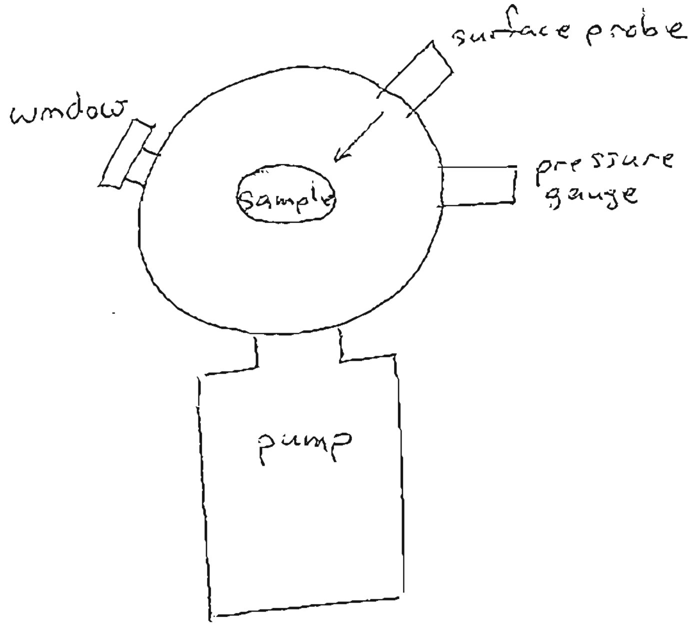
Surface Analysis ⇒ Need for Vacuum Technology



Different Types of Pumps

Different Types of Gauges

Different Types of Vacuum Chambers / Fittings

Advances in Vacuum Technology

Different Types of Pumps

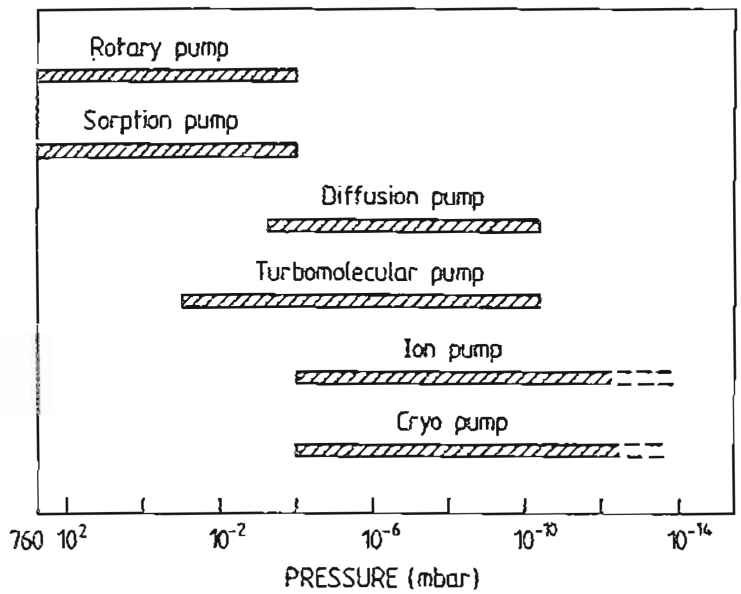


Fig.I.2. Pressure ranges in which different types of pumps can be employed

– H. Lüth, p. 7
Surfaces and Interfaces of Solid Mat

The Pumping Equation

Particle number rate of change $= \frac{dN}{dt}$

$$\frac{dN}{dt} = \text{rate in} - \text{rate out}$$

$$\frac{dN}{dt} = \frac{dN_{in}}{dt} - \frac{dN_{out}}{dt}$$

$\frac{dN_{in}}{dt} =$ particle flux from vessel walls x wall area

$$\frac{dN_{in}}{dt} = \nu A_v$$

$\frac{dN_{out}}{dt} =$ rate of particles being pumped out

$$pV = NkT$$

constant pressure $\quad p\frac{dV}{dt} = \frac{dN_{out}}{dt} kT \qquad \frac{dV}{dt} \equiv S$

