Thin Film Technology Lecture 2

Vacuum Technology

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2019

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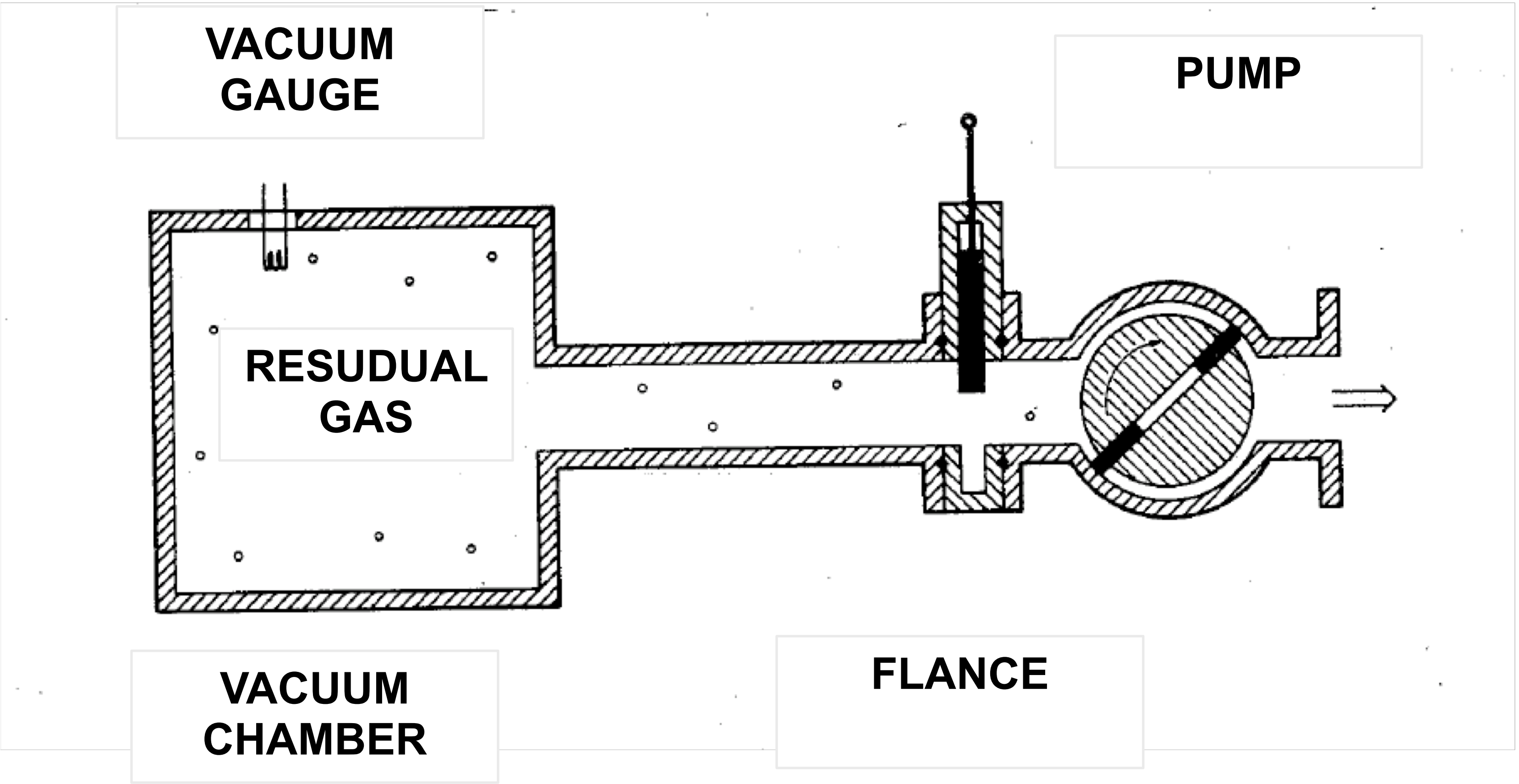
School of Chemical
Technology

Vacuum system



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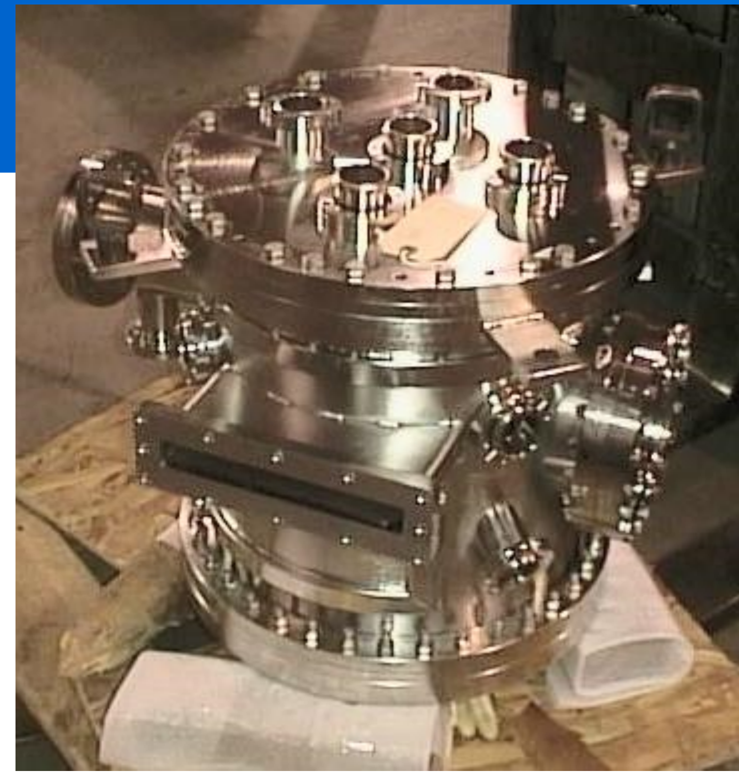

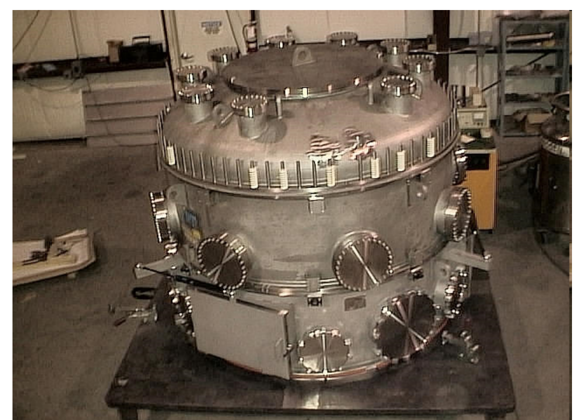

Large surfaces, upscaling

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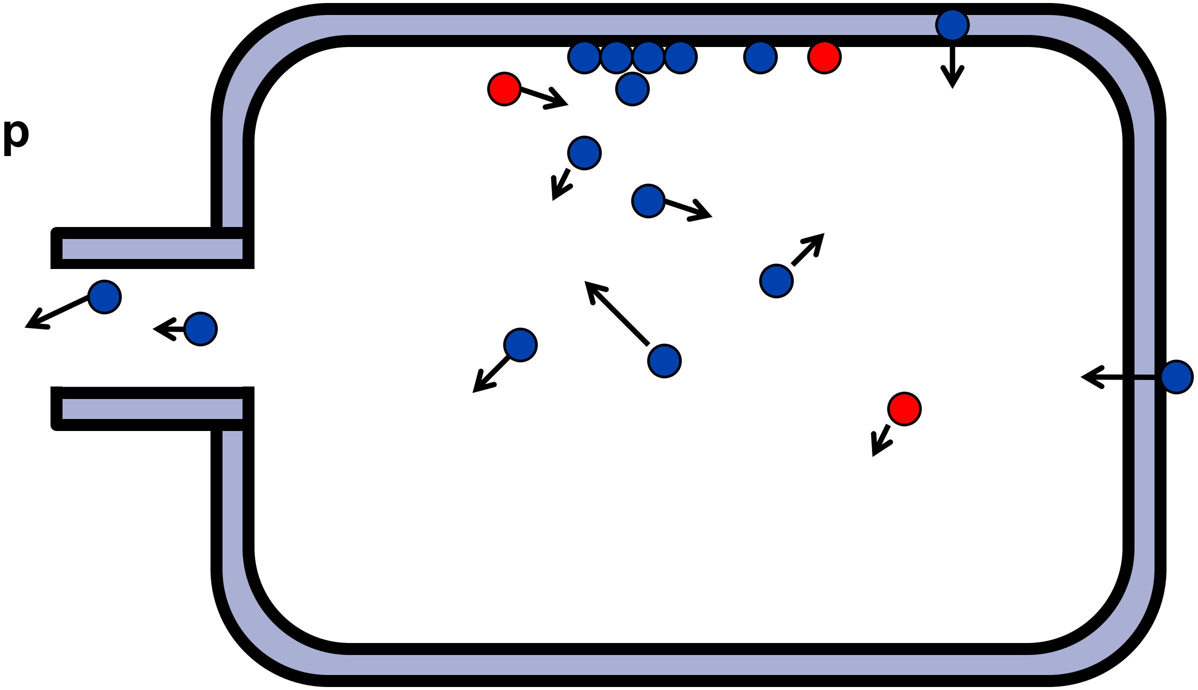
Residual gas

