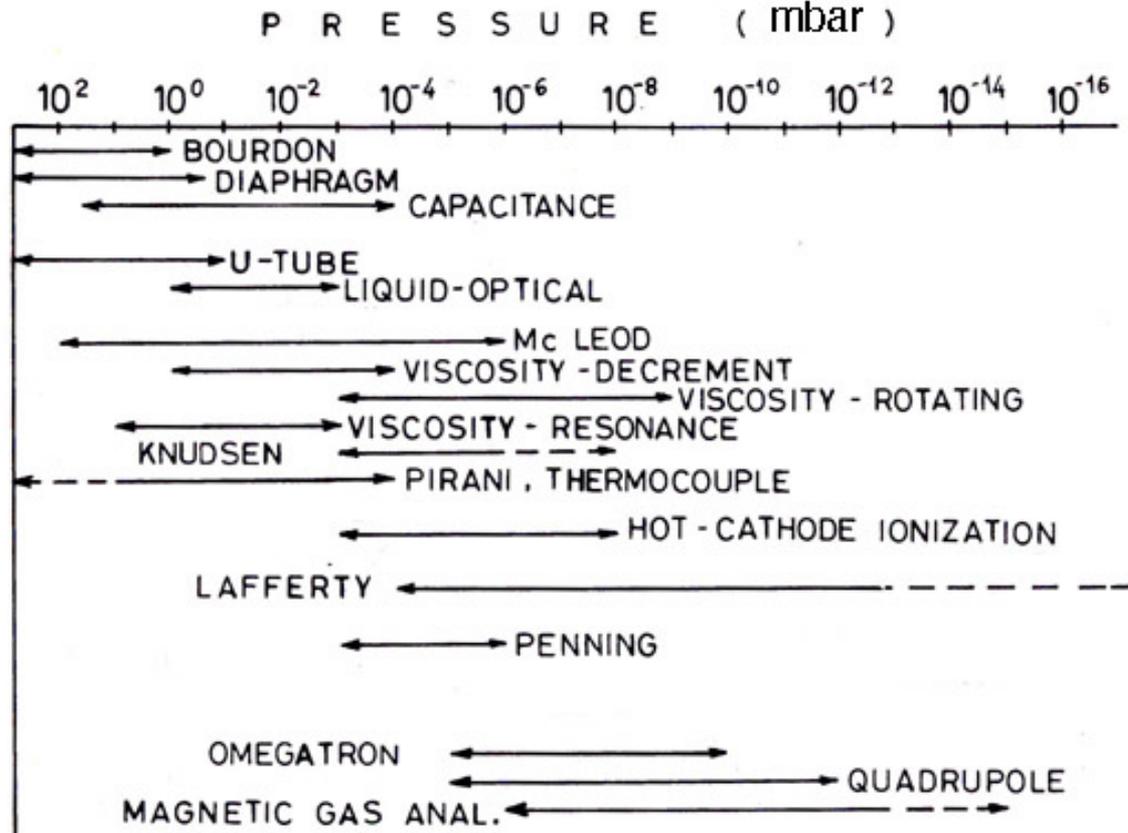
large surface area (charcoal)

