

Vacuum technology

Aspects of flow

For current, flow rate is directly proportional to potential difference and inversely proportional to resistance.

$$I = V/R \text{ or } I = \Delta V/R$$

For a fluid flow, $Q = (P_1 - P_2)/R$ or $\Delta P/R$

Using reciprocal of resistance, called conductance, we have, $Q = C (P_1 - P_2)$

There are two kinds of flow, volumetric flow and mass flow

Volume flow rate, $S = vA$

v – the average bulk velocity, A the cross sectional area

$S = V/t$, V is the volume and t is the time.

Mass flow rate is $S \times$ density.

$G = \rho vA$ or $\rho V/t$

Mass flow rate is measured in units of throughput, such as torr.L/s

Throughput = volume flow rate \times pressure

Throughput is equivalent to power.

Torr.L/s \rightarrow (g/cm²)cm³/s \rightarrow g.cm/s \rightarrow J/s \rightarrow W

It works out that, $1W = 7.5$ torr.L/s

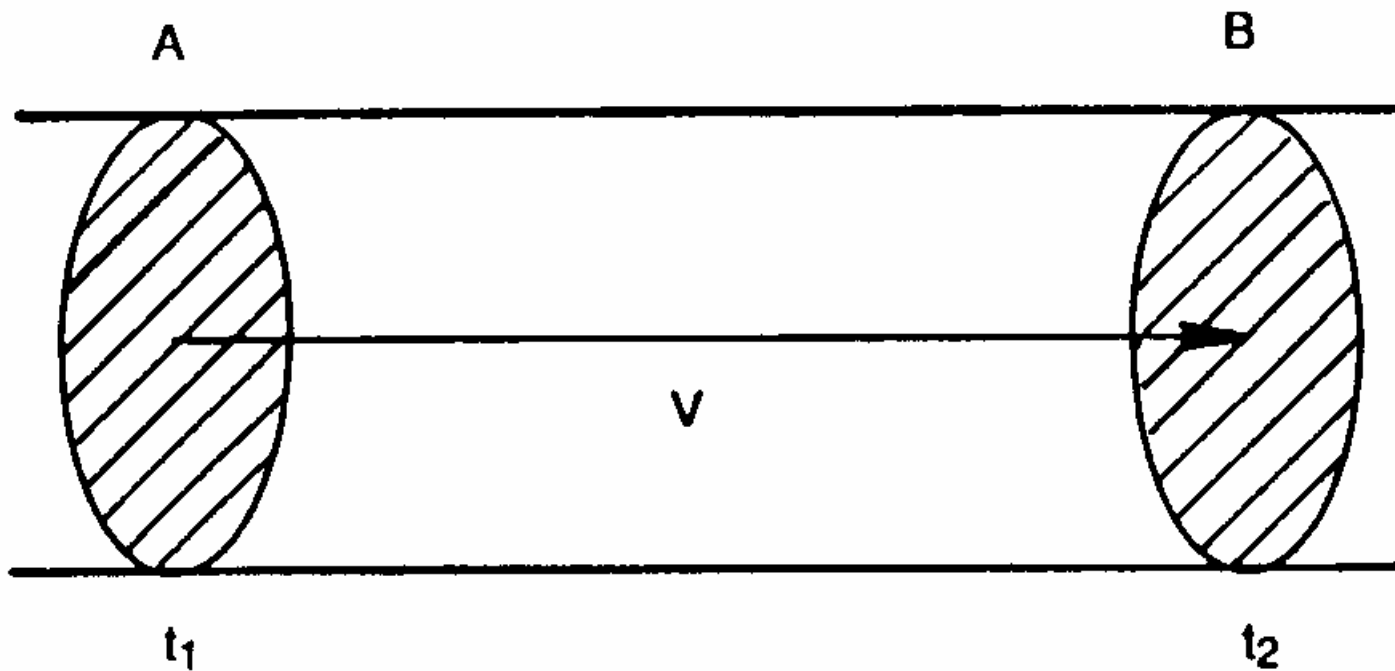


Figure 3.3 Concept of volumetric flow.

Types of flow

1. Laminar: Occurs when the ratio of mass flow to viscosity (Reynolds number) is low for a given diameter.

This happens when Reynolds number is approximately below 2000.

$$Q \sim P_1^2 - P_2^2$$

2. Above 3000, flow becomes turbulent

$$Q \sim (P_1^2 - P_2^2)^{0.5}$$

3. Choked flow occurs when there is a flow restriction between two pressure regions. Assume an orifice and the pressure difference between the two sections, such as 2:1. Assume that the pressure in the inlet chamber is constant. The flow relation is, $Q \sim P_1$

4. Molecular flow: When pressure reduces, MFP becomes larger than the dimensions of the duct, collisions occur between the walls of the vessel. $Q \sim P_1 - P_2$

There are also other flows such as surface diffusion, permeation and diffusion of one gas through another.

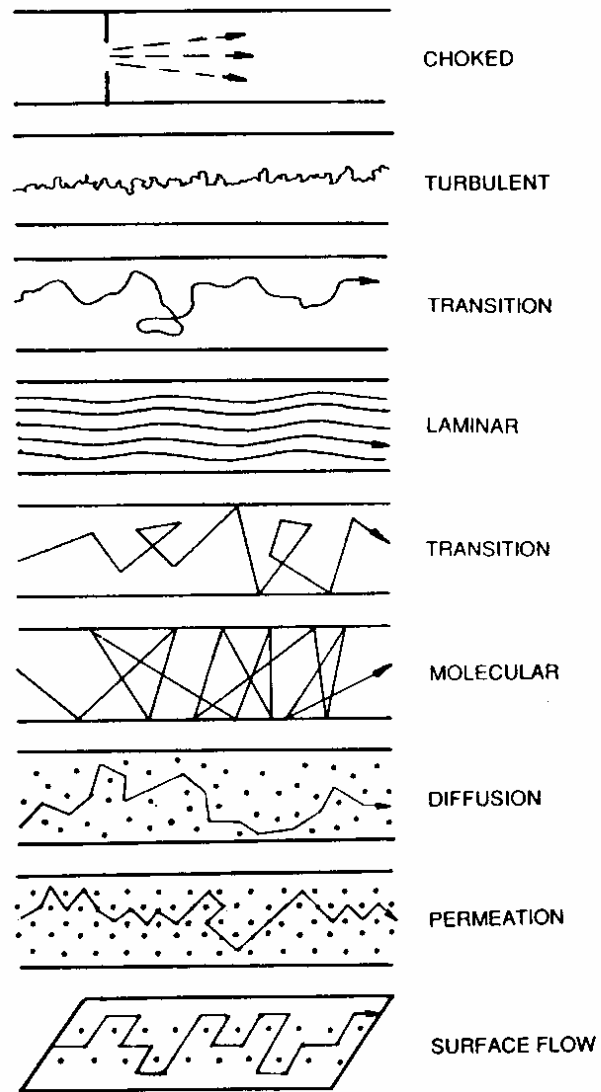
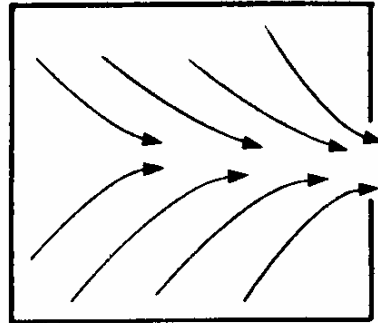
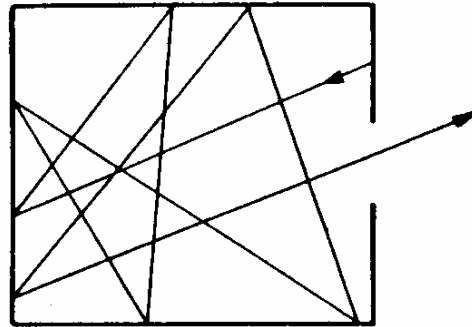


Figure 3.4 Molecular trajectories at various types of flow.

Different kinds of flow patterns



VISCOUS



MOLECULAR

Figure 3.8 Viscous and molecular flow patterns.

Number of molecules striking unit area from all sides,

$$n = [3.5 \times 10^{22} P]/(MT)^{0.5} \text{ per cm}^2 \text{ per s}$$

To convert this to volume that strikes per unit area we need to divide by number density.

$$S = n/N = 3640 (T/M)^{0.5} \text{ cm}^3/\text{s} \cdot \text{cm}^2$$

For air at RT, this gives, $3640(295/28.7) = 11.6 \text{ L/s}\cdot\text{cm}^2$

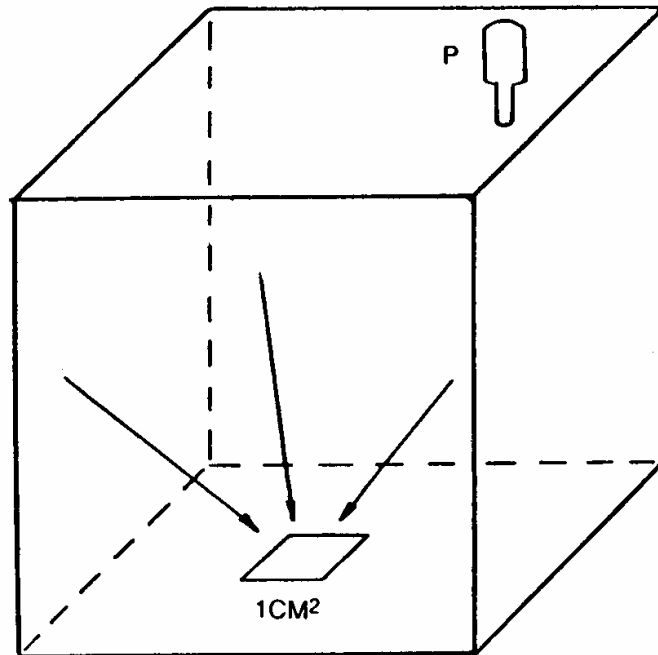


Figure 3.9 Unit surface exposed to molecular “bombardment.”

Flow through an orifice

Assume the flow through an orifice as shown below.

Pressure in the top chamber is constant and it is very small or near zero below.

The flow through orifice is, $A \times 11.6 \text{ L/s.}$, A is the area in sq. cm.

Molecules come to the orifice from all angles, but the flow can be represented in terms of a velocity.

$$\begin{aligned} &11.6 \text{ L/cm}^2\cdot\text{s} \\ &= 11,600 \text{ cm}^3/\text{cm}^2\cdot\text{s} \\ &= 116 \text{ m/s} \end{aligned}$$

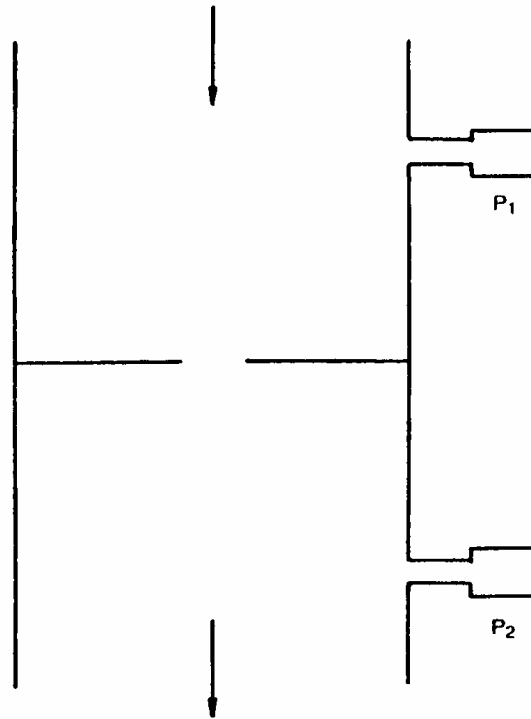


Figure 3.10 Orifice geometry.

Conductance

$$C = Q/(P_1 - P_2) = \rho v A / \Delta p$$

P is the pressure, v is the velocity, A cross sectional area and Δp is the pressure difference.

Pumping speed

In the case of an orifice, this can be given as, $S = C = Q/P$ as P_2 is much smaller than P_1 .

For constant pumping speed, $S = V \ln(P_1/P_2) / (t_1 - t_2)$

V is the volume of the chamber, P_1 and p_2 are two pressure points and t_1 and t_2 are times at which these pressure points occurred.

How to measure pumping speed?

$S = Q/P - P_0$, P is the pressure when gas is leaked and P_0 is the ultimate pressure.