Pumping of:
Residual gas:
- •Adsorption – Desorption
- •Diffusion of dissolver or trapped gas
- •Permeation trough materials
- •Leaks



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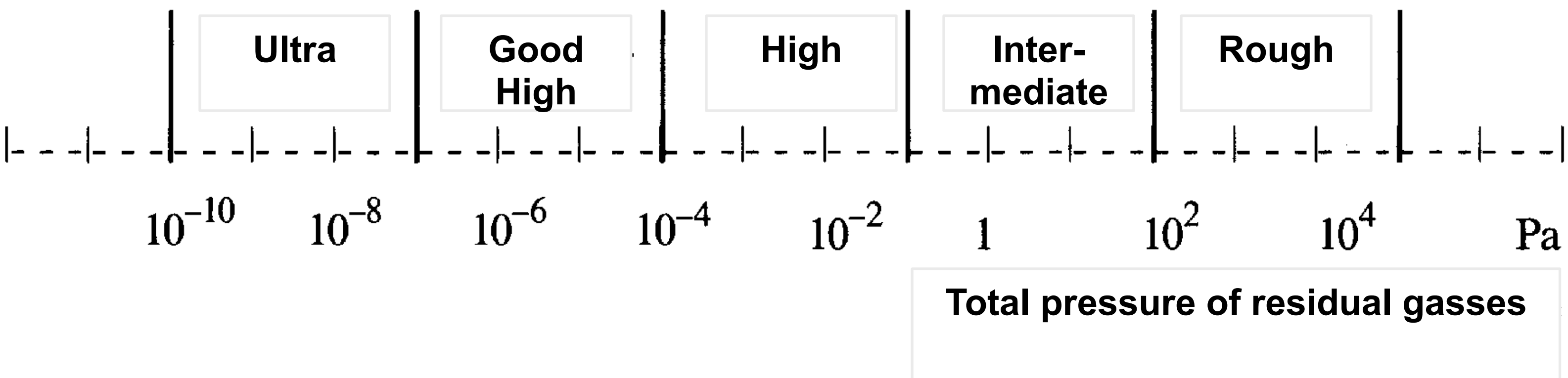
Units of pressure

Pressure units

	Pascal (Pa)	Bar (bar)	Technical atmosphere (at)	Atmosphere (atm)	Torr (Torr)	Pound-force per square inch (psi)
1 Pa	≡ 1 N/m^2	10^{-5}	1.0197×10^{-5}	9.8692×10^{-6}	7.5006×10^{-3}	145.04×10^{-6}
1 bar	100,000	≡ 10^6 dyn/cm^2	1.0197	0.98692	750.06	14.5037744
1 at	98,066.5	0.980665	≡ 1 kgf/cm^2	0.96784	735.56	14.223
1 atm	101,325	1.01325	1.0332	≡ 1 atm	760	14.696
1 torr	133.322	1.3332×10^{-3}	1.3595×10^{-3}	1.3158×10^{-3}	≡ 1 Torr; ≈ 1 mmHg	19.337×10^{-3}
1 psi	6.894×10^3	68.948×10^{-3}	70.307×10^{-3}	68.046×10^{-3}	51.715	≡ 1 lbf/in^2



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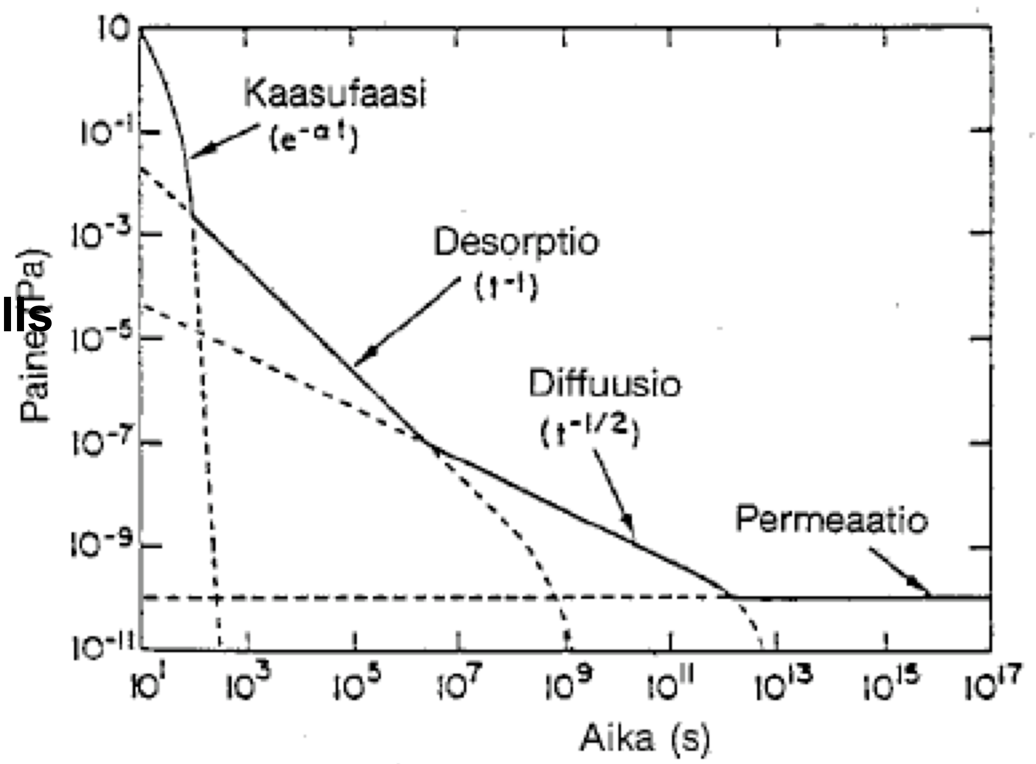
Sources of residual gas

- High vacuum
  - pumping speed
  - leak
- Good High vacuum
  - desorption from walls
  - baking
- Ultra high vacuum
  - impurities
  - internal leaks
  - material selection
  - diffusion
  - permeation



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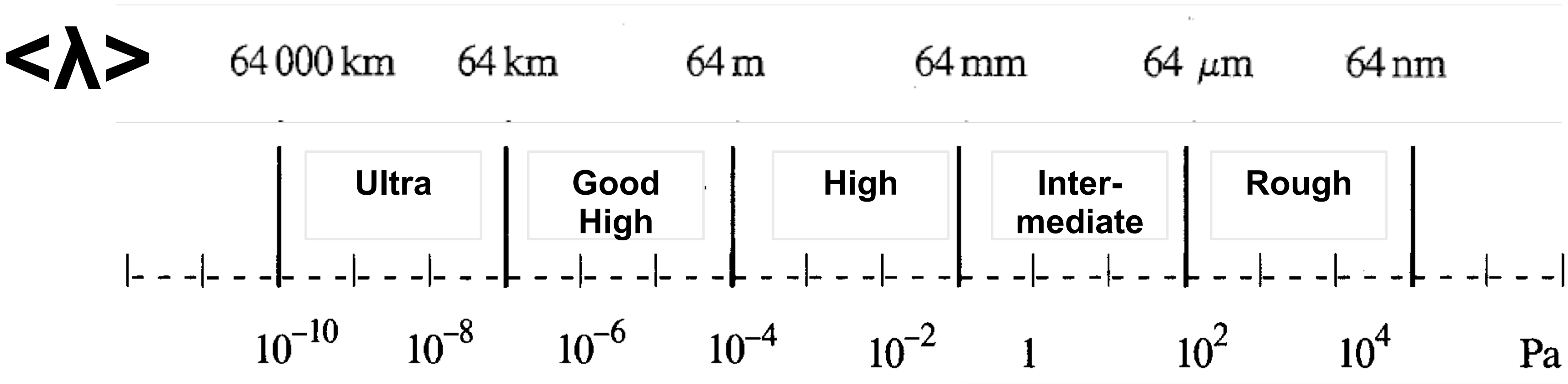
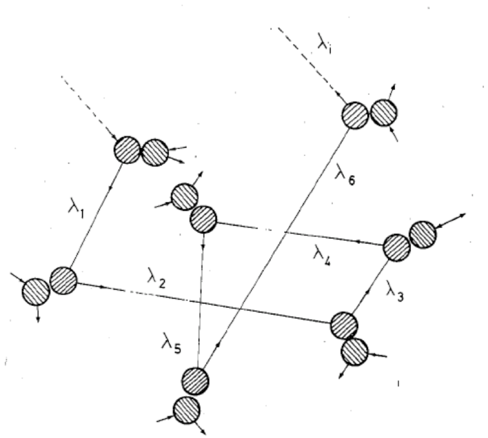
Average mean free path (distance between collission) in nitrogen residual gas

