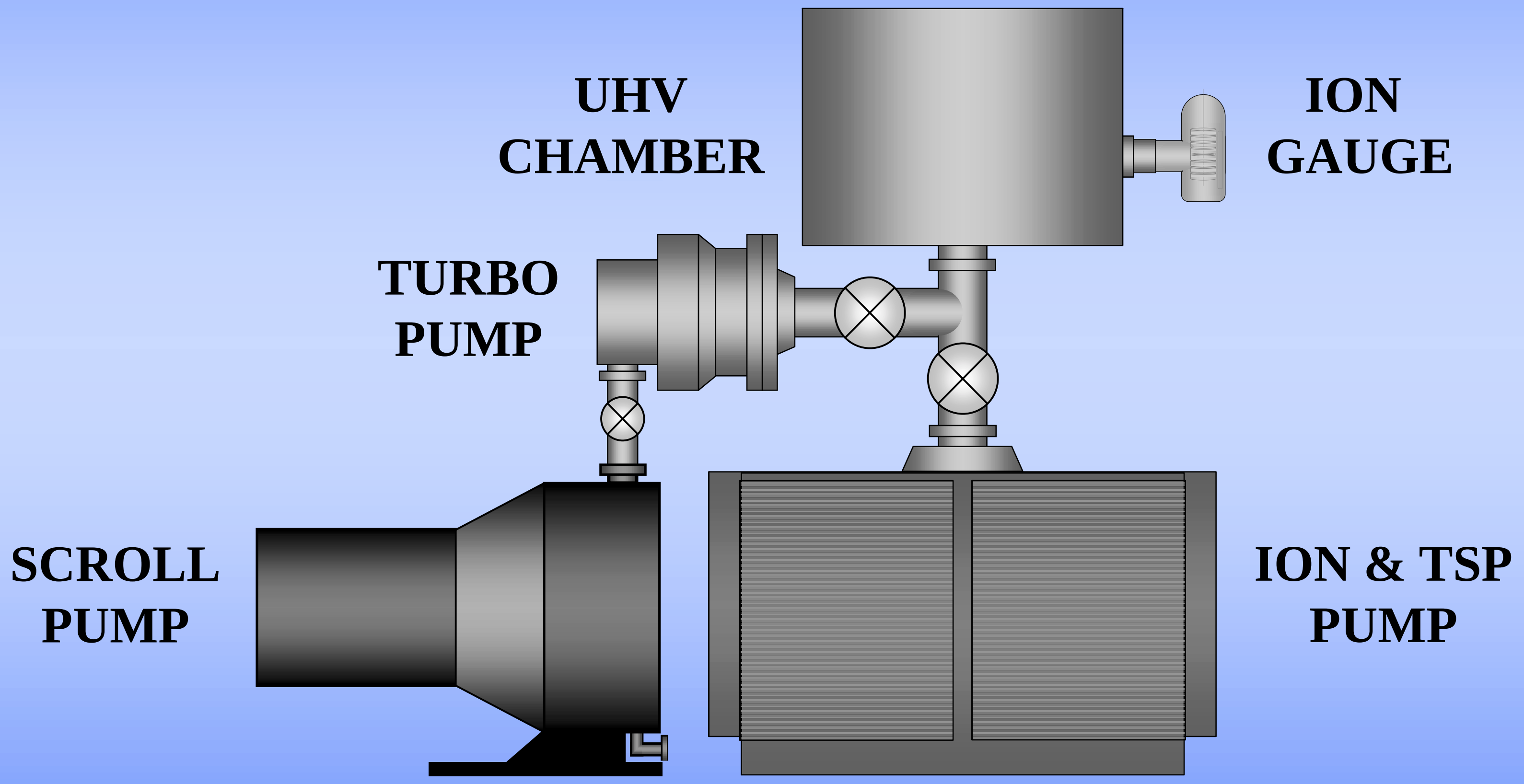
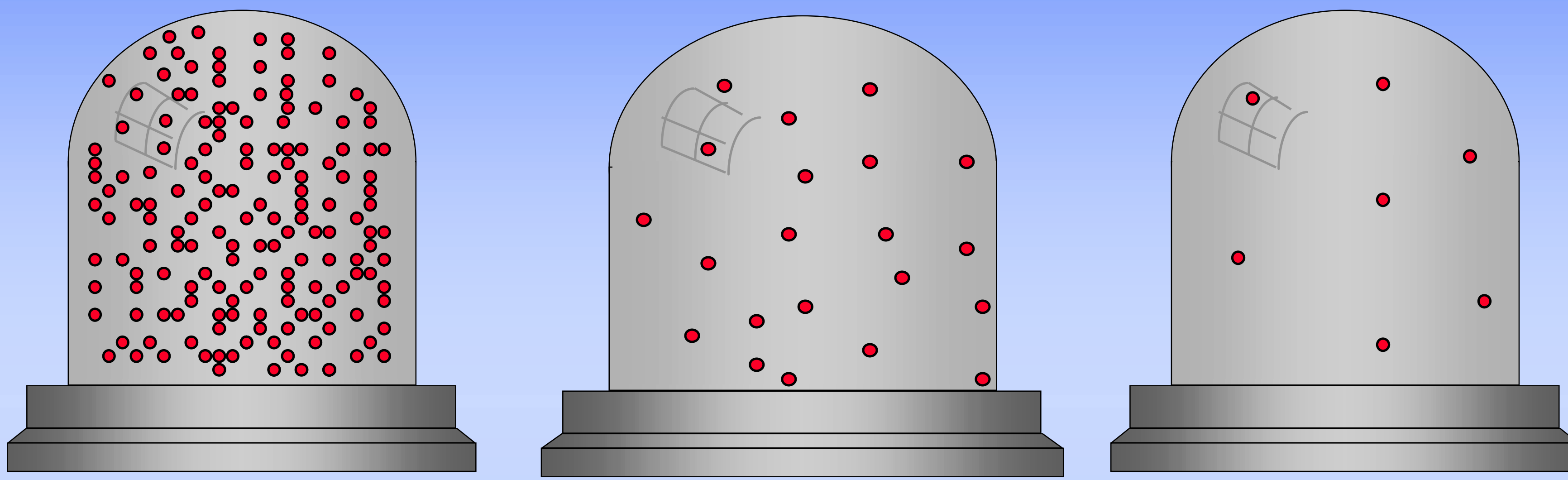
Vacuum Systems

- ✔ System Pressure
- ✔ Total Gas Load
- ✔ Materials Selection & Outgassing
- ✔ System Pumping Speed
- ✔ Gauges
- ✔ System Operation
- ✔ Discussion on Accelerator Vacuum

Basic UHV System



Degrees Of Vacuum



ROUGH	HIGH	ULTRAHIGH
ATM to 10^{-3} TORR	10^{-3} to 10^{-9} TORR	10^{-9} to 10^{-12} TORR
	>30M mole./cc	

Vacuum Characteristics

Pressure (Torr)	Major Gas Load
Atm.	Air (N_2,O_2, H_2O, Ar, CO_2)
10^{-3}	Water Vapor (75 %- 95%)
10^{-6}	H_2O, CO
10^{-9}	CO, N_2, H_2
10^{-10}	CO, H_2
10^{-11}	H_2 ($3x10^5$ molecules/cm^3)

