Vacuum Technology

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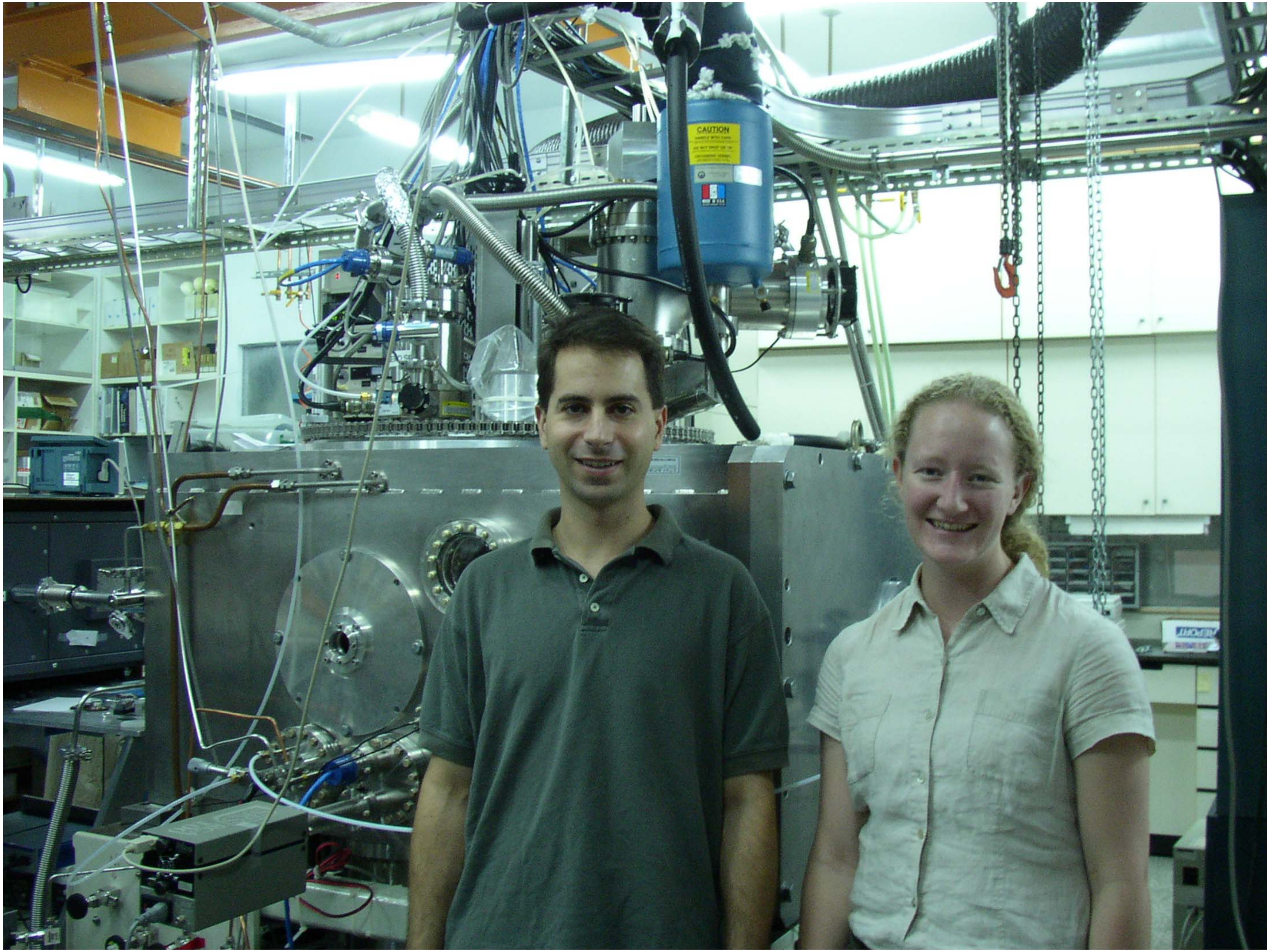
A very useful reference book:

