Introduction to Accelerator Physics, Zakopane, Poland, 1-13 October 2006

Vacuum in Accelerators

Oswald Gröbner

1) Introduction and some basics
2) Vacuum pumps and gauges
3) Gas desorption
4) Components and materials

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Pressure and Molecular Density

Ideal gas law: $P\ V = \frac{N}{No} R\ T$

P pressure, V volume, T temperature
N number of molecules
R gas constant = 8.31 kJ $kmol^{-1}$ K^{-1},
No = 6.02 10^{26} molecules $kmol^{-1}$

Molecular density $n = N/V$

Pressure : $P = n\ k\ T$

Boltzmann constant k = 1.38 10^{-23} J/

Note : $R = No\ k$

Note: In nearly all cases, it is the gas density rather than the pressure, which matters.

Units :

Pressure : Pa (N/m^2), mbar = 100 Pa, Torr = 133 Pa
Gas load : Pa m^3 = 7.5 Torr l, mbar l ~ 2.4 10^{19} molecules at RT
Specific outgassing rate : Gas release from the walls
Pa $m^3/s/m^2$ ~ 7.5 10^{-4} Torr l/s/cm^2
Leak rate : Pa m^3/s or W, mbar l/s or Torr l/s

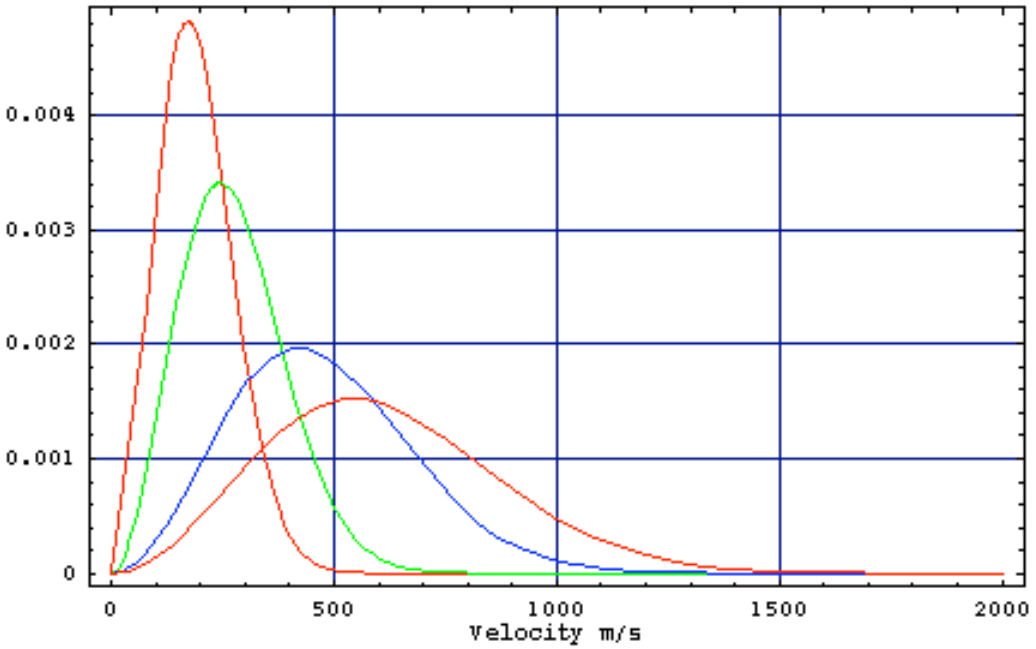
Distribution of Molecular Velocities

Maxwell-Boltzmann distribution of molecular velocities at the temperature T

$$\frac{1}{N}\frac{dN}{dv} = \frac{4}{\sqrt{\pi}}\left(\frac{m}{2kT}\right)^{\frac{3}{2}} v^2 e^{-\frac{mv^2}{2kT}}$$

The average velocity is given by (m = M m_o): $\bar{v} = \sqrt{\frac{8kT}{\pi M m_o}}$, numerically $\sim 146\sqrt{\frac{T}{M}}$ (m s^{-1})

Molecular velocities for N_2 at 50, 100, 300 and 500K.



Mean molecular velocities at 20°C (m/s)

H_2	N_2	Air	A	Kr
1754	470	464	393	272

Wall collisions

Rate of molecular impacts on the walls $\nu = \frac{1}{4} n \bar{v}$

Mean Free Path

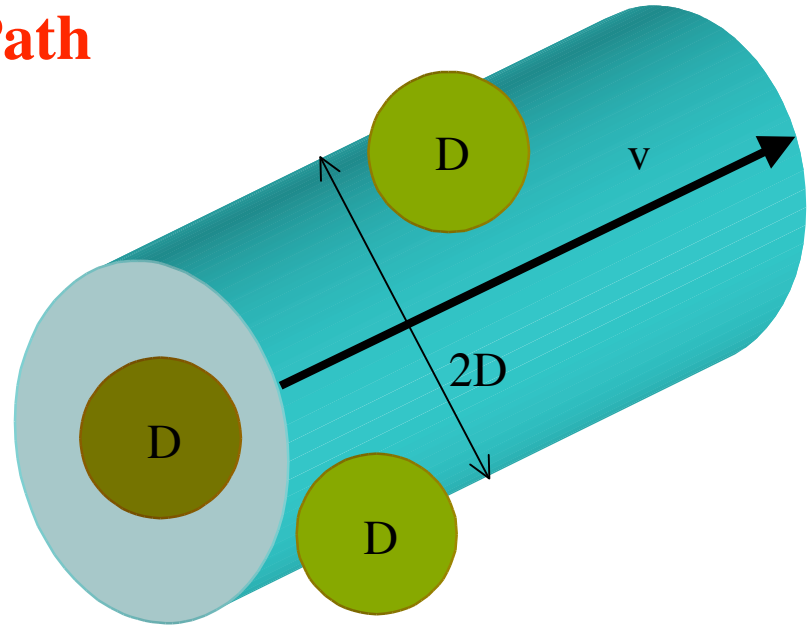
$$l = \frac{1}{\sqrt{2}\,\pi D^2 n}$$

D molecular diameter (~3 10^{-8} m)

Distance traversed per second $\bar{v}$
Molecule collides with other molecules contained within a cylinder of radius *D*.

Number of collisions: $Z \approx \pi D^2 \bar{v}\, n$

Mean free path $l = \frac{\bar{v}}{Z} = \frac{1}{\sqrt{2}\,\pi D^2 n}$



It also follows that $n\,l \propto P\,l \approx const.$

For air $n\,l \approx const$ is ~ 2.5 10^{14} m^{-2} for N_2 at 20 °C and 1 Pa -> l ~ 9 mm

Mean Kinetic Energy

The kinetic energy : $E_{kin} = \frac{1}{2} m \bar{v}^2 = \frac{1}{2} M m_o \left(\frac{8kT}{\pi M m_o} \right) = \frac{4}{\pi} kT$

M molecular weight, $m_o = 1.66\ 10^{-27}$ kg
does not depend on the molecular mass, M, but only on temperature T.
In **thermal equilibrium** heavy molecules move sufficiently slowly and light molecules move sufficiently fast to carry on average the same kinetic energy.

Total and Partial Pressures

For each gas component n_1, n_2, n_3,… the contribution to the total pressure : $P_i = n_i\ kT$

The total pressure is the sum of all partial pressures: $P = \sum_i P_i = k\,T \sum_i n_i$

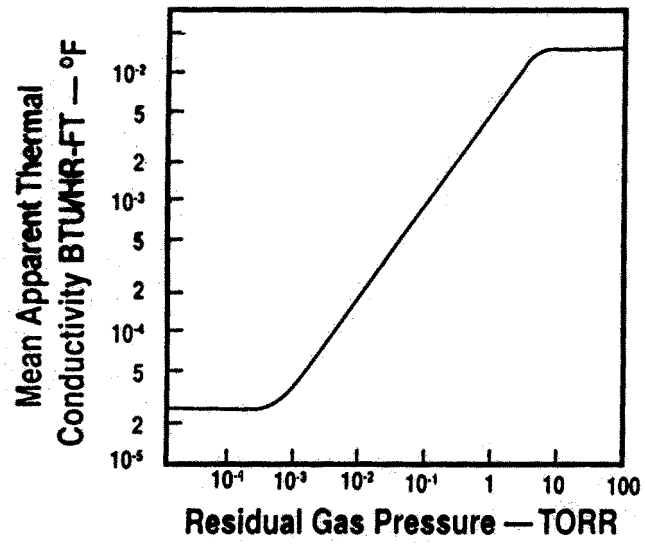
Partial pressures for atmospheric air

Gas	%	Pi (Pa)
N_2	78.1	$7.9\ 10^{4}$
O_2	20.5	$2.8\ 10^{3}$
Ar	0.93	$1.2\ 10^{2}$
CO_2	0.0033	4.4
Ne	$1.8\ 10^{-3}$	$2.4\ 10^{-1}$
He	$5.2\ 10^{-4}$	$7\ 10^{-2}$

Thermal Conductivity

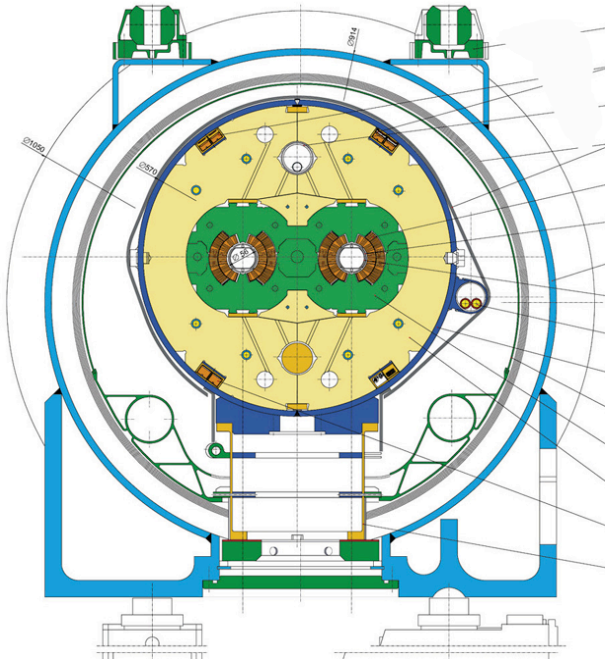
Thermal conductivity of a gas is independent of the pressure when the pressure is well above the molecular flow regime.
In the transition regime, the heat transfer is proportional to the pressure and to the temperature difference. Principle of pressure measurement with a Pirani gauge.