Vacuum System Performance

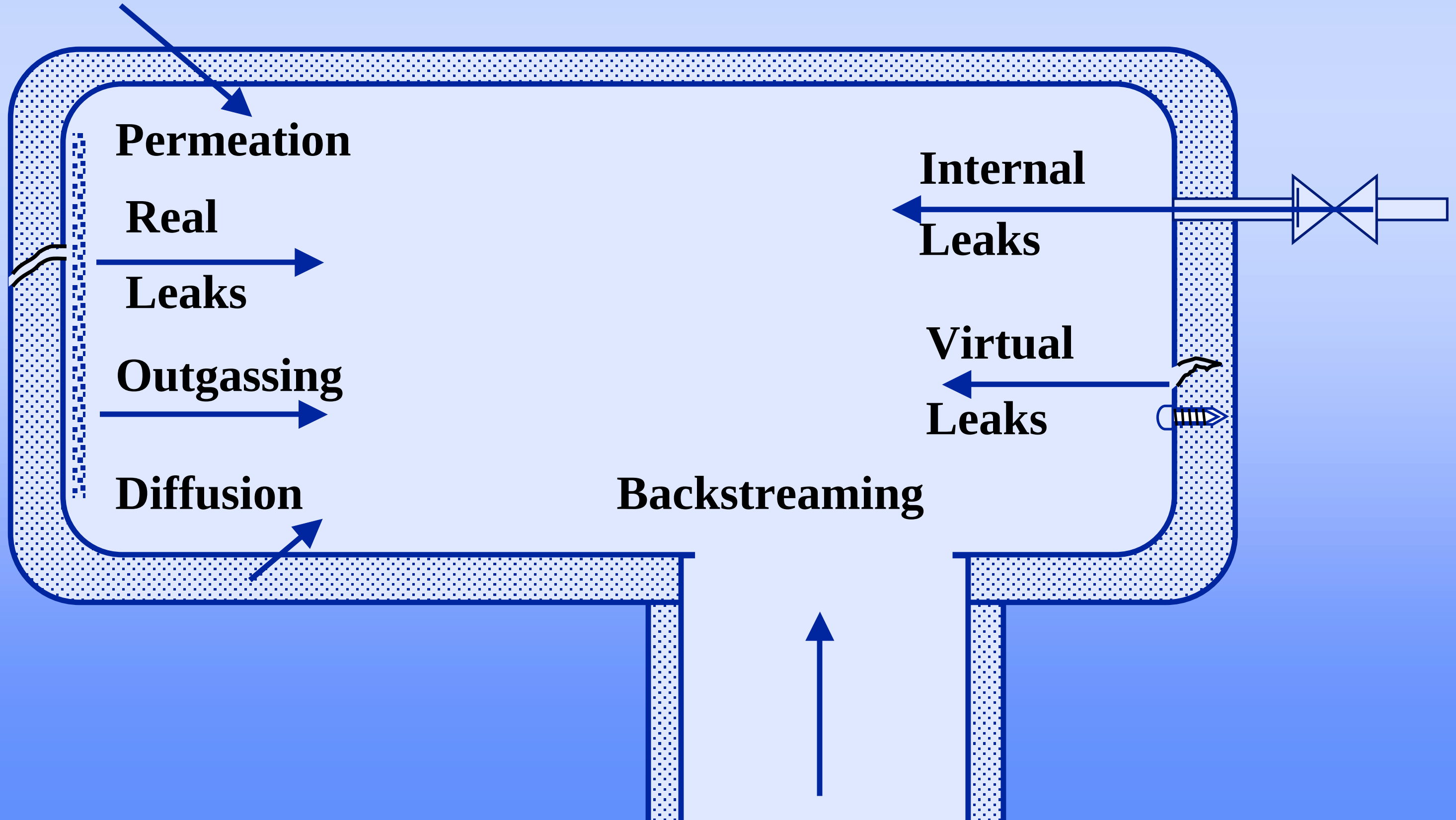
- Vacuum system performance is determined by
  - System Design (volume, conductance, surface, materials)
  - Gas Load (rate gas evolves within or enters the volume)
  - Pump Performance (pump speed, compression)

- Equilibrium Pressure (P) in a vacuum system is determined by the total Gas Load (Q) and the System Pumping Speed (S)

$$P = \frac{Q}{S}$$

Vacuum System Gas Load

- Vacuum system gas load results from
  - Leaks (real and internal leaks)
  - Surface Condition (outgassing and virtual leaks)
  - System Materials (diffusion and permeation)



System Pressure - Rough Vacuum

This relation provides approximate pumpdown times in rough vacuum. Outgassing becomes significant at lower pressures and accuracy fails.

$$t = c \cdot \frac{V}{S} \ln\left(\frac{P_i}{P_l} \right)$$

The pressure evolution in a vacuum system of volume V and effective pumping speed S is given by:

P(t) = Pi exp (-S * t / V)

System Pressure - Leaks or Permeability

If Q_∞ represents a constant gas load due to leaks or permeability of the vessel walls then the ultimate pressure is determined by the gas load and system pumping speed rather than a physical limitation of the pump.

$$P_\infty = \frac{Q_\infty}{S}$$

Thus a term for the constant gas load is added

$$-V\frac{dP}{dt} + Q_\infty = S \cdot P$$

System Pressure - Outgassing

For qualitative purposes, the outgassing rate of a surface in high vacuum can be represented as:

$$Q = Q_0 e^{-\frac{t}{\tau}}$$

where Q_0 is the initial outgassing rate, t is the time, and τ is rate outgassing decays with time (assumed to be constant over a reasonable time).

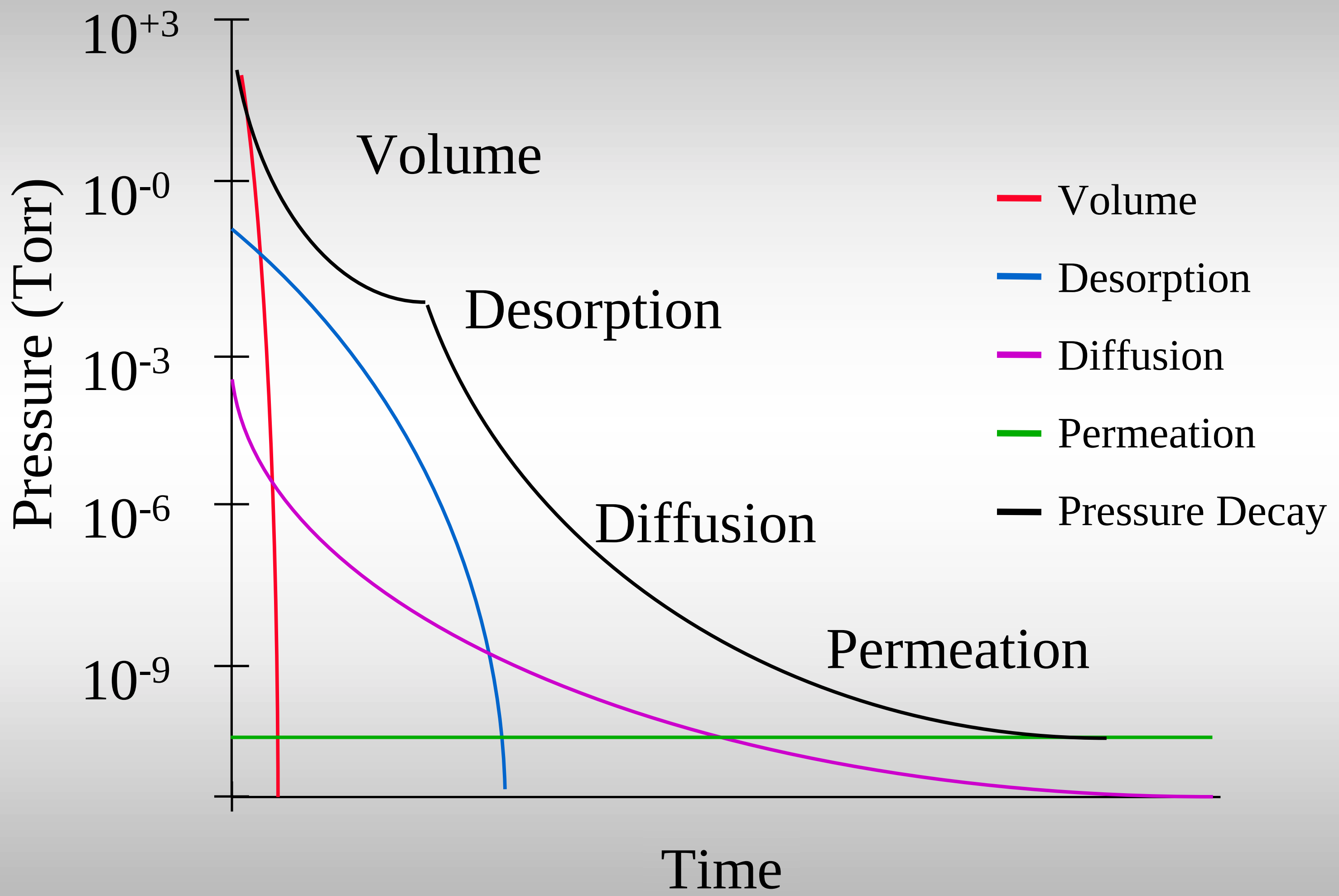
$$Q = Ae^{-at} + Be^{-bt}$$

System Pressure - Pumpdown

The solution for pressure decay relative to time that includes the volume gas (1st term), outgassing (2nd term), leaks and permeation (3rd term) is given by:

$$-V\frac{dP}{dt}+Q_0e^{-\frac{t}{\tau}}+Q_\infty=S\cdot P$$

Gas Load Limiting Pumpdown



Total Gas Load

The gas load is the *rate* gas enters the system volume
The total gas load on a vacuum system is comprised of:

$$Q_{TOTAL} = Q_{VOLUME} + Q_{LEAK} + Q_{OUTGAS} + Q_{DIFFUSION} + Q_{PERMEATION}$$

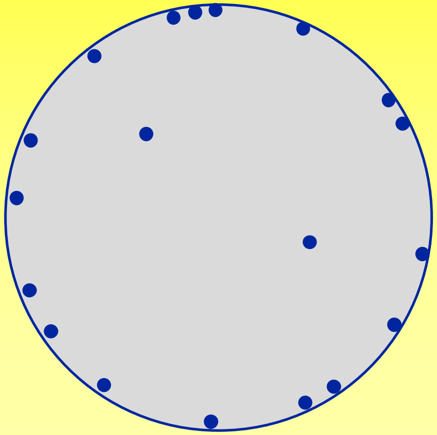
•Q (gas load, throughput, leak rate) is expressed in units of *pressure • volume/time*