heater for regeneration

Vapour pressure

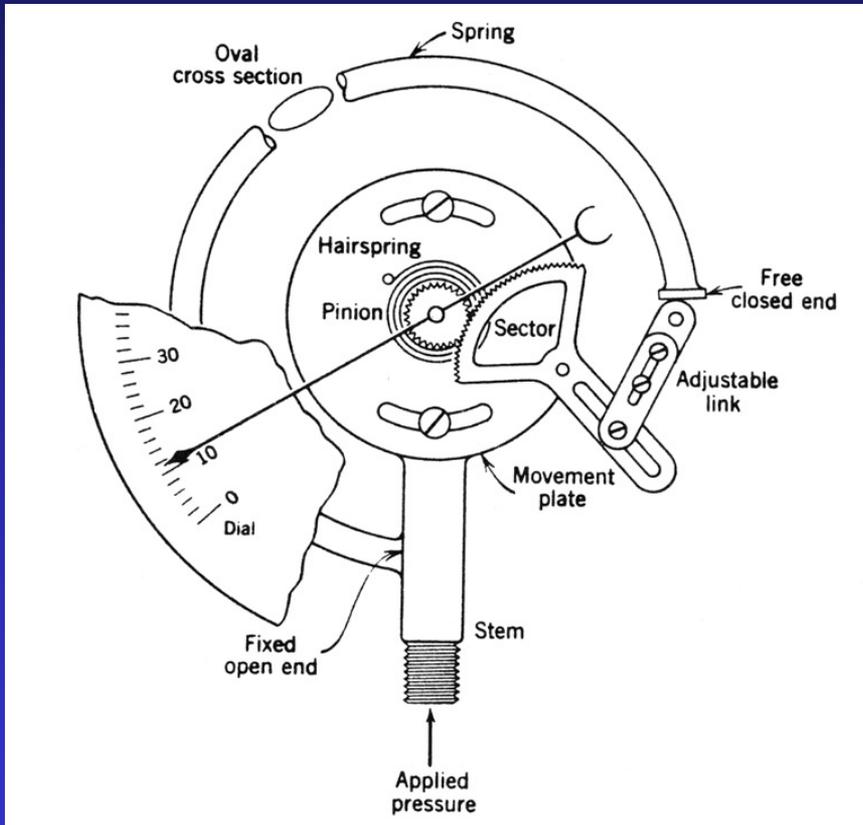


# Measurements of Pressure



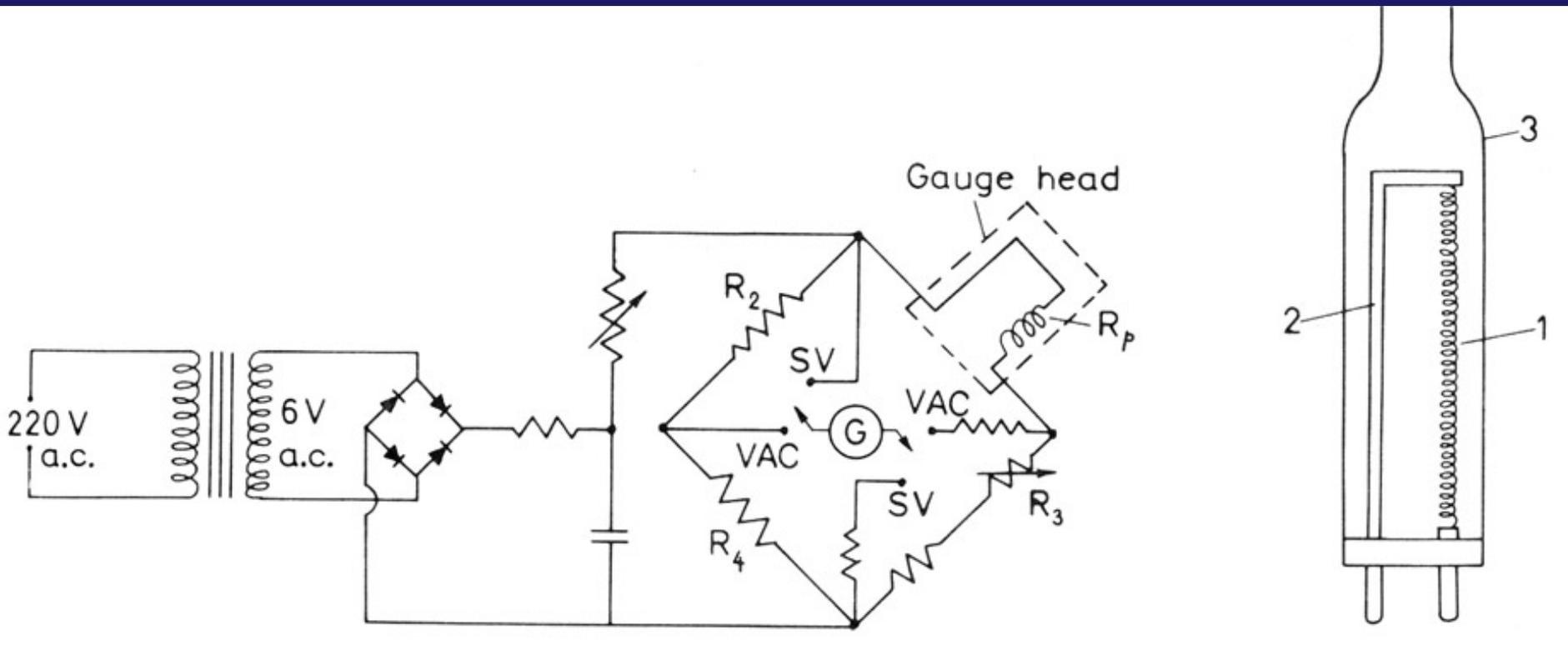
# Mechanical Gauges

Bourdon gauge (10 mbar to 1 bar)



# Thermal Conductivity Gauges

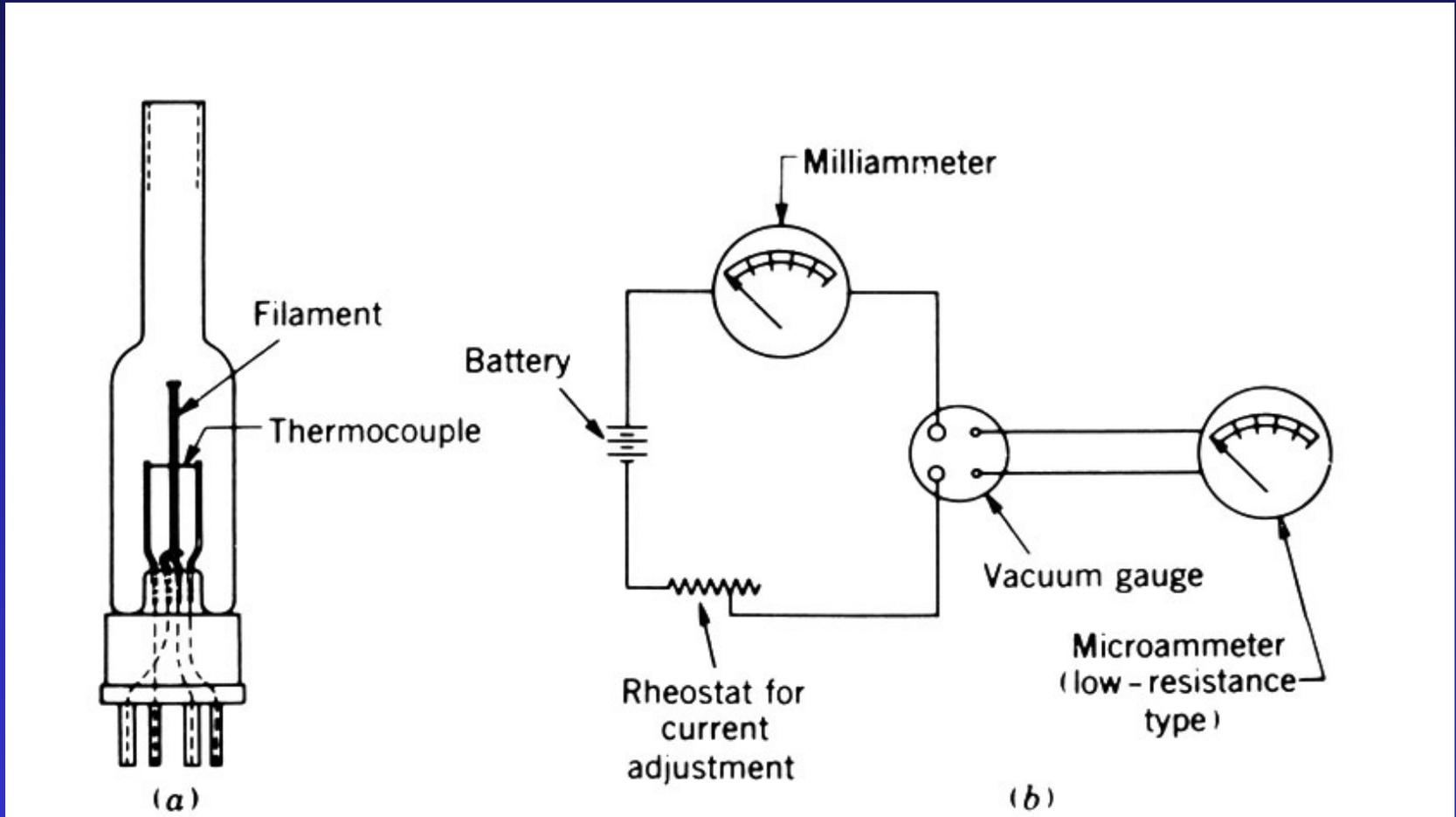
Pirani Gauge ( $10^{-4}$  mbar to 1 bar)



