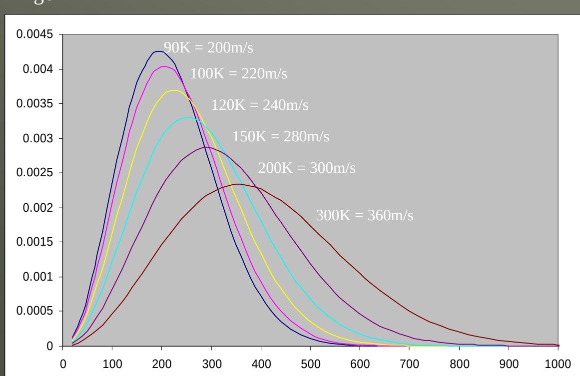
Maxwell's Distribution of Speed

$$f(s) = 4\pi\left(\frac{M}{2\pi RT}\right)^{\frac{3}{2}} s^2 e^{\frac{-Ms^2}{2RT}}$$

Argon

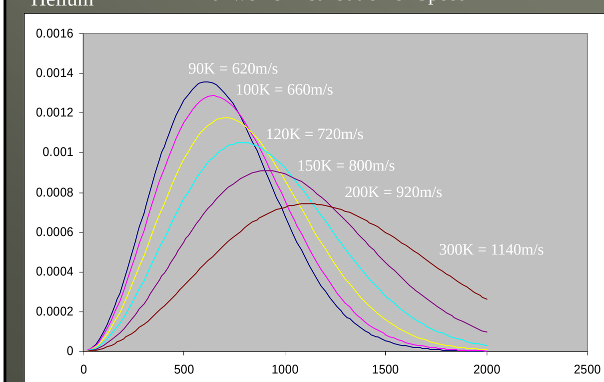
Maxwell's Distribution of Speed



Speed(m/s)

Helium

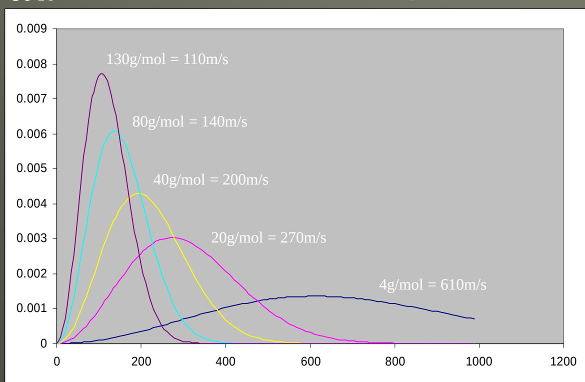
Maxwell's Distribution of Speed



Speed(m/s)

90 K

Maxwell's Distribution of Speed



Speed(m/s)

Collision Cross Section:

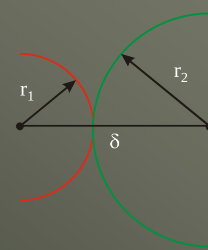
Ideal elastic hard sphere collision:

$$\Omega = \pi(r_1 + r_2)^2$$

Where Ω is the collision cross-section

$$\delta = r_1 + r_2 = \left(\frac{\Omega}{\pi}\right)^{\frac{1}{2}}$$

Where δ is the collision distance



These equations negate potential interactions between the two molecules (atoms), attractive and repulsive, and assume spherical geometry.

Mean Free Path (λ):

#collisions per unit time:

$$Z_1 = \pi d^2 \langle v \rangle N$$

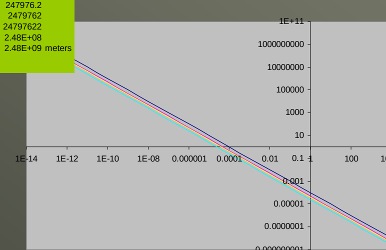
Mean free path (length b/w collisions)

$$\lambda = \frac{\langle v \rangle}{Z_1} = \frac{\langle v \rangle}{\pi(r_1 + r_2)^2 \sqrt{2} \langle v \rangle N}$$