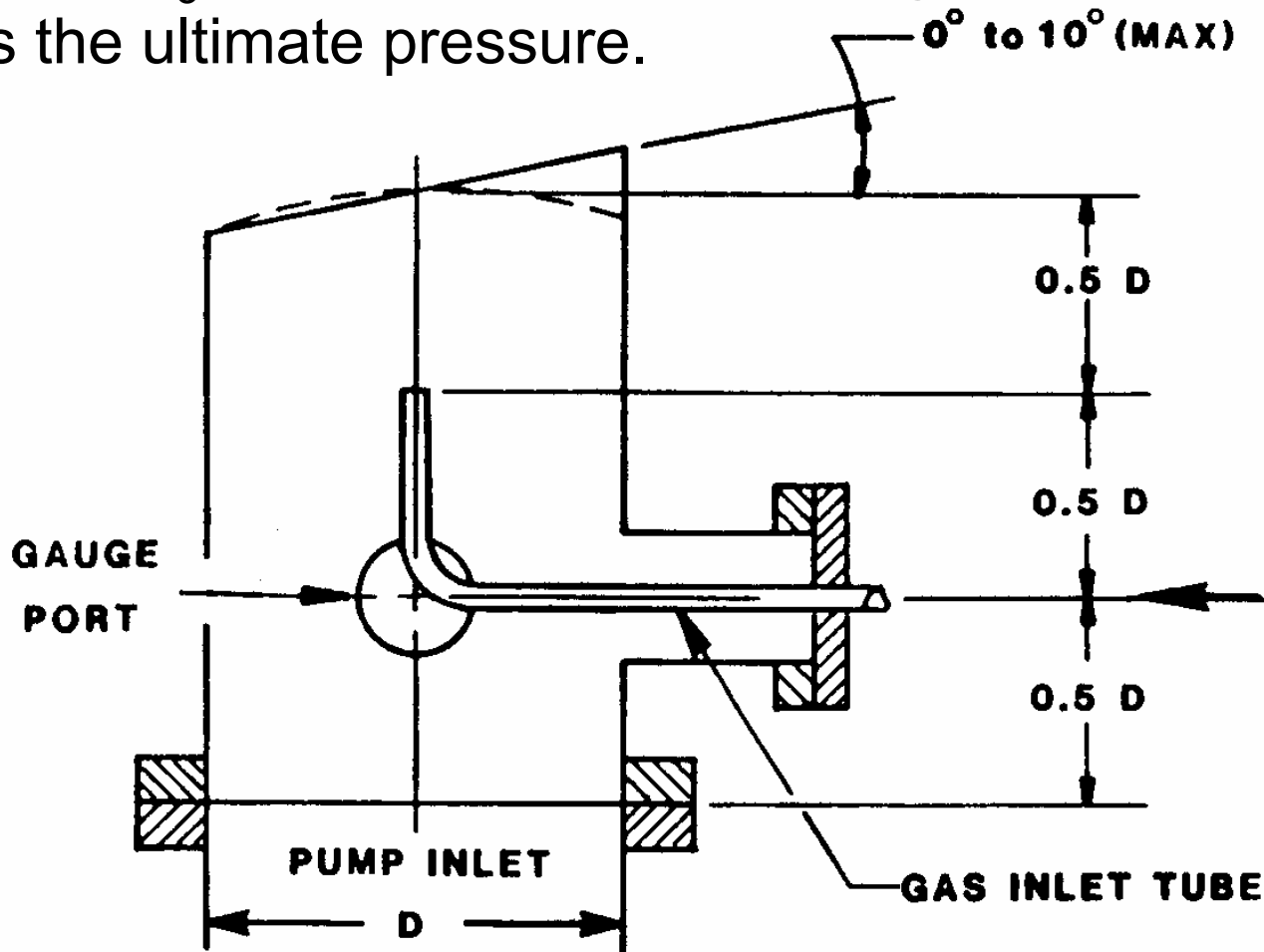


Figure 3.12 System for measuring pumping speed.

Pumps

There is no single pump for UHV technology. Various pumps are used to take the system from atmosphere to UHV

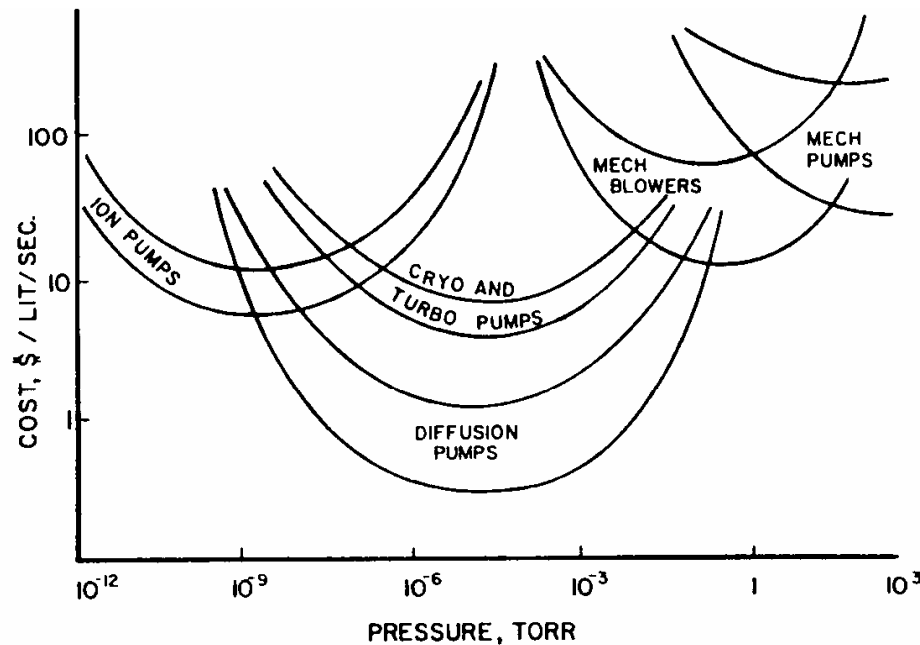


Figure 4.2 Pressure regions in which various vacuum pumps are most effective (1985 \$ values).

Time for pumping

This is a difficult parameter to calculate or predict in view of several aspects such as out gassing (virtual leak). When one disregards outgassing, $-Vdp/dt = Sp$

$$T = (V/S)\ln(P_o/P_f)$$

This is valid only in the high pressure region, above 10 torr and above this range many factors, such as permeation, outgassing, etc. become important.

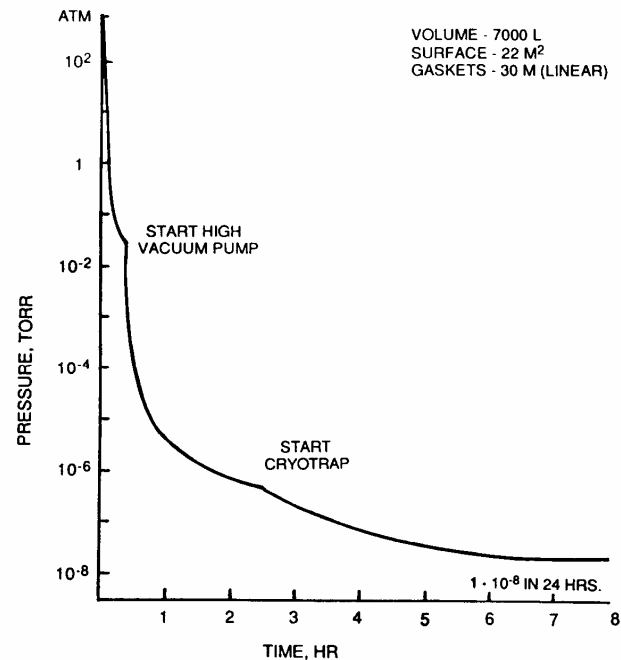


Figure 4.4 Typical evacuation progress for a large chamber.

Typical vacuum system

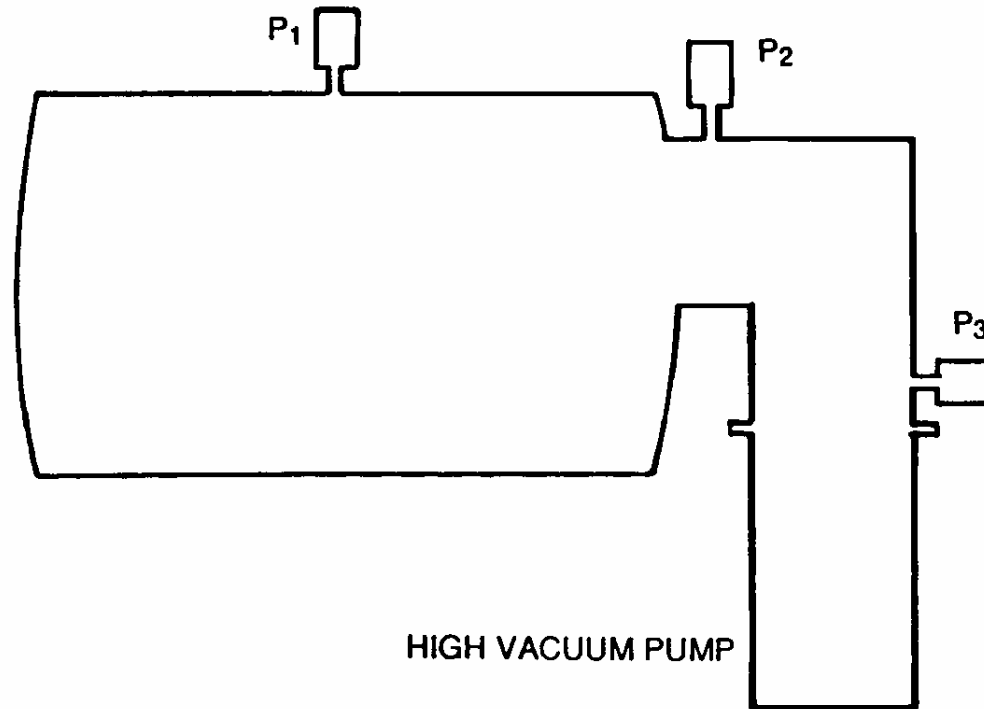


Figure 4.5 Schematic view of a vacuum chamber and a pump.

Virtual leaks

There are several possibilities of such leaks in every vacuum system.

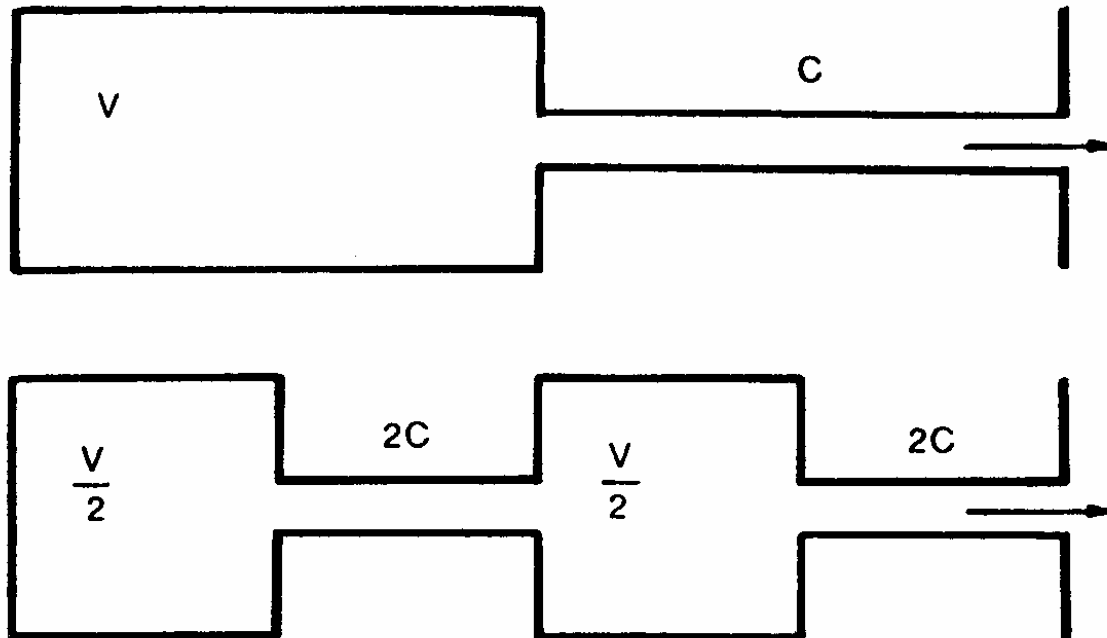


Figure 4.7 Schematic view of a virtual leak.

Typical vacuum system and process of evacuation

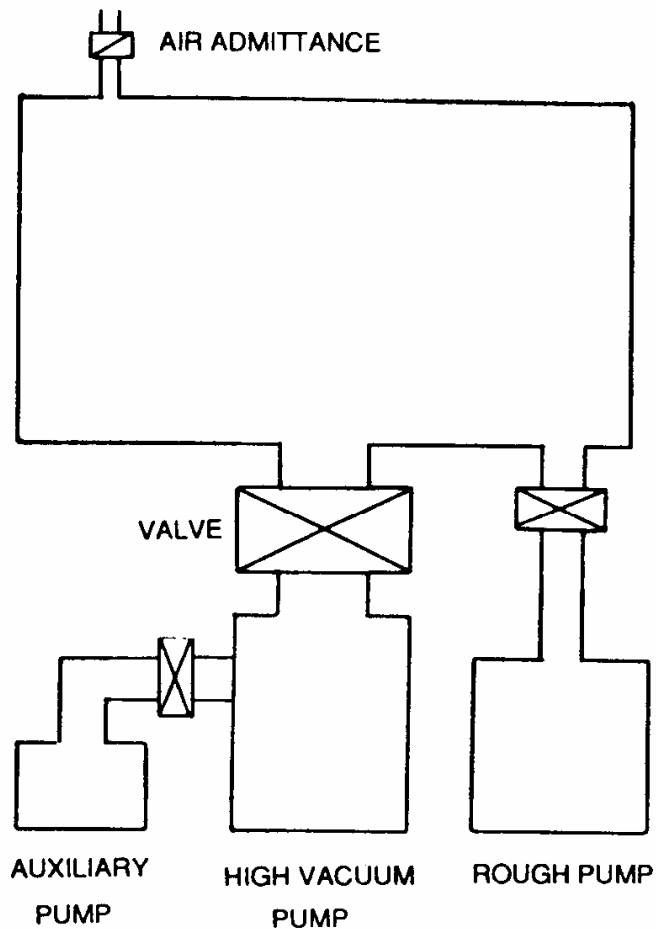


Figure 4.21 Schematic view of a typical vacuum system.