–Torr•liters/sec, atm•cc/sec, sccm, mBar•liters/sec, Pa•m^3/hr

Example:To reach 10^{-12} Torr in a system with 1000 l/s pumping speed, the gas load must be less than 10^{-9} Torr l/s.

$$S \cdot P = Q \qquad 1000\ \text{l/s} \cdot 10^{-12}\ \text{T} = 10^{-9}\ \text{T} \cdot \text{l/s}$$

Significance of Adsorbed Gas



P (mbar)	Molecules on Surface / Molecules in Volume	Time to Form Monolayer (sec)
10^{-3}	0.5	2.2×10^{-3}
10^{-6}	500	2.2
10^{-9}	500,000	2.2×10^{3}

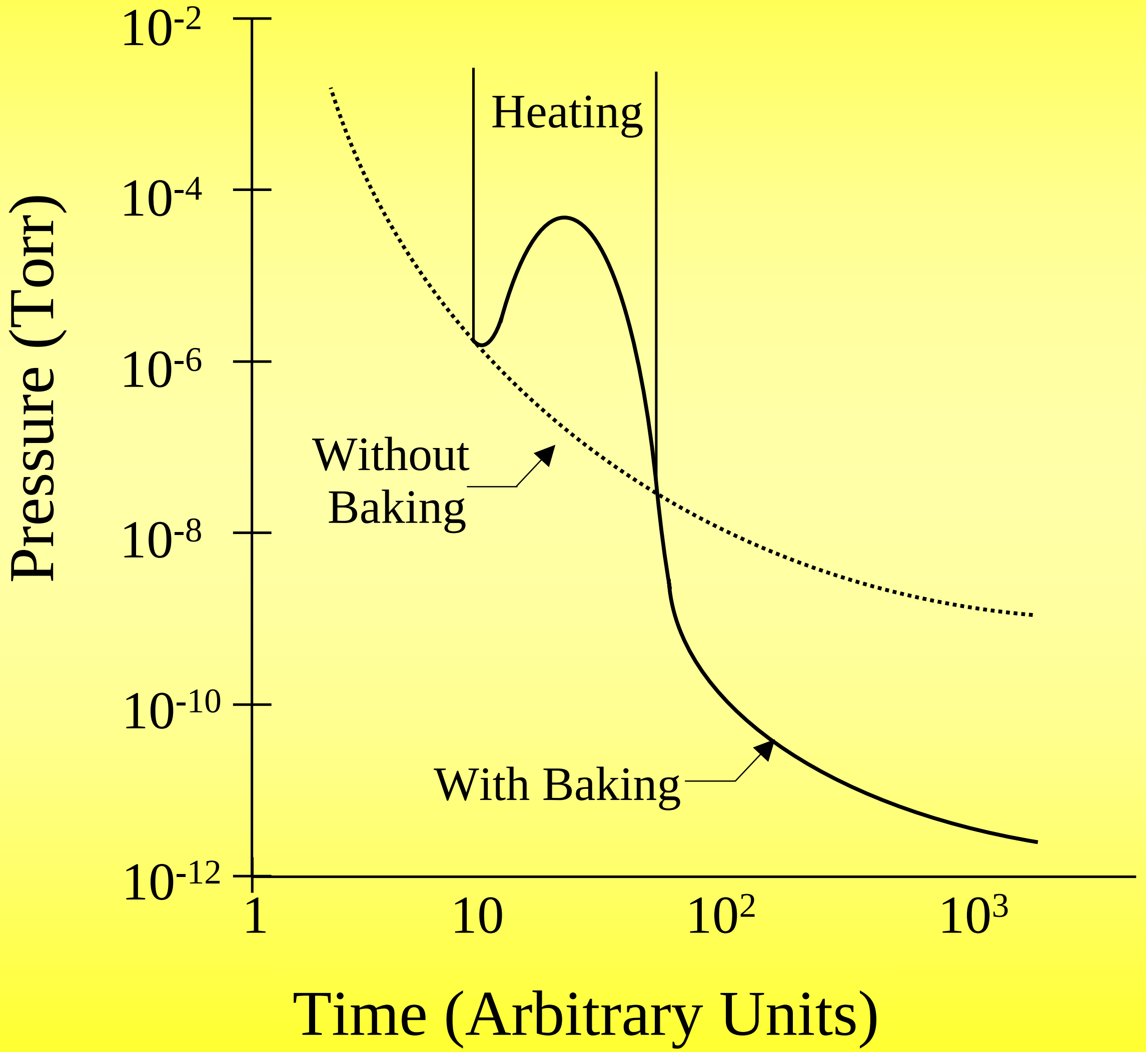
$$Q_{outgas} = q_{outgas} \cdot A$$

where q_{outgas} is the rate of outgassing per unit area and A is the surface area exposed to the vacuum.

Rate of outgassing is dependent upon the base material, temperature, time and treatment.

- *Untreated (as received)*
- *Machined (cutting oil used, etc...)*
- *Degreased (method and solvents)*
- *Post fabrication treatment (baking, degassing)*

Degassing By Baking



Common UHV Materials

Stainless Steel: use as vacuum chambers, flanges…

Low outgassing rate, Weldability, Corrosion resistance

Copper: Used as conductors and seals

Low outgassing rate if properly cleaned

Aluminum: use as chambers due to thermal property and cost

Higher outgassing, harder to weld

- **Ceramics** (Alumina (Al_2O_3)) : insulators
- **Other metals and inorganic compound: Inconel, Kovar….**

Average outgassing rates*

Outgassing rates in Torr liter/sec cm^2

	Exposure to vacuum			Surface Condition			
	1 hour	10 hours	>24 hrs	untreated	degreased	polished	baked
Aluminum (anodized)	$3x10^{-5}$	$3x10^{-7}$	$8x10^{-8}$	$3x10^{-5}$	$3x10^{-5}$	N/A	$5x10^{-10}$
Aluminum	$8x10^{-7}$	$5x10^{-8}$	$1x10^{-10}$	$8x10^{-7}$	$1x10^{-8}$	$1x10^{-8}$	$5x10^{-13}$
Brass	$2x10^{-6}$	$6x10^{-7}$	$1x10^{-7}$	$1x10^{-6}$	$1x10^{-6}$	$8x10^{-6}$	N/A
Beryllium	$1x10^{-6}$	$5x10^{-7}$	$1x10^{-9}$	$1x10^{-6}$	$5x10^{-7}$	$1x10^{-6}$	N/A
Copper	$1x10^{-7}$	$5x10^{-9}$	$1x10^{-10}$	$1x10^{-7}$	$1x10^{-8}$	$1x10^{-9}$	$1x10^{-12}$
Copper (OFHC)	$8x10^{-9}$	$2x10^{-9}$	$3x10^{-11}$	$8x10^{-9}$	$8x10^{-9}$	$5x10^{-7}$	$1x10^{-12}$
Delrin	$6x10^{-6}$	$1x10^{-7}$	$7x10^{-7}$	$6x10^{-6}$	not available	not available	$8x10^{-7}$
Lead	$1x10^{-7}$	$2x10^{-8}$	$4x10^{-9}$	$1x10^{-8}$	$5x10^{-8}$	$1x10^{-8}$	N/A
Mild Steel	$2x10^{-6}$	$2x10^{-7}$	3x108	$2x10^{-6}$	$5x10^{-7}$	$5x10^{-8}$	$5x10^{-10}$
1018 Steel (Ni plated)	$2x10^{-6}$	$5x10^{-7}$	$1x10^{-8}$	not available	not available	not available	not available
Gold Sheet	$8x10^{-8}$	not available	5x10-9	$8x10^{-8}$	$1x10^{-8}$	not available	not available
Titanium	$1x10^{-9}$	not available	$5x10^{-10}$	$1x10^{-9}$	not available	not available	$2x10^{-12}$
Stainless steel	$5x10^{-8}$	$1x10^{-8}$	$1x10^{-10}$	$7x10^{-8}$	$1x10^{-9}$	$5x10^{-9}$	$3x10^{-13}$

*Data taken from several sources, averaged for air. For info on specific material or gas specie refer to original documentation.