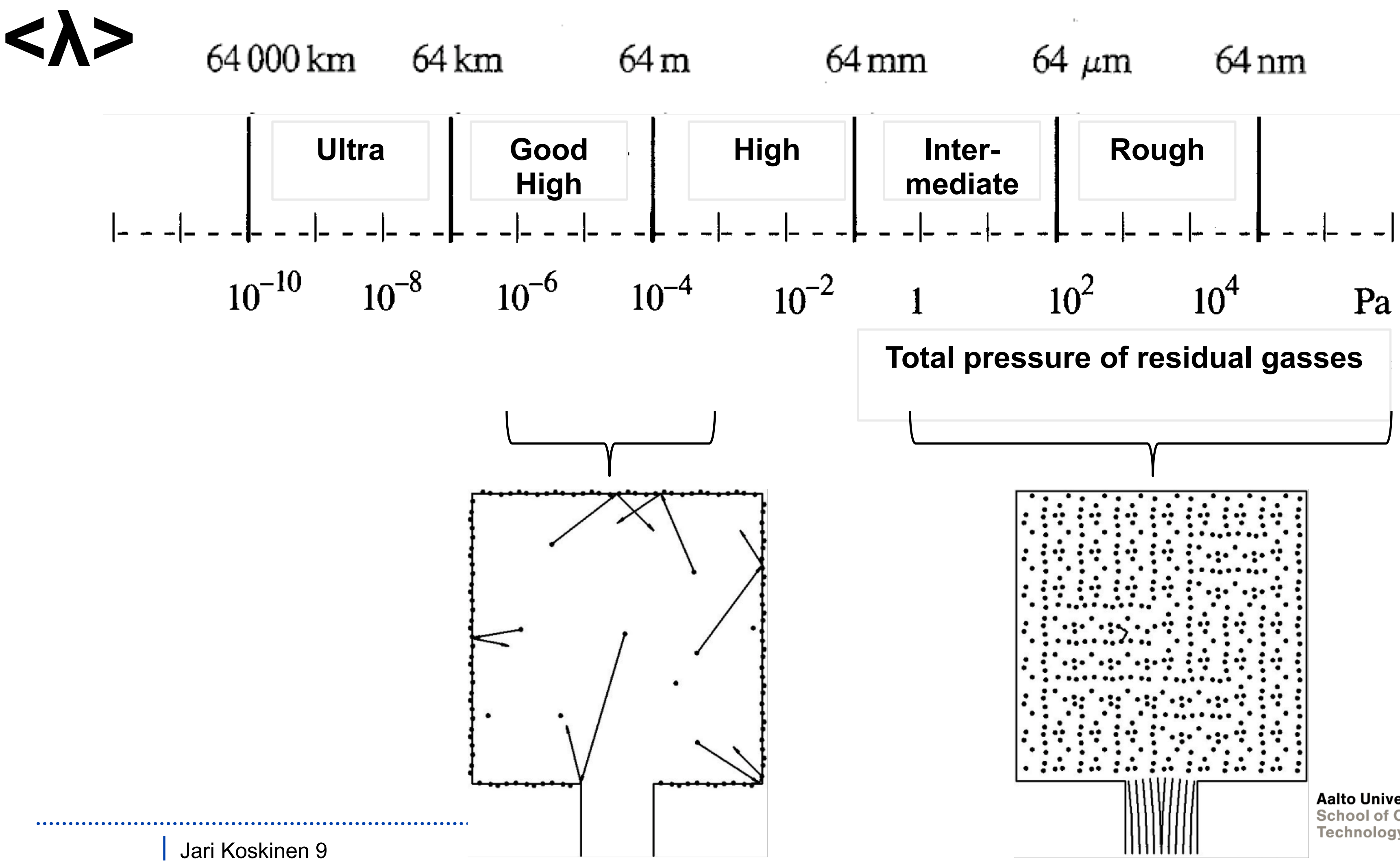




$$\langle \lambda \rangle = \frac{1}{\pi \cdot \sqrt{2} \cdot \rho_N \cdot \xi^2}$$

ρ_N = N/V

Average mean free path (distance between collission) in nitrogen residual gas



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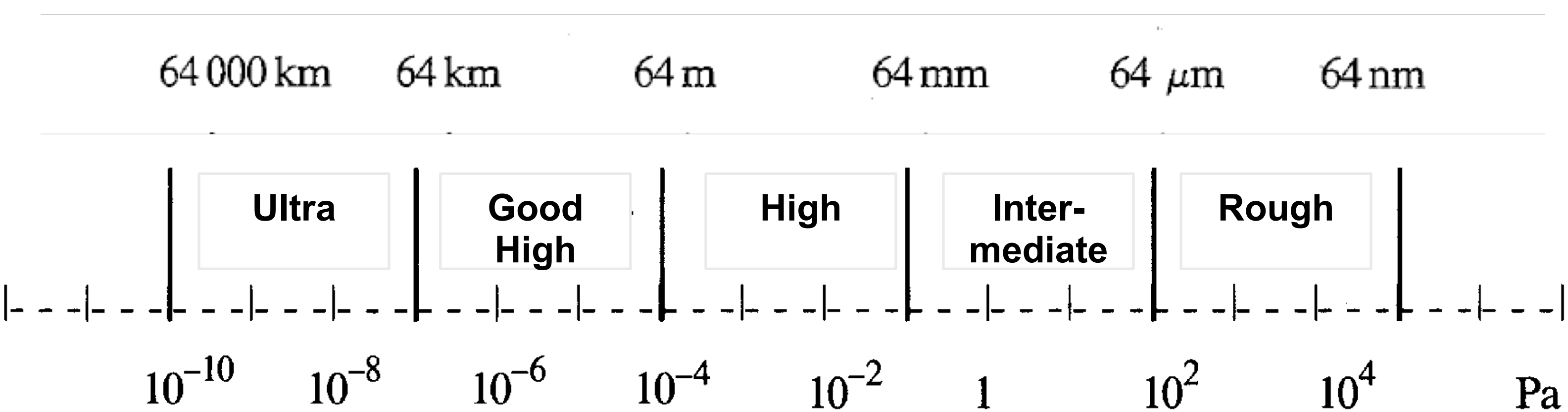
Phases of residual gas

d = diameter of chamber

- **Viscotic** $\langle\lambda\rangle < d/100$
- **Intermediate**
- **Molecular** $\langle\lambda\rangle \gg d$