10^{-3} Torr < P < 10 Torr



At very low pressures, the heat transfer by conduction is negligible : vacuum for thermal insulation in cryogenics.

LHC Cryodipole



Molecular Flow at low pressure

Knudsen relation: gas flow $Q \propto \Delta P$ applies if the mean free path >> relevant dimensions of system

Molecular flow conductance $$c = \frac{\frac{4}{3}\bar{v}}{\int_0^L \frac{H}{A^2} dl} \quad (\mathrm{m}^3/\mathrm{s})$$

L length of the element (L >> transverse dimensions).
H perimeter, A cross section of the element.

The conductance is proportional to the mean molecular velocity, i.e. to $\sqrt{\frac{T}{M}}$.

A cylindrical duct with uniform section and radius r : $$c = \frac{4}{3}\bar{v}\left\langle\frac{r^3}{L}\right\rangle \sim 306 \cdot \left\langle\frac{r^3}{L}\right\rangle\sqrt{\frac{T}{M}}.$$

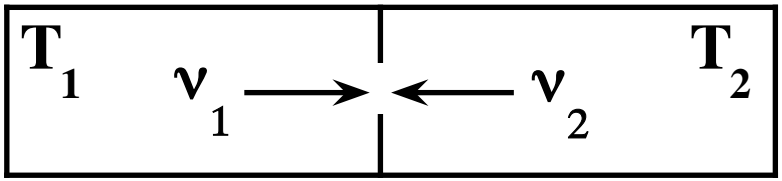
An orifice (pumping orifice, L~0) : $$c = \frac{1}{4}\bar{v}\,A \sim 36.5 \cdot A\sqrt{\frac{T}{M}}.$$

Conductance of elements in series or in parallel add the same as for electric circuits

Series : $\frac{1}{c} = \frac{1}{c_1} + \frac{1}{c_2}$ and parallel: $c = c_1 + c_2$

For complicated geometries it is often necessary to use Monte Carlo calculations for the molecular flow.

Thermal transpiration



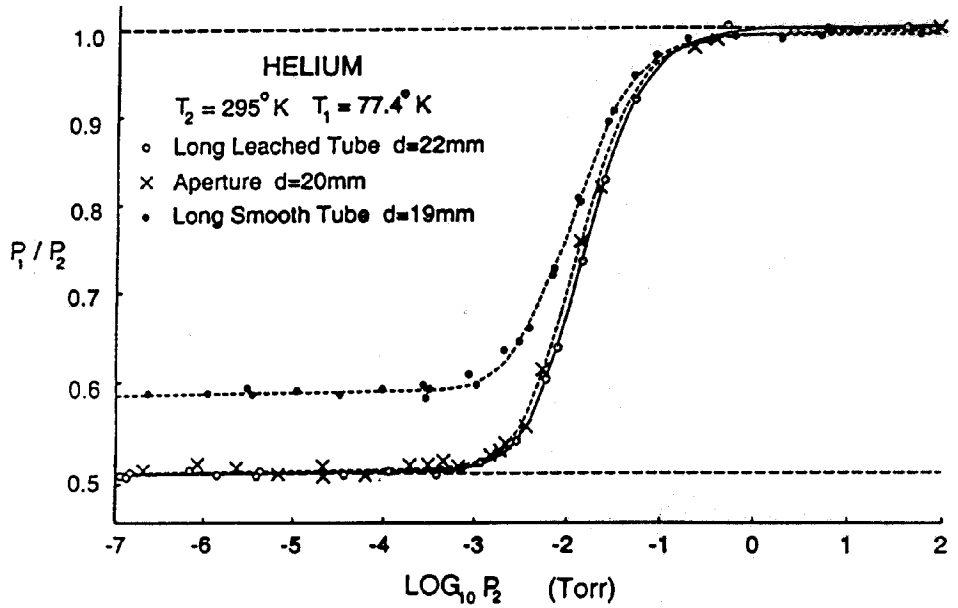
At high pressure, the pressures on both sides are equal.

In molecular flow, the net number of molecules traversing the separating wall must be zero.

$$\nu_1 = \nu_2$$

Since $\nu = \frac{1}{4}\bar{v}n$ and $\bar{v} = \sqrt{\frac{8kT}{\pi m}}$

$$n_1\sqrt{T_1} = n_2\sqrt{T_2} \quad \text{or} \quad \frac{P_1}{\sqrt{T_1}} = \frac{P_2}{\sqrt{T_2}}$$



Lumped Vacuum System

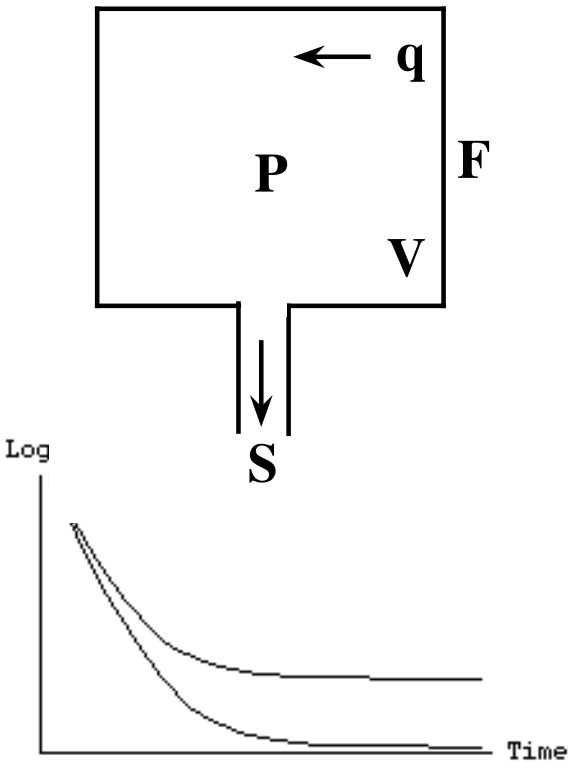
V volume (m^3), F surface (m^2)

P pressure (Pa), S pumping speed (m^3/s)

q specific outgassing rate (Pa $m^3/s/ m^2$)

Stationary conditions (P is independent of volume) $P = \frac{q\ F}{S}$

Dynamic pressure $V \frac{\partial P}{\partial t} = q F - S P$



Solution (constant K depends on initial conditions)

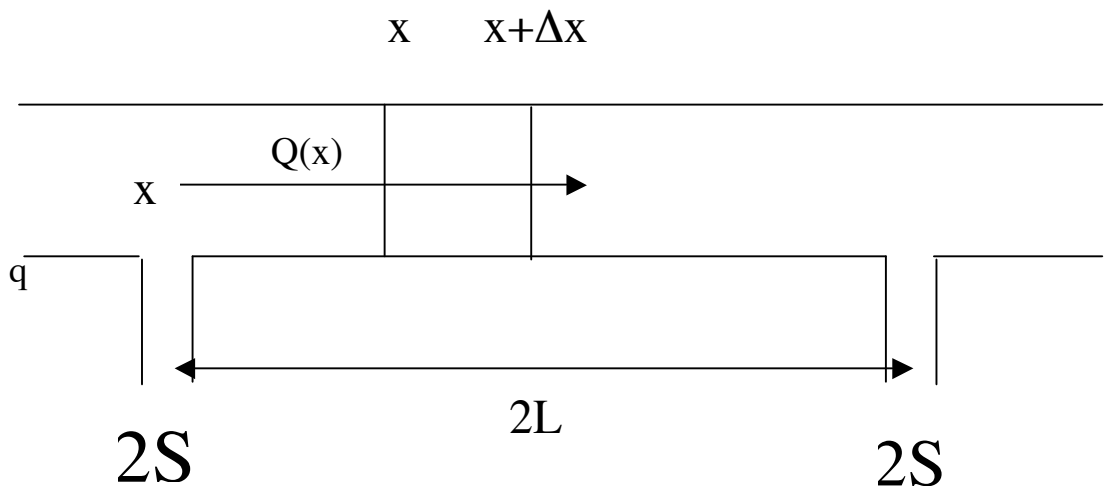
$$P(t) = K\, e^{-\frac{S}{V}t} + \frac{q\,F}{S}$$

The time constant of the pump down: $\frac{V}{S}$

To obtain a low pressure : Low outgassing rate of the surface, No leaks !

Large pumping speed

Linear Vacuum System (Accelerators)



Gas flow: Q(x) [Pa m^3 s^{-1}], specific outgassing rate: q(x) [Pa m s^{-1}]

Specific surface area per unit length: A[m], molecular conductance for unit length: c [m^4 s^{-1}]

$$\frac{dQ}{dx} = A\,q \quad \text{and} \quad Q(x) = -\,c\,\frac{dP}{dx}$$

$$c\,\frac{d^2P}{dx^2} = -\,A\,q$$

By symmetry $\left[\frac{dP}{dx}\right]_{x=\pm L} = 0$ and at x = 0 $P(x=0) = \frac{Q(x=0)}{2S}$

$Q(0) = 2\,A\,q\,L$

Parabolic pressure distribution: $P(x) = A\,q\left(\frac{2Lx - x^2}{2c} + \frac{L}{S}\right)$

Average pressure, relevant for the beam: $P_{av} = \frac{1}{2L}\int_0^{2L} P(x)dx = A\,q\left(\frac{L^2}{3c} + \frac{L}{S}\right)$

By increasing of the pumping speed *S*, the average pressure is limited by the conductance:

$$P_{av\,\min} = \frac{A\,q\,L^2}{3c}$$

Two requirements : -> Large beam pipe diameter and close pump spacing

Many accelerators use 'linear pumps' ->
- Integrated ion pumps -> HERA
- Linear NEG pumps -> LEP
- Linear cryo-pumps -> LHC

Beam Lifetime due to Vacuum

Beam loss by Bremsstrahlung : $-\frac{dE}{dx} = \frac{E}{X_o}$

Lifetime $\frac{1}{\tau} = -\frac{1}{N}\frac{dN}{dt} = \frac{c\rho}{X_o}W$

X_o radiation length, c speed of particles and $\rho = \frac{m_0 M}{kT}P$ is the density of the residual gas at the pressure P.

