UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION
INTERNATIONAL ATOMIC ENERGY AGENCY
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
I.C.T.P., P.O. BOX 586, 34100 TRIESTE, ITALY, CABLE: CENTRATOM TRIESTE

H4.SMR/1013-4

# SCHOOL ON THE USE OF SYNCHROTRON RADIATION IN SCIENCE AND TECHNOLOGY:
*"John Fuggle Memorial"*

**3 November - 5 December 1997**

***Miramare - Trieste, Italy***

---

# *UHV Techniques*

**O. Gröbner**
**CENTRE, Geneva - Switzerland**

MAIN BUILDING STRADA COSTIERA, 11 TEL. 2240111 TELEFAX 224163 TELEX 460392 ADRIATICO GUEST HOUSE VIA GRIGNANO, 9 TEL. 224241 TELEFAX 224531 TELEX 460449
MICROPROCESSOR LAB. VIA BEIRUT, 31 TEL. 2249911 TELEFAX 224600 TELEX 460392 GALILEO GUEST HOUSE VIA BEIRUT, 7 TEL. 2240311 TELEFAX 2240310 TELEX 460392
ENRICO FERMI BUILDING VIA BEIRUT, 6 (TELEPHONE, FAX AND TELEX THROUGH MAIN BUILDING)

Trieste, November 1997

# UHV - Techniques

### O. Gröbner

### CERN

1) Some basic facts
2) Building blocks of a vacuum system
3) How to get clean ultrahigh vacuum
4) Desorption phenomena
5) Examples from synchrotron light sources

Oswald Gröbner
CERN
LHC-VAC
CH-1211 Geneva 23
Switzerland

email : Oswald.Grobner@cern.ch

# Basic Formulae

Molecular density encountered by the circulating beam

Pressure is a force per unit area

$$P = \text{const}\ n\ m\ \langle v^2 \rangle$$

n = number of molecules/m3
m = mass of a molecule
$\langle v^2 \rangle$ = mean square velocity of the molecules

<u>Units of pressure</u> :

| | | |
|---|---|---|
| Pascal | 1 Pa | = 1 Newton/$m^2$ |
| bar | 1 bar | = $10^5$ Pa |
| Torr | 1 Torr | = 133 Pa |

The relation between pressure and molecular density is derived from Avogadro's number and the definition of the volume per gram mole

$$V_o = 22.4\ l \text{ at STP}$$

At a temperature of 273 °K
and 1 Atmosphere = $1.013\ 10^5$ Pa
one Mole contains $6.023\ 10^{23}$ molecules.

1 Pa l contains $2.65\ 10^{17}$ molecules at 273 °K
1 Torr l contains $3.53\ 10^{19}$ molecules at 273 °K

# Molecular Concentration

$$n = \frac{N}{V}$$

V volume

N number of molecules

$$\rho = n M m_o$$

$\rho$ specific mass

M molecular mass

$$m_o = 1.6604\ 10^{-27} \quad g$$

## Pressure

p force per unit surface

Pascal, $N/m^2$, Torr, bar

1 Torr = 133 Pa

1 mbar = 100 Pa

mean momentum of a molecule

$$\bar{q} = M m_o \bar{v}$$

$\bar{v}$ mean velocity follows from the Maxwell-Boltzmann distribution

# Maxwell - Boltzmann Velocity distribution

velocity : $v^2 = \dot{x}^2 + \dot{y}^2 + \dot{z}^2$

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

the maximum of the distribution gives the most probable velocity

$$v_m = \sqrt{\frac{2\,k\,T}{m}} = 1.29\;10^2\,\sqrt{\frac{T}{M}} \qquad (m\,/\,s)$$

the mean velocity of the molecules is

$$\boxed{\bar{v} = \sqrt{\frac{8\,k\,T}{\pi\,m}} = 1.13\;v_m}$$

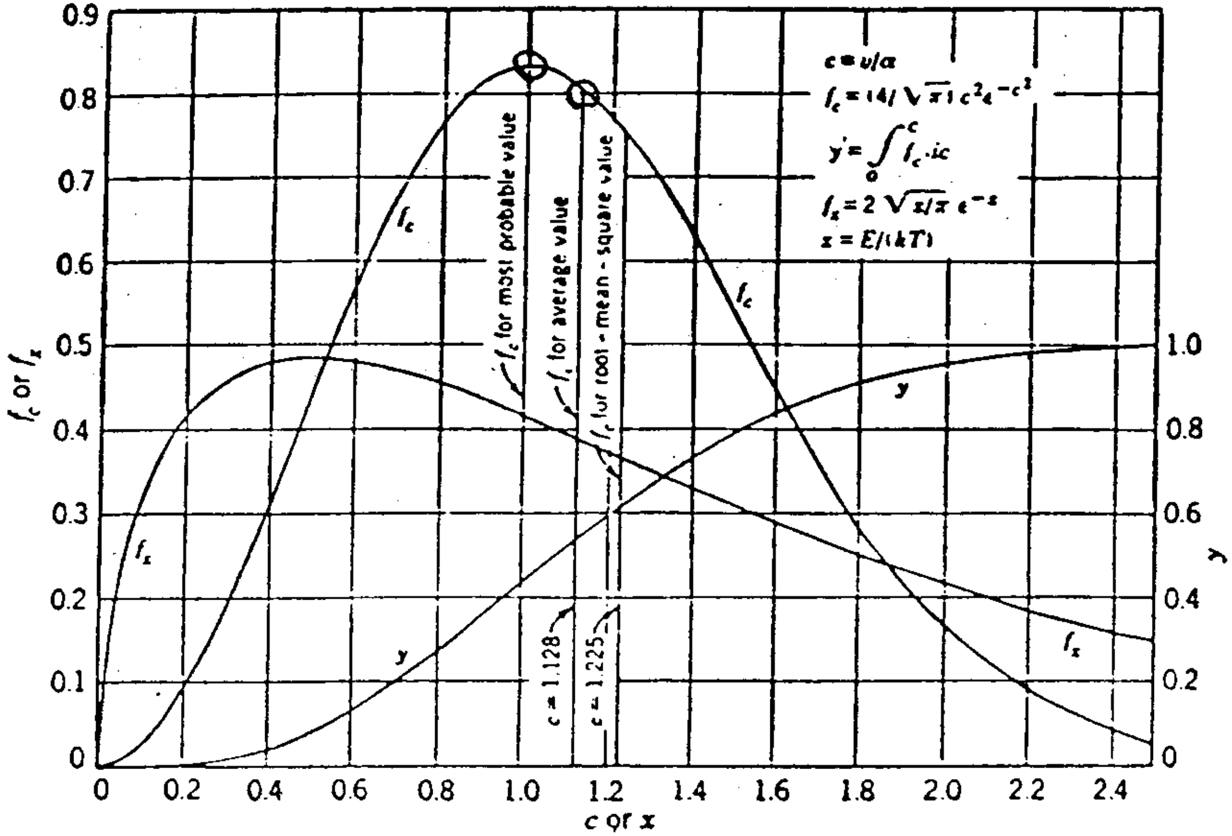


Fig. 1.1. Plots illustrating Maxwell-Boltzmann distribution laws. Plot $f_c$ shows distribution function for random velocity, $c$ expressed in terms of the most probable velocity $\alpha$; plot $f_x$ shows distribution function for energy, $E$, in terms of $x = E/(kT)$; $y$ corresponds to the fraction of the total number of molecules for which the random velocity (expressed in terms of $\alpha$) is less than or equal to a given value $c$.

## 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 |

# Wall collisions

$\nu$ = const. $n$ $\bar{v}$

$\nu$ frequency of wall collisions

const. = 1/4

ainsi

$$\nu = \frac{1}{4}\, n\, \bar{v}$$

substituting $$\bar{v} = \sqrt{\frac{8\,k\,T}{\pi\, m}}$$

gives

$$\nu = n \sqrt{\frac{k\,T}{2\,\pi\, m}}$$

# Pressure

$$p = \text{const.}\ \bar{q}\ v$$

Taking into account the random movement of the individual molecules $\quad \text{const.} = \pi/2$

Combining the previous results

$$p = \frac{\pi}{2} m \sqrt{\frac{8\,kT}{\pi\, m}}\ n \sqrt{\frac{kT}{2\,\pi\, m}}$$

and finally :

$$\boxed{p = n\ k\ T}$$

Expressed in units of Mole : $\quad n = \frac{N_a}{V_o}$

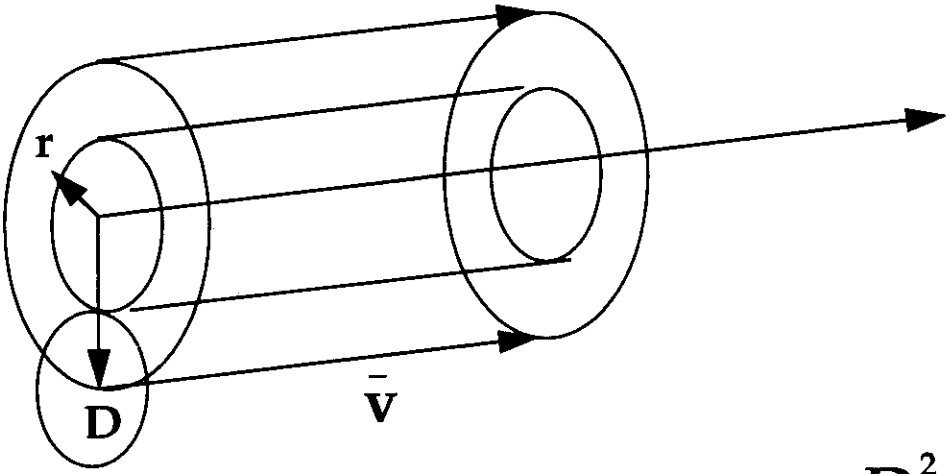
$$\boxed{p\ V_o = N_a\ k\ T = R\ T}$$

R macroscopic gas constant

# Mean free path, collisions

$D = 2r$ molecular diametre

$\bar{v}$ = mean velocity of a molecule



Volume of cylinder $\pi D^2 \bar{v}$

molecular density $n$

Per second a molecule traverses a distance given by its mean velocity. During this time, the molecule will collide with the molecules inside the cylinder of radius D

Number of collisions $Z = \pi D^{2}\,\bar{\ }\;\; n$

In reality, the other molecules also move and this leads to a correction factor $\sqrt{2}$

$$\boxed{l = \frac{\bar{v}}{Z} = \frac{1}{\sqrt{2}\,\pi\, n\, D^2}} \quad \text{-->} \quad \boxed{l\, n \propto l\, p = \text{constant}}$$

# Vacuum characteristics

gas : Nitrogen, $N_2$, 20°C, M = 28

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

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

$\rho = M\, m_o\, n$ $\qquad$ $M\, m_o = 4.65\ 10^{-26}$ kg ,

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

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

$l = \frac{1}{\sqrt{2}\ \pi\ d^2\ n}$ $\qquad$ d (N2) = $3.15\ 10^{-10}$ m

# Conductance for molecular flow

molecular flow : mean free path >> distance or dimensions of the system

Knudsen :

$$Q = \text{const. } \bar{v} \, (p_1 - p_2)$$

$$Q = c \, (p_1 - p_2)$$

conductance $c \ (m^3 \ s^{-1})$

$$\boxed{c = \frac{4}{3} \frac{\bar{v}}{\int_0^L \frac{H}{A^2} dL}}$$

A section

H perimeter

L length

Note :

c does not depend on the pressure

c proportional to molecular velocity, hence the conductance increases with temperature and decreases with molecular weight $\propto \sqrt{\frac{T}{M}}$

Example: circular hole :

$$c = \frac{1}{4} \bar{v} A \qquad \bar{v} = \sqrt{\frac{8kT}{\pi M m_0}} \qquad c = 36.4 \ A \sqrt{\frac{T}{M}}$$

cylindrical tube :
length L
radius r

$$c = 305 \left( \frac{r^3}{L} \right) \sqrt{\frac{T}{M}}$$

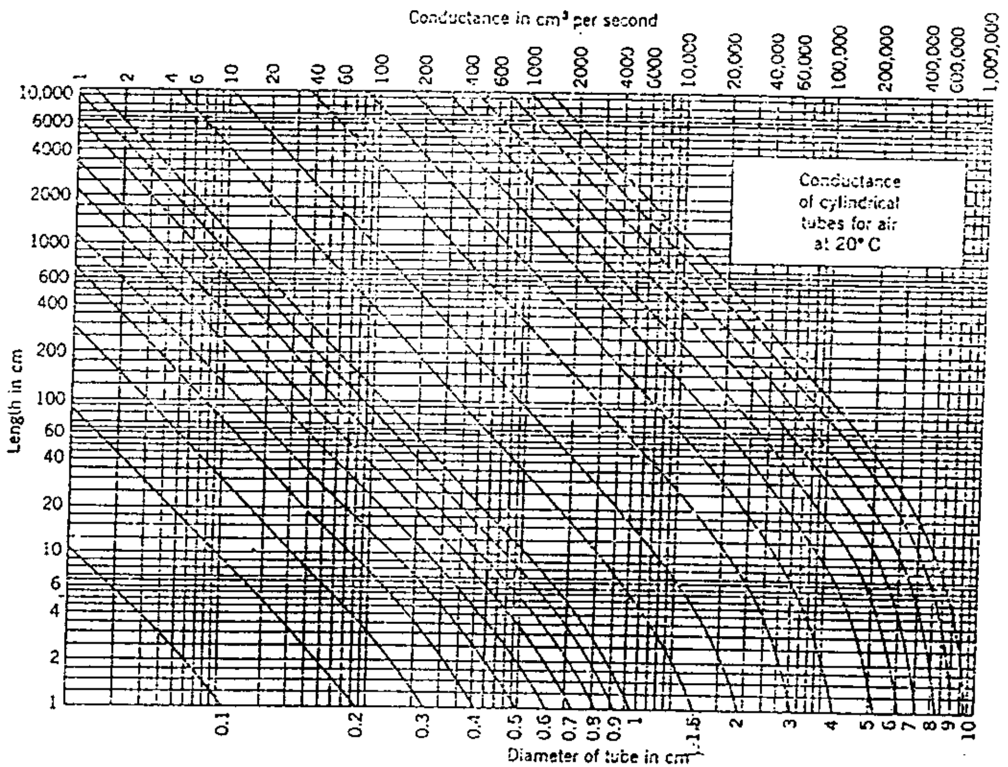


Fig. 2.1. Plots of conductance of cylindrical tubes for air at 20° C calculated according to equation 2.40.

# Total and partial pressures

each gas component $n_1, n_2, n_3,$

contributes a partial pressure

$$p_i = n_i \, k T$$

the total pressure becomes

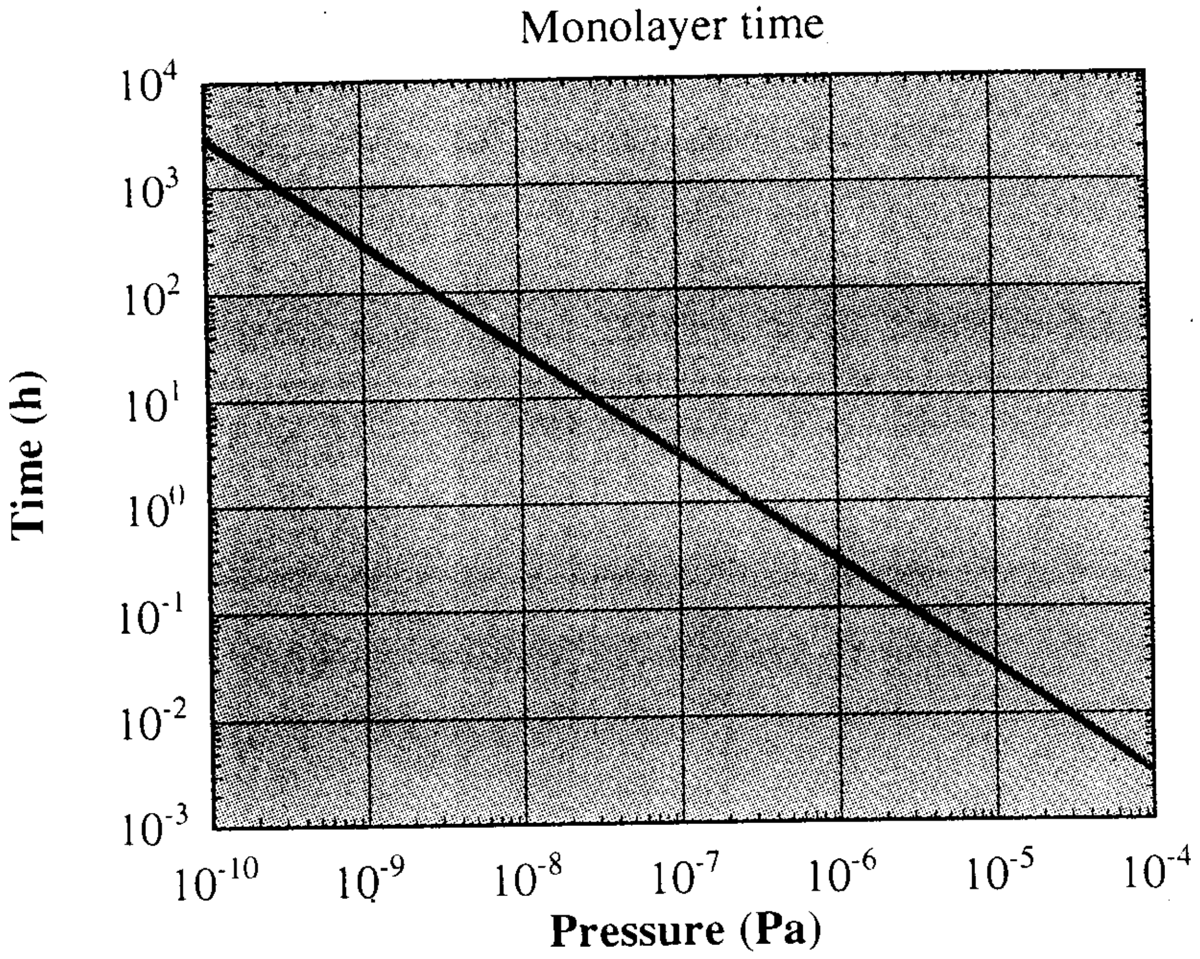
$$p = \sum p_i = k \, T \sum n_i$$

-> total pressure measurement

-> partial pressure measurement

# Partial Pressures for Air

| | % | $P_i$ (Pa) |
|---|---|---|
| $N_2$ | 78.1 | $7.9\ 10^4$ |
| $O_2$ | 20.95 | $2.79\ 10^3$ |
| 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 | $8.7\ 10^{-6}$ | $1.16\ 10^{-3}$ |
| $O_3$ | $1.1\ 10^{-6}$ | $1.46\ 10^{-4}$ |