Average outgassing rates (cont'd)

Outgassing rates in Torr liter/sec cm^2

	Exposure to vacuum			Surface Condition			
	1 hour	10 hours	>24 hrs	untreated	degreased	polished	baked
Epoxy (Shell Epon)	$2x10^{-5}$	$1x10^{-6}$	not available	not available	not available	N/A	$8x10^{-8}$
Buna N	$8x10^{-6}$	$2x10^{-6}$	$8x10^{-7}$	$8x10^{-6}$	$8x10^{-7}$	N/A	$4x10^{-8}$
Neoprene	$3x10^{-6}$	$8x10^{-7}$	$4x10^{-8}$	$3x10^{-6}$	$6x10^{-7}$	N/A	$2x10^{-9}$
Mylar	$8x10^{-7}$	$1x10^{-7}$	$7x10^{-9}$	$8x10^{-7}$	N/A	N/A	$2x10^{-9}$
Acrylic	$2x10^{-6}$	$1x10^{-6}$	$5x10^{-7}$	$2x10^{-6}$	$8x10^{-7}$	N/A	$1x10^{-8}$
Teflon (poly'fluoro'lene)	$2x10^{-7}$	$8x10^{-8}$	$2x10^{-8}$	$2x10^{-7}$	N/A	N/A	$8x10^{-9}$
Nylon (polyamide)	$5x10^{-6}$	$3x10^{-7}$	$4x10^{-8}$	$5x10^{-6}$	N/A	N/A	$6x10^{-9}$
Lexan (polycarbonate)	$7x10^{-7}$	$2x10^{-7}$	$6x10^{-8}$	$1x10^{-7}$	N/A	N/A	$8x10^{-9}$
PVC	$5x10^{-7}$	$3x10^{-7}$	$1x10^{-7}$	$5x10^{-7}$	N/A	N/A	$8x10^{-8}$
Silicon rubber	$7x10^{-6}$	$8x10^{-7}$	$6x10^{-8}$	$7x10^{-7}$	$2x10^{-7}$	N/A	$6x10^{-10}$
Silastic (sealant)	$5x10^{-5}$	$3x10^{-6}$	$6x10^{-7}$	$8x10^{-5}$	N/A	N/A	$5x10^{-8}$
Viton	$8x10^{-7}$	$5x10^{-8}$	$2x10^{-8}$	$8x10^{-7}$	$1x10^{-7}$	N/A	$5x10^{-10}$
Steatite (ceramic)	$5x10^{-8}$	$1x10^{-8}$	$7x10^{-9}$	N/A	N/A	N/A	N/A
Pyrex (7740)	$1x10^{-7}$	$2x10^{-8}$	$5x10^{-9}$	not available	not available	N/A	$2x10^{-9}$

System Pumping Speed

To achieve the best possible vacuum or lowest system pressure with a given pump, it is necessary to maximize effective pumping speed at the chamber while minimizing gas load.

$$S_{EFF} = \frac{SC}{S + C} = \frac{S}{1 + S / C}$$

$C >> S$	$S_{EFF} = S$
$C \sim S$	$S_{EFF} = S / 2$
$C << S$	$S_{EFF} = C$

Maximum theoretical pumping speed S_{EFF} into a 12” diam chamber is about 8000 liter / sec

Conductance in molecular flow (Long round tube)

$$C = 3.81 \times \frac{d^3}{l} \times \sqrt{\frac{T}{M}} \quad \text{(l/sec)}$$

d = diameter of tube in cm
l = length of tube in cm
T = temperature (K)
M = A.M.U.