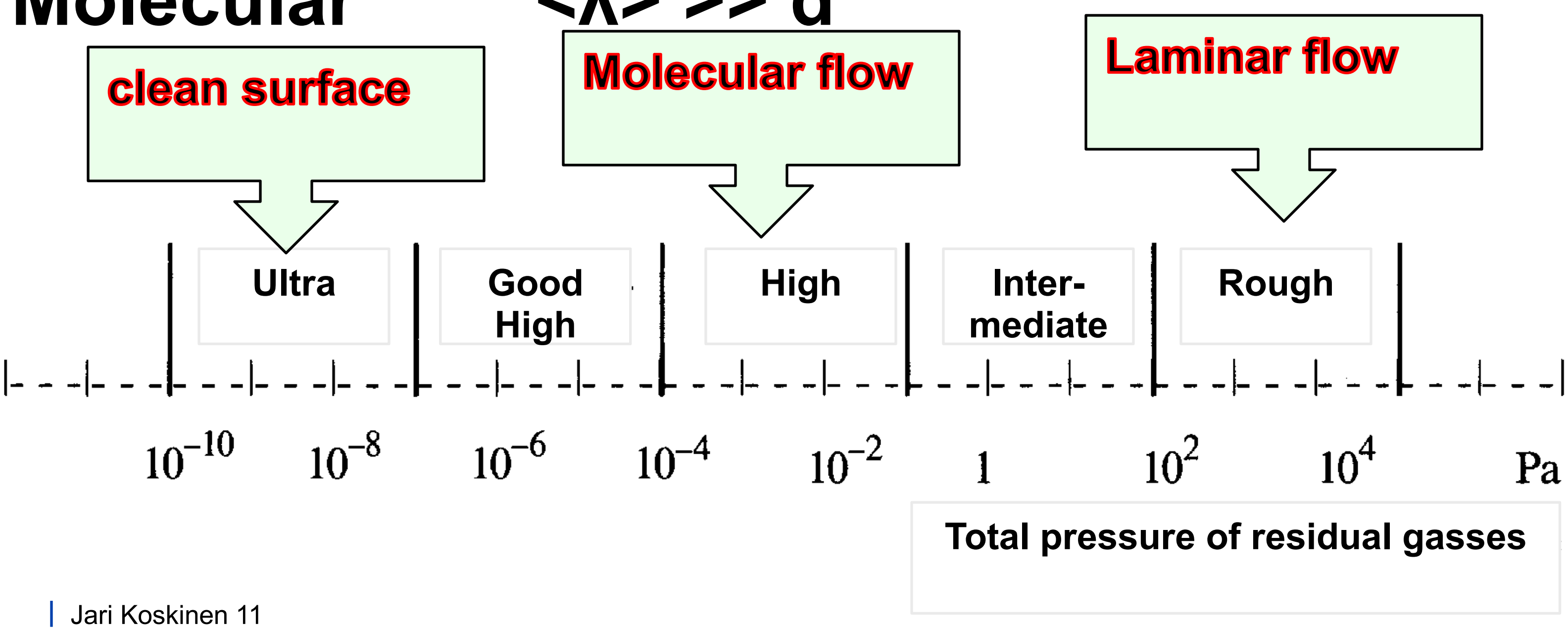
Total pressure of residual gasses

Phases of residual gas

d = diameter of chamber

- Viscotic $\langle\lambda\rangle < d/100$
- Intermediate
- Molecular $\langle\lambda\rangle \gg d$

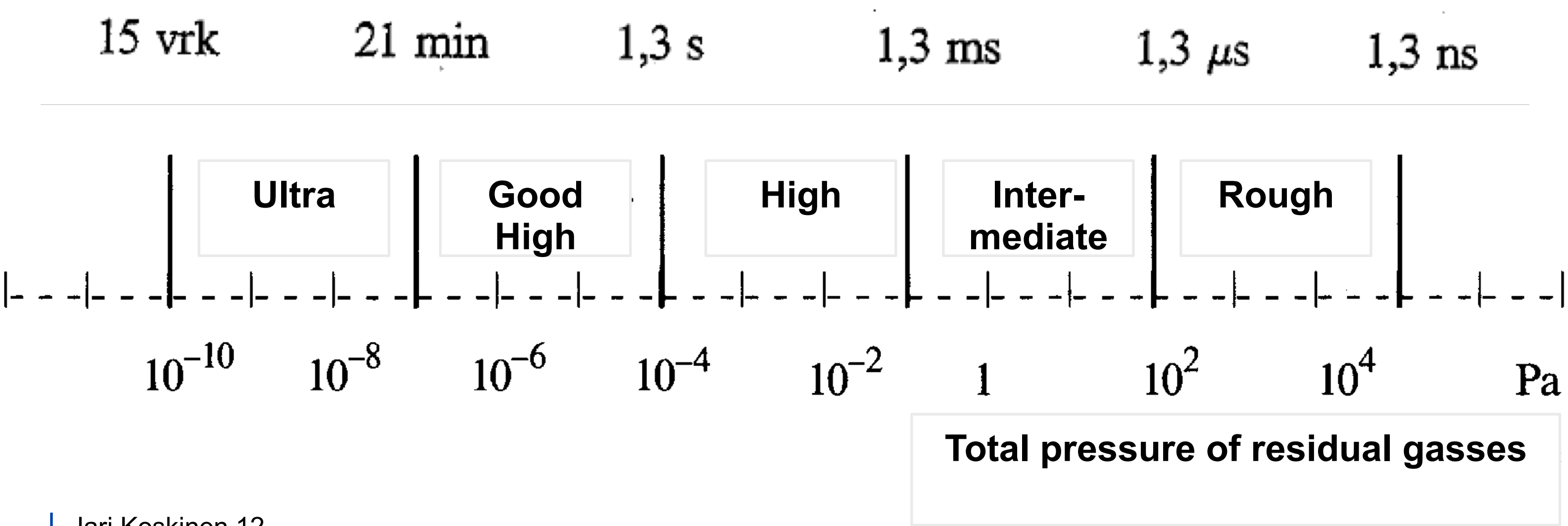
Filament does not oxidise



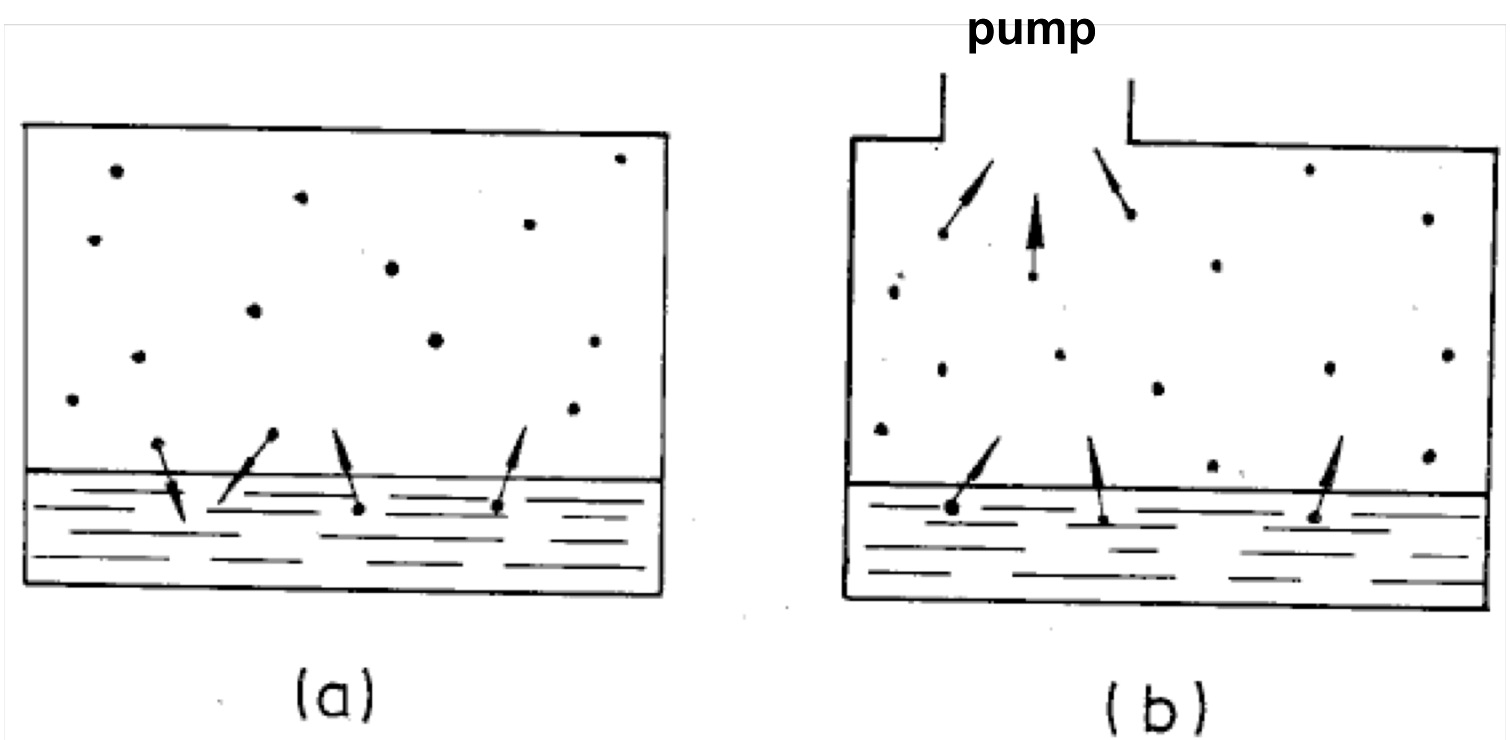
Time to form one molecular layer on surface

u<μ> average molecule mass
ζ diameter of molecule

$$\tau_m = \frac{(2 \cdot \pi \cdot <\mu> \cdot u \cdot k \cdot T)^{1/2}}{\xi^2 \cdot P}$$



