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Introduction to Clean Room and vacuum systems

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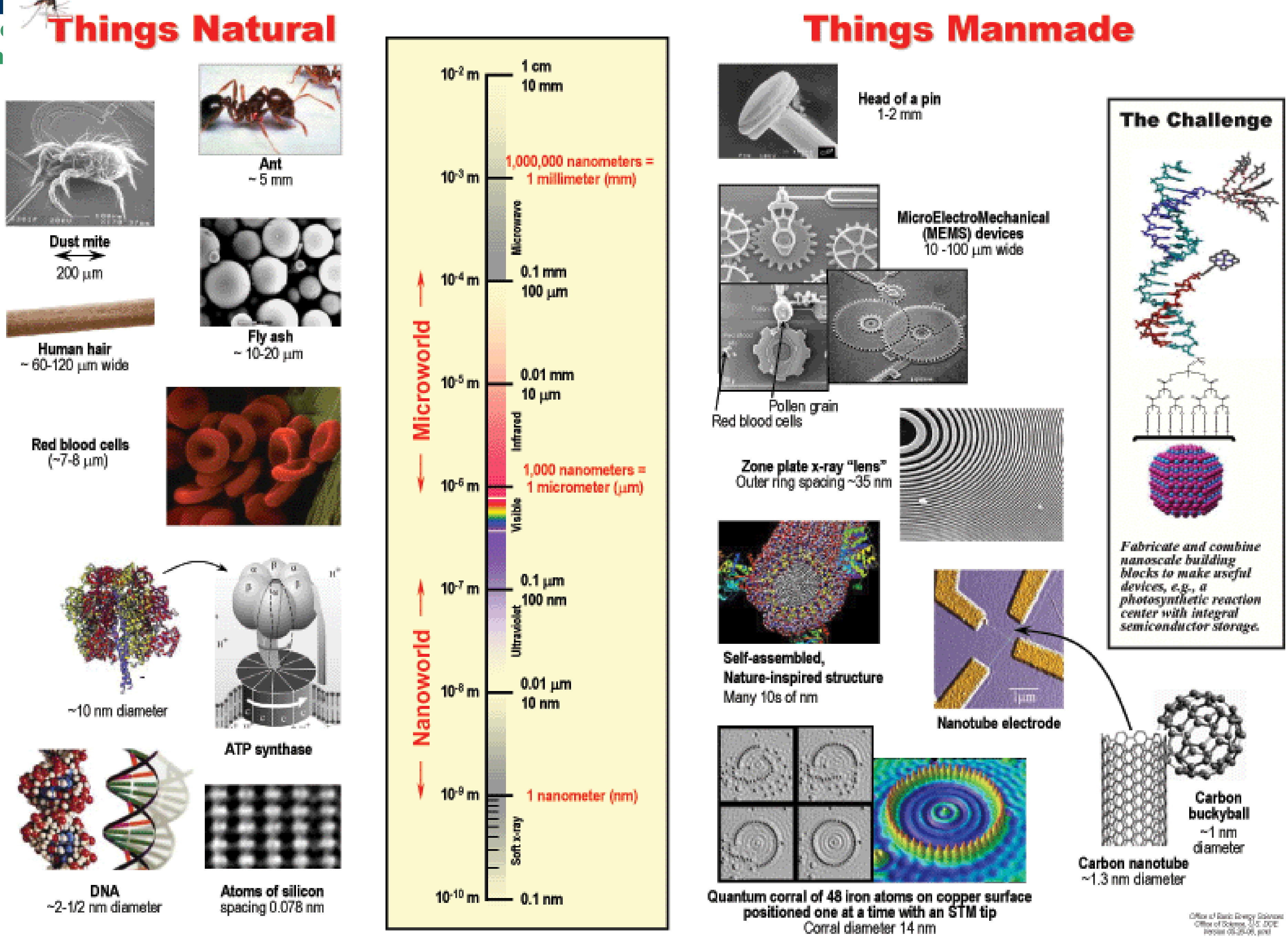
TÉCNICO LISBOA

The Scale of Things – Nanometers and More



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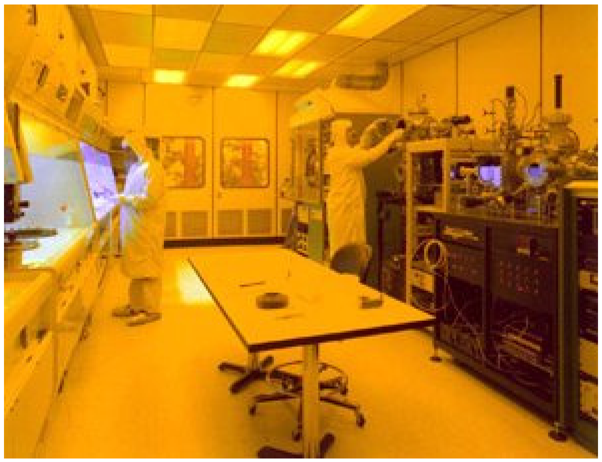
Wafer processing - I

Clean room environment

Semiconductor clean room:

- controlled temperature (20ºC), air pressure, humidity (30%)
- controlled airbone particulates
- controlled vibration
- controlled lighting



If you've never done it before, putting on a bunny suit can take 30 to 40 minutes. The **Intel pros** can do it in five.

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250 m^2 Class 10 and 100 clean room
250 m^2 Class 10000 (grey area)

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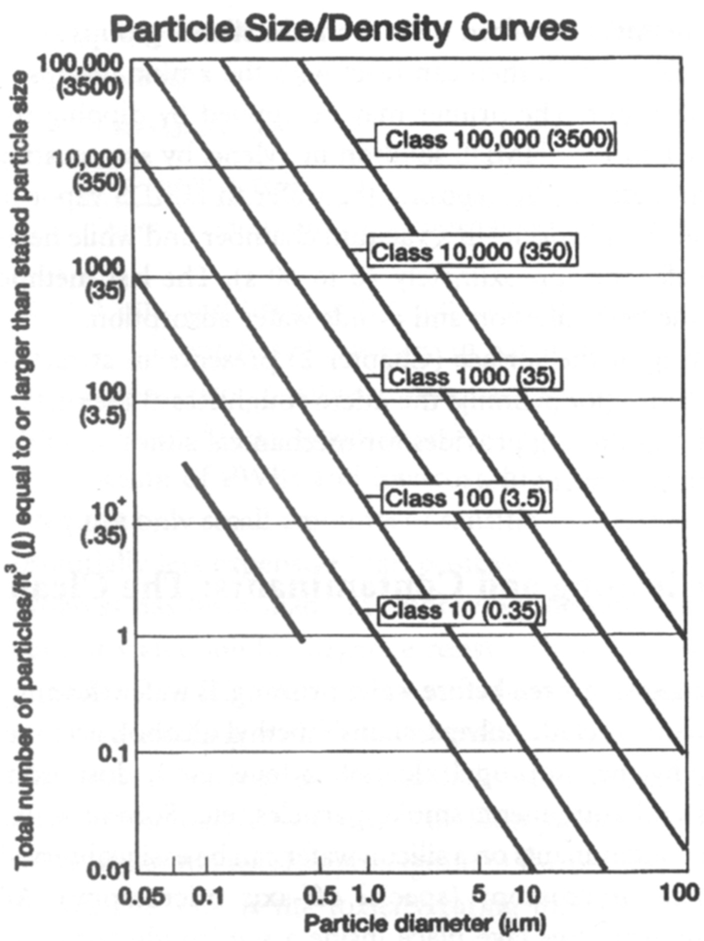
HEPA(High Efficiency Particulate Air Filter)

