- SEMESTER –VI (HONOURS)
- PAPER : DSE-4T
- TOPIC: VACUUM SYSTEMS

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Vacuum : Basics, Pumps and Measurement (Gauges)

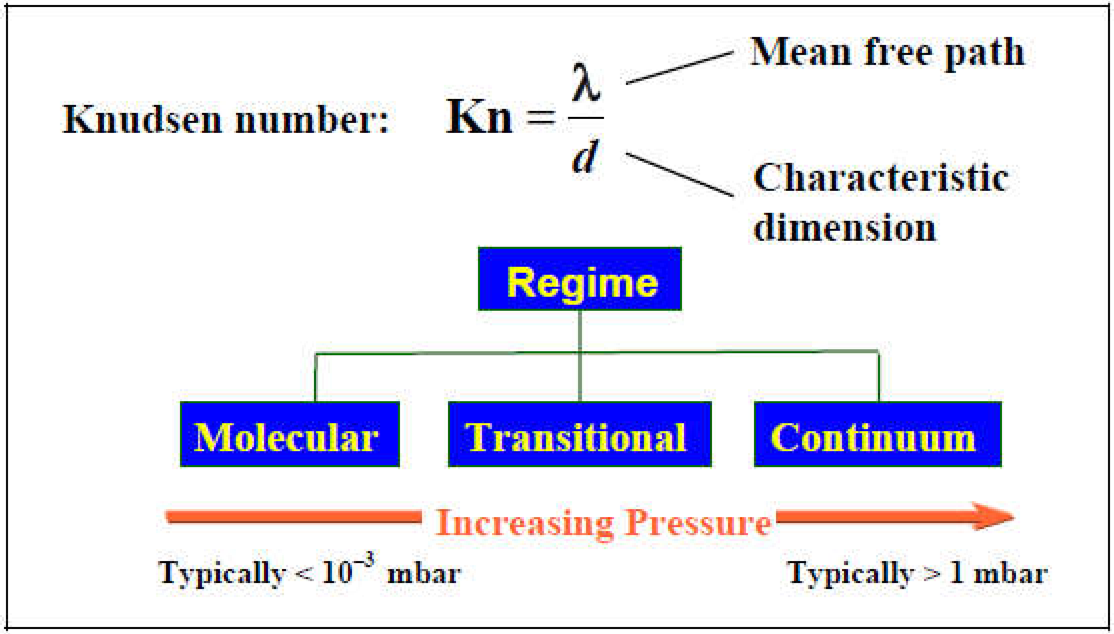
Introduction

Vacuum : space devoid of matter

The concept of vacuum was from Italy in 1640s

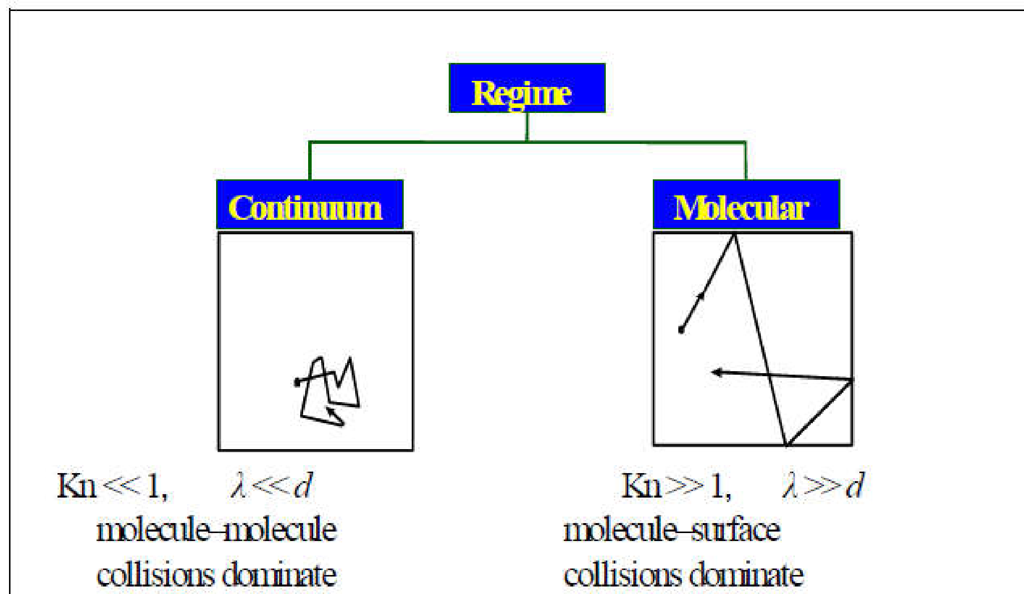
Early inventions due to vacuum are

- **Incandescence bulb**
- **Invention of electrons (cathode rays)**
- **X – rays**
- **Almost all inventions of subatomic particles**



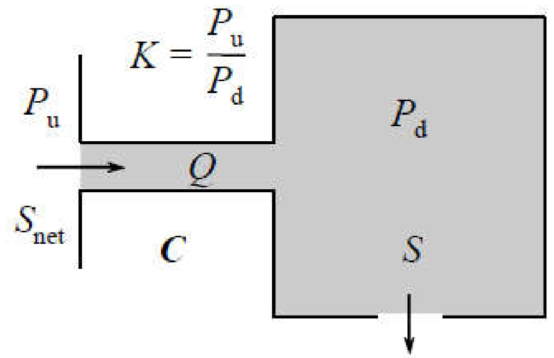
Definitions:

- $Kn < 0.01$ continuum state
- $0.01 < Kn < 1$ transitional state
- $Kn > 1$ molecular state.



Conductance

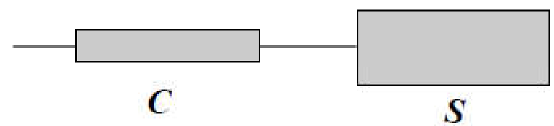
$$C = \frac{Q}{P_u - P_d}$$



Pumping Speed

defined as the volume of gas passing the plane of the inlet port per unit time when the pressure at the pump inlet is P

$$S = Q/P$$



Pumping speed can be combined with a conductance in the same way as conductances in series

$$\frac{1}{S_{net}} = \frac{1}{S} + \frac{1}{C}$$

While gas throughput (Q) can be measured at any plane in the system, P and S refer to quantities measured at the pump inlet

Hence it is important to have large conductance by making ducts between pump and chamber as short and wide as possible