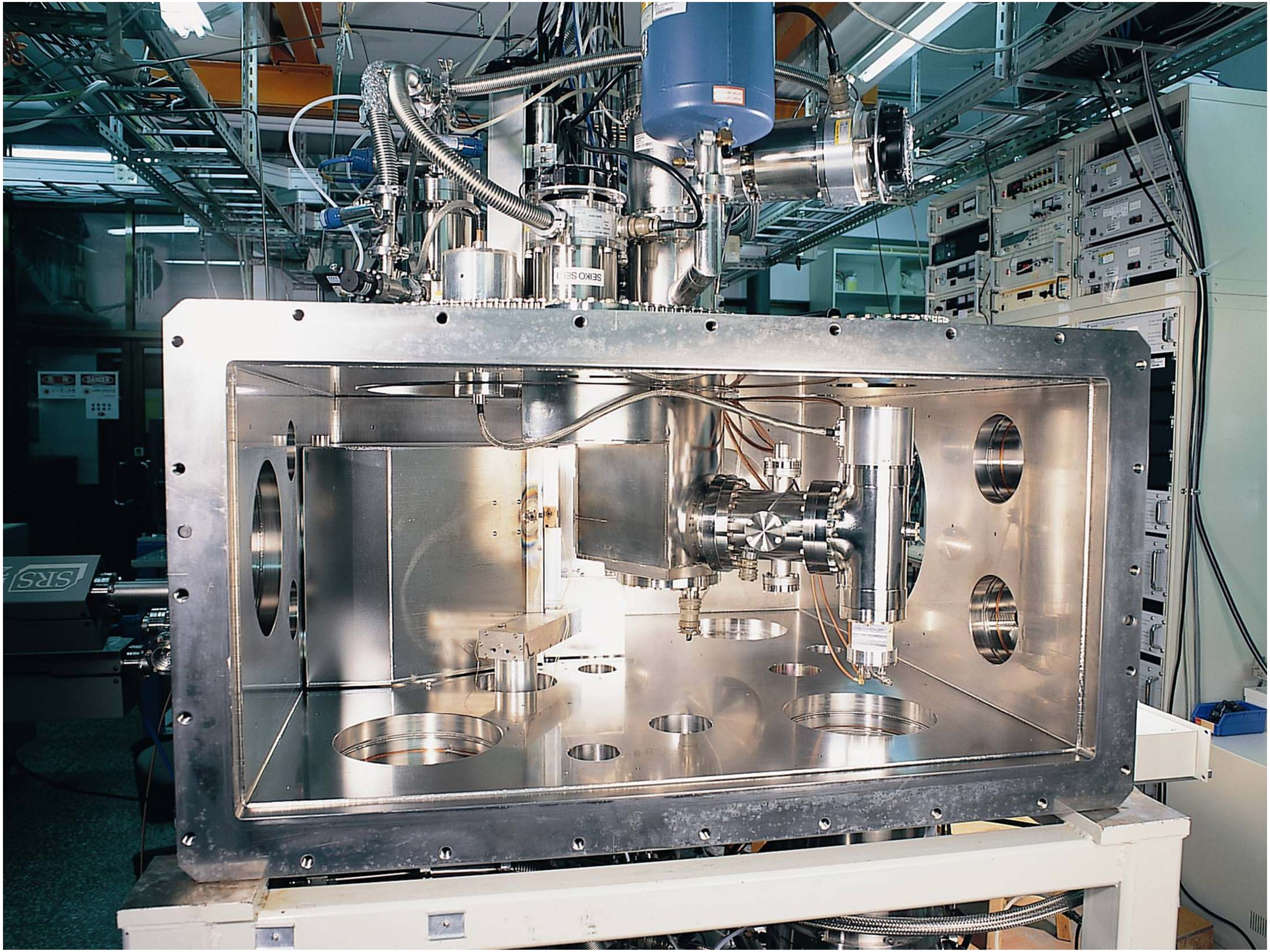
Building Scientific Apparatus

A practical guide to design and construction

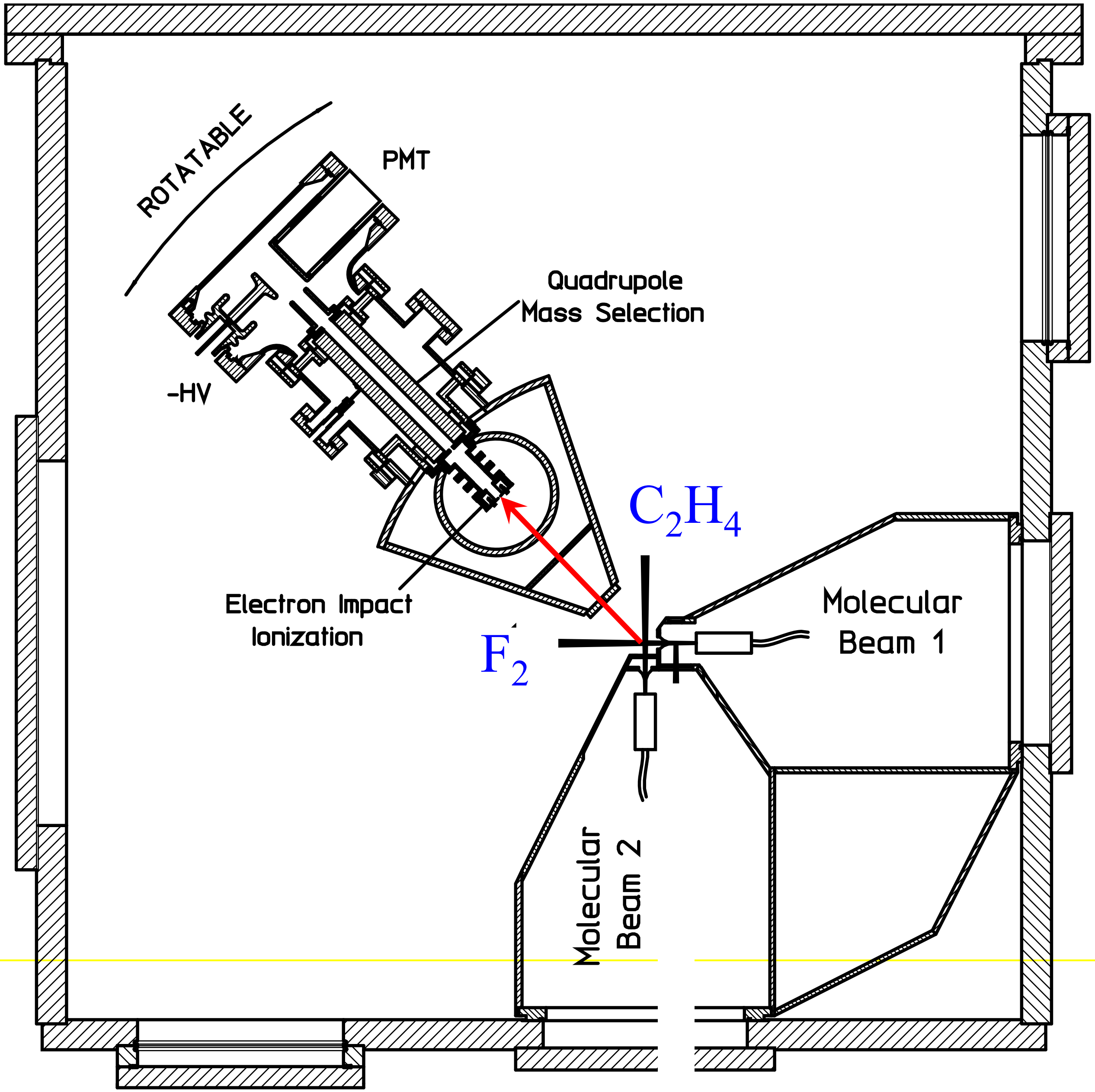
by John H. Moore, C. C. Davis and M. A. Coplan