- for maintaining contamination control
- Filtering particles down to 0.3 microns



ISO 14644-1 cleanroom standards

	particles/m³					
Class	0.1 µm	0.2 µm	0.3 µm	0.5 µm	1 µm	5 µm
ISO 1	10	2				
ISO 2	100	24	10	4		
ISO 3	1,000	237	102	35	8	
ISO 4	10,000	2,370	1,020	352	83	
ISO 5	100,000	23,700	10,200	3,520	832	29
ISO 6	1,000,000	237,000	102,000	35,200	8,320	293
ISO 7				352,000	83,200	2,930
ISO 8				3,520,000	832,000	29,300
ISO 9				35,200,000	8,320,000	293,000

Cleanroom class comparison

The following classes are mostly equivalent, although the testing standards diffe

ISO 14644-1	FED STD 209E
ISO 3	1
ISO 4	10
ISO 5	100
ISO 6	1,000
ISO 7	10,000
ISO 8	100,000

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Vacuum systems

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Vacuum basics

- **What is a vacuum?**
  - Any gas at sub-atmospheric pressure
  - Vacuum is really the absence of gas
  - Vacuum is not absolute, but a continuous range of conditions
    - 15 orders of magnitude in common usage

- **Pressure is Force per Unit Area**
  - Pounds/sq. in
  - Newtons / sq.meter
  - Tons/ sq. angstrom
  - Atmospheric Pressure
    - 14.7 pounds/sq. in.
    - 10^5 Newtons/sq. meter
      - approx. ton/sq ft
      - approx. kg(force) / sq.cm.

- **SI UNITS:**
  - Pascal = 1 Newton/ sq. meter
  - 1 atm = 10^5 pascals
  - Non-Si Units: (common units)
  - Torr, millitorr
  - Bar, millibar
- **Torr is an archaic unit but widely used and widely understood**
  - Avoiding it is difficult

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What is vacuum

10 ^{3} Torr
10 ^{2} Torr
10 ^{1} Torr
1 Torr
10 $^{-1}$ Torr — 100 millitorr
10 $^{-2}$ Torr — 10 millitorr
10 $^{-3}$ Torr — 1 millitorr
10 $^{-4}$ Torr
10 $^{-5}$ Torr
10 $^{-6}$ Torr
10 $^{-8}$ Torr
10 $^{-9}$ Torr
10 $^{-10}$ Torr

1 Atm = 760 Torr
= 1bar

Sputtering machines

Ideal gas law: $PV = NkT$

Pressure

Volume

\# molecules

Temperature

$k = 1.38 \times 10^{-23}$ Joules/molecule/Kelvin
(Boltzmann's Constant)

(T const) => $P \sim N$

- Mean free path (lambda)
  - How far does a molecule go before it strikes another?
- Impingement rate --- Surface Flux
  - How many molecules strike the surface in a given period of time?

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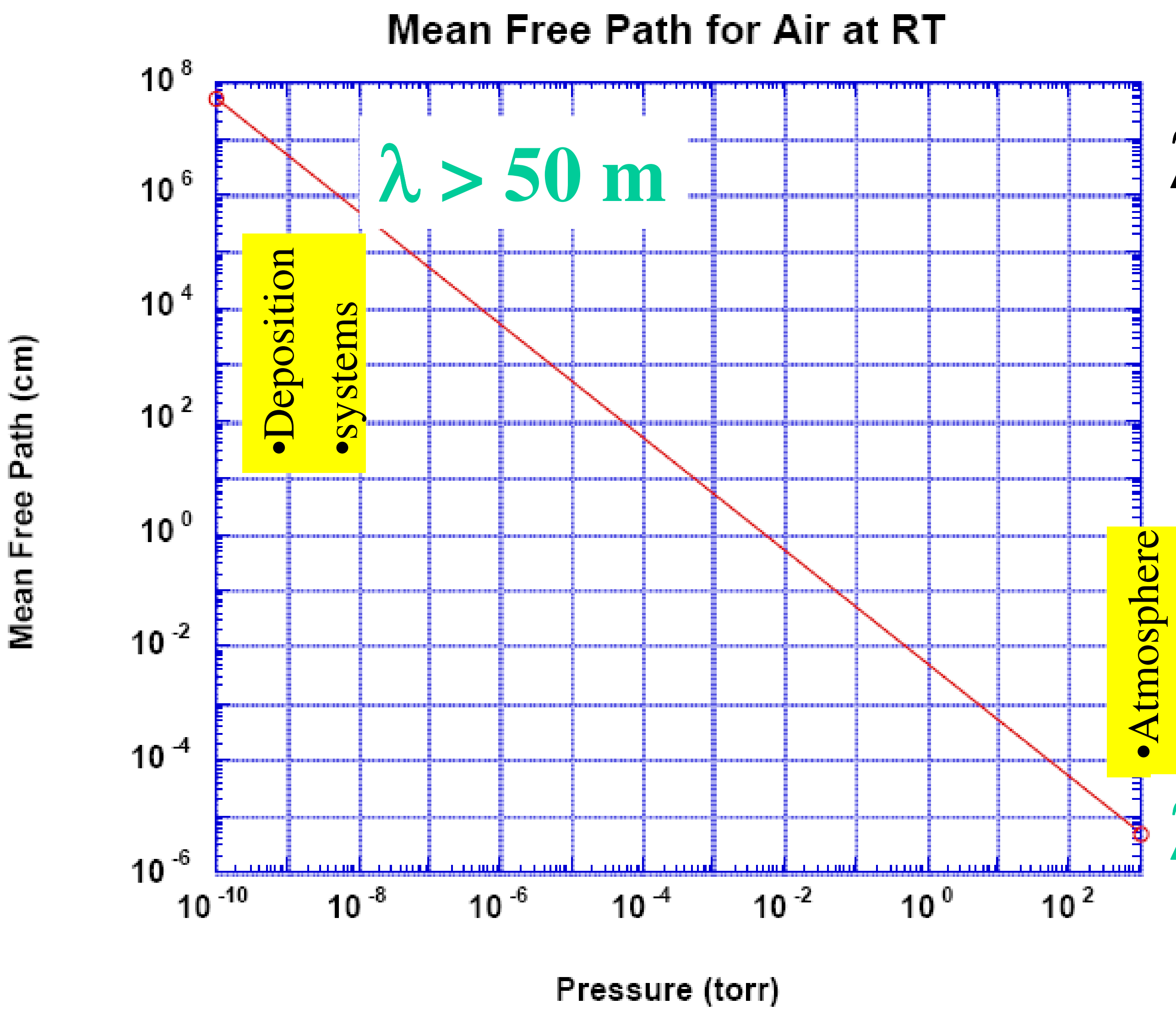
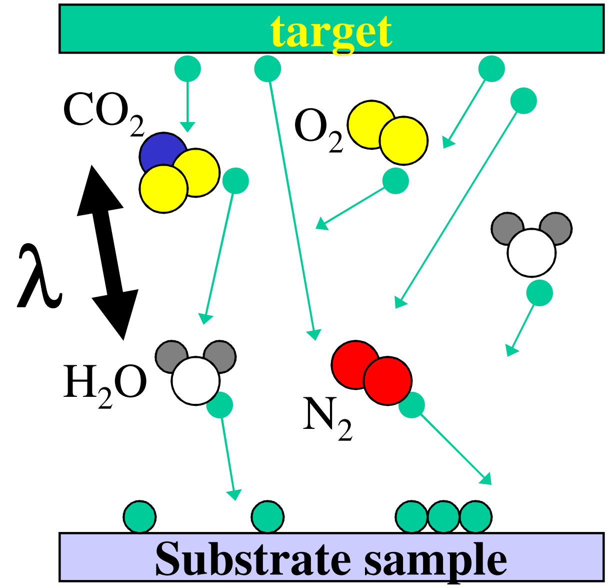
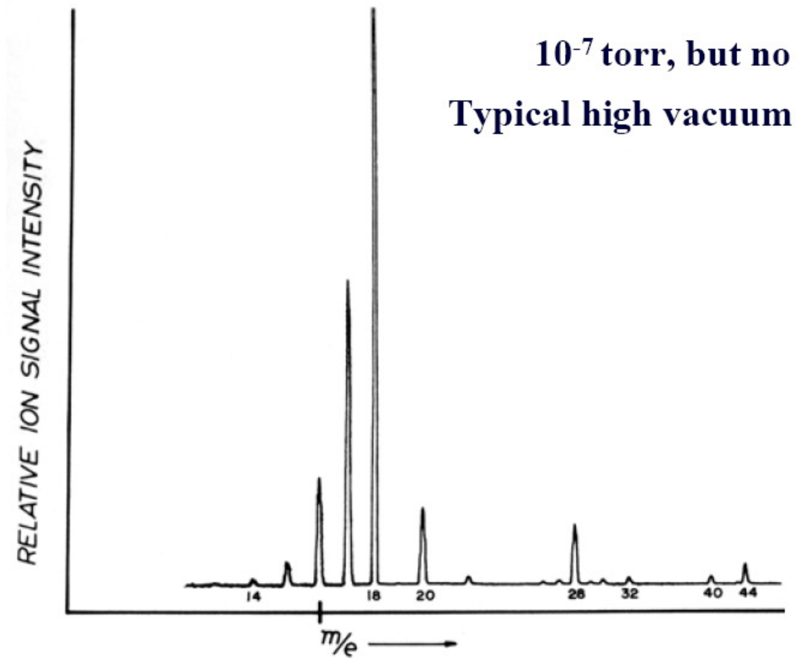