Here $W = \log(E/\Delta E)$

Represents the probability per radiation length to emit a photon with an energy larger than the energy acceptance of the machine so that the particle will be lost.

The lifetime $\tau = \frac{X_o}{c\rho W} \propto \frac{X_o}{P}$

For nitrogen or CO one finds typically $\tau P = 3.4 10^{-8}$ (Torr hours)

Consequence : UHV is required for storage rings.
Heavy molecules with short radiation length must be avoided.

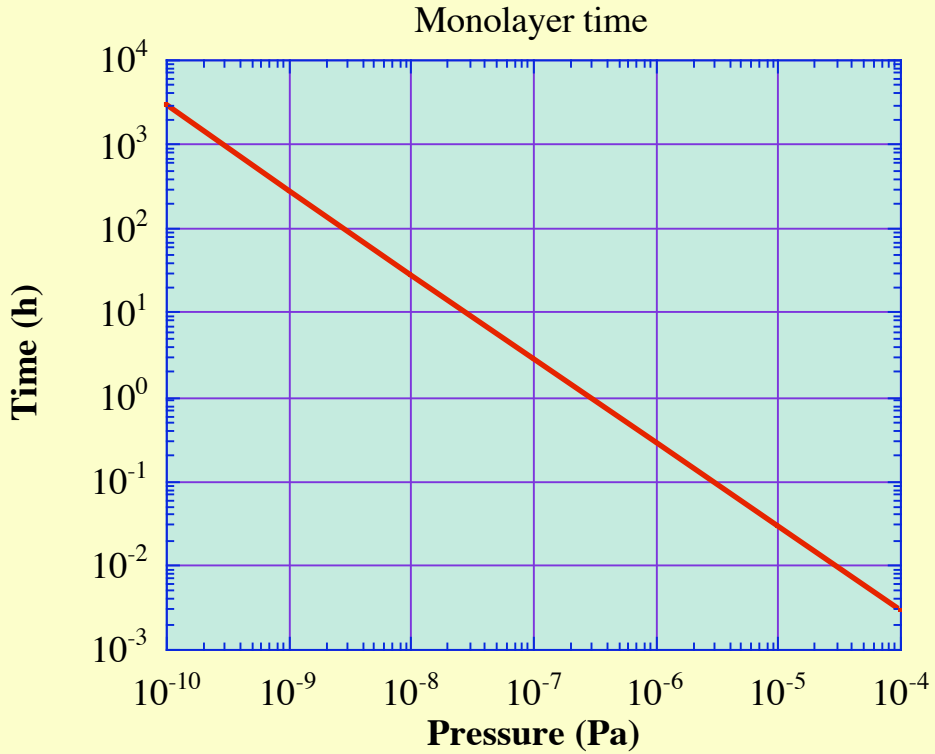
Time to form one monolayer

$$t = \frac{\Theta}{\frac{1}{4}\bar{v}\, s\, n}$$

Mono layer coverage:
Θ (~ 3 10^{19} molecules m^{-2})
Molecular velocity $\bar{v}$ (m s^{-1})
Gas density n (molecules m^{-3})
Sticking probability s < 1

UHV becomes indispensable for surface analysis and for thin film technology
-> Historically the main motivation to develop uhv techniques

Note: Area occupied per molecule
$A \sim 2\sqrt{3}r^2$



Rotary Pumps

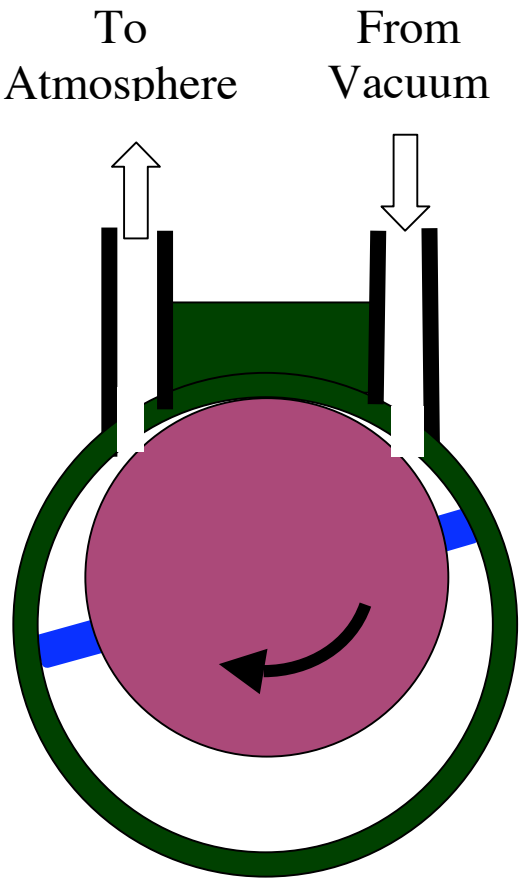
Single stage and double stage pumps

Oil sealed moving pistons

Typical end pressure : 10^{-2} to ~10^{-3} mbar

Typical pumping speed : 4 to ~ 40 m^3/h
Adequate for systems with small volume

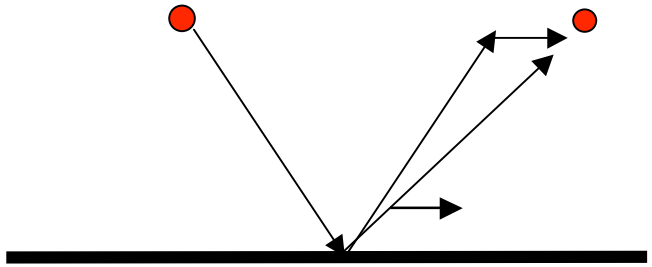
Filter for oil vapour is required.



Dry pumps, without oil, are available but rather expensive!

Turbomolecular Pump

Molecules collide with the surface and gain a velocity component in the direction of the movement.



Rotor v

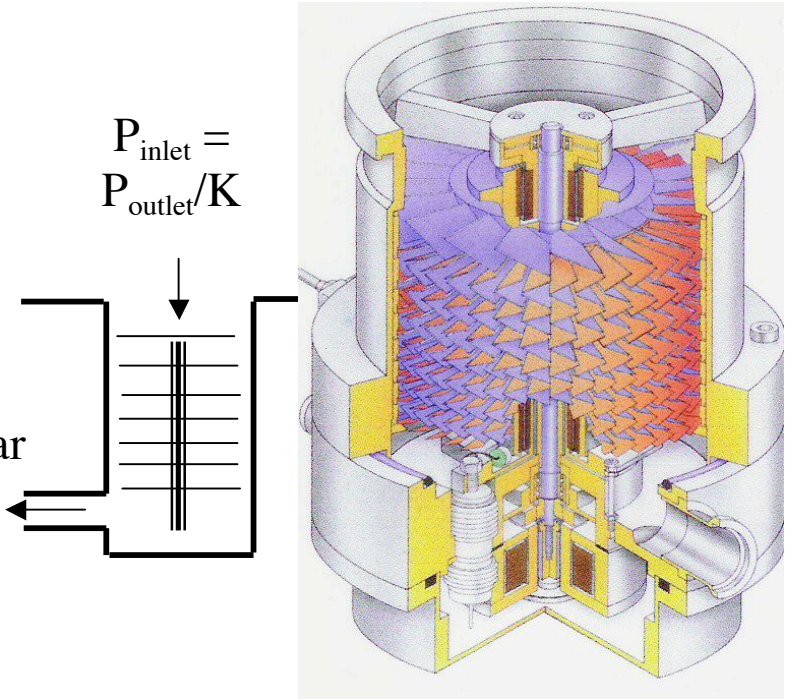
Pumping speed of a turbomolecular pump $S \propto v\ A$

S independent of pressure.
v rotational speed, typically > 40000 rpm
A: area of entrance flange

Compression ratio of the pump $K = \frac{P_{outlet}}{P_{inlet}}$

$P_{inlet} = P_{outlet}/K$

$P_{outlet} = 10^{-3}$ mbar



K is an exponential function of the molecular weight and of the rotational speed. ($K \sim 10^3$ for H_2 to 10^9 for N_2)
Compression ratio large for heavy molecules

'clean vacuum'

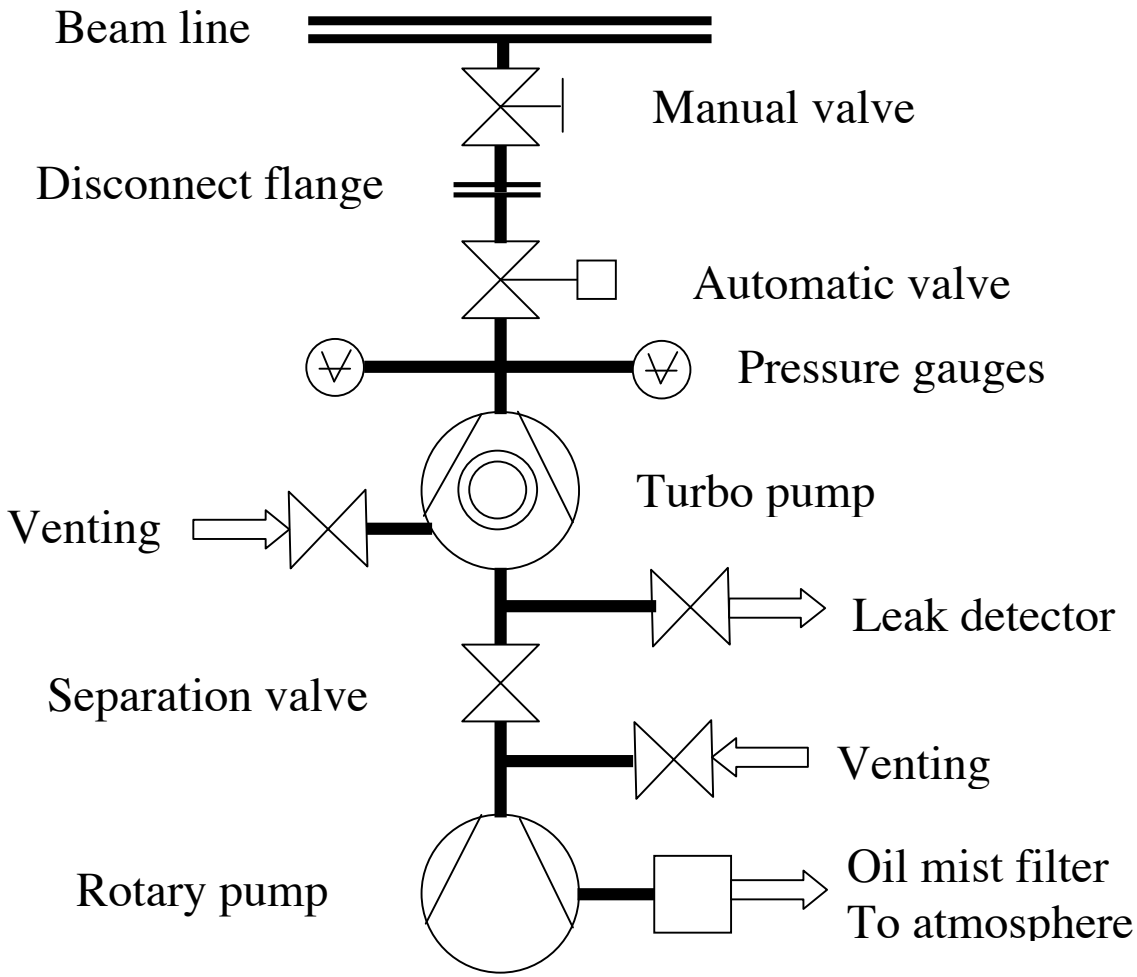
since heavy hydrocarbon molecules are well pumped.
Oil contamination from a primary pump is eliminated.