Process of evacuation

Initial pumping

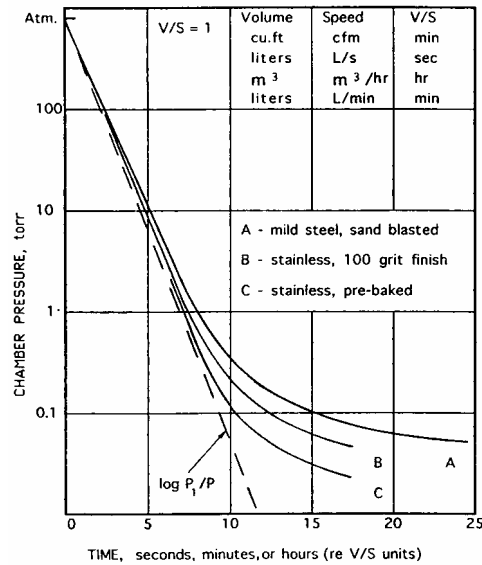


Figure 4.28 Initial evacuation process for typical metal systems with some elastomer seals for $V/S = 1$, shown on a log-linear graph (any consistent set of units can be used).

Crossover region

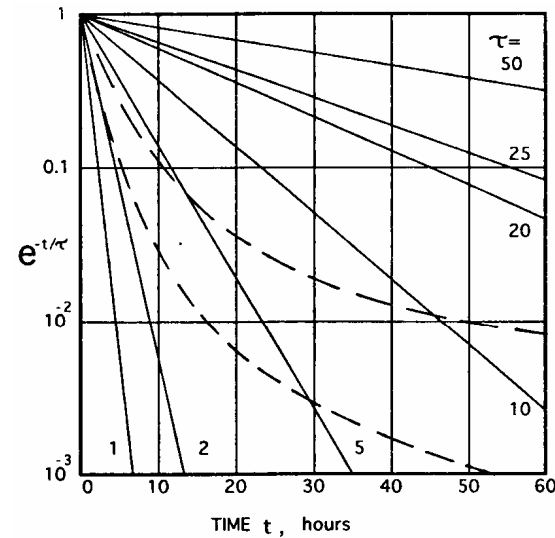


Figure 4.29 Outgassing curves (dashed lines) superimposed on a grid of values of τ (Eq. 4.23). The upper curve is stainless steel, mechanically polished; the lower curve is stainless steel, chemically cleaned.

Coarse vacuum pumps

Rotary pumps

Mechanical diagrams

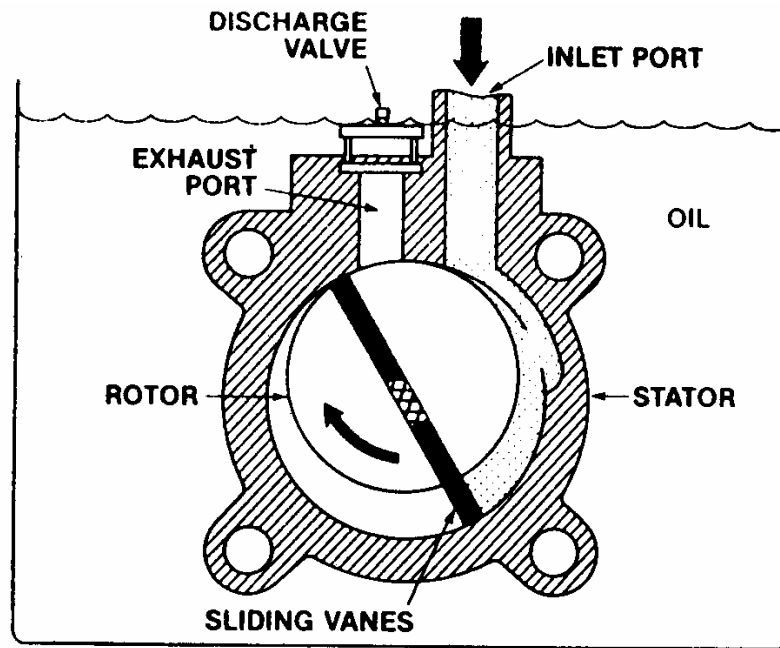
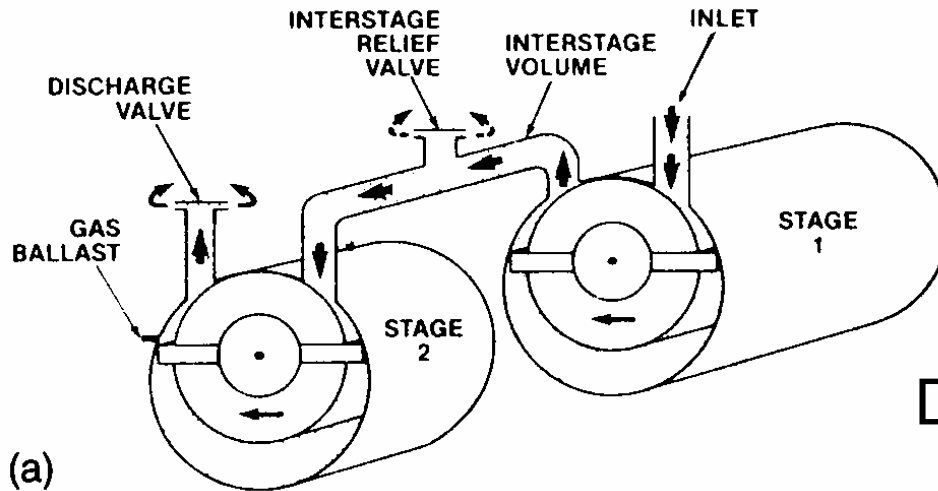


Figure 5.5 Basic mechanism of a sliding vane pump.



Double stage pump

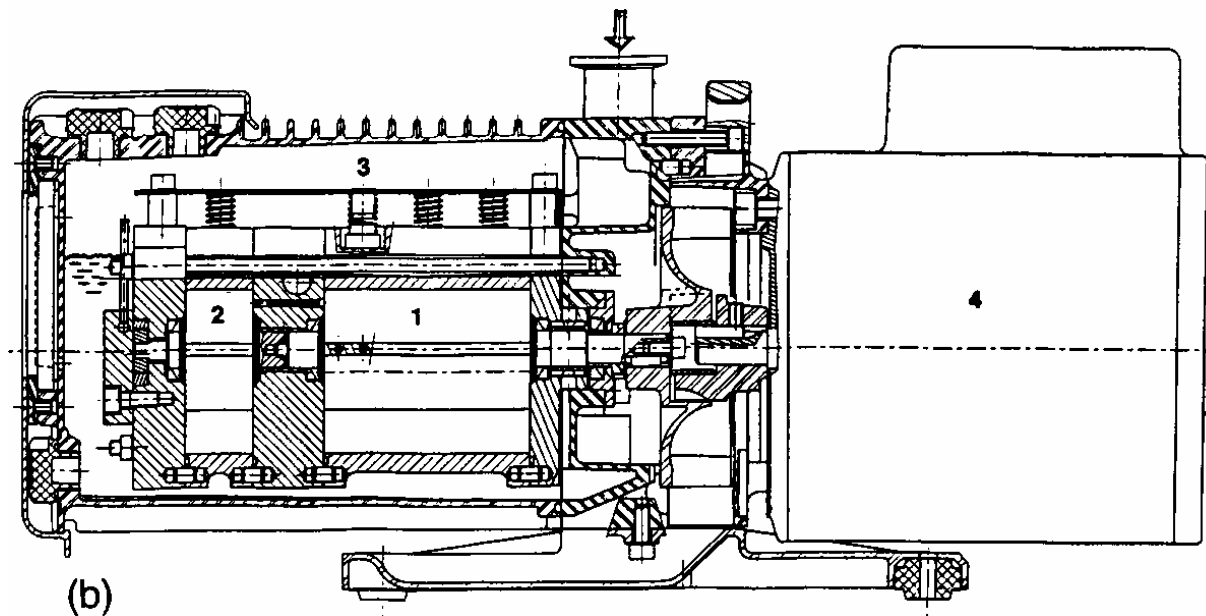


Figure 5.6 (a) Two-stage pump. (b) Cross section of a two-stage, oil-sealed, rotary-vane pump; (1) inlet stage, (2) second stage, (3) relief valve, (4) motor. (Courtesy of Alcatel Vacuum Technology.)

Pumping speed

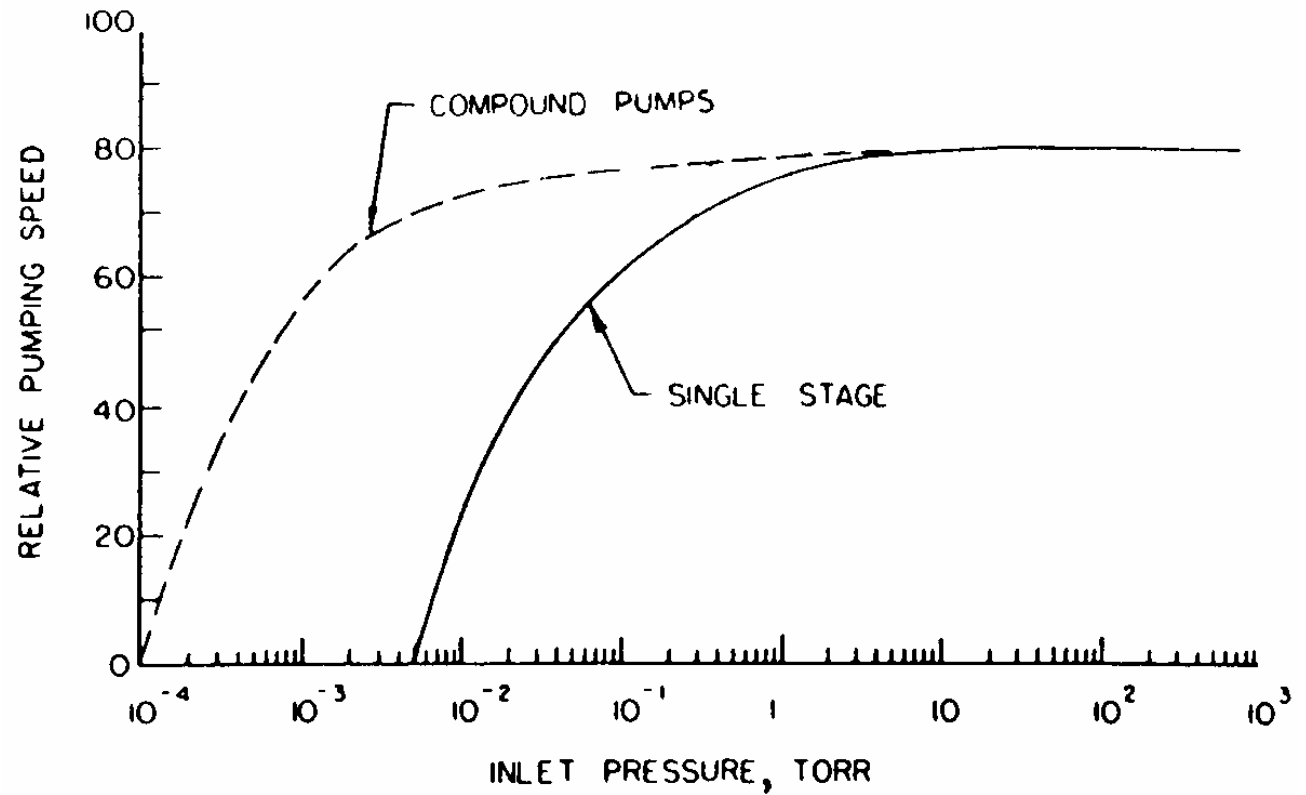


Figure 5.7 Pumping speed at various inlet pressures.

Diffusion (vapour jet) pumps

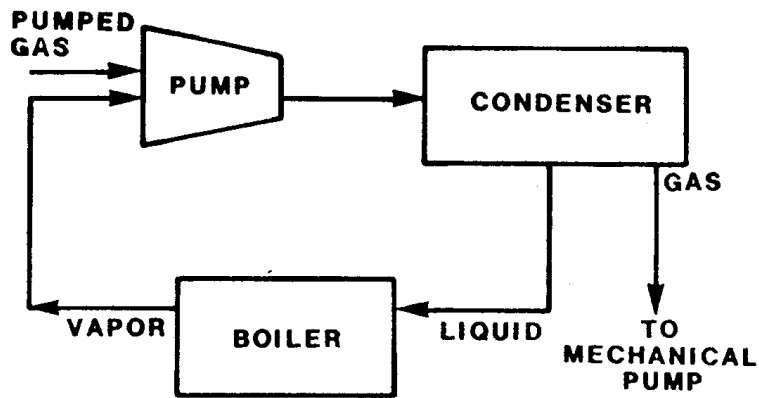


Figure 6.1 Pumping vapor cycle and gas flow in a vapor jet pump.