K : Compression ratio is ratio between the Upstream and down stream pressures

$$Q = P_d S = (P_u - P_d)C$$

$$\therefore C = \frac{S}{K-1} \quad \text{or} \quad K = 1 + \frac{S}{C}$$

Mechanism and various types of pumps

- Positive displacement pumps
  - Expand a cavity, seal, exhaust, repeat
- Momentum transfer pumps (molecular pumps) or Kinetic vacuum pumps
  - High speed liquids or blades to knock gasses around
- Entrapment
  - Create solids or adsorbed gases (cryopumps)

Classification based on regime they are used

- Roughning pumps
  - Rotary mechanical pumps
  - Diaphragm pumps
  - Scroll pumps
- High vacuum pumps
  - Diffusion pumps
  - Turbo molecular pumps
  - Cryo pumps
  - Ion pumps

Roughing pumps

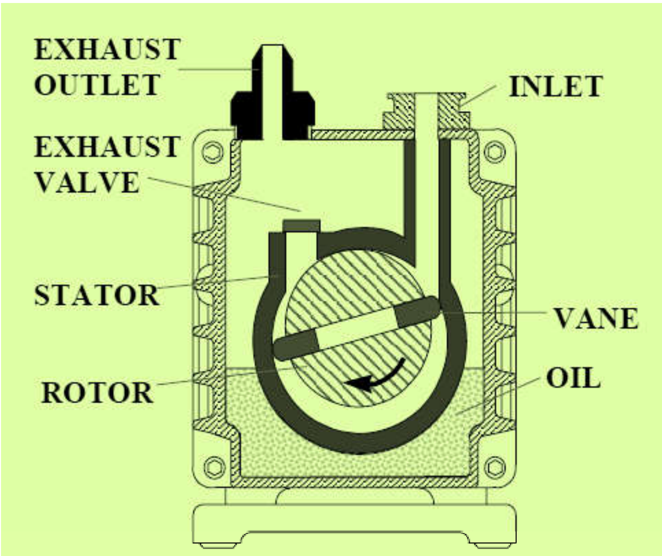
- Pumps from atm pressure down to rough vacuum (0.1 Pa, $1X10^{-3}$ torr)
- Necessary because high vacuum pumps have trouble starting from atmospheric pressure
- Usually Rotary Vane pumps, Rotary piston pumps, Scroll pumps, Screw pumps etc.
- Can have oil or not

Primary pumps: exhaust to atm

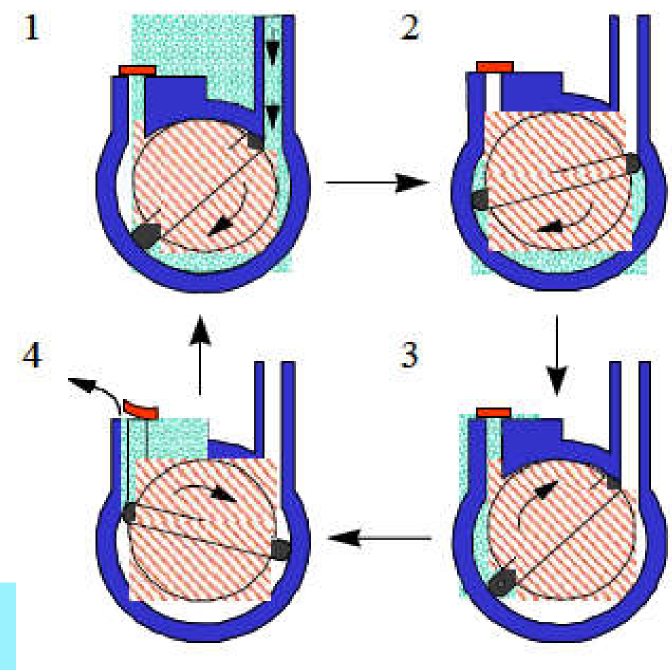
Secondary pumps: exhaust to backing (primary pumps)

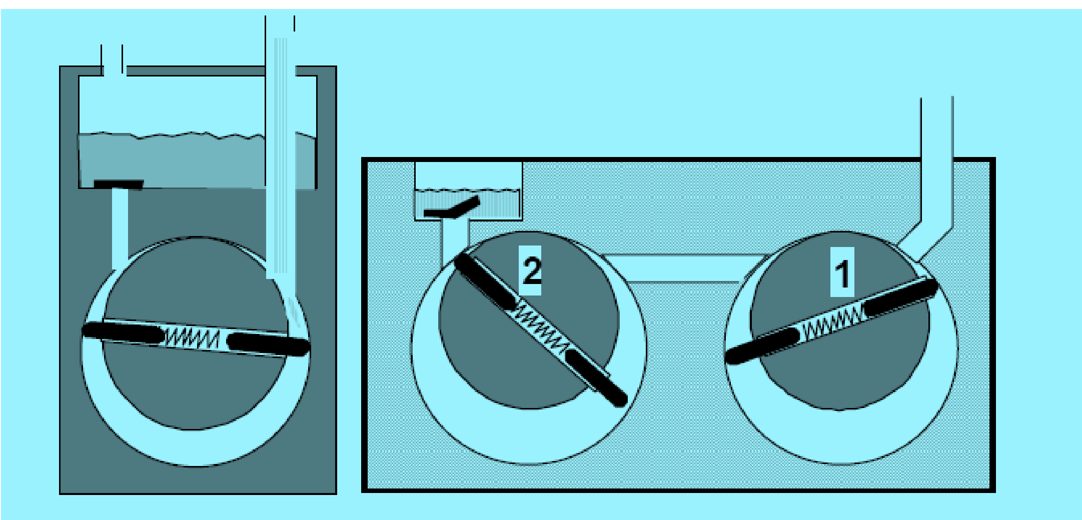
	Wet pumps	Dry pumps
Capital cost	Low	High
Oil loss	Can be high at > 1 mbar	Very low
System contamination	Backstream at < 0.1 mbar	Very low
Add on costs	Oil return/filtration	Not necessary
Aggressive process	Not suitable	Resistant
Purge	Sometimes	Almost always