Mobile pumping unit for LEP vacuum system

External pumps required for initial pump down only.

During operation of the accelerator, the manual separation valve is closed.

The mobile pumps can be removed from the tunnel for maintenance and to avoid radiation damage.



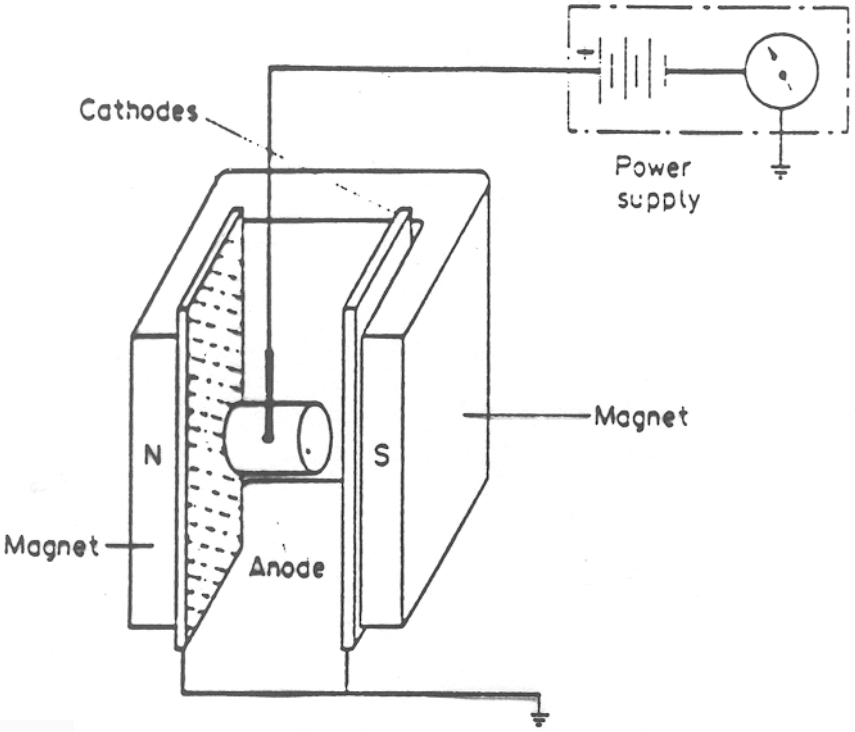
Sputter-Ion-Pump

Configuration of a parallel electric and magnetic field produces self-maintained discharge plasma.
-> Penning configuration

Ionised residual gas molecules are accelerated towards the Ti cathode and 'trapped' and removed from the gas phase.

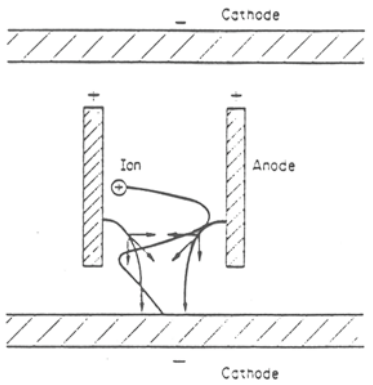
Sputtering of Ti from cathode produces a clean gettering film.

In a particle accelerator, the magnetic field is provided by bending magnets. --> integrated, linear ion-pumps.



Basic configuration of a sputter-ion pump.

To increase the pumping speed, arrays of cells are used



Pumping action

Gettering -> chemisorption of active species H_2, CO, N_2, O_2, CO_2

Diffusion of H_2 into the Ti- cathode (re-diffusion!)

Cracking of inert hydrocarbons into C, H, O which can be pumped (chemisorbed) separately

Nobel gases: energetic ions of He, Ne, A by implantation into the cathode: “ion burial” of energetic ions. -> Argon instability after pumping of air.

To increase the discharge intensity and thus the pumping speed it is desirable to increase the sputtering rate of the titanium cathode

➔ Triode Sputter-Ion pump with grazing incidence of ions on a grid cathode

Note:

Molecules are not removed from the vacuum system.
Important memory effect of previously pumped gas (Argon).

Surface Pumping

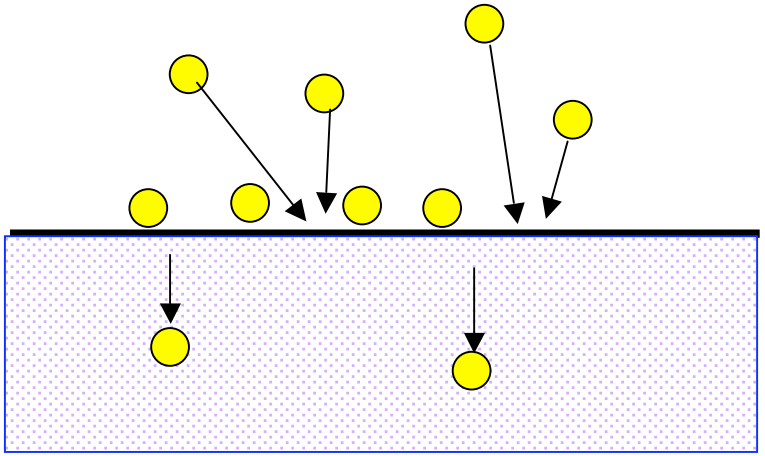
Getters (chemisorption E~eV)

Evaporable getter pumps (Ti sublimators)

Non Evaporable Getters (NEG)

Ti, Zr, V

Surface pumping -> $S \propto \frac{1}{4}\bar{v}\, nF$



Gettering surface achieved by sublimation from a Ti-filament.

Or by surface activation (heating -> reduction of surface oxide layer and diffusion of O into the bulk)

Cryo-pumps (physisorption E~ meV)

Sorption (capacity ~ monolayer)

Condensation (vapour pressure)

Monolayer Capacity

To illustrate the significance of a monolayer of gas, let us assume an evacuated sphere which has one monolayer molecules adsorbed on the inner surface.

$$N_{ads} = 4\pi r^2 \Theta$$

In case this gas is desorbed it would correspond to a volume density

$$n = \frac{N_{ads}}{V} = \frac{3\Theta}{r}$$

Taking, e.g. 1 m^3 as the volume and $\Theta \approx 3 \cdot 10^{19} m^{-2}$ the pressure at room temperature would increase to

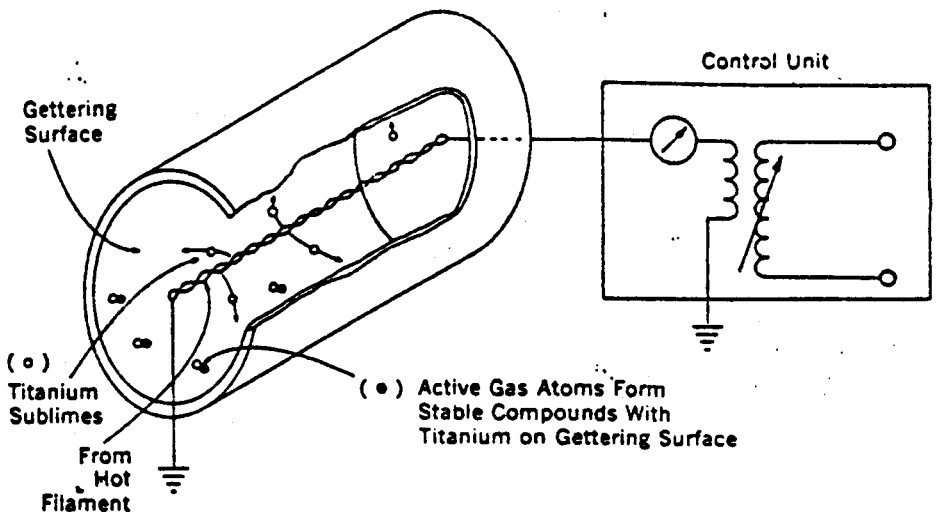
$$p = n\,kT \approx 0.4\ Pa$$

Hence:
To reach uhv conditions, the 'surface gas' is extremely important.

Inversely, adsorbing molecules permanently on an 'active' surface (getters or cryo-pumps) is an extremely efficient pumping principle.

Evaporable getters: Titanium sublimation pump

Deposition of a thin film of fresh Ti on the inner surface of the vacuum chamber
Filament temperature ~ 1300 C
To increase the lifetime of the pump one uses pump holders with several filaments (3 – 6)



Depending on the amount of gas pumped, the film has to be regenerated
- typically after 10^{-6} Pa h
The pumping speed increases with the surface of the pump and can be very substantial.

Note : only chemically active molecules can be pumped.

