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SCHOOL ON SYNCHROTRON RADIATION

6 November - 8 December 2000

Miramare - Trieste, Italy

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UHV Technology

O. Gröbner
CERN, European Organization for Nuclear Research
Geneva, Switzerland

UHV - Technology

O. Gröbner
CERN, LHC-VAC

1) **Some basic facts**

2) **Building blocks of a vacuum system**

3) **How to get clean ultra high vacuum**

4) **Desorption phenomena**

5) **Practical examples from machines**

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Literature

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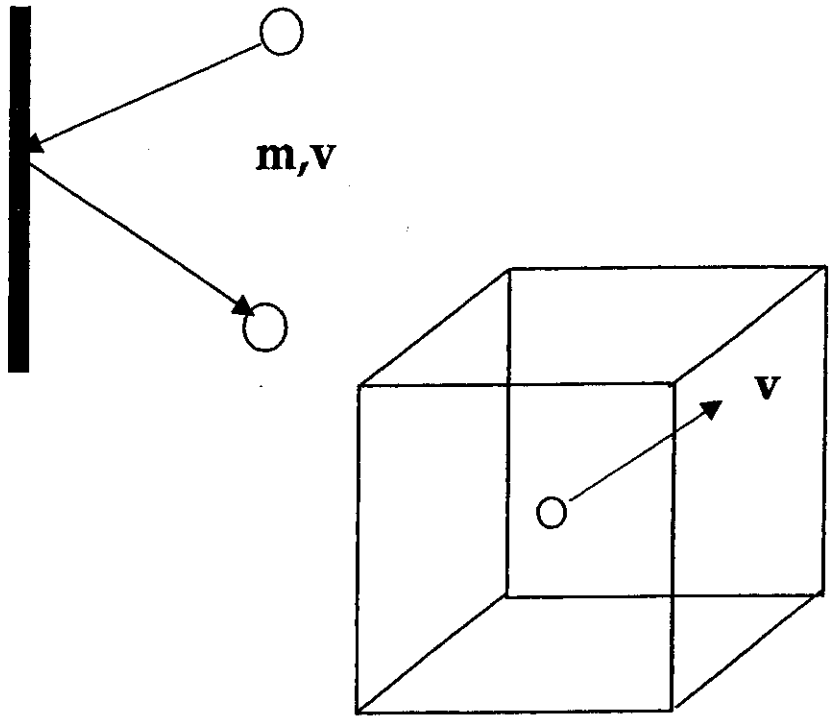
Pressure



Momentum transfer to the walls: $2m\bar{v}$

m is the mass of a molecule: $M\ m_o$

Frequency of wall collisions expressed by ν

Pressure due to molecular collisions: $p = const\, m\bar{v}\,\nu$

Where the constant factor is obtained as $\frac{\pi}{2}$.

With the frequency of wall collisions $\nu = \frac{1}{4}\bar{v}\,n$

the pressure can be expressed as $p = \frac{\pi}{8} m\bar{v}^2 n$

The pressure is proportional to the mean kinetic energy of the molecules. Pressure and gas density are related:

$$p = n\ k\ T$$

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Molecular Concentration and Density

Number density:

$n = \frac{N}{V}$ with N number of molecules

V volume

Pressure:

$$p = n\ k\ T$$

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

the pressure is due to the momentum transfer of molecules striking the wall.

Units :

Pressure : Pa (N/m^2)

mbar = 100 Pa

Torr = 133 Pa

Gas load : Pa m^3 = 7.5 Torr l

Torr l ~ $3.2\ 10^{19}$ molecules at RT

At STP the molar volume 22.4 l

contains $6.02\ 10^{23}$ molecules

Leak rate : Pa m^3/s or W

Torr l/s

Specific outgassing rate :

Pa $m^3/s/m^2$ ~ $7.5\ 10^{-4}$ Torr l/s/cm^2

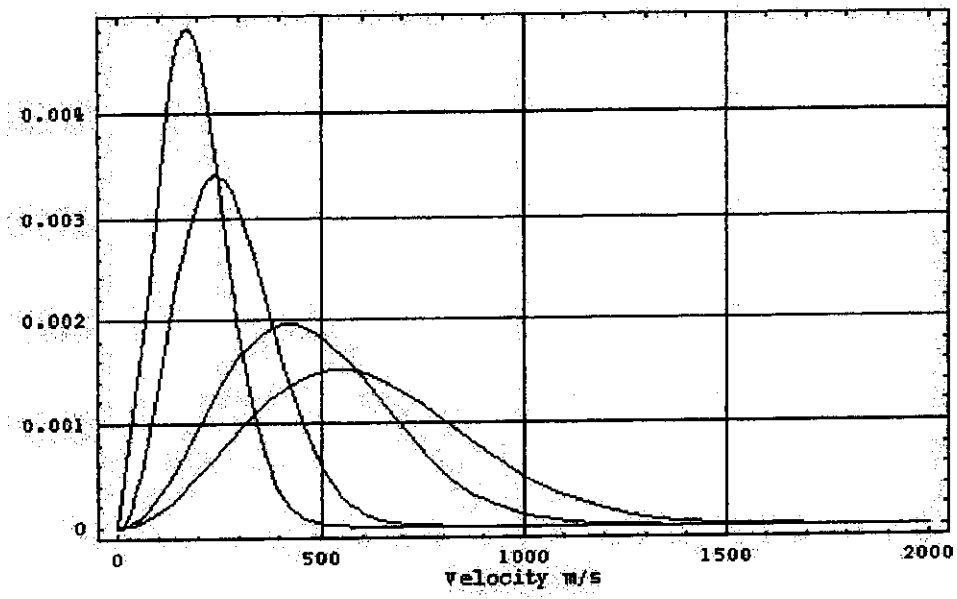
Distribution of Molecular Velocities

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 ($m = M\, m_0$)

$$\bar{v} = \sqrt{\frac{8kT}{\pi M m_0}} \text{ , numerically } \sim 146\sqrt{\frac{T}{M}} \quad (\text{m s}^{-1})$$



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

Mean Velocity at 20 °C

Molecule	M	v (m/s)
Hydrogen	2.016	1754
Nitrogen	28.01	470
(Air)	28.98	464
Argon	39.95	393
Krypton	83.8	272

Mean Kinetic Energy

The kinetic energy :

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

M molecular weight
$m_o = 1.66\ 10^{-27}$ kg

does not depend on the molecular mass but only on the temperature. 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,...
its individual contribution to the pressure :

$$p_i = n_i\ kT$$

The total pressure is therefore the sum of the partial pressures:

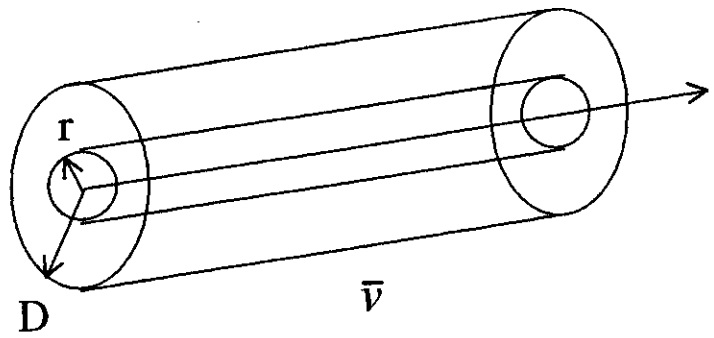
$$p = \sum_i p_i = kT \sum_i n_i$$

Partial Pressures for Air

	%	Pi (Pa)
N_2	78.1	$7.9\ 10^{4}$
O_2	20.95	$2.79\ 10^{4}$
Ar	0.93	$1.24\ 10^{2}$
CO_2	0.033	4.39
Ne	$1.8\ 10^{-3}$	$2.39\ 10^{-1}$
He	$5.2\ 10^{-4}$	$6.92\ 10^{-2}$
Kr	$1.0\ 10^{-4}$	$1.33\ 10^{-2}$
H_2	$5.0\ 10^{-5}$	$6.65\ 10^{-3}$
Xe	$8.7\ 10^{-6}$	$1.16\ 10^{-3}$
O_3	$1.1\ 10^{-6}$	$1.46\ 10^{-4}$

Mean Free Path between Collisions

Molecular density: n
Diameter of the molecules: $D = 2r$
Mean molecular velocity: $\bar{v}$



Volume of the cylinder traversed by a molecule per second : $\pi D^2 \bar{v}$
Each molecule will collide with all other molecules contained within the cylinder of radius D.

Hence the number of collisions: $Z = \pi D^2 \bar{v} n$.

A correction factor $\sqrt{2}$ is necessary to account for the fact that molecules are not stationary but move into and out of the cylinder volume, and molecules do not move along a straight line.

The mean free path is defined as

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

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

D molecular diameter (~3 10^{-8} m)
The product $n\,l \approx const$
For air, $n\,l$ ~ 2.5 10^{14} m^{-2} . For N_2 at RT and 1 Pa l ~ 0.9 mm

Vacuum characteristics

gas : Nitrogen, N_2, 20°C, M = 28

	pressure Pa	n m^{-3}	ρ kg m^{-3}	ν $m^{-2}\ s^{-1}$	l m
atm	10^{5}	$2.5\ 10^{25}$	1.16	$2.9\ 10^{27}$	$9\ 10^{-8}$
primary vacuum	1 10^{-1}	$2.5\ 10^{20}$ $2.5\ 10^{19}$	$1.16\ 10^{-5}$ $1.16\ 10^{-6}$	$2.9\ 10^{22}$ $2.9\ 10^{21}$	$9\ 10^{-3}$ $9\ 10^{-2}$
high vacuum	10^{-4} 10^{-7}	$2.5\ 10^{16}$ $2.5\ 10^{13}$	$1.16\ 10^{-9}$ $1.16\ 10^{-12}$	$2.9\ 10^{18}$ $2.9\ 10^{15}$	$9\ 10^{1}$ $9\ 10^{4}$
uhv	10^{-10}	$2.5\ 10^{10}$	$1.16\ 10^{-15}$	$2.9\ 10^{12}$	$9\ 10^{7}$

$$n = \frac{\rho}{kT} \qquad kT = 4.04\ 10^{-21}\ \text{Joule}$$

$\rho = M\, m_O\, n$ with $M\, m_O = 4.65\ 10^{-26}$ kg ,

$m_O = 1.66\ 10^{-27}$ kg

$$\nu = \frac{1}{4}\ n\ v \qquad v = 1.45\ 10^{2}\ \sqrt{\frac{T}{M}}$$

$$l = \frac{1}{\sqrt{2}\pi d^{2} n} \qquad \text{and} \qquad d(N_2) = 3.15\ 10^{-10}\ \text{m}$$

Conductance for Molecular Flow

Mean free path >> relevant dimensions
Knudsen relation: gas flow $Q \propto \Delta p$.

Molecular conductance $c = \frac{4}{3} \frac{\bar{v}}{\int_0^L \frac{H}{A^2} dl}$ (m³/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 :

$$c = \frac{4}{3} \bar{v} \left(\frac{r^3}{L} \right) \sim 306 \cdot \left(\frac{r^3}{L} \right) \sqrt{\frac{T}{M}}.$$

An orifice (pumping hole, L~0) :

$$c = \frac{1}{4} \bar{v} \, A \sim 36.5 \cdot A \sqrt{\frac{T}{M}}.$$

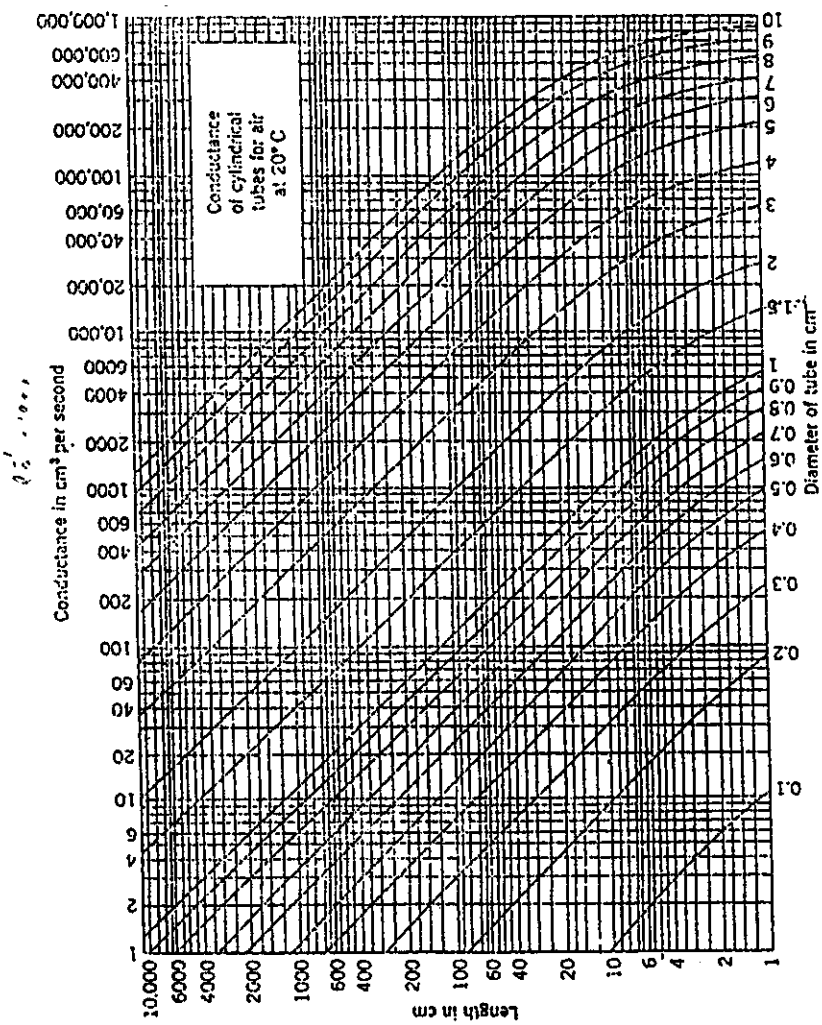


Fig. 2.1. Plots of conductance of cylindrical tubes for air at 20° C calculated according to equation 2.40.

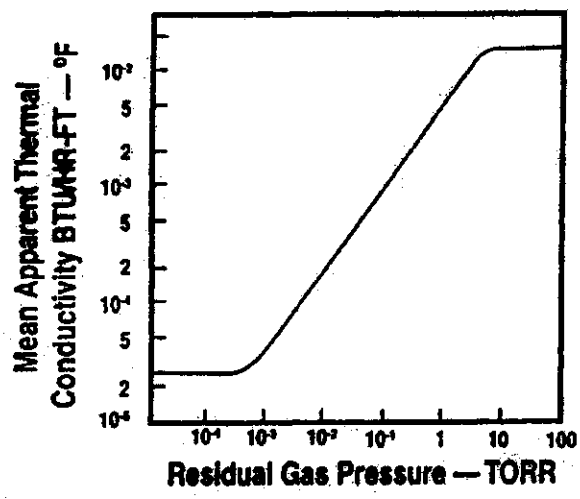
Thermal Conductivity

Thermal conductivity of a gas is independent of the pressure when the pressure is well above the molecular flow regime.

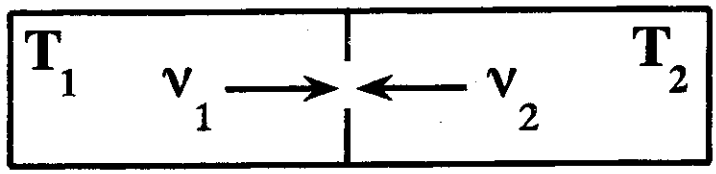
In the transition regime, the heat transfer is proportional to the pressure and to the temperature difference.

$$10^{-3} \text{ Torr} < P < 10 \text{ Torr}$$

At very low pressures, the heat transfer by conduction is negligible -> Insulation vacuum for cryogenic systems.



Thermal transpiration

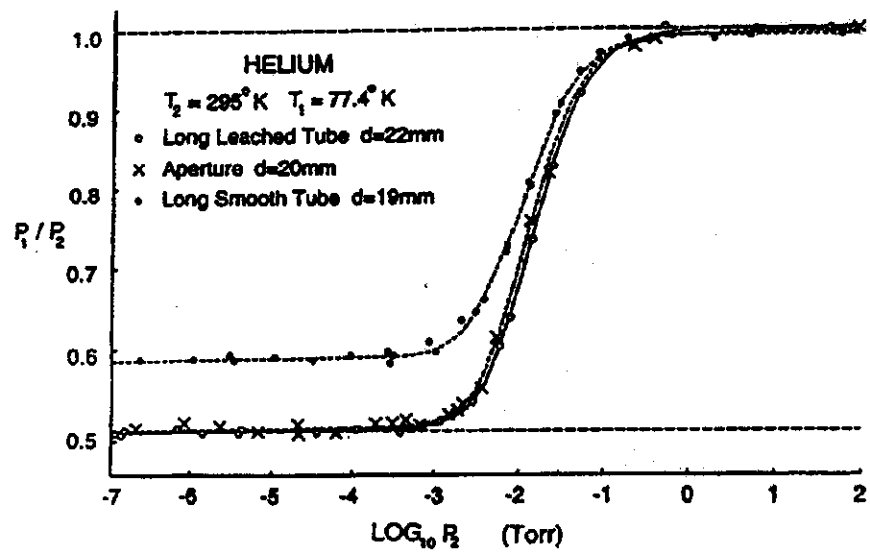


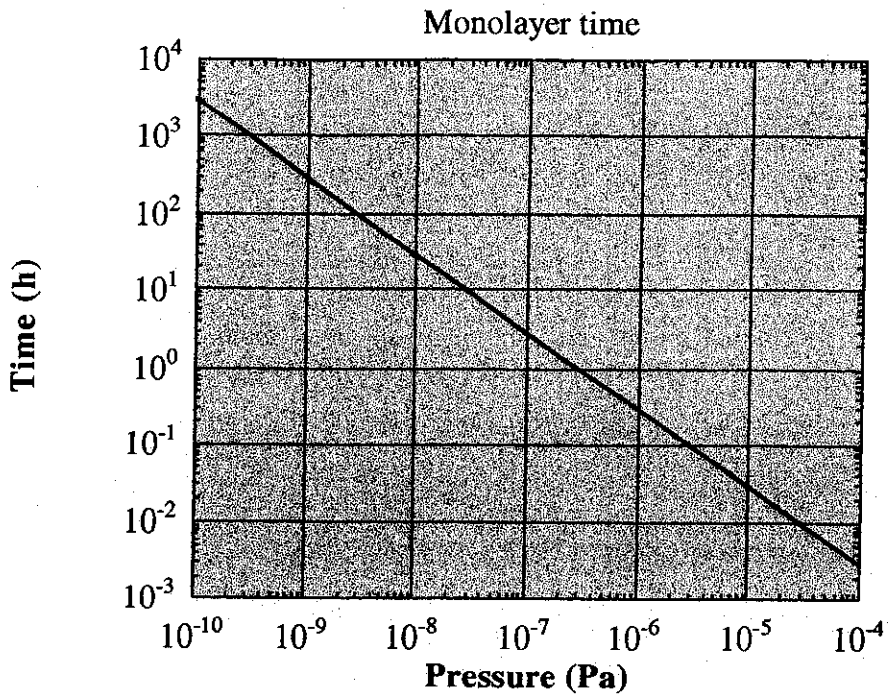
At high pressure, the pressures on both sides are equal.
In molecular flow, the net number of molecules traversing the separating wall will be zero.

$$\nu_1 = \nu_2$$

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

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





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

monolayer 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 requirements for surface analysis systems

Beam Lifetime and Loss Rate of Particles

Loss by Bremsstrahlung :

$$-\frac{dE}{dx} = \frac{E}{X_0}$$

here X_0 represents the radiation length of the material

Then $$\frac{1}{\tau} = -\frac{1}{N}\frac{dN}{dt} = \frac{c\rho}{X_0} W$$

with c the particle velocity (relativistic particles)
and $\rho = \frac{m_0 M}{kT} P$ the density of the residual gas with the pressure P

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

represents the machine dependent probability per radiation length of emitting a photon with an energy larger than the energy acceptance of the beam so that the particle is lost.