Vapour and liquid in vacuum



balance:
condensation = evaporation

balance:
pumping = evaporation
pressure constant until all liquid is pumped

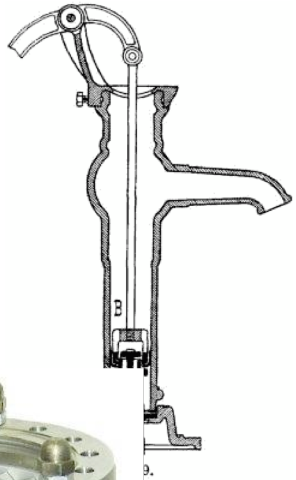
Critical temperatures and pressures for some residual gasses

Gas or vapor		T_c (°C)	P_c (MPa)	ρ_M (kg/m^3)
Helium	He	—268	0,23	69,3
Hydrogen	H_2	—240	1,30	31,0
Nitrogen	N_2	—147	3,40	311
Carbon monoxide	CO	—140	3,50	301
Argon	Ar	—122	4,86	531
Oxygen	O_2	—118	5,08	410
Methane	CH_4	—82	4,64	162
Carbon dioxide	CO_2	31	7,38	468
Chlorine	Cl_2	144	7,71	573
Ether	$(C_2H_5)_2O$	195	3,61	265
Ethanol	C_2H_5OH	243	6,38	276
Carbon tetraclor.	CCl_4	283	4,56	558
Water	H_2O	374	22,11	326

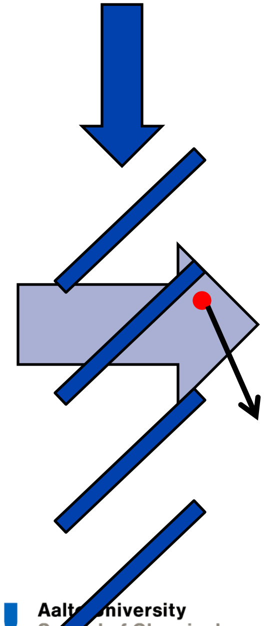
above T_c no liquid

Vacuum pumps

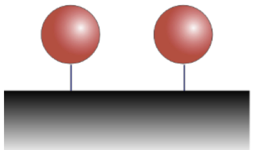
- Positive displacement (mechanical pumps)



- Momentum transfer (molecular pumps)



- Entrapment



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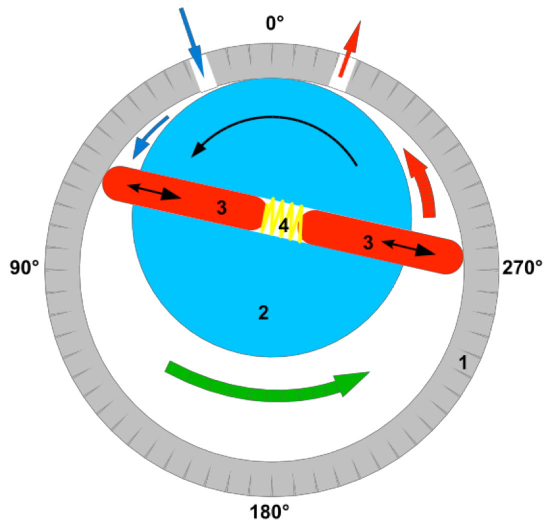
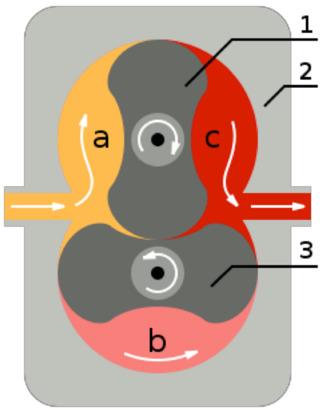
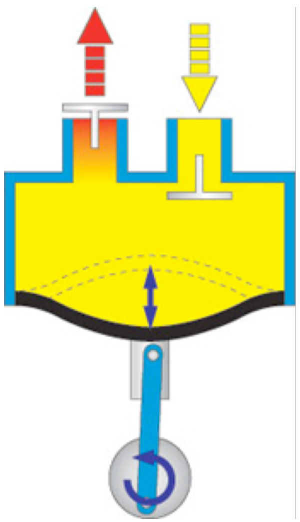
Mechanical pumps