Non-Evaporable Getters or Bulk getters (NEG) :

Getter material (e.g. Ti, Zr, V) produced in the form of an alloy e.g. with Al and used as a bulk material.
For LEP : metal ribbon coated with a thin layer of getter powder has been used.

Clean, active gettering surface is produced by heating under vacuum. Gas adsorbed on the surface diffuses into the bulk and a 'clean' surface can be obtained.
Activation requires heating from 350 °C up to 700°C for one hour depending on the specific getter.

Combination of evaporable getters and of bulk getters has been developed at CERN ->
sputter deposited getter films
few μm film coated directly onto the inner surface of vacuum chambers.
Activation by baking the system to ~200 °C

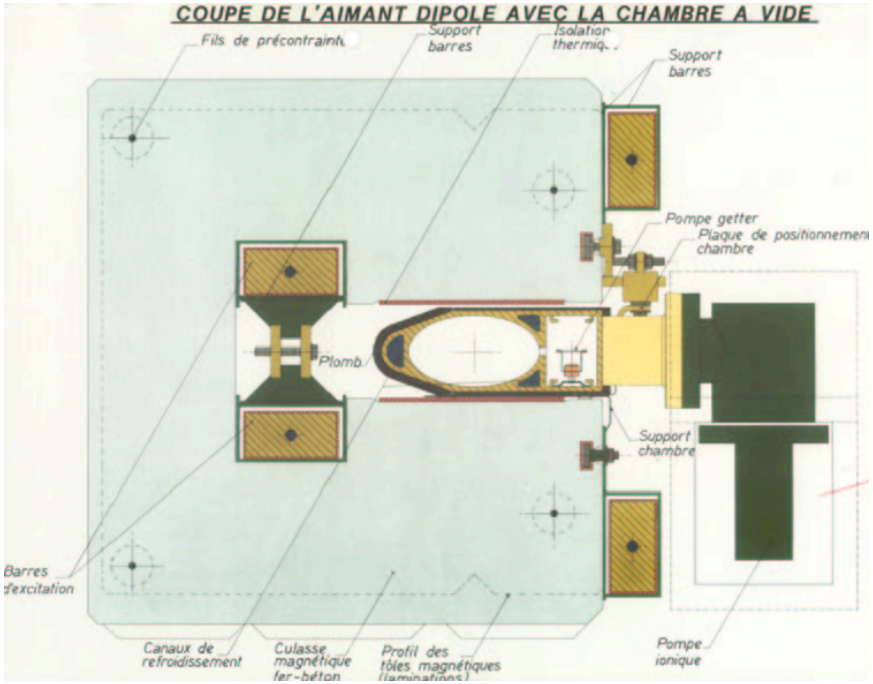
First use in insertion chambers (ESRF) and for room temperature LHC vacuum.

Note: Getters have a limited total pumping capacity and a memory effect of gas previously pumped.
Getters pump only chemically active gas i.e. nobel gases and hydrocarbons (methane, …) are NOT pumped. Combination with ion pumps is required

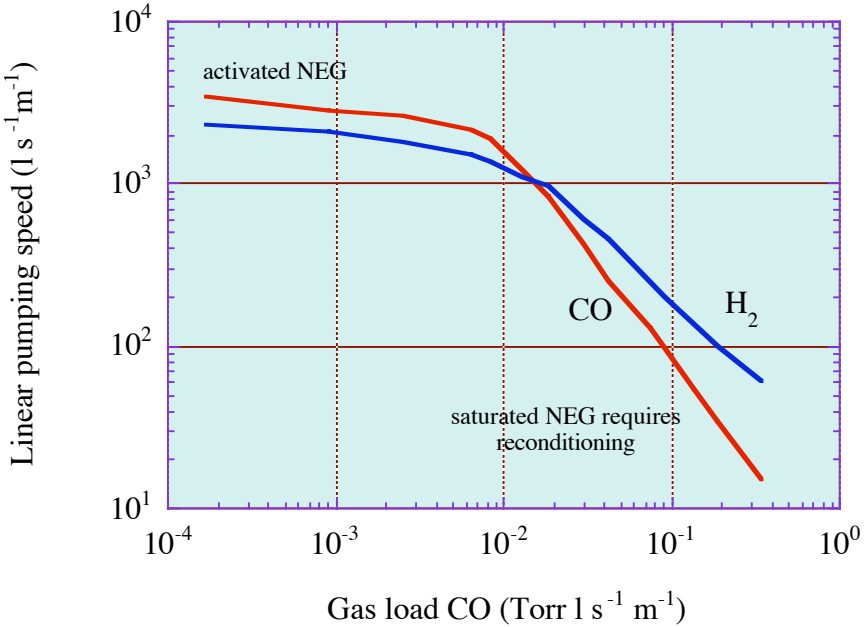
NEG Pumps in LEP

Non-evaporable getters used as main pumping system in LEP : Al+Zr alloy coating on a metal ribbon. Initial pumping speed decreases with the quantity of gas pumped. Periodic reactivation required -> Few times per year only.

Section of the LEP vacuum system in dipole magnet



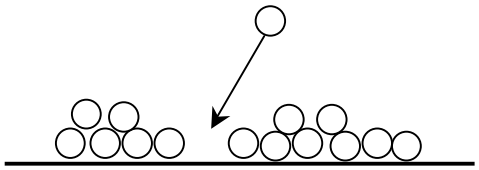
Linear pumping speed vrs. gas load



Cryopumps

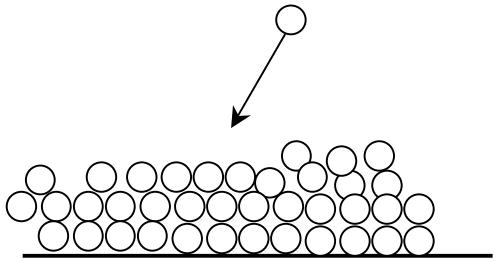
Adsorption of molecules at low temperature -> e.g. at liquid helium temperature

Sorption



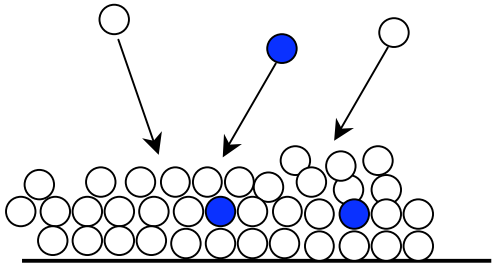
Adsorption of gas molecules with low surface coverage, to avoid the effect of the vapour pressure of the condensate. Increasing the effective surface area by a coating with a large specific surface area e.g. charcoal. -> Adsorption isotherms.

Condensation



adsorption in multi-layers -> limitation due to the vapour pressure of the condensed gas.

Cryo-trapping



Cryo-sorption of a gas e.g. H_2 or He with a high vapour pressure in the presence of an easily condensable carrier gas e.g. Ar.

Characteristics of cryo-pumping :

Large pumping speed proportional to the surface, F as long as the saturated vapour pressure of the adsorbed gas layer is low compared to the system pressure.

$$S = S_O\left(1 - \frac{p}{p_S}\right)$$

Pumping speed S_o can be close to the theoretical limit, s~1.
Limit pressure : -> vapour pressure of the adsorbed gas.

At 20 K all gases with the exception of He, H_2 and Ne can be condensed in large quantities at uhv pressures.
At 4.5 K pumping of large quantities of H_2 requires cryosorbing materials with large specific surface area, to stay well away from the saturated vapour pressure.
Pumping of He is difficult
-> avoid helium leaks!

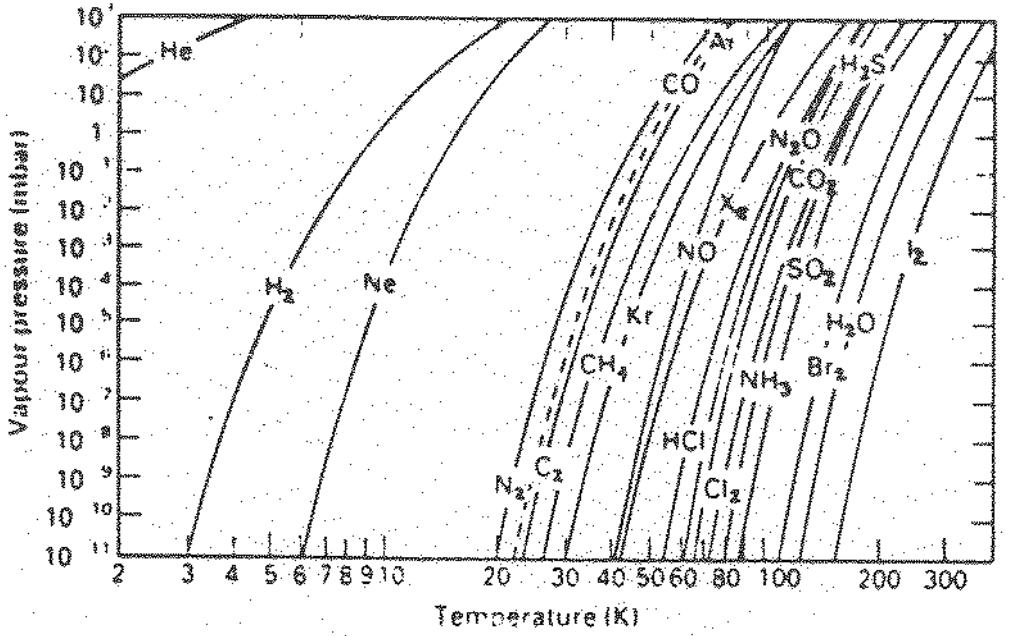
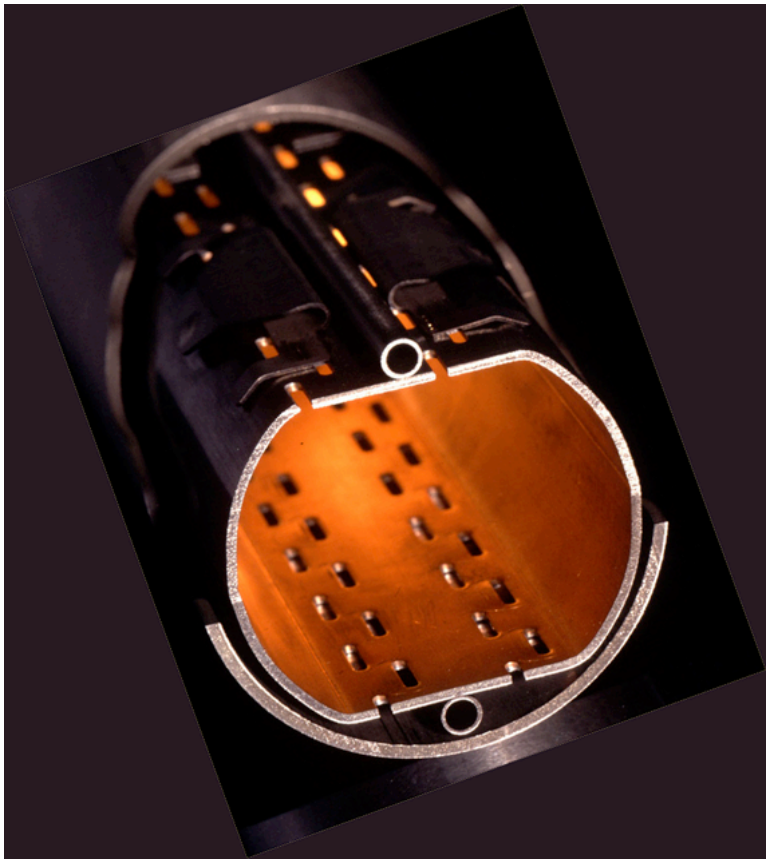