Resistance change of a gas cooled wire is measured with a bridge circuit under constant joule heating

# Thermocouple Gauge

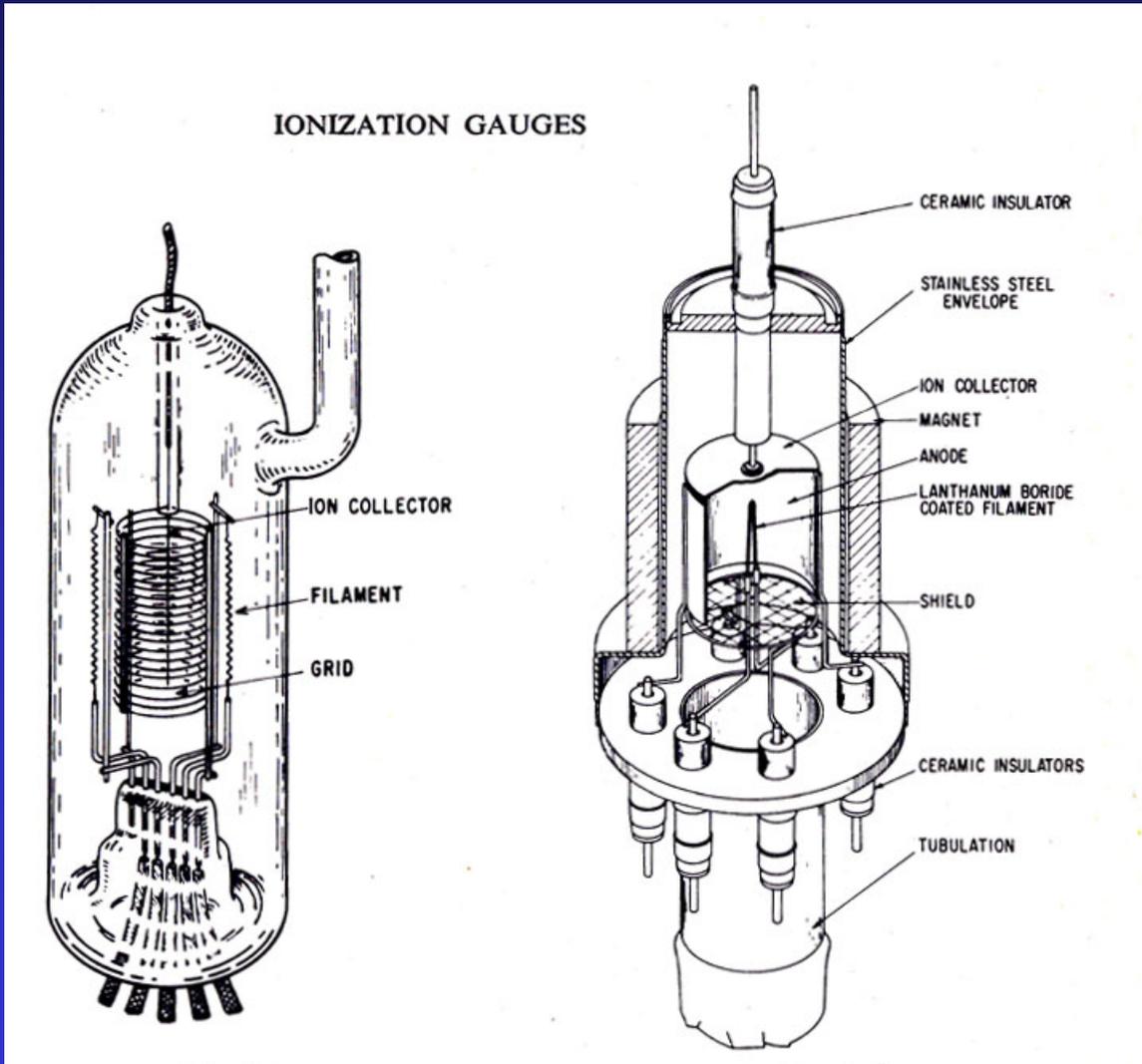
( $10^{-4}$  mbar to 1 bar)