$\lambda \sim 50$ nm



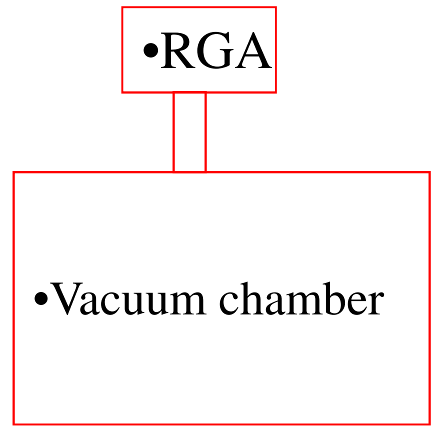
•Residual gas analyzer (RGA)

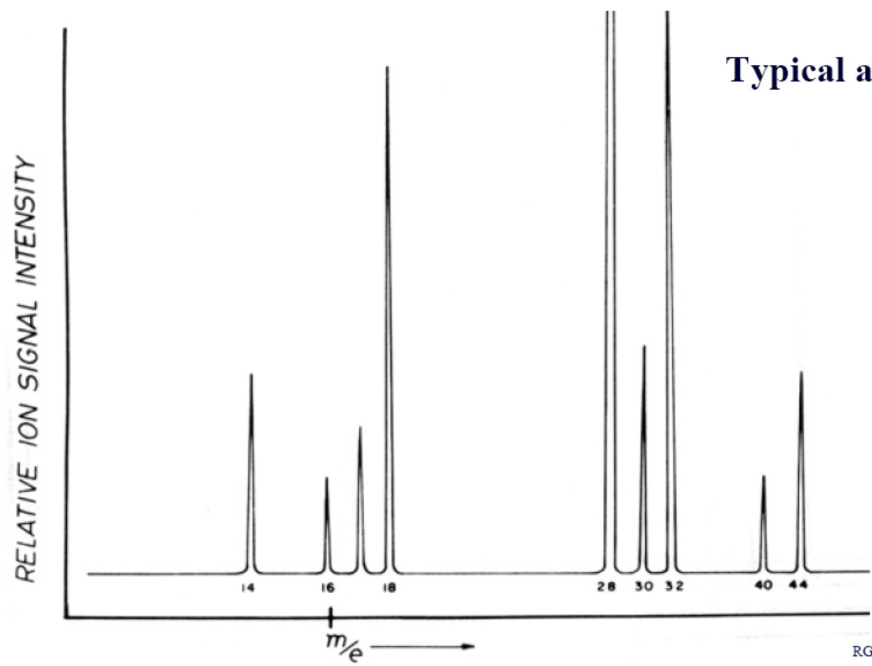


10^{-7} torr, but no leak.

Typical high vacuum spectrum.

RGA spectra from AVS





Typical air leak.

RGA spectra from AVS

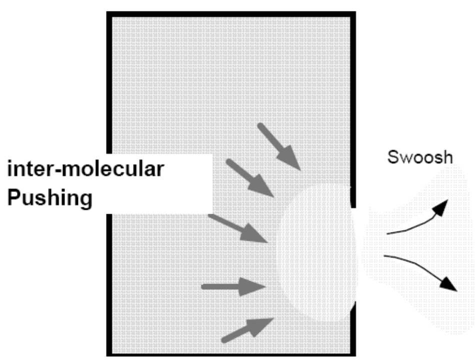
Mass	Species	Explanation
0		Zero Blast , unfiltered fragments
1	H	Cracking of hydrogen
2	H_2	Dominant Species at UHV
4	He	Permeation through polymers or leak detection residue
16	O	Crcking of O2 or H20. Electron Desorption from Surfaces
16	CH_4	Methane produced in system by ion pumps
18	Water	Dominant Species except at UHV
19	F	ionic ghost, see below
20	Ne, Ar^{++}	Inert Gases not pumped well by ion pumps
28	N_2	Air leak if accomanied by 14
28	CO	A major constituent at UHV. Desorption
35	Cl	Process gas or residue or ionic ghosts (see below)
37	Cl isotope	
40	Ar	Inert Gases not pumped well by ion pumps
>40		Generally hydrocarbon contamination
intervals of 14		CH_2 groups cracked off long hydrocarbon chain
16,19,35,37		Residue of O,F,Cl desorbed from surfaces in RGA by electron bombardment. Artifacts.