$$\Rightarrow \frac{dN_{out}}{dt} = \frac{pS}{kT}$$

$$\Longrightarrow \frac{dN}{dt} = \nu A_v - \frac{pS}{kT}$$

$$\Rightarrow \nu A_v = \frac{dN}{dt} + \frac{pS}{kT}$$

$$pV = NkT$$

constant volume $\quad \frac{dp}{dt}\frac{V}{kT} = \frac{dN}{dt}$

$$\Rightarrow \nu A_v = \frac{dp}{dt}\frac{V}{kT} + \frac{pS}{kT}$$

$$\boxed{\nu A_v = \frac{V}{kT}\left(\frac{dp}{dt} + \frac{pS}{V}\right)}$$

constant volume equation

$$q A_v = V\frac{dp}{dt} + pS$$

$$q A_v = Q + pS$$

or

$$kT\frac{dN}{dt} = (kT\nu)A_v - pS$$

$$= \frac{d}{dt}(NkT) = \frac{d}{dt}(PV) = Q$$

$Q \equiv$ throughput

$q = kT\nu$

$$\Rightarrow \boxed{Q = q A_v - pS}$$

more general formula

Example 1:

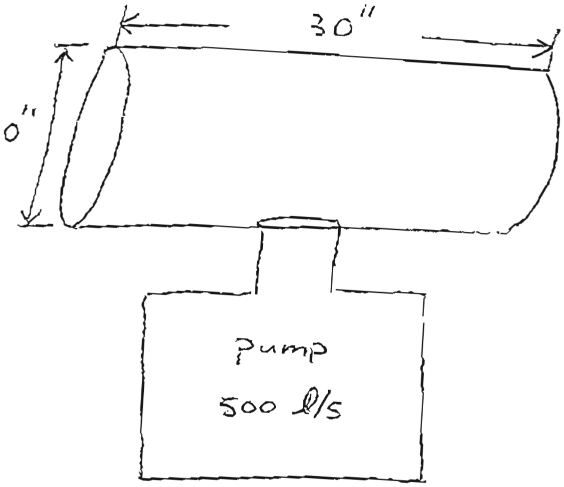
Suppose constant pressure $\frac{dp}{dt} = 0$

$\boxed{\text{here } Q \text{ is zero}}$

$$\Rightarrow \quad vA_v = \frac{pS}{kT}$$

$$\Rightarrow \quad \boxed{p = \frac{kT}{S} vA_v = \frac{q A_v}{S}} \qquad q \equiv kTv$$

$$\text{Area} = \pi (5'')^2 \left(\frac{.0254\,m}{''}\right)^2 (2) + 2\pi (5'') \left(\frac{.0254\,m}{''}\right)^2 (30'')$$



$$A_v = .709\ m^2$$

$q\,\cancel{\nu}$ for baked stainless steel

$$q\,\cancel{\nu} = 400 \times 10^{-11}\ W/m^2$$

$$\cancel{(kT = .025\,eV)\left(\frac{1.602\times10^{-19}\,J}{eV}\right) = 4.01\times10^{-21}\,J}$$

$$S = 500\ l/s = .5\ m^3/s$$

$$\Rightarrow \quad p = \frac{\cancel{\text{[illegible]}}}{(.500\,m^3/s)} (400\times10^{-11}\,W/m^2)(.709\,m^2)$$