The beam lifetime becomes

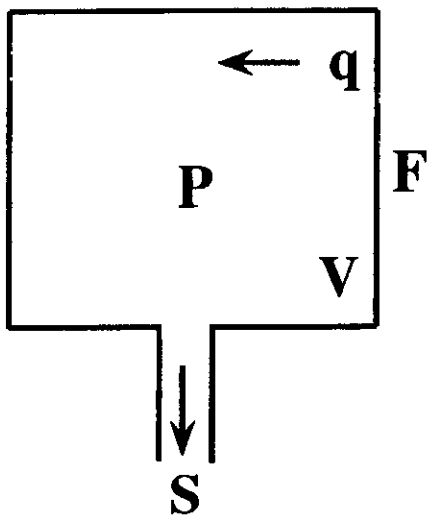
$$\tau = \frac{X_0}{c\rho W} \propto \frac{X_0}{P}$$

For nitrogen or CO one finds

$$\tau P = 3.4 10^{-8} \text{ (Torr hours)}$$

This justifies the requirement of uhv conditions in a storage ring. Heavy molecular species must be avoided.

Basic Vacuum System



volume	V (m^3)
surface	F (m^2)
pressure	P (Pa)
pumping speed	S(m^3/s)
specific outgassing rate	q(Pa m/s)

Stationary conditions

$$P = \frac{q\,F}{S}$$

Dynamic conditions

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

A solution (the constant K depends on the initial conditions)

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

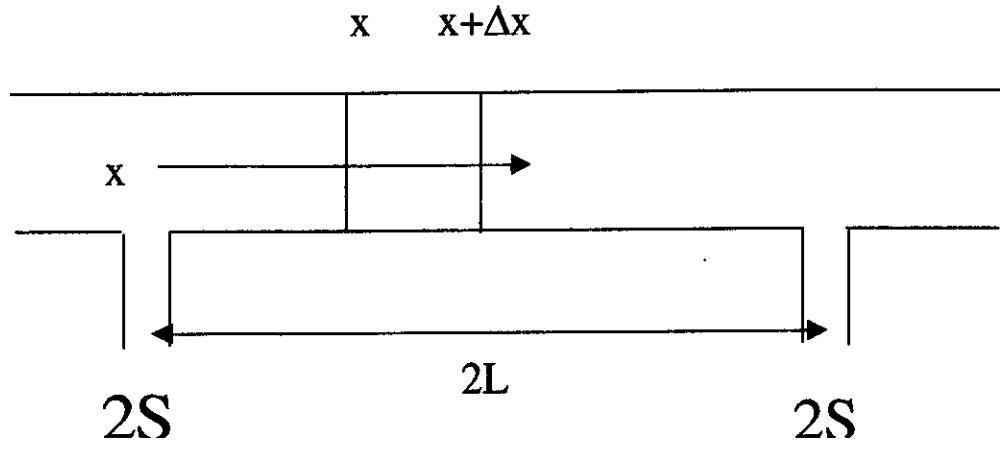
The time constant of the system: $\frac{S}{V}$

To obtain a low pressure:

1) Low outgassing rate of the surface

2) Large pumping speed

Linear Vacuum System



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]
Specific molecular conductance of the tube:	c	[m^4 s^{-1}]

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

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

Boundary conditions for this configuration :

By symmetry $\left[\frac{dP}{dx}\right]_{x=\pm L} = 0$ and the pressure at x = 0

$$P(x=0) = \frac{Q(x=0)}{2S}$$

$$Q(0) = 2\,A\,qL$$

One obtains a parabolic pressure distribution :

$$P(x) = Aq\left(\frac{2Lx - x^2}{2c} + \frac{L}{S}\right)$$

The average pressure relevant for the circulating beam lifetime is

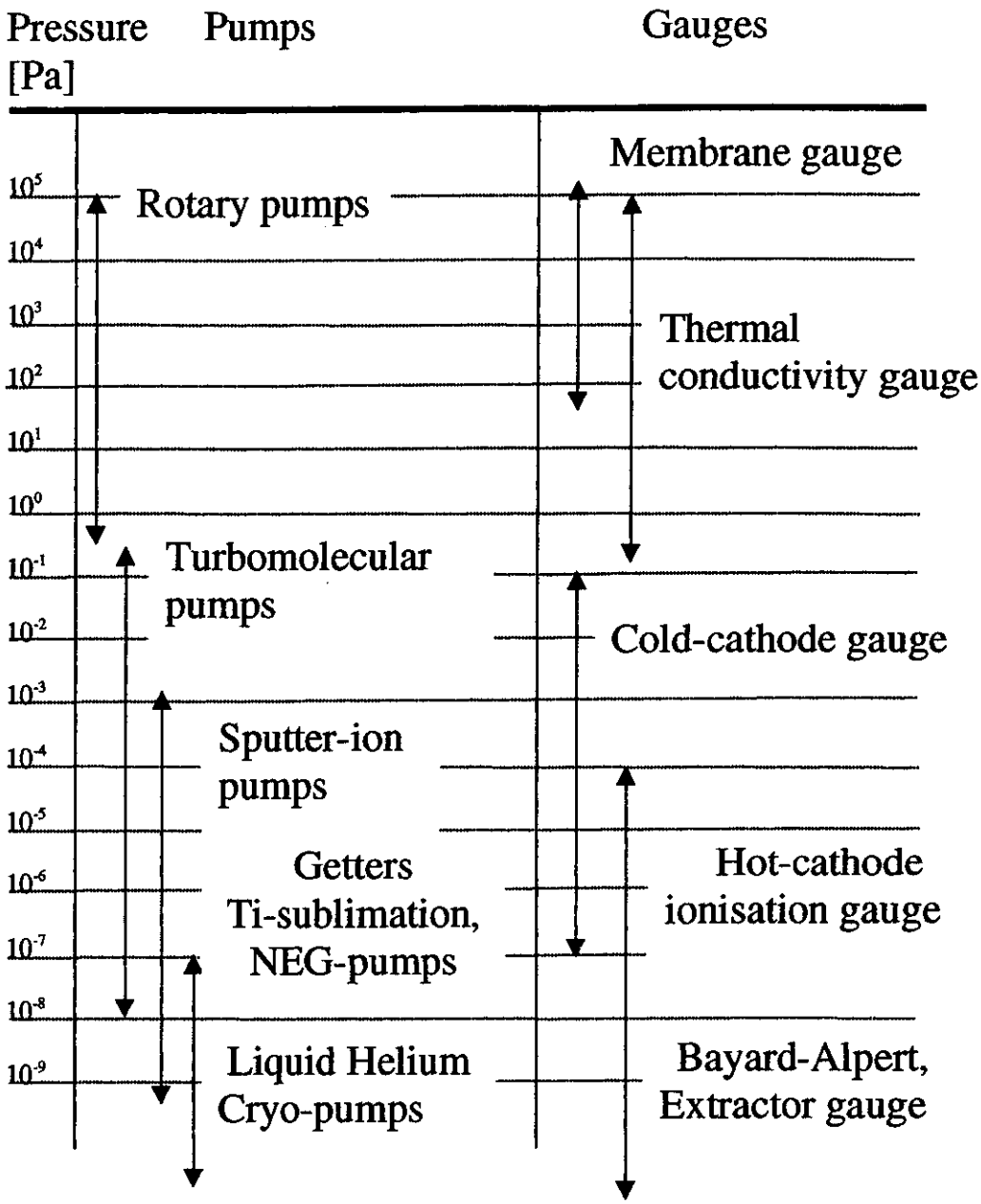
$$P_{av} = \frac{1}{2L}\int_0^{2L} P(x)dx = Aq\left(\frac{L^2}{3c} + \frac{L}{S}\right)$$

Note : the pressure is limited by the molecular conductance of the system.

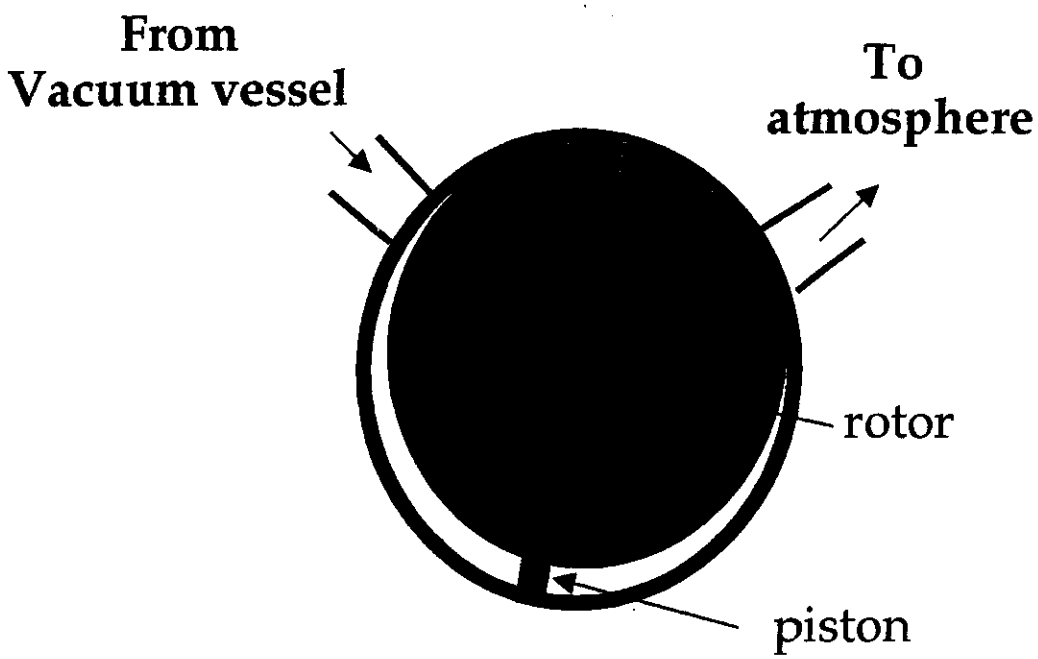
Independent of the increase of the pumping speed S, the average pressure is limited to the value :

$$P_{\min} = \frac{A\,qL^2}{3c}$$

Vacuum pumps and vacuum gauges used in accelerator vacuum systems



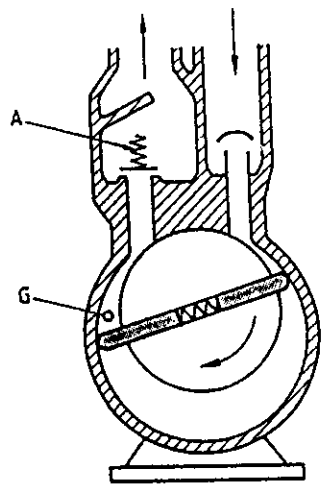
Rotary Pump

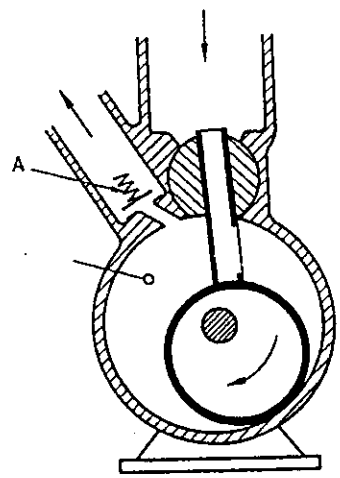


Lubrification: oil

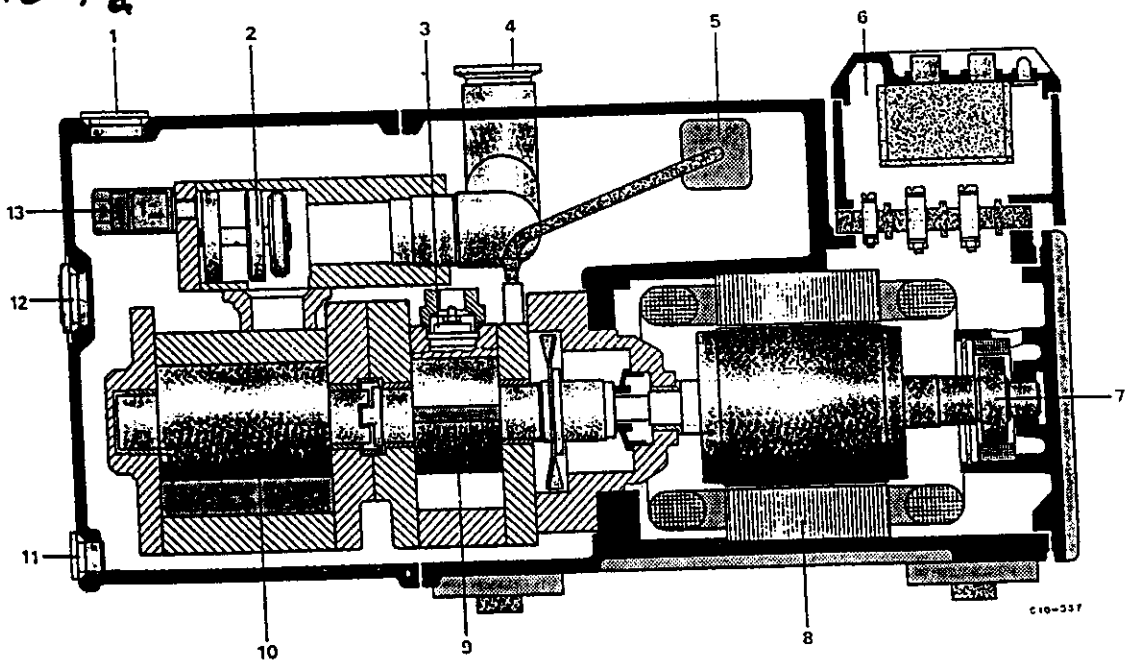
limit pressure : 0.1 Pa

pumping speed ~ 4 - 30 m^3 / h

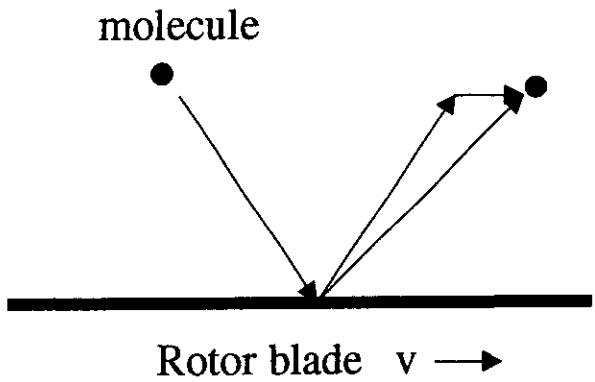




$\sim 10^{-1}$ Pa



Turbomolecular Pump



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

The pumping speed of a turbomolecular pump

$$S \propto vA$$

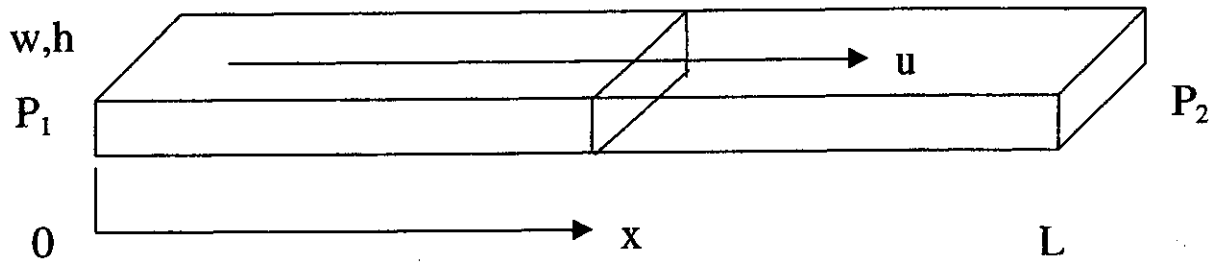
v rotational speed and
A pump geometry.

The compression factor of the pump is defined as

$$K = \frac{P_{outlet}}{P_{inlet}} .$$

K is an exponential function of the molecular weight and of the rotational speed.
Hence the compression ratio is large for heavy molecules -> 'clean vacuum' without heavy hydrocarbon molecules (no contamination by oil vapour from a primary pump) can be obtained

The Molecular Pump Principle



The molecular conductance of a rectangular duct, with the perimeter $H = 2(w+h)$ and the section $A = w \cdot h$ is given by :

$$c = \frac{4}{3} \frac{\bar{v}}{\int_0^x \frac{H}{A^2} dl} = \frac{2}{3} \bar{v} \frac{h^2 w^2}{x(h+w)}.$$

In molecular flow : $\frac{dP}{dx} = \frac{Q}{c}$.

Assuming that one surface is moving with the speed u, the gas flow which traverses a given cross section corresponds to : $Q = PV = P\frac{u}{2}A$.

Thus $$\frac{dP}{dx} = \frac{u}{2c} AP .$$

Integrating this equation over the length of the duct

$\int_{P_1}^{P_2} \frac{dP}{P} = \frac{u}{2c} A \int_0^L dx$ one obtains the result :

$$K = \frac{P_2}{P_1} = e^{\frac{u}{2c}AL} .$$

K defines the compression ratio of a pump i.e. the ratio between input and output pressures.

K increases exponentially with the molecular weight, and with the rotational speed of the pump.

Typical values of commercial pumps :

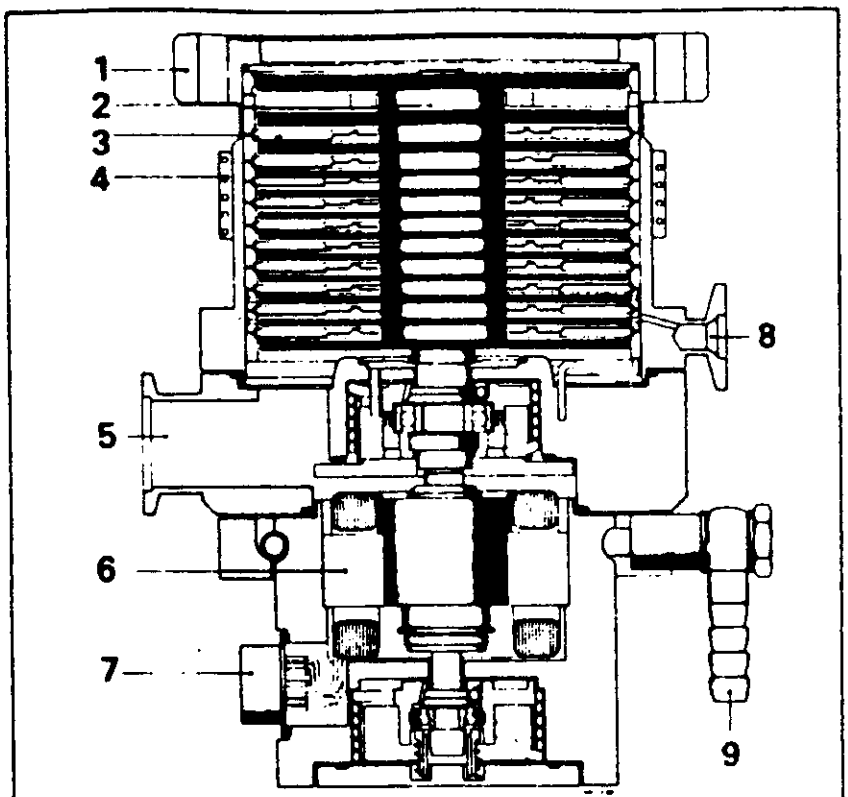
for hydrogen ~2 10^3

for nitrogen ~ 10^8 !