Figure 2. Vapour pressures of some common gases (from Bentley[9]).

Cryopumps in accelerators

In combination with superconducting magnets or accelerating cavities, at little (or no) extra cost very effective linear integrated cryo-pumps can be obtained in an otherwise conductance limited vacuum systems.

Large freedom in the design of cryopumps : since the cold walls of the vacuum system act as pumps (LHC).



The limitations of cryopumps due to the exposure to environmental room temperature radiation and to the bombardment by beam induced energetic particles (photons, electrons, ions) must be taken into account.
Imposes -> LN_2 cooled baffles and the LHC beam screen. This requirement arises not only for heat load reasons but mainly to avoid re-desorption of molecules.

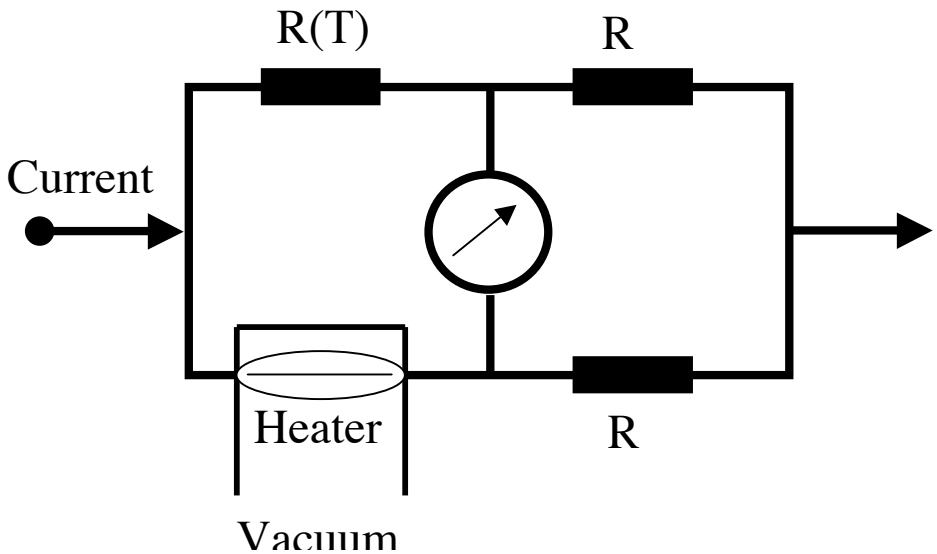
Pirani gauge, thermal conductivity gauge

Uses the variation of the thermal conductivity with pressure

Reliable and simple system.

Pressure range:

atmospheric pressure to < 0.1 Pa



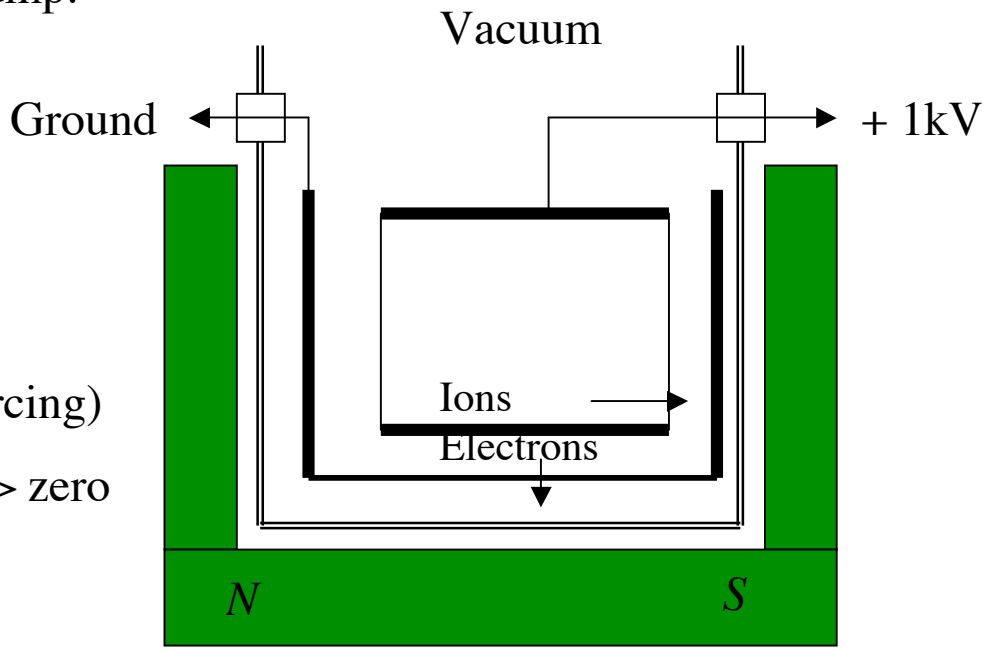
A resistor with a large temperature coefficient is mounted inside the vacuum and is heated to a constant temperature. The required heating current to maintain the bridge balanced is a measure of the pressure.

The electronic circuitry provides temperature compensation (R(T) and linearization of the pressure reading.

Cold Cathode Ionisation Gauge, Penning Gauge

Based on the operating principle of an ion pump:

Discharge current is ~proportional to pressure.



Useful pressure range: 10^{-2} to 10^{-7} Pa

At high pressure the discharge is unstable (arcing)

At low pressure the discharge extinguishes -> zero pressure reading

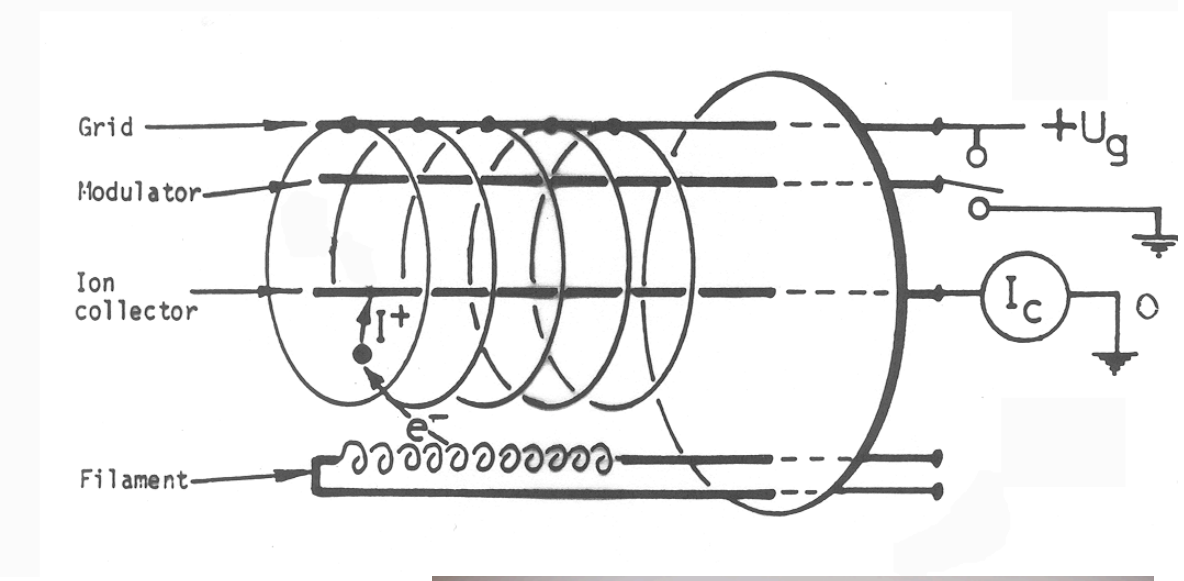
Leakage current in the cables and in the gauge can simulate a higher pressure.

Contamination of the gauge may change the calibration.

Extended operation at high pressure will ‘contaminate’ the gauge -> required demounting and cleaning of the gauge. Improved version for low pressures on the market: Inverted magnetron gauge.

Hot Filament ionization Gauge

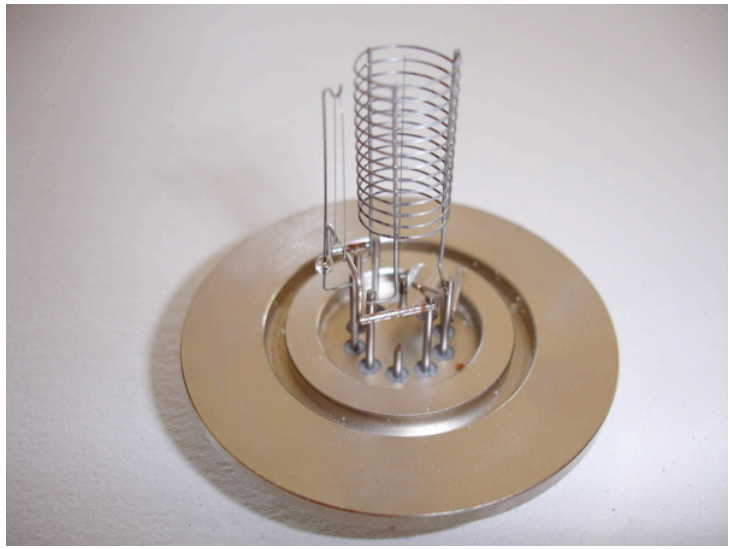
Operating principle :
Residual gas molecules are ionized by the electrons emitted from a hot filament.
Ions are collected by a "collector electrode".
This ion current is proportional to the gas density, n, and hence to the pressure, P.