- MFP << "a" **Fluid like**

  "crowded"

  - Molecules interact with each other more than walls
  - Act as a "fluid"
  - Flow
  - Diffusion
  - Viscosity
- Familiar region
- Molecules act on each other
- We can act on the gas " as a whole"
- Essentially most of "rough" vacuum range

Viscous Flow

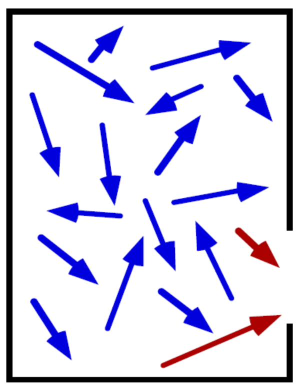


- MFP >> "a" **Molecule like**

  "sparse"/ "vacant"

  - A "sparse" gas on the scale of the tube dimension
  - Molecules interact only with the walls
  - Every molecule to itself
  - No intermolecular forces or energy transfer
- We can only act on ONE MOLECULE AT A TIME
- A VERY UNFAMILIAR REGIME.
- Most of mid, high and ultra high vacuum

Free Molecular Flow



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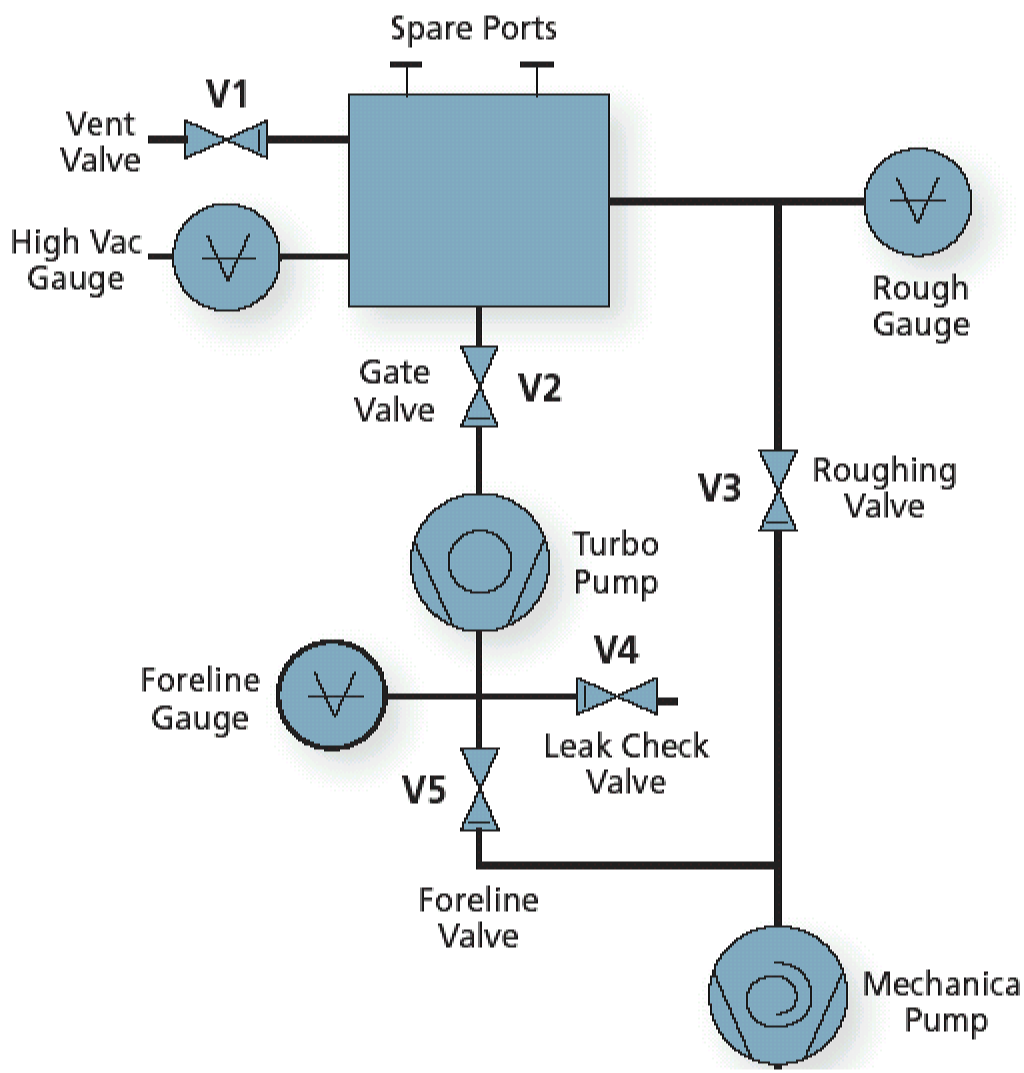
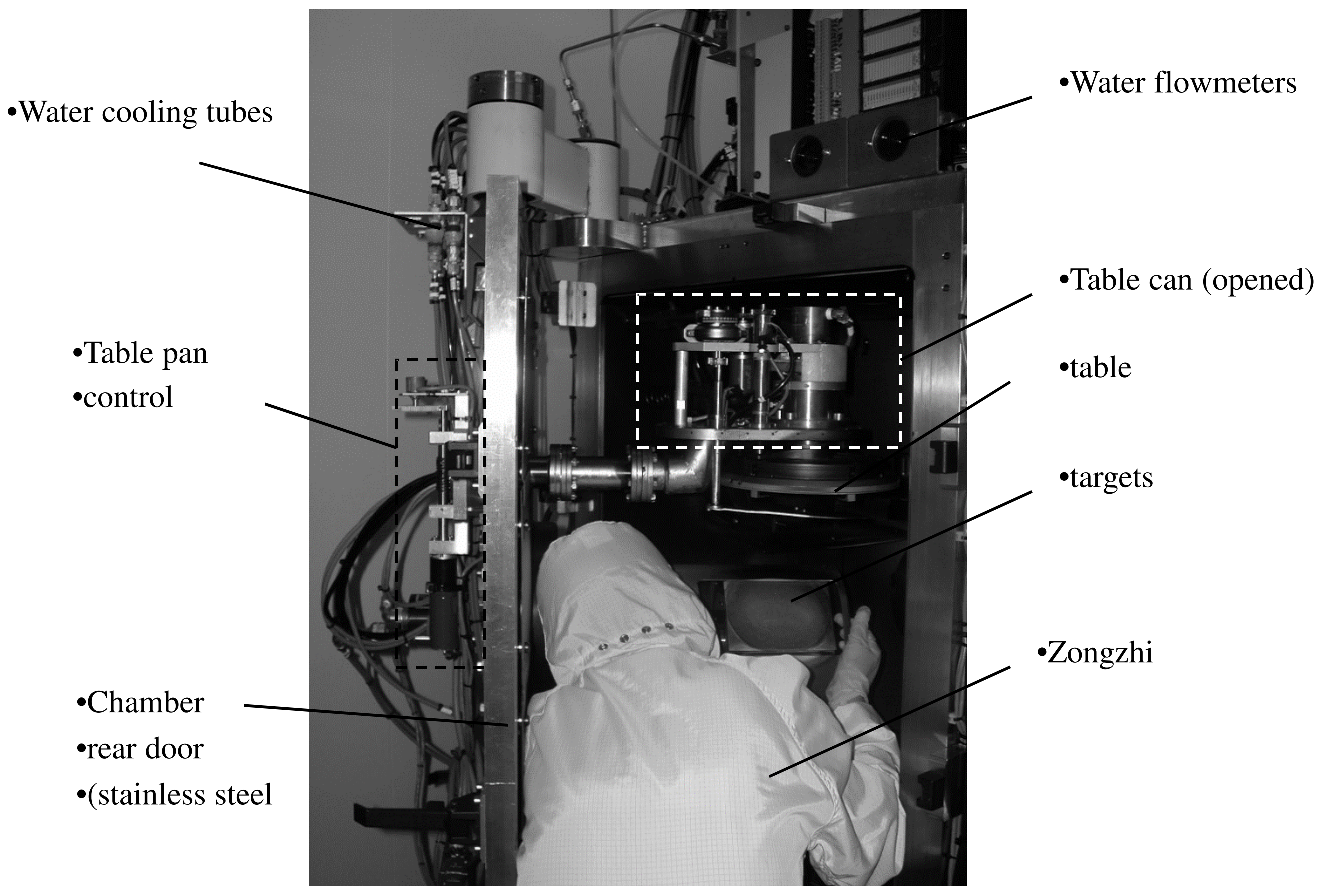
Vacuum systems



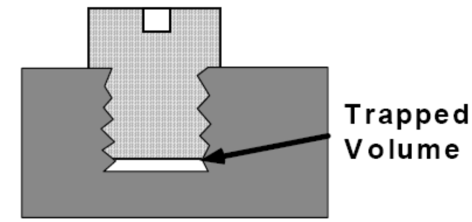
Vacuum chambers need to have several holes...