A large compression ratio for heavy molecules results in a 'clean vacuum' without hydrocarbon (C-H) contamination.

The pumping speed S is proportional to the rotational speed and depends on the geometry of the pump.

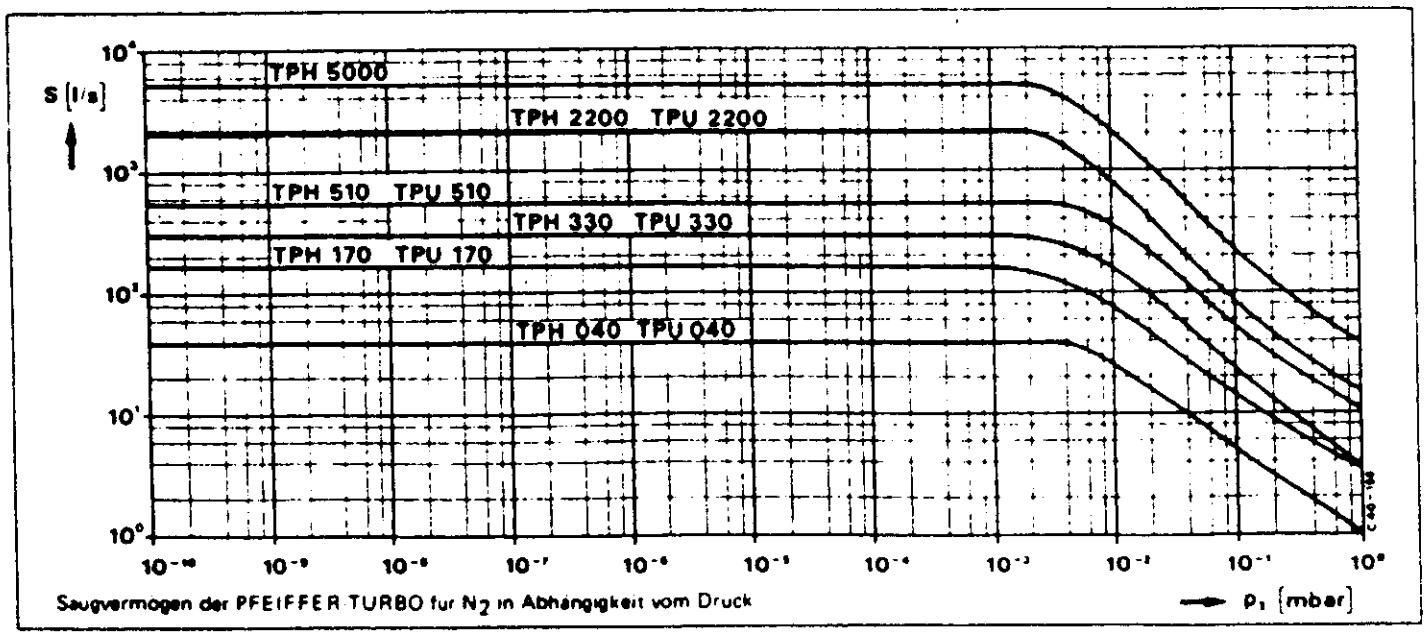
S does not depend on the molecular weight M.



Schnittdarstellung der PFEIFFER-TURBO TPU 170

1 UHV-Anschluss	4 Heizung	7 Elektrischer Anschluss
2 Rotor	5 Vorvakuumanschluss	8 Flutanschluss
3 Stator	6 Motor	9 Kuhlwasseranschluss

~ 40 000 t/min
> 60 000



Saugvermogen der PFEIFFER-TURBO fur N_2 in Abhängigkeit vom Druck

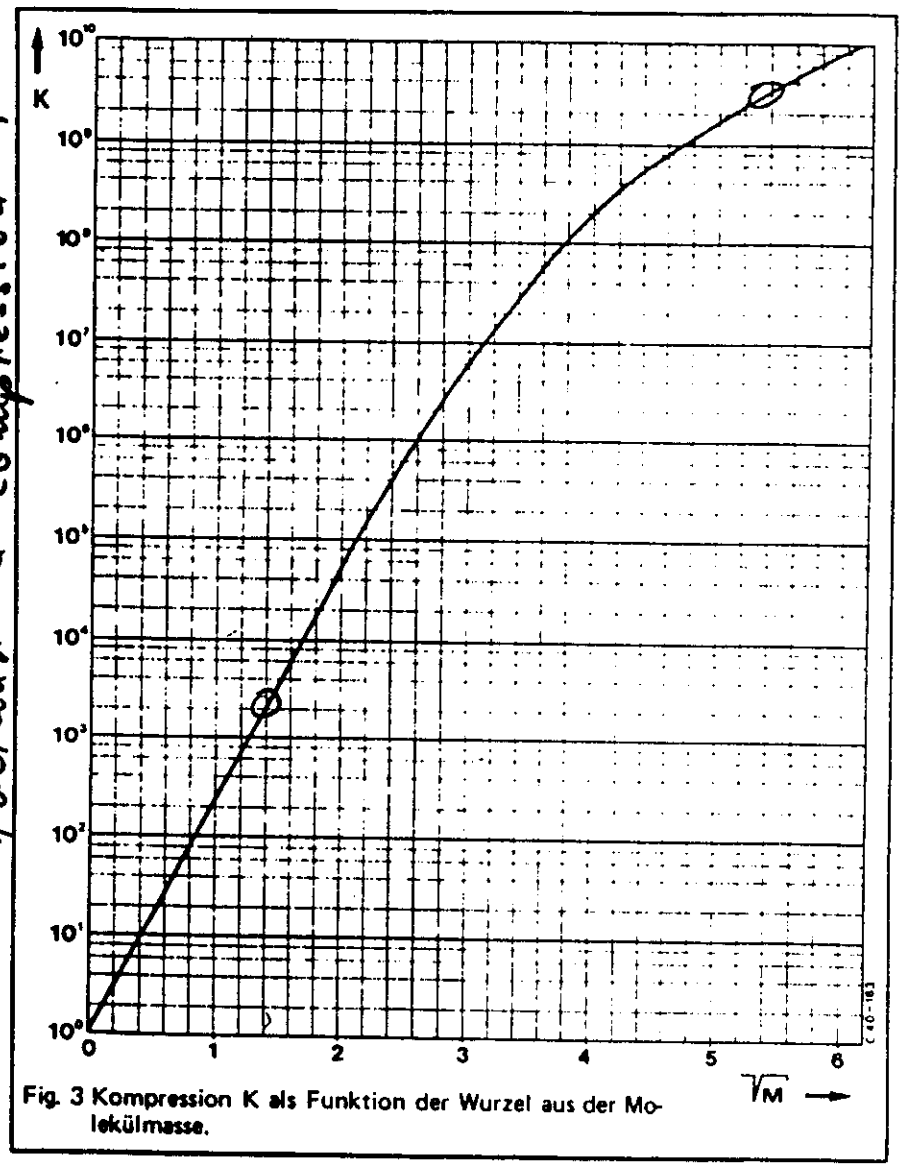


Fig. 3 Kompression K als Funktion der Wurzel aus der Molekülmasse.

Ion Pump

"Penning" configuration

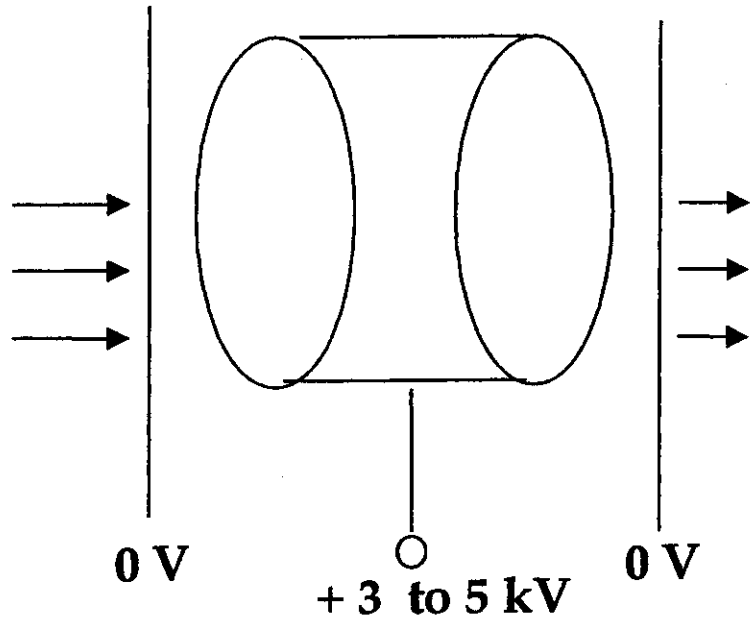
electric field E

magnetic field B

E parallel to B

B ~ 0.1 T

Penning cell



Pumping mechanism :

adsorption of molecules CO, CO_2, N_2

gettering

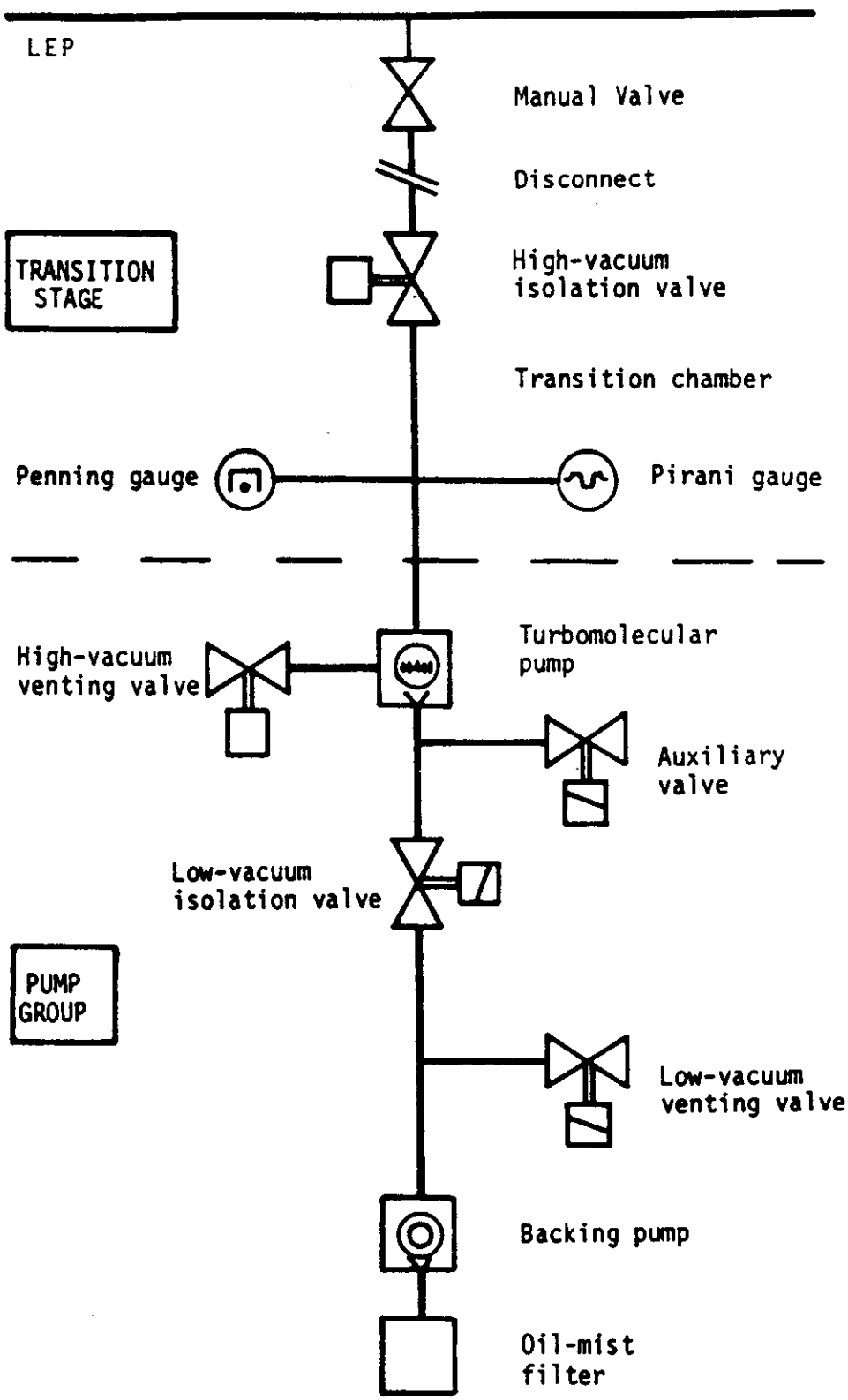
diffusion H_2

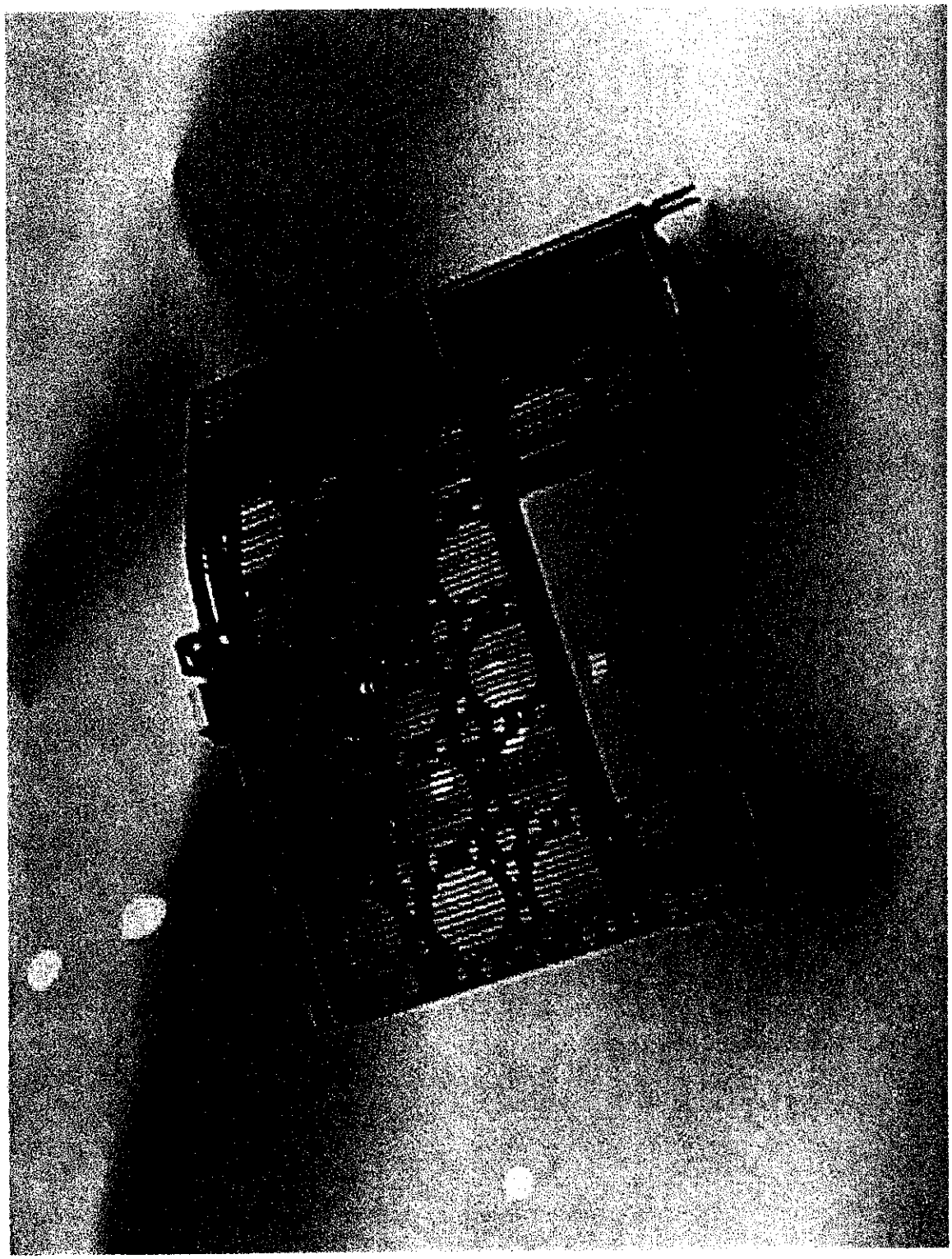
cracking of molecules C - H

" Ion burial " noble gases He, Ar

Sputtering of titanium at the cathode

The pump contains a large array of single Penning cells in a common housing to increase the pumping speed


LEP
Manual Valve
Disconnect
TRANSITION STAGE
High-vacuum isolation valve
Transition chamber
Penning gauge
Pirani gauge
Turbomolecular pump
High-vacuum venting valve
Auxiliary valve
Low-vacuum isolation valve
PUMP GROUP
Low-vacuum venting valve
Backing pump
Oil-mist filter



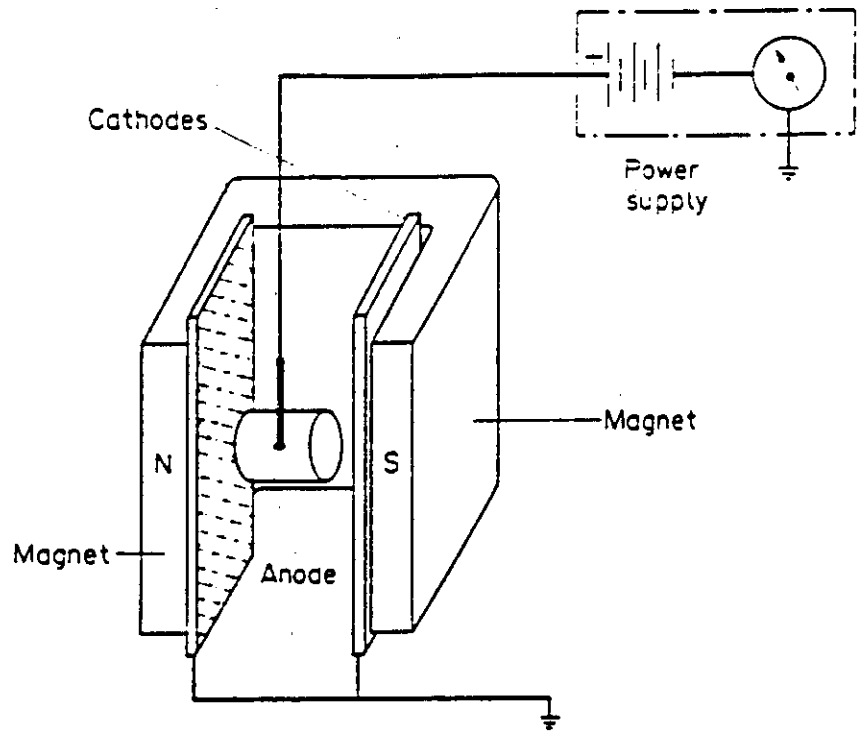


Figure 8. Basic configuration of a sputter-ion pump.