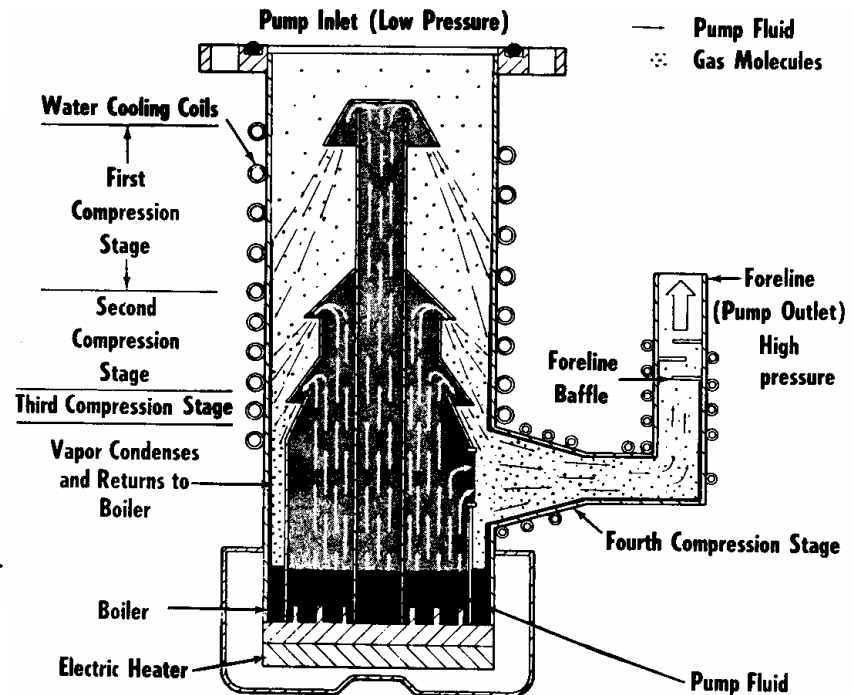
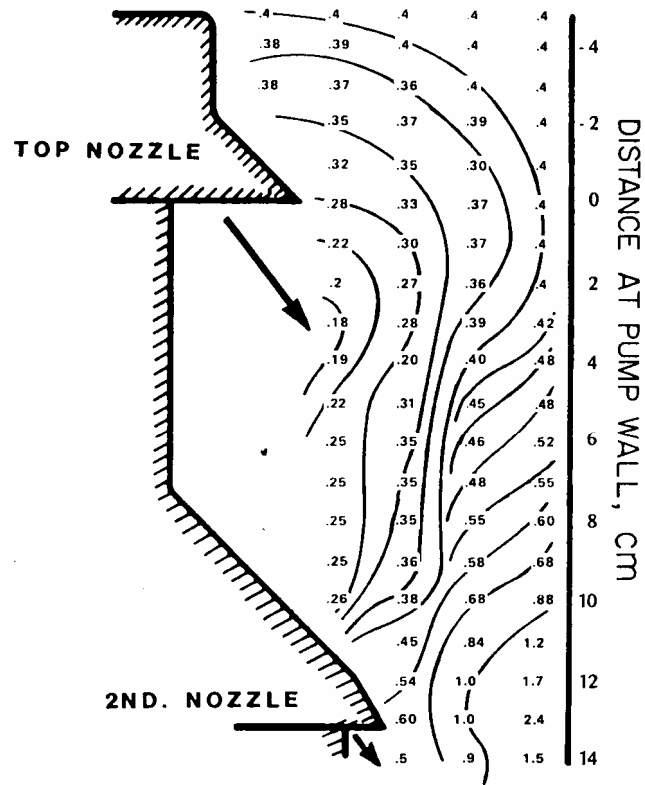


Figure 6.2 Pumping mechanism of a vapor jet pump.



Vapour streams

Figure 6.3 Pressure distribution of the pumped gas in the vicinity of the nozzle. Inlet pressure, 0.4 mtorr.

Diffstack pump

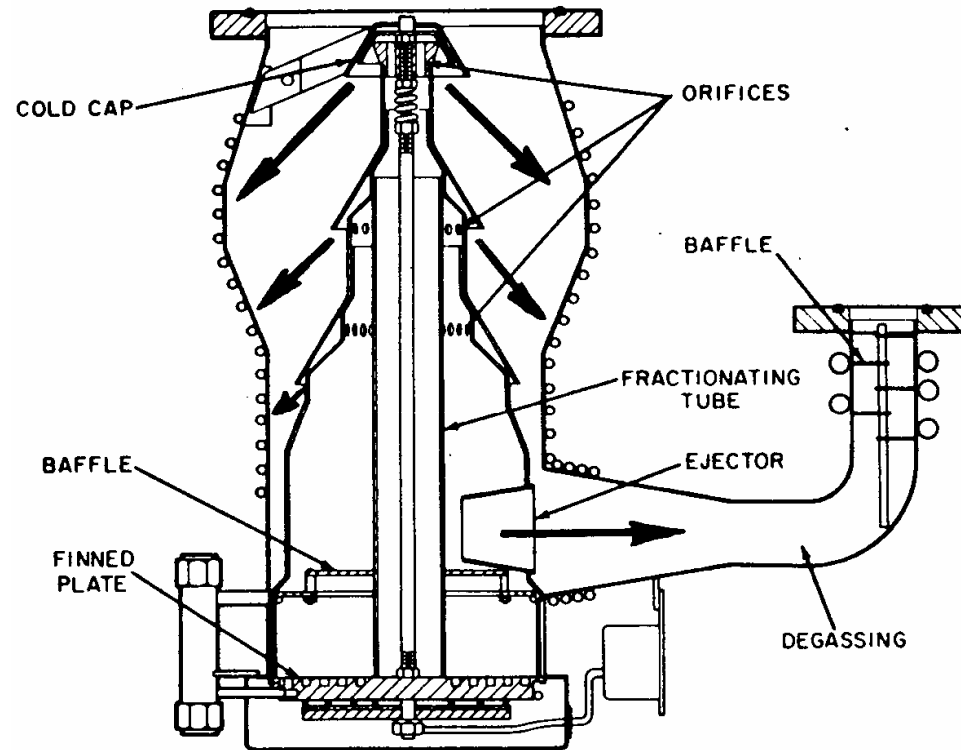


Figure 6.5 Schematic cross section of a four-stage pump (Varian VHS type).

Variation of pumping speed

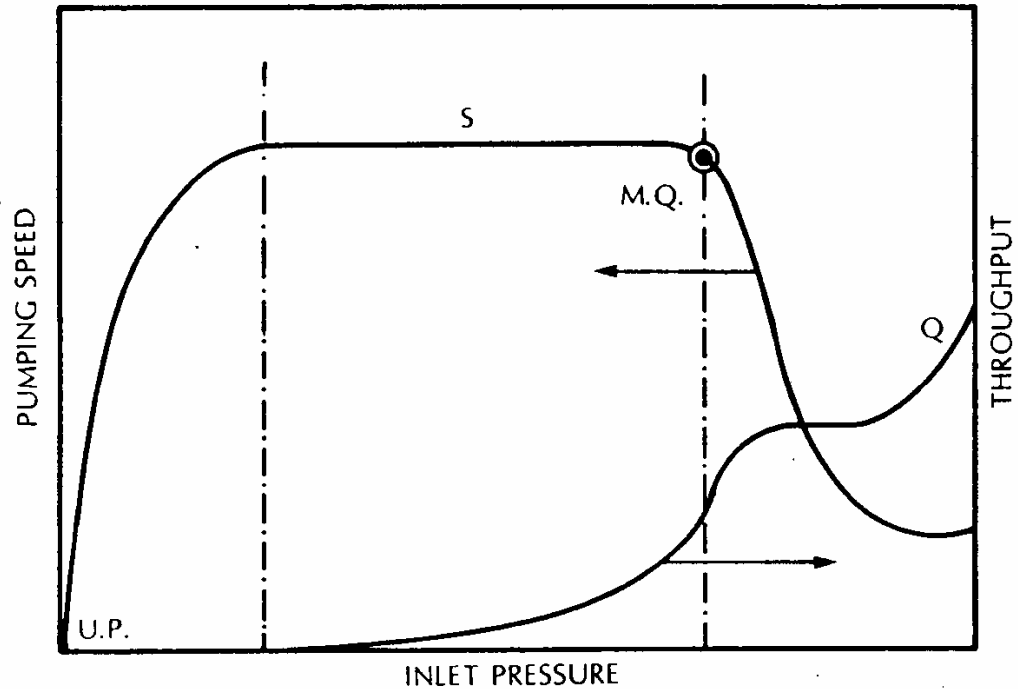


Figure 6.6 Usual representation of volumetric capacity (pumping speed).

UHV Chamber

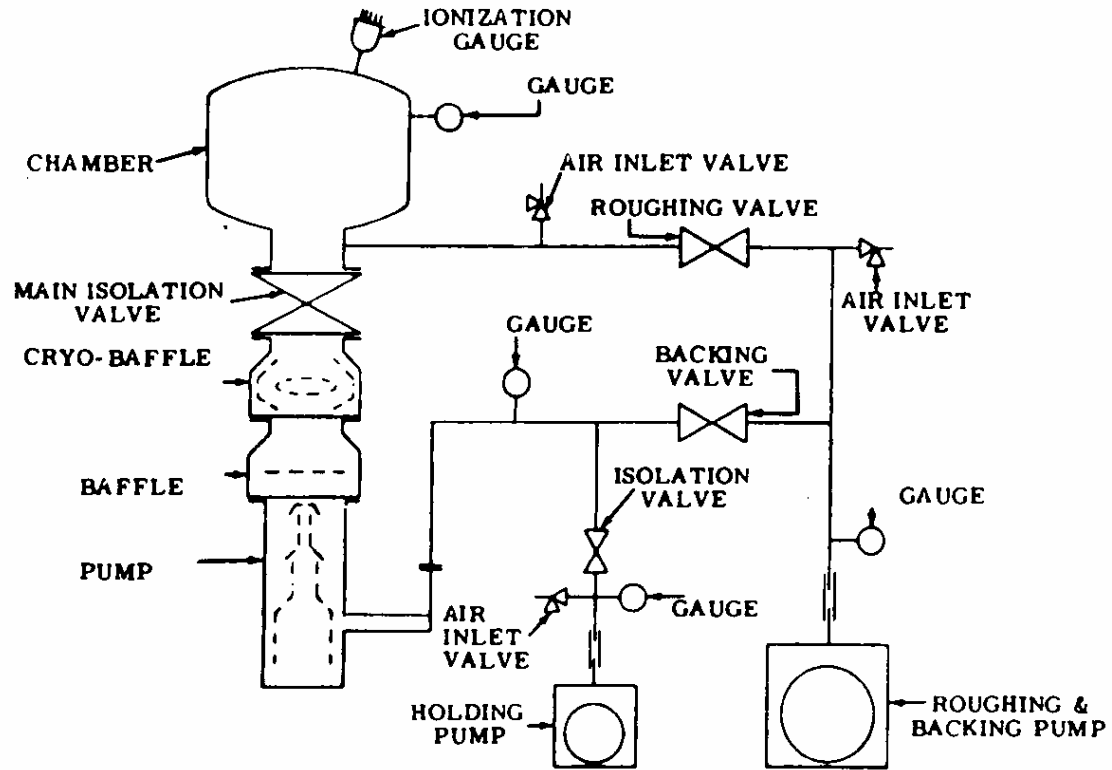


Figure 6.7 Typical arrangement of valves for a diffusion pump system.

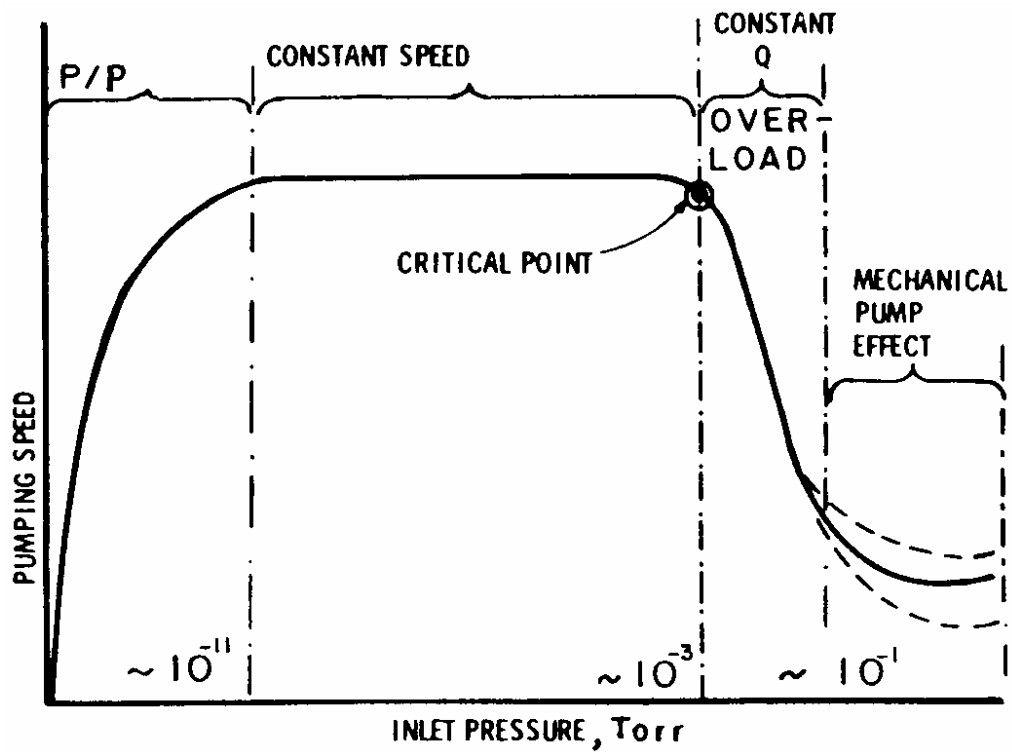


Figure 6.8 Pumping speed versus inlet pressure in four different performance regions.