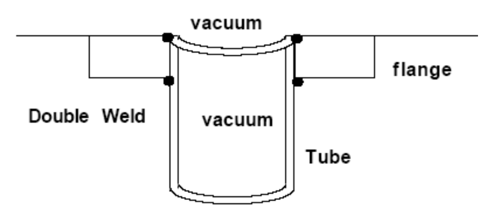
Problems:

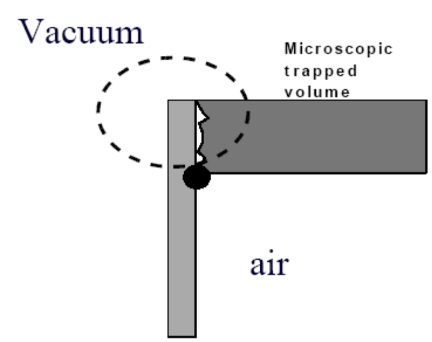
- . Material degasing
- . Water adsorbed

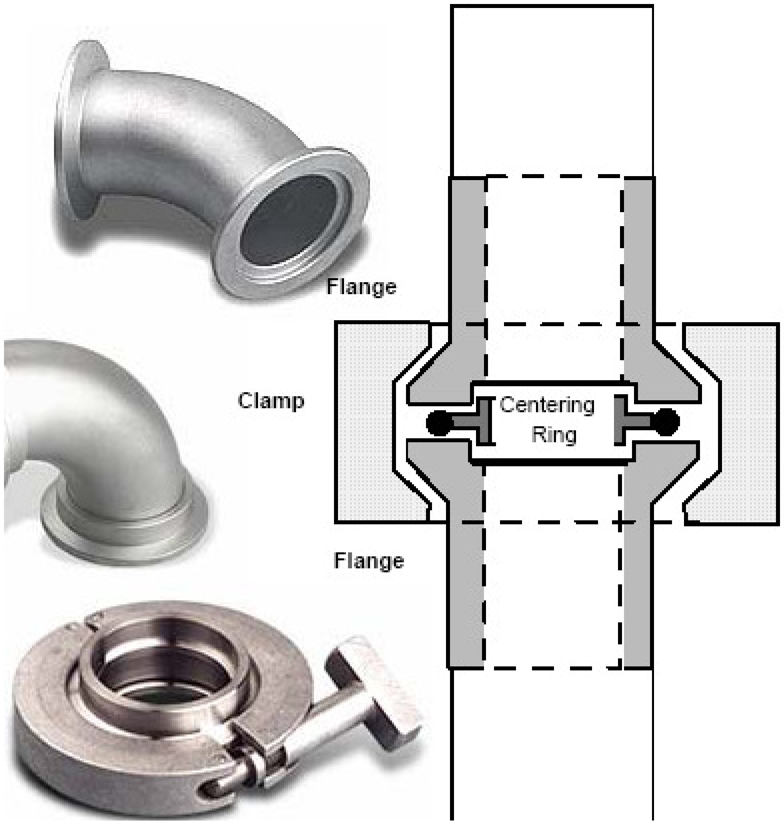
An un-vented screw



Vented screws??






Flange
Clamp
Centering
Ring
Flange

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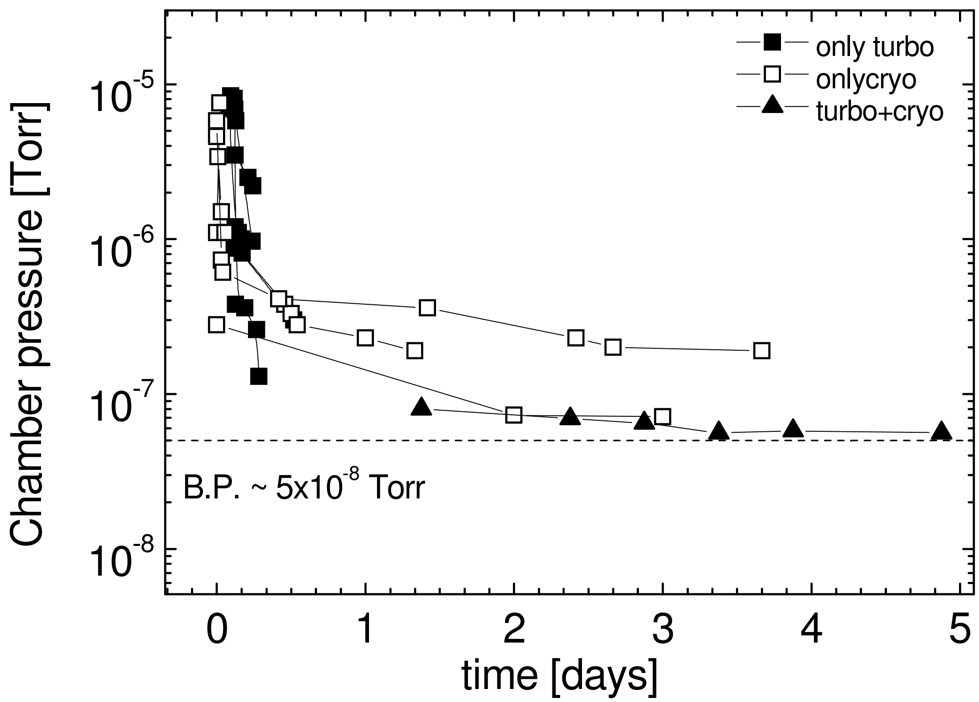