Example: 4 cm diameter, 100 cm tube, N_2, 295 K

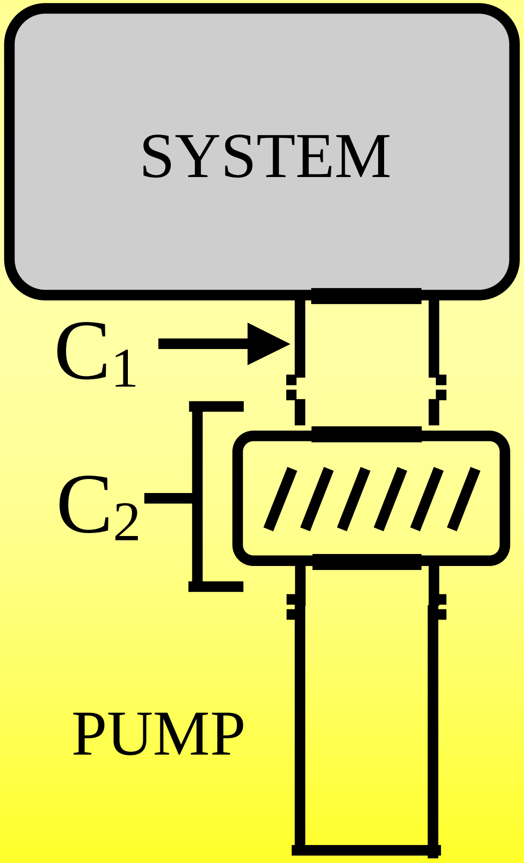
C = ~ 8 l/s

Series Conductance

Tube (C_1): 200 l/s
Baffle (C_2): 200 l/s

$$C_T = \frac{200 \times 200}{200 + 200} \text{ (l/s)}$$

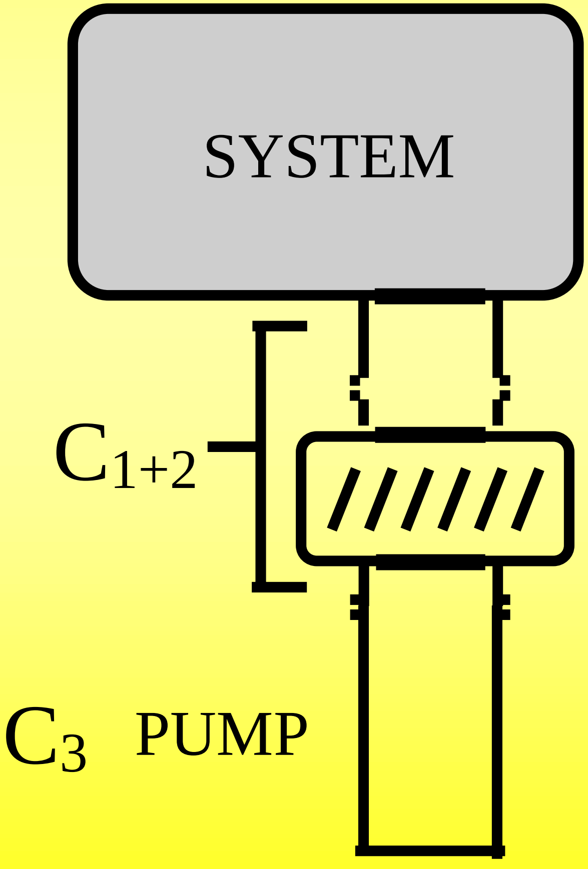
$$C_T = 100 \text{ (l/s)}$$



Series Conductance

Tube + Baffle (C_{1+2}): 100 l/s

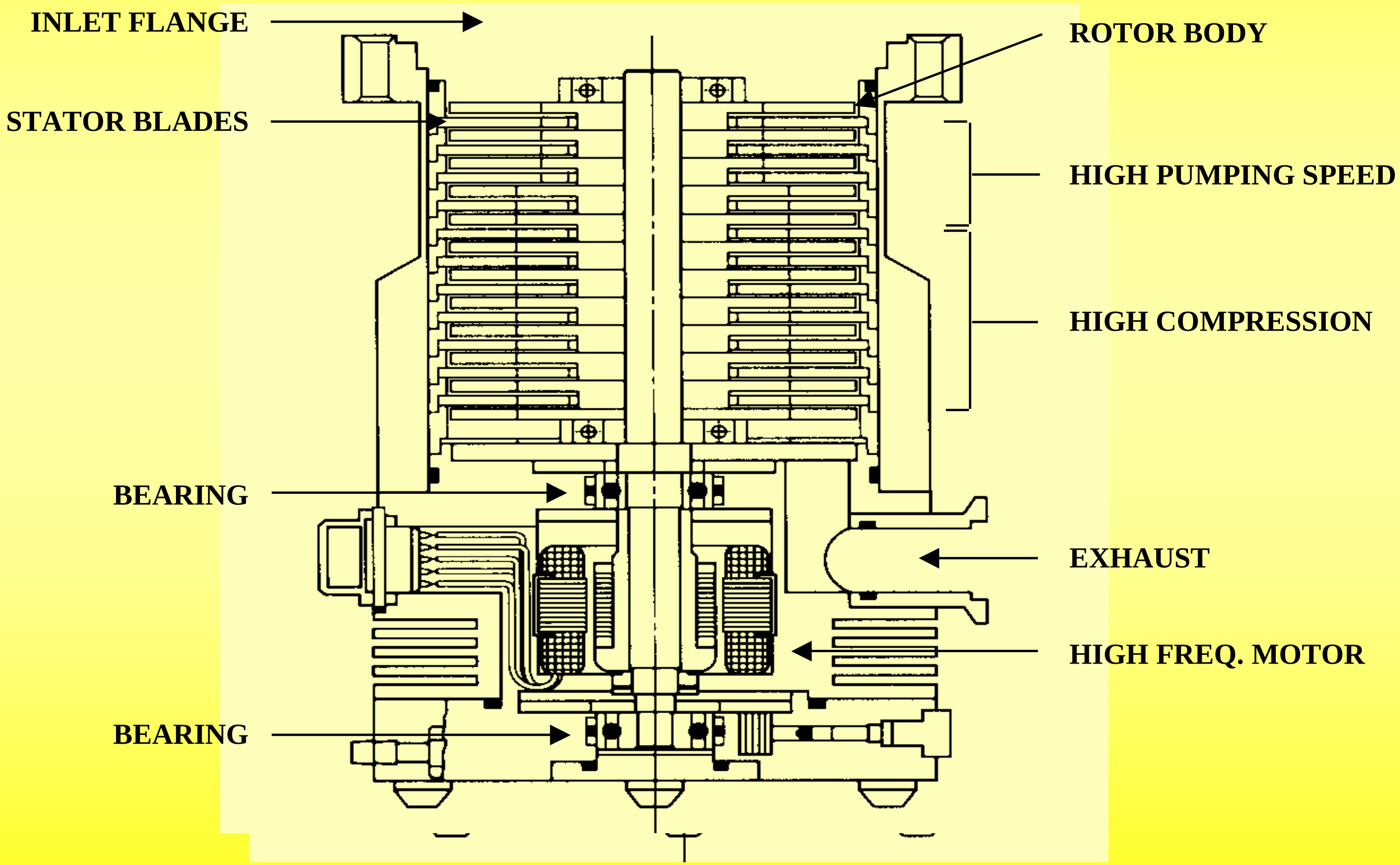
Pump (C_3): 200 l/s



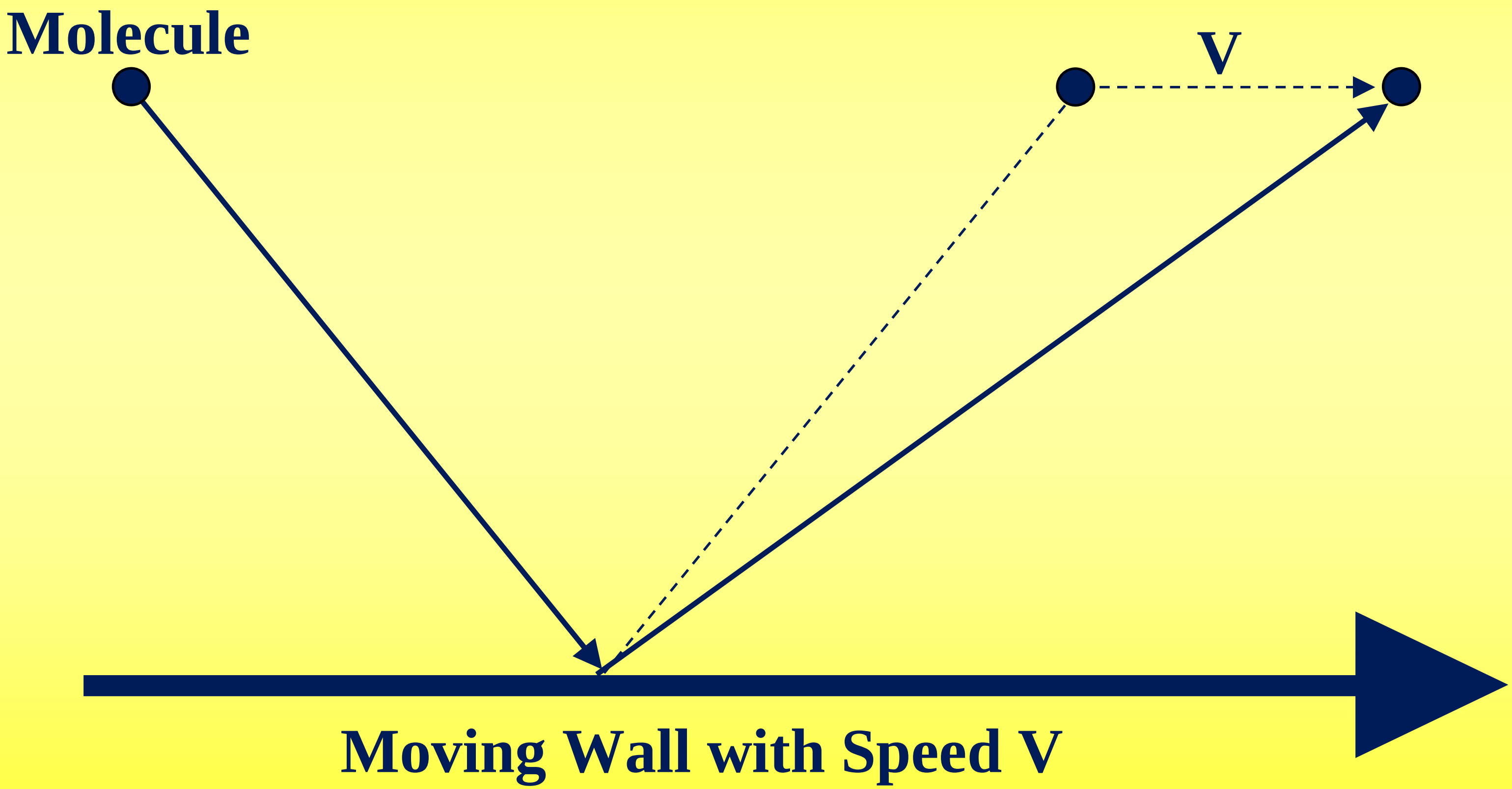
$$C_T = \frac{200 \times 100}{200 + 100} \text{ (l/s)}$$