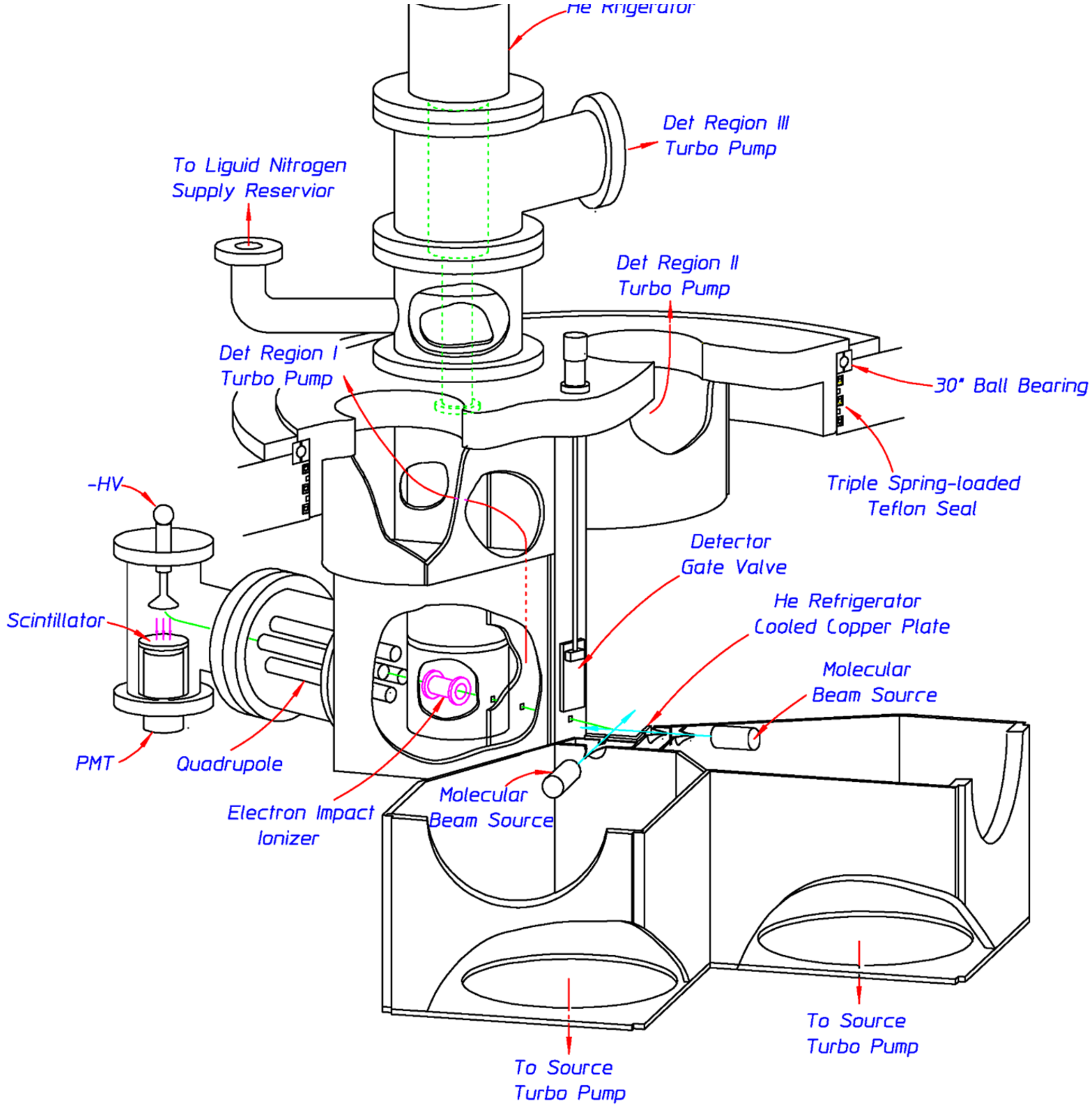
2ed, 3rd or 4th edition


CAUTION


SEIKO SEIKI
SRS
DANGER

Horizontal Cut View of the Crossed Beam Chamber at R410, IAMS




He Rrigerator
Det Region III
Turbo Pump
To Liguid Nitrogen
Supply Reservior
Det Region II
Turbo Pump
Det Region I
Turbo Pump
30" Ball Bearing
Triple Spring-loaded
Teflon Seal
-HV
Detector
Gate Valve
He Refrigerator
Cooled Copper Plate
Scintillator
Molecular
Beam Source
PMT
Quadrupole
Molecular
Beam Source
Electron Impact
Ionizer
To Source
Turbo Pump
To Source
Turbo Pump

Outlines:

Mean Free Path of gas molecules: Viscose flow Vs. Molecular flow

Gas flow: Throughput, Conductance, Pumping speed, *time*

Pumps: Mechanical pump, Roots, Turbo, Diffusion, Dry pumps

Gauges: Mechanical, Thermal conductance, Ionization,

Chambers: Joints (metal, elastomer), parts

Practical concerns:

- **Surface**
- **Material:** SUS, Al alloy, ceramic, plastic,
- **Sealing, Virtual leak**
- **Baking**
- **Leak test**
- **UHV**

Mean Free Path: 平均自由徑

The average distance that ***a molecule*** travels between successive collisions.