$$\lambda = \frac{1}{\pi(r_1 + r_2)^2 \sqrt{2} N}$$

	He	N2	CO2	C6H6	
x-section	0.21	0.43	0.52	0.88	nm^2
10000	1E-08	5.07E-09	4.2E-09	2.48E-09	
1000	1E-07	5.07E-08	4.2E-08	2.48E-08	
100	1E-06	5.07E-07	4.2E-07	2.48E-07	
10	1E-05	5.07E-06	4.2E-06	2.48E-06	
1	0.0001	5.07E-05	4.2E-05	2.48E-05	
0.1	0.00104	0.000507	0.00042	0.000248	
0.01	0.01039	0.005075	0.004197	0.00248	
0.001	0.10391	0.050749	0.041965	0.024798	
0.0001	1.03914	0.507486	0.419652	0.247976	
0.00001	10.3914	5.074862	4.196521	2.479762	
0.000001	103.914	50.74862	41.96521	24.79762	
0.0000001	1039.14	507.4862	419.6521	247.9762	
0.00000001	10391.4	5074.862	4196.521	2479.762	
0.000000001	103914	50748.62	41965.21	24797.62	
1E-10	1039138	507486.2	419652.1	247976.2	
1E-11	1E+07	5074862	4196521	2479762	
1E-12	1E+08	50748621	41965206	24797622	
1E-13	1E+09	5.07E+08	4.2E+08	2.48E+08	
1E-14	1E+10	5.07E+09	4.2E+09	2.48E+09	meters
Torr					

$$\lambda = \frac{5 \bullet 10^{-3} Torr \cdot cm}{P_{Torr}}$$

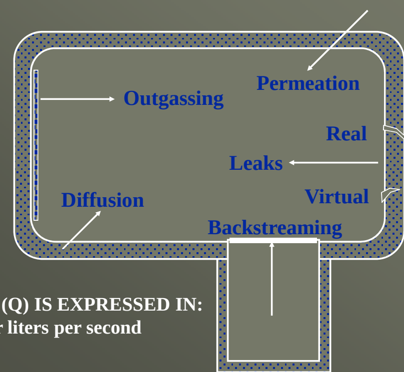


Gas Flow

2 regimes

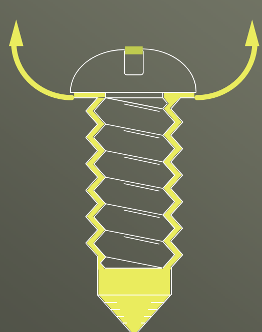
Viscous Flow ← ~100mTorr → Molecular Flow

Higher Pressure | Lower Pressure

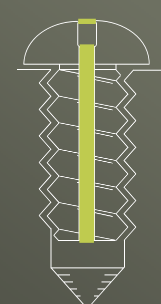


GAS LOAD (Q) IS EXPRESSED IN:
mbar liters per second

Trapped Volumes



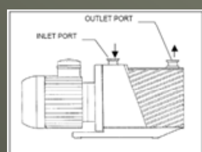
Vented Screw



Pumping Speed

$$S \equiv \frac{dV}{dt}$$ L/s, m^3/s, ft^3/min (cfm)

$$S_p \equiv \frac{dV}{dt}$$



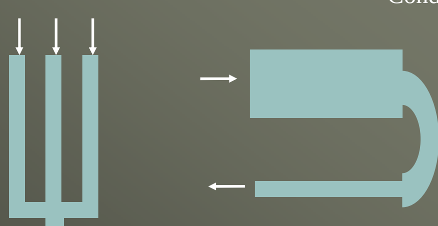
The mass rate of flow through a vacuum system is known as throughput (Q), torr L/s

$$Q \equiv PS$$

The ability of an apparatus to transmit gas is known as conductance (C), same units as pumping speed.

$$Q = (P_1 - P_2)C$$

Conductance



$$C_{parallel} = C_1 + C_2 + C_3 + ...$$

$$C_{series} = \left[\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + ...\right]^{-1}$$