Temperature of gas cooled resistive wire is measured via thermocouples

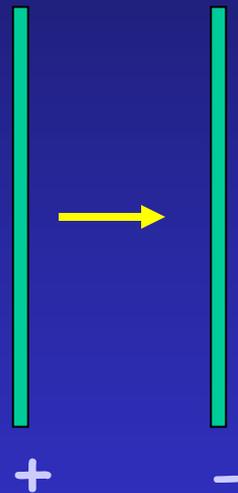
# Ionisation Gauges

Hot cathode ionisation ( $10^{-7}$  mbar to  $10^{-2}$  mbar)



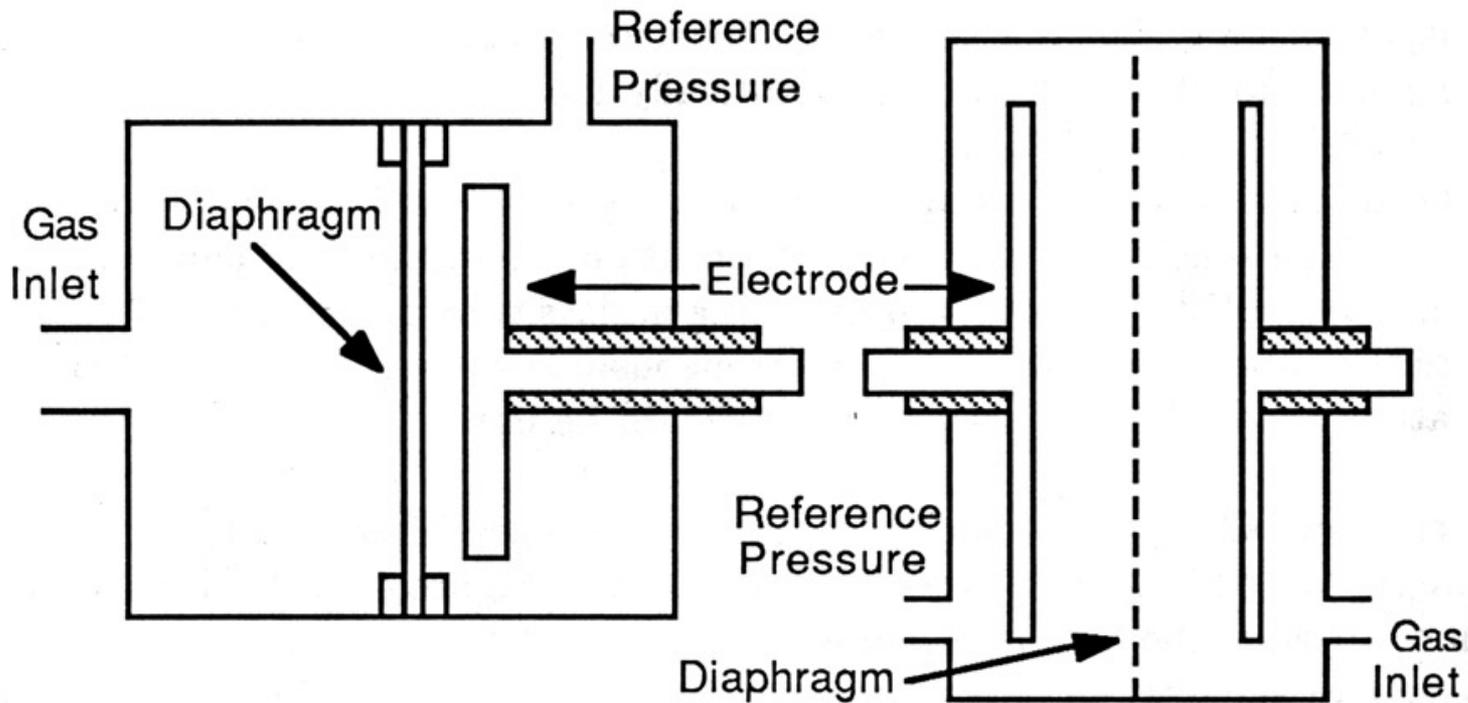
# Ionisation Gauges

Penning cold cathode ionisation ( $10^{-7}$  mbar to  $10^{-2}$  mbar)