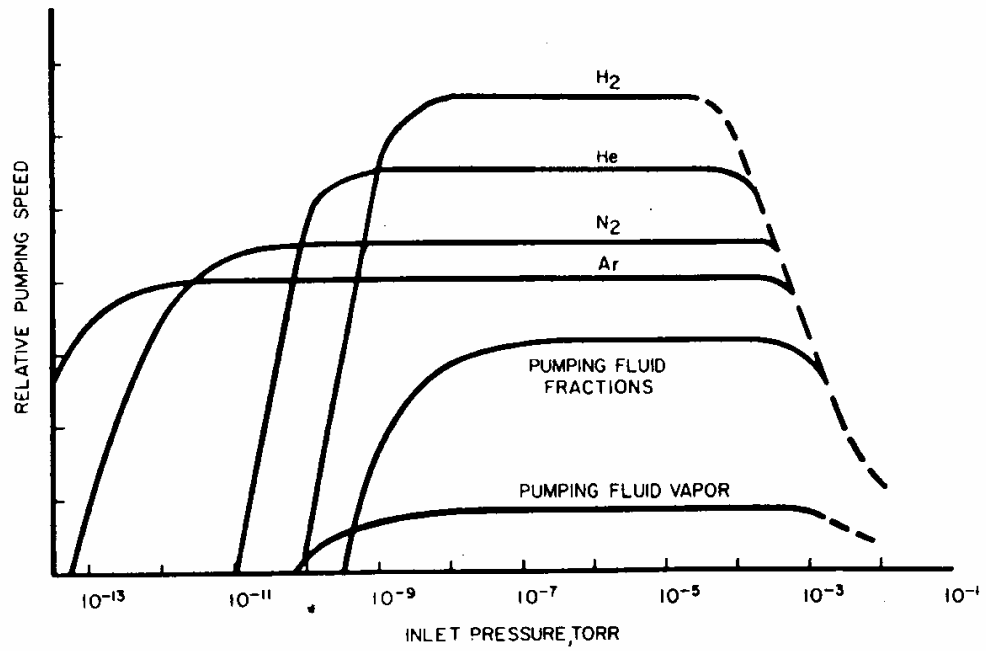


Figure 6.10 Typical performance with various gases present in the vacuum system.

Back streaming

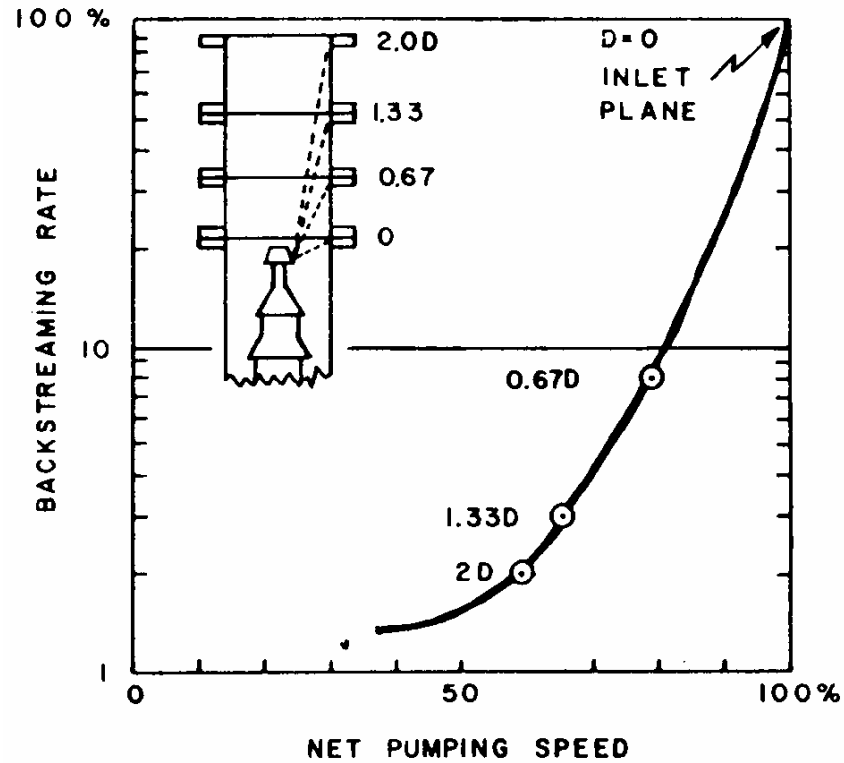


Figure 6.19 Plot showing relative backstreaming rates at various distances from the pump.

Turbomolecular Pumps

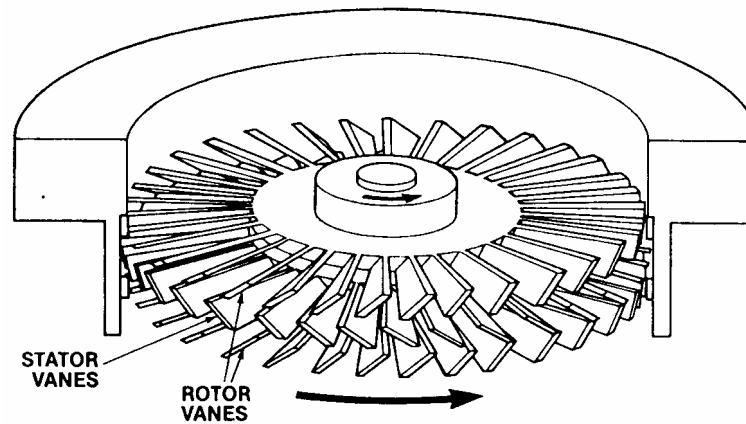
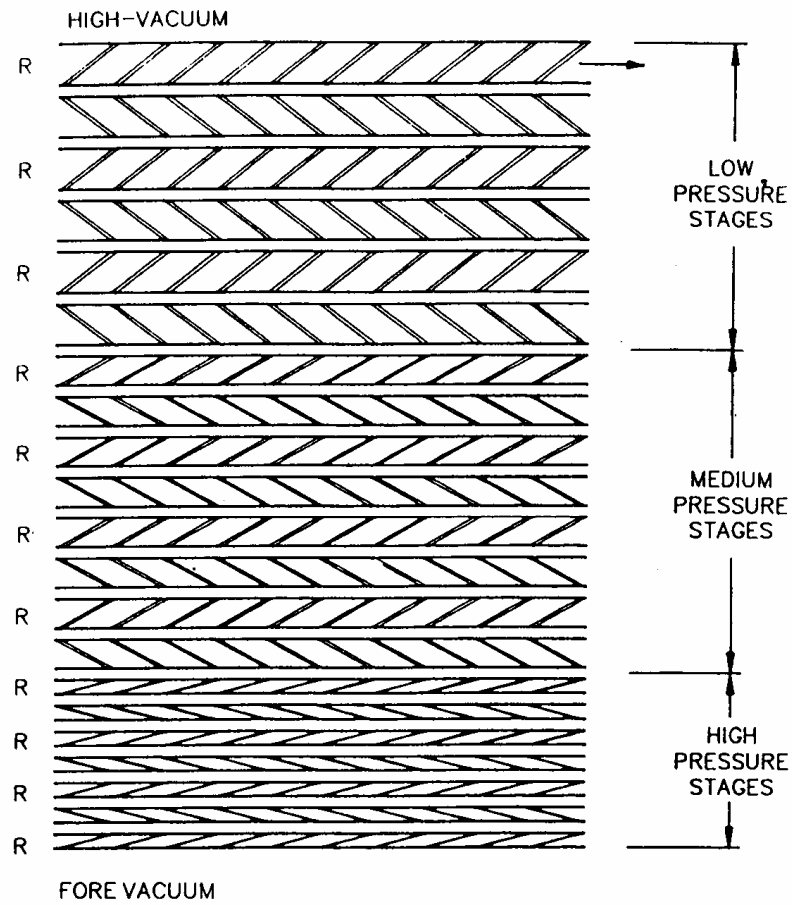


Figure 7.15 View of an axial-flow pump. Two rotors and a stator are shown.



R=ROTOR

Figure 7.17 Typical assembly of rotors and stators for conventional pumps.

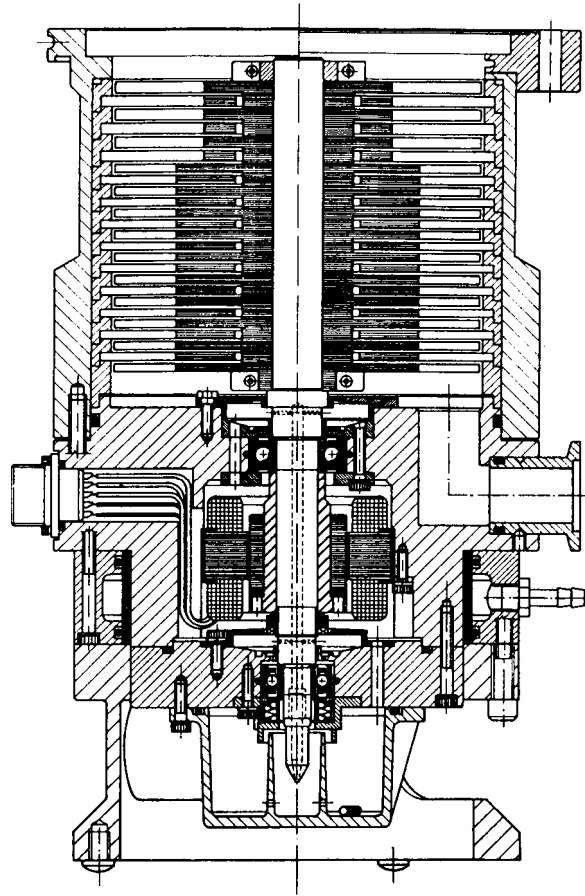


Figure 7.20 Cross section of a typical, conventional turbopump.

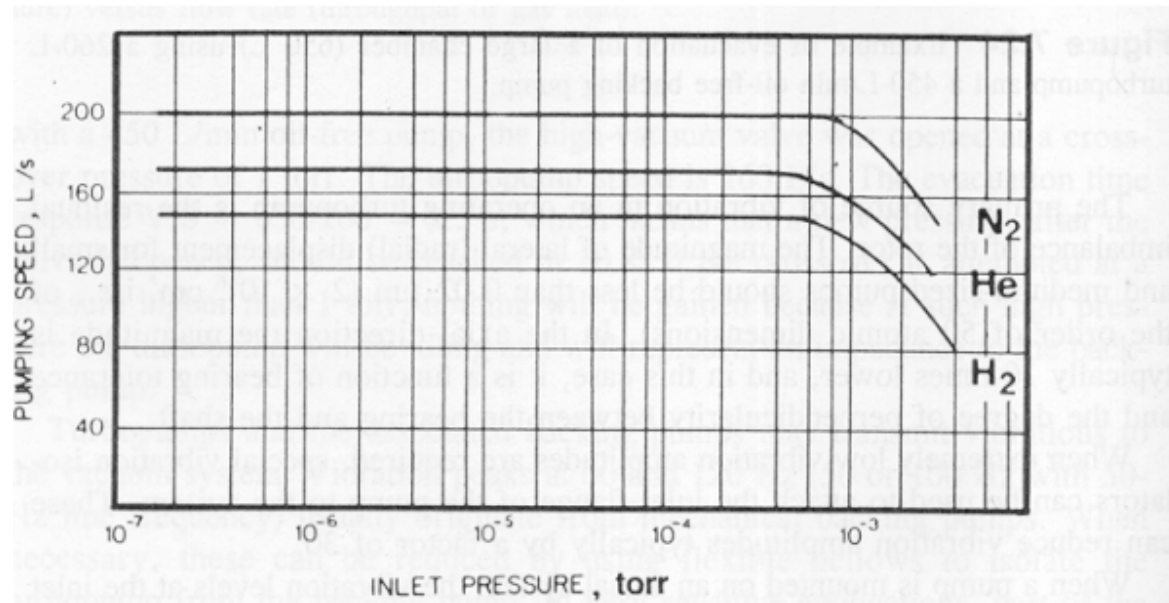


Figure 7.25 Pumping speeds of a conventional turbopump for nitrogen, helium, and hydrogen.