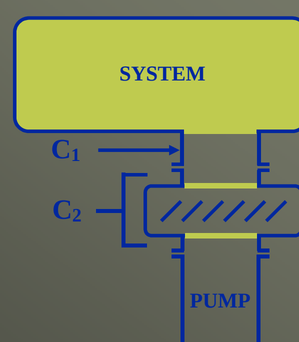
Series Conductance

$$R_T = R_1 + R_2$$

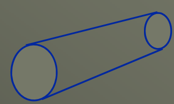
$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2}$$

$$\frac{1}{C_T} = \frac{C_1 + C_2}{C_1 \times C_2}$$

$$C_T = \frac{C_1 \times C_2}{C_1 + C_2}$$



Conductance in Viscous Flow



Under viscous flow conditions doubling the pipe diameter increases the conductance sixteen times.
The conductance is INVERSELY related to the pipe length

Viscous Flow (Long Round Tube; air)

$$C = 1.38 \times 10^2 \times \frac{d^4}{l} \times \frac{P_1 + P_2}{2} \ \text{(l/sec)}$$

d = diameter of tube in cm
l = length of tube in cm
P_1 = inlet pressure in torr
P_2 = exit pressure in torr

Viscous Flow (Long Round Tube; nitrogen)

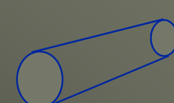
EXAMPLE:
d = 4 cm P_1 = 2 torr
l = 100 cm P_2 = 1 torr

$$C = 138 \times \frac{d^4}{l} \times \frac{P_1 + P_2}{2} \ \text{(liter/sec)}$$

$$C = 138 \times \frac{256}{100} \times \frac{3}{2} \ \text{(liter/sec)}$$

$$C = 530 \ \text{(liter/sec)}$$

Conductance in Molecular Flow



Under molecular flow conditions doubling the pipe diameter increases the conductance eight times.
The conductance is INVERSELY related to the pipe length.

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.

Conductance in Molecular Flow (Long Round Tube)

EXAMPLE:
T = 295 K (22 ^{O}C)
M = 28 (nitrogen)

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

$$= 3.81 \times \frac{d^3}{l} \times \sqrt{\frac{295}{28}}$$

$$= 12.36 \times \frac{d^3}{l} \quad \text{(l/sec)}$$

EXAMPLE:
T = 295 K (22 ^{O}C) d = 4 cm
M = 28 (nitrogen) l = 100 cm

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

$$= 3.81 \times \frac{d^3}{l} \times \sqrt{\frac{295}{28}}$$

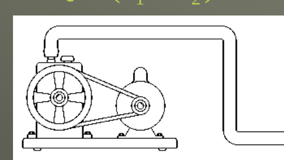
$$= 12.36 \times \frac{d^3}{l} \quad \text{(l/sec)}$$

$$= 12.36 \times 0.64$$

$$= 7.9 \text{ (l/sec)}$$

$$Q = (P_1 - P_2)C$$

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



$$S = \frac{Q}{P_1}$$

Using the conductance equation, and knowing that mass transfer is the same (Q) throughout the system; substitute the pressure values for the pumping speed at aperture and pump.

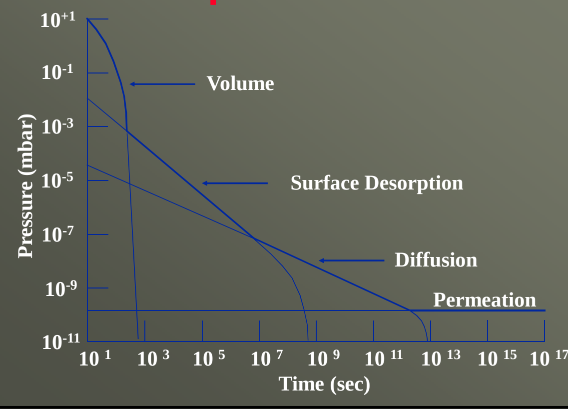
$$\frac{1}{S} = \frac{1}{S_p} + \frac{1}{C}$$

Pumpdown time

Pumpdown time is also useful info. This can identify slow leaks, outgassing, etc.