$$C_T = 67 \quad \text{(l/s)}$$

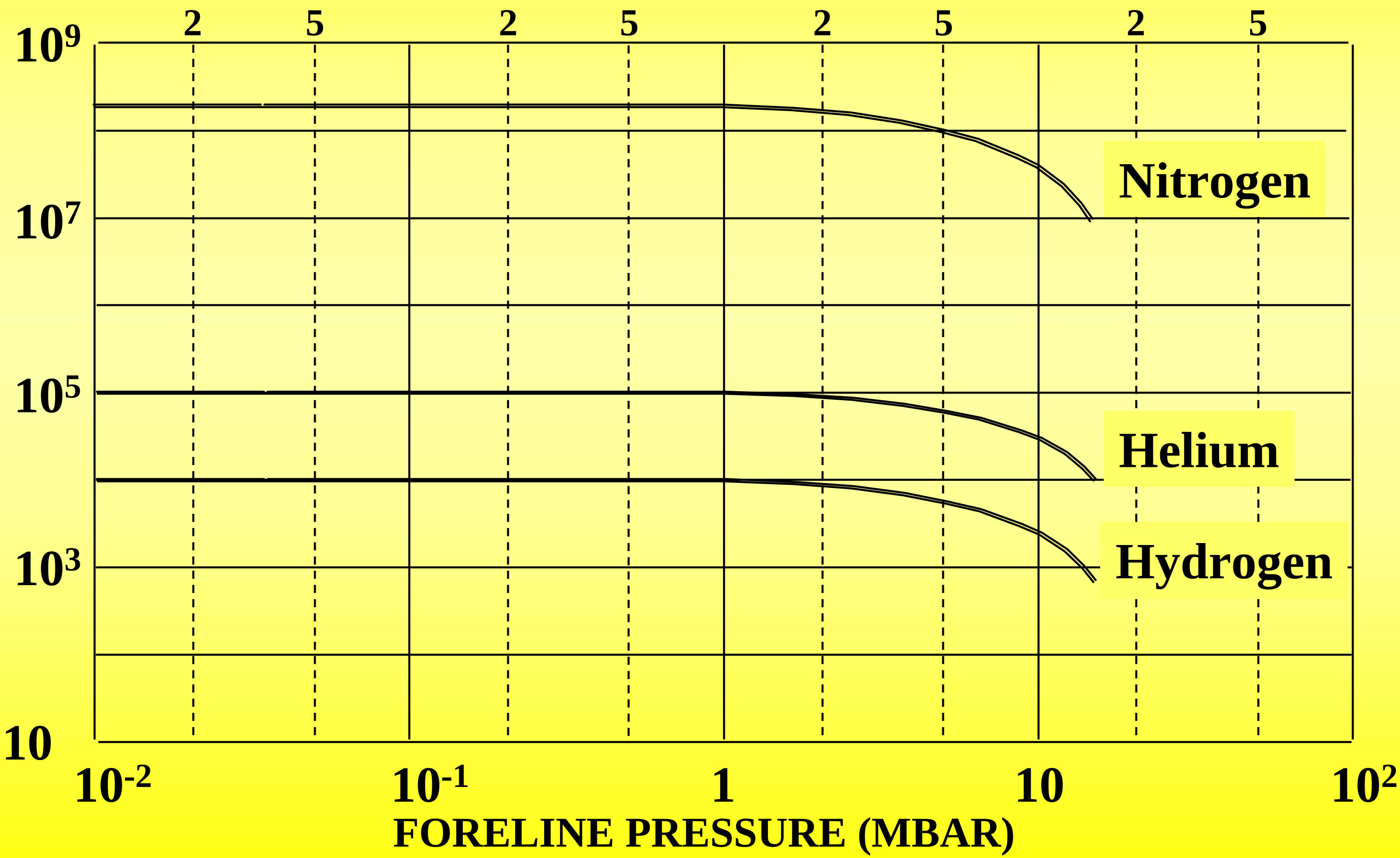
Turbomolecular Pump



TURBOMOLECULAR PUMP (TMP) PRINCIPLE OF OPERATION



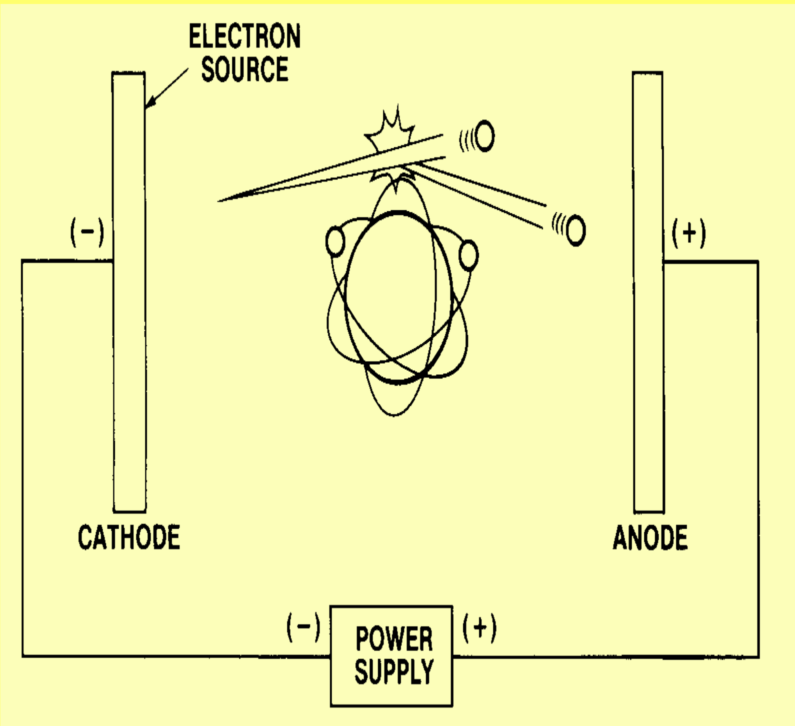
COMPRESSION RATIO FOR VARIOUS GASES AS A FUNCTION OF THE FORELINE PRESSURE

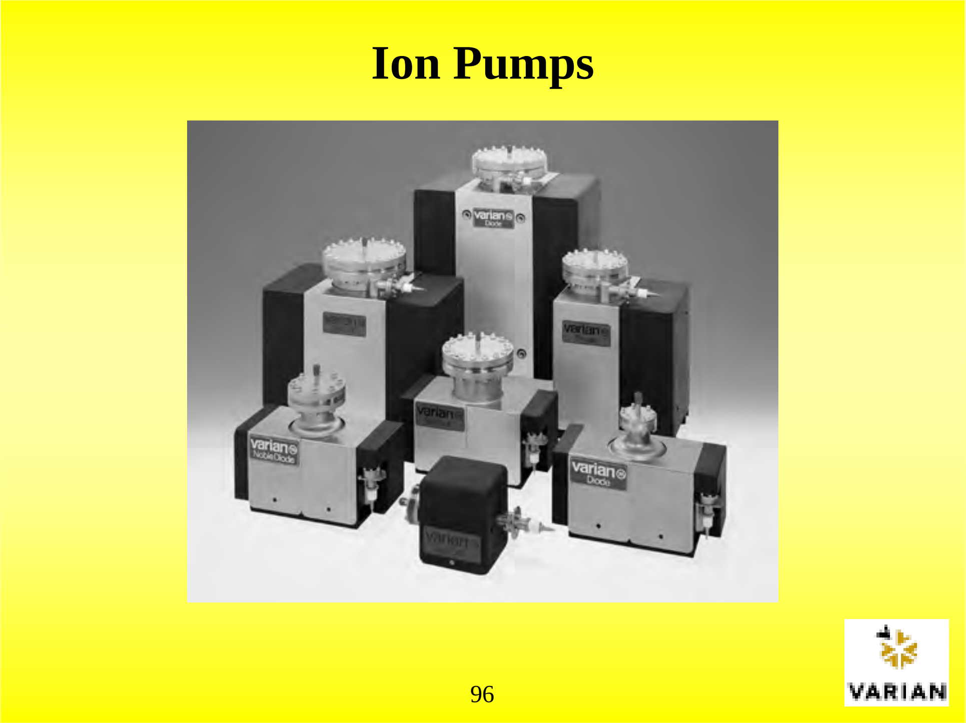


ION PUMP
PRINCIPLE OF OPERATION

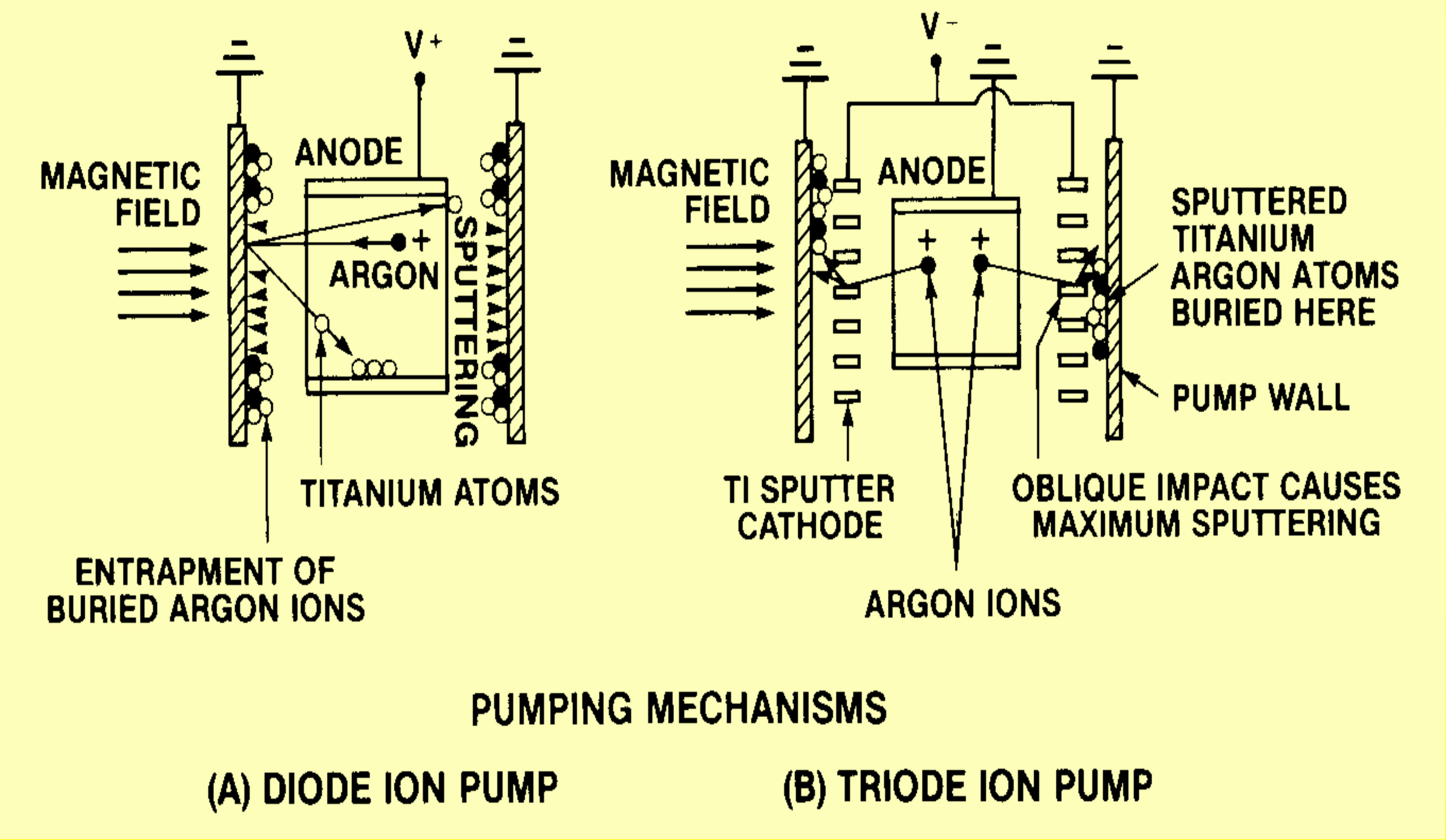
- Electric discharge in crossed electric and magnetic field (Penning cell)
- Ion bombardment of the cathode
- Deposition of a chemically reactive film (Ti) (Sputtering)
- Gas sticks on the Ti film (chemisorption)