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

| | |
|---|---|
| monolayer coverage | $\Theta$ |
| molecular velocity | $\bar{v}$ |
| gas density | n |
| sticking probability | s = 1 |

# Lifetime and Lossrate of beam particles

Loss by Bremsstrahlung

$- dE/dx = E/X_0$

$X_0$ Radiation length

$-1/N \; dN/dt = c\rho/X_0 \; W = 1/\tau$

Density $\rho = m_0/kT \; M \; P$ and

$W = \ln(E/\Delta E)$ represents the propability of emitting a photon with an energy $h\nu > \Delta E$ per radiation length

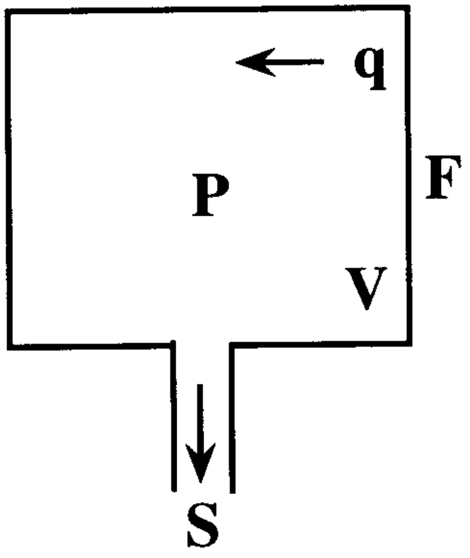
The beam lifetime

$\tau = X_0/c\rho W = \text{const} \; X_0/P$

For CO :

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

# Vacuum System



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

in stationary conditions

$$P = \frac{qF}{S}$$

in dynamic conditions

$$V\frac{\partial P}{\partial t} = qF - SP$$

solution (K follows from initial conditions)

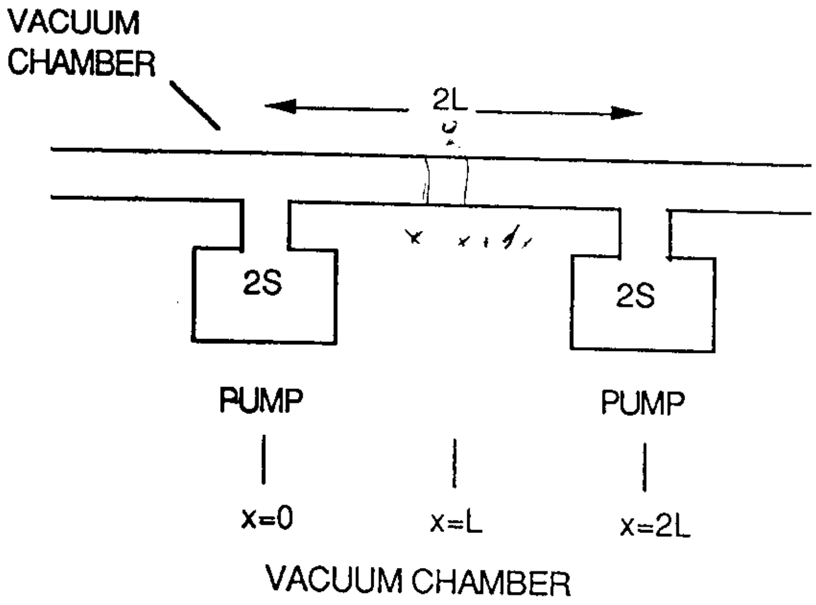
$$P(t) = K e^{-\frac{S}{V}t} + \frac{qF}{S}$$

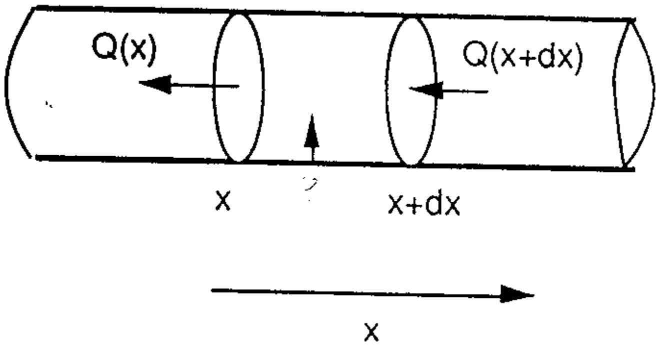
time constant for pumpdown is given by $\frac{S}{V}$

low pressure in the system requires a **low outgassing rate**

and a **high pumping speed**

# SIMPLE MACHINE





THE GAS FLOW **Q** THROUGH THE TUBE IS GIVEN BY THE EQUATION

$\frac{dQ}{dx} = -c \frac{d^2P}{dx^2}$

$$Q = - c \; dP/dx$$

where P is the gas pressure (Torr)

V is the volume per unit length of tube (l $m^{-1}$)

w is the perimeter of the tube (m)

c is the specific conductance of the tube (l $s^{-1}$ m)

a is the gas desorption per unit length of tube (Torr l $s^{-1}$ $m^{-1}$)

q is the gas desorption per unit area of tube (Torr l $s^{-1}$ $m^{-2}$)

a=q w

THE CHANGE IN THE NUMBER DENSITY OF MOLECULES IN THE VOLUME ELEMENT **Vdx** BETWEEN **x** AND **x+dx** IS

$$V\ dx\ dP/dt = a\ dx + c\ [dP/dx]_{x+dx} - c\ [dP/dx]_x$$

$$V\ dP/dt = a + c\ (d^2P/dx^2)$$

IN THE STEADY STATE $dP/dt=0$

$$d^2P/dx^2 = -c/a$$

BOUNDARY CONDITIONS

BY SYMMETRY AT x=L $dP/dx= 0$

AT x=0 and x=2L $P=aL/S$

$$cdP/dx=aL$$

THE FINAL SOLUTION IS

$$P = aL/S + aLx/c - ax^2/2c$$

MAX. PRESSURE

$$P_{max} = aL/S + aL^2/2c$$

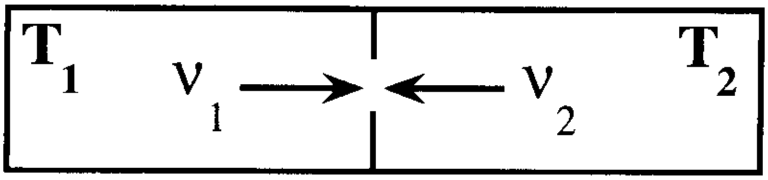
AVERAGE PRESSURE

$$P_{av} = aL/(1/S + L/3c)$$

# Unequal temperatures

Vacuum system with one part at T1 and a second part, containing e.g., the measuring gauges. Volume 1: P1 and n1

## Thermal transpiration



--> The rate of molecules striking the opening from side 1 must balance the molecules from side 2 hence $\nu_1 = \nu_2$

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

it follows that $n_1\sqrt{T_1} = n_2\sqrt{T_2}$

or

$$P_1 \Big/ \sqrt{T_1} = P_2 \Big/ \sqrt{T_2}$$

## 5. VACUUM PUMPS AND VACUUM GAUGES USED IN LARGE ACCELERATOR VACUUM SYSTEMS

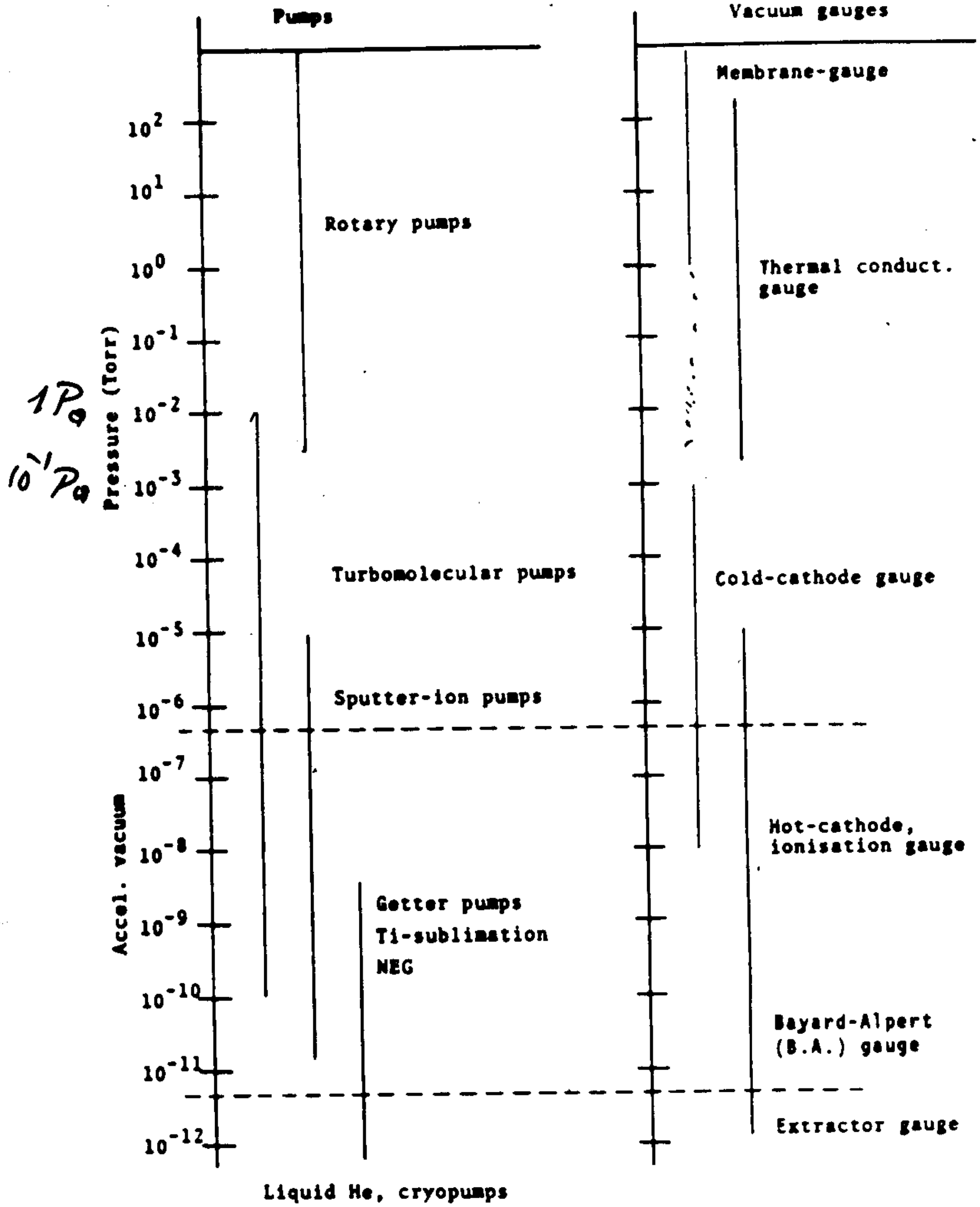
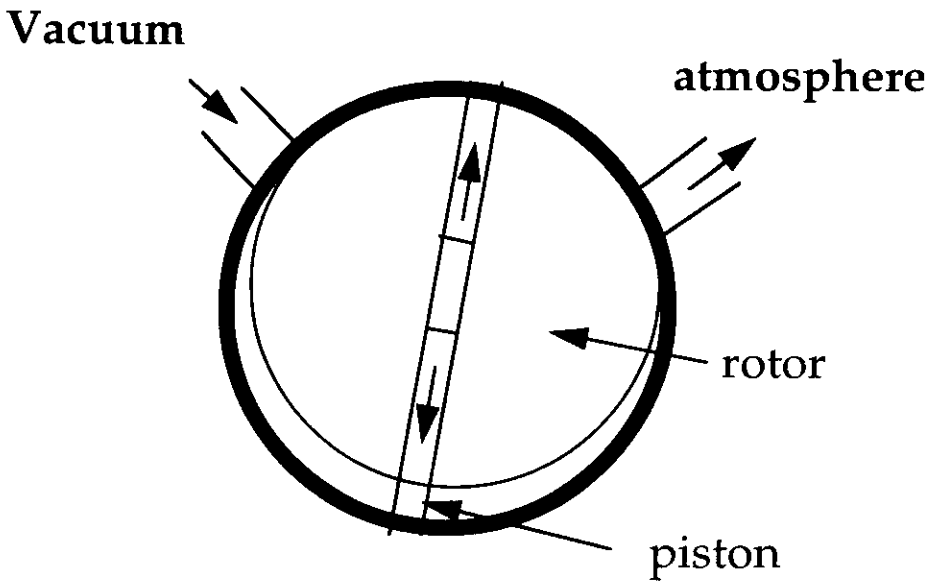