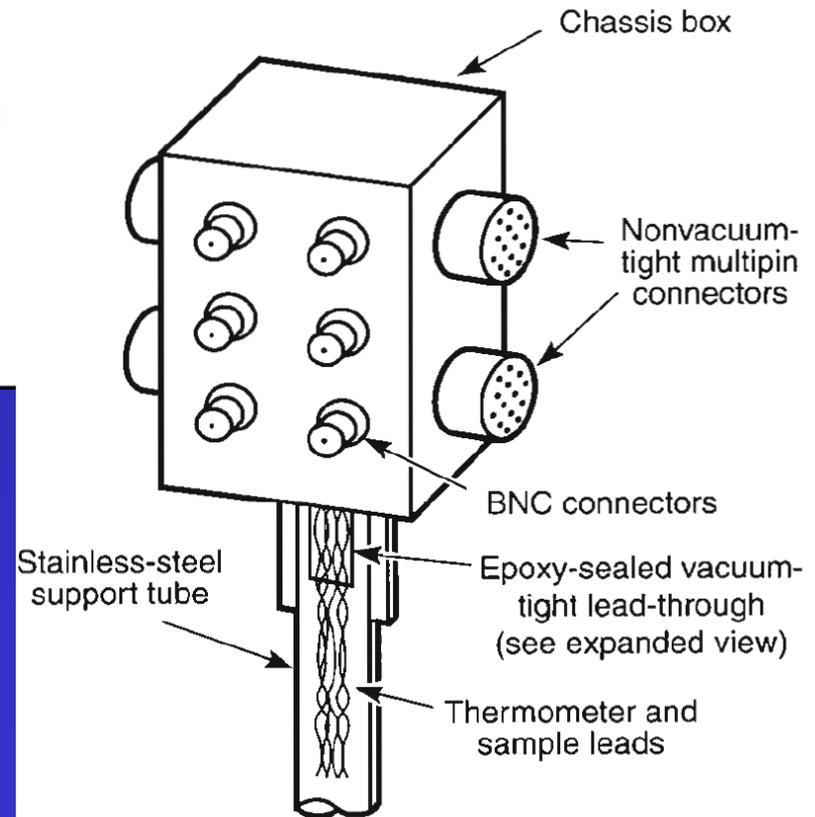
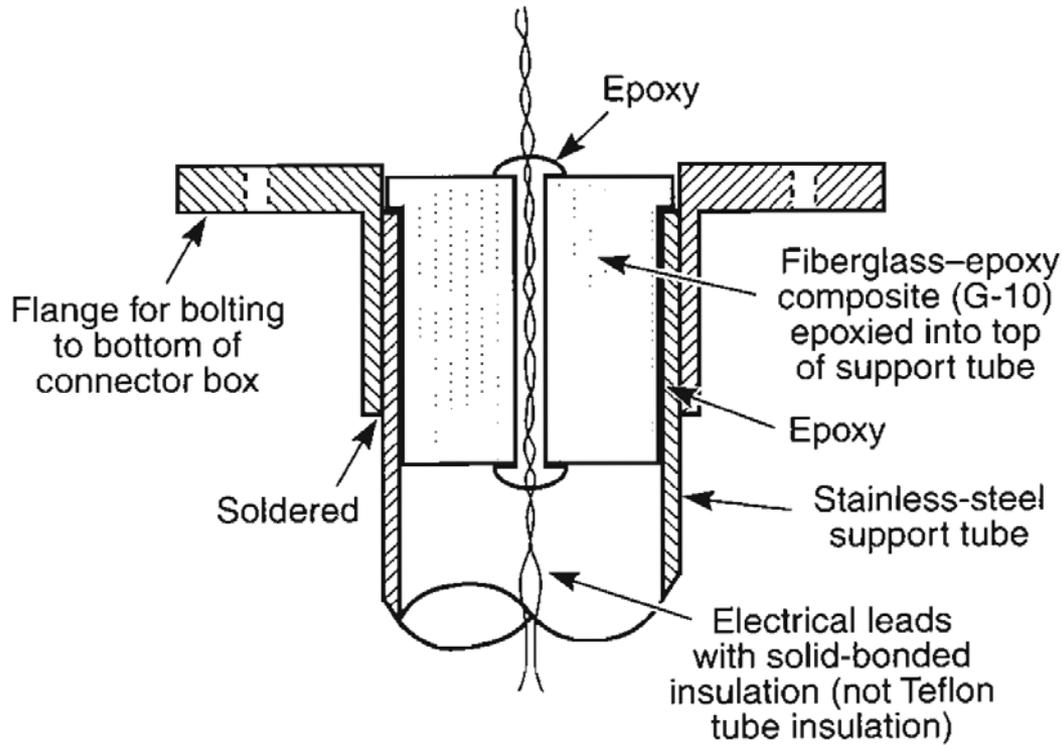


High voltage  $\rightarrow$  gas ionisation  $\rightarrow$  plasma  $\rightarrow$  measurement of ionisation current