Rotary vane

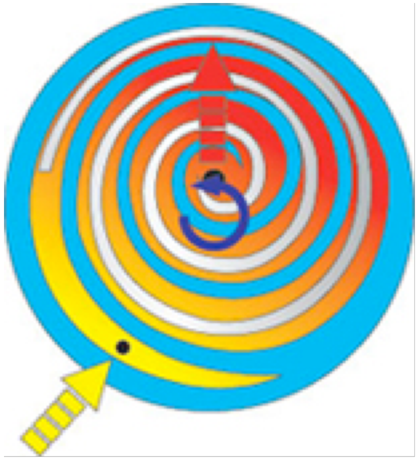


Roots



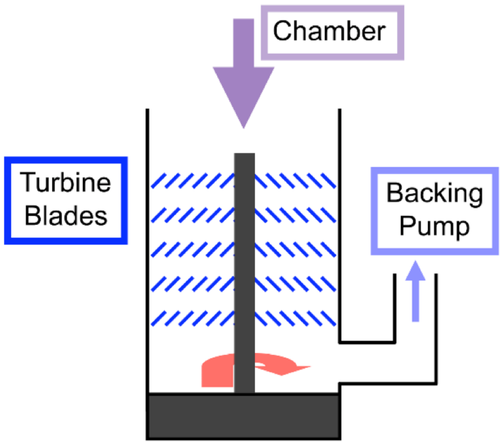
Diafragma

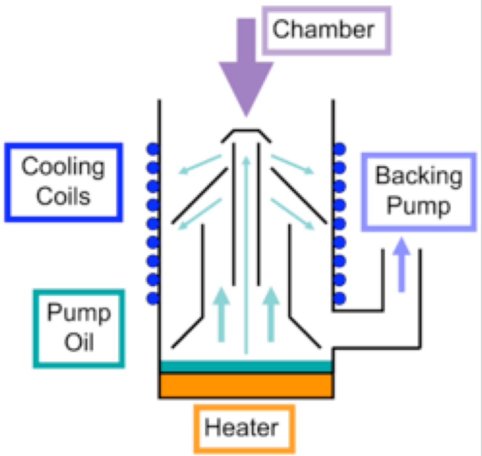
Mechanical pumps



Scroll pump

Momentum transfer

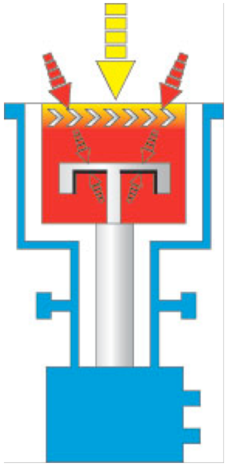




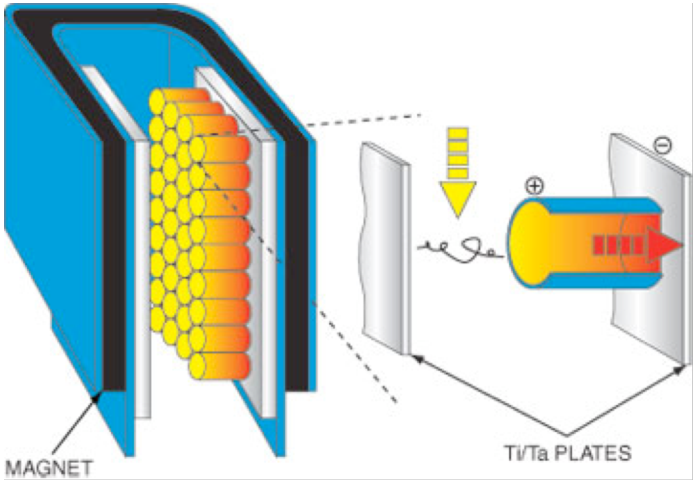
Turbo molecular

Oil diffusion pump

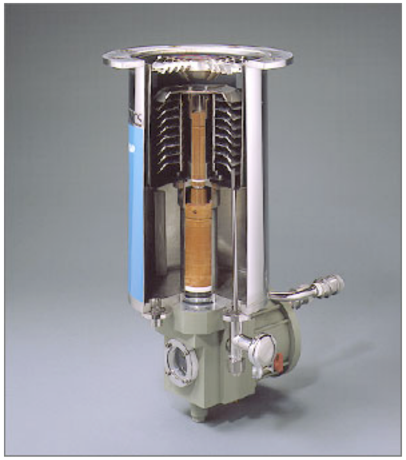
Entrapment



cryo pump



ion pump



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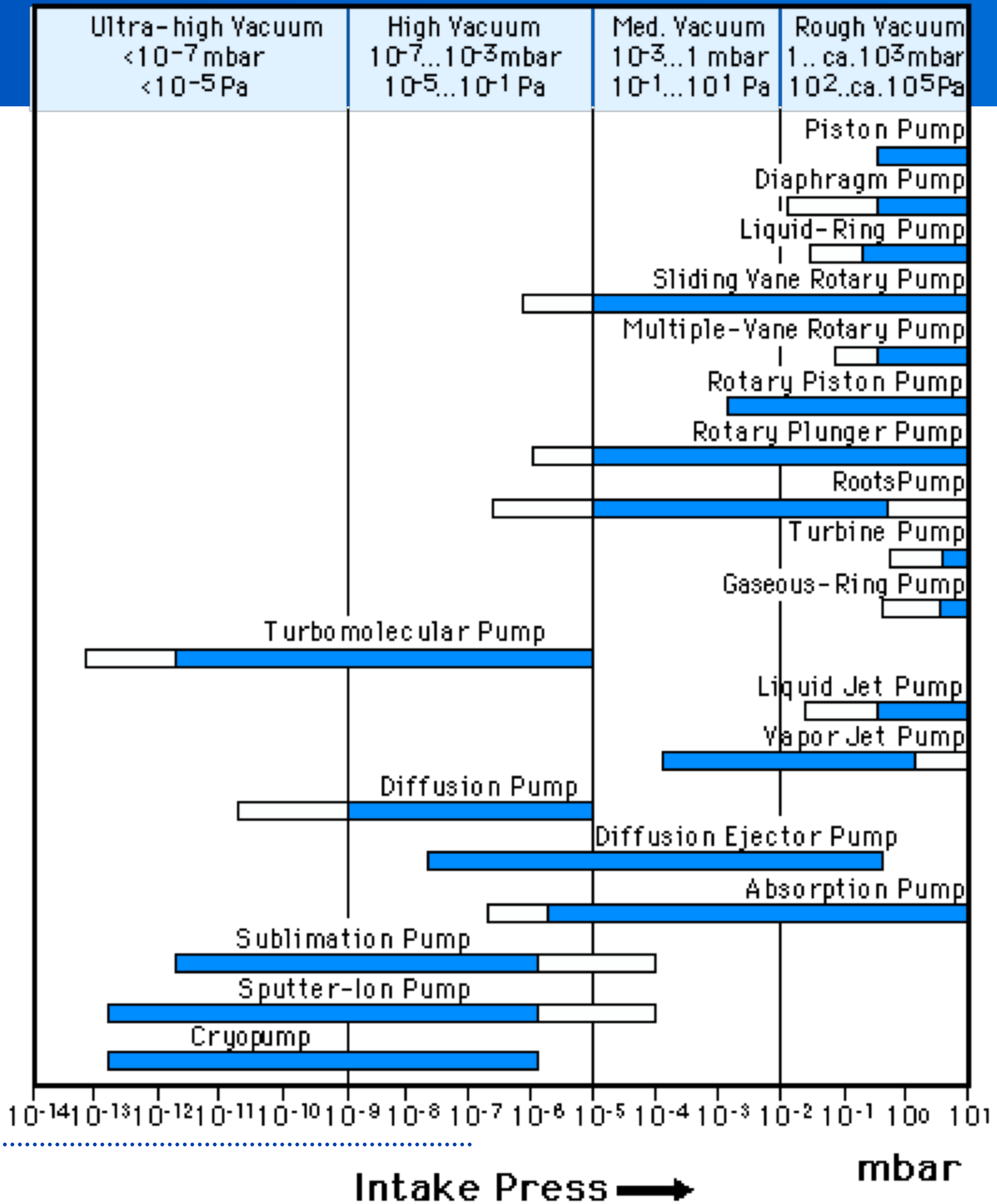
Pumps and vacuum ranges



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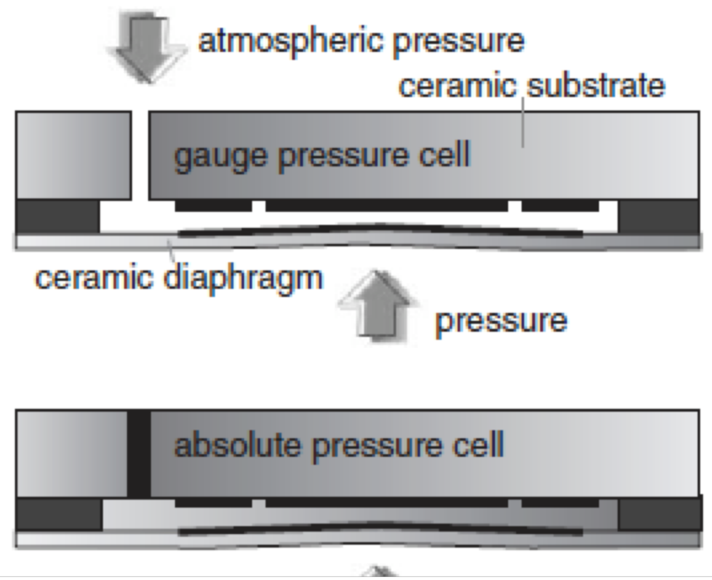
Vacuum gauges

- Mechanical – diaphragm
- Electronic
    - Piezoresitive (strain gauge)
    - Capacitive
    - Magnetic
    - Piezoelectric
    - Optical
    - Potentiometric
    - Resonant
- Thermal conductivity – Pirani
- Ionzation gauge
- Hot cathode
- Cold cathode (Penning)



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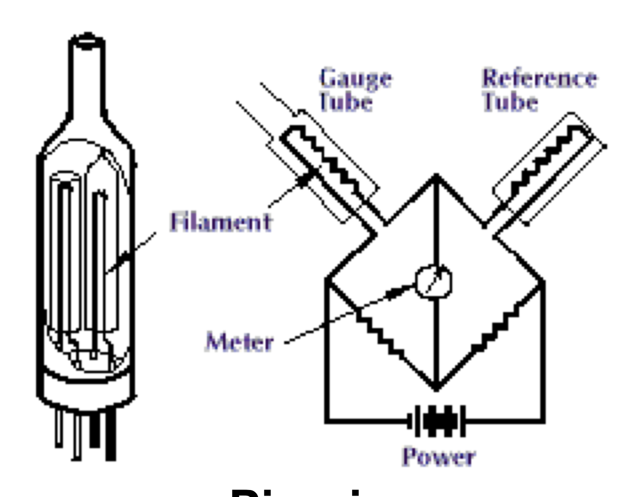
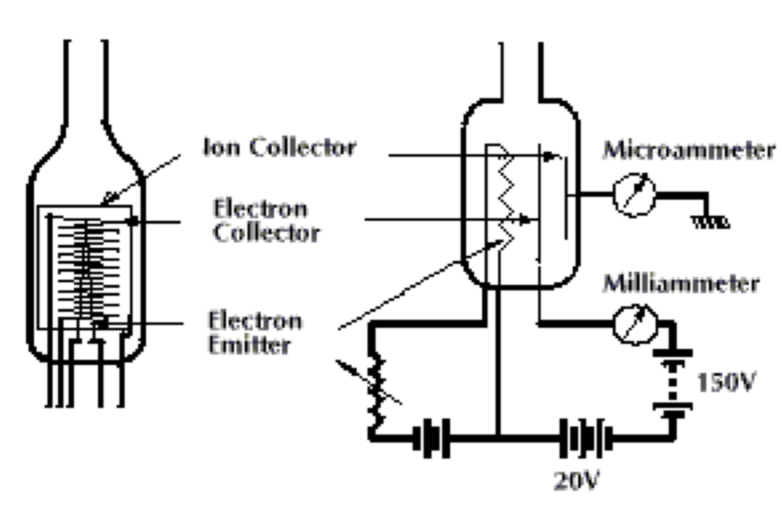
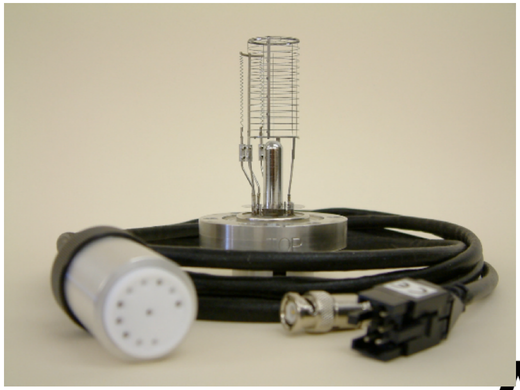
Gauges