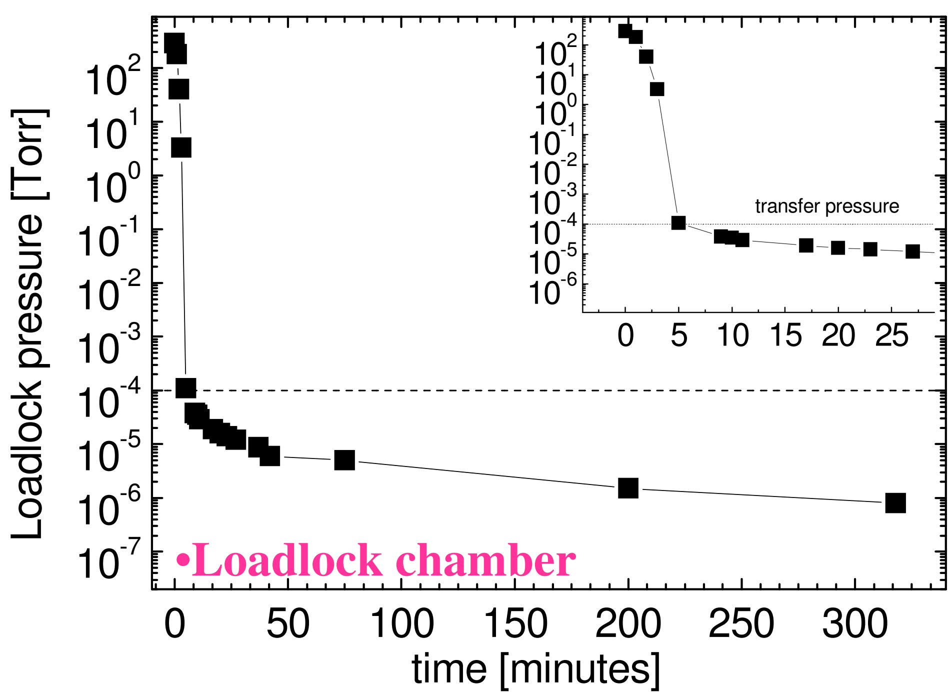

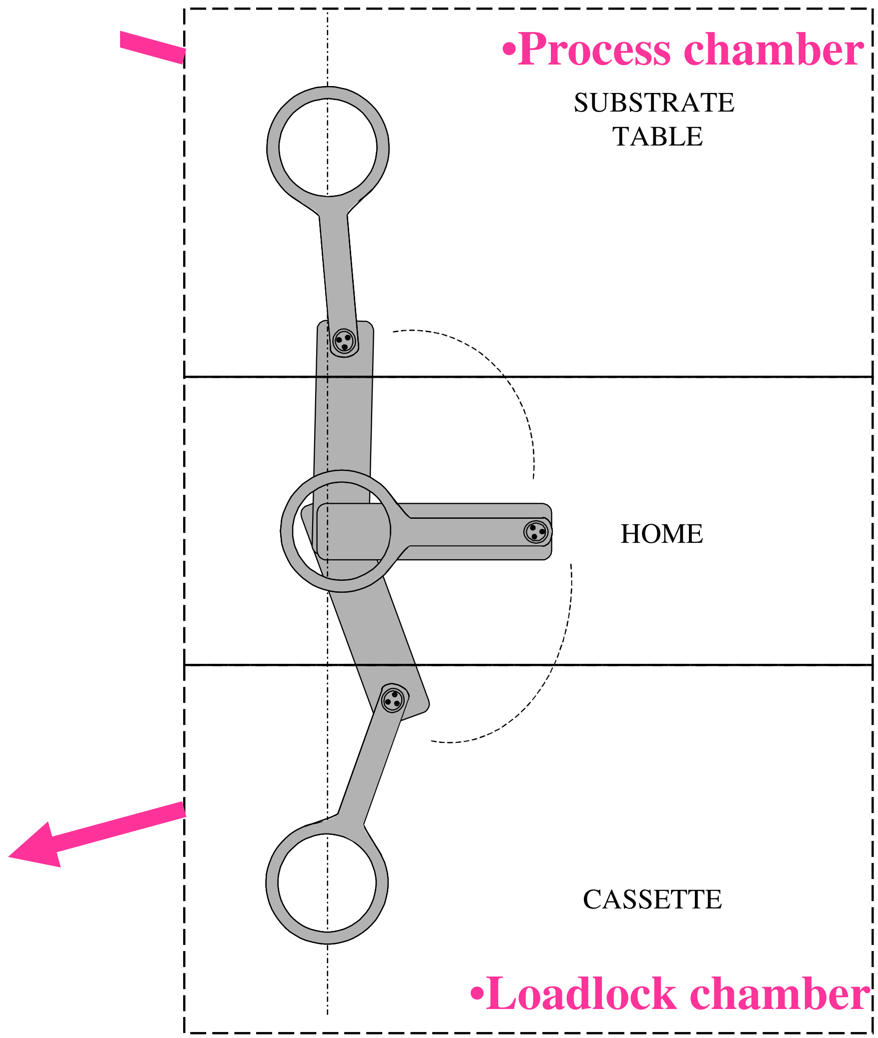

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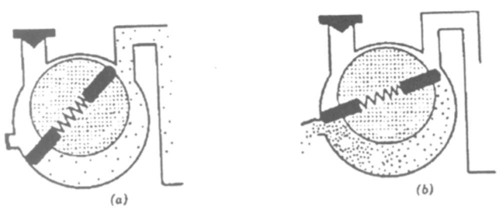
•Rotary pumps



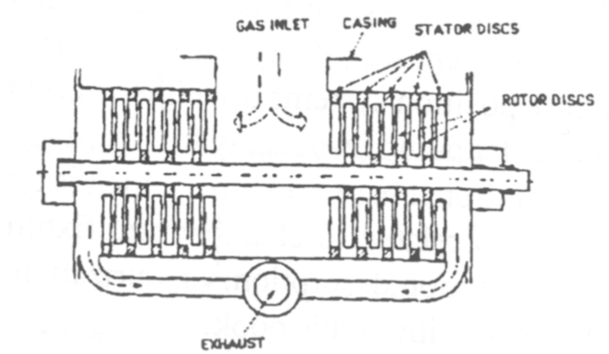
Induction Exhaust

Rotary Pump

•- 1st stage pumps

- ultimate pressure ~10^{-4} Torr
- Requires a purge vapor line

•Turbomolecular pumps



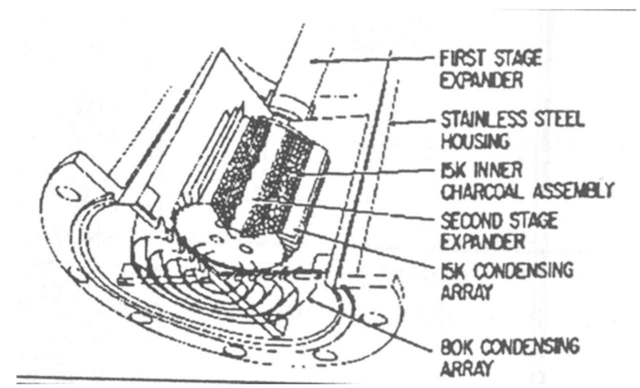
•Momentum transfer from the disks to the gas molecules.

•Separation rotor to disks ~ free mean path (molecular regime)

•- 2nd stage pumps

- ultimate pressure ~10^{-10} Torr
- requires a backing pump

•Cryogenic pumps



•- 2nd stage pumps

- ultimate pressure ~10^{-11} Torr

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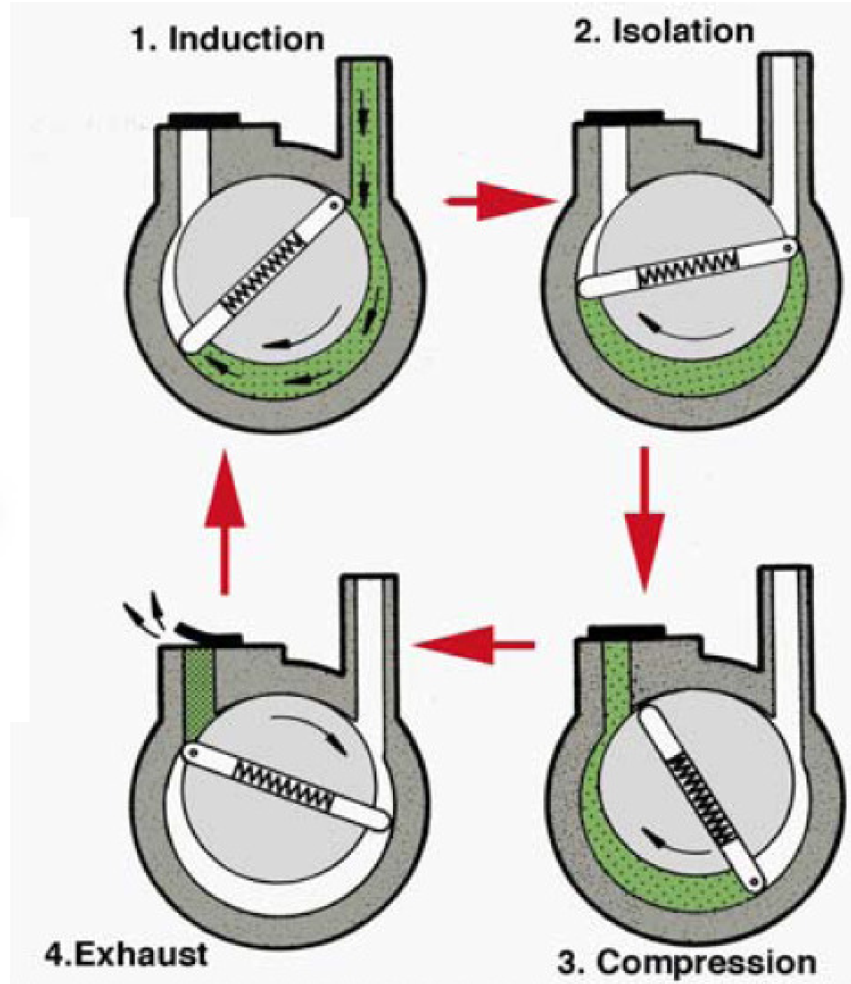
Rough vacuum pumps