Fig. 4

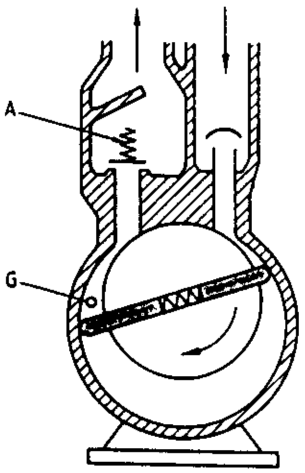
## Rotary Pump

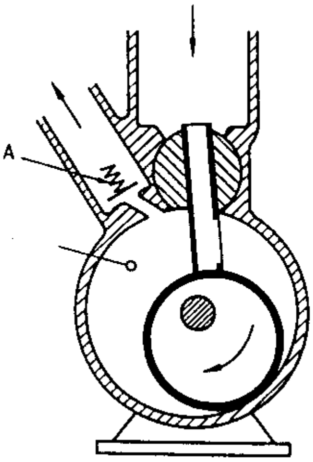


Lubrification: oil

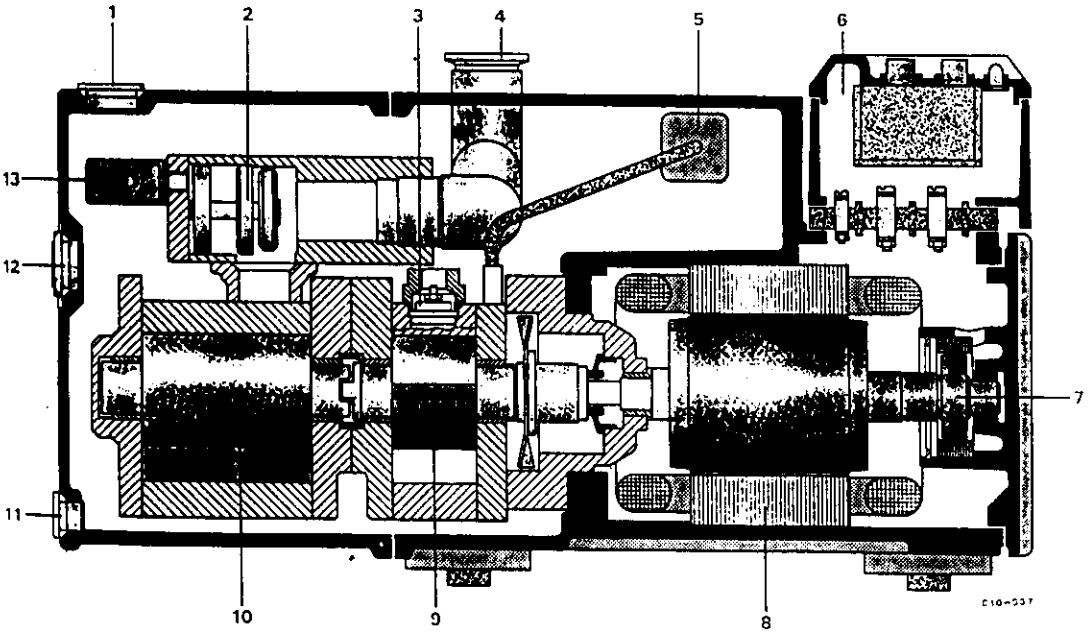
limit pressure : 0.1 Pa

pumping speed ~ 4 - 30 $m^3$ / h

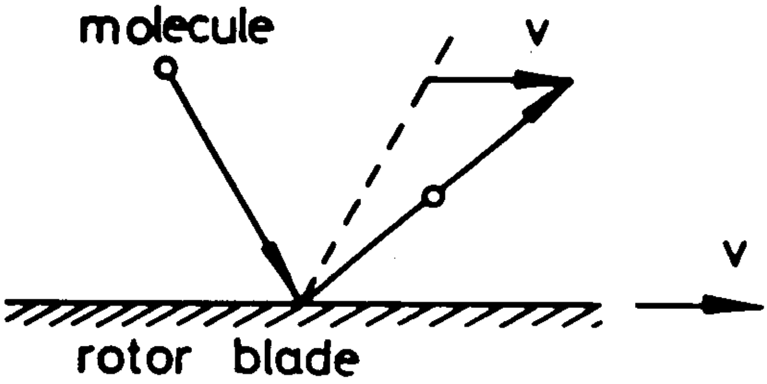


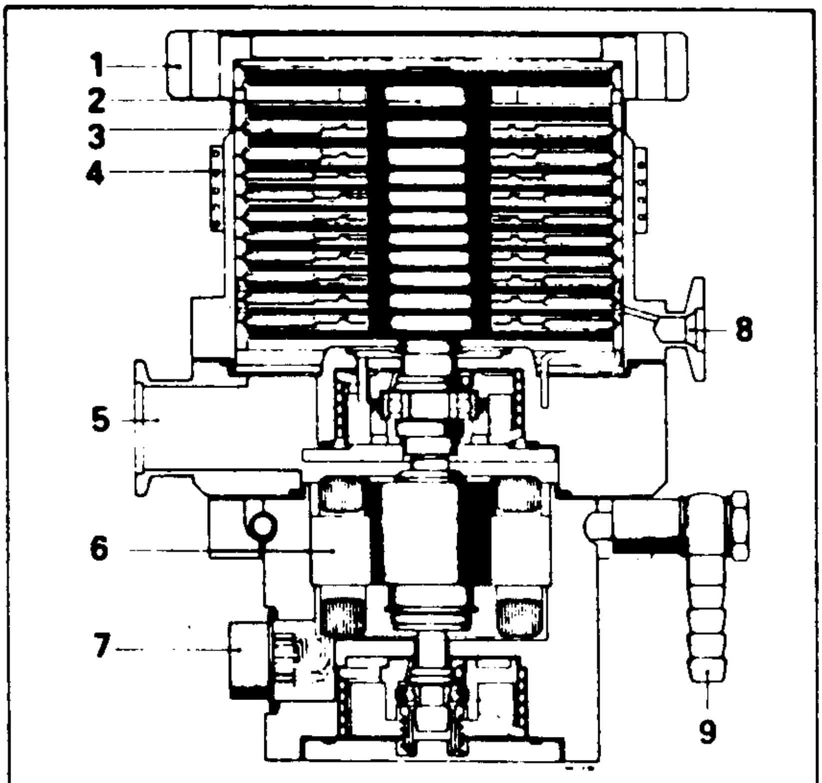


$\sim 10^{-1}$ Pa



# Turbo molecular Pump

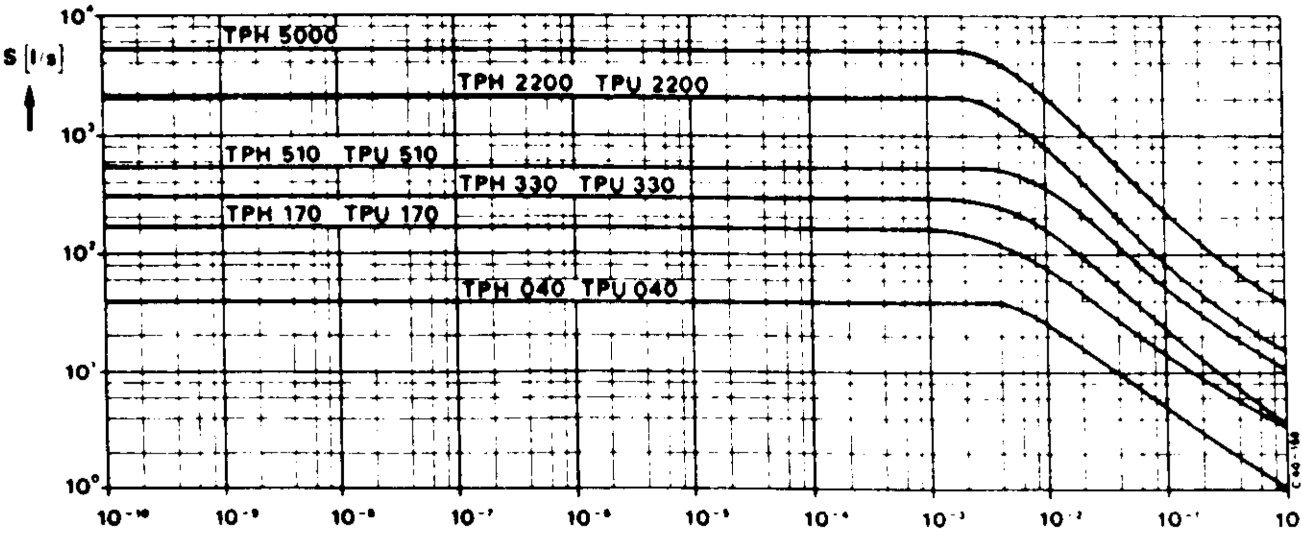




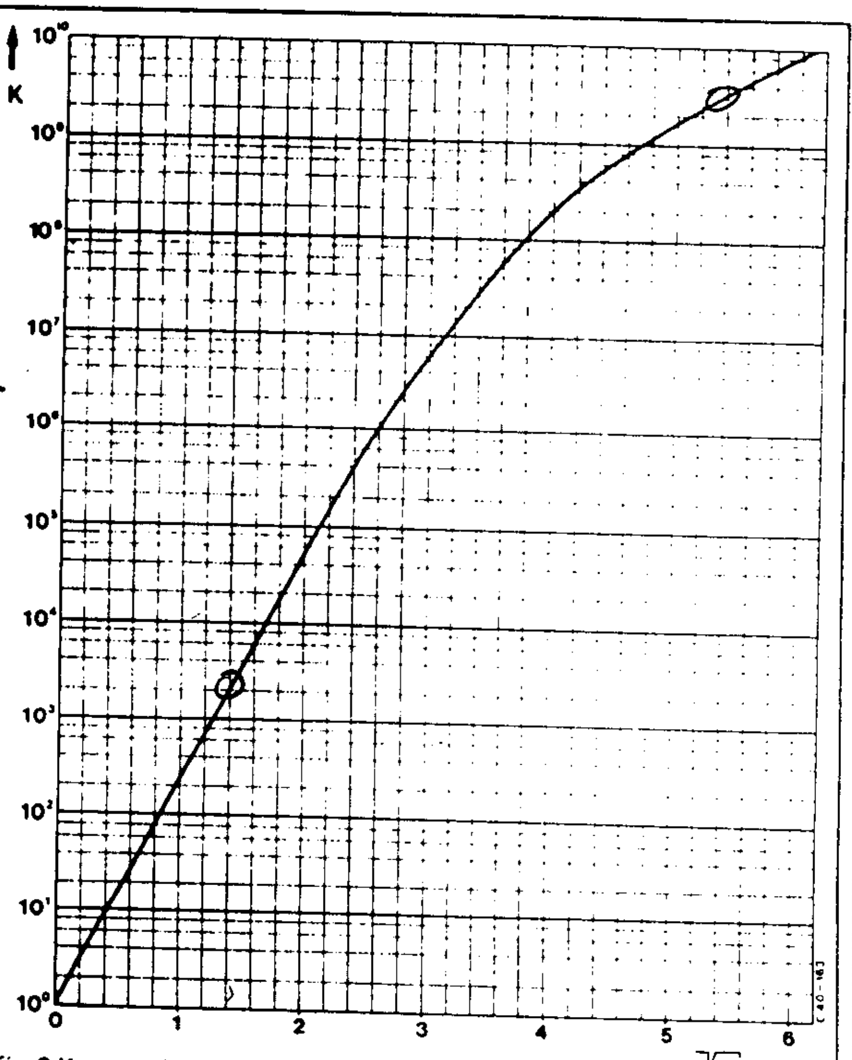
**Schnittdarstellung der PFEIFFER-TURBO TPU 170**

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

~ 40 000 t min
≯ 60 000



Saugvermögen der PFEIFFER TURBO für $N_2$ in Abhängigkeit vom Druck



facteur de compression K

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

Pumping speed of a turbomolecular pump

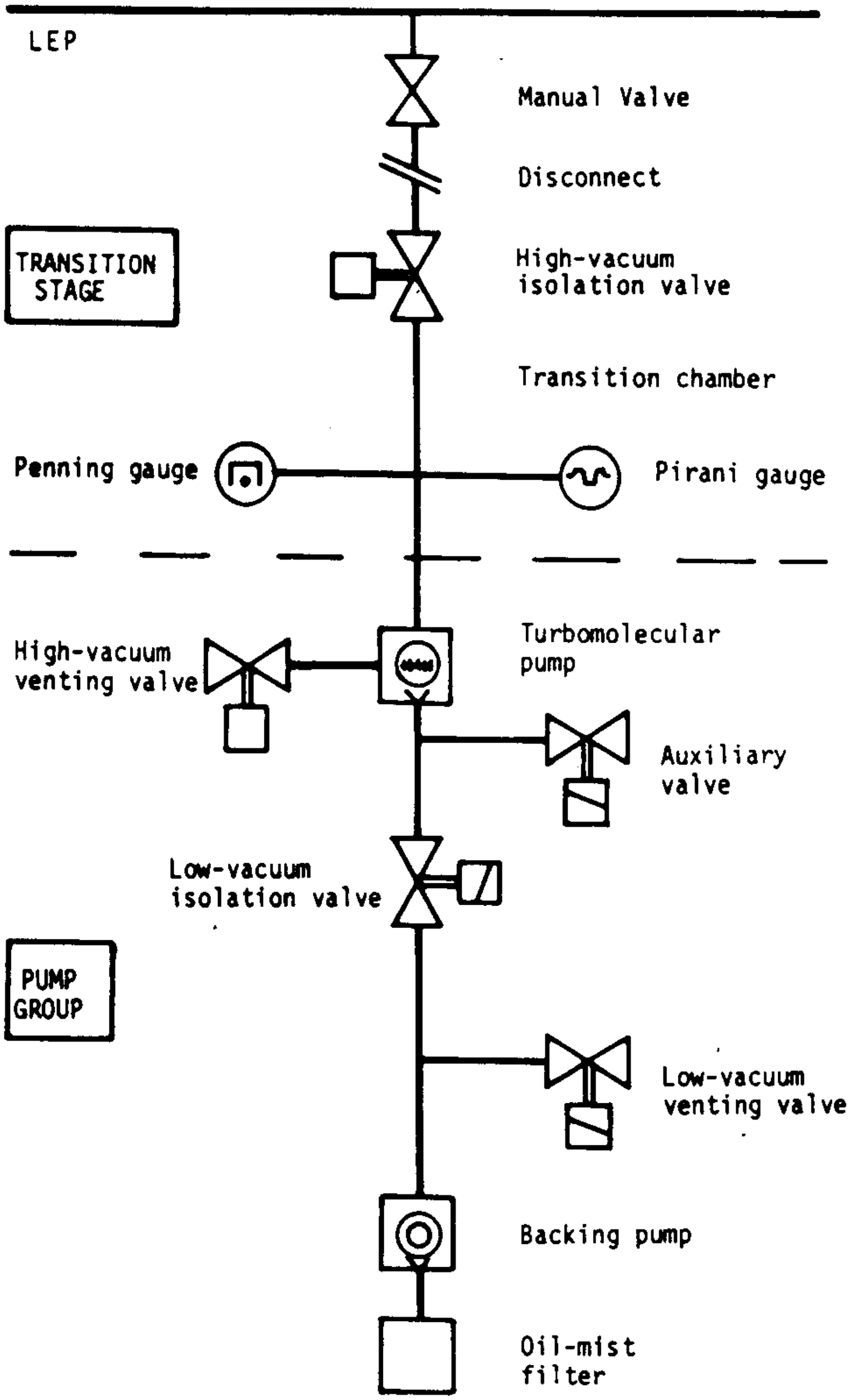
$$S \cong u\ G$$

**G** pump geometry

**u** rotation speed

The compression factor is an exponential function of the molecular weight, hence large compression obtained for heavy molecules -> clean vacuum

The pumping speed is independent of the molecular mass


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

# Ion Pump

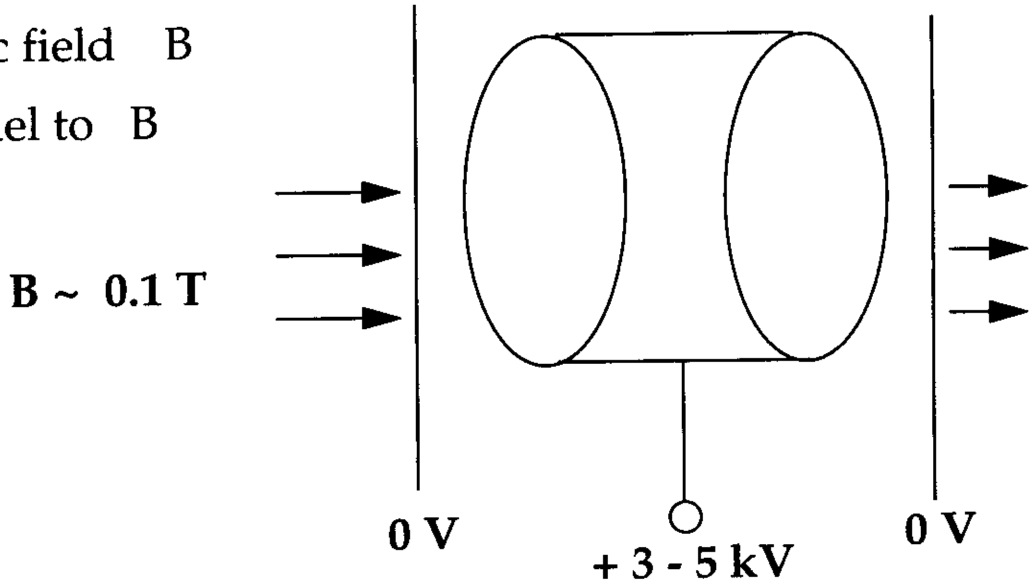
"Penning" configuration

electric field E

magnetic field B

E parallel to B

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

A pump contains a large array of single Penning cells in a common housing

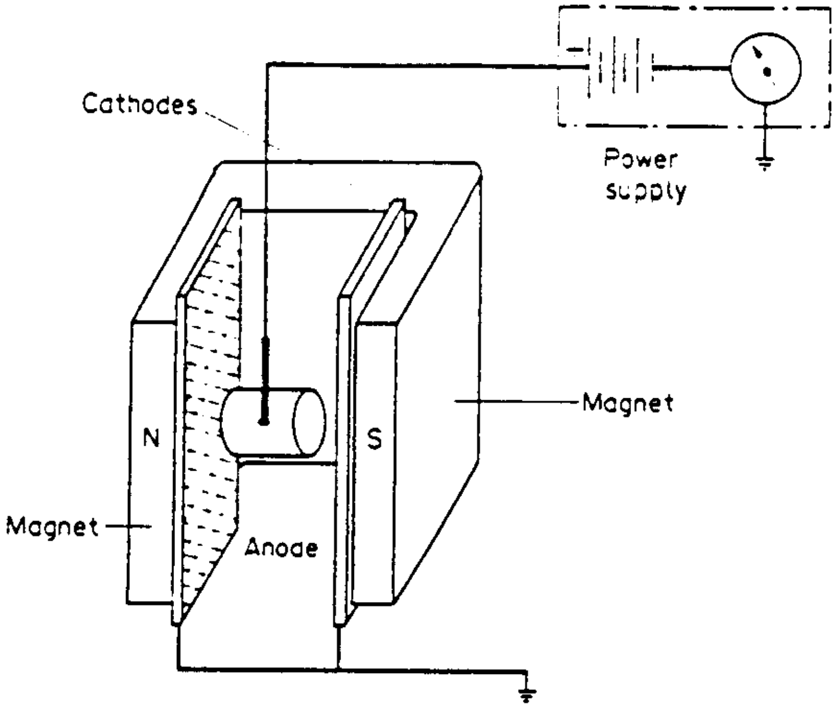


Figure 8. Basic configuration of a sputter-ion pump.

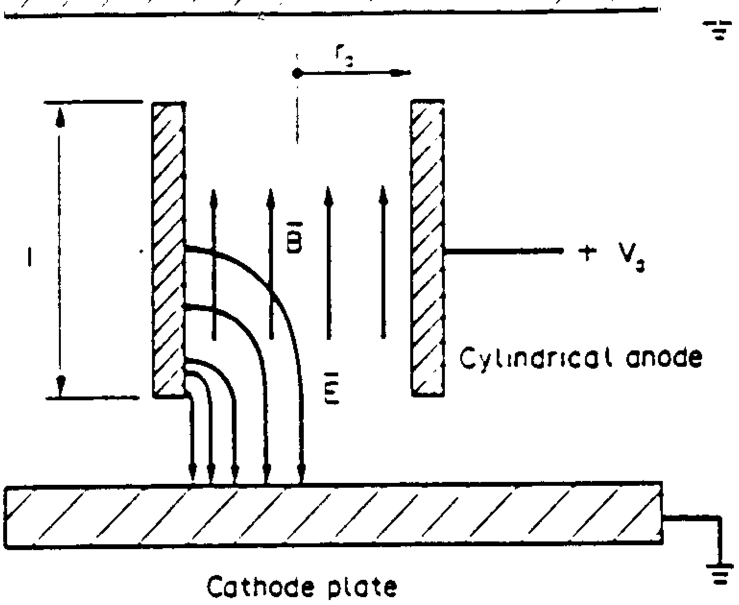


Figure 4. Long-anode Penning structure.