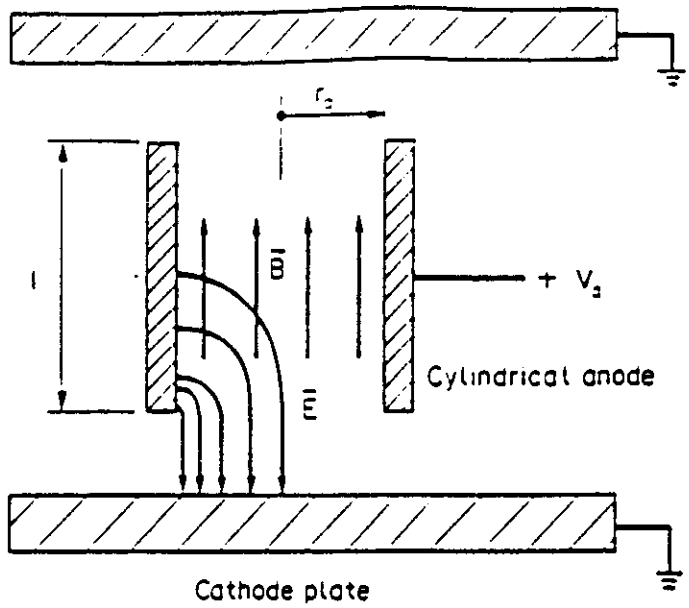
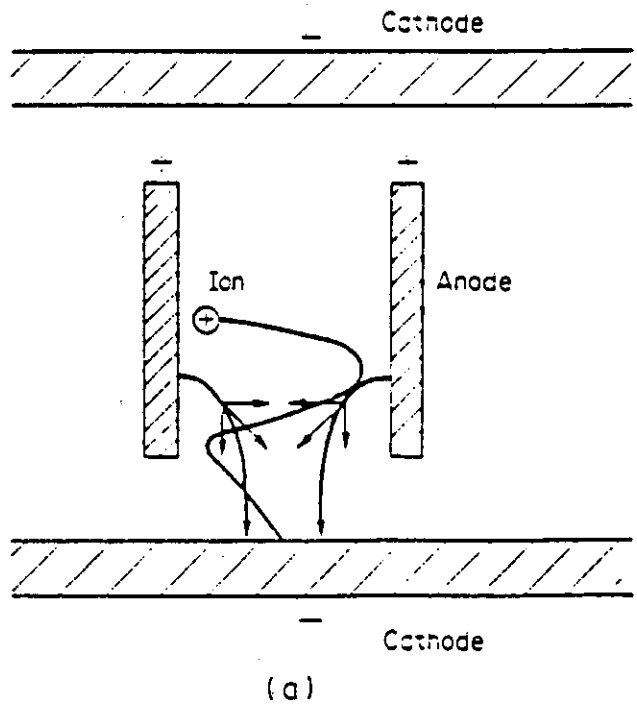
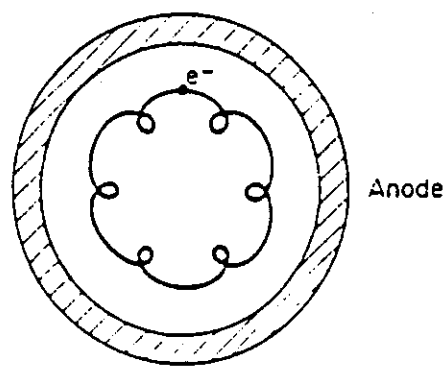


Figure 4. Long-anode Penning structure.



(a)



(b)

Figure 5. Examples of particle trajectories in a Penning cell. (a) Ion

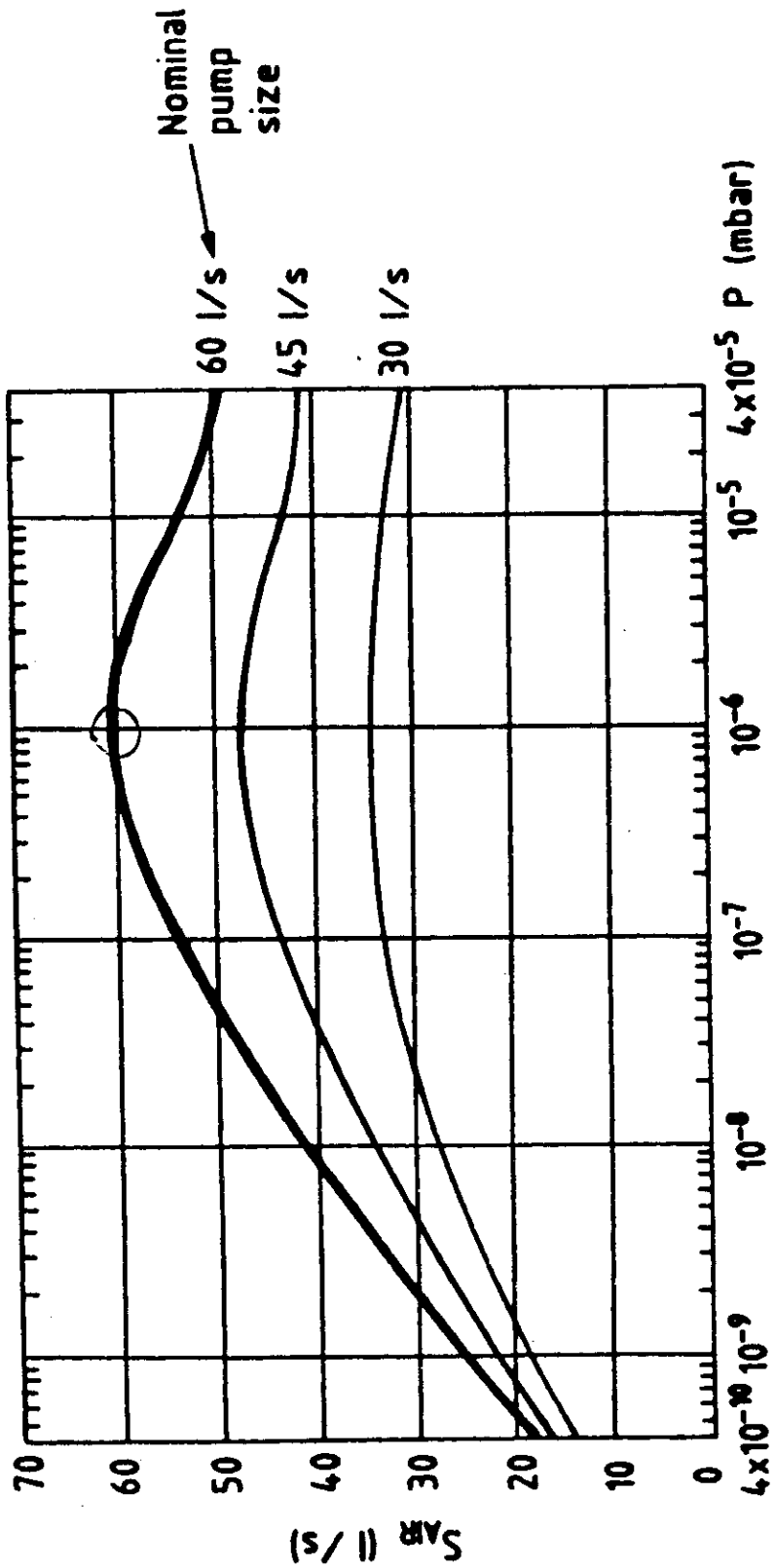


Fig. 9 Pumping speed for air for a saturated pump

Penning Discharge in a Sputter-Ion-Pump

The ratio of the discharge current and the pressure is approximately constant. This effect can be used to measure the pressure in the vacuum system.

-> Cold cathode gauge, "Penning gauge".

In a particle accelerator, the magnetic field, B can be provided by the bending magnets. -->

integrated, linear ion-pumps.

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 pumps.

Surface Pumping

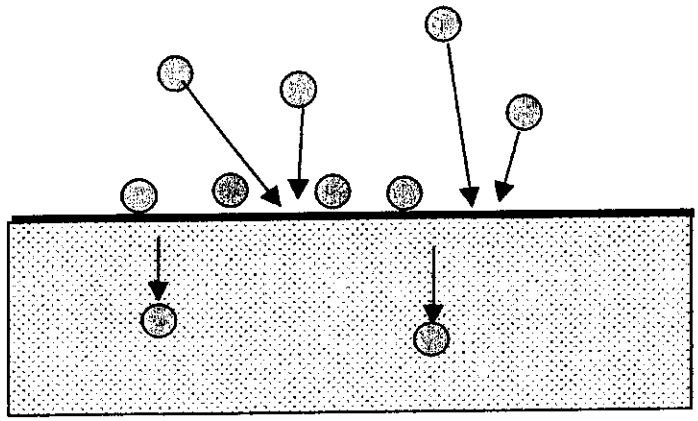
Getters (chemisorption E~eV)

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 (Ti-filament)

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

Cryo-pumps (physisorption E~ meV)

Sorption (capacity ~ monolayer)

Condensation (vapour pressure)

Ti-Sublimation pump

An actice Ti-film is deposited on the internal surface of the vacuum system by heating a Ti-filament to about 1300°C

(duration a few minutes)

Practical pumps consist of a filament holder inserted in the vacuum system and an external power supply (12V, 50A)

Usually more than one filament is provided (filament burn-out)

The Ti film gradually saturates e.g. at 10^{-6} Pa it takes about 1 hour. Then a fresh film has to be deposited

The intrinsic pumping speed is very significant: at 20°C and unit sticking

H2, N2	24	m/s
CO	48	m/s
H2O	32	m/s

Bulk Getter, Non Evaporable Getter, NEG

A bulk getter provides pumping without the need of sublimating a fresh, active film of e.g. Titanium.

The NEG requires instead an initial activation by heating to approx. 500-700°C during 1 hour. During this process, gas on the surface diffuses into the bulk of the getter drive by the gradient of concentration. Inside the getter the gas molecules form stable chemical compounds.

As in the case of surface getter, the bulk getter has to be regenerated when its surface has been saturated with an adsorbed layer of gas molecules.

For H2, the diffusion rate is already significant at room temperature and the pumping of H2 is reversible. During heating of the getter, H2 rediffuses and can be released from the getter.

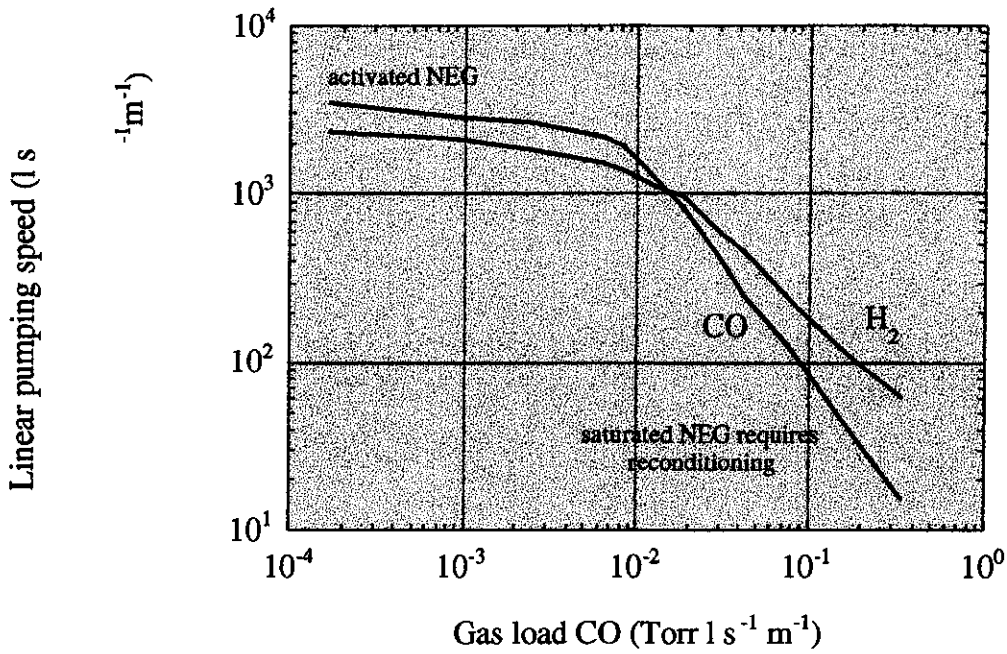
Total capacity is limited

Pumping speed is a strong function of the quantity already pumped. -> see pumping speed curves

application -> main pumping for the 27 km long LEP vacuum system

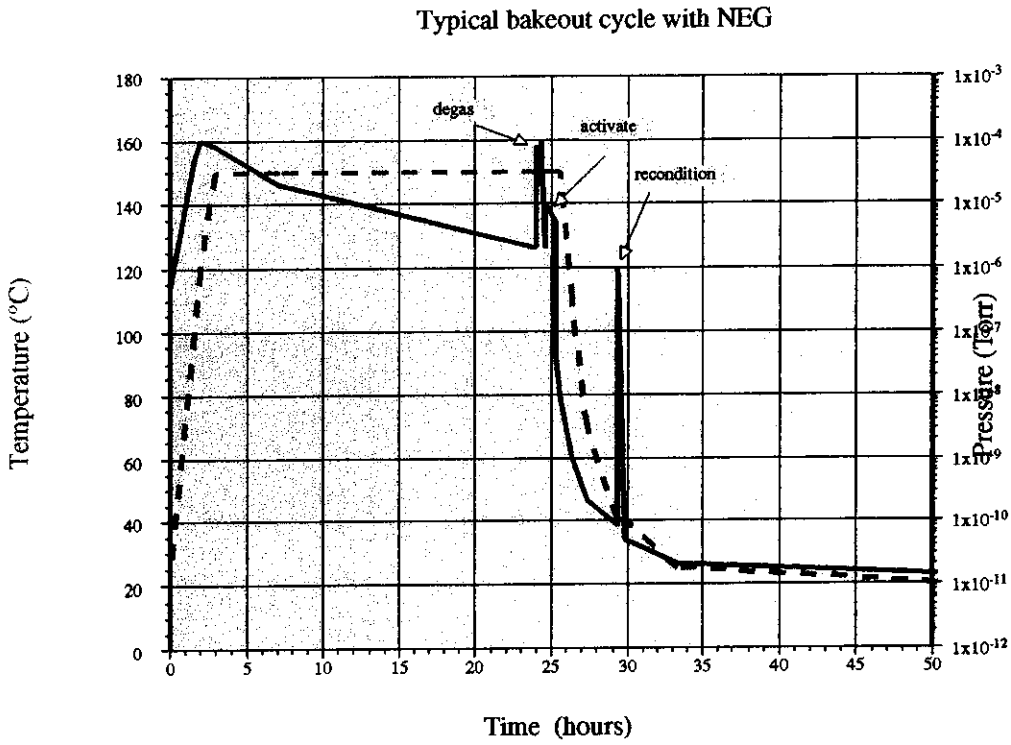
readily applied as a "distributed" pump since it is supplied in the from of a 'getter strip' by the firm SAES-Getters, Italy

Pumping speed of St101 getter



Reduction of the pumping speed due to the gradual saturation of the surface with adsorbed molecules. During re-activation, these molecules diffuse into the bulk and a fresh, clean surface is obtained for a subsequent pumping cycle.

LEP vacuum system with NEG pumping



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

Cryo-Pumps

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

Pumping mechanisms :

A) **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.

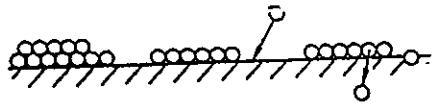
B) **Condensation**

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

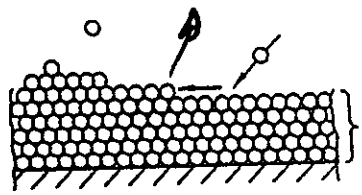
C) **' Cryo-trapping**

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

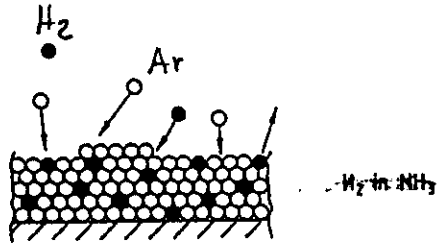
A



B



C



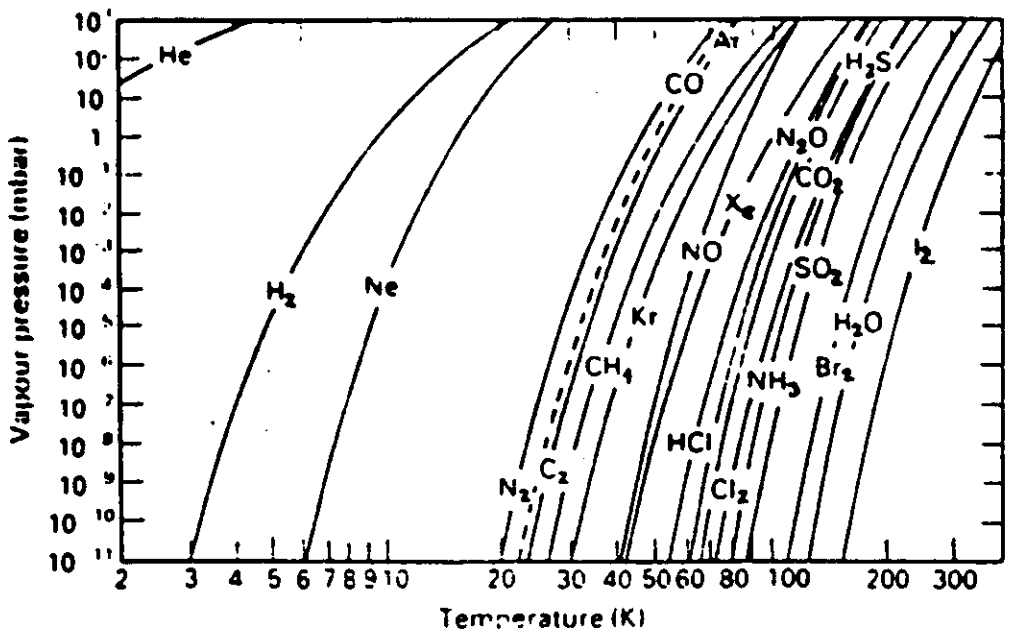
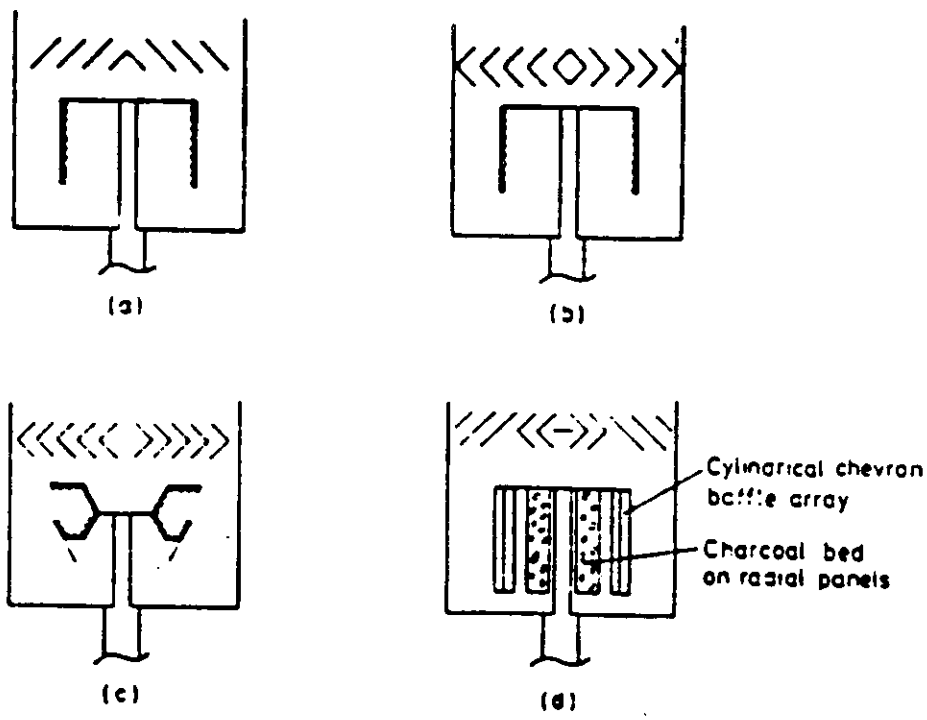


Figure 2. Vapour pressures of some common gases (from Bentley[9]).