- **Advantages:**
  - Reliable
  - Cheap
  - Removes gases permanently

•Rotary pumps

- **Disadvantages:**
  - Noisy
  - Dirty
  - Oily
  - Big
  - Heavy



Four Stages in the Cycle of a Rotary-Vane Pump

Most “mechanical pumps” require a Pump Fluid

- **Functions:**
  - Lubricant
  - Sealant
  - Heat Transfer/coolant
  - Corrosion Protection

•Syntetic oils

•(Fomblin , 400€/l

Requisite Properties:

- Chemically stable
- Thermally stable
- Appropriate lubricating ability
- Appropriate viscosity
- Low vapor pressure

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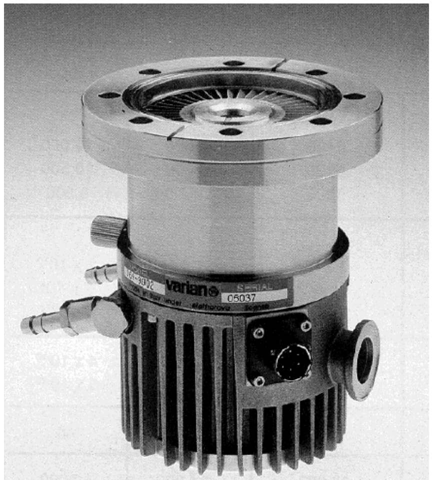
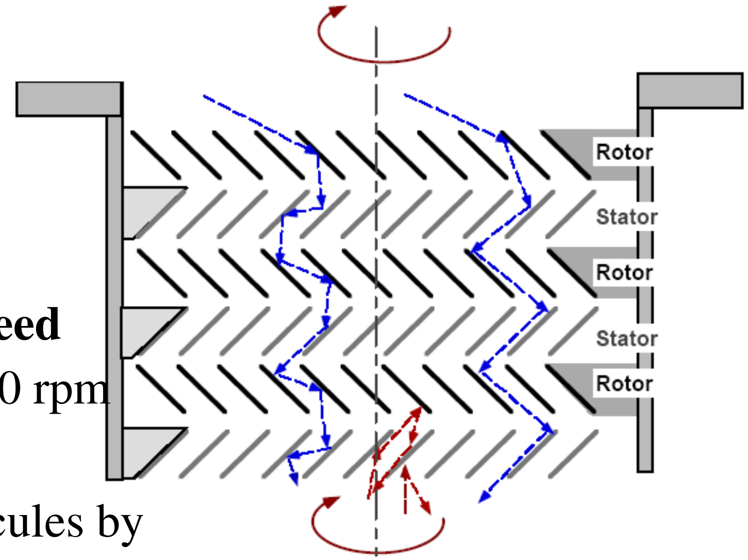
•High vacuum pumps

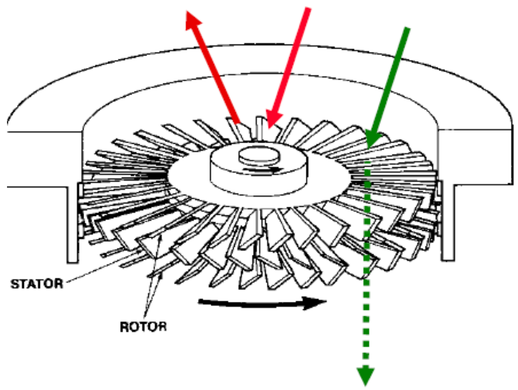


•Turbomolecular pumps

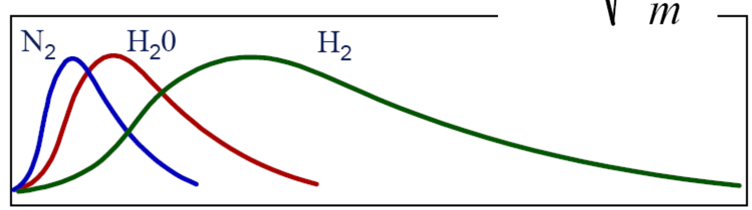


- **Blade speed ~ molecular speed**
  - 40 000 – 80 000 rpm
- Multiple stages
- Transfer of momentum to molecules by collision with high speed turbine blades

- **Pumping speed proportional to blade speed**
- **Only the tips pump well**
- **Pumps very badly when not up to full speed**
- **Can take 15 minutes to get up to speed (big ones)**
- **Variety of sizes:**
  - **100 l/sec small and compact**
  - **2500 l/sec BIG and EXPENSIVE**



$$v_o = \sqrt{\frac{2kT}{m}}$$



- **Vibration**
- **Needs a backing pump**
- **Catastrophic failure (metal**

- **Can pump reactive gases**
- Heavy gases are pumped better (slower)
- At ultimate pressures, the residual gas is 99% H_2

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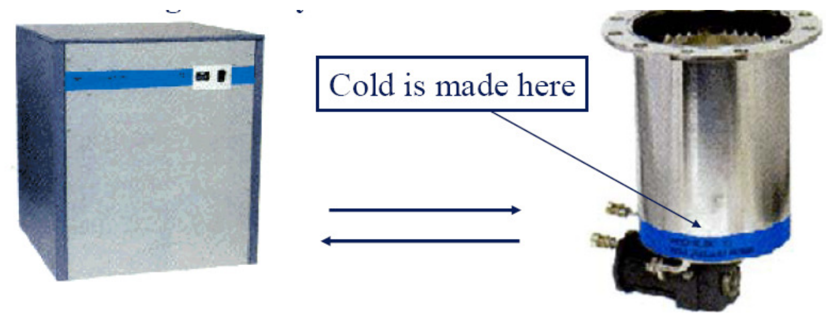
•High vacuum pumps