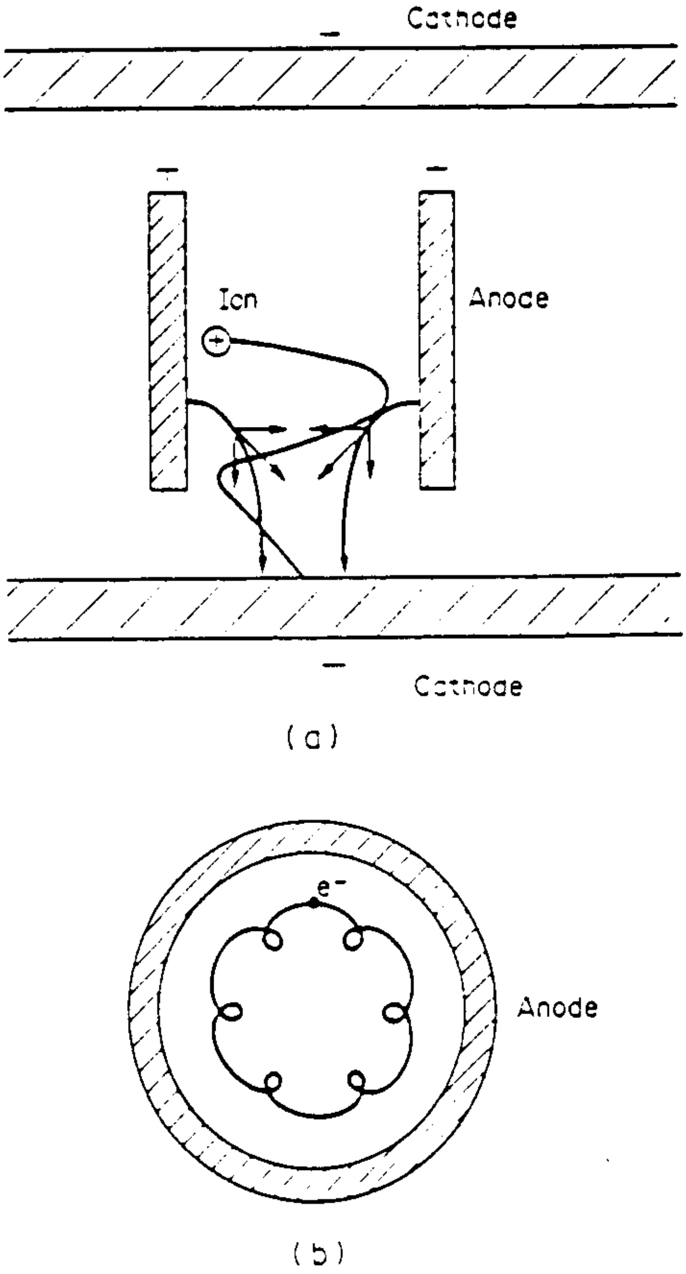


Figure 5. Examples of particle trajectories in a Penning cell. (a) Ion

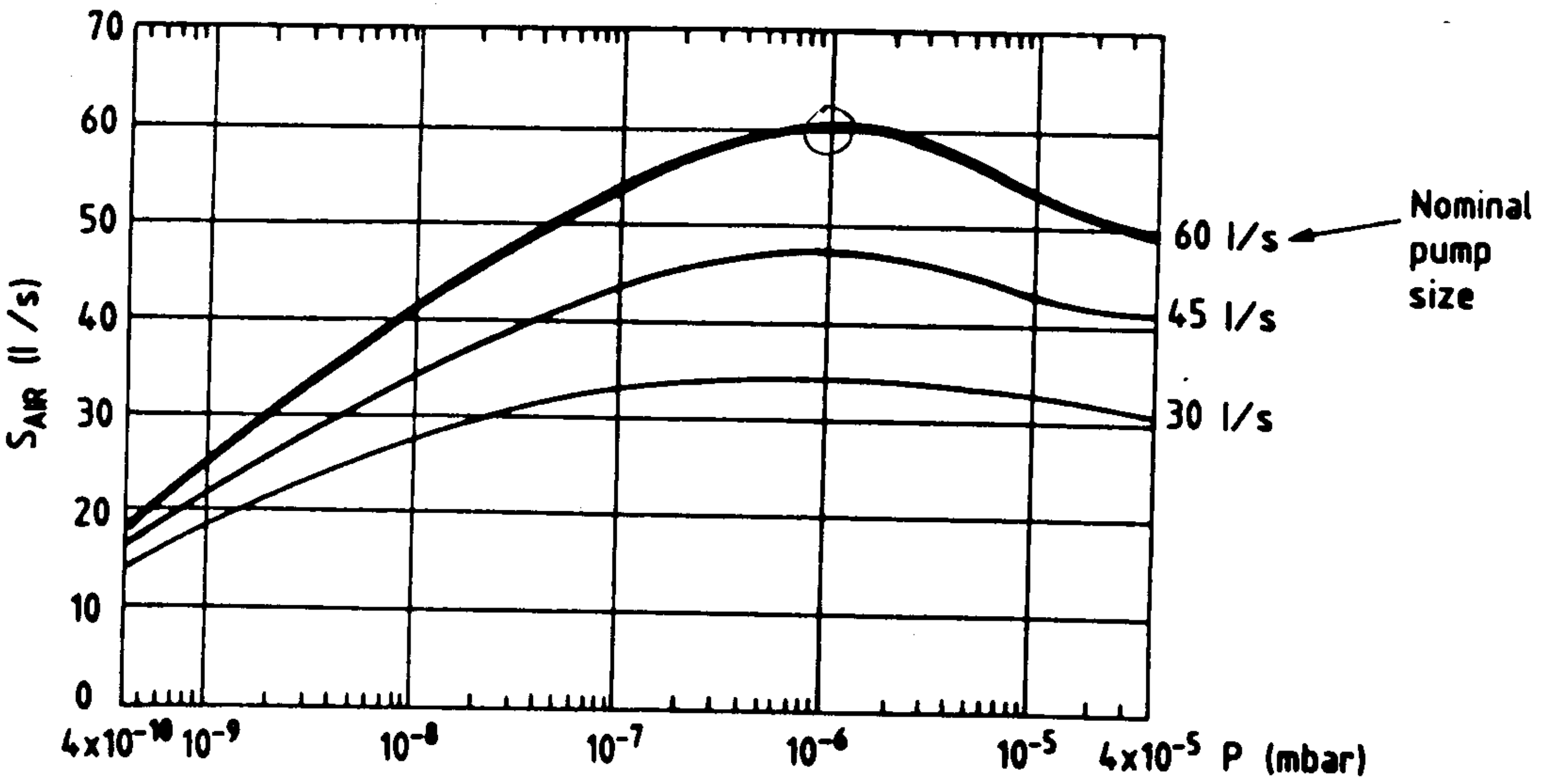


Fig. 9 Pumping speed for air for a saturated pump

# Getter Pumps

The getter forms chemically stable compounds with the gas molecules:

$H_2$, $O_2$, $N_2$, CO, $CO_2$

noble gases : He, Ar, and $CH_4$ ... are not pumped

Pumping speed: related to the molecular velocity

$F = 1/4\ v$ and $v = (8\,k\,T/\pi\,m)^{1/2}$

therefore $F = 36.38\,(T/M)^{1/2}$

molecules have a certain probability, $\alpha$, to be adsorbed by the getter, hence the actual pumping speed depends on the coverage of the gettering surface -> saturated getter must be reactivated

Titanium sublimation pumps

NEG, Non Evaporable Getter pumps

## 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.

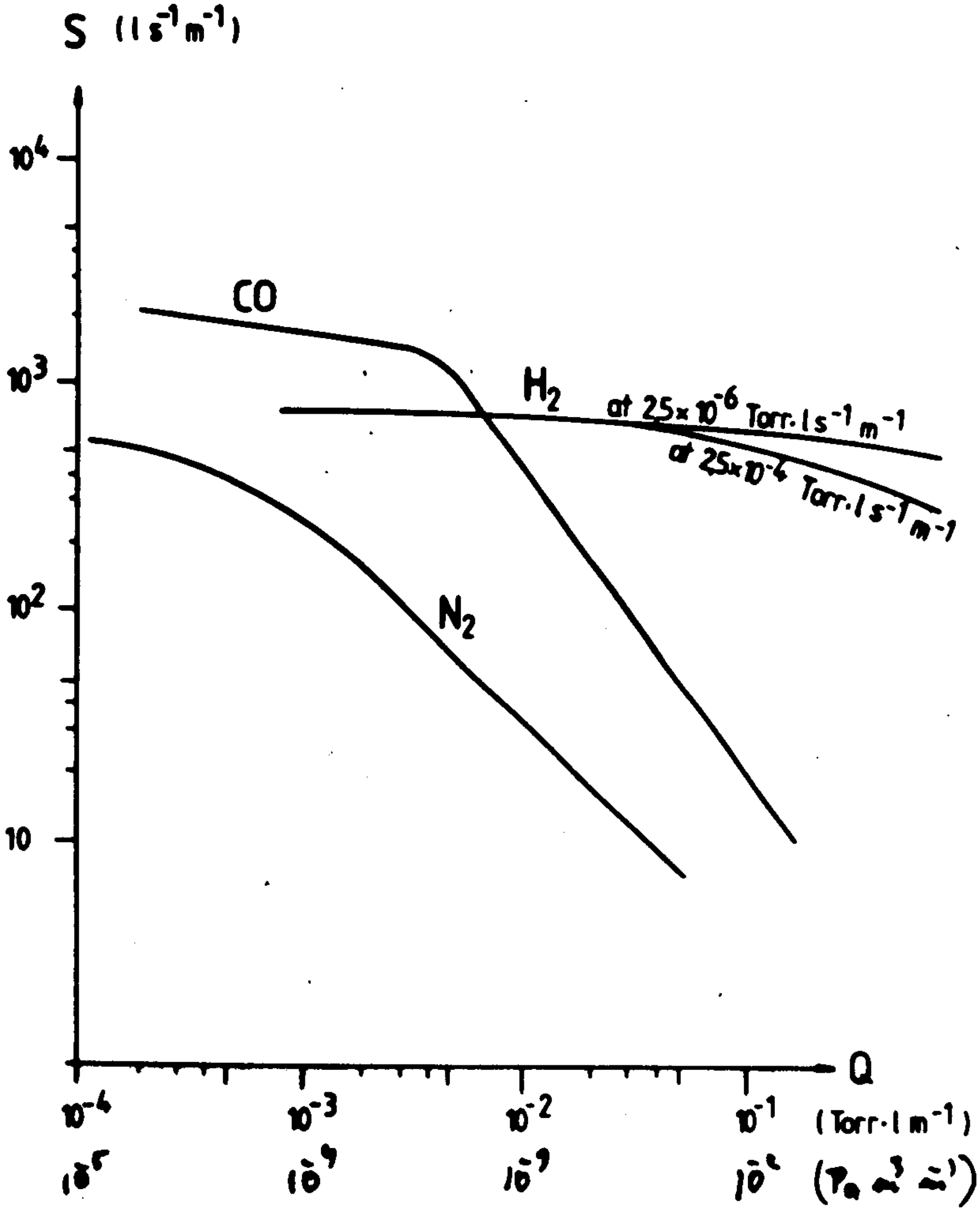
For H2, the diffusion rate is already significant at room temperature and the pumping of H2 is reversible. During heating of the getter, H2 rediffuses and can be released from the getter.

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


S (l s^-1 m^-1)
10^4
10^3
10^2
10
CO
H2
at 25×10^-6 Torr.l s^-1 m^-1
at 25×10^-4 Torr.l s^-1 m^-1
N2
Q
10^-4
10^-3
10^-2
10^-1
(Torr·l m^-1)
10^-5
10^-4
10^-3
10^-2
(Pa m^3 m^-1)

8.1

---

# Cryo pumps

## Principle of operation

### 1) Cryo-sorption

adsorption of gas on the cold surface forming a mono-molecular layer.

When the surface is completely covered, the pressure is given by the saturated vapour pressure curves for the given gas. He, and H2 have very high vapour pressures even at 4.2 °K. Effective surface can increased by 'active charcoal 'coating.

### 2) Cryo-condensation

Pumping of thick layers of gas. The quantity of gas exceeds the monolayer coverage -> vapour pressure

### 3) Cryo-Trapping

A gas like H2, which is difficult to pump, is pumped in the presence of a readily condensable gas like Ar. H2 molecules are trapped by the Ar

## Aspects of Cryo pumping

Large pumping speed

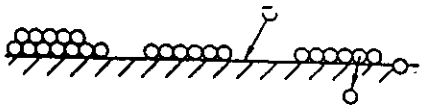
low base pressure (SVP must be avoided)

large pumping capacity -> Cryo-condensation

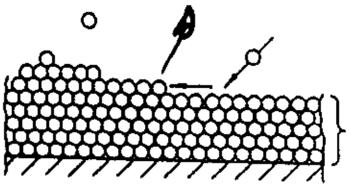
very 'clean' pump -> no pumping oils

atractive when combined with s.c magnets

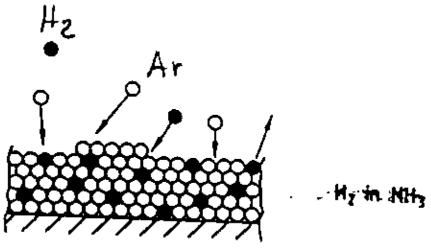
Ⓐ



Ⓑ



Ⓒ


$H_2$
Ar
$H_2$ in $NH_3$

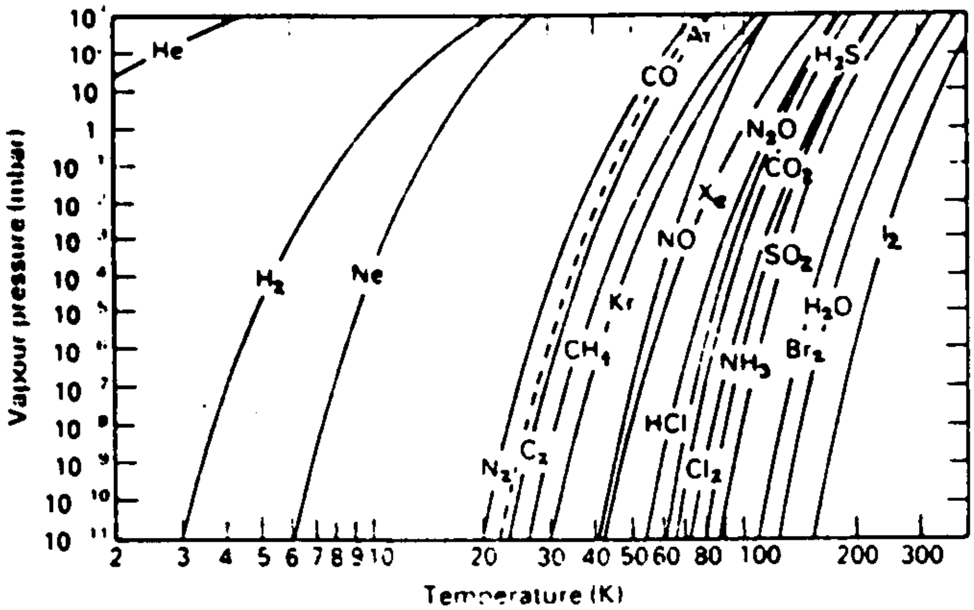
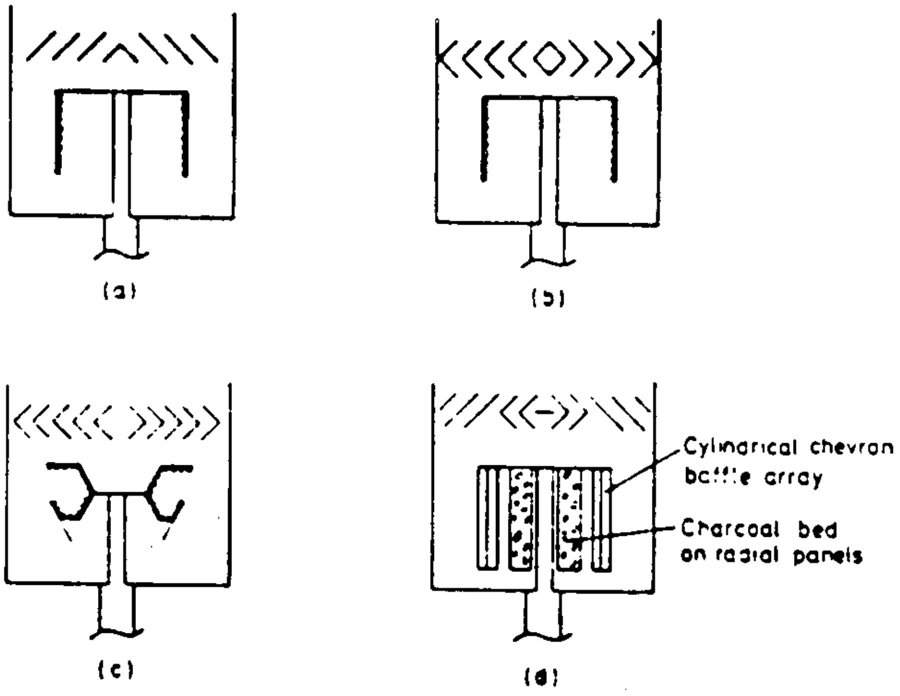


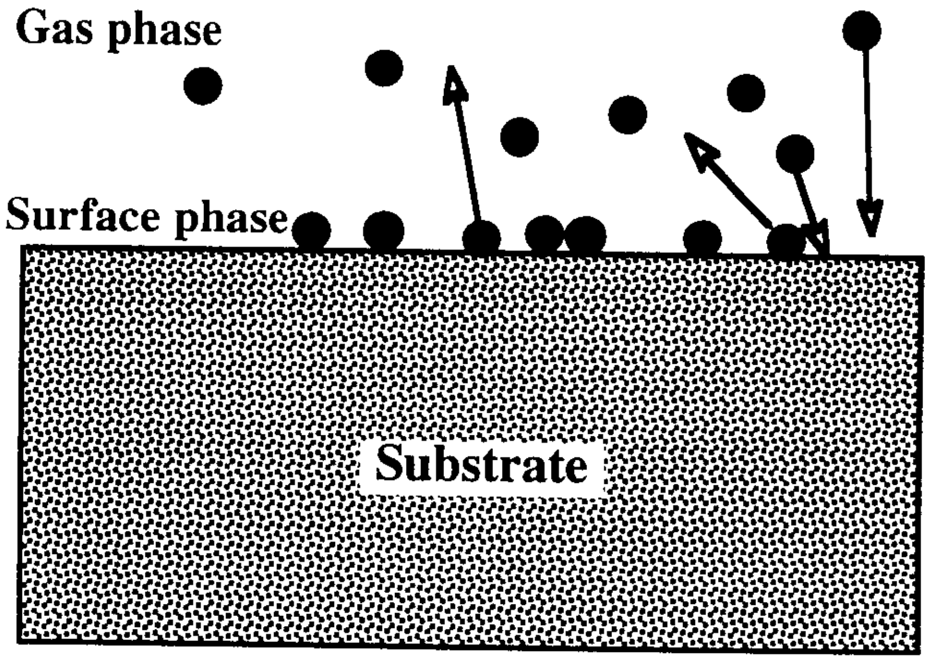
**Figure 2.** Vapour pressures of some common gases (from Bentley[9]).



(a) (b)

(c) (d)

## Vapour pressure and Adsorption isotherms



surface coverage Θ (molecules/cm$^2$)
pressure P

$$P = f(\Theta, T)$$

for large coverage, (many monolayers)

P -> saturated vapour pressure

# Pirani Gauge

Reliable and simple

Fast time response, good precission

Large pressure range :

atmosphere -> < 0.1 Pa

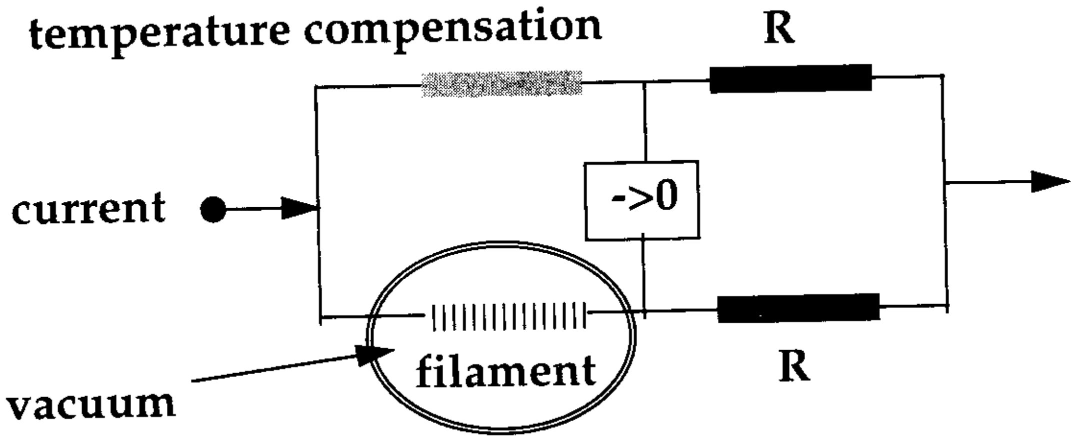
Principle

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

## Hot cathode ionisation gauge

Residual gas is ionised by electrons emitted from a hot filament. The positive ion current on a collector electrode is proportional to the pressure.