The ionization probability Pi (number of ion–electron pairs produced $m^{-1}\,Pa^{-1}$) depends on the type of molecule and on the kinetic energy of the electrons.

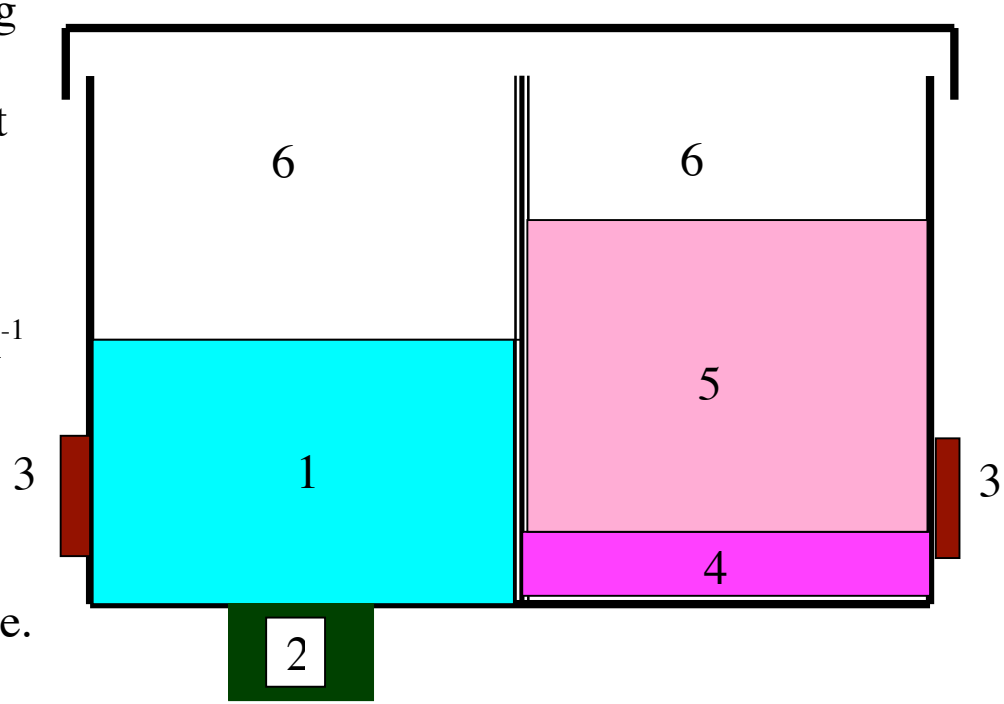
Ion collector current : $I^+ = Ie\ Pi\ L\ P$

Ie emission current of the filament
L path length of the electrons
P pressure



Chemical solvent pre-cleaning procedure

Removal of gross contamination and machining oils using the appropriate solvents
Perchloroethylene (C_2Cl_4) vapour degreasing at 121°C (no longer applicable)
Ultrasonic cleaning in alkaline detergent (pH =11)
Rinsing in cold demineralised water < 5 μS cm^{-1}
Drying in a hot air oven at 150°C
Wrapping in clean Al-foil or paper



Large number of methods exist:
Cleaning method will depend on the material i.e. stainless steel, aluminium, copper

All subsequent handling with **clean gloves**.
Contamination by any residues in the air must be avoided.
No car exhaust gases, No smoking!!

Legend: 1) hot detergent, 2) ultrasonic generator, 3) heaters, 4) hot solvent bath, 5) solvent vapour zone, 6) cooling zone.

Leaks and leak detection

Common leaks to atmospheric pressure:

Gaskets
Porosities in the materials
Cracks and porosities in welds

Virtual leaks: are not found by a conventional leak check

Porosities, a dead volume enclosed inside the system

Example of a virtual leak: The volume enclosed by a bolt in a threaded hole.

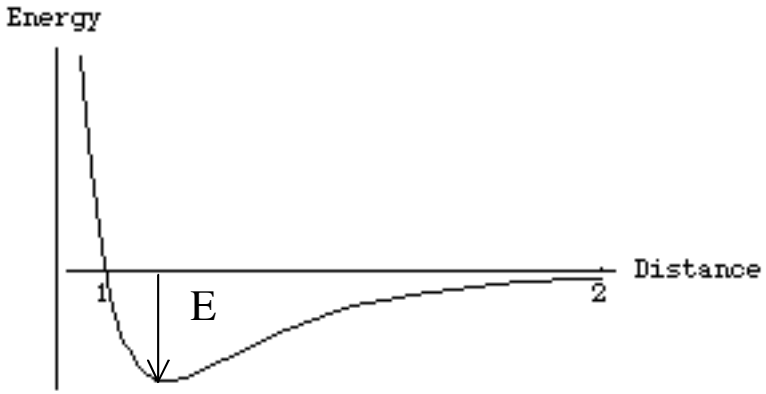
Solution: bolts have to be drilled with a central hole or a separate hole must be drilled to pump the dead volume.

In a large vacuum system, leak checks of all sub-components are mandatory.
A global leak check after complete assembly should only concern those joints, which have been made during the final installation phase in the accelerator.

Thermal desorption

Specific desorption rate : q [Pa m^3 s^{-1} m^{-2}]

$$q = Const \cdot e^{-\frac{E}{kT}}$$



Molecular residence time : $\tau = \frac{1}{\nu_o} \cdot e^{\frac{E}{kT}}$

E Binding energy, activation energy for desorption

$\nu_o \sim 10^{13}$ s^{-1} vibration frequency in the surface potential

Physisorbed molecules E < 30 kJ/mole (0.3 eV)

Chemisorbed molecules E > 80 kJ/mole (0.8 eV)

Residence time for physisorbed molecules at R.T. ~ 10^{-7} s

at 80 K ~ 50 y

Bakeout between 150 – 300°C : reduced residence time.

Reduction for H_2O, CO, CO_2 (by factors of 10^{-2} to 10^{-4})

Above 400-500°C-> cracking of hydrocarbon molecules.

Important : Thermal desorption strongly reduced at cryogenic temperatures.

Thermal outgassing rates of some materials

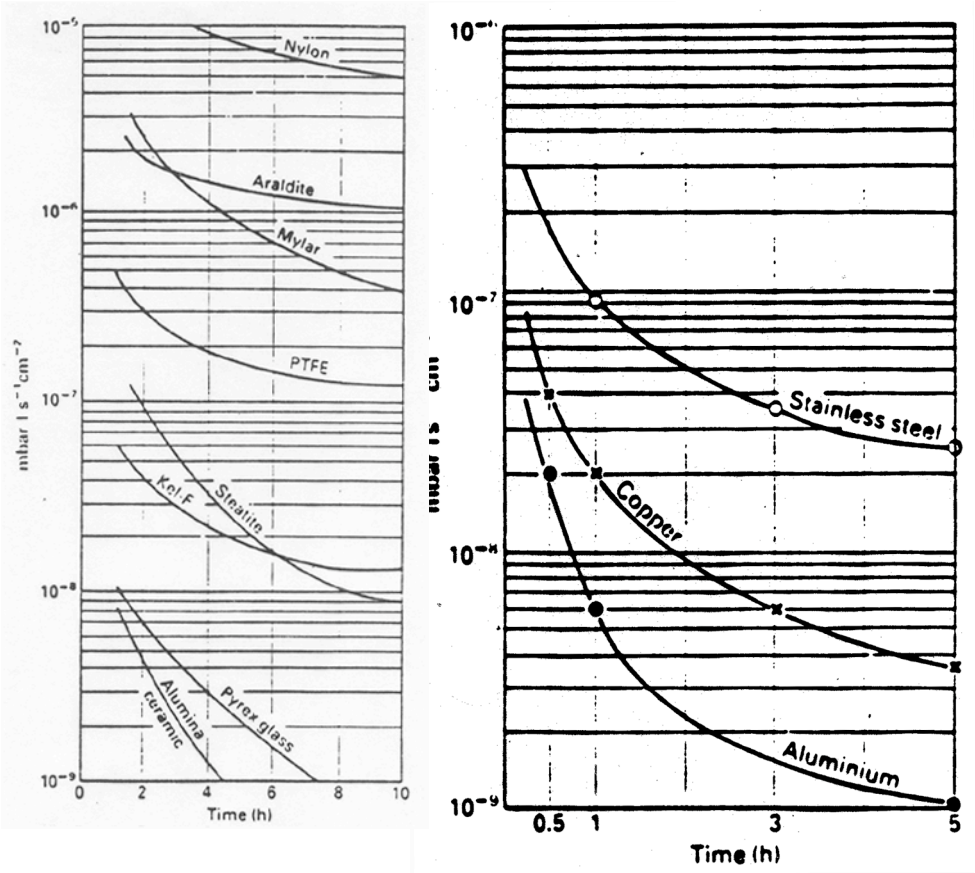
Comparison of organic materials and of metals

Unbaked samples (usually H_2O dominates)