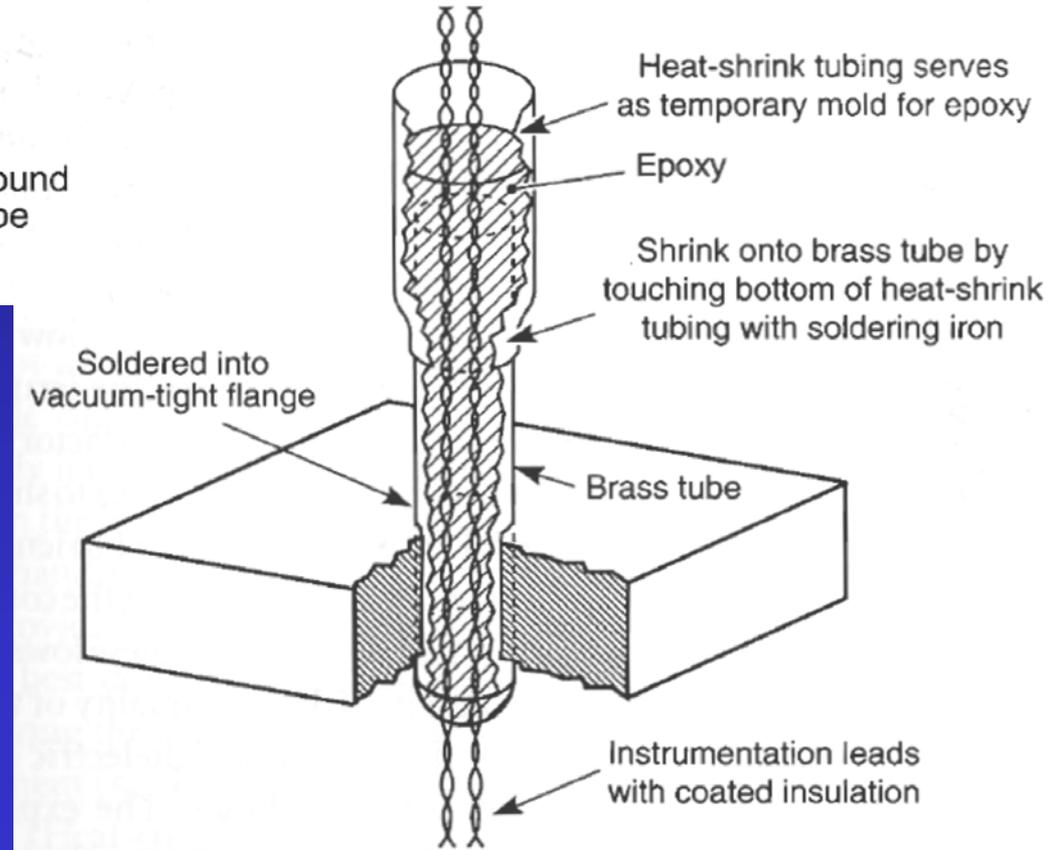
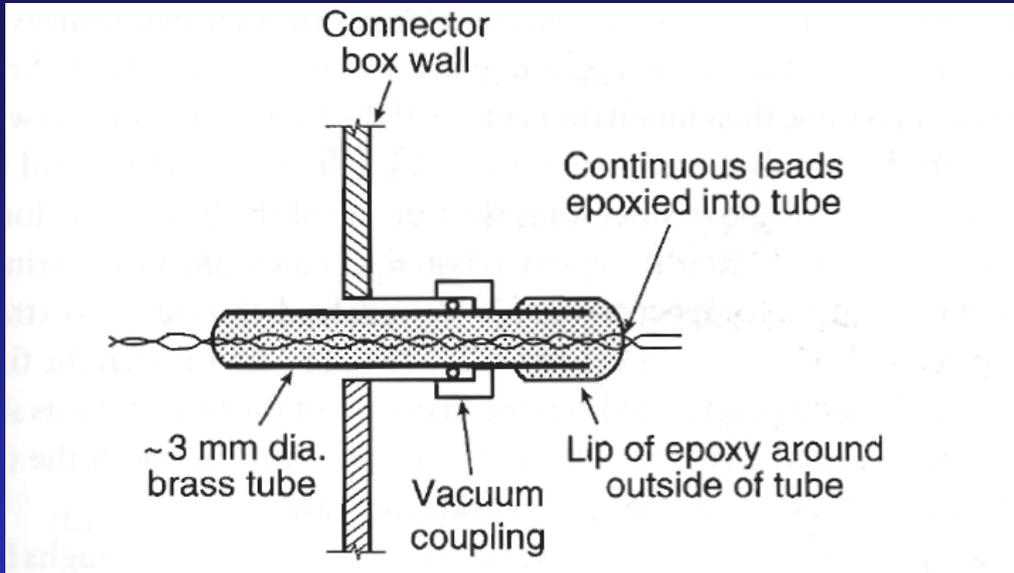
# Capacitance Gauge