Advantages of cryo-pumping :

Large pumping speed

Low limit pressure : -> limitation occurs only by the vapour pressure of the condensed gas

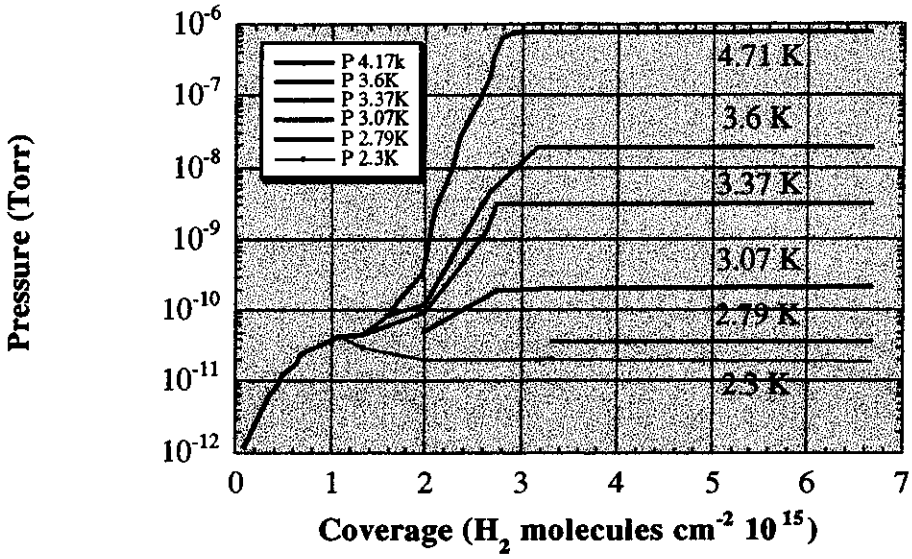
Large capacity -> Attention !! a hazardous over-pressure may build-up during warming up of a cryo-pumped system. ! -> a safety valve required !

-> 'clean' vacuum -> absence of heavy hydro-carbon molecules.

-> in combination with superconducting magnets or accelerating cavities, very effective integrated cryo-pumping can be obtained -> e.g. LHC vacuum system.

-> the walls of the vacuum system act as pumps (LHC).

Hydrogen vapour pressure



The saturated vapour pressure limits the total quantity of gas which can be cryosorbed at low pressure.

Increase of the specific surface area of a cryo pump by using special cryo-sorbing materials with a large specific surface -> charcoal.

Pirani Gauge

Reliable and simple

Fast time response, good precission

Large pressure range :

atmosphere -> < 0.1 Pa

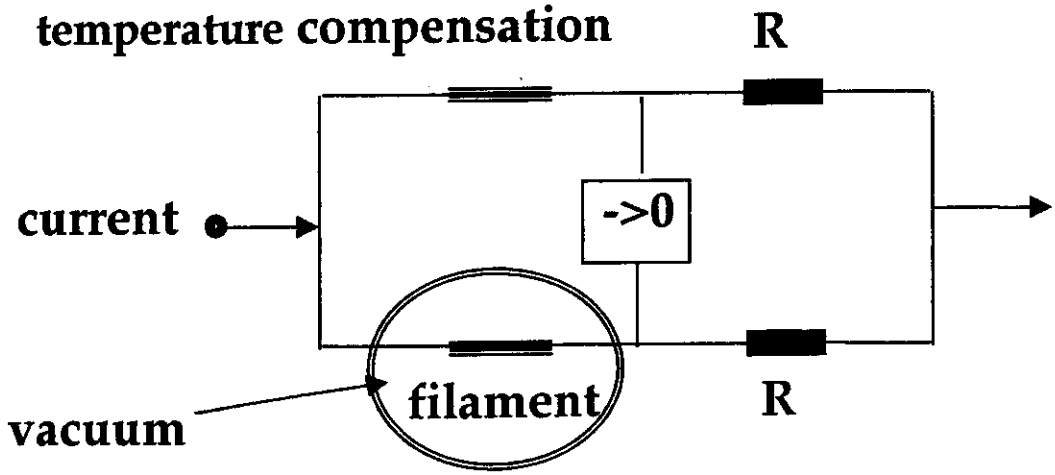
Principle

The thermal conductivity of a gas depends on the pressure within certain limits.

A resistor with a high temperature coefficient is mounted in the vacuum and heated by a constant current. (approx. 120°C),

The current required to maintain a constant temperature (resistance) is a direct measurement of the gas pressure.

Electronic circuitry provides a linearisation of the pressure indication (Wheatstone bridge)



Cold cathode gauge
Penning gauge

Basic principle : same as for ion pump

Intensity of the Penning discharge:

$$I / P = \text{const}$$

useful pressure range

$$10^{-2} > P > 10^{-7} \quad \text{Pa}$$

Limitation

at high pressure : discharge is unstable

at low pressure : discharge extinguishes

Problems : leakage current,
cable insulation

Contamination of the anode my affect the proportionality between discharge current and pressure

Ionisation Gauge

Hot Filament Gauge

Operating principle :

Residual gas molecules are ionised 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 the pressure, P.

The ionisation probability Pi (number of ion–electron pairs produced per m and per Pa) depends on the type of molecule and on the kinetic energy of the electrons.

Ion collector current :

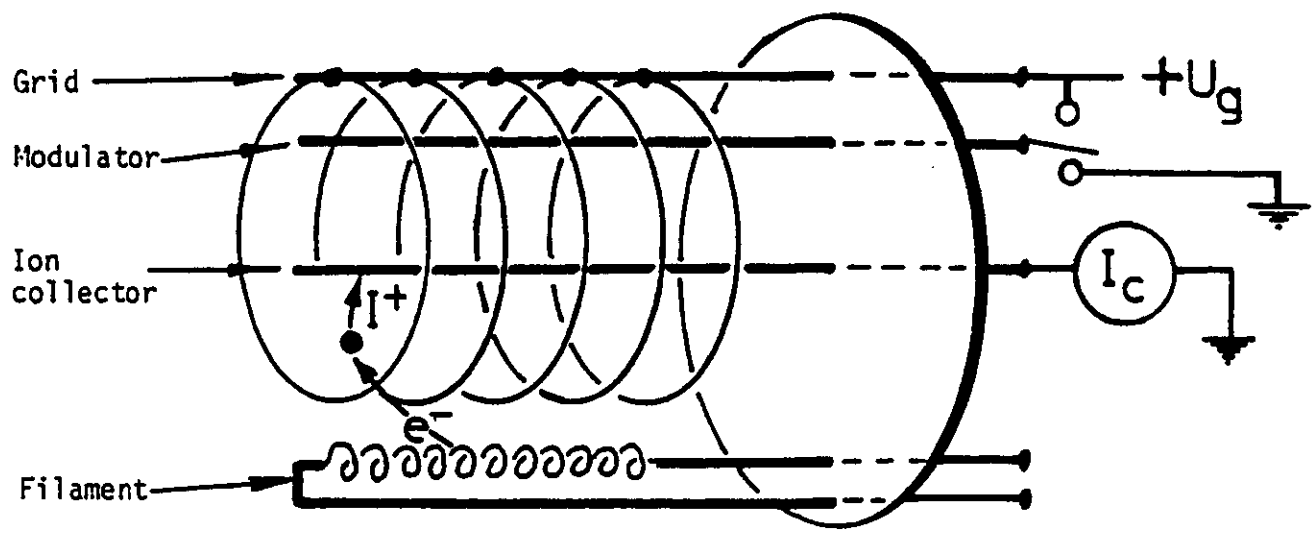
$$I^+ = Ie\ Pi\ L\ P$$

Where :

Ie emission current of the filament

L path length of the electrons

P residual pressure


Grid
Modulator
Ion
collector
Filament
I+
e⁻
+Ug
Ic

Gauge Sensitivity

$$S = P_I \; L \quad [\mathrm{Pa}^{-1}]$$

Obtained by a calibration measurement with a known pressure (N_2)

-> Nitrogen equivalent pressure N_2.

-> To measure a pressure for another gas, the relative gauge sensitivity for this particular gas with respect to nitrogen must be known.

S_i/S_{N2} must be known for different gas species.

For H_2, one finds typically $S_{H2}/S_{N2} \sim 0.38$

Outgassing of an Ionisation Gauge

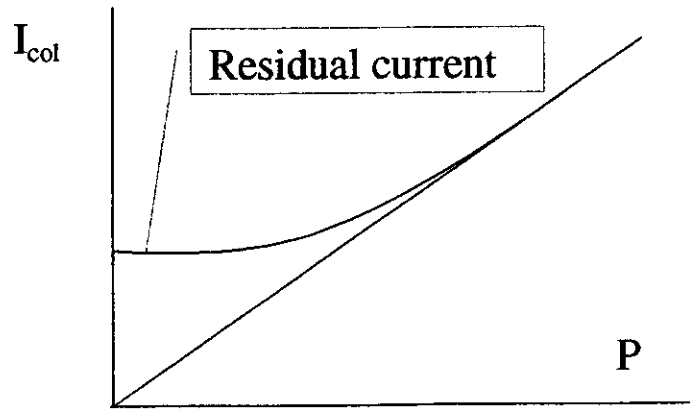
Electrons emitted from the filament, reach the grid electrode with an energy of approximately ~ 150eV and may heat-up the grid and desorb gas molecules.

-> pressure increase which disturbs the measurement.

-> To suppress this effect, the grid and all other electrodes must be cleaned.

A common method to avoid this disturbance: the emission current is increased to heat the grid electrode temporarily to a very high temperature. -> Outgassing.

Pressure limitation : residual current -> limit pressure



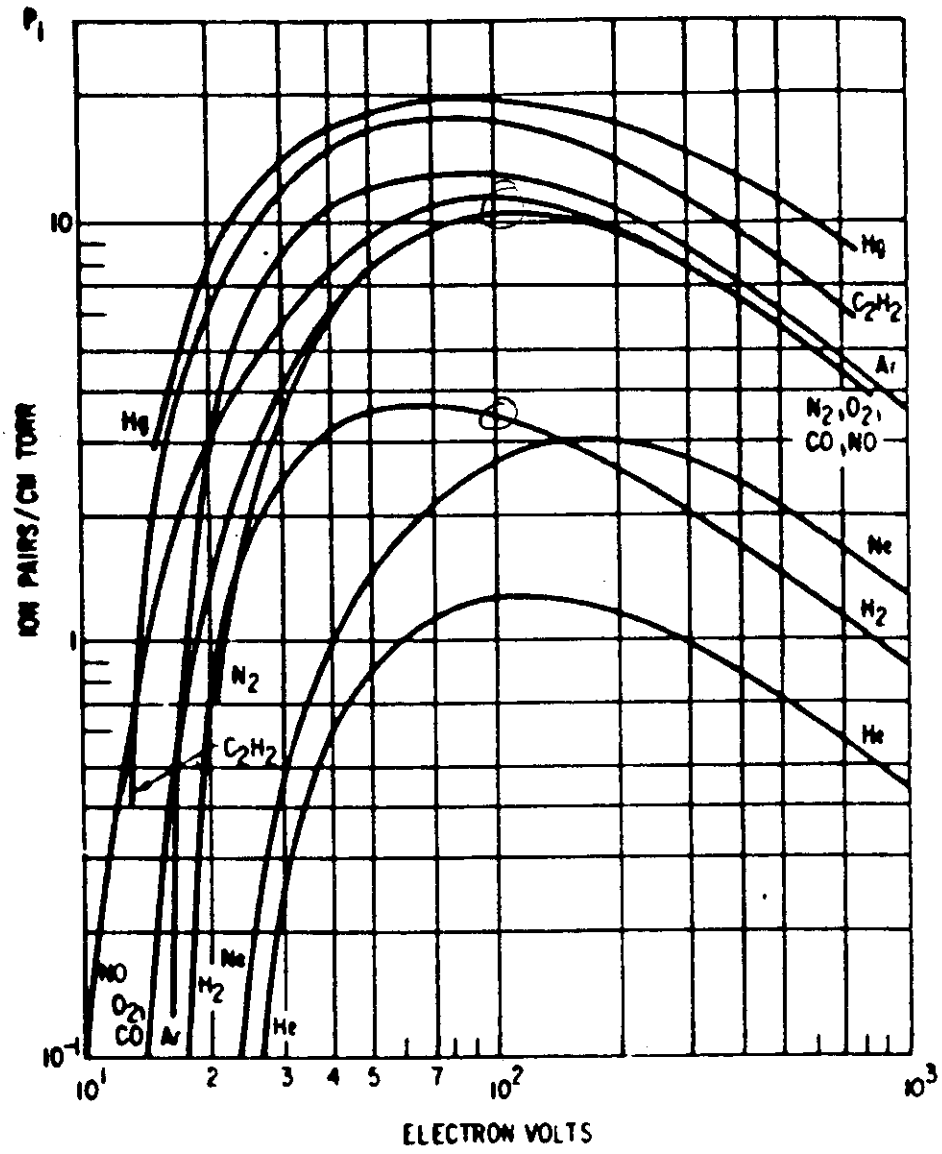


FIGURE 2. Probability of ionization as a function of electron energy for various gases at 1 Torr and 0°C [3]

X-Ray Limit of an Ionisation Gauge

Electrons which hit the grid produce soft photons (x-rays) due to Bremsstrahlung.

A small fraction of these photons can reach the collector electrode and liberate photo-electrons which return to the grid -> this current is equivalent to a positive, x-ray current, I_x, which is independent of the pressure.

The correction of this effect can be done by the « modulation » method

'Modulated Bayard-Alpert' gauge

Modulator electrode	
measurement (1), + U_{grille},	$I_1 = I^+ + I_x$
measurement (2), 0 V,	$I_2 = \alpha I^+ + I_x$
Corrected collector current	$I^+ = \frac{I_1 - I_2}{1-\alpha}$

The modulation factor : $1-\alpha$

can be determined easily by an independent measurement at high pressure where $I^+ >> I_x$.

Alternative design of an ionisation gauge:

Ions are 'extracted' from the grid volume to a collector which is optically screened from the photons of the grid.

-> Extractor gauge

Partial Pressure Measurement

Combination of an ion source with a mass spectrometer.

1) Ion source
2) Quadrupole mass filter
3) Ion collector, Farady-cup or secondary electron multiplier

Operating principle of a quadrupole mass filter :

Ions with different mass to charge ratio are injected into the quadrupole structure. As they traverse the structure, ions are subjected to a periodically varying transverse electric field which excites transverse oscillations.

Ions with an incorrect charge to mass ratio have unstable orbits, are lost and do not reach the collector.

The ion trajectories are described by the equations :

$$\ddot{x} + (\frac{e}{m} r_o^2)\Phi x = 0$$

$$\ddot{y} - (\frac{e}{m} r_o^2)\Phi y = 0 \quad and \quad \ddot{z} = 0$$

r_o is the radius of the structure and Φ the potential:

$$\Phi = U - V\cos(\omega t).$$

With $a = 4\frac{e}{m}\frac{U}{\omega^2 r_o^2}$ and $q = 2\frac{e}{m}\frac{V}{\omega^2 r_o^2}$ -> Mathieu

equation

$$\frac{d^2u}{ds^2} + \{a - 2q\cos(2s)\}u = 0$$

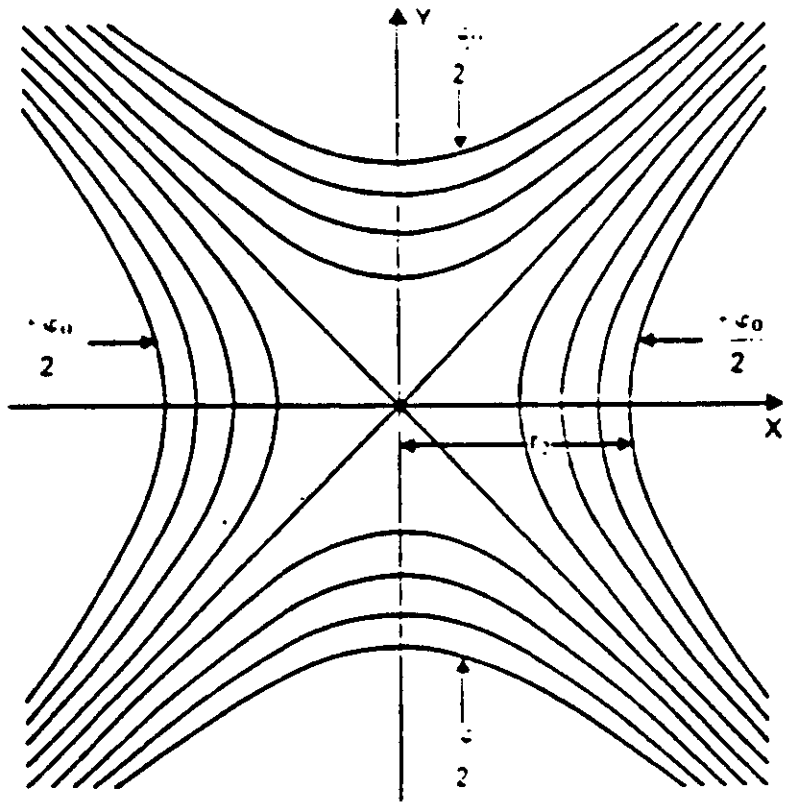


Figure 1. Quadrupole field.