Speed of gas molecules: for air (80% N_2 + 20% O_2) at 20 ^oC

$$\bar{v} = \sqrt{\frac{8kT}{\pi m}} = 500 \,\mathrm{m/s}$$

$$\lambda \cong \frac{5\times10^{-3}}{P(\mathrm{torr})}\,\mathrm{cm}$$

for molecules of 3 Å diameter

$P = 760$ torr	$\lambda = 700$ Å	$\tau = 0.14$ ns
$P = 1$ torr	$\lambda = 50$ μm	$\tau = 100$ ns
$P = 10^{-3}$ torr	$\lambda = 5$ cm	$\tau = 100$ μs
$P = 10^{-6}$ torr	$\lambda = 50$ m	$\tau = 0.1$ s

If mean free path < container dimension

⇒ ***Viscous flow*** region

Molecule motion is <u>dependent</u> on each other

Molecule-molecule collisions dominate ⇒ ***Flow dynamics***

If mean free path > container dimension

⇒ ***Molecular flow*** region

Molecule motion is <u>independent</u> of each other

Molecule surface collisions dominate ⇒ ***Vacuum***

Rev. Sci. Instrum. 73, 3872 (2002)

Ambient Pressure Photoelectron Spectroscopy

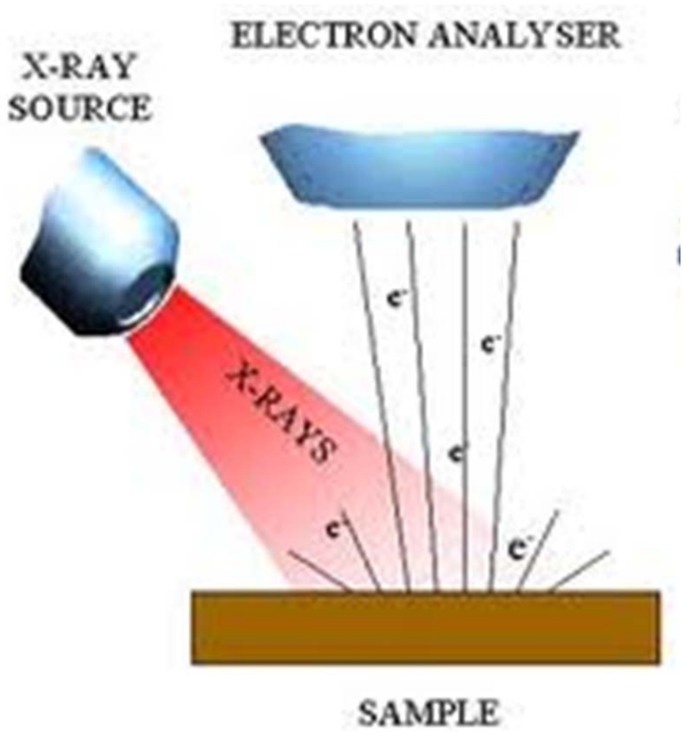
For electrons at 500 eV,

the mean free path is 2 mm at 1 torr.

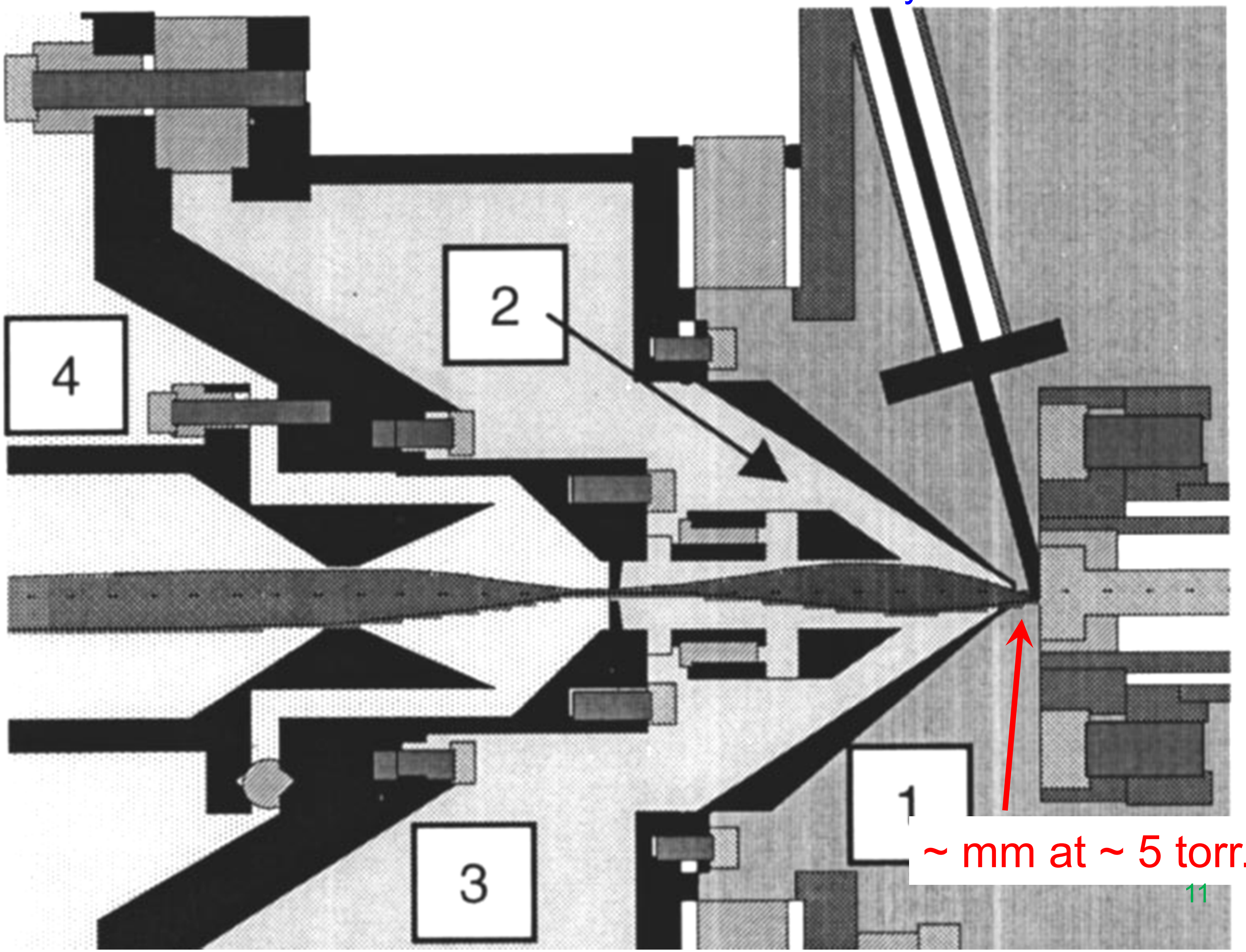
The molecule mean free path is much shorter!