•Ultra-pure Helium working fluid
•External compressor

•Cryo Pump



•Expansion head

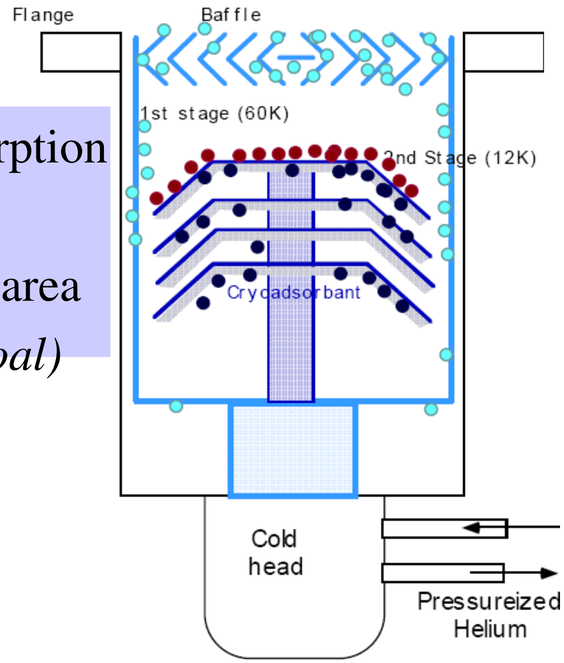
•Cryogenic pumps

•Gas condensation + adsorption

⇓

•cold surface and/or large area

•*(porous: activated charcoal)*



- **Advantages:**
  - Clean
  - Fast at moderate cost
  - Can be BIG
  - HV and UHV compatible to 10^{-9} torr
  - Almost Infinite Capacity (except He, H_2)
- **Disadvantages:**
  - Store Large quantity of gas
  - Toxics
  - Reactives
  - Vibration
  - Heat Sensitivity

•Not for reactive gases

Periodically saturates with adsorbed gases

- Saturate the pores so it wont pump He/H_2
- Physically obscure the entry way with "ice"
  - the frosty refrigerator problem

Capacity.

- Almost infinite for H_20, N_2, O_2
- Limited for H_2 , He
- Moderate for Ar

- **Months between regenerations**

Cryopumps are capture pumps.

Gases pumped are retained only while the pump is cold.

Gases stored may be toxic, flammable, or result in high pressures when the pump is warmed up.

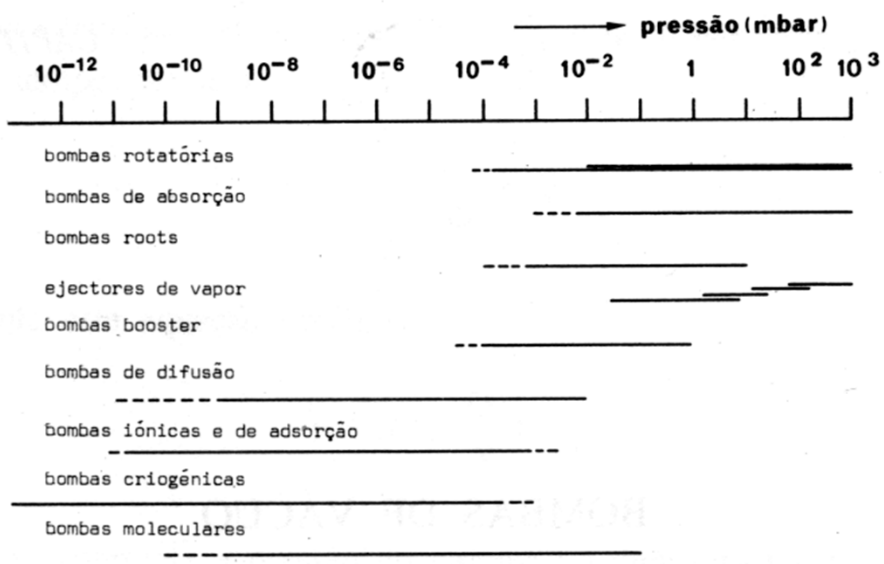


Fig. 3.1 — *Zonas de pressão correspondentes às bombas indicadas*

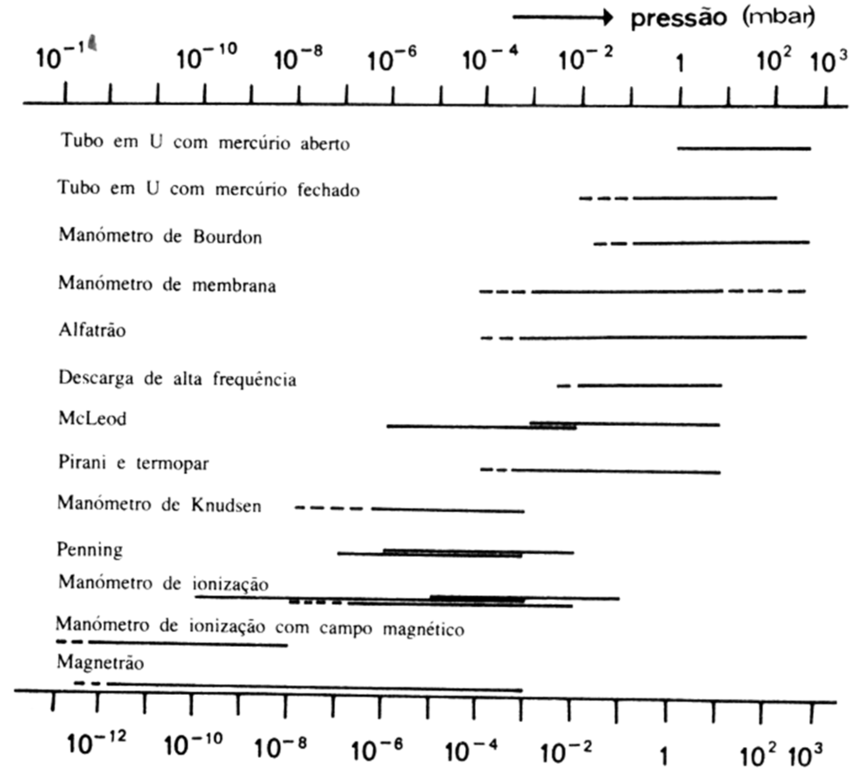


Fig. 4.15 — *Zonas de trabalho de vários vacuómetros*

•Pirani

•Ultimate pressure

•detection ~10^{-4} Torr

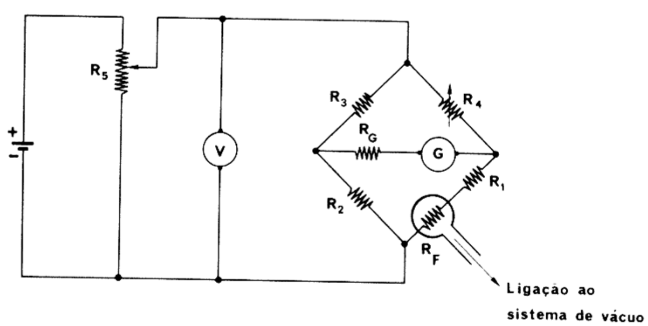


Fig. 4.7 — *Circuito de medida para um Pirani*

•*Pressure increase → lower filament temperature*

•*→ Lower resistance*

•Penning

•Ultimate pressure

• detection ~10^{-8} Torr

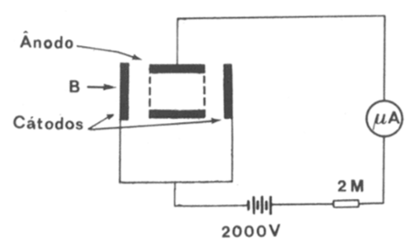


Fig. 4.13 — *Manómetro de ionização de cátodo frio — Penning*

A presença de um campo magnético faz aumentar o percurso dos electrões e portanto eleva a eficiência de ionização.

•Bayard-Alpert

•Ultimate pressure

•detection ~10^{-11} Torr