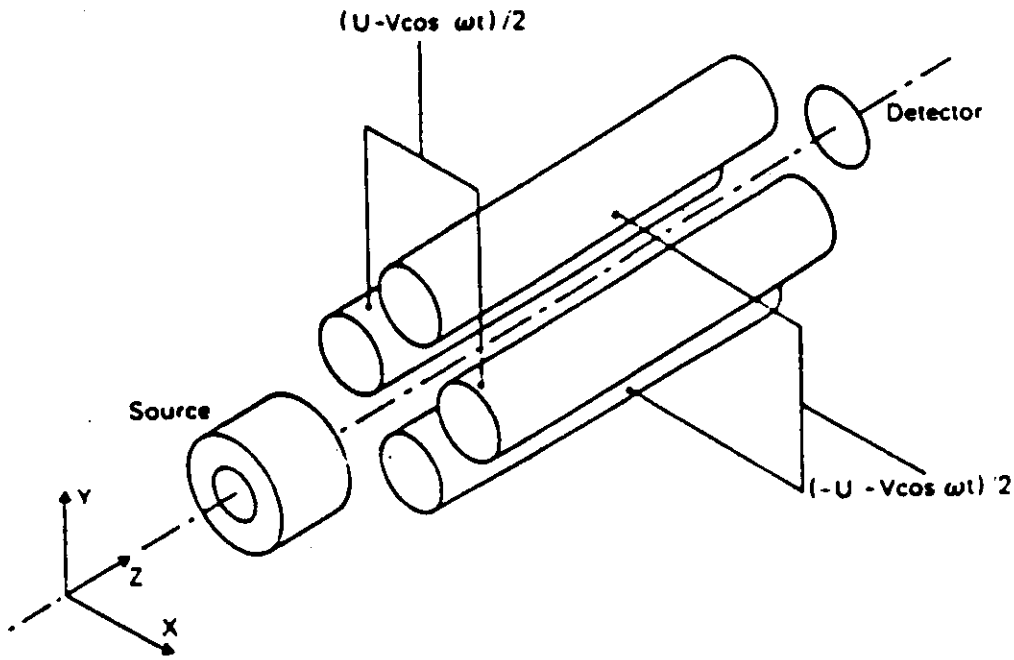
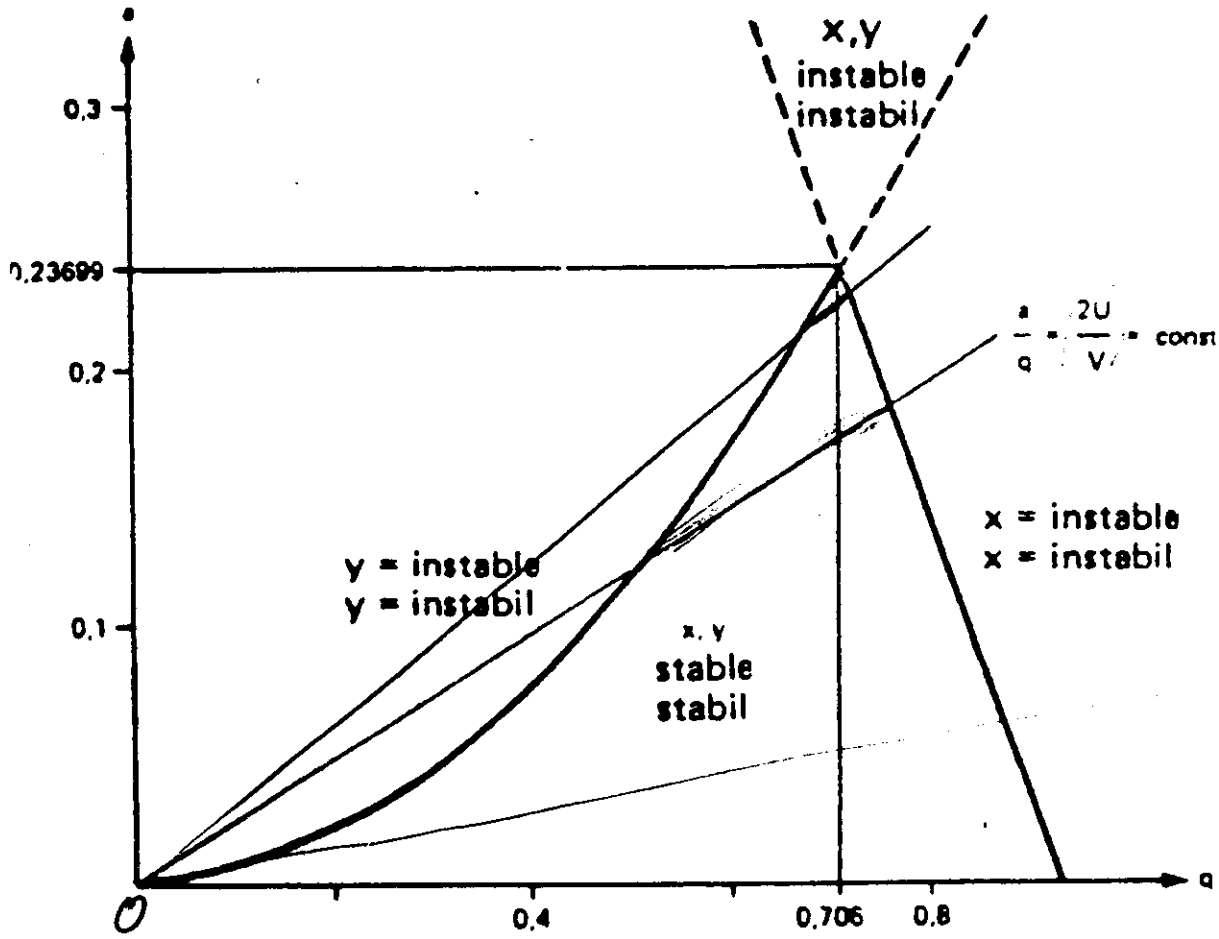
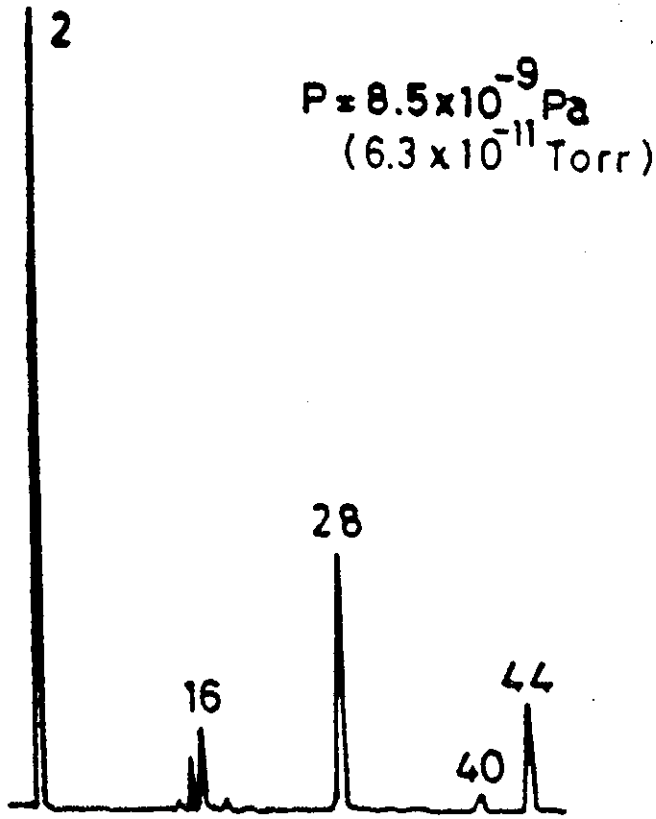
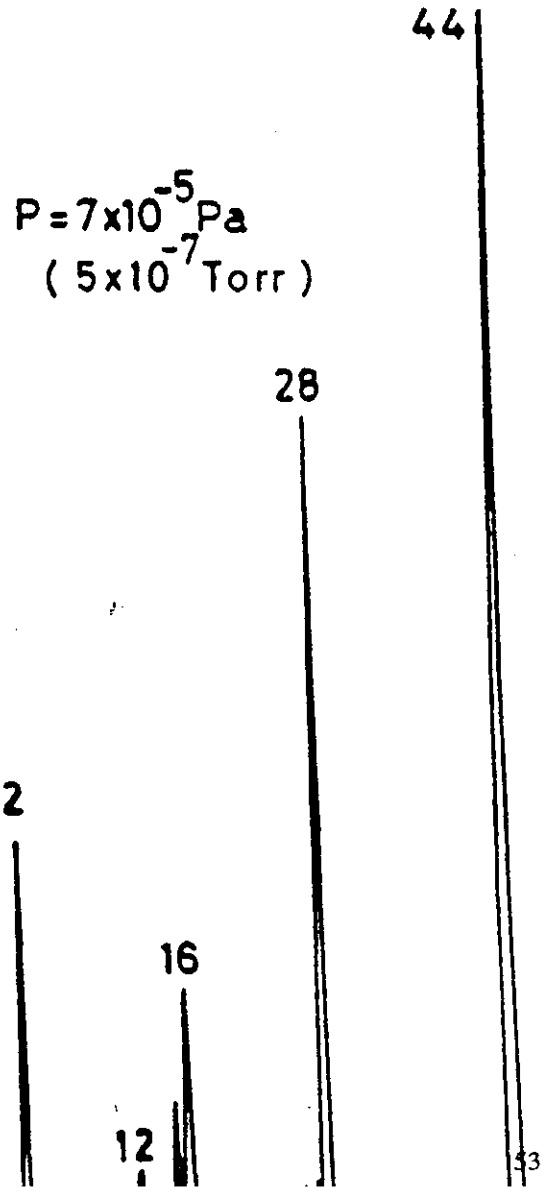


Figure 2. Quadrupole analyser.


x,y
instable
instabil
0,3
0,23699
0,2
0,1
y = instable
y = instabil
x, y
stable
stabil
x = instable
x = instabil
0
0,4
0,706
0,8
q



The residual gas spectrum before exposing the test chamber to synchrotron radiation.



The residual gas spectrum during exposure to synchrotron radiation.

Tableau 3

HAUTEURS RELATIVES DES PICS PRINCIPAUX -

Mol. \ m/q	2	12	13	14	15	16	17	18	20	22	25	26	27	28	29	30	32	38	39	40	41	42	43	44	45
H_2	100																								
CH_4	2,4	1,6	4,2	10,7	85	100	1,2																		
NH_3				3,8	4,1	90	100																		
H_2O						1,8	27	100																	
N_2				6,2										100	0,7	0,01									
CO		1,1		0,9		0,2								100	1,1	0,2									
C_2H_4		2	4	6							12	62	65	100	2,2										
C_2H_6			1	3	5						4	23	33	100	22	26									
Ar									13											100					
CO_2		3,5	-	0,28		7,5				2,8				18,5	0,3									100	1,1
C_3H_6		1	2	4	5						2	11	38	1				19	71	29	100	68	2		
C_3H_8				2	6							9	39	59	100	2		5	17	2	12	6	23	29	

Cleaning Procedures

Chemical solvent precleaning

Vacuum bakeout at 150°C to 300°C

Argon gas glow-discharge cleaning

High temperature vacuum firing (950°C)

Definition of cleanliness depends on the particular application!

Clean, dustfree handling without 'finger prints' after the precleaning

O. Gröbner, CERN LHC-VAC

Chemical solvent pre-cleaning procedure

1) Removal of gross contamination and machining oils using the appropriate solvents

2) Perchloroethylene (C_2Cl_4) vapour degreasing at (121°C) today no longer applicable

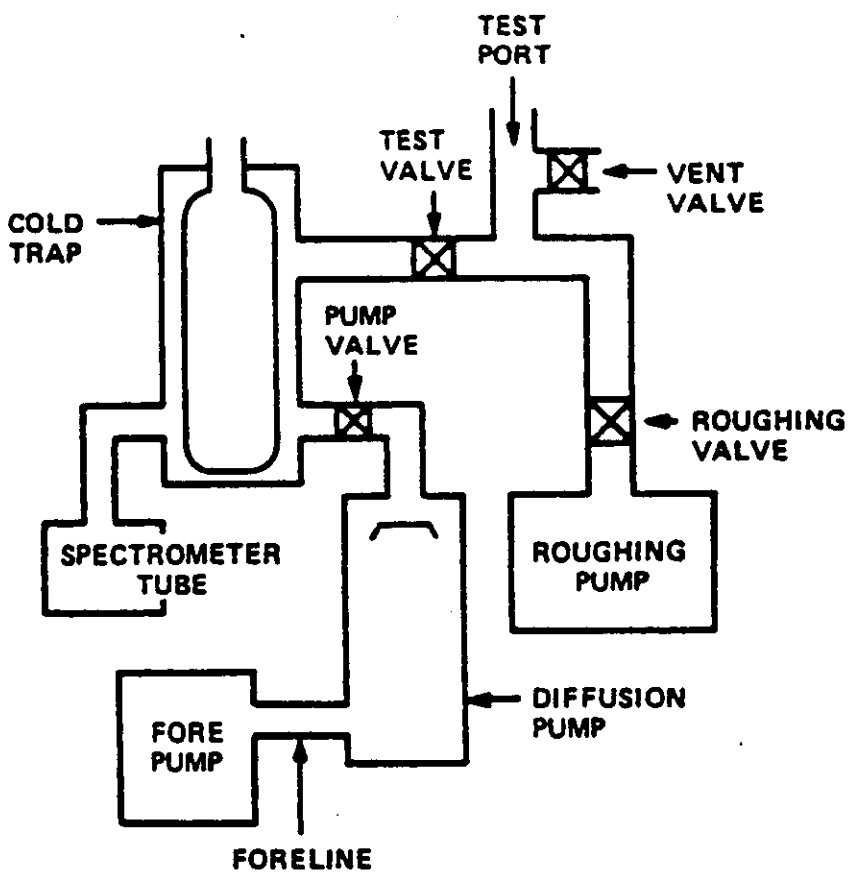
3) Ultrasonic cleaning in alkaline detergent (pH =11)

4) Rinsing in cold demineralised water (conductivity < 5 $\mu S\ cm^{-1}$)

5) Drying in a hot air oven at 150°C

6) Wrapping in clean Al-foil or paper

CONVENTIONAL LEAK DETECTOR



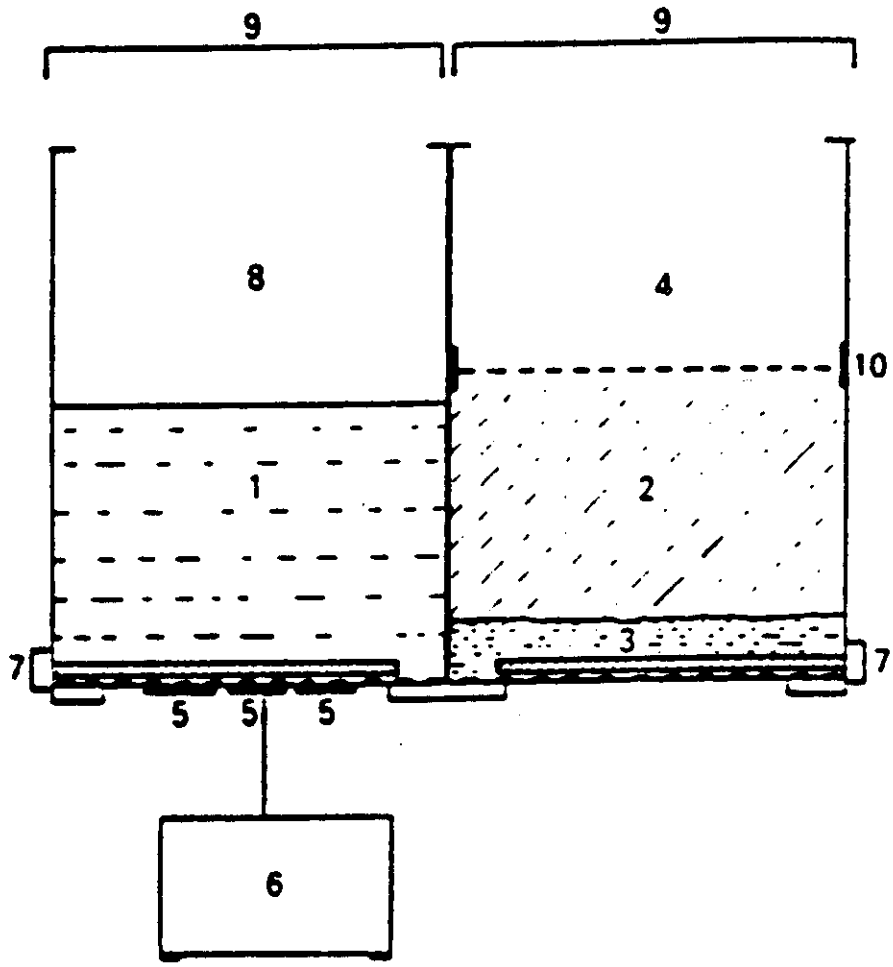


Figure 1. Typical commercially available twin tank cleaner. Key. 1. Hot solvent ultrasonic agitation. 2. Hot vapour zone approx. 60°C. 3. Boiling solvent. 4. Cooling zone. 5. Ultrasonic transducers. 6. Ultrasonic oscillator drive unit 20 kHz. 7. Immersion heater. 8. Draining zone after ultrasonic bath. 9. Compartment lids. 10. Cooling pipes.