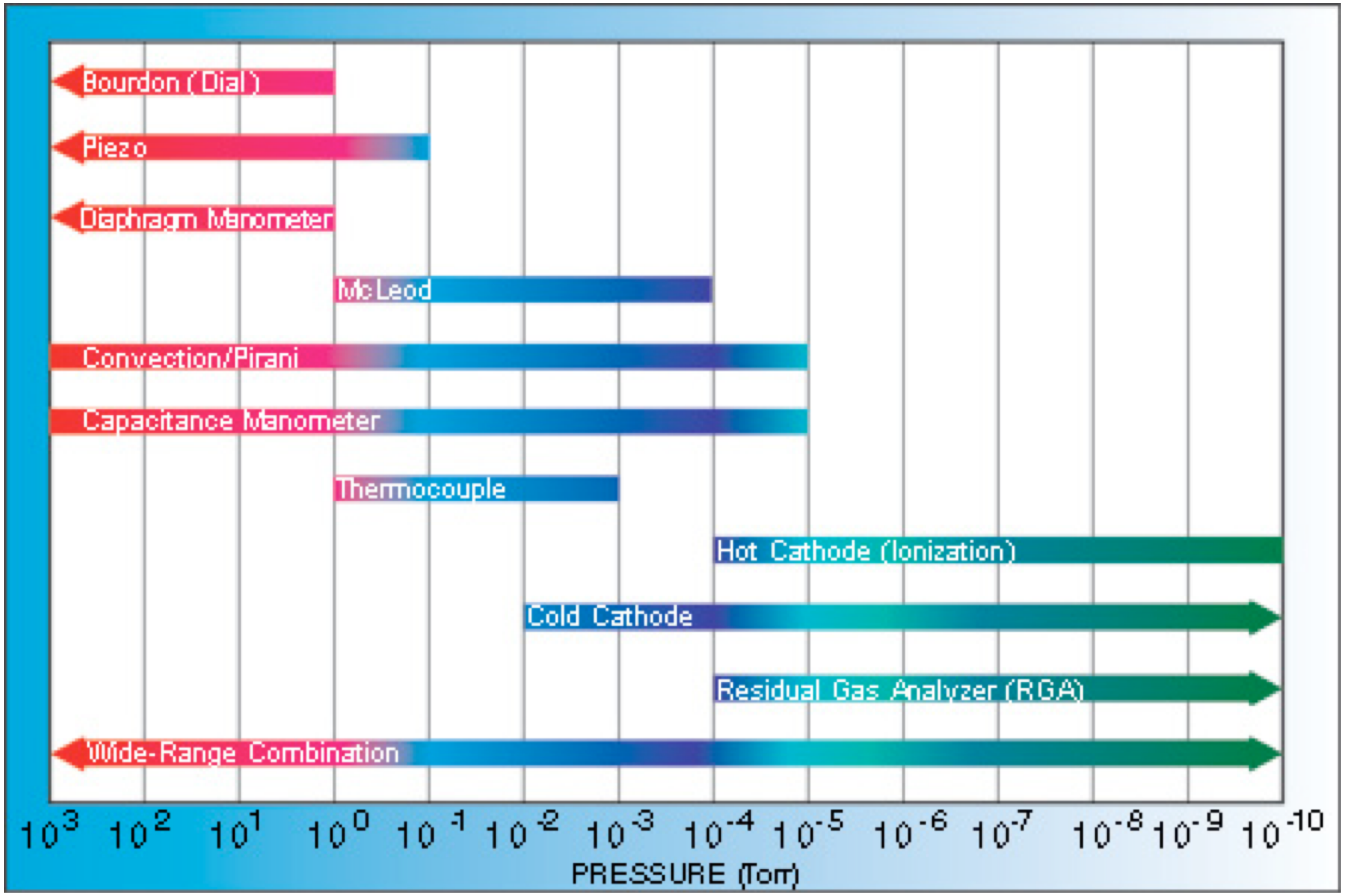


Pirani



ionization gauge hot filament





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Residual gas analyser

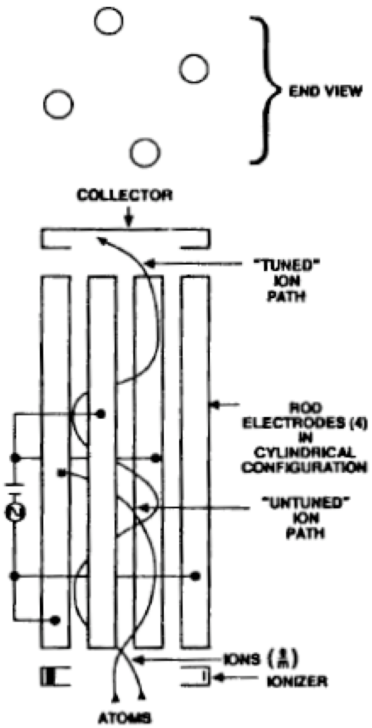
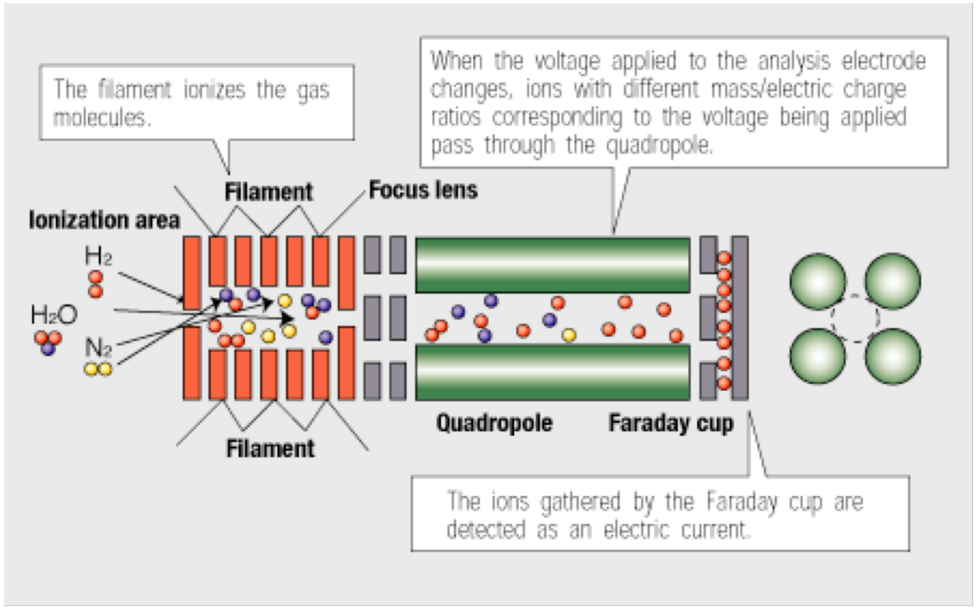


Figure 3-1 cont. A quadrapole mass spectrometer.