-> Filament, grid and collector electrodes

| | |
|---|---|
| $P_i$ | ionisation probability for molecules |
| $I_e$ | electron emission current |
| L | pathlength of the electrons |

$$I^+ = I_e \; P_i \; L \; P$$

The product of $P_i$ L is called the sensitivity of the gauge and can be determined by calibration against a known pressure Si ($Pa^{-1}$)

The gauge sensitivity depends on the type of molecules -> Nitrogen equivalent pressure

Limitations

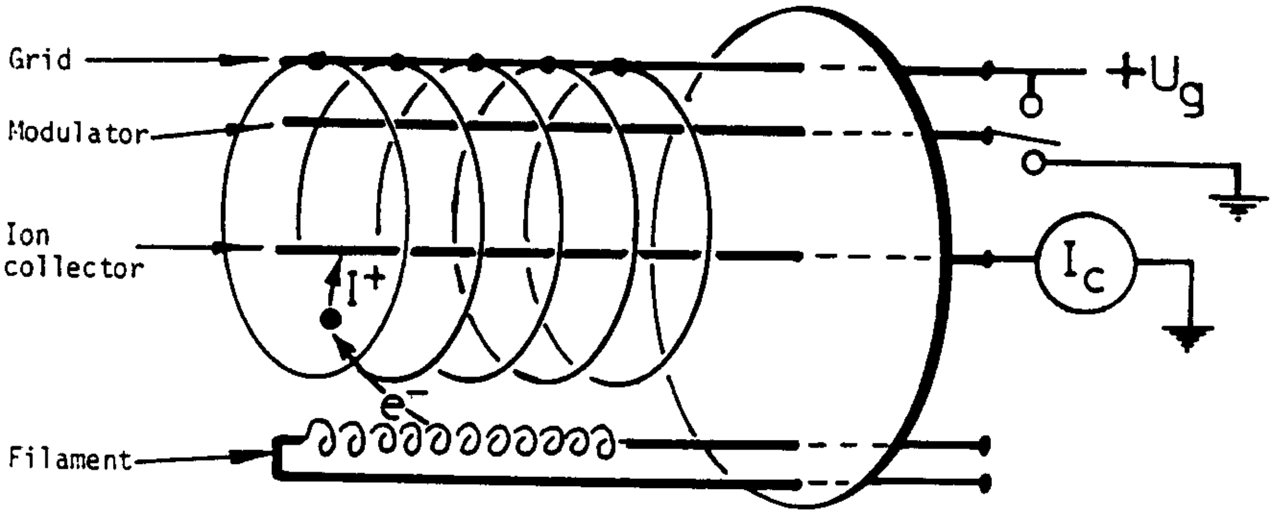
high pressure : space charge affects sensitivity

low pressure : outgassing due to electron bombardment of the grid increases the pressure -> outgassing

x-ray limit due to photoelectrons from the collector electrode . Residual current is equivalent to approx. $10^{-8}$ Pa

improvements -> modulated Bayard Alpert gauge

-> extractor gauge


Grid
Modulator
Ion collector
$I^+$
$e^-$
Filament
$+U_g$
$I_c$

## Bayard-Alpert gauge with modulator electrode

## Extractor gauge

x-ray limit :

electrons produce Bremsstrahlung photons at the grid. Photons which arrive at the collector can produce photoelectrons which go to the positive grid. The photocurrent from the collector is equivalent to a positive ion current Ix, hence pressure reading is limited by this effect

Addition of a modulator electrode

modulator at gridpotential $I_c = I^+ + I_x$

modulator at ground $I_c = \alpha I^+ + I_x$

two measurements permit to eliminate $I_x$

the modulation factor, $\alpha$, can be determined through a measurement at high pressure where $I_x$ is negligible.

Alternative solution:

The collector is shielded optically from the grid. Ions are extracted from the ionisation volume to an external collector.

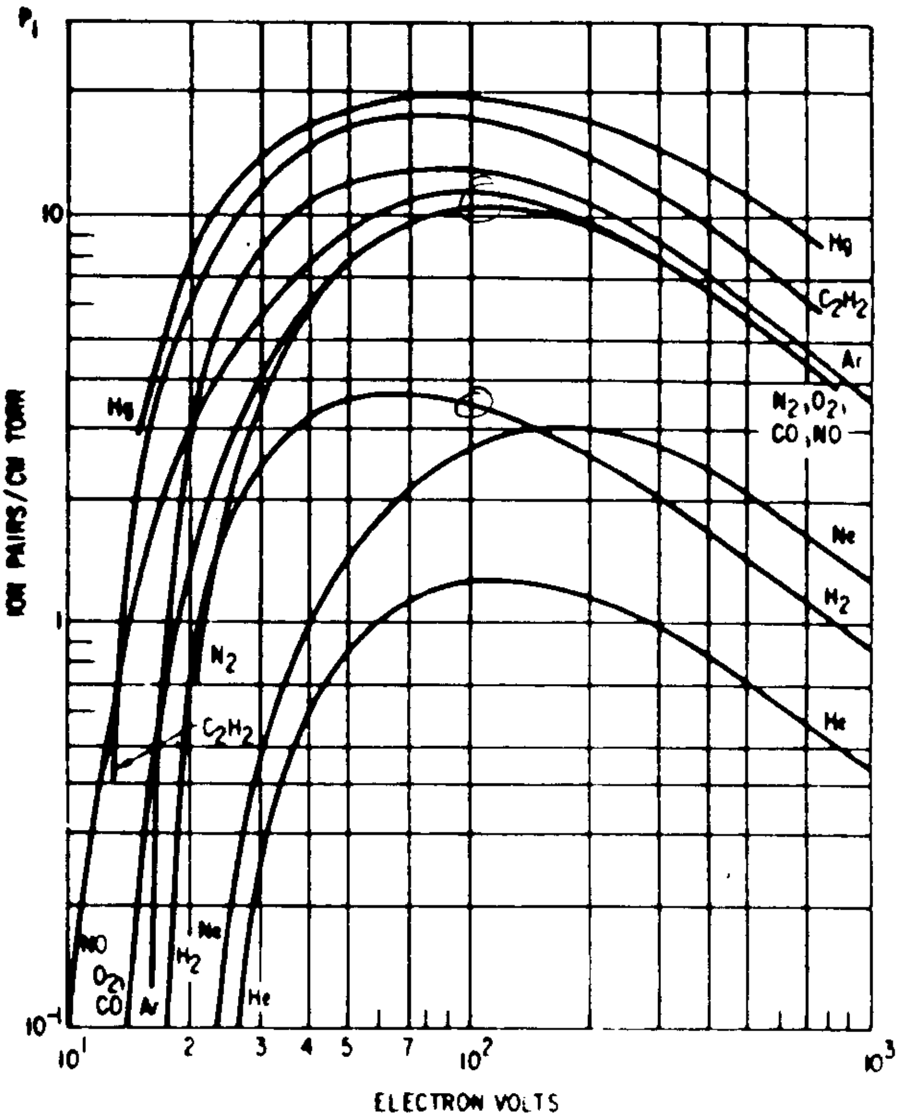


FIGURE 2. Probability of ionization as a function of electron energy for various gases at 1 Torr and 0°C[3]

## Partial pressure measurement:

## Quadrupole mass filter

Ions produced from the residual gas traverse a mass filter. Only ions with the correct ratio e/m reach the collector.

To increase the sensitivity, a secondary electron multiplier can be used.

relative calibration for different gas species made by controlled gas inlet of a test gas.

Absolute calibration can be performed against a calibrated total pressure gauge.

Analysis of the residual gas spectrum is based on known kracking patterns for the different gas species since a given parent molecule can produce a series of ions with different e/m values.

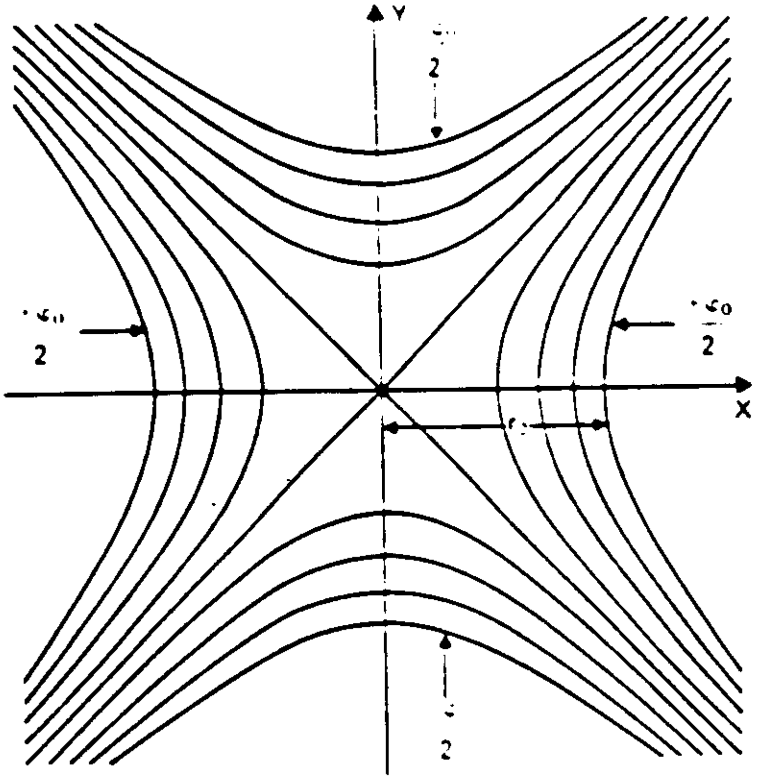


Figure 1. Quadrupole field.

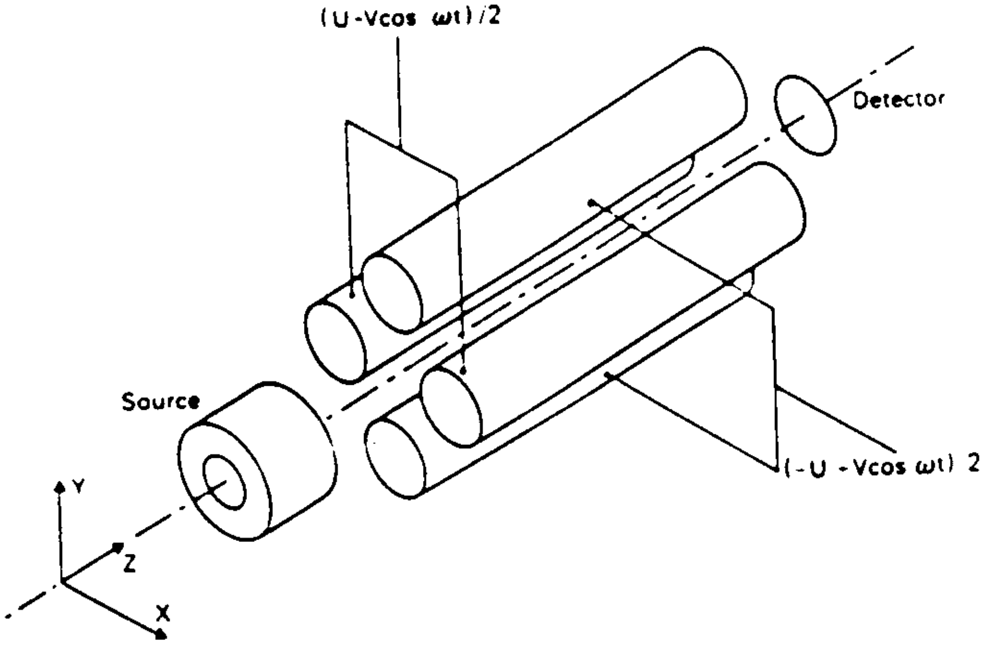
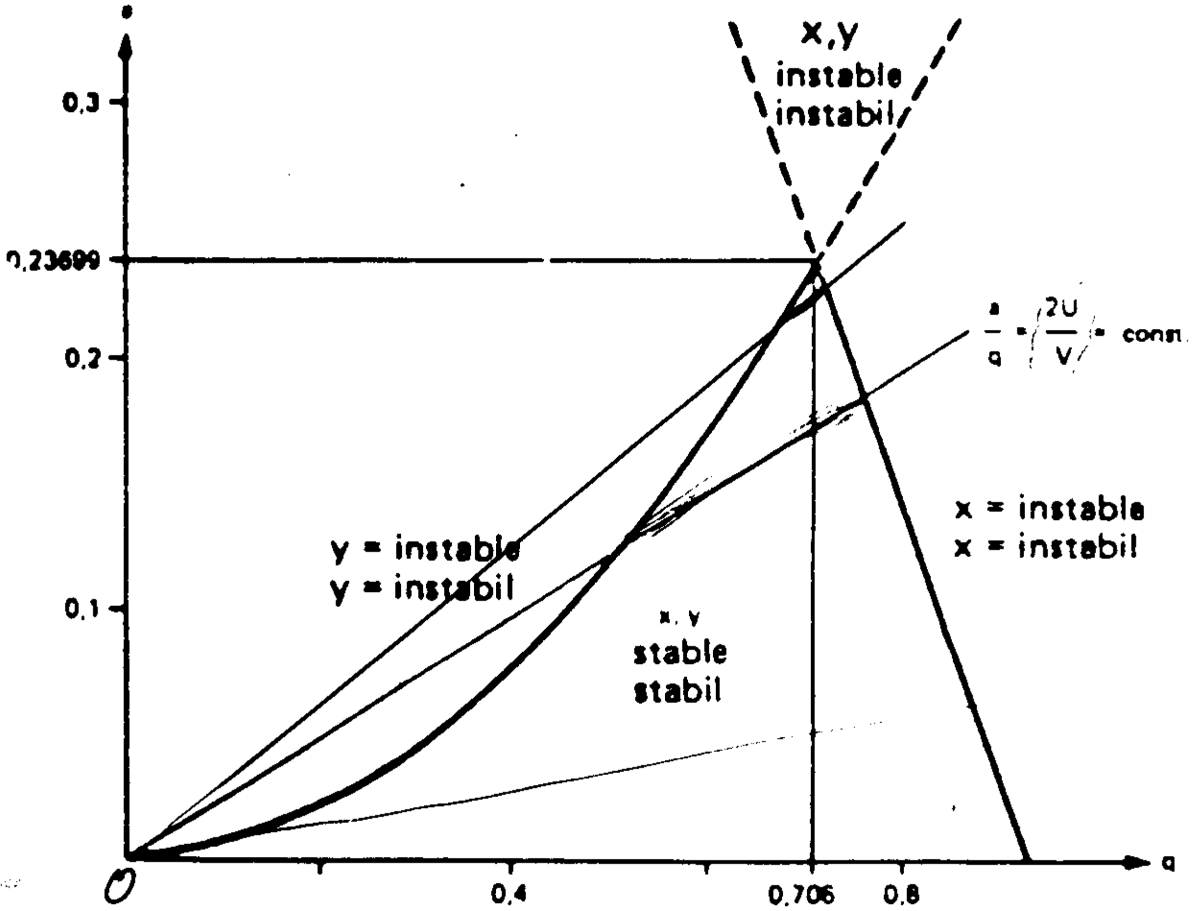
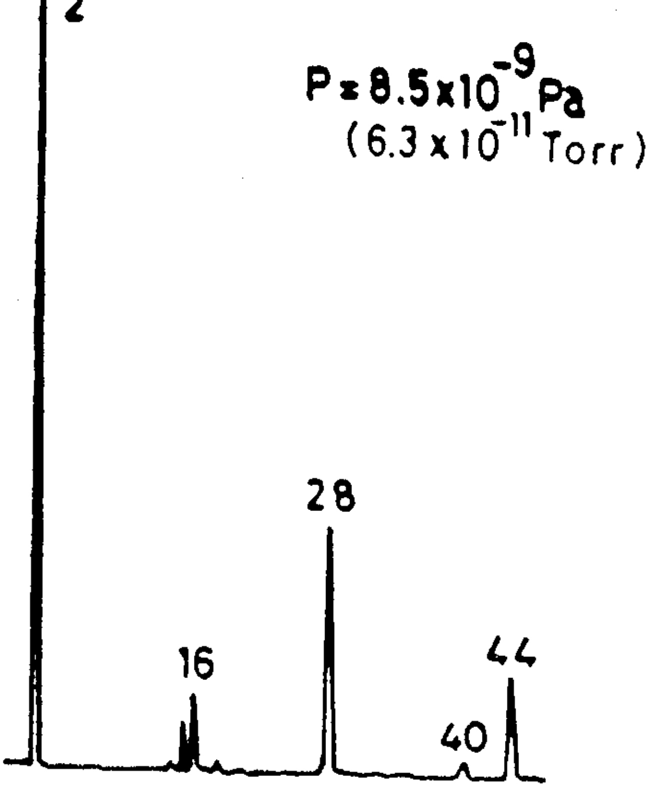
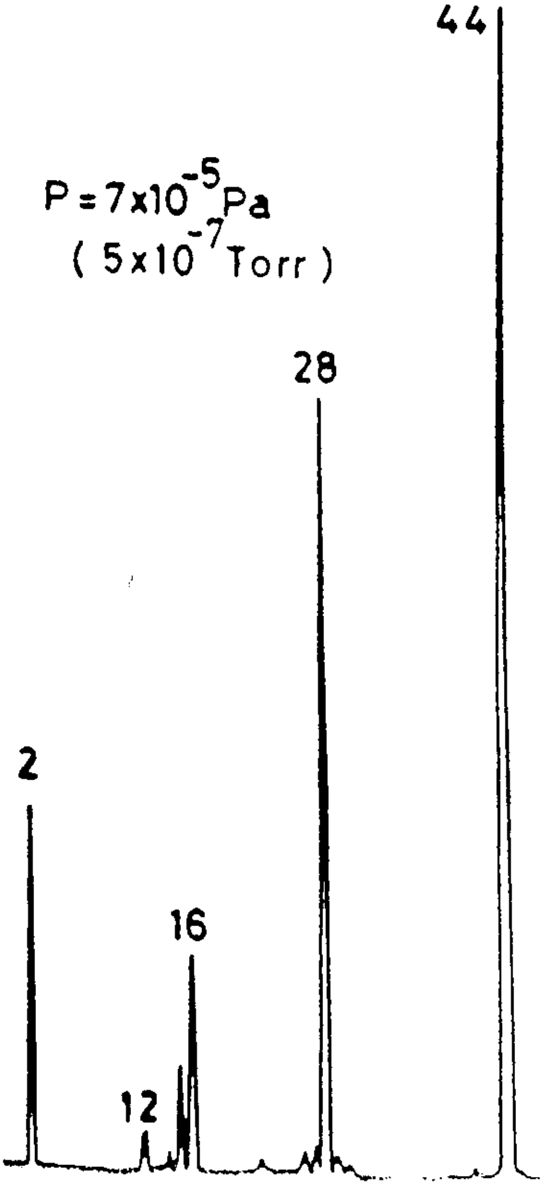


Figure 2. Quadrupole analyser.


a
0,3
0,23699
0,2
0,1
0
0,4
0,706
0,8
q
x,y
instable
instabil
$\frac{a}{q} = \left(\frac{2U}{V}\right) = const.$
x = instable
x = instabil
y = instable
y = instabil
x, y
stable
stabil



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



The residual gas spectrum during exposure to synchrotron radiation.