$P = 760$ torr	$\lambda = 700$ Å
$P = 1$ torr	$\lambda = 50$ μm
$P = 10^{-3}$ torr	$\lambda = 5$ cm
$P = 10^{-6}$ torr	$\lambda = 50$ m

for Molecules



Rev. Sci. Instrum. 73, 3872 (2002);



Pumping speed:

$$PV = nRT \qquad\qquad n \propto PV \qquad \text{at } T = \text{const}$$

For a typical pump, the amount of gas being pumped out is proportional to ***P***, such that the pumping speed ***S*** is defined as

$$\frac{\delta(PV)}{\delta t} = PS \qquad S = \frac{1}{P}\frac{\delta(PV)}{\delta t}$$

S in Liters per Second, L/s

Throughput

$$Q = PS$$

in torr·L/s

$$\frac{dn}{dt} \propto \frac{dPV}{dt} = Q = SP$$

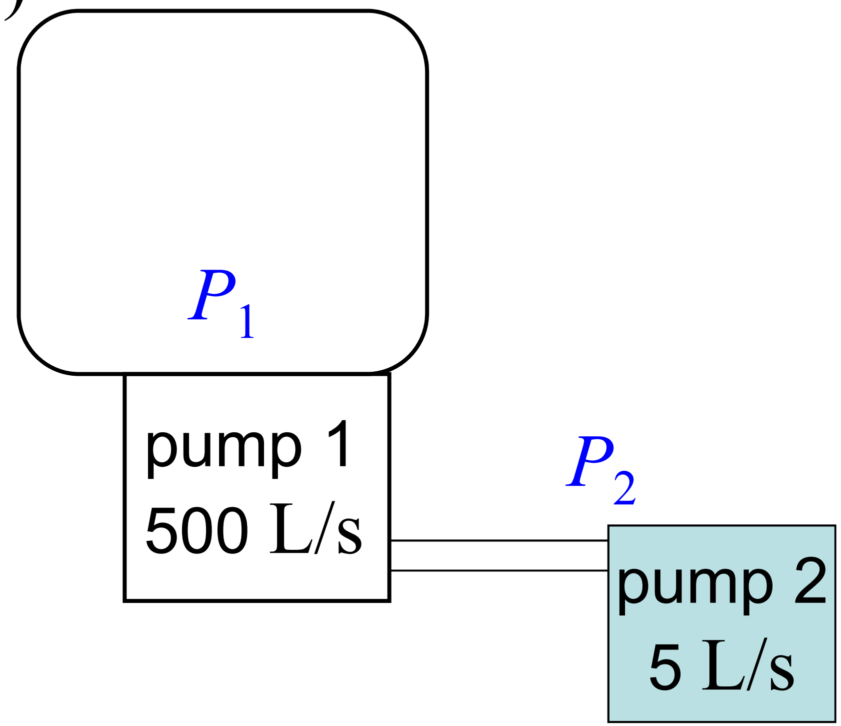
at $T = \text{const}$

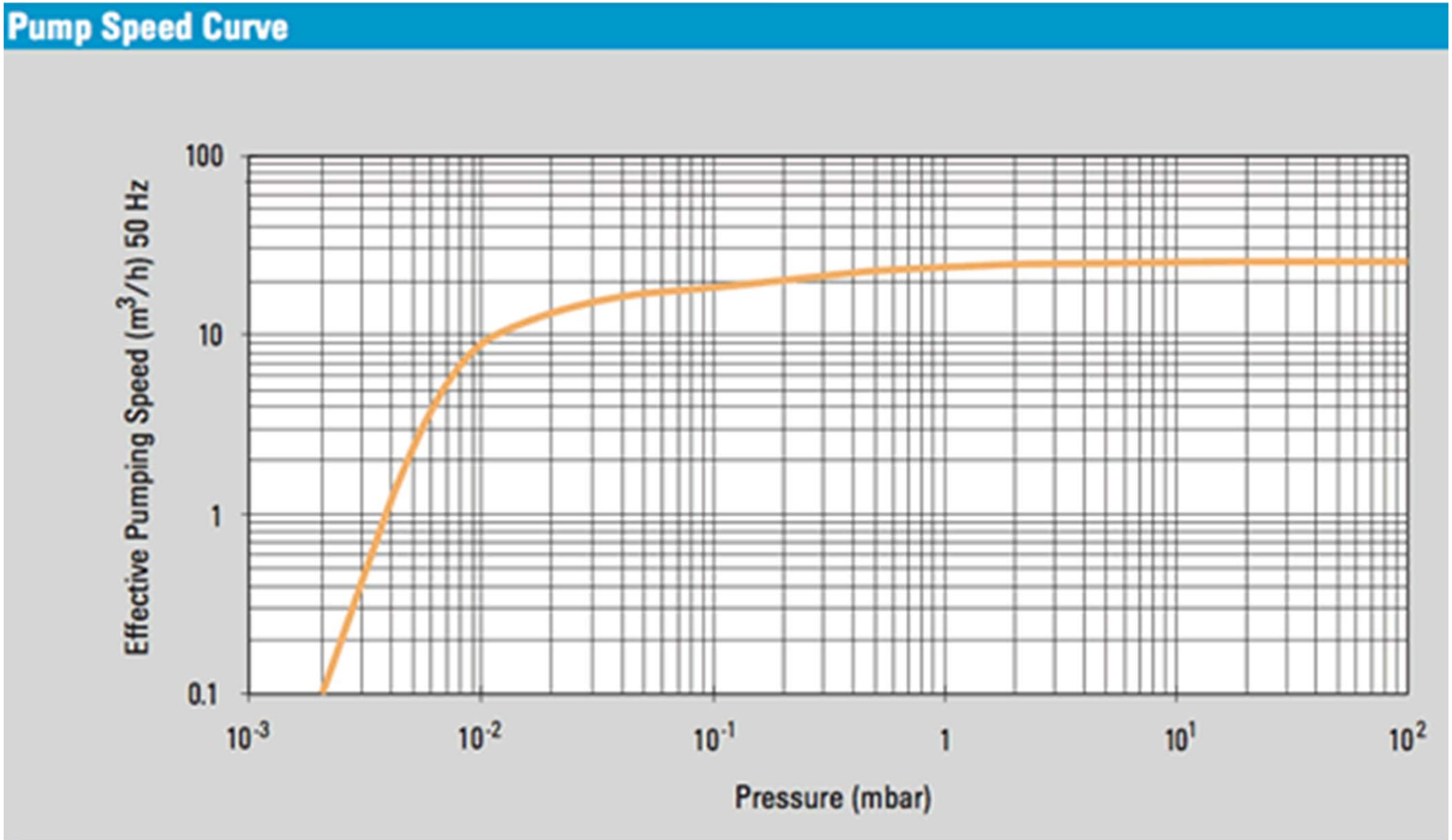
Usually, throughput is conserved. (Steady state)