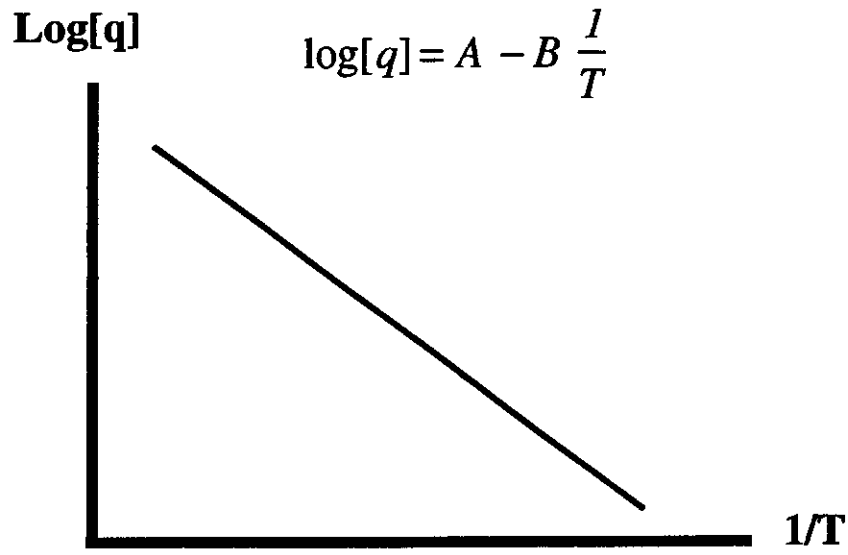
Desorption

Thermal desorption
Specific desorption rate :

q [Pa $m^3 s^{-1} m^{-2}$]

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

E activation energy for desorption



Bakeout between 150 – 300°C
Gives a significant gain for H_2O, CO, CO_2
At higher temperature > 400-500°C -> cracking of hydrocarbon molecules (C-H)
Reduction of the thermal outgassing at cryogenic temperatures

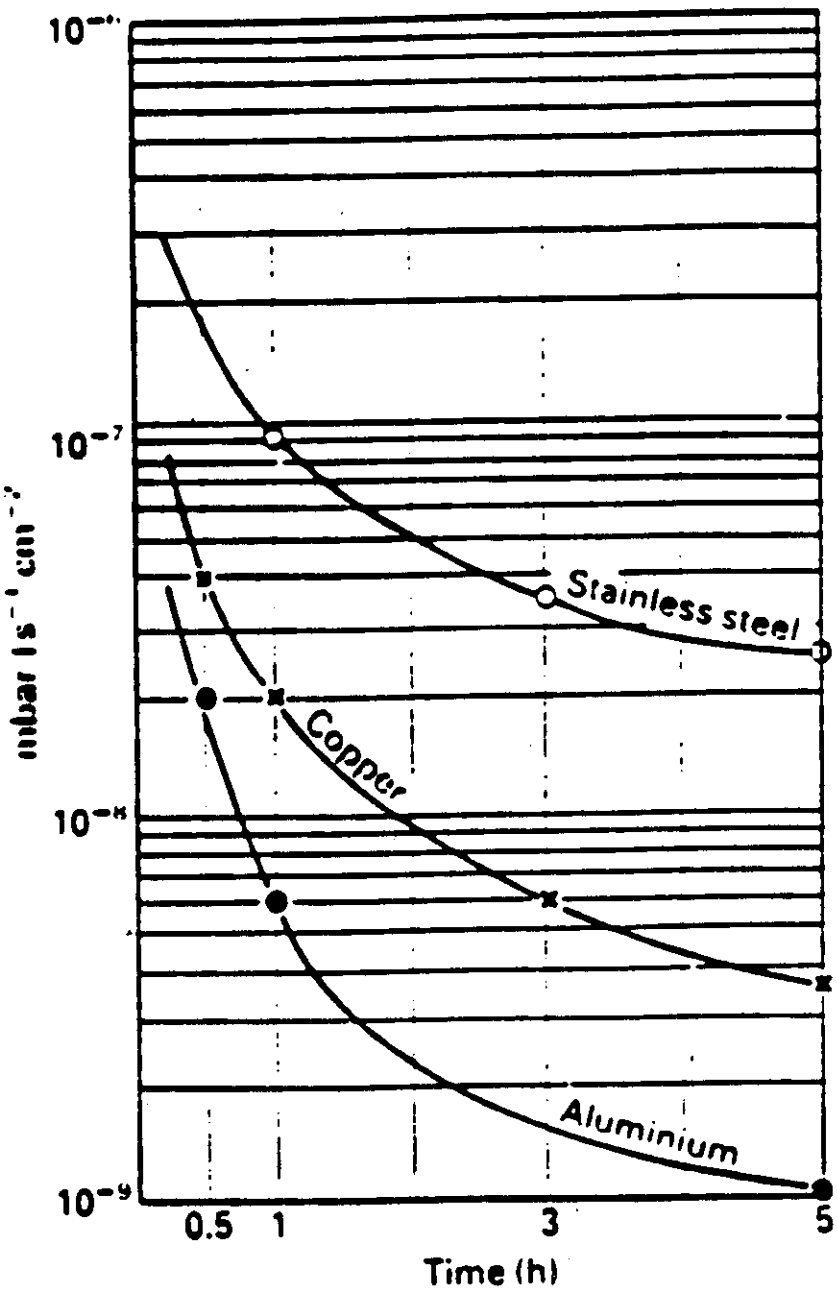


Figure 1. Typical outgassing rates for copper, aluminium and stainless steel at room temperature.

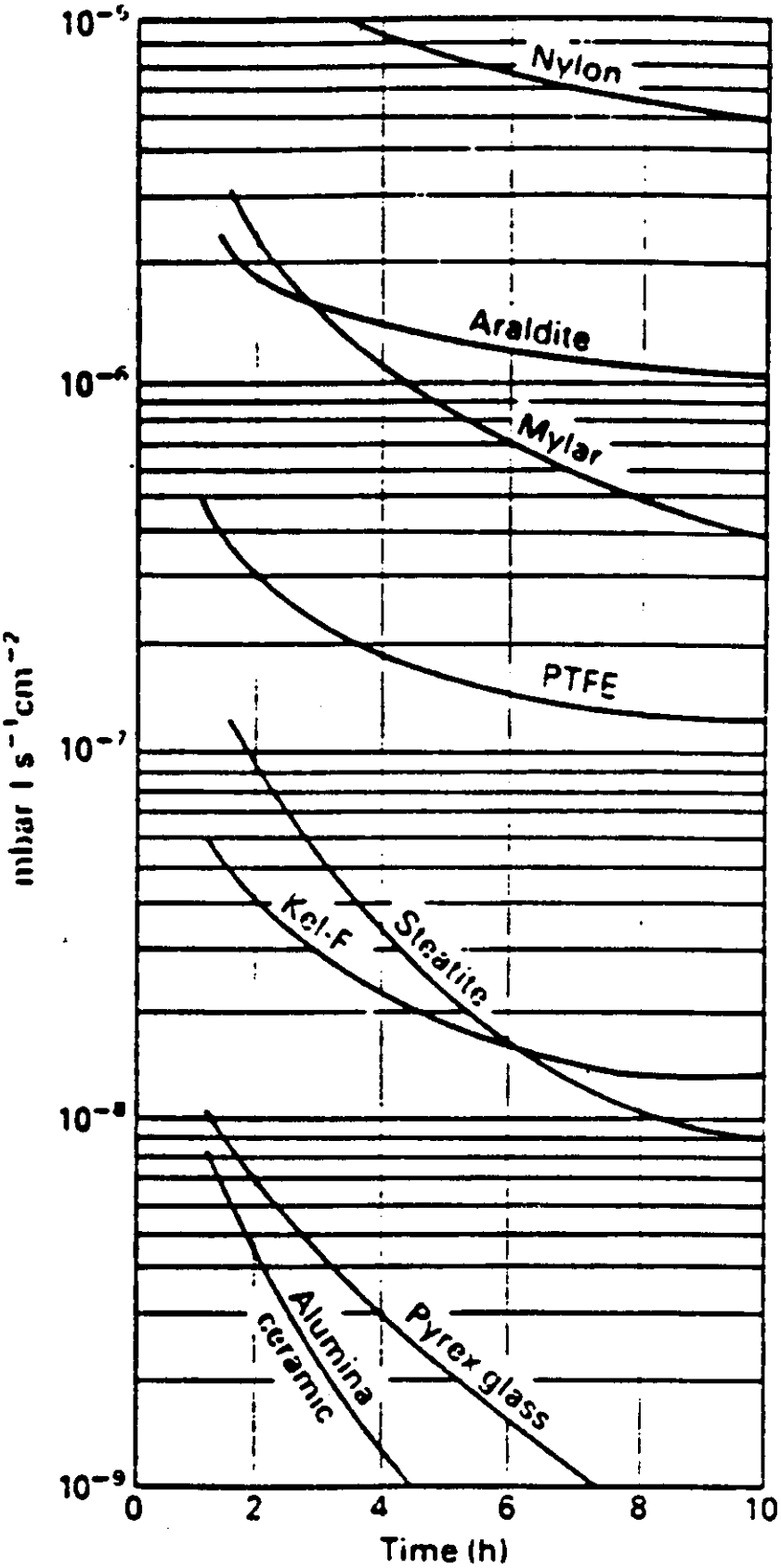


Figure 2. Typical outgassing rates for some plastic materials compared to ceramics and glass.

Synchrotron Radiation Induced Desorption

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

E, beam energy of electrons (GeV)
I, beam current (mA)
ρ, bending radius (m),

Critical energy of the S.R. spectrum (eV) $\varepsilon_c = 2.2 \cdot 10^3 \frac{E^3}{\rho}$

Photon flux (s^{-1}) $\dot{\Gamma} = 8.08 \cdot 10^{17} I E$

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

Gas desorption occurs in two steps :

-> photons -> produce photo-electrons

-> photo-electrons -> excite molecules which subsequently may desorb thermally

Gas flow : $Q = \eta \dot{\Gamma}$

$Q = K \eta I E + Q_o$ with Q_o, the static, thermal desorption.

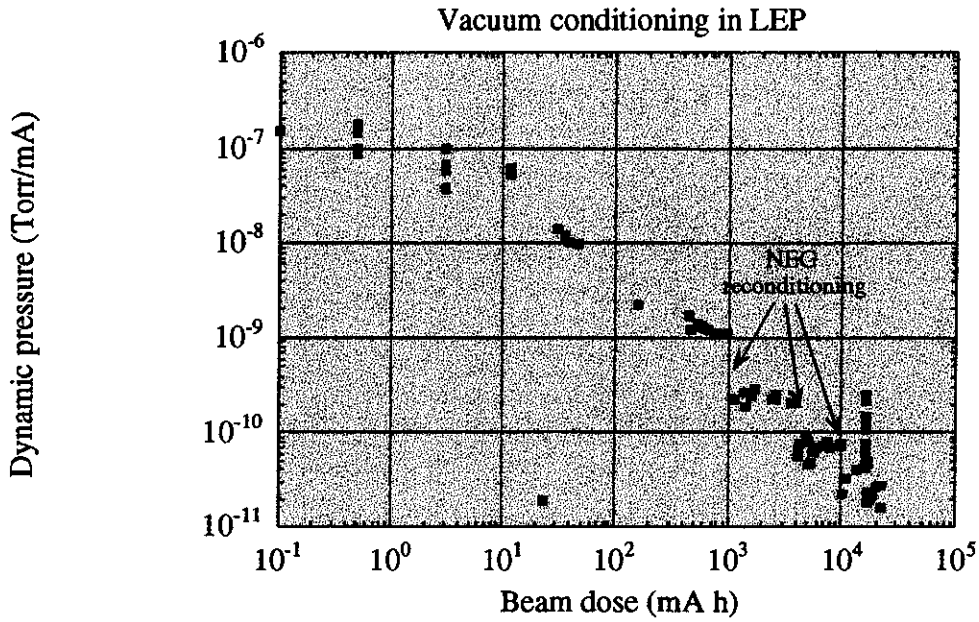
η, molecular desorption yield (molecules per photon).

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

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

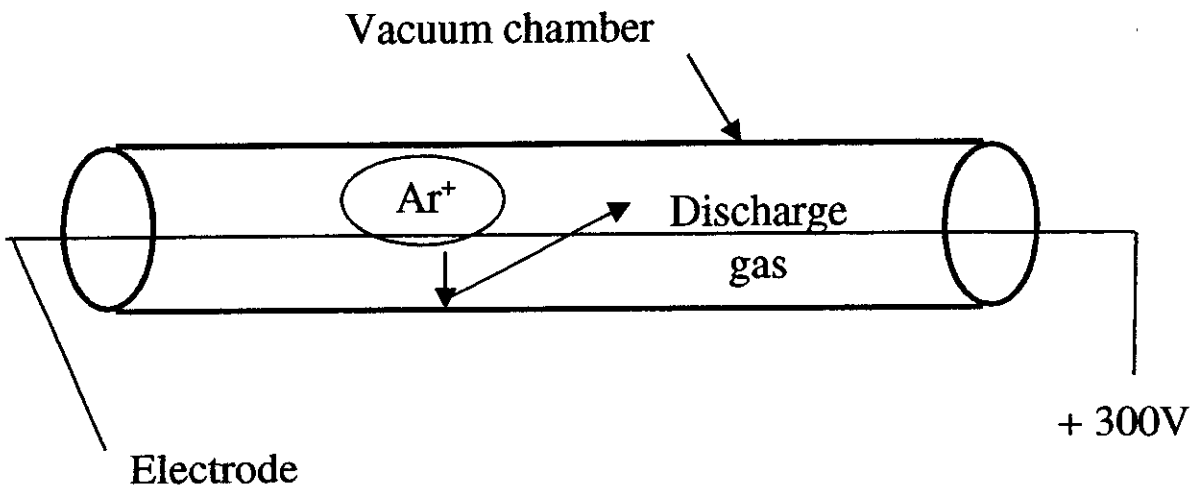
'Beam cleaning' (scrubbing) of the vacuum system.

Beam scrubbing of the LEP vacuum system



Dose scale may be given in terms of accumulated photons/m or in Ah.

Glow-Discharge Cleaning



Cleaning of the surface by ion bombardment
(usually Argon or some other inert gas)

Dose approx. 10^{18} -10^{19} ions/cm^2

Argon pressure between 10^{-1} – 10^{-2} Pa for optimum conditions

Desorption of chemisorbed, strongly bound molecules corresponding to a high activation temperature.

Effective cleaning by removing the top layer of the surface by sputtering. -> Tokamak vacuum systems

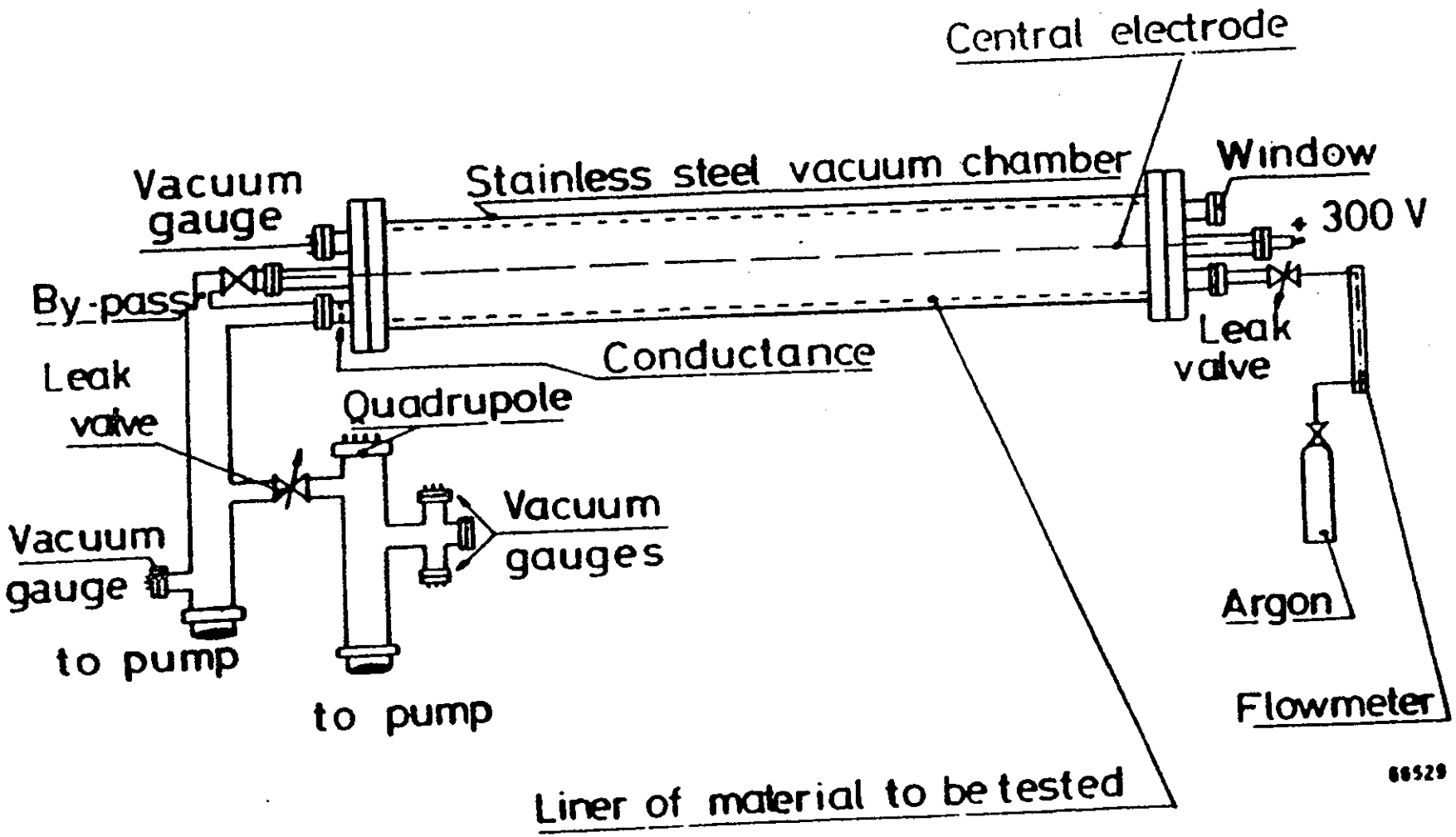
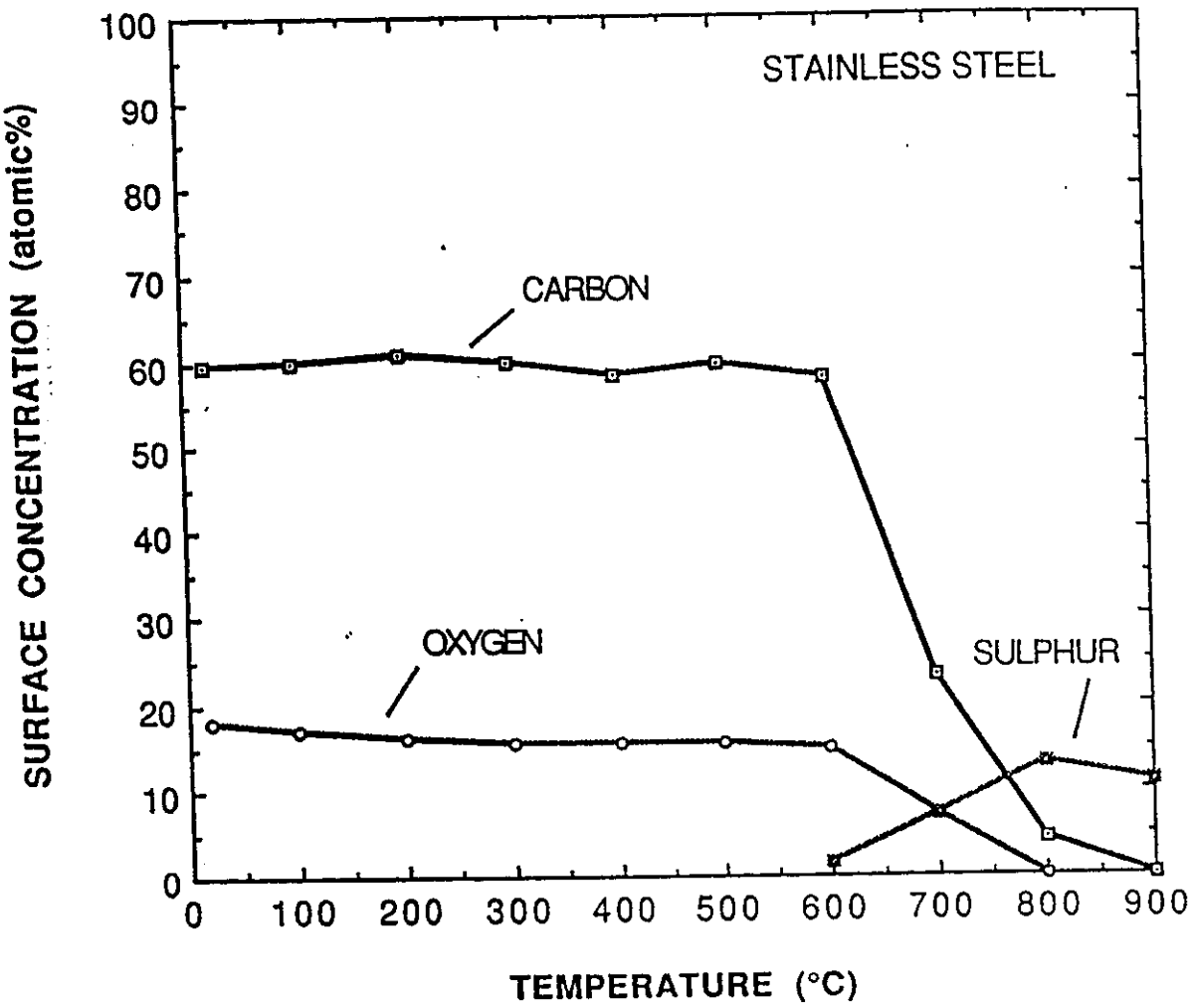