$$\underline{p = 5.67 \times 10^{-9}\ Pa}$$

1 atm = 760 torr = 10^5 Pa

$\Rightarrow$

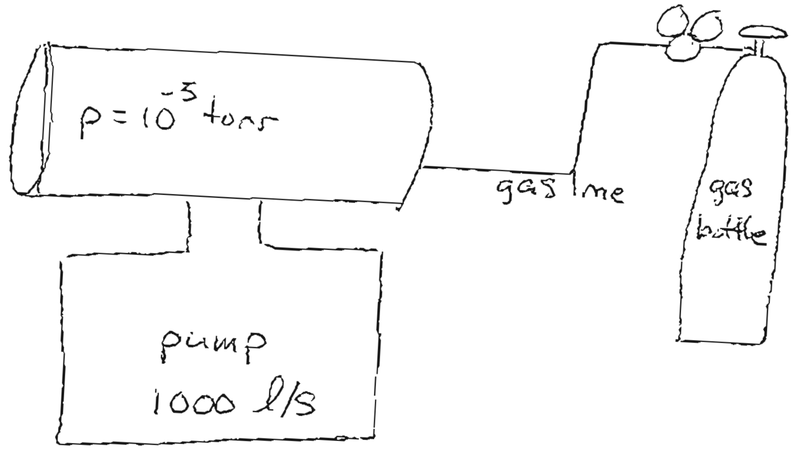
$$p = 5.67\times10^{-9}\,Pa \left(\frac{760\ \text{torr}}{10^5\ Pa}\right)$$

$$\underline{p = 4.3 \times 10^{-11}\ \text{torr}}$$

a very respectable pressure

Example 2

Gas flow Conditions



Question:
What is the "flow rate" of gas in the gas line in sccm?

1 sccm = 1 standard cubic centimeter per minute

In thise case,

$$q A_0 << pS$$

$$\Rightarrow |Q| = pS = \text{throughput} = kT \frac{dN}{dt}$$

Key Point is constant throughput

$$\Rightarrow pS\Big|_{chamber} = pS\Big|_{gas\ line}$$

$$\frac{(10^{-5}\ \text{torr})(1000\ l/s)}{(760\ \text{torr})} = S$$

1 atm

$$S = 1.32 \times 10^{-2}\ \text{scc/s}$$

$$\boxed{S = .79\ \text{sccm}}$$

standard cubic cm per minute

Example 3

Suppose there exists a leak in the chamber at a rate of particles per second of L

$$vA_0 \rightarrow vA_0 + L$$

Assuming $L \gg vA_0$ and constant volume (of chamber)

$$\Rightarrow \quad L = \frac{V}{kT}\left(\frac{dp}{dt} + \frac{pS}{V}\right)$$

To determine the leak rate, one could turn off the pump $\Rightarrow S \rightarrow 0$