Rotary vane pump



1 Inlet exposed
2 Trapped volume
3 Compression
4 Exhaust





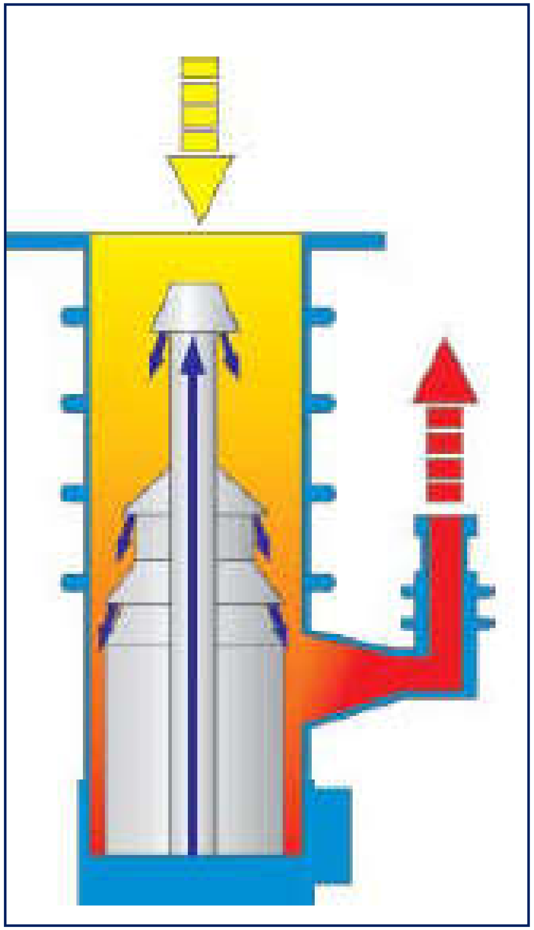
Typical compression ratios: 10^6

Single stage pumps : 10^{-2} torr

Double stage pumps: 10^{-4} torr

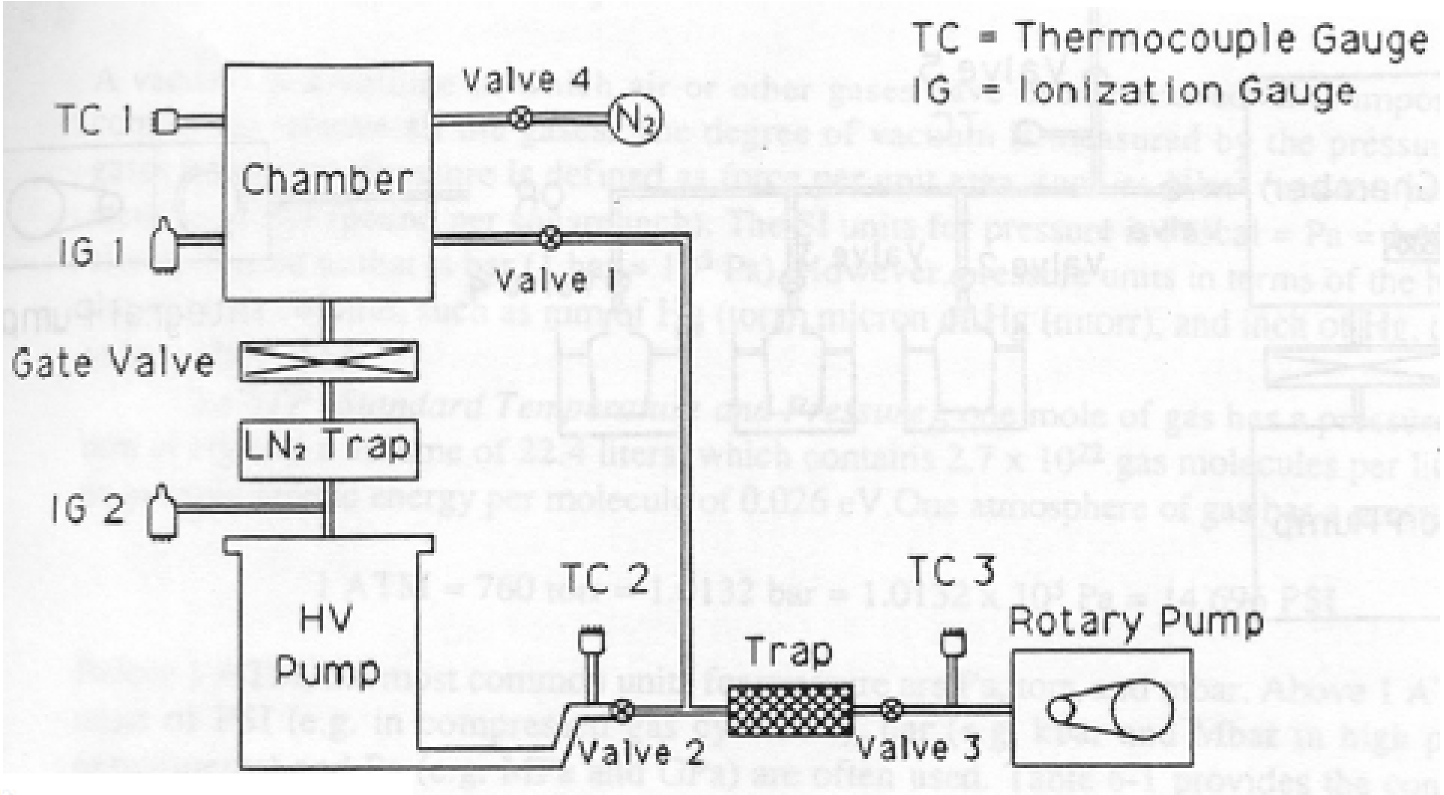
Oil diffusion pumps

- No moving parts in the pump
- Designed to operate in molecular region
- Can operate between 10^{-2} torr to 10^{-10} torr
- Typical pumping speed at RT is 11.7 A liter/s but operates only 0.4 of this value
- (A 15 cm diameter diffusion pump spped is 827 liter/s)
- Pumping is due to the action of fluid jets of boiling oil (silicone oil)
- Disadvantage
- Major problem in DP is back streaming of oil into the chamber
- Oil gets contaminated and needs replacement



Schematic of oil diffusion pump

Vacuum systems
Diffusion pump system

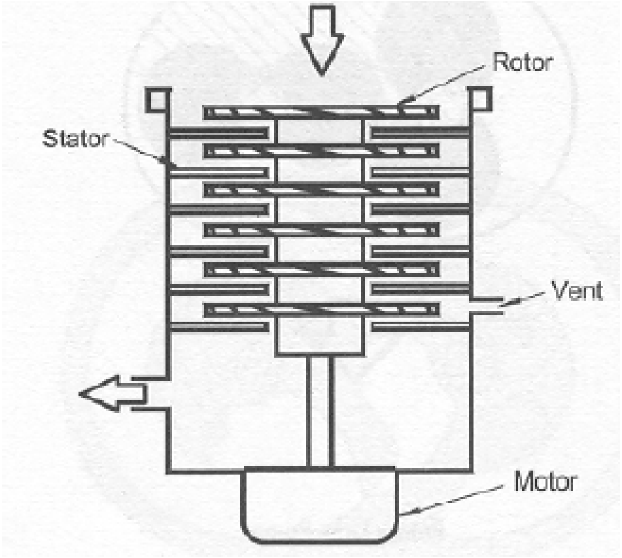


Safeguards:

- Water interlock
- Temperature interlock
- Pressure interlock

Turbo molecular pumps

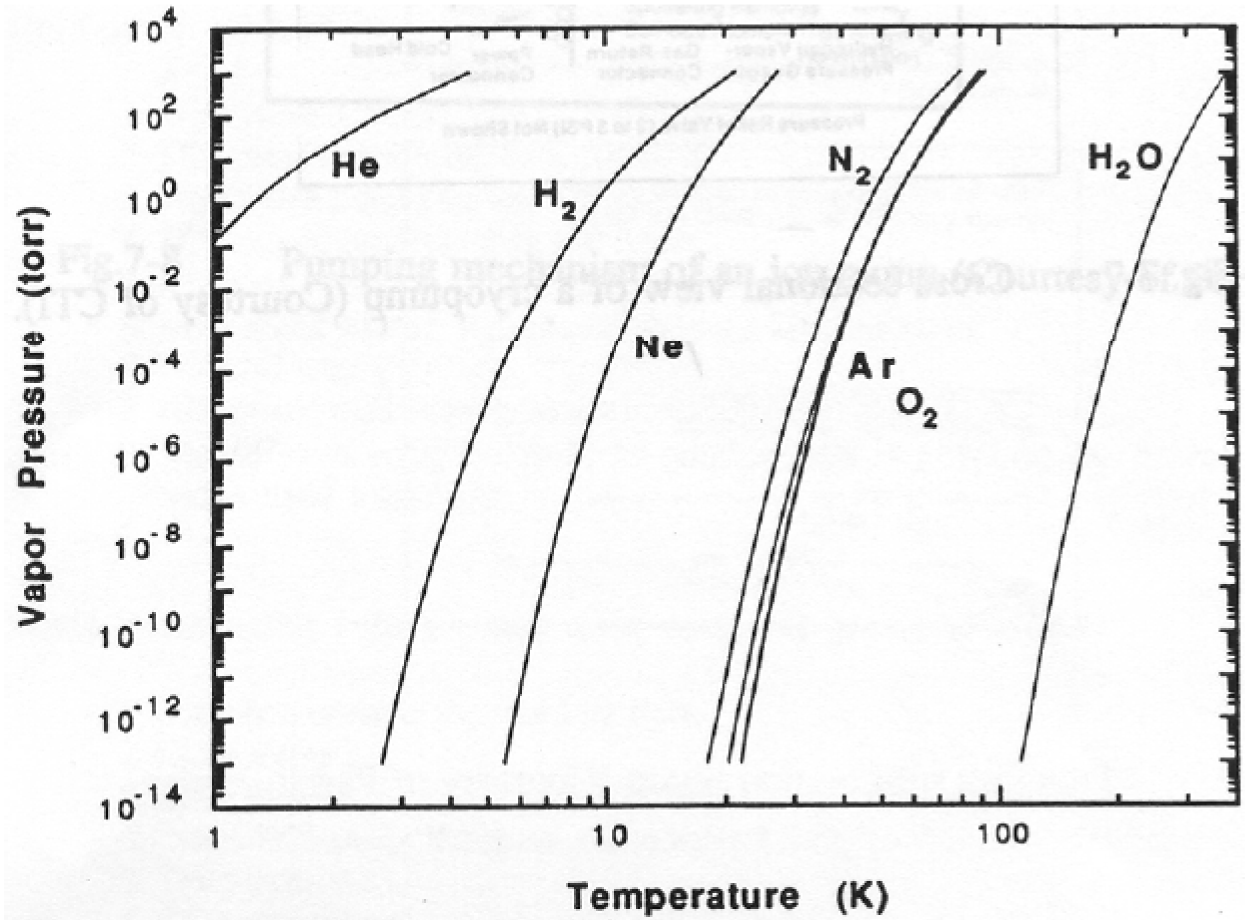
- **Oil free high vacuum pump**
- **Gas molecules interact with spinning blades and are preferentially forced downward**
- **Typical pumping speeds are 1000 liter/s**
- **Generally work between 10-3 and 10-7 Torr and ultimate pressures are 10^{-10} torr**
- **Effectively oil less pumping**



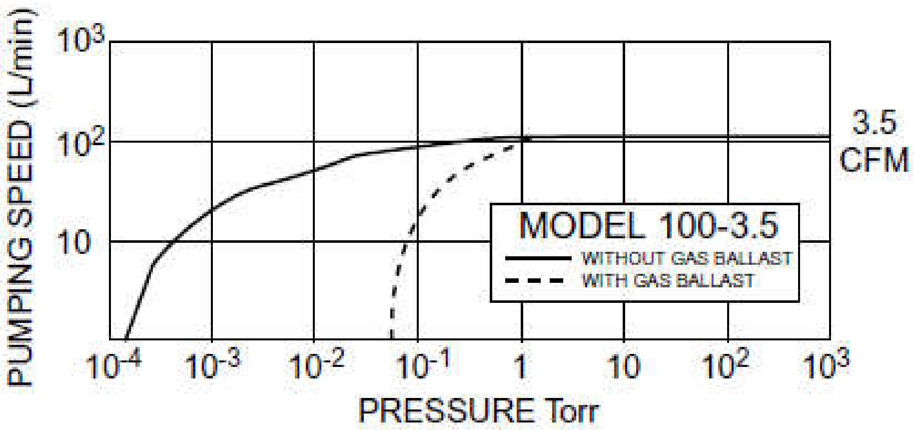
Next class

Vacuum leaks

Vacuum gauges


Vapor Pressure (torr)
Temperature (K)
He
H2
Ne
N2
Ar
O2
H2O
10^4
10^2
10^0
10^-2
10^-4
10^-6
10^-8
10^-10
10^-12
10^-14
1
10
100