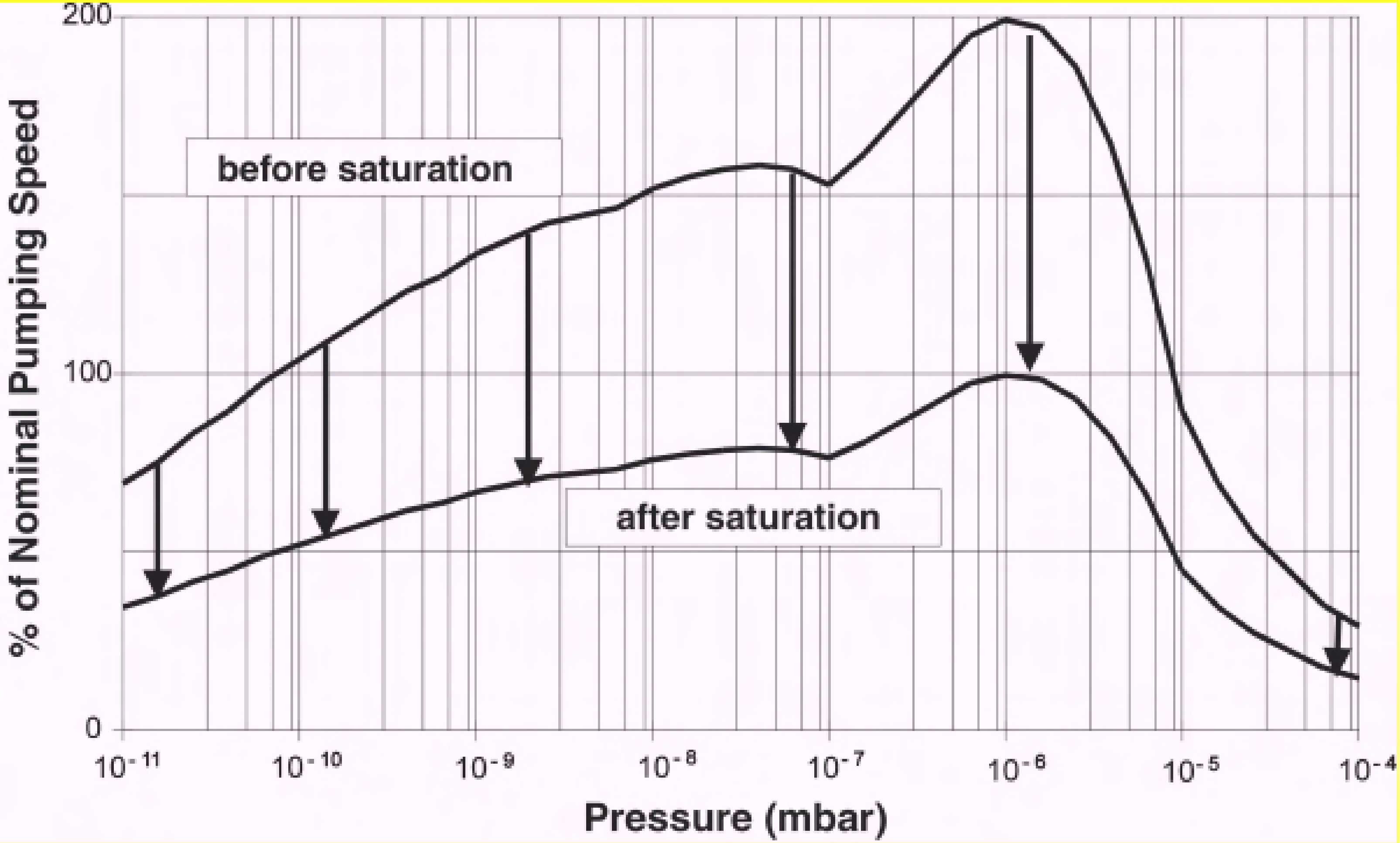
Ion pump


ELECTRON
SOURCE
(-)
(+)
CATHODE
ANODE
(-)
POWER
SUPPLY
(+)