Central electrode
Vacuum gauge
Stainless steel vacuum chamber
Window
300 V
By-pass
Conductance
Leak valve
Leak valve
Quadrupole
Vacuum gauges
Vacuum gauge
to pump
to pump
Argon
Flowmeter
66529
Liner of material to be tested

Figure 12


STAINLESS STEEL
CARBON
OXYGEN
SULPHUR
SURFACE CONCENTRATION (atomic%)
TEMPERATURE (°C)
0
10
20
30
40
50
60
70
80
90
100
0
100
200
300
400
500
600
700
800
900

Choice of materials

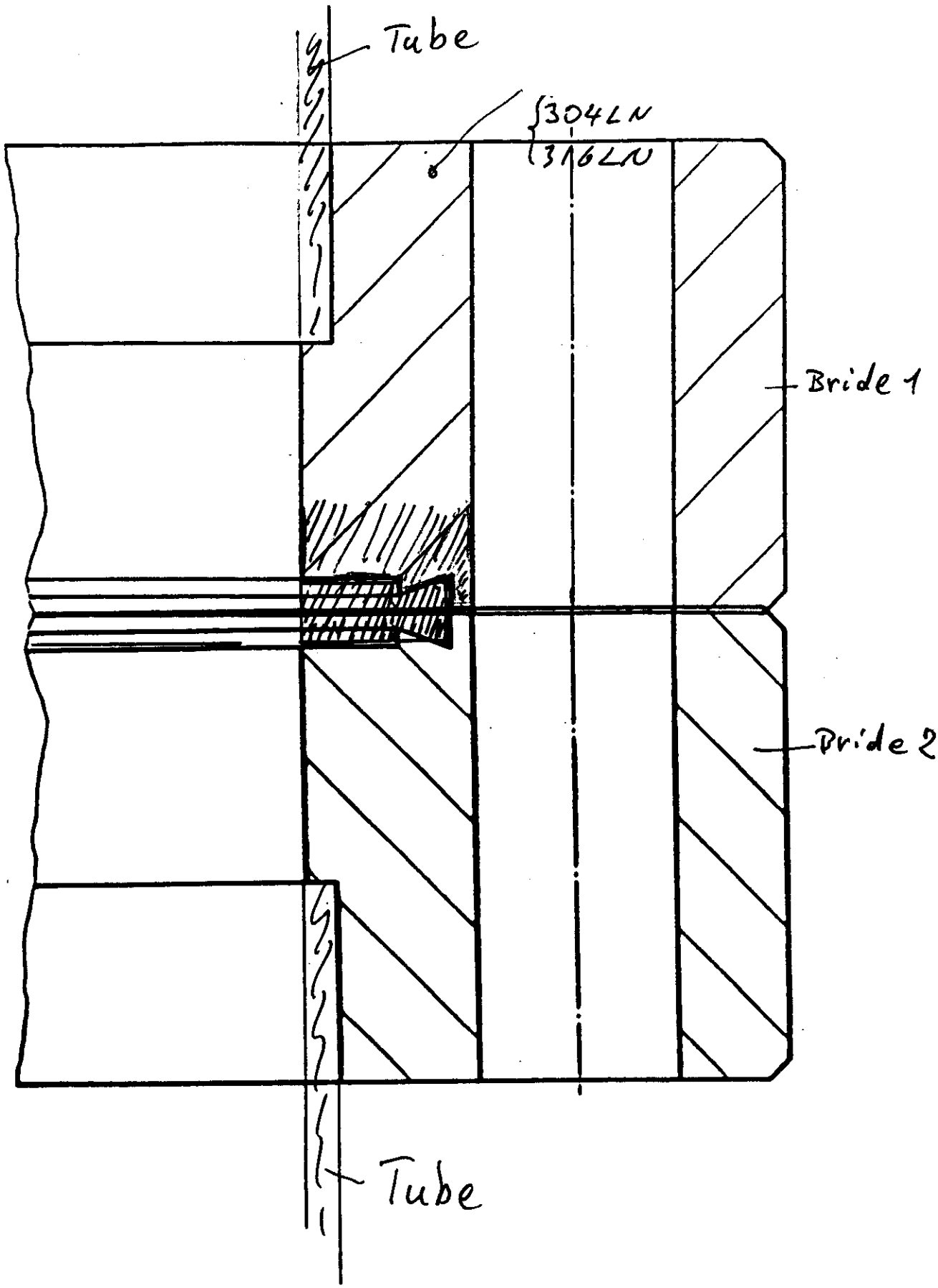
low outgassing rate
low vapor pressure
temperature resistant -> bakeout
thermal and electrical conductivity
corrosion resistance
low induced radioactivity
high mechanical strength
machining
welding
low cost

Examples:

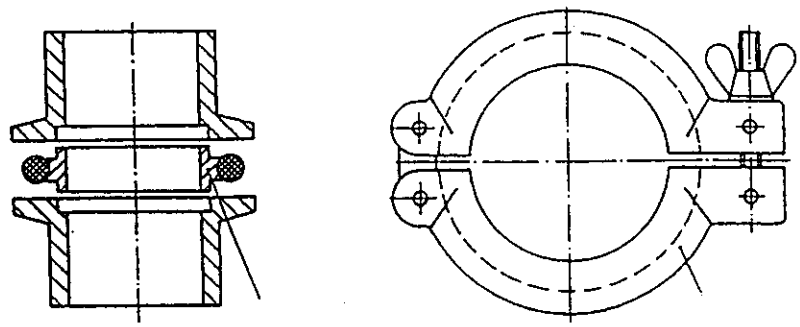
Stainless steel
Aluminium
Copper

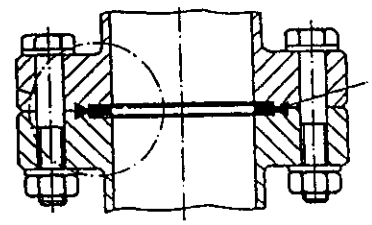
Ceramics
- low porosity
- electrically
- insulating
- brazing to metal

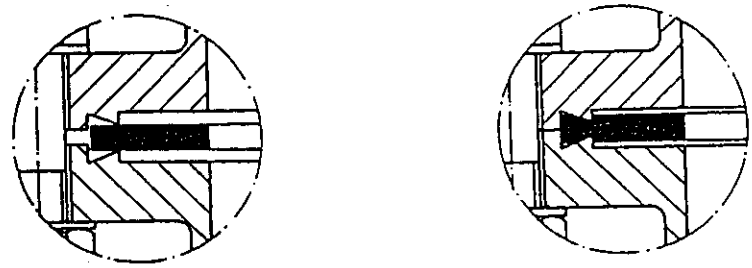
Polymers, Plastics only for very particular applications

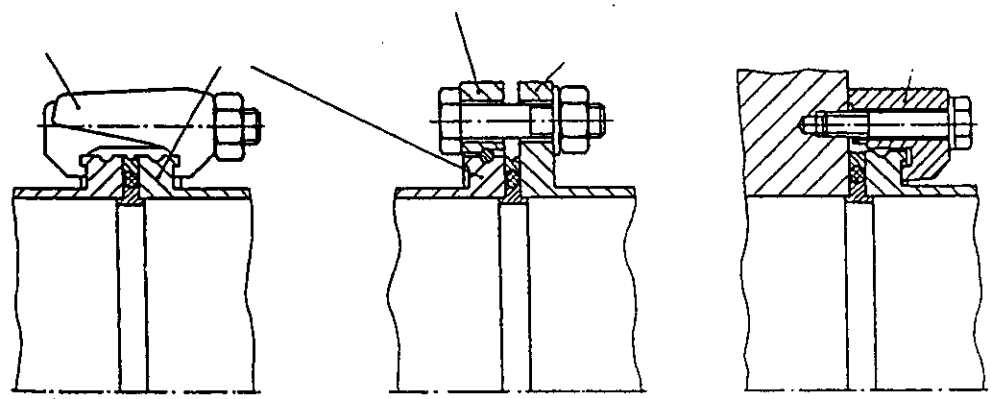


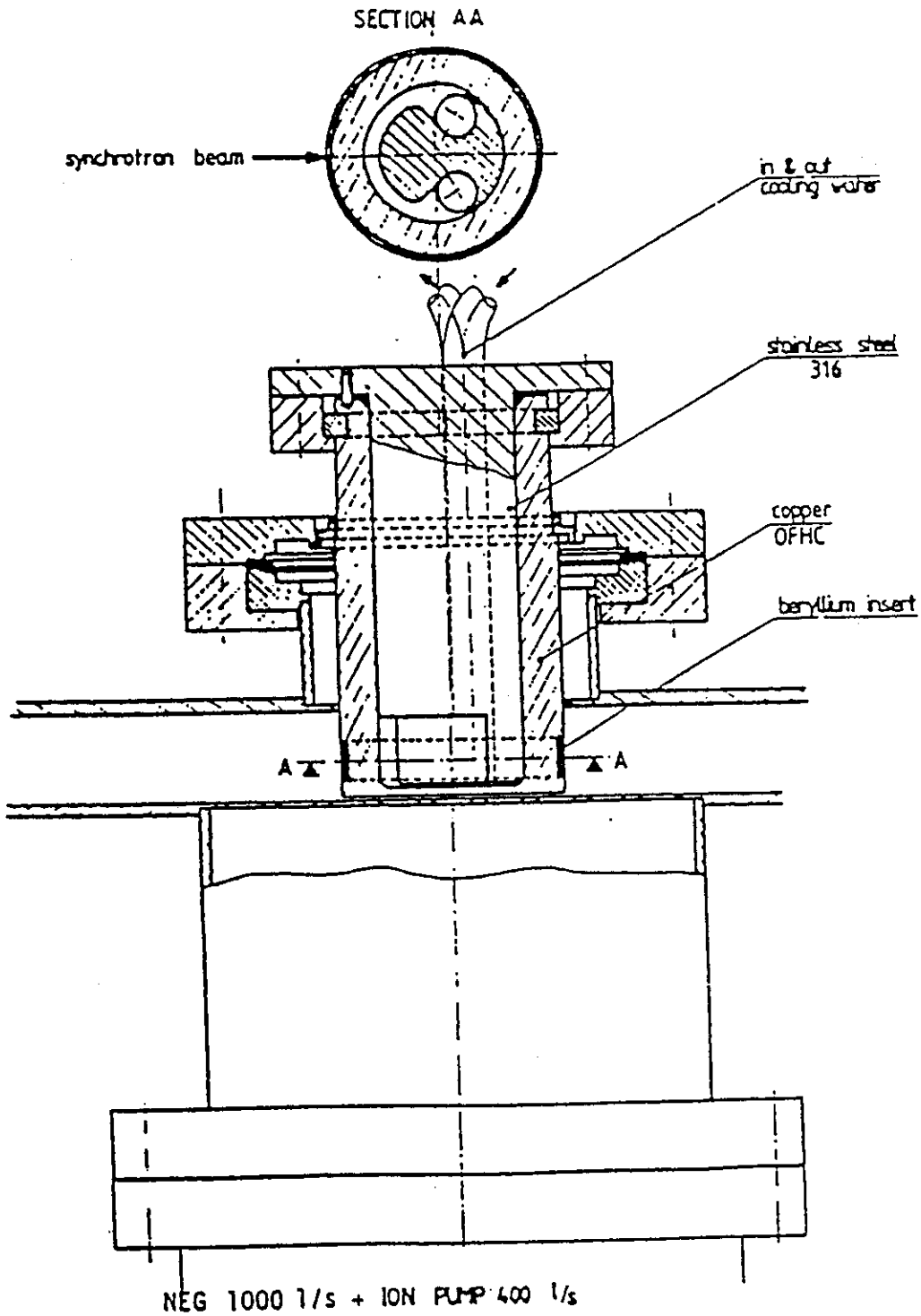
Type "ConFlat"





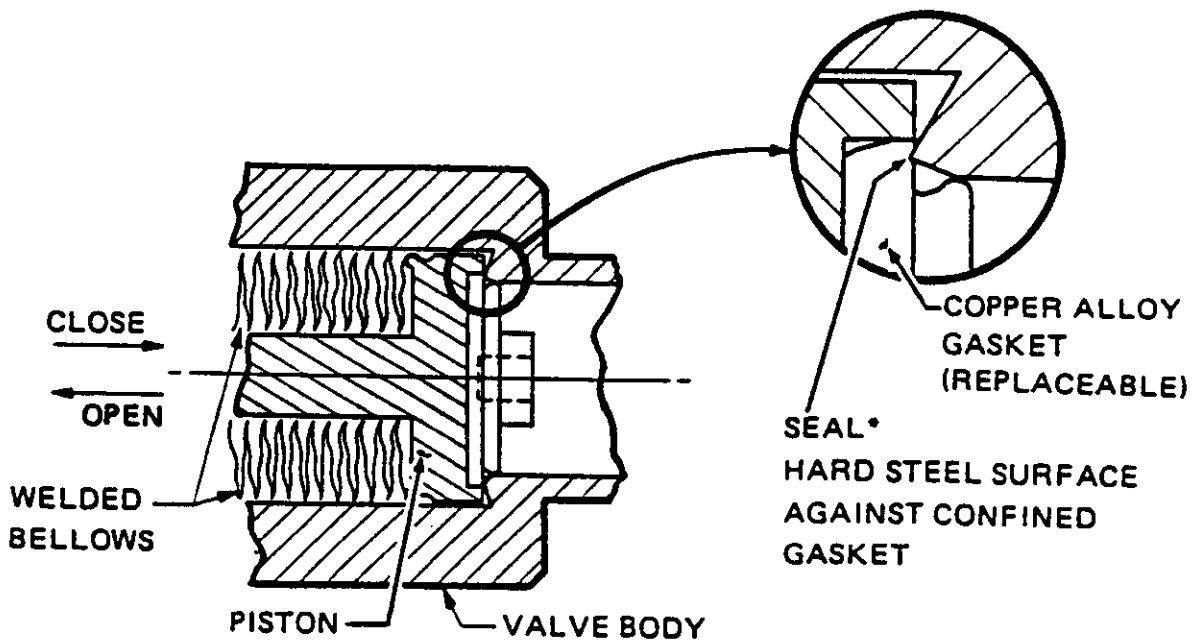




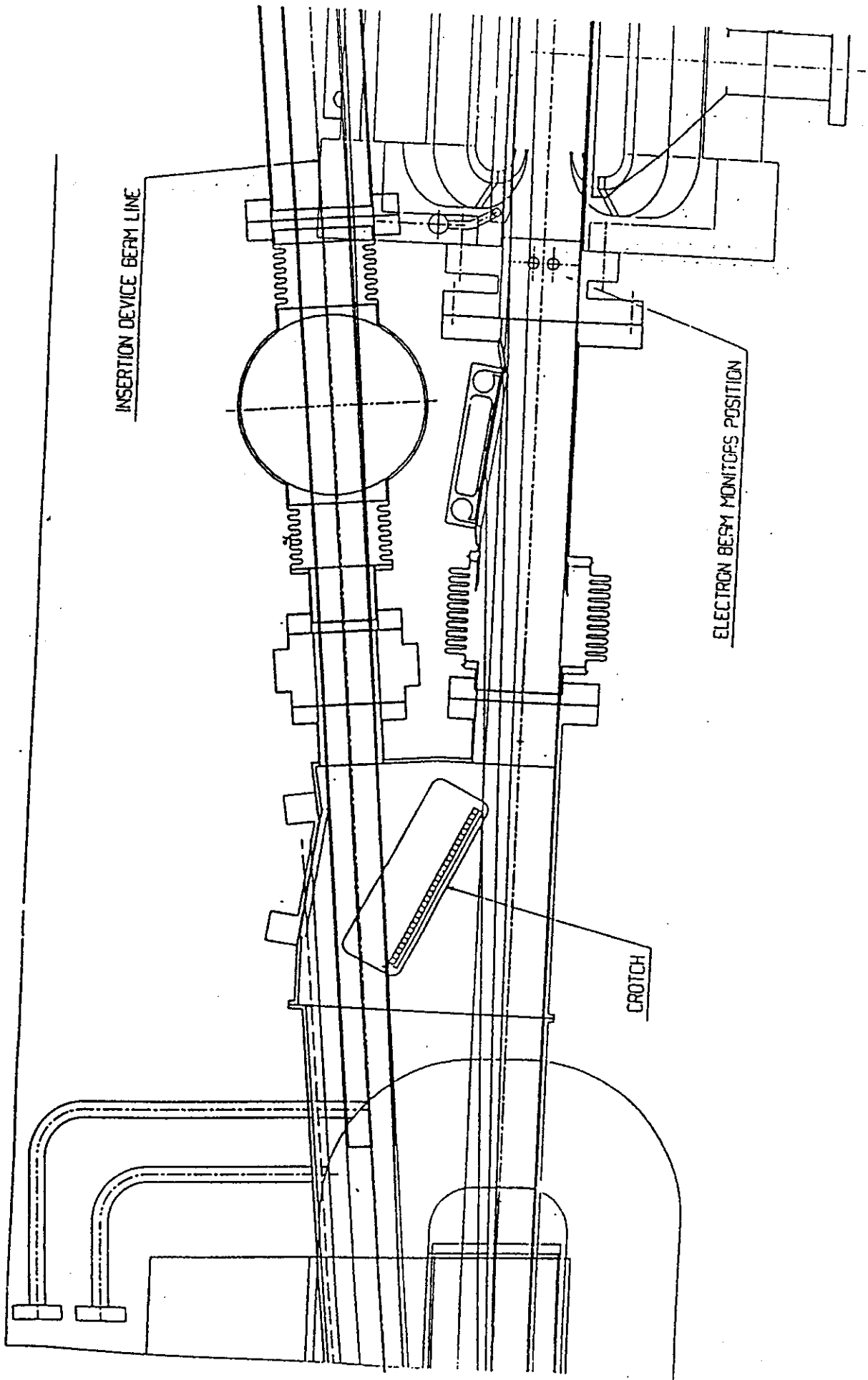


CROSS SECTION VACUUMCHAMBER AT CROTCH

Fig. 7.4.5.1



* SEAL IS IDENTICAL IN ALL VALVES; PARTIAL VALVE BODY SHOWN IS THAT OF MINI-VALVE.


INSERTION DEVICE BEAM LINE
ELECTRON BEAM MONITORS POSITION
CROTCH