$$t = \frac{V}{S}\ln\left(\frac{P_o}{P}\right)$$

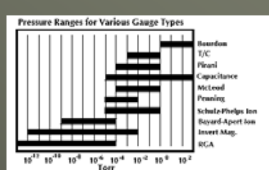
Pumpdown Curve



Pressure Gauges

Four Major Types

1. Mechanical Gauge
2. Thermal-Conductivity
3. Viscous-Drag
4. Ionization Gauge

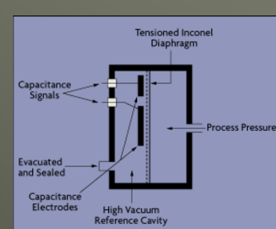


Capacitance Manometer

Range: 1000 Torr to 1×10^{-4} Torr

Accuracy: 0.01%

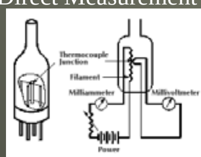
Response: 10ms



Thermal-Conductivity

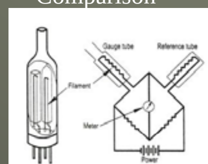
Heat loss to the surrounding gas

Direct Measurement



Thermocouple Gauge

Comparison

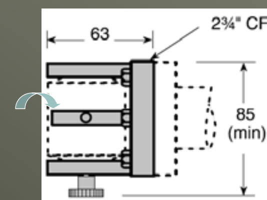


Pirani Gauge

Range: 10 Torr to $1x10^{-3}$ Torr
Accuracy: 0.5%
Response: 10ms

Viscous-Drag

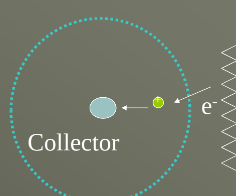
Range: $1x10^{-1}$ Torr to $1x10^{-6}$ Torr
Accuracy: 3%
Response: seconds

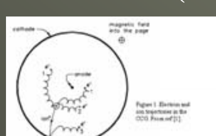


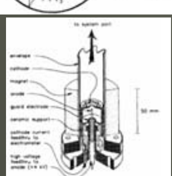
Measure time from 415-405Hz

Ionization Gauge

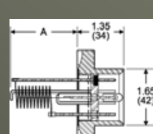
2 types
1. Hot Cathode (Ion Gauge)
2. Cold Cathode (Penning Gauge)







Range: $1x10^{-3}$ to $1x10^{-10}$ Torr
Response: ms



Other Gauges

Mass Spectrometry (RGA)

Range: $1x10^{-5}$ to $1x10^{-14}$ Torr
Accuracy .01%
Response: ms

Pumps

3 Types

1. Mechanical
2. Diffusion
3. Entrainment

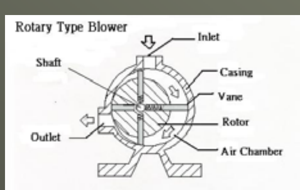
Mechanical Pumps

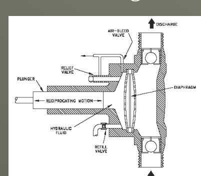
1. Rotory Vane Pumps
2. Roots Blower
3. Scroll Pump
4. Diaphragm Pumps

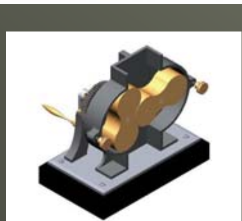
} Rough Pumps Atm-100mTorr

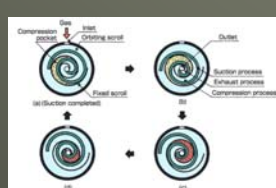
5. Molecular Drag Pump — 1 - $1x10^{-6}$ Torr
6. Turbomolecular Pump — $1x10^{-3}$ - $1x10^{-8}$ Torr