Tableau 3

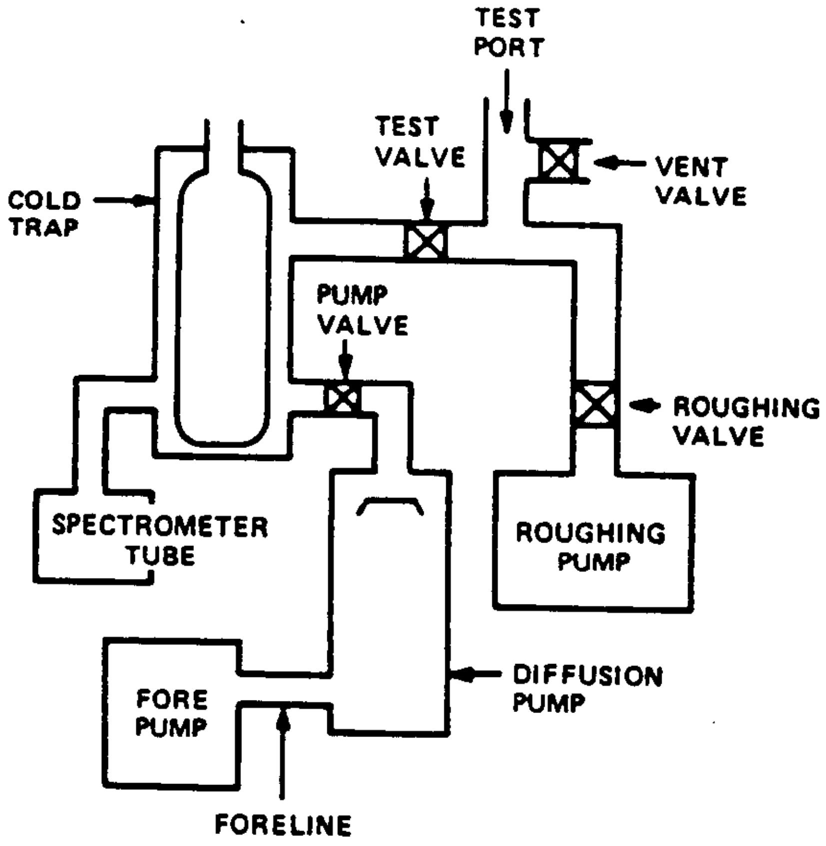
## HAUTEURS RELATIVES DES PICS PRINCIPAUX -

$O_2$

10c

| 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 | |

# CONVENTIONAL LEAK DETECTOR



# 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

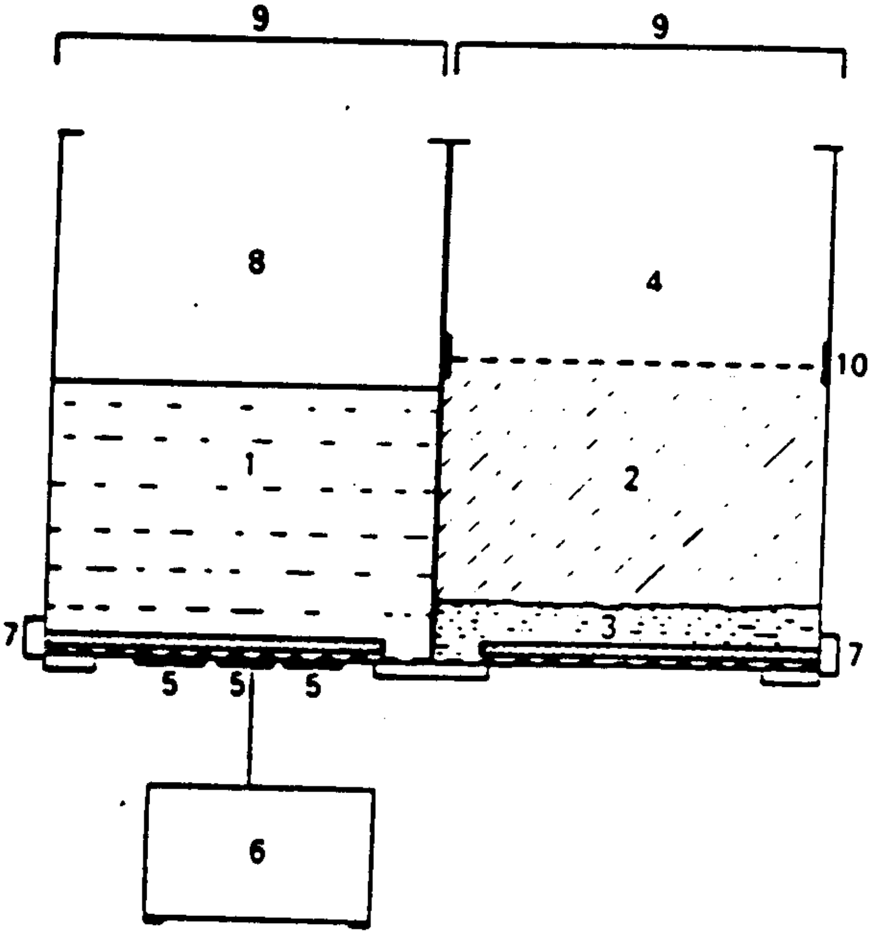


**Figure 1.** Typical commercially available twin tank cleaner. Key. 1. Hot solvent ultrasonic agitation. 2. Hot vapour zone approx. 60°C. 3. Boiling solvent. 4. Cooling zone. 5. Ultrasonic transducers. 6. Ultrasonic oscillator drive unit 20 kHz. 7. Immersion heater. 8. Draining zone after ultrasonic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

# CHEMICAL SOLVENT PRECLEANING PROCEDURE

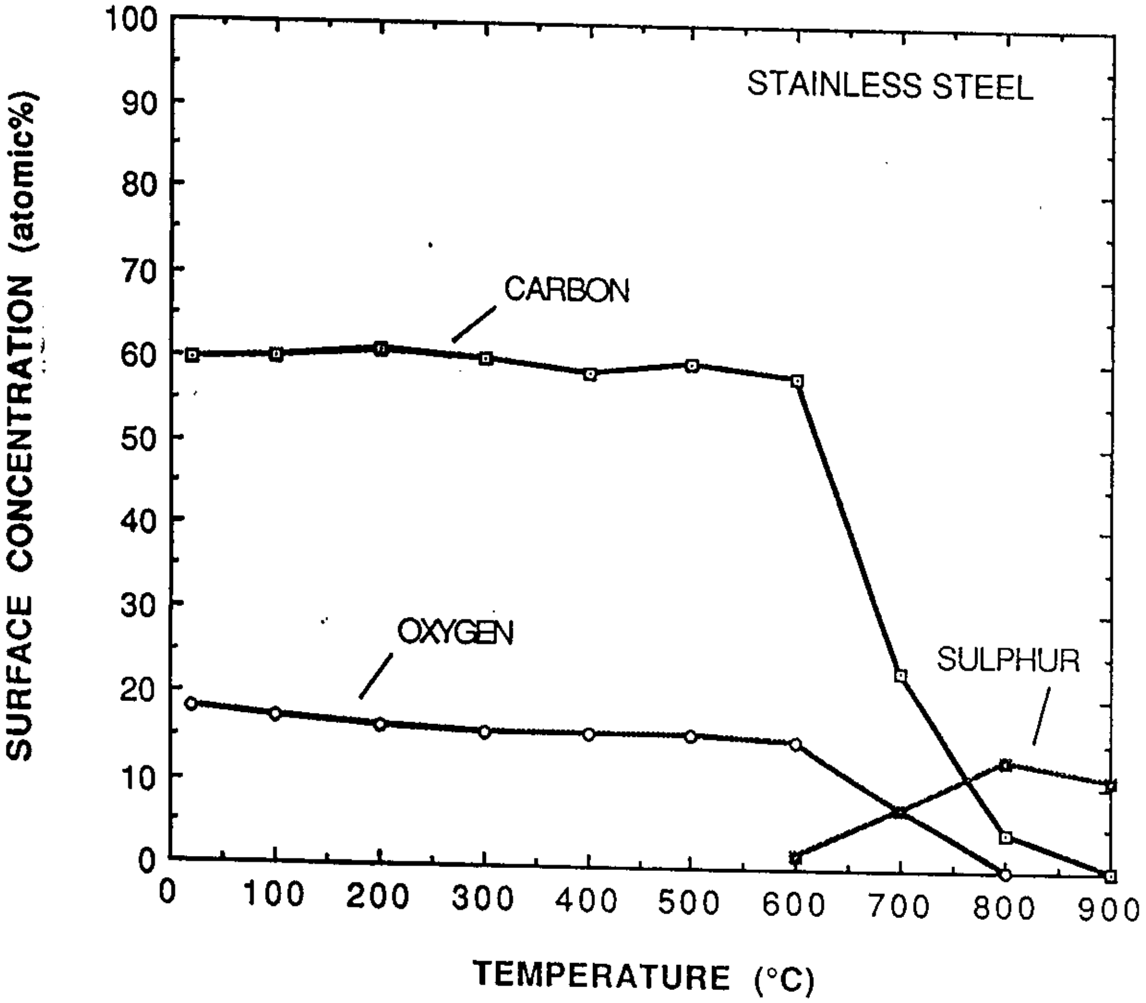
(a) Removal of gross contamination and machining oils using the appropriate solvents.

(b) Perchloroethylene ($C_2Cl_4$) vapour degreasing (121°C).

(c) Ultrasonic cleaning in alkaline detergent (pH=11).

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

(e) Drying in a hot air oven at 150°C


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

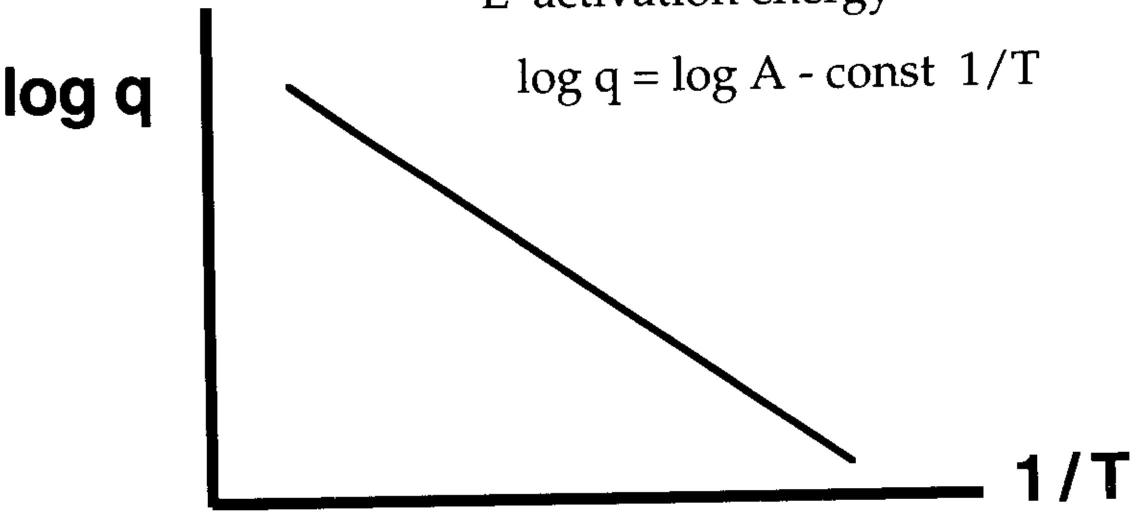
# Thermal Desorption

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

$$q = A \exp(-E/kT)$$

E activation energy

$$\log q = \log A - \text{const}\ 1/T$$



Bakeout at 150 - 300°C gives a significant reduction in outgassing rate. At high temperature, hydrocarbons are cracked and the indicidual components CO, CO2, H2 are pumped readily.