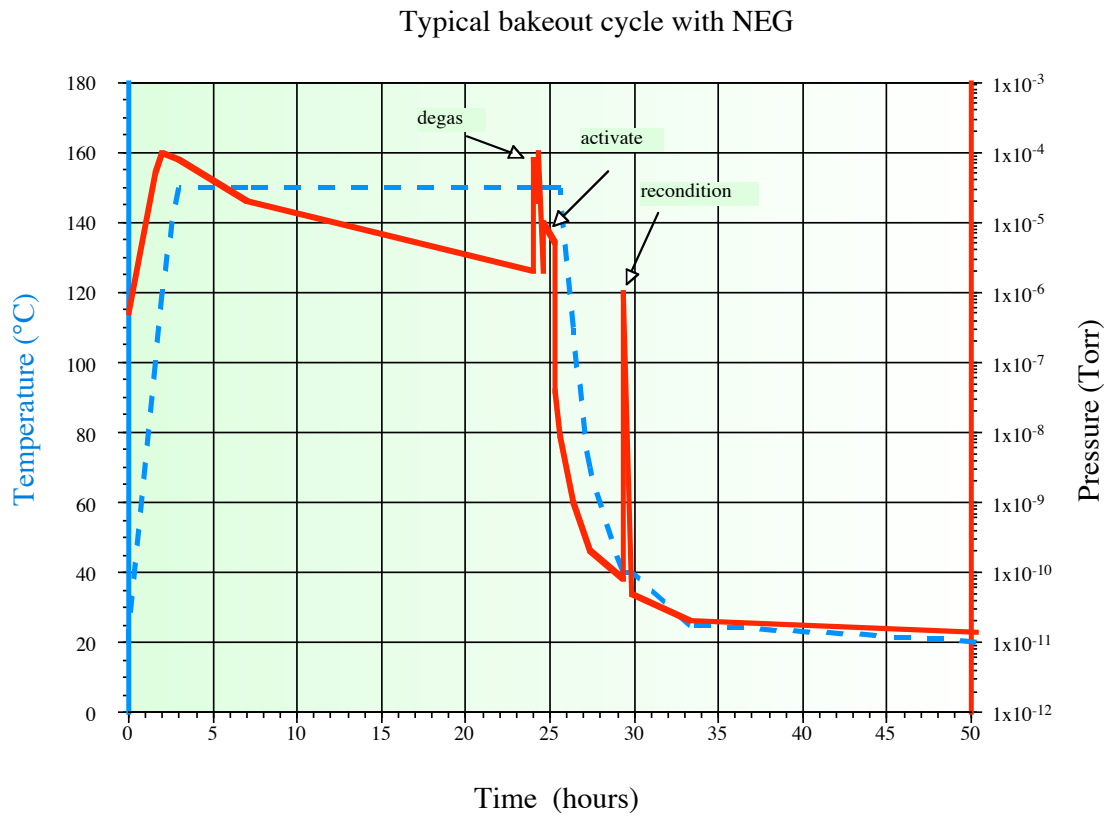
Baked samples
(24 hours at 150°C to 300 °C)

Typical values after 50 hours of pumping :
(units : Torr l s^{-1} cm^{-2})

Gas	Al, Stainless steel
H_2	5 10^{-13}
CH_4	5 10^{-15}
CO	1 10^{-14}
CO_2	1 10^{-14}



Preparation of LEP vacuum system with NEG pumps



Within less than 12 hours after the bakeout uhv conditions can be achieved.

Synchrotron Radiation Induced Desorption

Radiated power (W) : $P_\gamma = 88.6 \frac{E^4 I}{\rho}$

E, energy of electrons (GeV)

I, beam current (mA),

Linear photon flux (m^{-1} s^{-1}) $\frac{d\Gamma}{ds} = 1.28 \cdot 10^{17} \frac{I E}{\rho}$

ρ, bending radius (m),

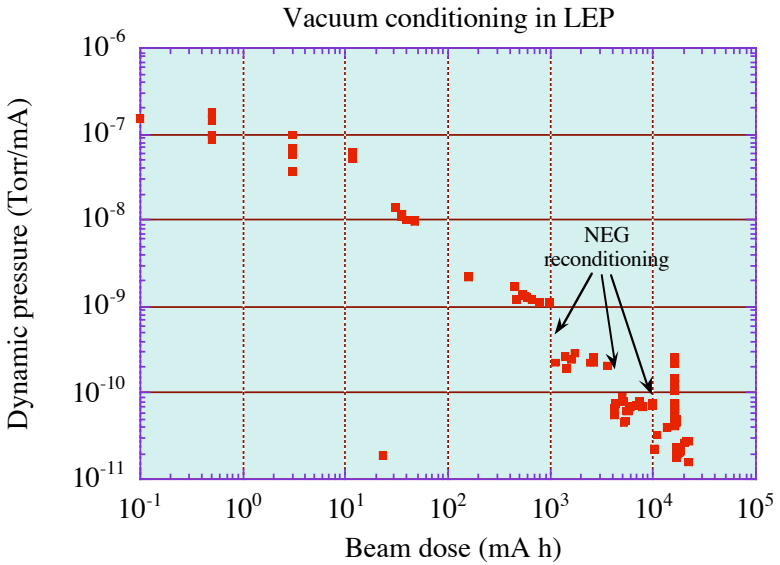
Gas desorption occurs in two steps : 1 -> photons -> produce photo-electrons
2-> photo-electrons -> excite molecules which subsequently will desorb thermally

Gas flow : $Q = \eta \Gamma$ -> η molecular desorption yield (molecules per photon).

Dynamic pressure : $P_{dyn} = \frac{Q}{S}$.

The dynamic pressure increases proportionally with the beam intensity : $\frac{\Delta P}{I}$ (Pa/mA).

'Beam cleaning' (scrubbing) of the vacuum system is a vital procedure.



Ion Induced Pressure Instability

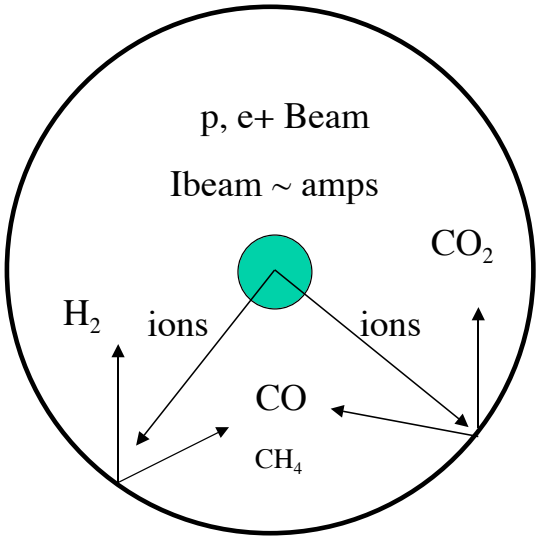
Ions produced from residual gas molecules and repelled
By positive spacecharge of the beam.

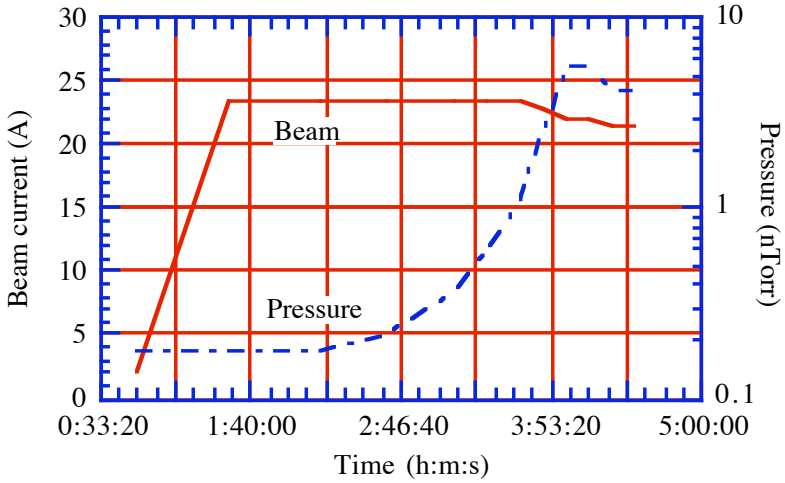
Critical current $(\eta I)_{crit}$ defines the stable pressure range.
Dynamic pressure

$$P(I) = \frac{P_o}{1 - \frac{\eta I}{e/\sigma S_{eff}}}$$

Molecular desorption yield η (molecules/ion)
unit charge e, ionisation cross section σ.
S_{eff} is the effective pumping speed of the system.

For the LHC with a beam screen the minimum pumping is provided by the pumping holes.





Pressure rise in the ISR

Criteria influencing the choice of materials

Low outgassing rate
Low vapour pressure
Temperature resistant -> bakeout
Thermal and electrical conductivity -> beam interaction
Corrosion resistance -> leaks
Low induced radioactivity -> handling
High mechanical strength -> 1dN/cm^2 external pressure!
Machining, welding, mounting/demounting requirement
Low cost

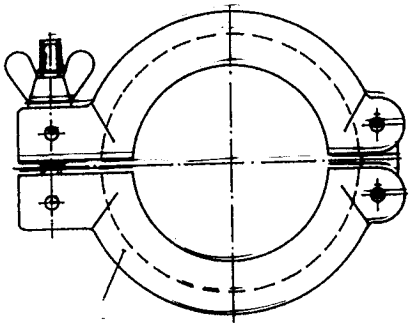
Common choices:

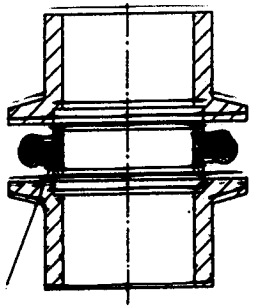
Stainless steel
Aluminium
Copper
Ceramics for electric insulation
- Low porosity -> leaks
- Brazing to metal -> leaks

For particular applications
Organic materials (e.g. as composite materials (carbon-fiber & epoxy), polymers to be used in small quantities

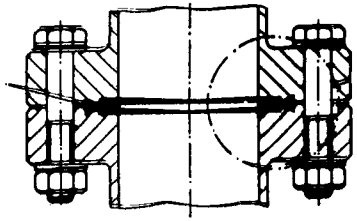
Flanges and gaskets for primary vacuum and high vacuum

Flange with clamp and elastomer seal for high vacuum systems

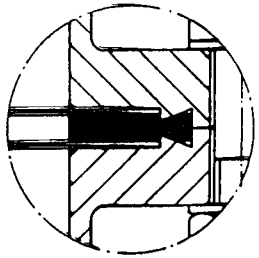


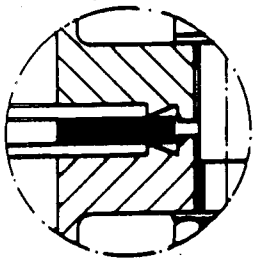


‘ConFlat’ flange for uhv systems



Copper gasket for ‘all metal’ vacuum system





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In preparation: Proceedings of CAS School May 2006 **Vacuum in Accelerator**s