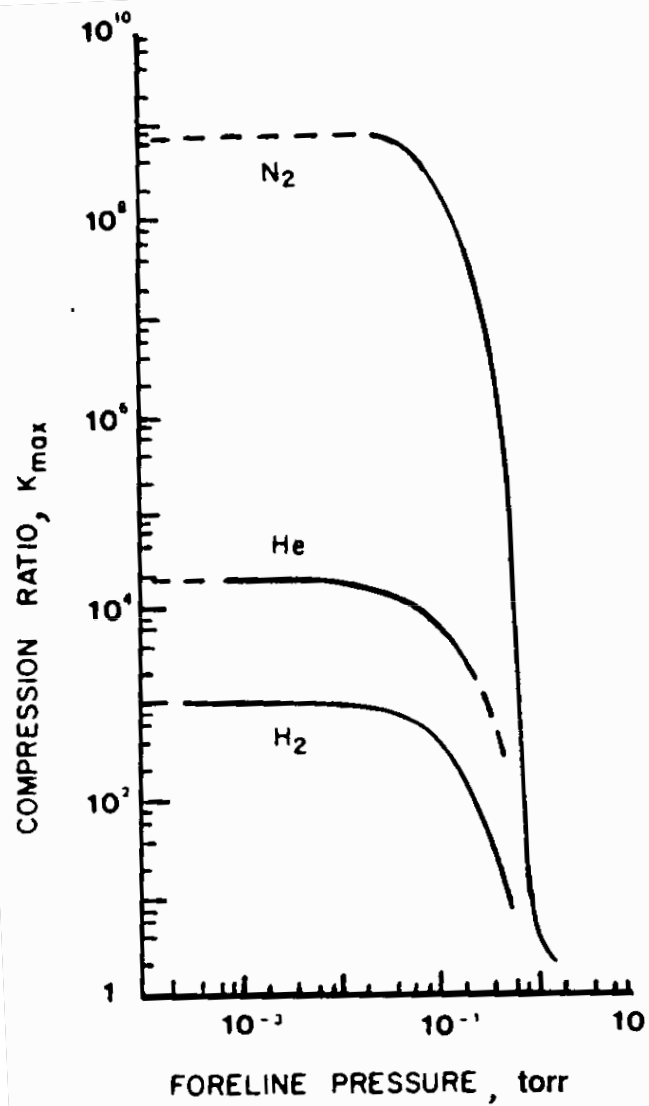


Figure 7.28 Decay of the maximum compression ratio at higher foreline pressures (for conventional pumps).

Why a turbo is better?

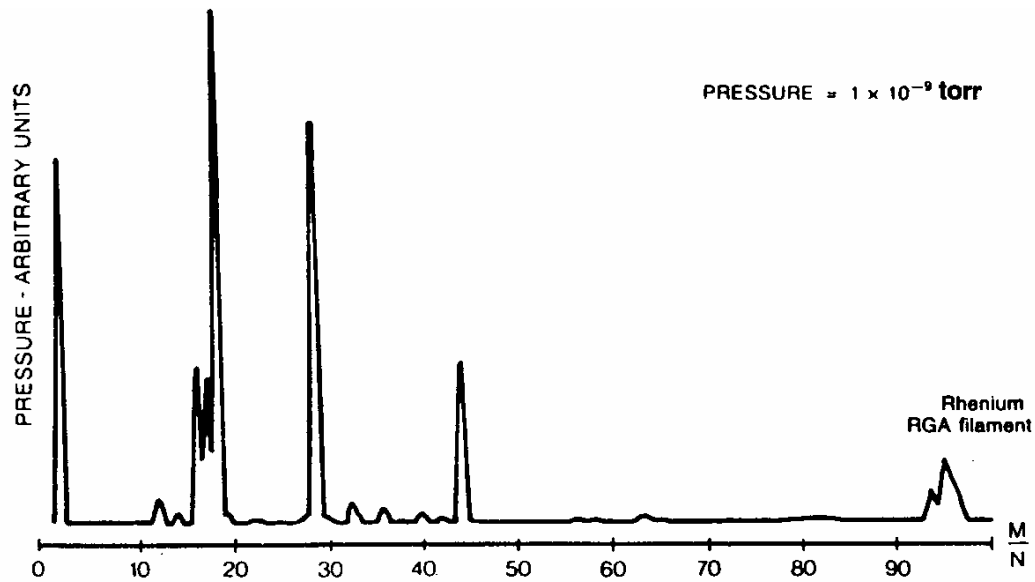


Figure 7.29 Residual gas spectrum in an unbaked small system pumped by a turbopump.

Cryo Pumps

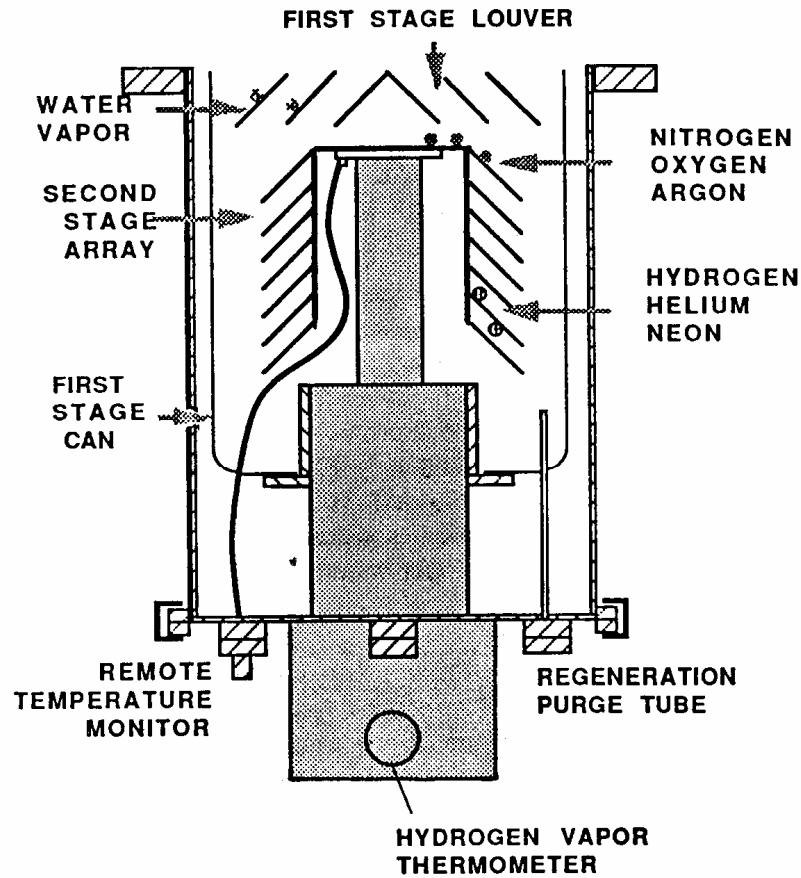


Figure 8.2 Schematic drawing of a typical cryopump.

Getter Pumps

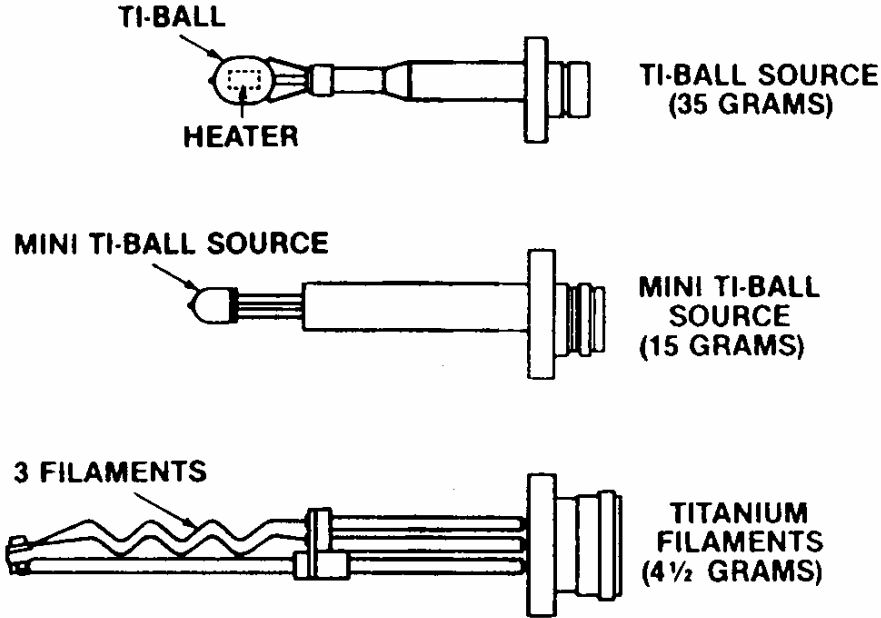
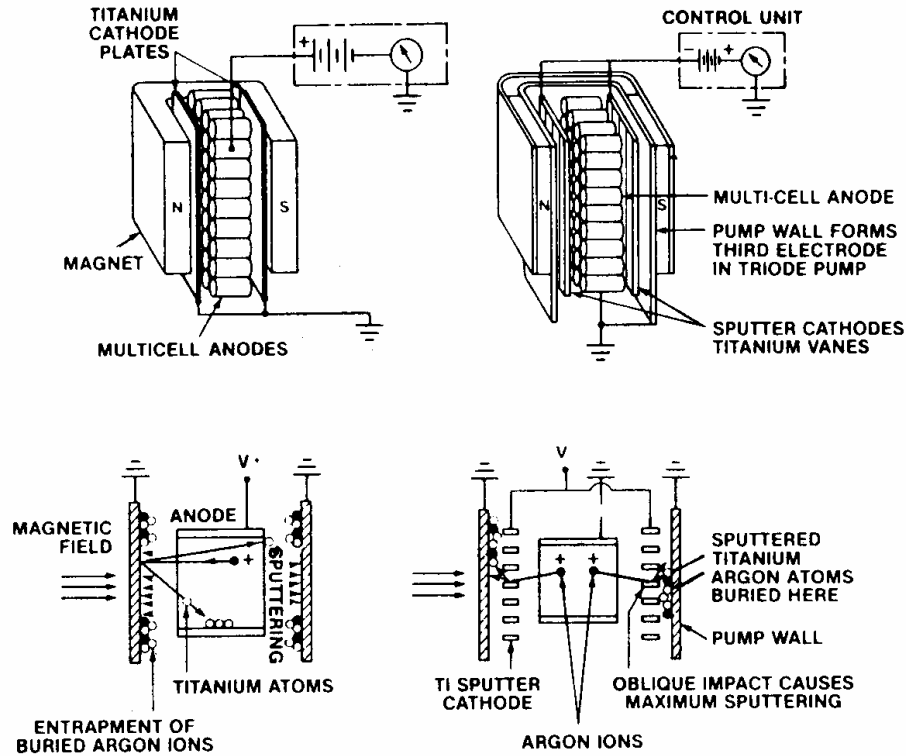


Figure 9.5 Various titanium evaporators.

Ion Pumps



(A) (B)

Figure 9.11 (A) Diode and (B) triode ion pumps.

UHV Instrumentation

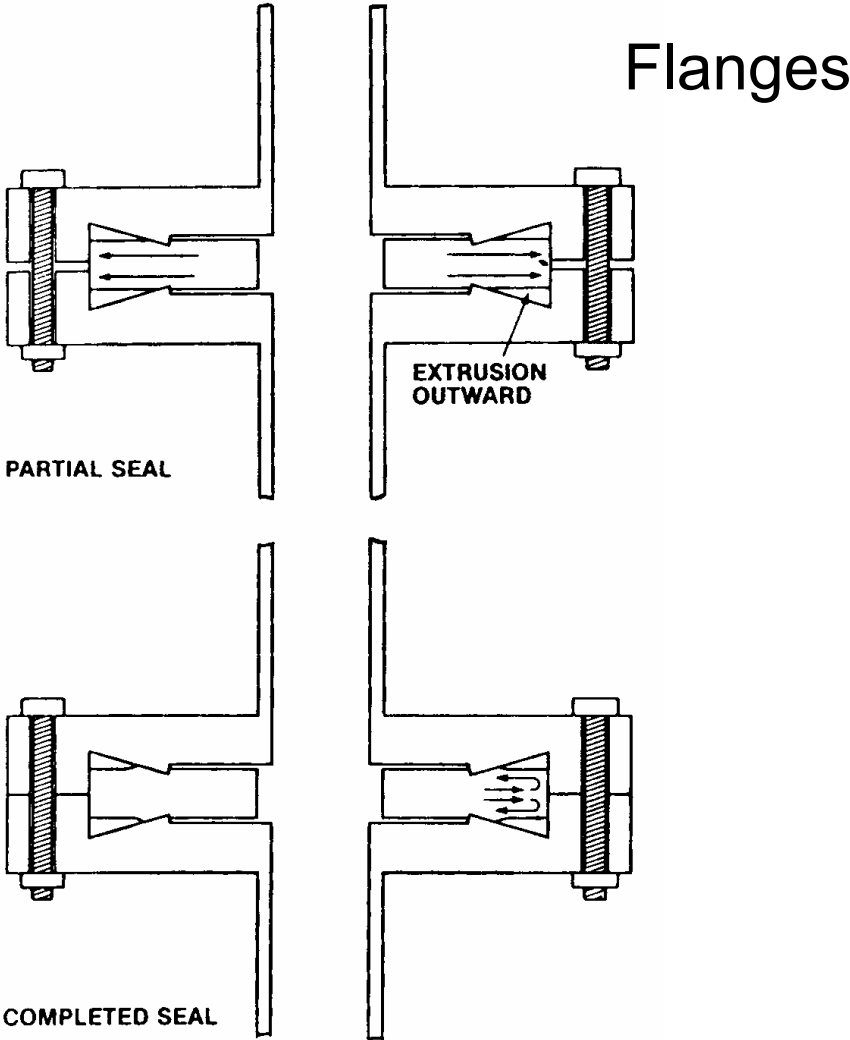


Figure 11.2 Design and action of ConFlat flanges.