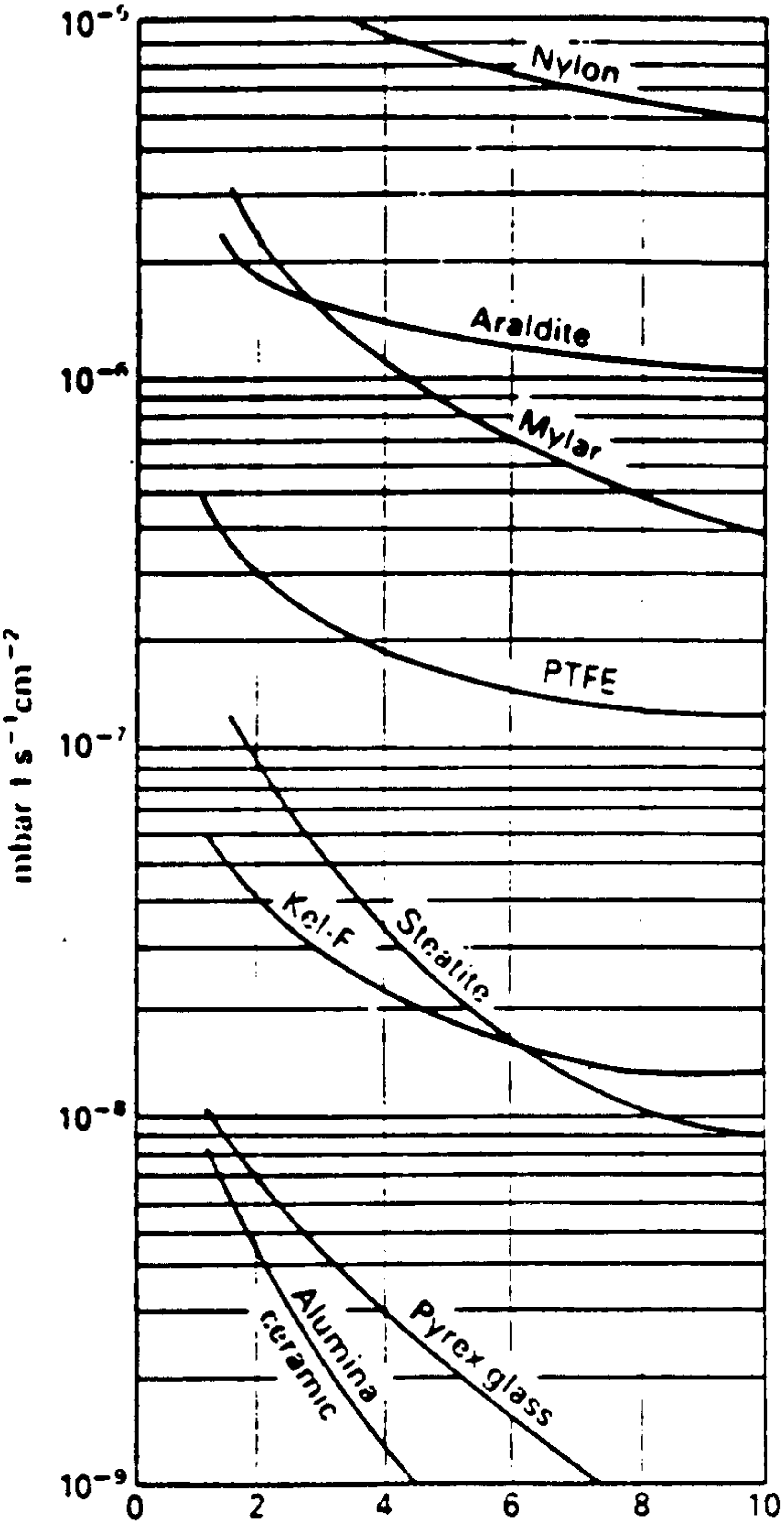


**Figure 2.** Typical outgassing rates for some plastic materials compared to ceramics and glass.

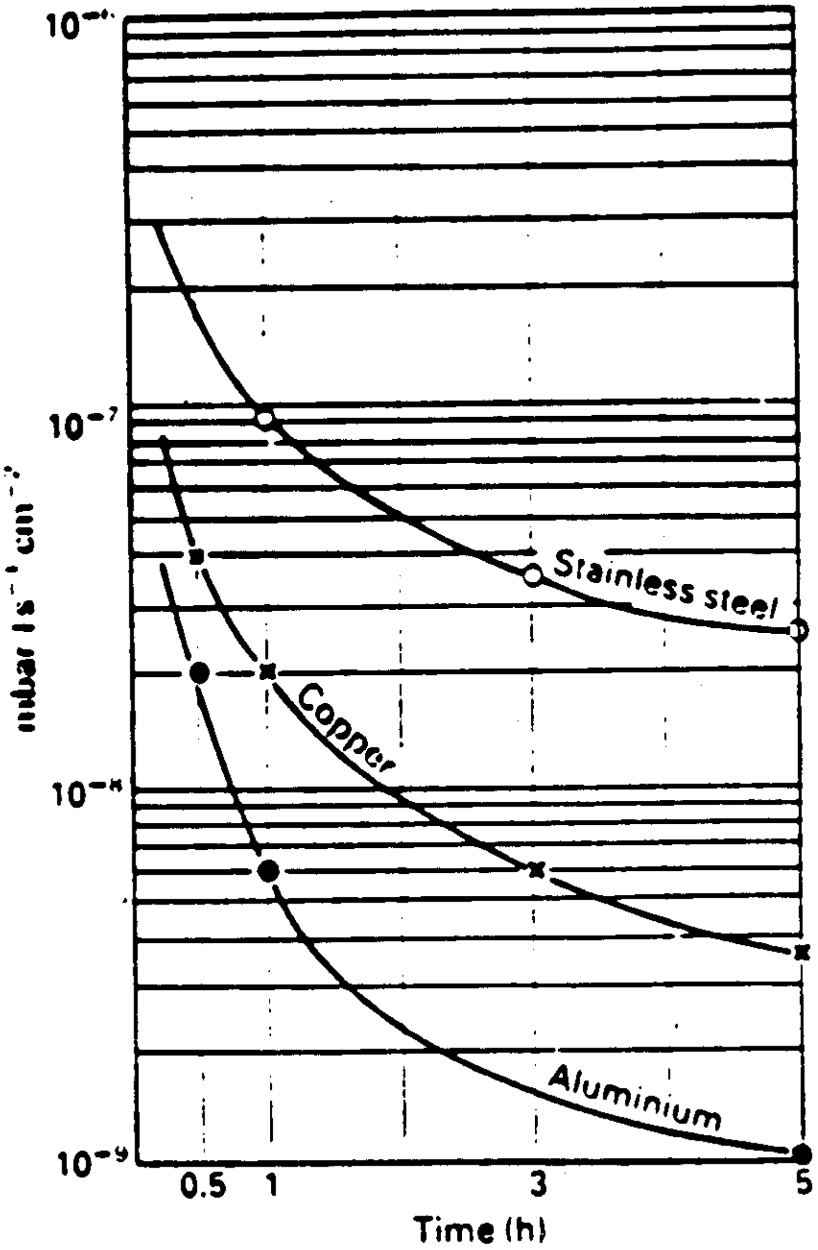
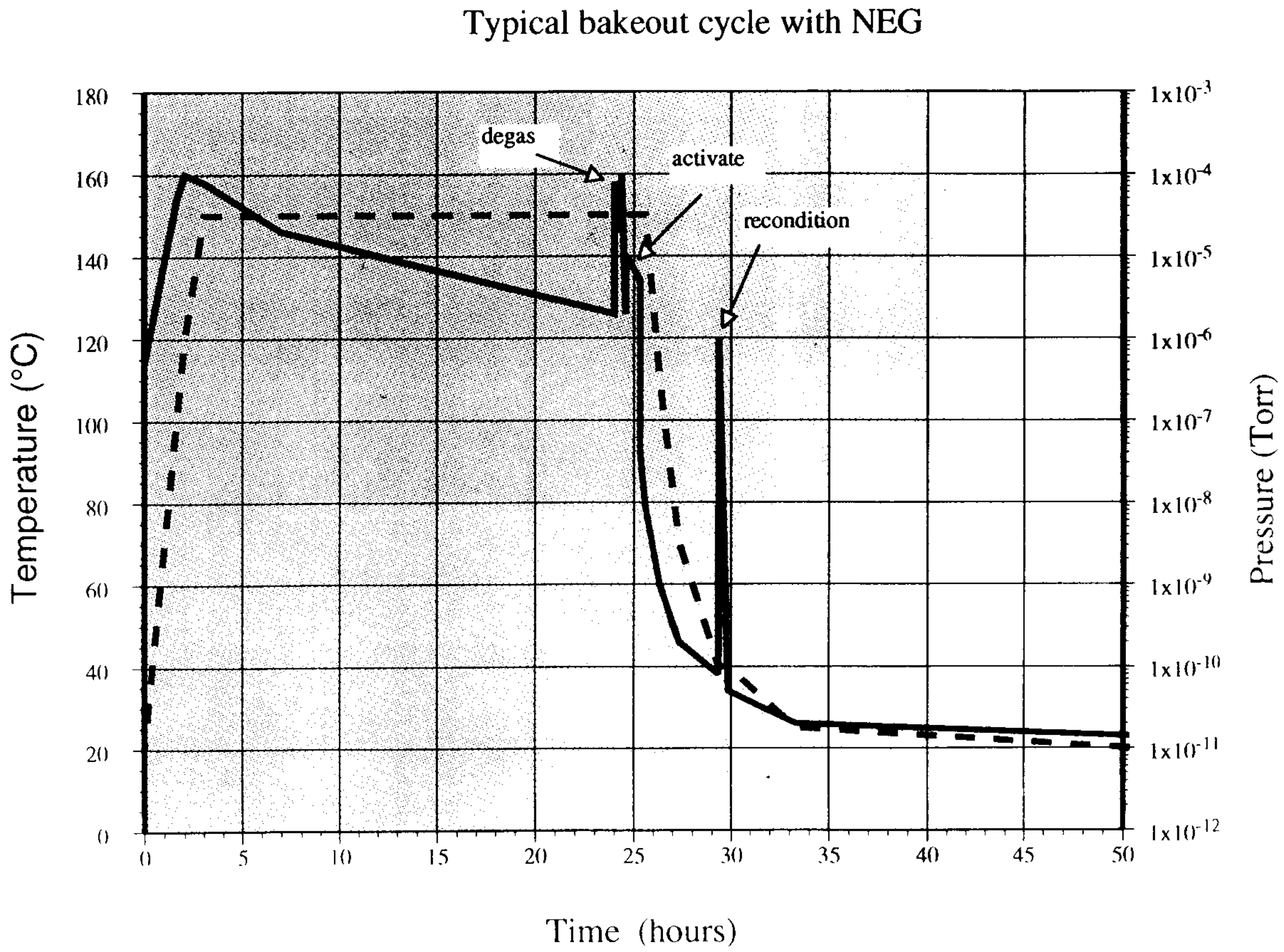


**Figure 1.** Typical outgassing rates for copper, aluminium and stainless steel at room temperature.


Typical bakeout cycle with NEG
degas
activate
recondition
Temperature (°C)
180
160
140
120
100
80
60
40
20
0
Pressure (Torr)
1x10-3
1x10-4
1x10-5
1x10-6
1x10-7
1x10-8
1x10-9
1x10-10
1x10-11
1x10-12
Time (hours)
0
5
10
15
20
25
30
35
40
45
50

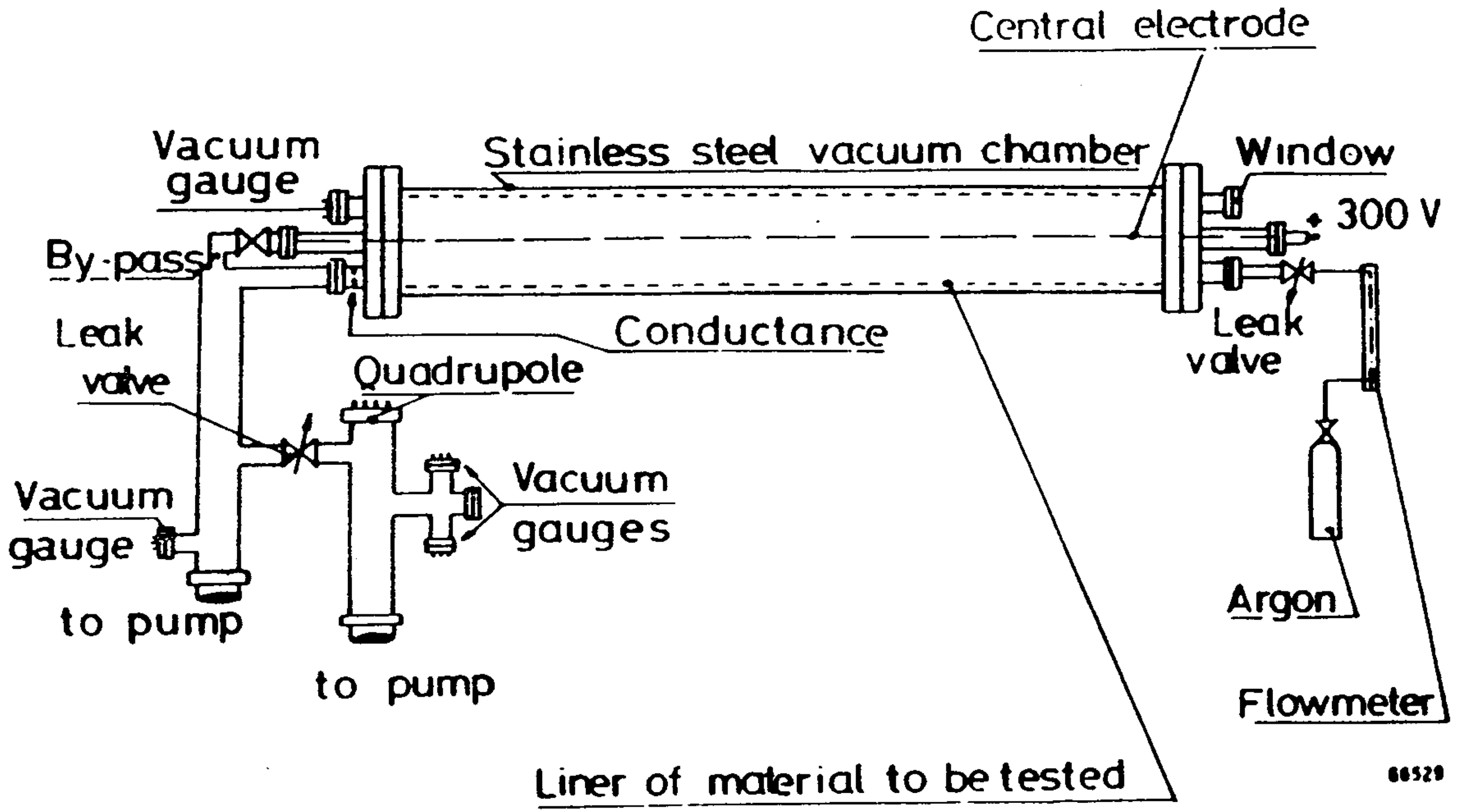

Central electrode
Vacuum gauge
Stainless steel vacuum chamber
Window
+ 300 V
By-pass
Leak valve
Conductance
Leak valve
Quadrupole
Vacuum gauges
Vacuum gauge
to pump
to pump
Argon
Flowmeter
Liner of material to be tested
66529

Figure 12

# Desorption by synchrotron radiation

Critical photon energy $2.9\ 10^{-7}\ \gamma^3\ /\ R$

Radiated power

$P\,(W) = 6\ 10^{-9}\ \gamma^4\ \ I\ /\ R$

I (A) beam current

R (m) magnetic bending radius

$\gamma$ total energy/ rest energy

Photon flux

$N\ (s^{-1}) = 4\ 10^{17}\ \gamma\ I$

and per m

$N\ (s^{-1}\ m^{-1}) = 6.37\ 10^{16}\ \gamma\ I/R$

Dynamic pressure rise by photon induced desorption

$$P = \eta\ N\ /(C\ S) + Po$$

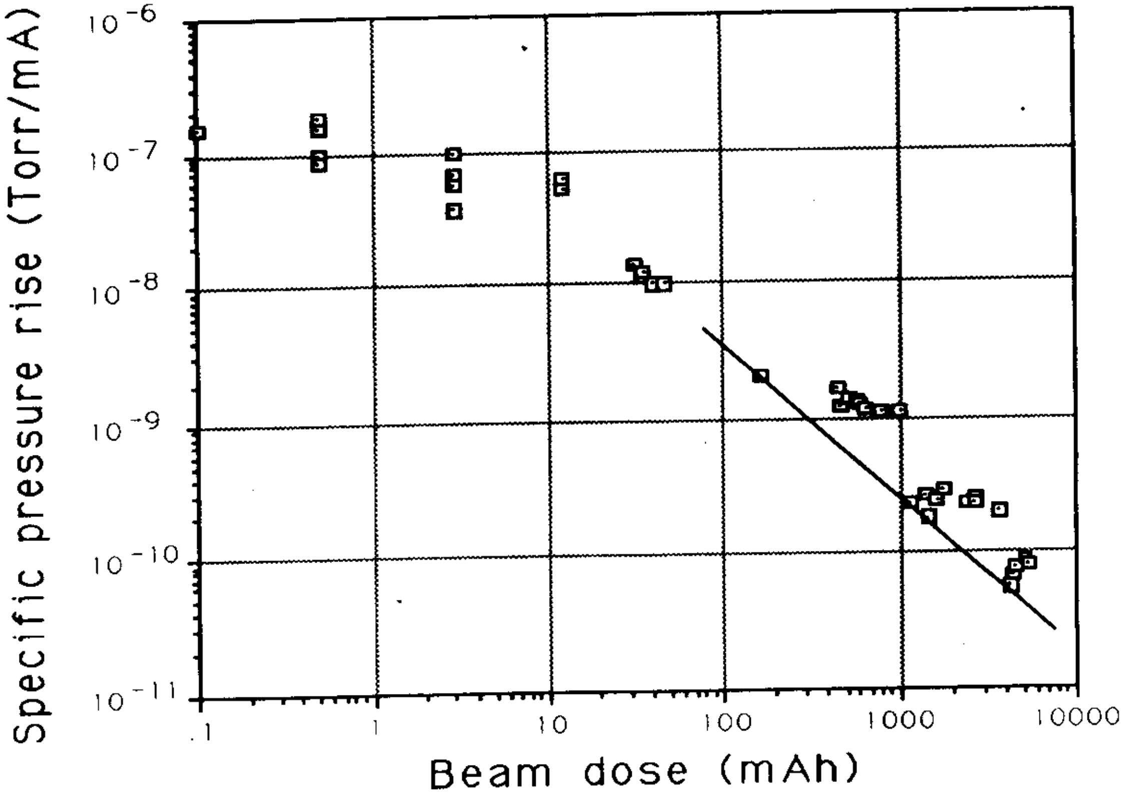
$\eta$ molecular desorption yield (molecules/photon)

S linear effective pumping speed (l/s/m)

C $3.2\ 10^{19}$ (molecules/Torr l)

Po static base pressure, without beam

# Beam cleaning in LEP



Beam cleaning during first year of operation.

Line joins points with fully activated NEG

# Choice of materials

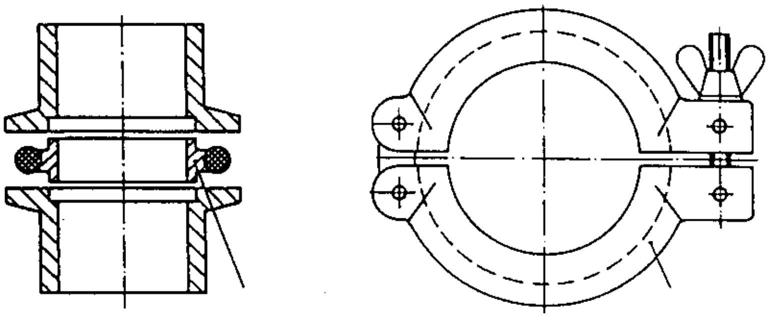
- low outgassing rate
- low vapor pressure
- temperature resistant -> bakeout
- thermal and electrical conductivity
- corrosion resistance
- low induced radioactivity
- high mechanical strength
- machining
- welding
- low cost

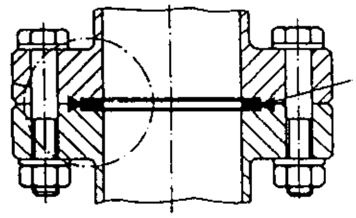
Examples:

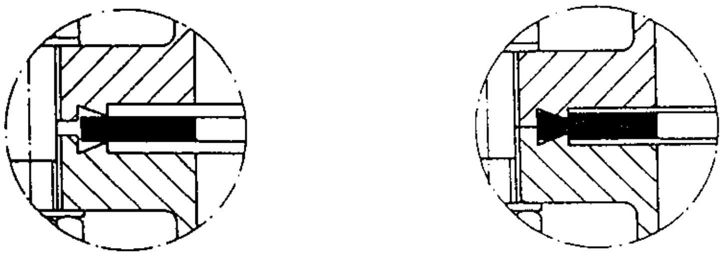
- Stainless steel
- Aluminium
- Copper

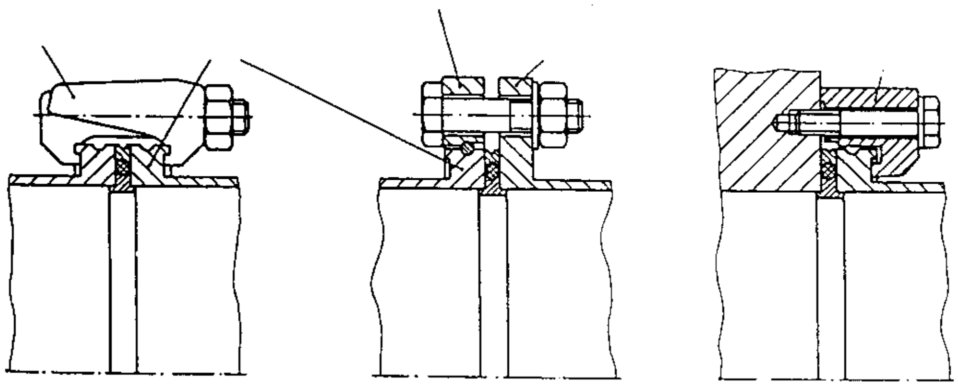
- Ceramics
  - low porosity
  - electrically insulating
  - brazing to metal