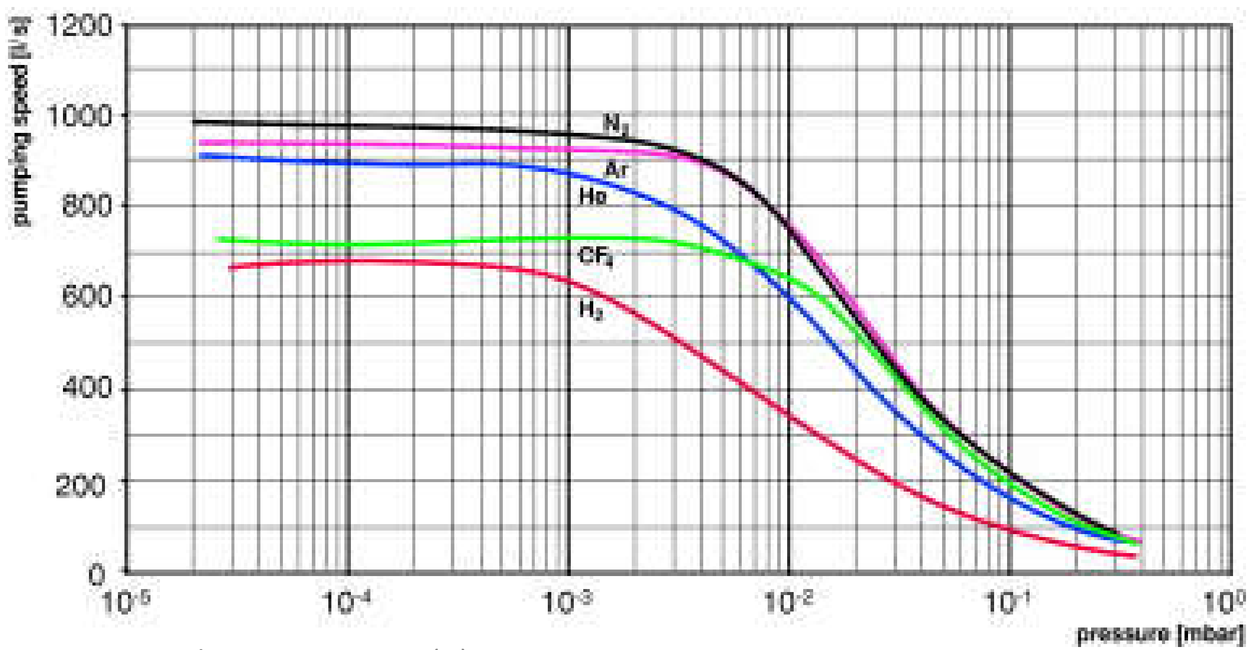
Pump Speed Curve



Rotary Vane:
Pump speed lower at low vacuum

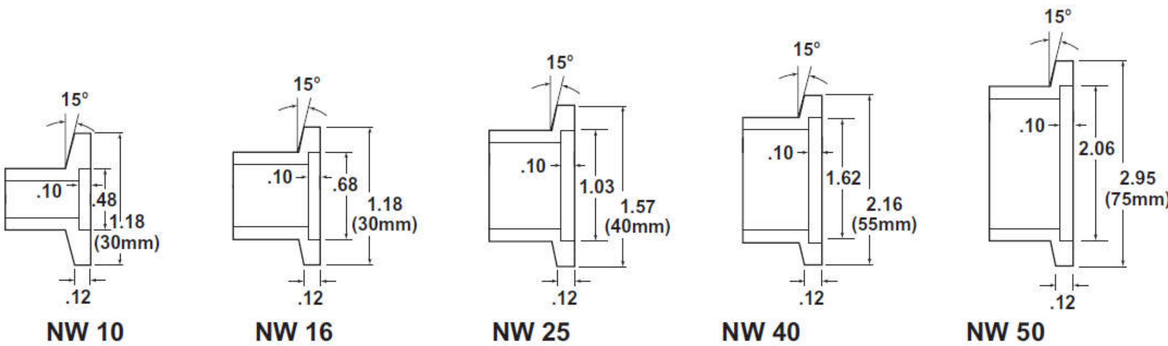
Turbo pumps: opposite

Pump Speed

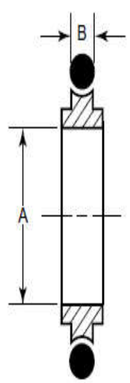


Pressure

Useful fitting terminology



Centering Rings, Stainless Steel with Viton O-Ring



Flange Size	A	B	Part Number	Price
NW-16	0.63 (16)	0.21 (5.3)	CTR-RING 16	$4.00
NW-25	0.984 (25)	0.21 (5.3)	CTR-RING 25	$5.00
NW-40	1.575 (40)	0.21 (5.3)	CTR-RING 40	$7.00
NW-50	1.969 (50)	0.21 (5.3)	CTR-RING 50	$9.00