Valves

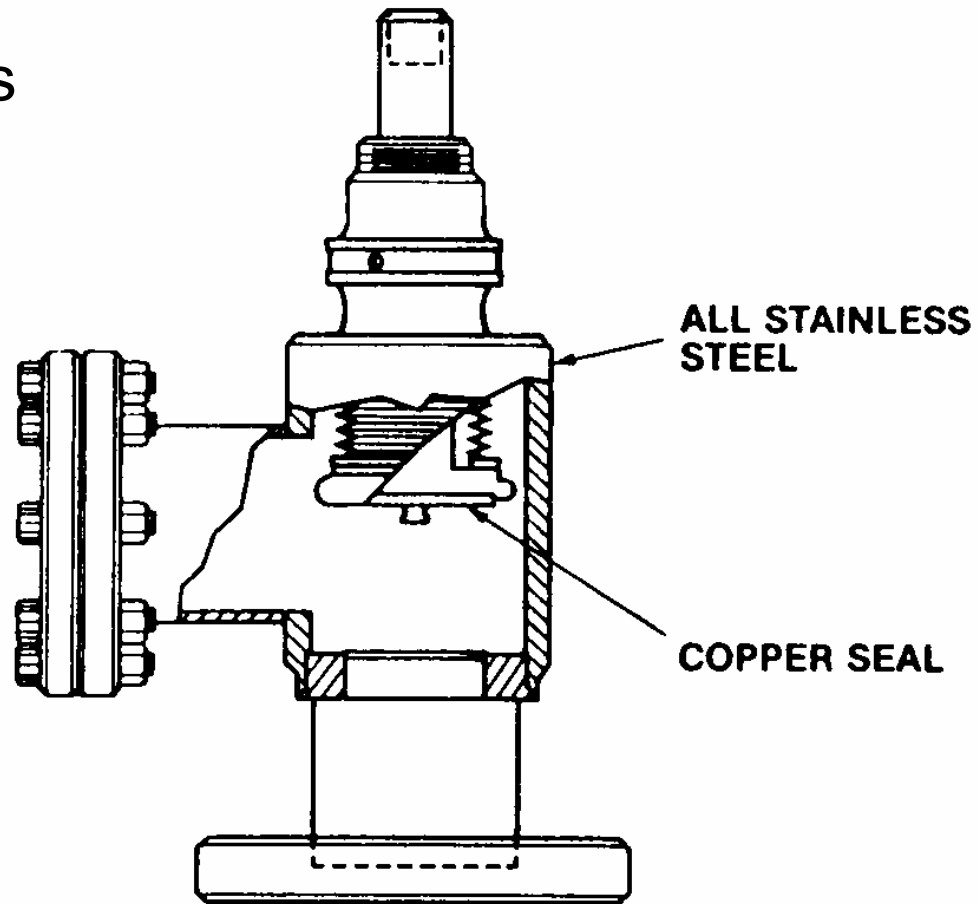


Figure 11.4 Example of a small all-metal valve.

UHV fittings

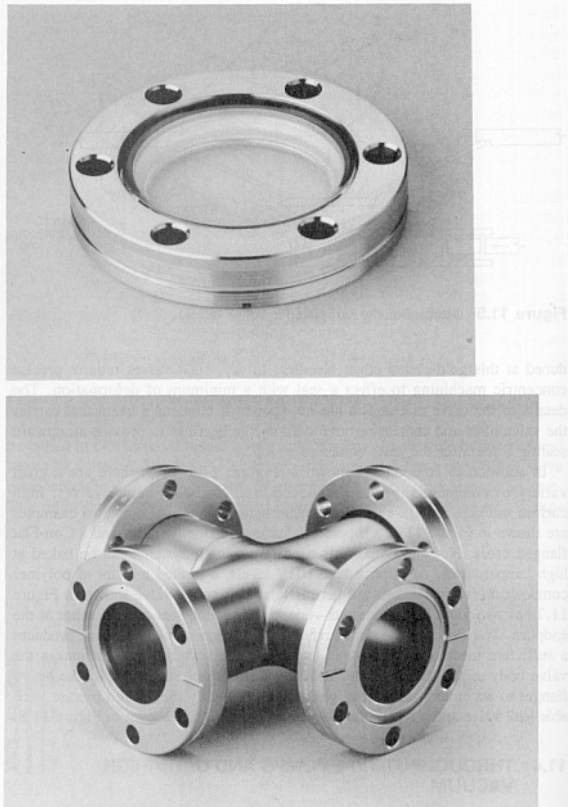


Figure 11.6 Examples of ultrahigh-vacuum hardware. Top, a glass-to-metal seal-type sight port; bottom, ConFlat flanged crosspiece.

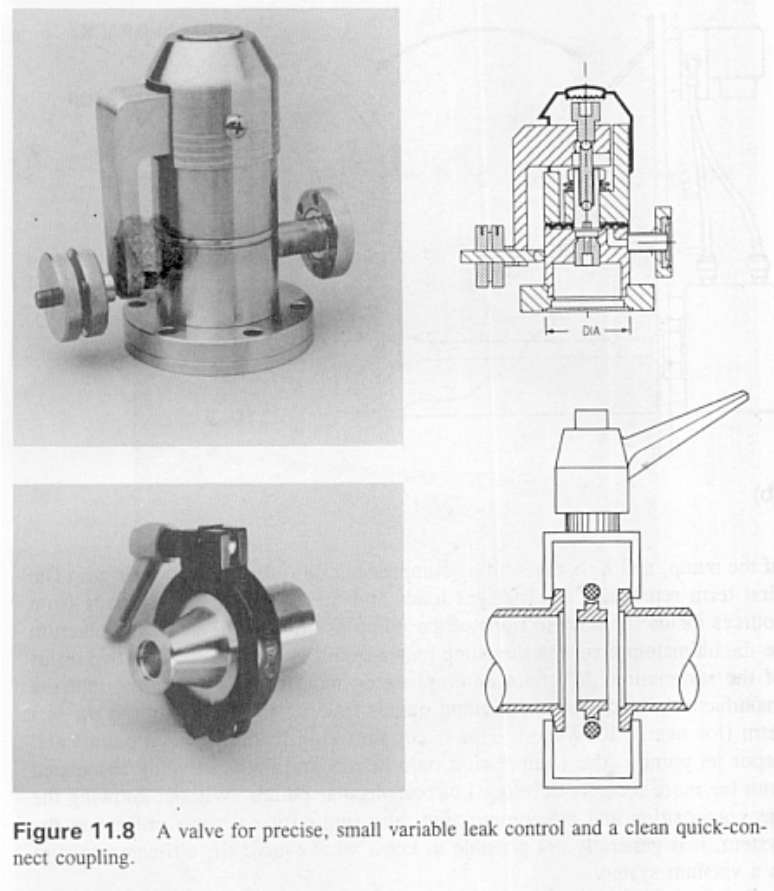


Figure 11.8 A valve for precise, small variable leak control and a clean quick-connect coupling.

Feedthroughs, view ports, gas admittance valves

Pressure measurement, mechanical

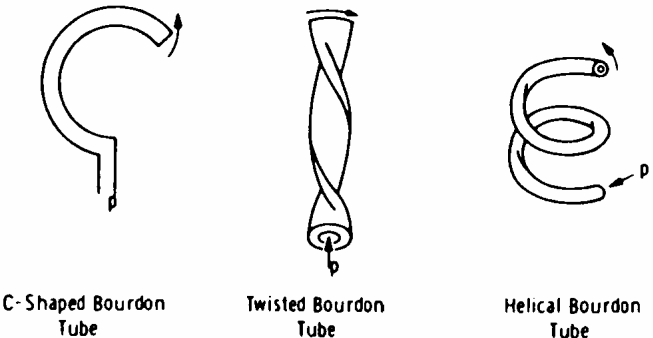
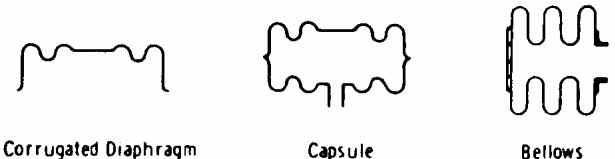
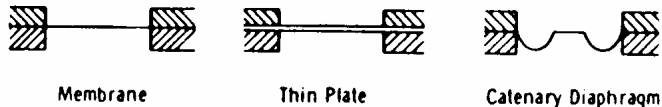


Figure 12.2 Pressure-sensitive elements used in mechanical manometers.

Capacitance

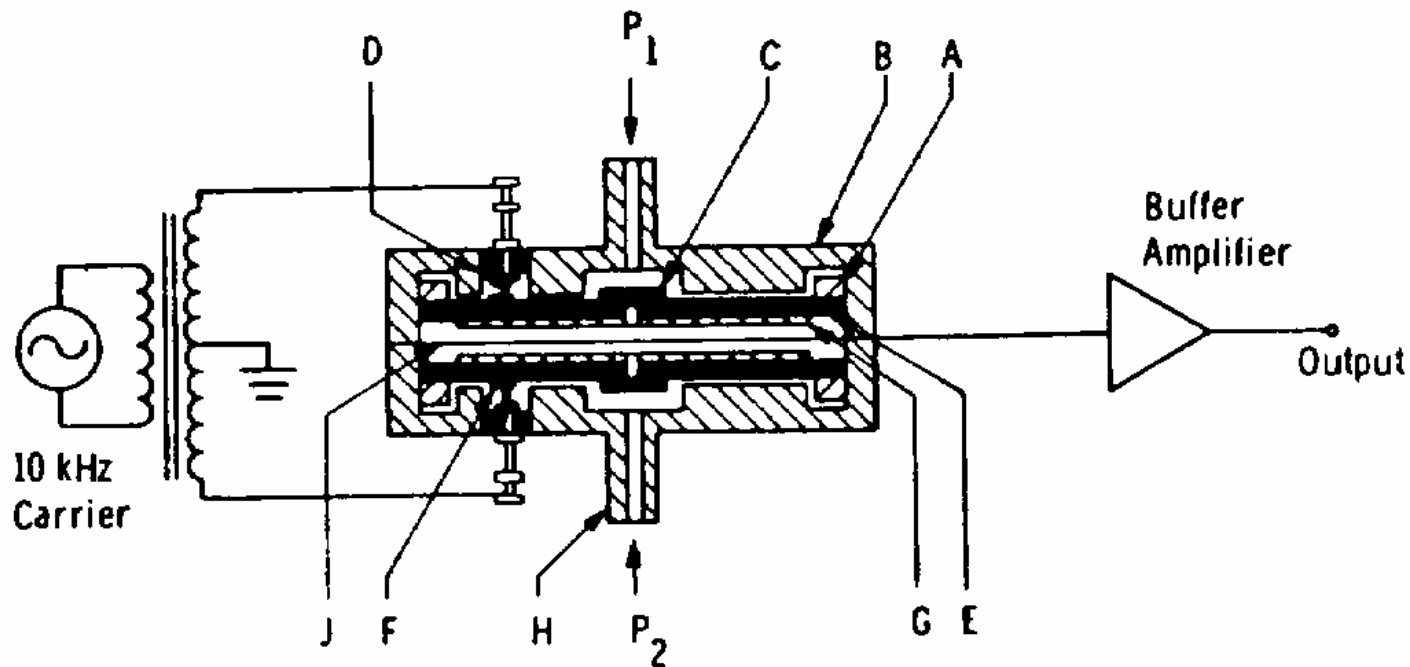


Figure 12.3 Capacitance manometer; (a) substrate support, (b) sealed housing, (c) screen, (d) jumper wire, (e) ceramic substrate, (f) film termination, (g) gold film, (h) pressure part, (j) diaphragm.

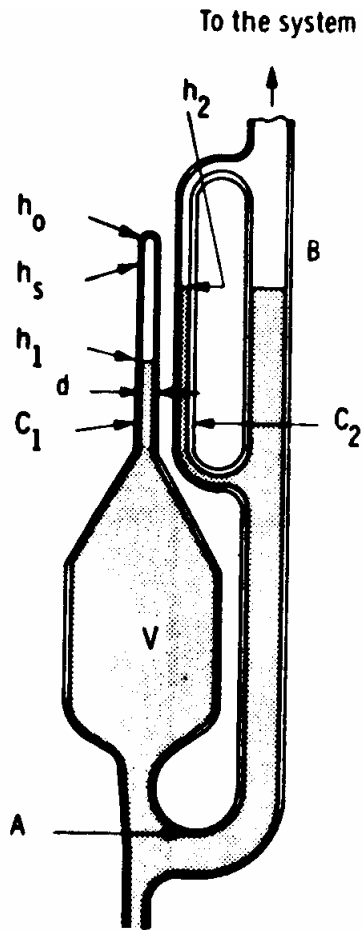


Figure 12.4 McLeod gauge (from C. M. Van Atta; Ref. 1)

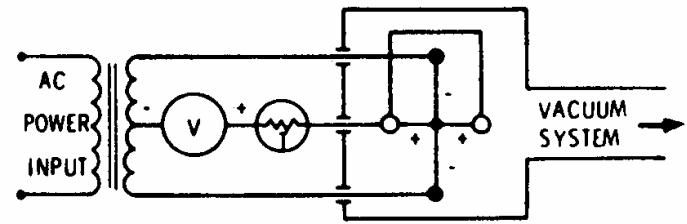
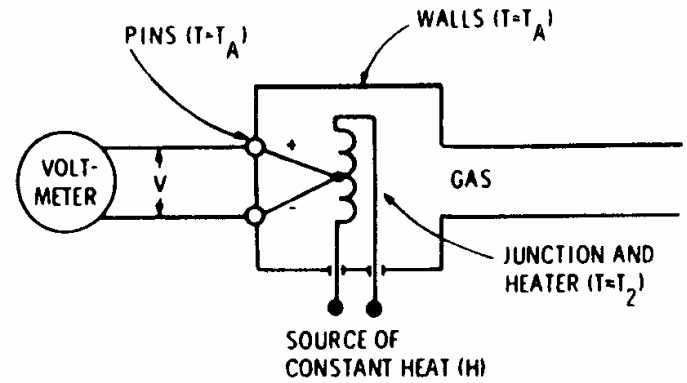


Figure 12.5 Thermocouple gauge.