$$Q = P_1 S_1 = P_2 S_2$$

$$P_1\,(500\ \mathrm{L/s}) = P_2\,(5\ \mathrm{L/s})$$

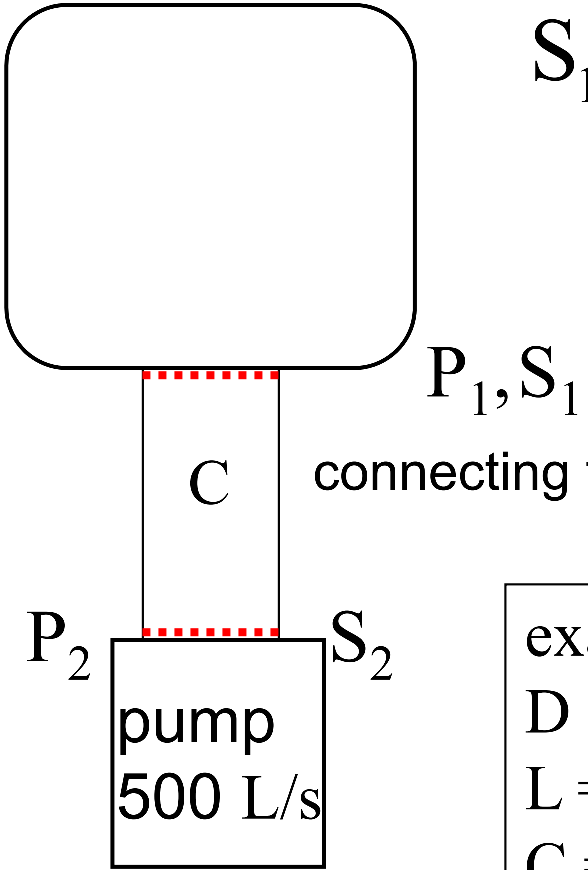
$$P_2 = 100\,P_1$$





Agilent DS602 Dual Stage Rotary Van Pump

$$\frac{1}{S_1} = \frac{1}{C} + \frac{1}{S_2}$$



D = diameter, in cm
L = length, in cm
C = conductance, in L/s

connecting tube, conductance $$C = 12\frac{D^3}{L}$$ @ molecular flow

example 1	example 2
D = 15 cm	D = 10 cm
L = 20 cm	L = 20 cm
C = 2025 L/s	C = 600 L/s
S_1= 401 L/s	**S_1= 273** L/s

Pump is expensive. Tube is cheap.

L > D

$$C = 12\frac{D^3}{L} = 12\,D^2\,\frac{D}{L}$$

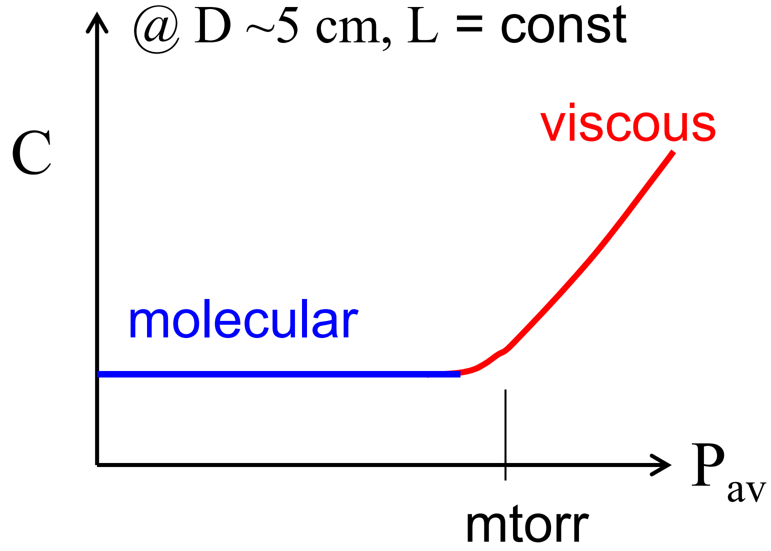
@ molecular flow, λ > D,
D ~ 5 cm, P < mtorr

λ = 5 cm @ 1 mtorr

$$C = 180\frac{D^4}{L}P_{av}$$

@ viscous flow, λ < D (P > mtorr)

D = diameter, in cm
L = length, in cm
C = conductance, in L/s
P_{av} = average pressure, in torr