Rough Pumps

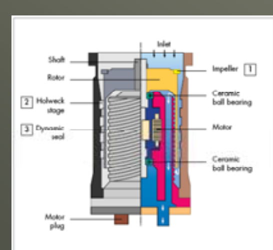








Turbo Pumps



Diffusion

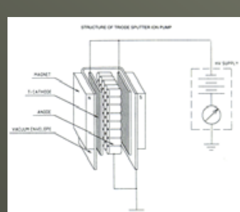
50-50000 L/s

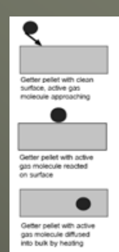
Entrainment

1. Sorption Pumps
2. Getter Pumps
3. Cryopumps
4. Ion Pumps

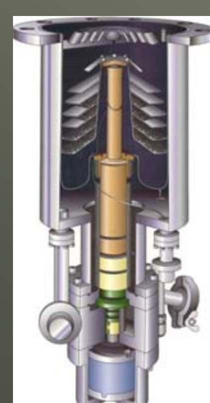
Getters and Ion

$GM + O_2 \rightarrow GMO$
$GM + N_2 \rightarrow GMN$
$GM + CO_2 \rightarrow CO + GMO \rightarrow GMC + GMO$
$GM + CO \rightarrow GMC + GMO$
$GM + H_2O \rightarrow H + GMO \rightarrow GMO + H$ (bulk)
$GM + H_2 \rightarrow GM + H$ (bulk)
GM + Hydrocarbons, C_xH_x, etc. $\rightarrow$ GMC + H (bulk)
GM + He, Ne, Ar, Kr, Xe (inert gases) $\rightarrow$ No Reaction





Cryo Pumps



Materials

Quartz and Pyrex
- UHV – He Leak

Ceramics – Alumina
- Good internal parts

Brass
- Contains Zinc – Outgasses at 10^{-6}

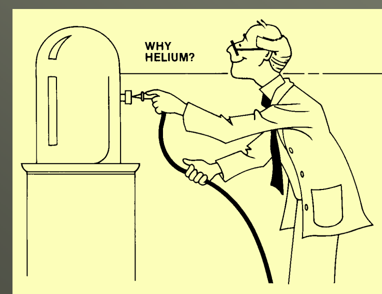
Copper and Oxygen Free
- Oxygen free reduces outgassing for heating

Stainless Steel 300 series (304, 316)
- Weldable

Aluminum 6000 series
- Porous and Oxide surface – outgasses better than stainless

Plastic
- Outgas at 10^{-7}
- Polyimide, Delron, Kapton – Good
- Be careful of wiring shield

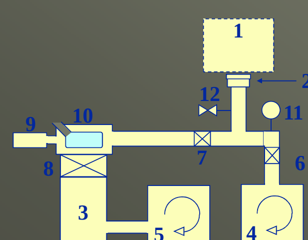
Why Helium is used



HELIUM

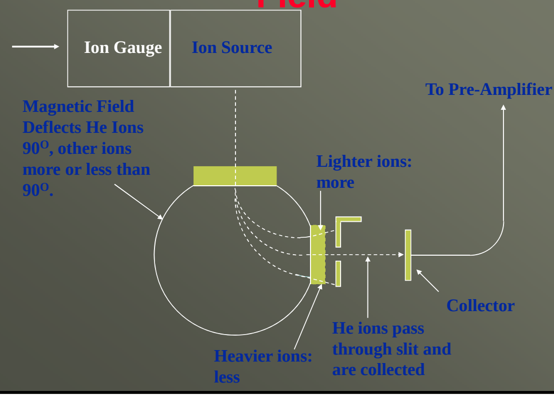
- Helium is very light and small
- Low concentration in air (0.0005%)
- Permits dynamic testing
- Permits non-destructive testing
- Helium is safe

CONVENTIONAL LEAK DETECTOR

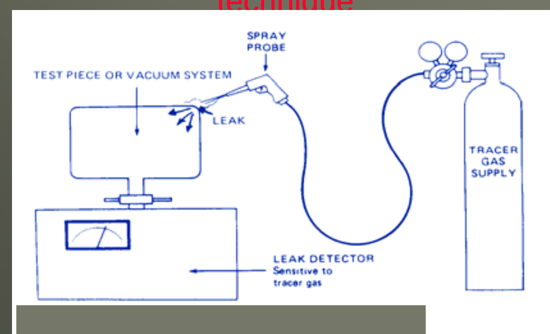


1 Test Piece
2 Test Port
3 High Vac. Pump
4 Roughing Pump
5 Fore Pump
6 RoughingValve
7 Test Valve
8 Pump Valve
9 Spectrometer Tube
10 Cold Trap
11 Roughing Gauge
12 Vent Valve

Ion Separation in Magnetic Field



Tracer probe leak detection technique



Leak detectors are calibrated with the “permeation leak”