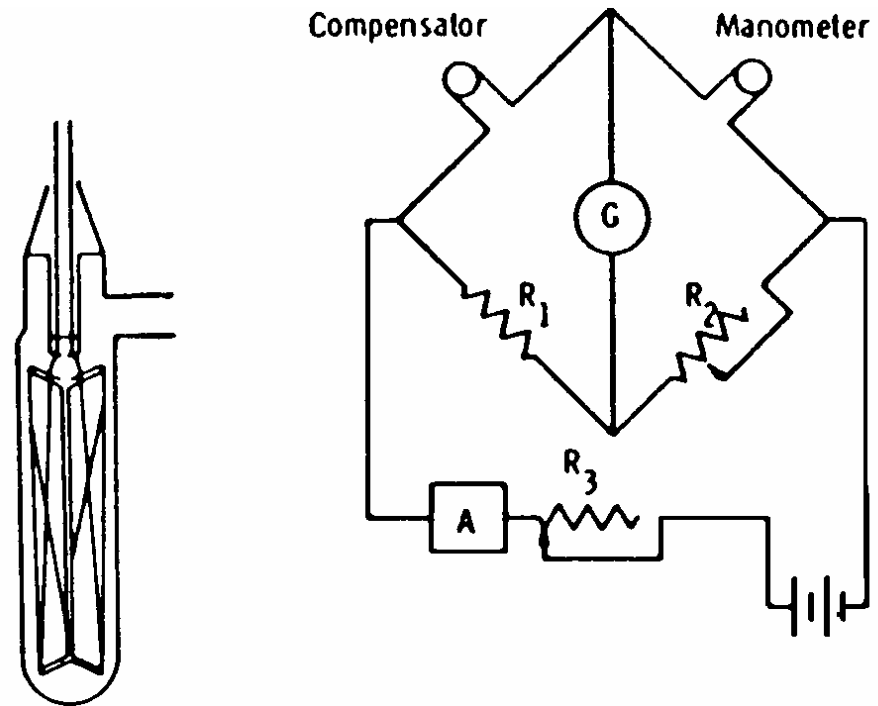


Figure 12.7 Pirani gauge.

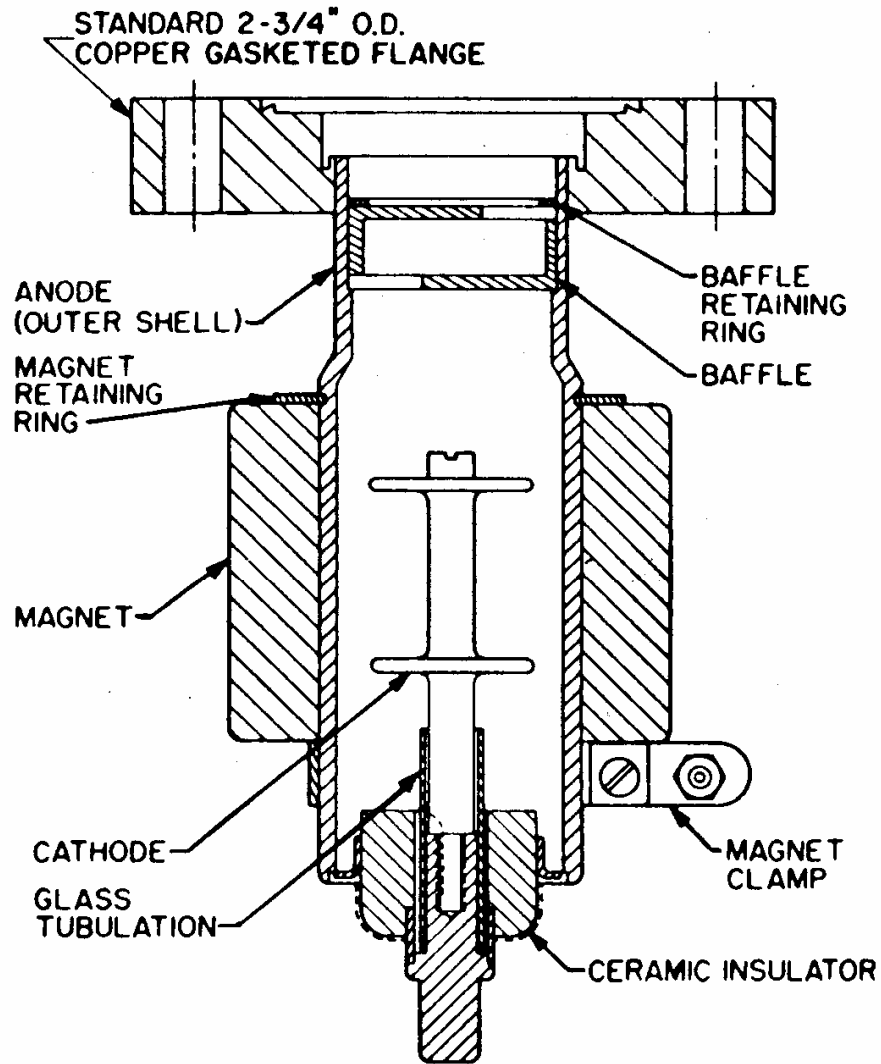


Figure 12.9 Cold cathode gauge (approximately actual size).

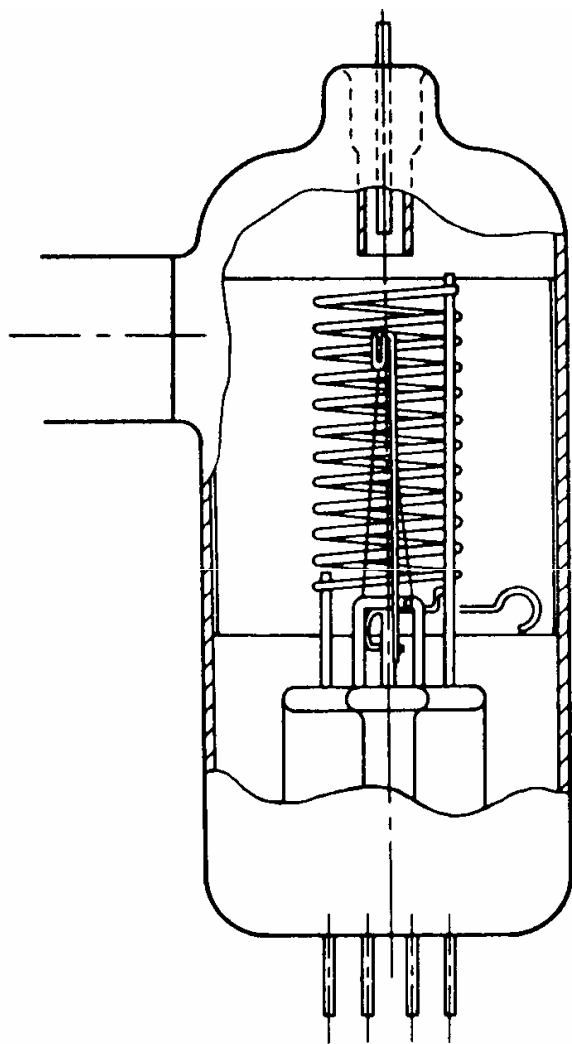


Figure 12.11 Bayard-Alpert ionization gauge (approximately actual size).

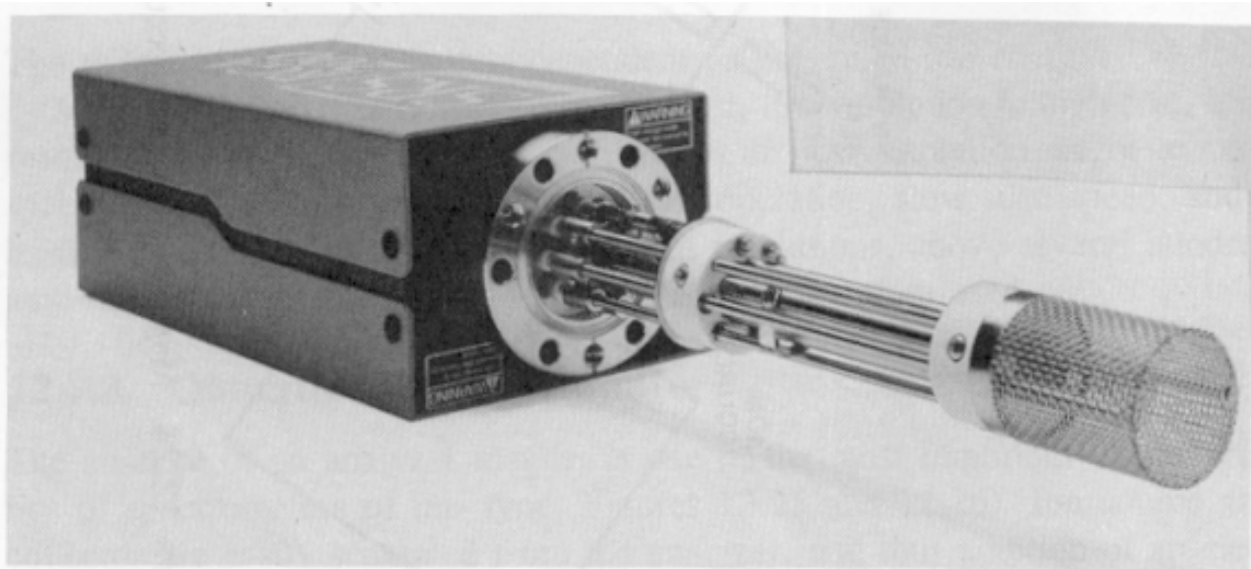


Figure 12.26 An RGA instrument with attached preamplifier section (Stanford Research Systems).

A chamber contains all these, in addition to your experiment!

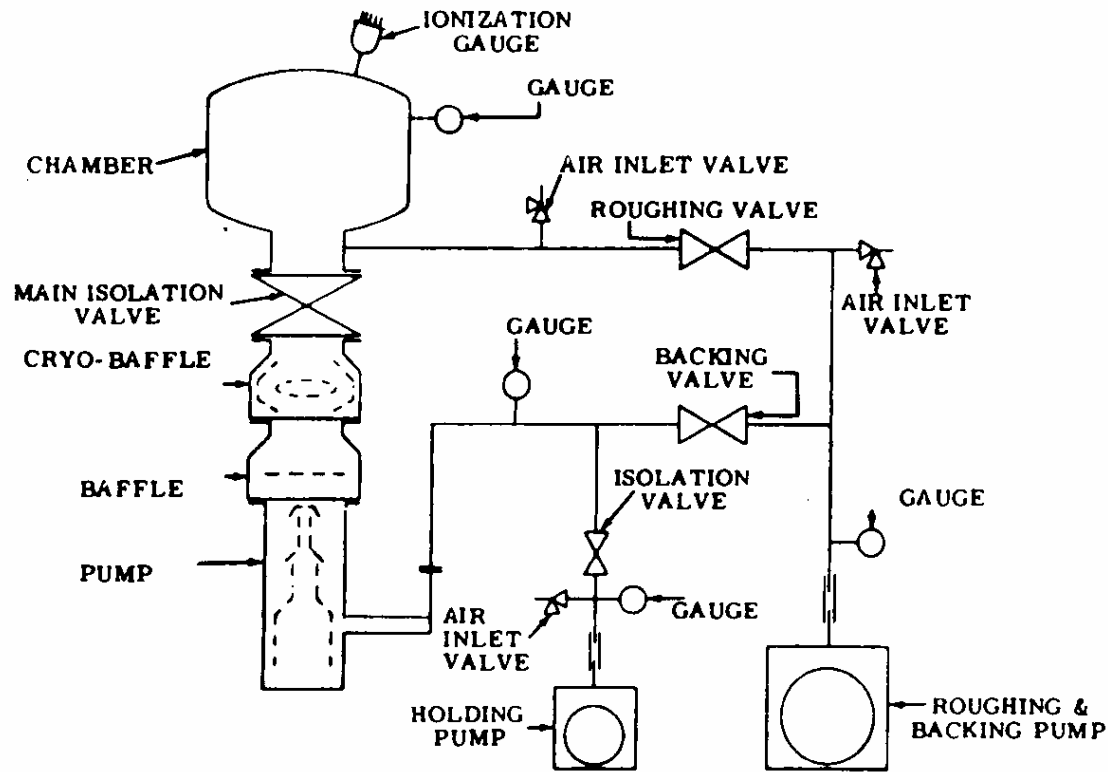


Figure 6.7 Typical arrangement of valves for a diffusion pump system.