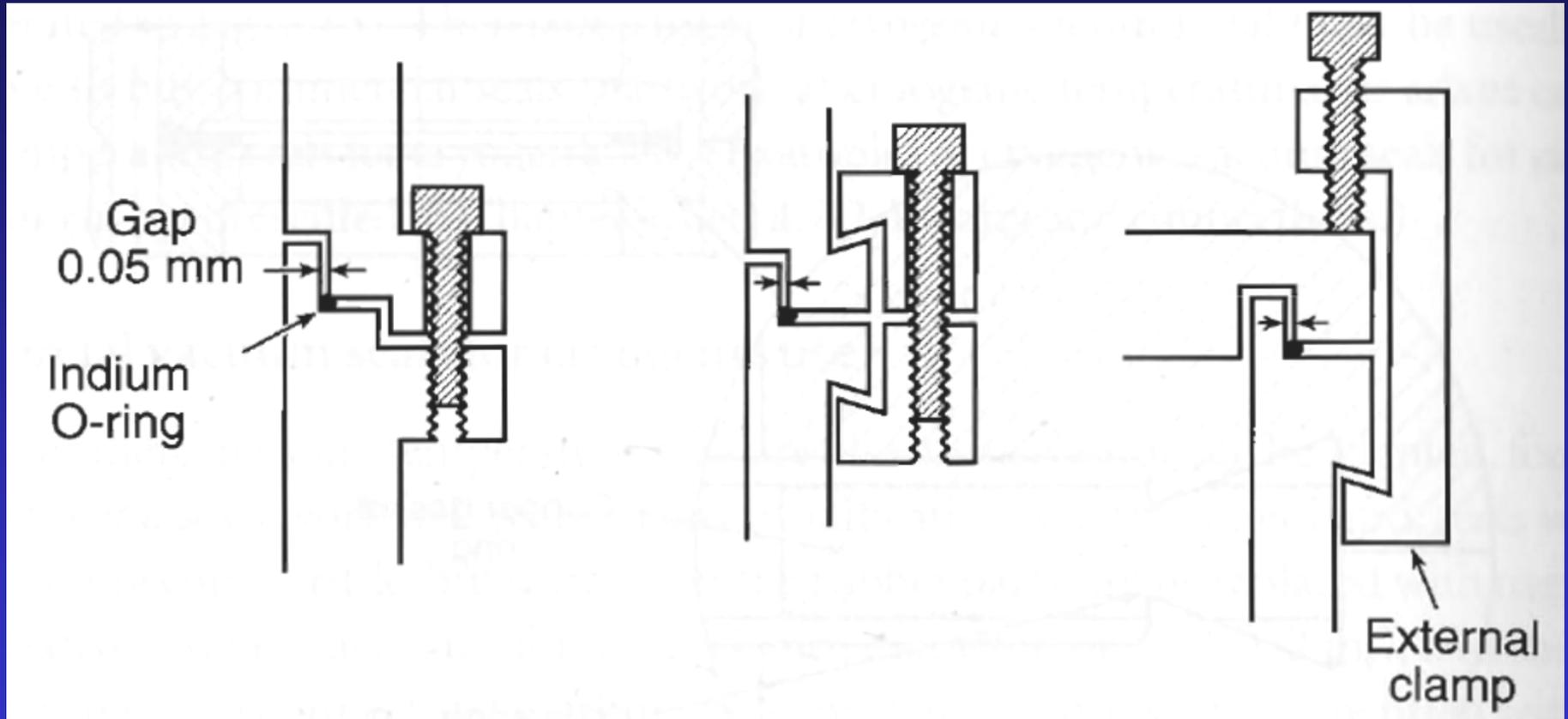
# Seals and Feed Throughs



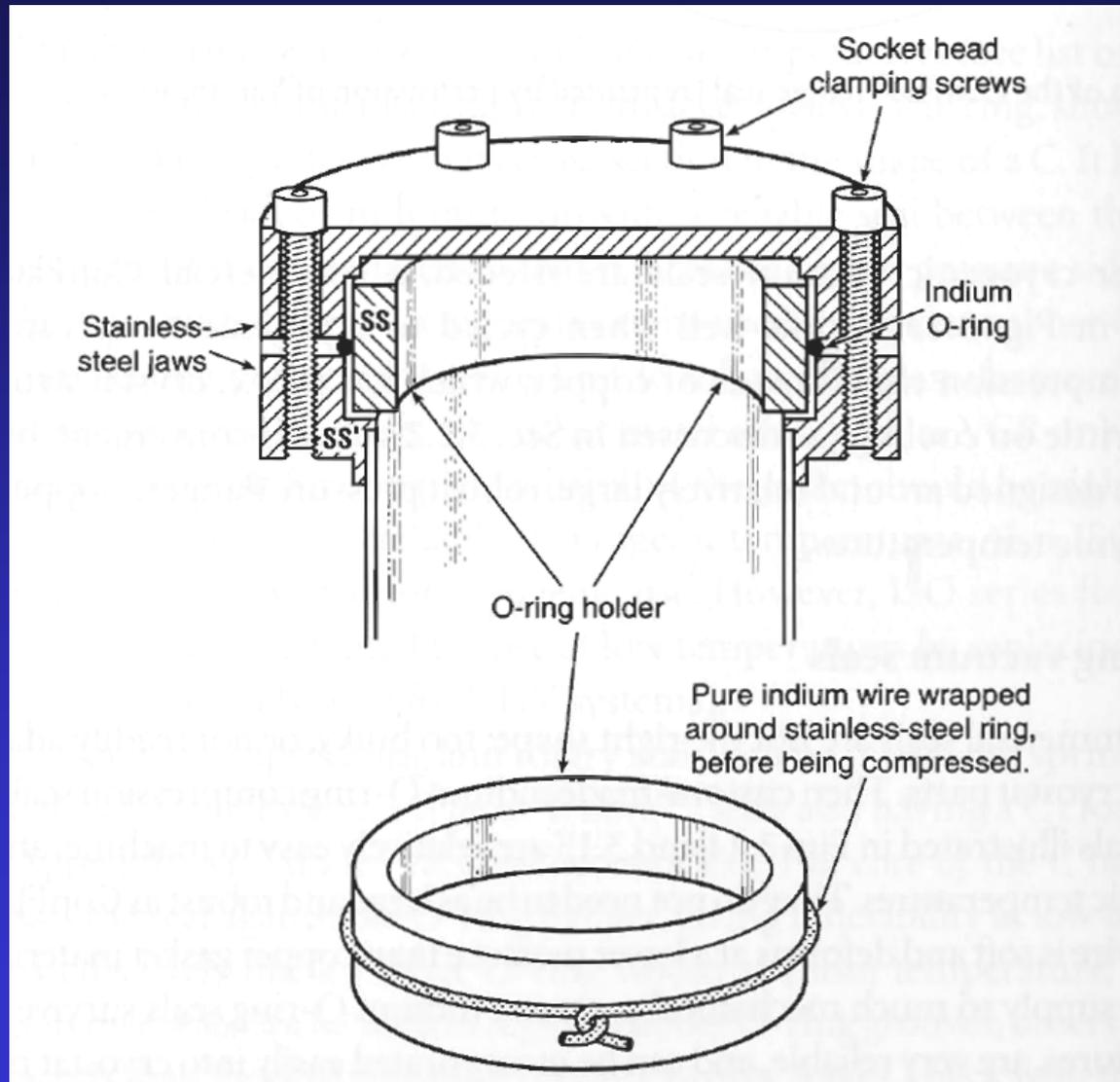
# Seals and Feed Throughs



# Indium Seals



# Indium Seals



# Leaks and Leak Detection

## Indications to have a leak in a cryostat:

oscillating base temperature