Then $$L = \frac{V}{kT}\frac{dp}{dt}$$

$$q_L = kTL = V\frac{dp}{dt}$$

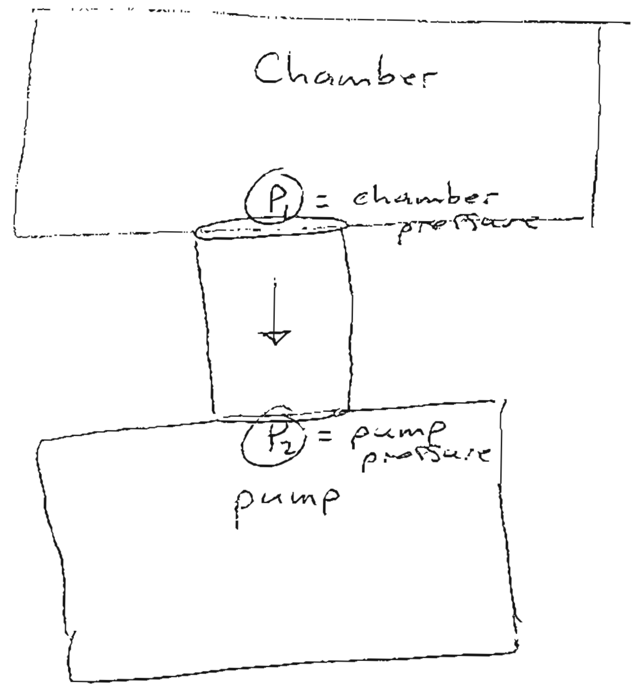
measuring dp/dt with a pressure gauge,

q_L is calculated

Modification of Equations for Pump tubing

must consider <u>conductance</u> C

$$C = \frac{\text{throughput}}{\text{pressure difference}}$$



$$C = \frac{Q}{\Delta P}$$

or $$Q = C\Delta P$$

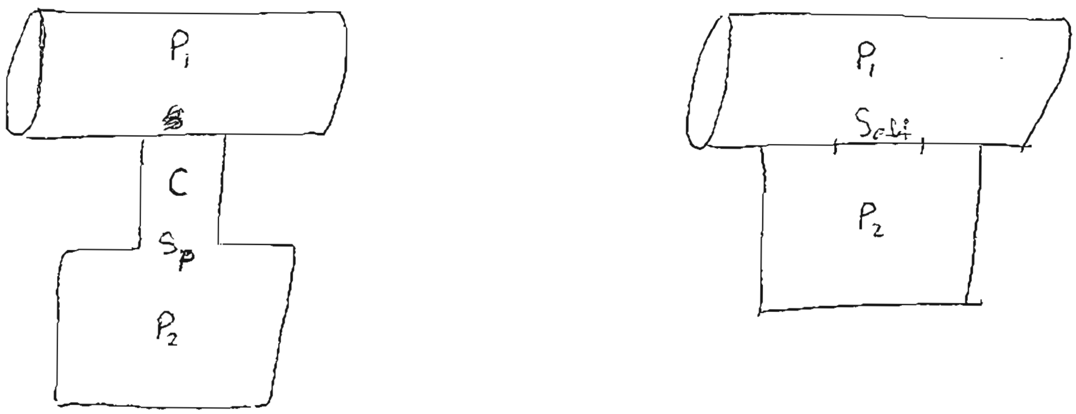
$$kT\frac{dN}{dt} = C\Delta P$$

$$\frac{dN}{dt} = \frac{C\Delta P}{kT}$$

Key Point is that any pipe or tube has a conductance which depends on the pressure.

The finite conductance always limits the effective pumping speed.

Effective Pumping Speed



Assume at the pump entrance, $Q = pS$

$(Q \gg qA)$

$$P_2 = \frac{Q}{S_p}$$

$$P_1 = \frac{Q}{S_{eff}}$$

By definition,

$$\frac{Q}{C} = \Delta P = P_1 - P_2$$

$$\Rightarrow P_1 = P_2 + \frac{Q}{C} = \frac{Q}{S_p} + \frac{Q}{C} = \frac{Q}{S_{eff}}$$

$$\Rightarrow \boxed{\frac{1}{S_{eff}} = \frac{1}{S_p} + \frac{1}{C}}$$

Similar to an electrical circuit

Conductances in parallel (parallel tubes)

have:

$$\boxed{C_T = C_1 + C_2 + \dots}$$

Conductances in series (series tubes)

have:

$$\boxed{\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \dots}$$

Different Flow Regimes

1. viscous flow (higher pressures) $(pd > 10\ \text{mbar}\cdot\text{mm})$

~ 10 torr mm

$\sim .4$ torr inch

$\Rightarrow$ • mean free path of molecule less than pipe dimensions

• molecule - molecule collisions important

$$\boxed{C\,(l/s) = 137\,\frac{d^4\,[cm^4]}{L\,[cm]}\,p\,[mbar]}$$

2. molecular flow (low pressure) $(pd < 0.1\ \text{mbar mm})$

$\Rightarrow$ • mean free path of ~~of~~ molecule greater than pipe dimensions

• molecule - wall collisions important

$$\boxed{C\,[l/s] = 12\,\frac{d^3\,[cm^3]}{L\,[cm]}}$$

viscous

$d = 10$ cm $L = 100$ cm, $p = 1$ mbar

$\Rightarrow C =$ 13700 l/s

molecular

$C = 120\ l/s$