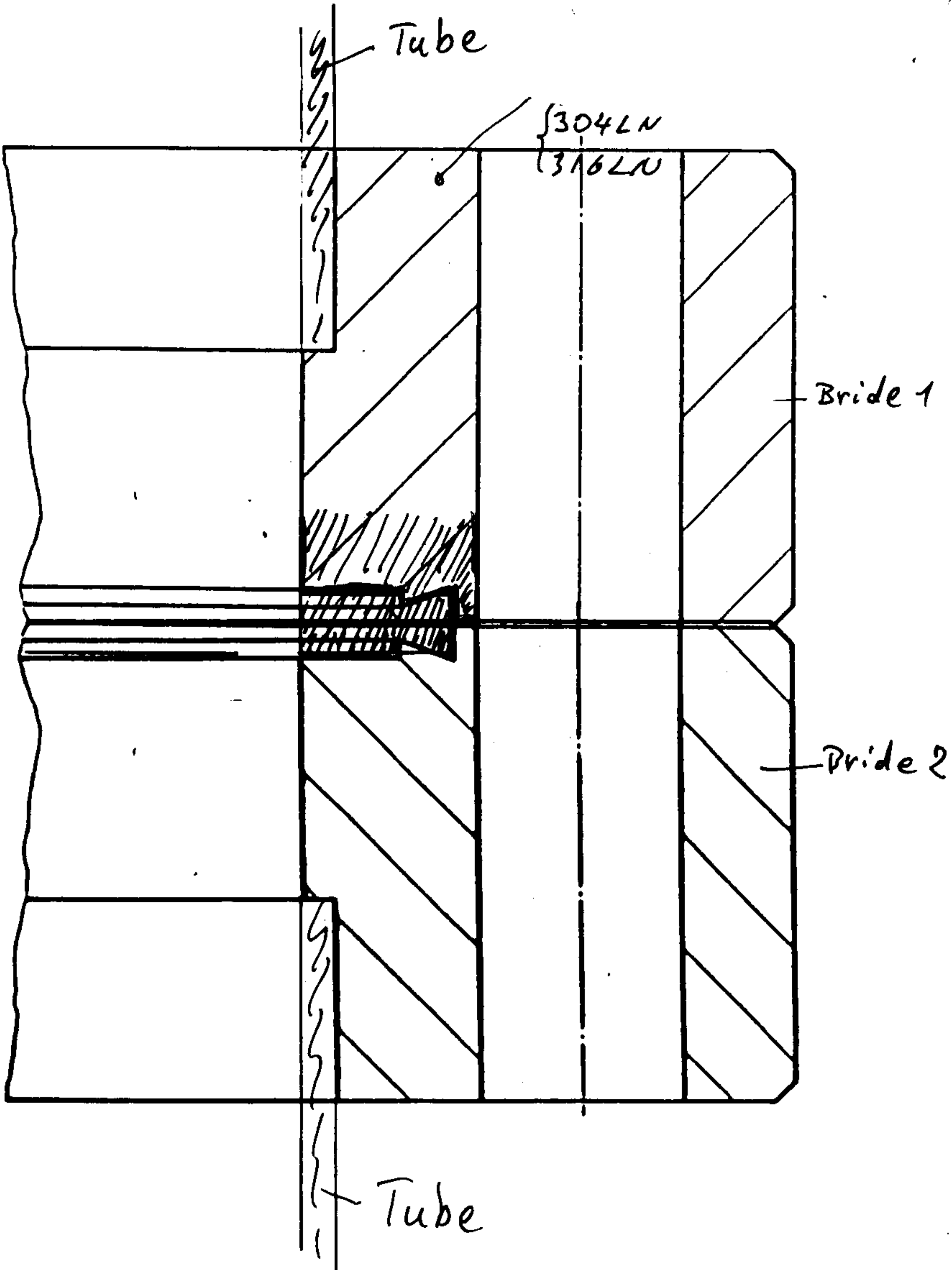
Polymers, Plastics only
for particular applications



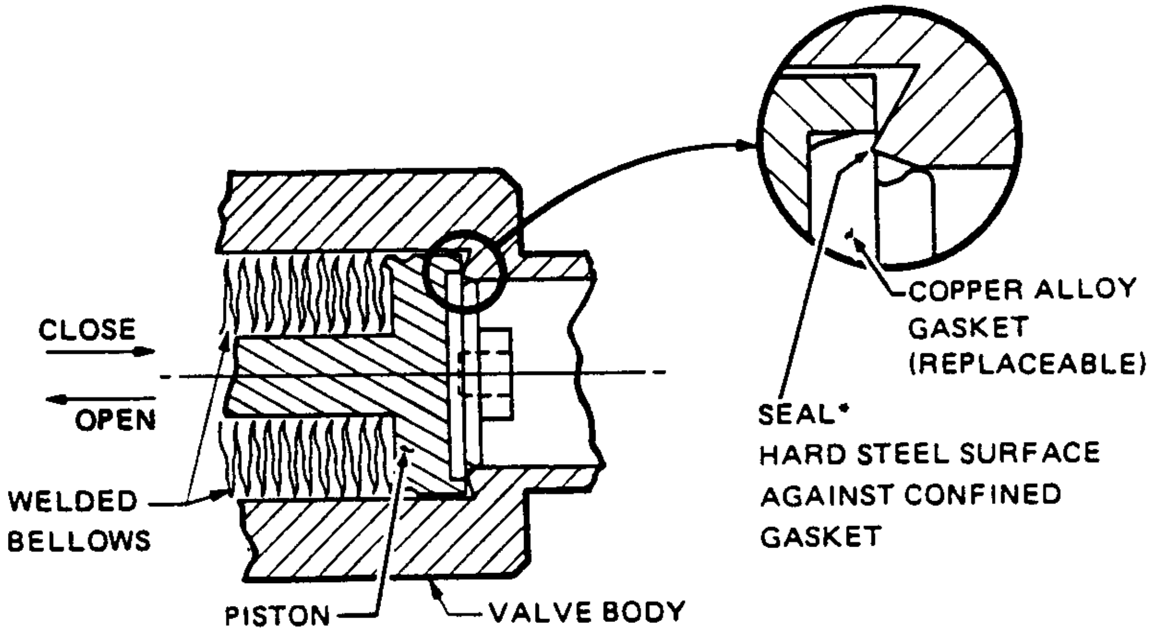








Type "Conflat"



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

Thermal induced stress $\varepsilon$ $(\mathrm{N/mm^2})$

$\varepsilon = E \;\Delta l/L$

$\Delta l/L = \alpha \;\Delta T$

and therefore

$\alpha$ coeff. of linear expansion /°C

$E$ Young's modulus $(\mathrm{N/mm^2})$

$\Delta T$ Temperature difference

$$\boxed{\varepsilon = E\,\alpha\,\Delta T}$$

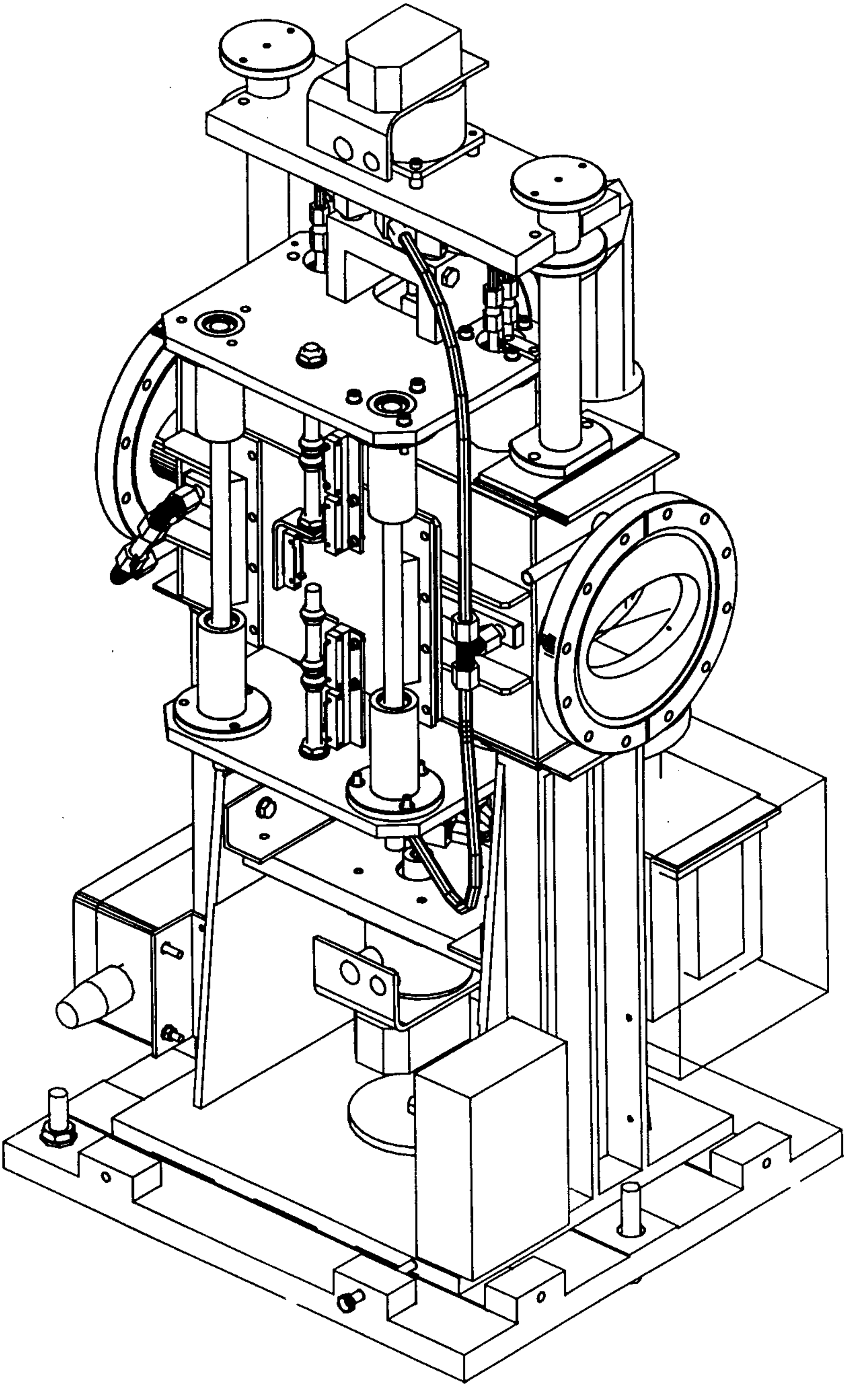
LEP vacuum chamber: the temperature in the region where the photons hit the wall increases by 17.8°C per kW/m deposited S.R. power.

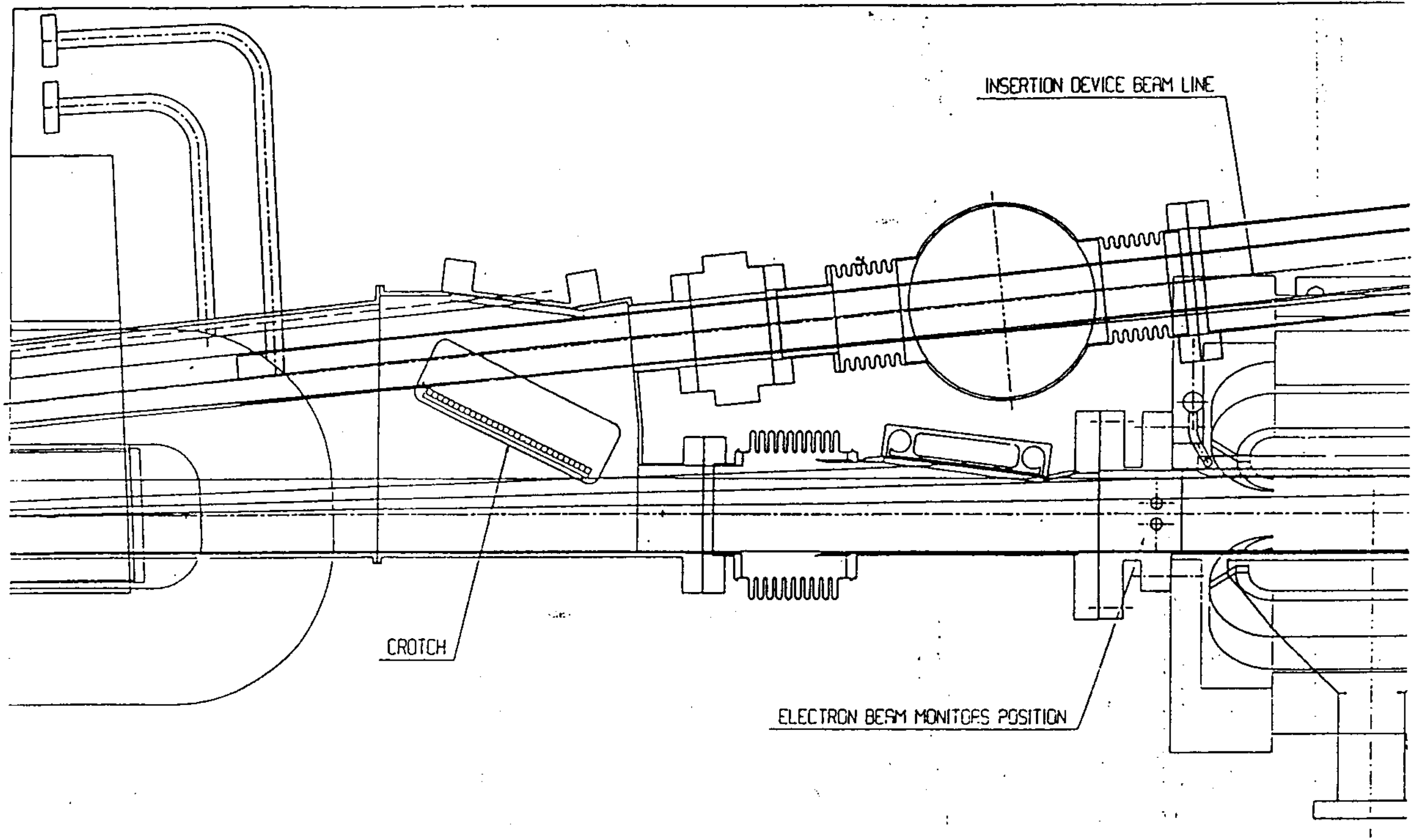
max. Power $= \varepsilon \;/\; (\alpha \;E \;17.8)$ kW/m

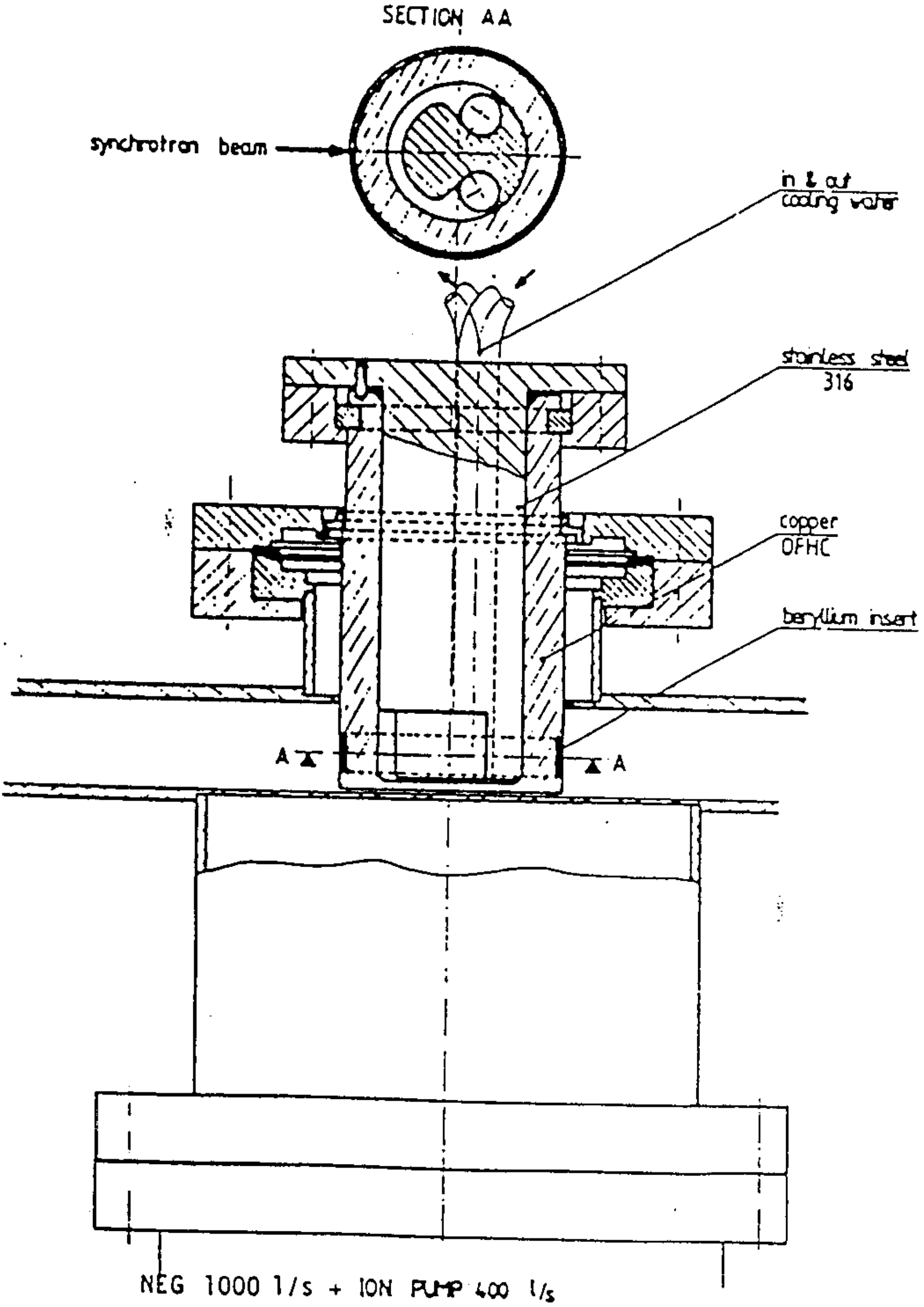
This exceeds 5.5 kW/m (equivalent to > 11 kW/m power from the beam)

Stress-limits(Al, Cu)

|  | AlMgSi 0.5 (LEP) | OFHC (soft) | OFHC (hard) | "GlidCop" |
|---|---|---|---|---|
| Young's Modulus (N/mm2) | 7.5E+4 | 1.2E+5 | 1.2E+5 | 1.2E+5 |
| tensile strength (0.2) (N/mm2) | 200. | 60. | 250. | 338. |
| coef. linear expansion ( 1/°C) | 2.7E-5 | 1.7E-5 | 1.7E-5 | 1.7E-5 |
| thermal cond. (W/°C/cm) | 2.37 | 3.85 | 3.85 | 3.8 |
| Max. chamber temperature (°C) | 98.77 | 29.41 | 122.55 | 165.69 |
| Temperature rise (°C/W/mm) | 17.80 | 11.60 | 11.60 | 11.60 |
| Max. linear power (W/mm) | 5.55 | 2.54 | 10.56 | 14.28 |




INSERTION DEVICE BEAM LINE
CROTCH
ELECTRON BEAM MONITORS POSITION



CROSS SECTION VACUUMCHAMBER AT CROTCH

Fig. 7.4.5.1