higher 1 K pot temperature

higher base temperature

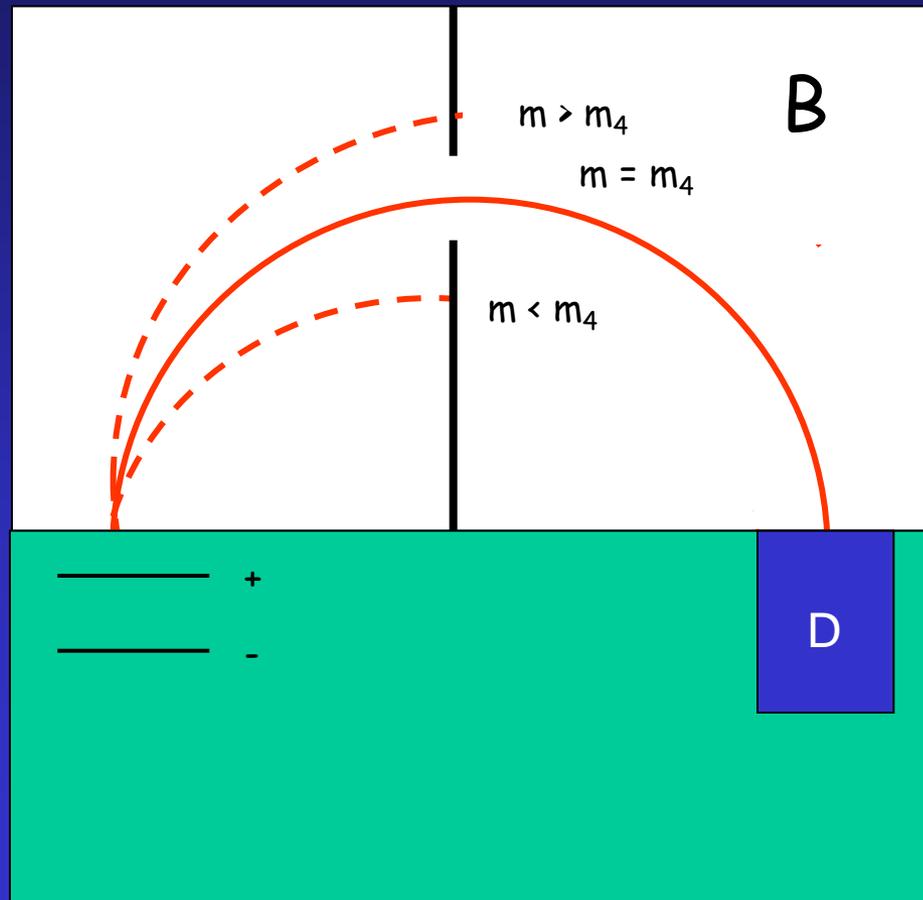
bad vacuum

thermal short

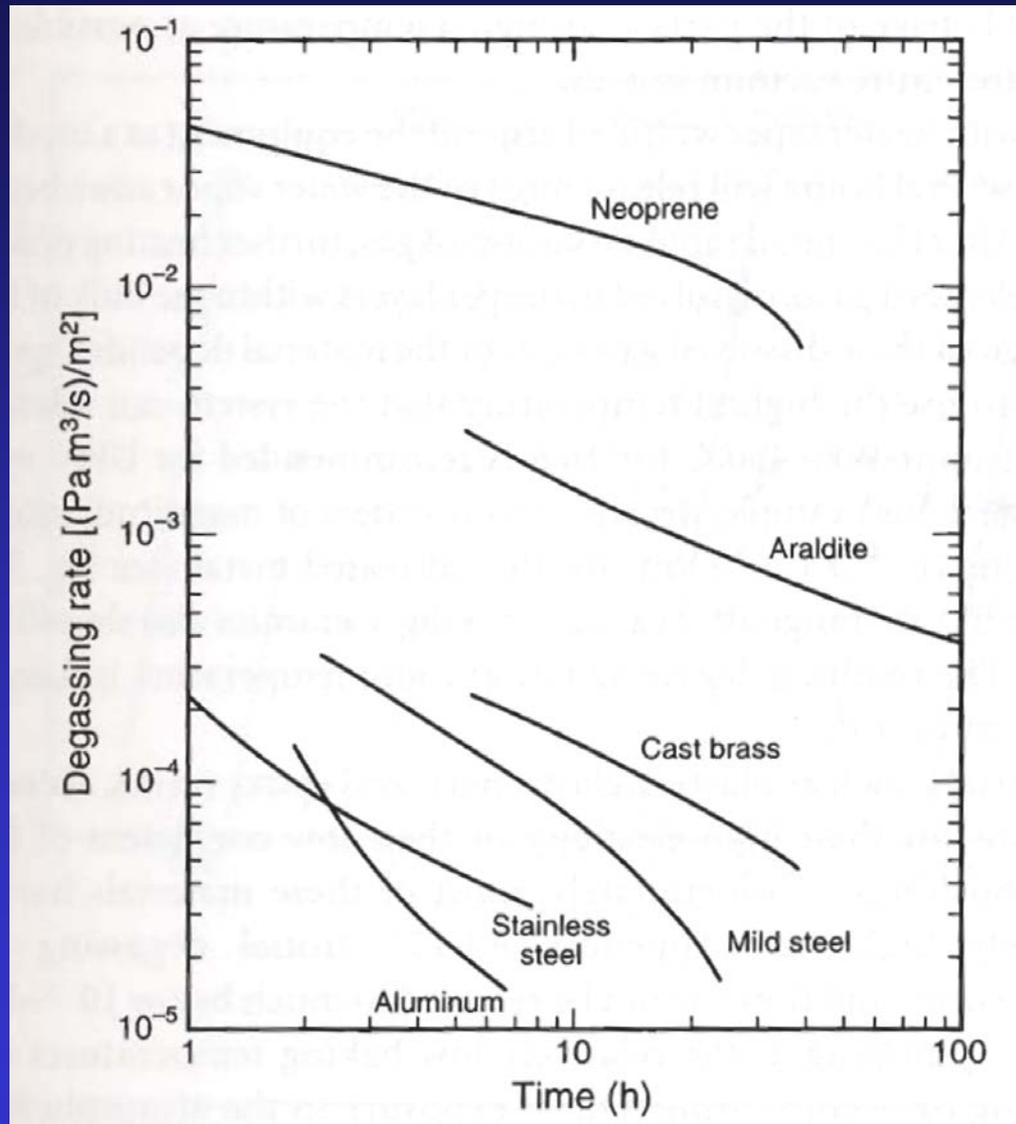


# Leaks and Leak Detection

mass spectrometer



# Outgassing



# Permeation