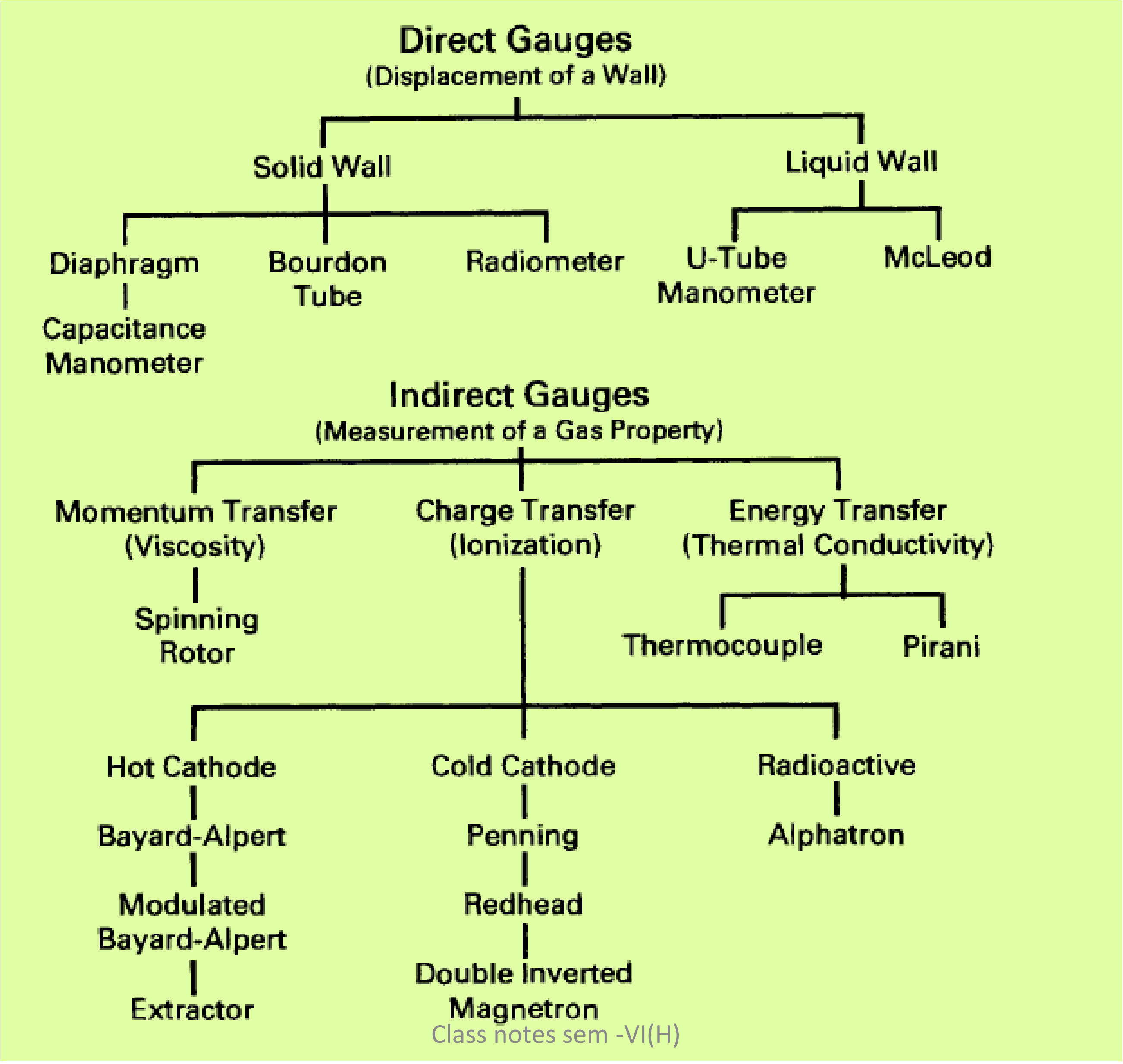
References

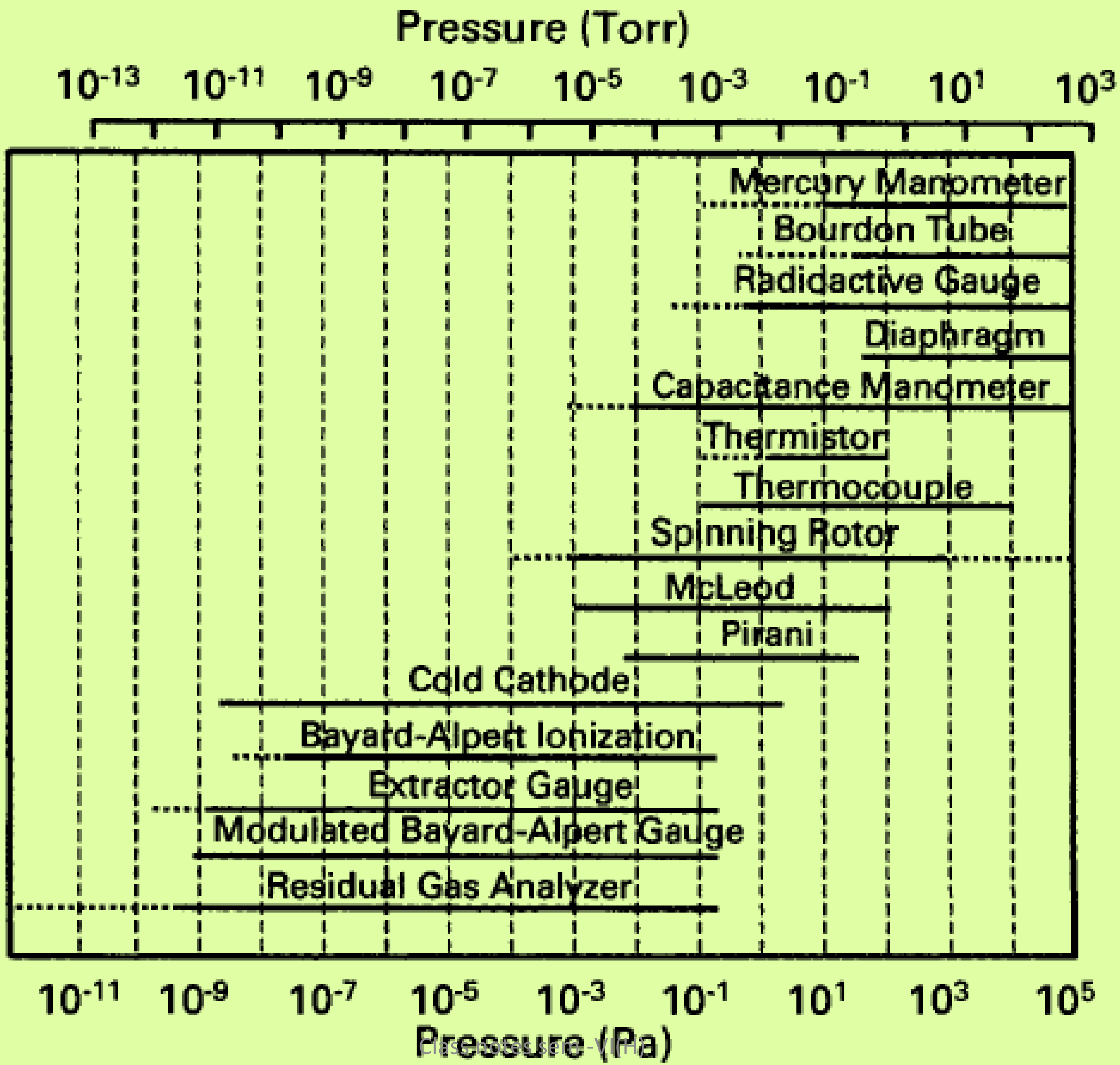
1. *Introduction to Materials Science of Thin films, Milton Ohring*
2. *www.vacuumresearchcorp.com/pdfs/valves/**nwflanges**06.pdf*
3. Liu, UCD Phy250-1, 2011, NanoFab (Presentation)
4. **Mechanical vacuum pumps,** *A.D. Chew,* BOC Edwards, Crawley, United Kingdom

Vacuum measurement

- Gauges are either direct- or indirect-reading.
- Those that measure pressure by calculating the force exerted on the surface by incident particle flux are called direct reading gauges.
- Indirect gauges record the pressure by measuring a gas property that changes in a predictable manner with gas density.