SRS RGA100 Residual Gas Analyzer

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Vacuum systems

Vacuum systems

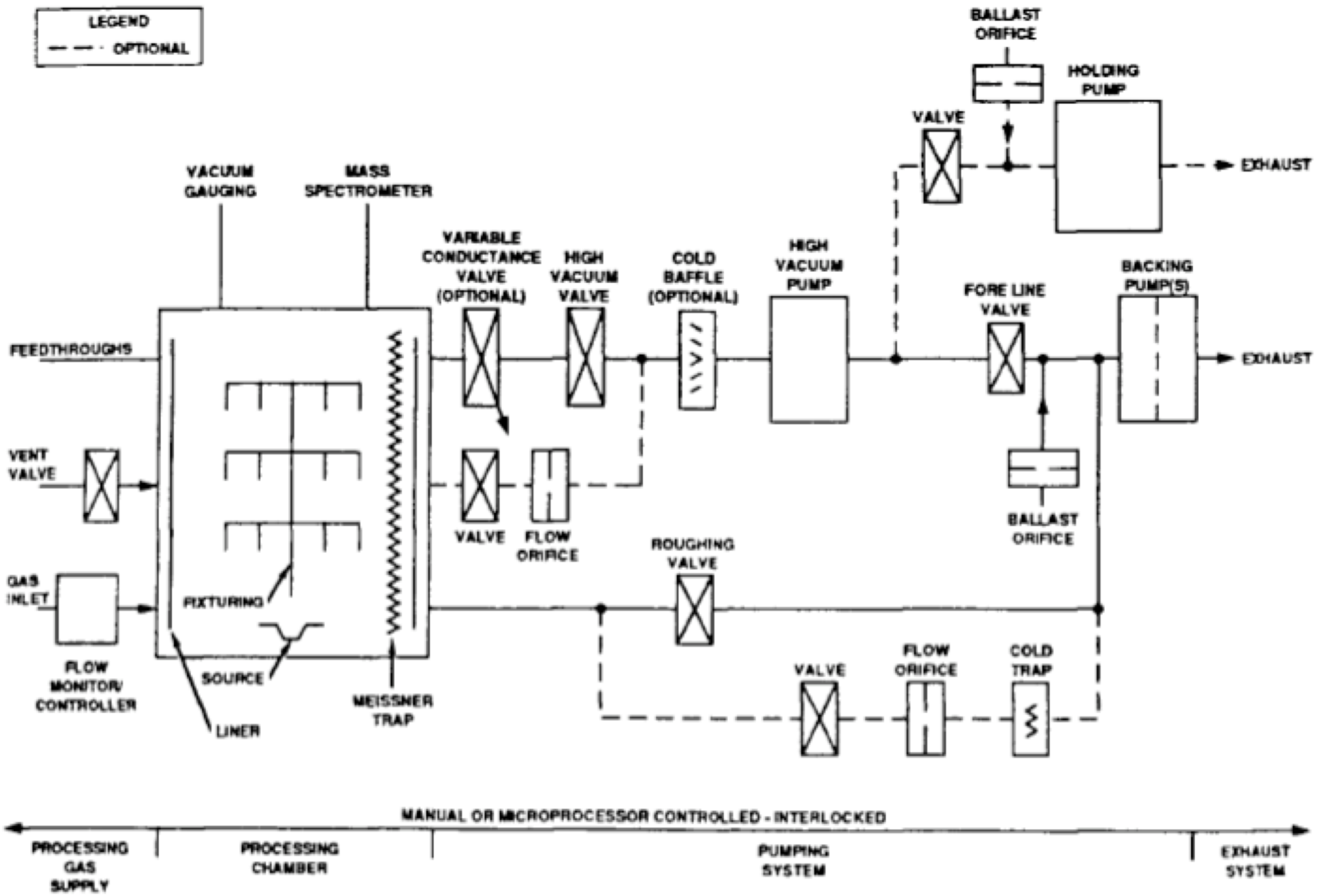


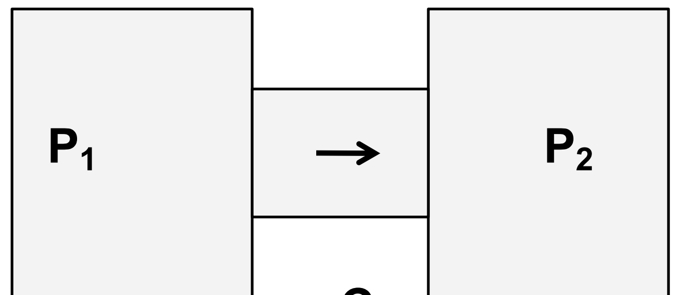
Figure 3-8. Vacuum/plasma processing system.

Handbook of Physical Vapor Deposition (PVD) Processing

Gas flow in vacuum systems

$Q = C(P_1 - P_2)$

Q gas troughput [pressure*volume/s]



C
conductance
l/s

in series:

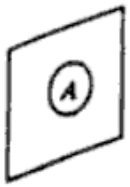
$$\frac{1}{C_{sys}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \cdots .$$

in parallel:

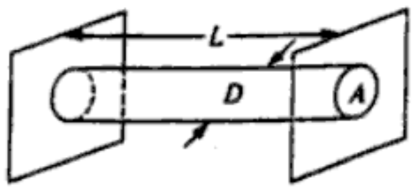
$$C_{sys} = C_1 + C_2 + C_3 + \cdots .$$

Conductance of various geometries

M. Ohring



$$C = 3.64A\left(\frac{T}{M}\right)^{1/2} = 11.7A$$



$$C = 6.18\frac{A^2}{DL}\left(\frac{T}{M}\right)^{1/2} = 12.2\frac{D^3}{L}$$

Vacuum systems

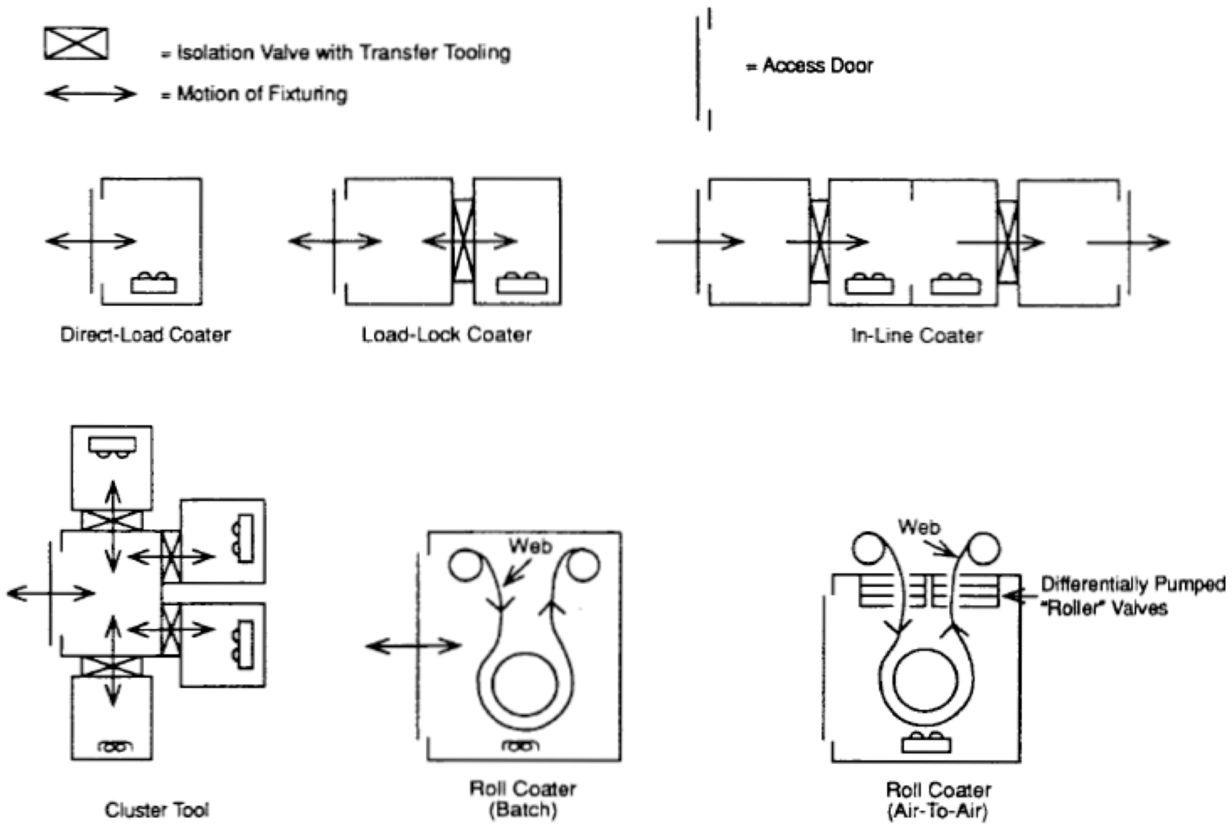


Figure 3-9. Deposition chamber configurations.

Handbook of Physical Vapor Deposition (PVD) Processing

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Vacuum system design

- Access—how large and heavy are the parts and fixturing?
- Do the parts need to have *in-situ* processing? e.g. outgassing, heating, plasma treatments, etc.
- System cleaning—is there a lot of debris generated in the process? Does the debris fall into critical areas such as valve sealing surfaces? How often will system cleaning be necessary?
- Cycle time for the system—production rate.
- How often do fixtures and tooling need to be changed?
- Is the processing sensitive to the processing environment?
- Sophistication of the operators—operator training.
- Maintenance.
- Safety aspects—high voltage, interlocks.
- Fail safe design—short or long power outages, water failure.
- Environmental concerns—exhaust to the atmosphere, traps.