Ion Pumps
varian
varian
Noble Diode
varian
Diode
96
VARIAN

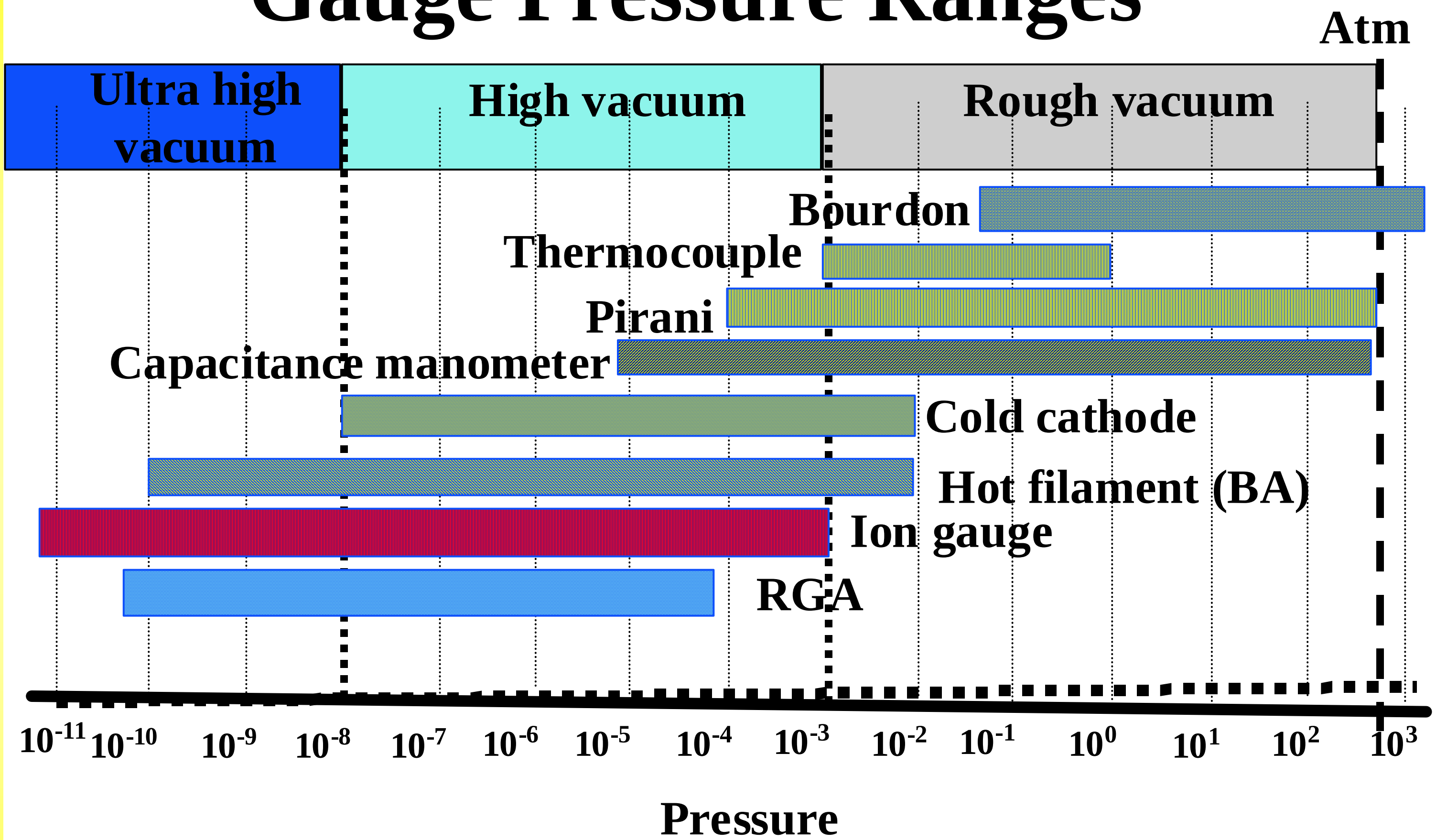
Diode and triode schematically



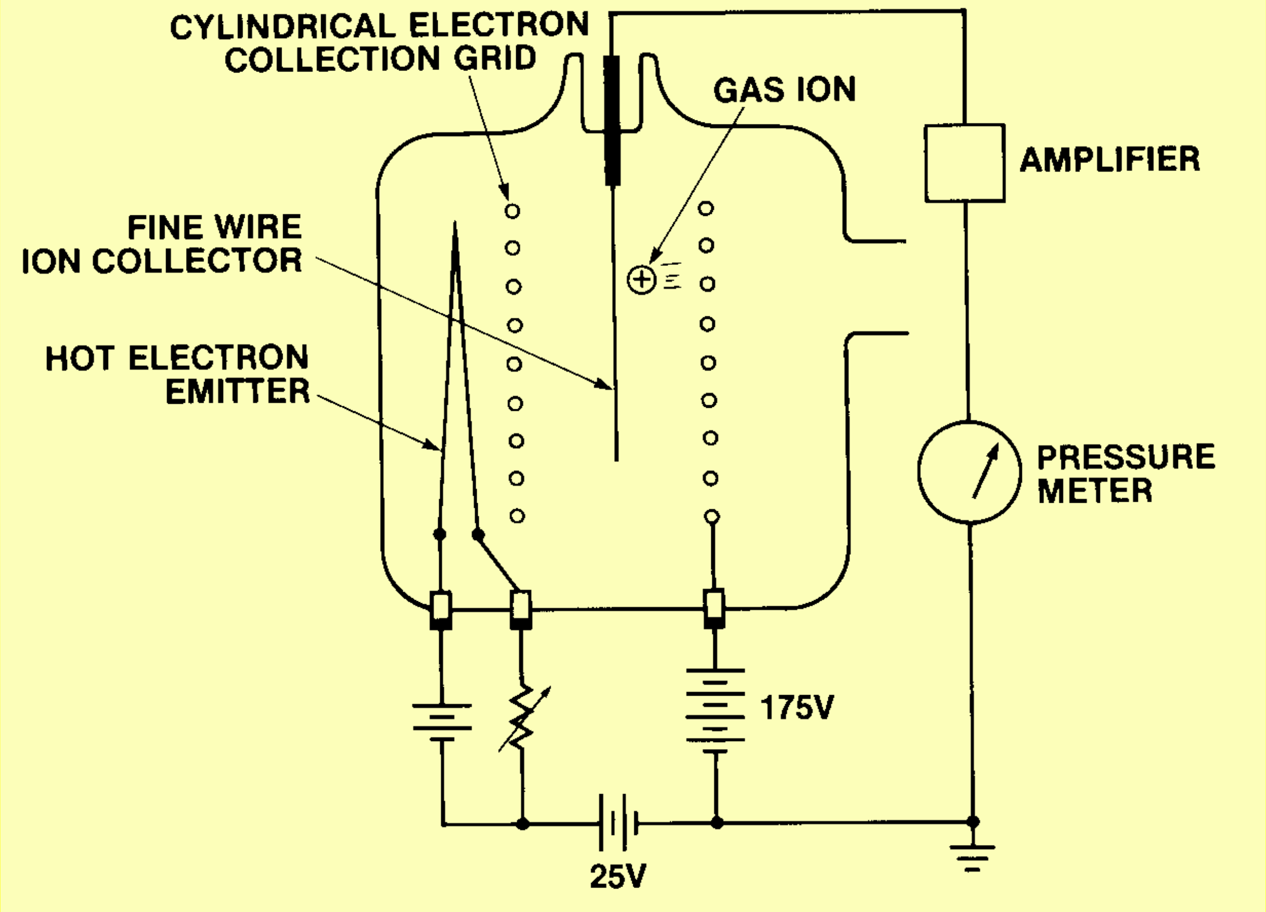


Ion Pump Pumping Speed

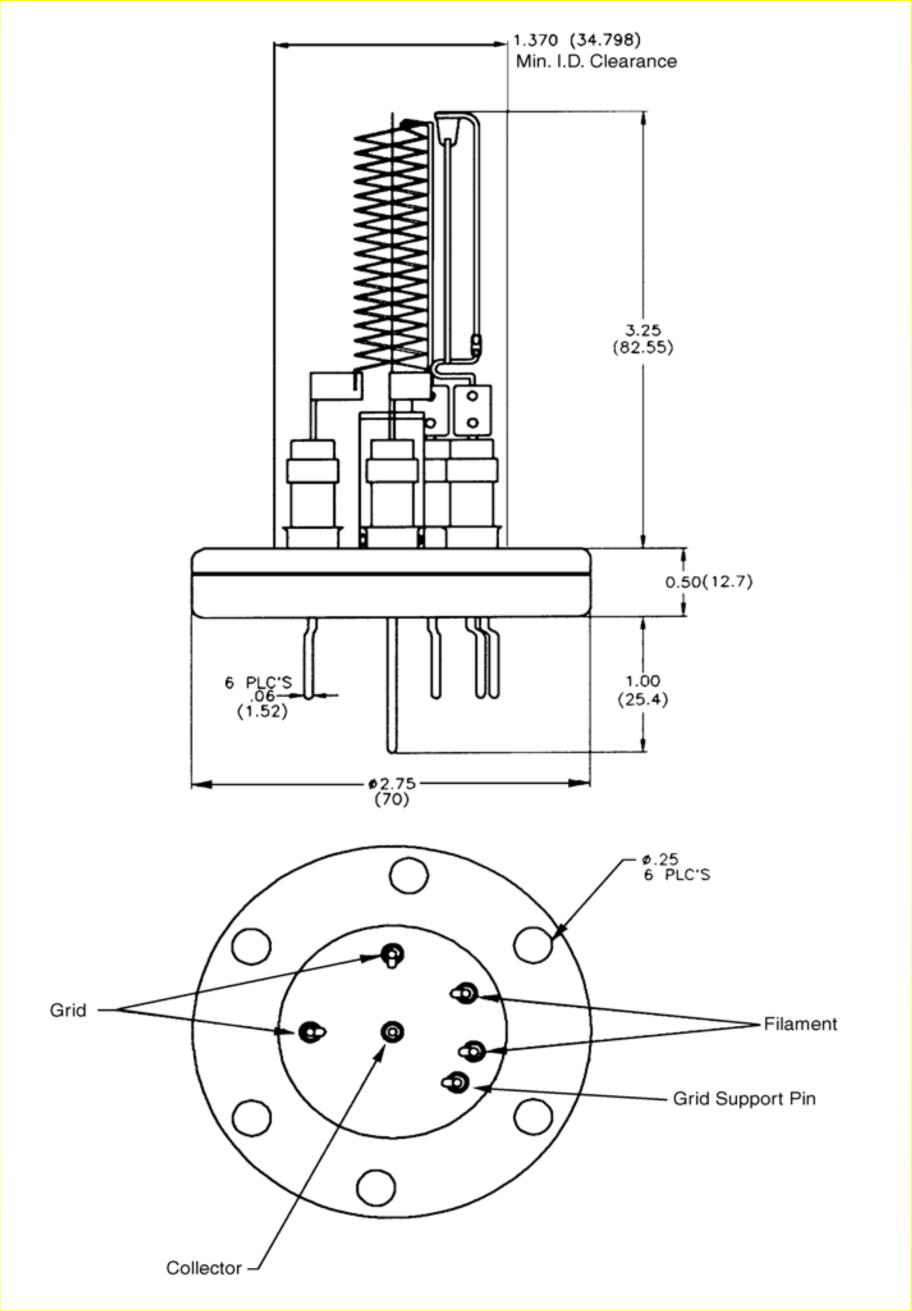
Gauge Pressure Ranges



Ionization current is the measure of pressure



Ion gauge
Cross-section



System Operation

1. Use turbo and scroll pumps to rough chamber and sump to approx.10^{-5} torr.
2. Bake at highest allowable temperature for several (overnite) hours.
3. Turn on TSP/ion pump towards end of bake period.
4. Valve out rough pump system

Pumpdown Curves