Classification of pressure gauges




Pressure (Torr)
10-13
10-11
10-9
10-7
10-5
10-3
10-1
10¹
10³
Mercury Manometer
Bourdon Tube
Radioactive Gauge
Diaphragm
Capacitance Manometer
Thermistor
Thermocouple
Spinning Rotor
McLeod
Pirani
Cold Cathode
Bayard-Alpert Ionization
Extractor Gauge
Modulated Bayard-Alpert Gauge
Residual Gas Analyzer
10-11
10-9
10-7
10-5
10-3
10-1
10¹
10³
10⁵
Pressure (Pa)

Indirect gauges

Thermal conductivity gauges are a class of pressure-measuring instruments that operates by measuring the rate of heat transfer between a hot wire and its surroundings

Examples

1. **Pirani gauge**
2. **Thermocouple gauge**

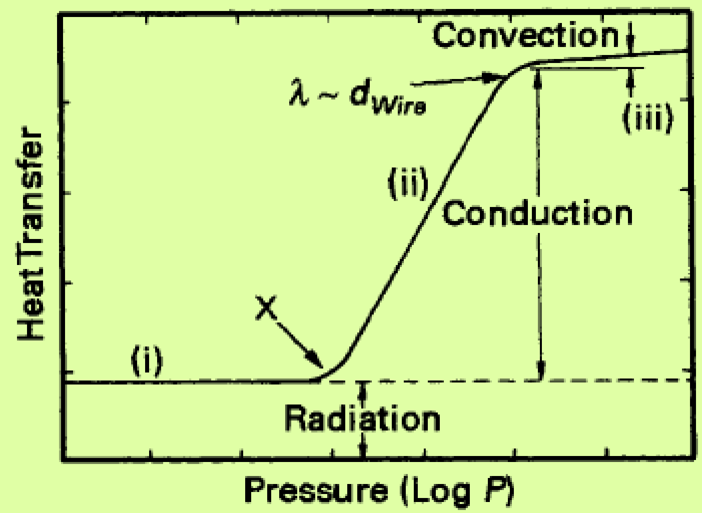


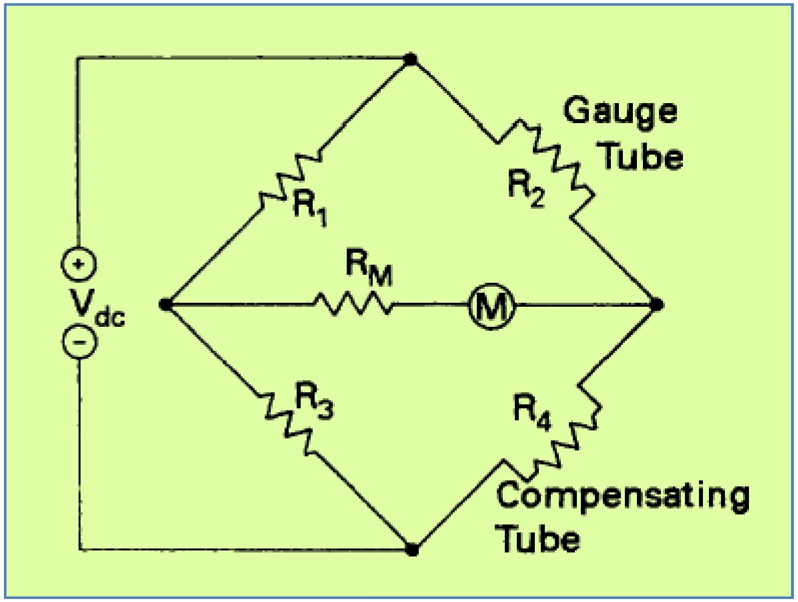
Fig. 5.5 Heat transfer regimes in thermal conductivity gauges, such as thermocouple gauges or Pirani gauges constructed from fine, heated wires. Three regions are illustrated: (i.) $\lambda \gg d_{Wire}$, (iii.) $\lambda \ll d_{Wire}$, and (ii.) intermediate. The location of the upper knee will differ, if the heated element is fabricated in a planar or coiled geometry. X = low-pressure limit; it is reached when the heat transfer is equals the radiation and end conduction losses.

Pirani Gauge

Pirani gauge is given to any type of thermal conductivity gauge in which the heated wire forms one arm of a Wheatstone bridge.

Construction of bridge:

The gauge tube is suitably evacuated to 10^{-4} Pa and R_1 is adjusted to balance the bridge.



Basic Pirani Gauge Circuit

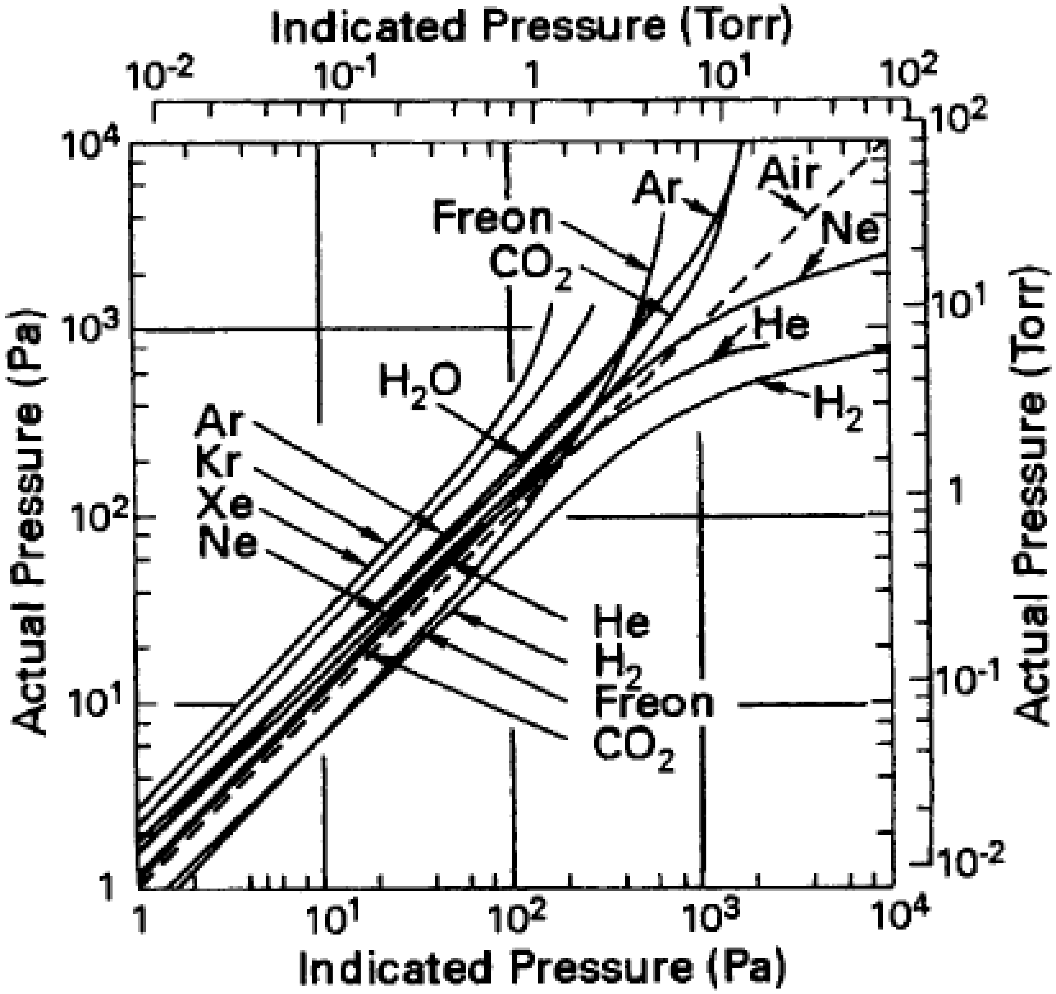
Modes of operation:

1. Constant Temperature method

2. Constant voltage or current method

The gauge tube is first evacuated to a suitably low pressure, say 10 -4 Pa and *R1 is adjusted for balance. A* pressure increase in the gauge tube will unbalance the bridge because the increased heat loss lowers the resistance of the hot wire. By increasing the voltage, more power is dissipated in the hot wire, which causes it to heat, increase its resistance, and move the bridge toward balance. In this method of gauge operation, called the constant temperature method and the most sensitive and accurate technique for operating the bridge, each pressure reading is taken at a constant wire temperature. To correct for temperature induced changes on the zero adjustment, an evacuated and sealed compensating gauge tube is used in the balance arm of the bridge. Bridges with a compensating tube can be used to 10" Pa.

The constant voltage and constant current techniques were devised to simplify the operation of the Pirani gauge. In each case the total bridge voltage or current is kept constant. The constant voltage method is widely used in modern instruments because no additional adjustments need to be made after the bridge is nulled at lower pressures. The out-of-balance current meter is simply calibrated to read the pressure.


Indicated Pressure (Torr)
10-2
10-1
1
10¹
10²
10²
10⁴
Ar
Air
Freon
Ne
CO2
10¹
He
10³
H2O
H2
Ar
Kr
Xe
Ne
1
10²
He
H2
10¹
Freon
10-1
CO2
10-2
1
1
10¹
10²
10³
10⁴
Indicated Pressure (Pa)
Actual Pressure (Pa)
Actual Pressure (Torr)

High vacuum gauges: Ionization gauges

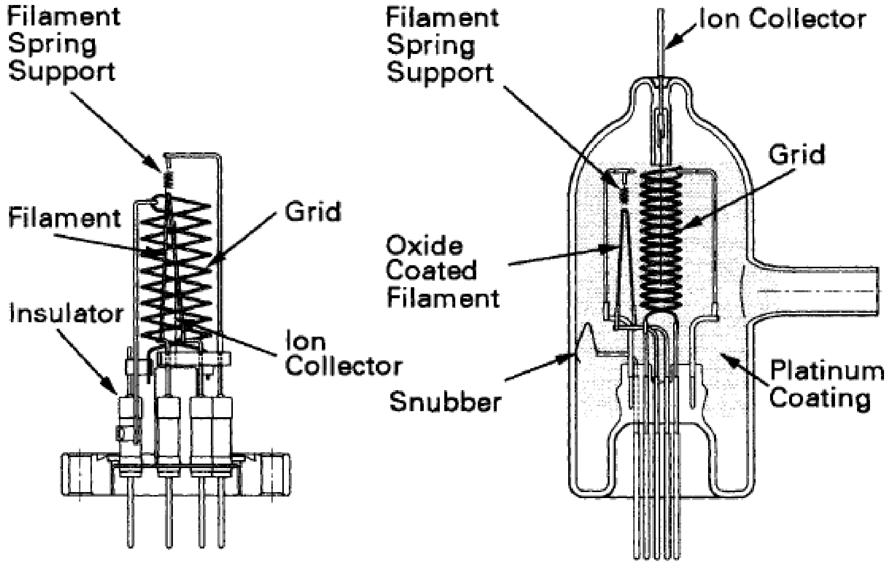
- **In the high and ultrahigh vacuum region, where the particle density is extremely small it is not possible, to detect the minute forces that result from the direct transfer of momentum or energy between the gas and a solid wall.**

- **In the region below 10^{-4} Pa, pressure is measured by ionizing gases, then counting and amplifying the ion signal.**

Types of gauges

1. **Cold Cathode gauges**
2. **Hot Cathode gauges**

Hot cathode gauge



The proportionality between the collector current and pressure is given by

$$i_c = S'i_eP$$

where ***i_c and i_e are the collector and emission currents, respectively, and S'*** is the sensitivity of the gauge tube

The sensitivity is dependent on the tube geometry, grid and collector voltages, the type of control circuitry, **and the nature of the gas being measured.**

Cold cathode gauge: Penning gauge

- The cold cathode gauge, developed by Penning in **1937 provides an** alternative to the hot cathode gauge

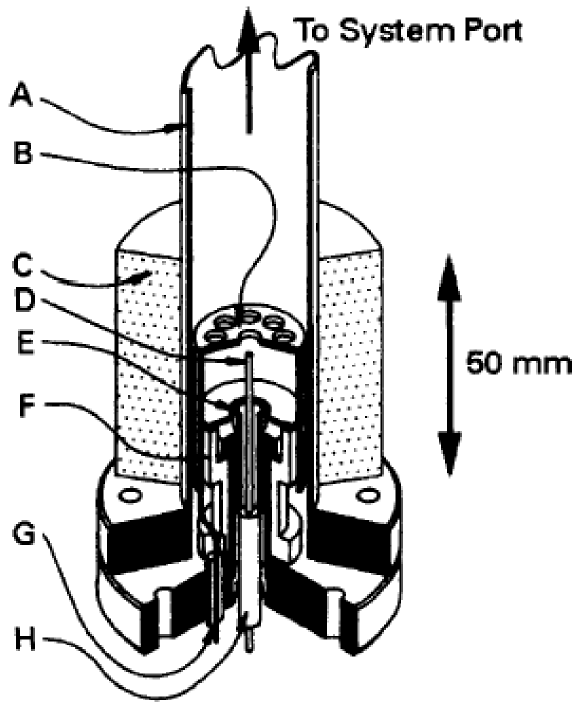


Fig. 5.17 Cold cathode gauge: A, envelope; B, cathode; C, magnet; D, anode; E, guard electrode; F, ceramic support; G, cathode current feedthrough; H, high voltage feedthrough. Reproduced with permission from *J. Vac. Sci. Technol. A*, **9**, p. 1977, R. N. Peacock, N. T. Peacock, and D. S. Hauschulz. Copyright 1991, AVS–The Science and Technology Society.