Serial Connection

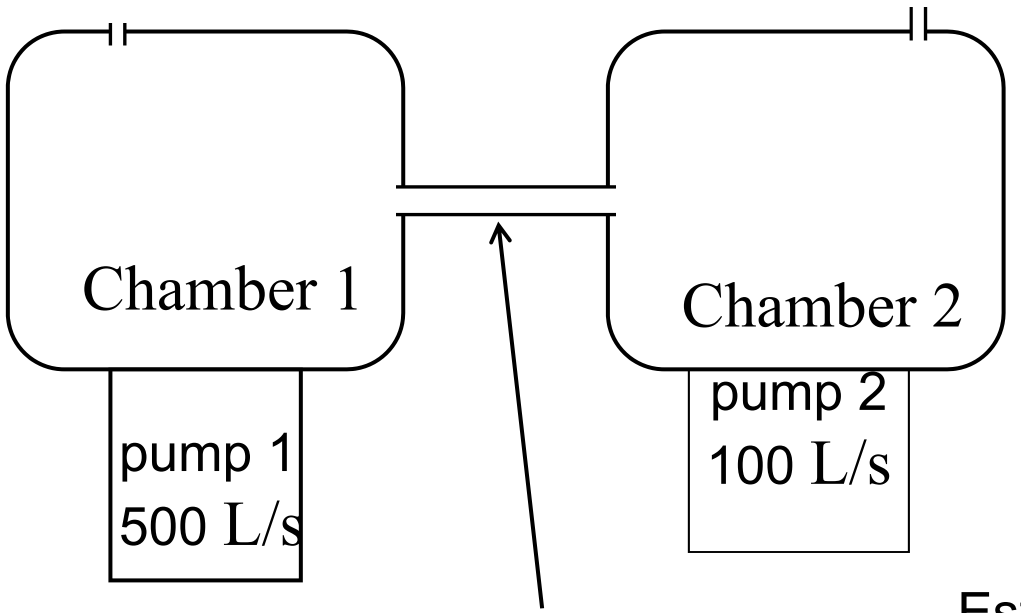
$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2}$$

Parallel Connection

$$C = C_1 + C_2$$

gas inlet, N_2
1×10^{-3} torr L/s

gas inlet, O_2
1×10^{-4} torr L/s



connecting tube
1 cm inner diameter
10 cm length

Estimate:

$P(N_2)$ in chamber 1

$P(N_2)$ in chamber 2

$P(O_2)$ in chamber 1

Pump down time

$$\frac{d\,\mathrm{PV}}{d\,\mathrm{t}} = -\mathrm{SP}$$

equation for the throughput

$$\frac{d\,\mathrm{P}}{d\,\mathrm{t}} = -\frac{\mathrm{S}}{\mathrm{V}}\mathrm{P}$$

$$\mathrm{P} = \mathrm{P}_0\, \mathrm{e}^{-\mathrm{t}/\tau}$$

$$\tau = \frac{\mathrm{V}}{\mathrm{S}}$$

$$t = \tau \ln\left(\frac{P_0}{P}\right) = 2.3\tau \log\left(\frac{P_0}{P}\right)$$

For example,
V = 1000 L

S = 500 L/s
τ = 2 s
every 2.3 τ, 10 x pressure drop

Why in the real world, it takes much longer from 10^{-6} torr to 10^{-7} torr?

Surface outgas

Pumps:

Mechanical:
Oil rotary vane, Roots
Dry vane, Scroll, Diaphragm

Diffusion

Turbo

Ion & Ti Sublimation

Cryo

Pumping Speed

Working pressure range

Compression Ratio

Gas species dependent

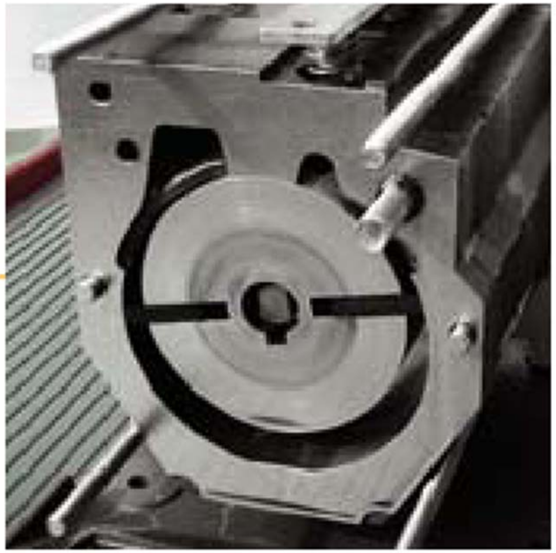


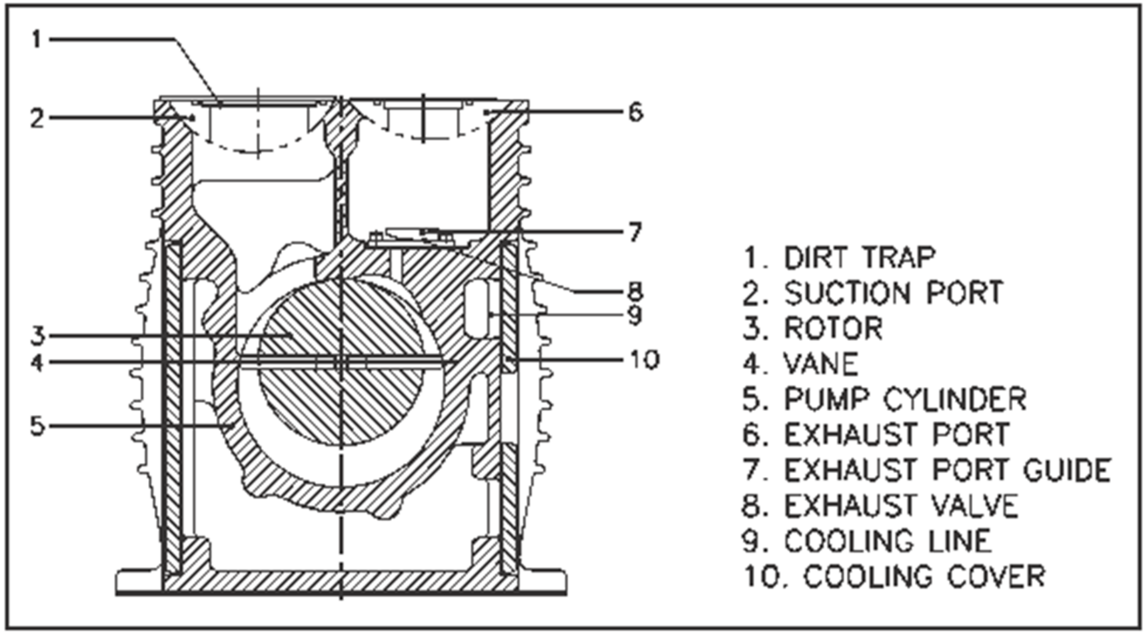
Rotary vane pump

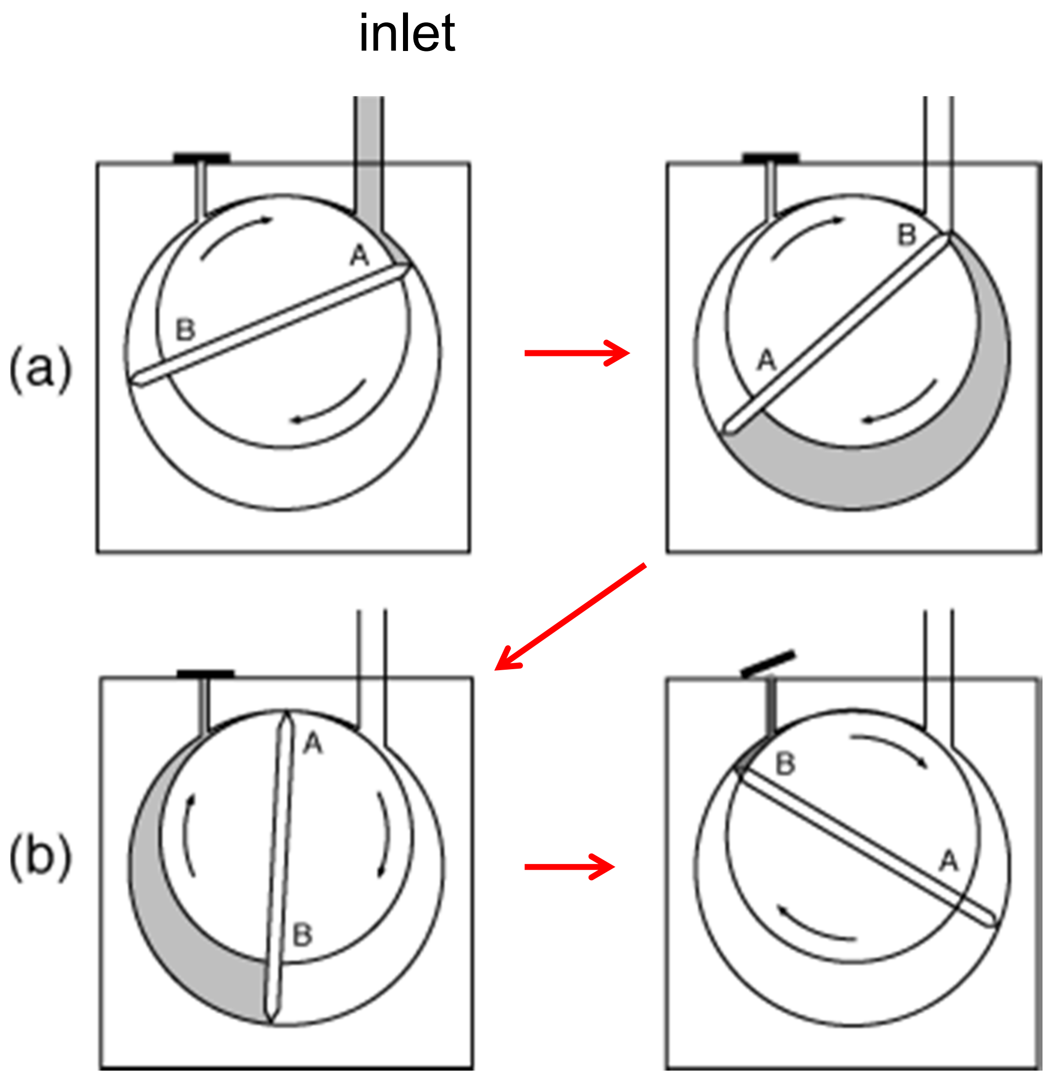
Mechanical Pump

single stage: down to 10^{-1} torr

two stage: down to 10^{-3} torr






inlet
(a)
A
B
B
A
(b)
A
B
B
A

Oil sealing, lubrication
back stream ⇒ **molecular sieve trap**

Dry (oil free) poor sealing
short lifetime
dust

limited by oil vapor & air back leak

Inlet pressure: 10^{-3} torr ~ torr ~ atm

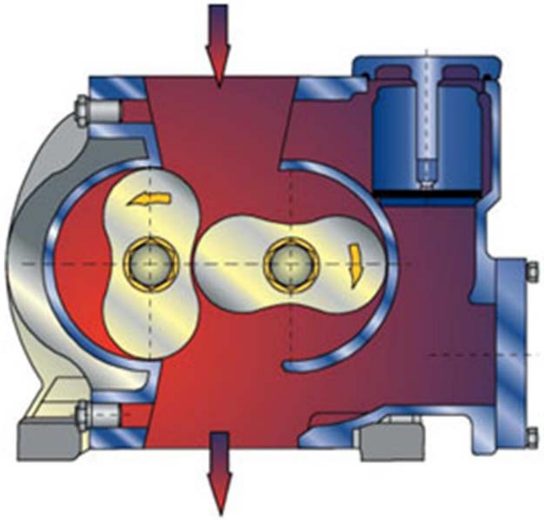
heavy load at high pressure

Outlet pressure: 1 atm ~ 1.1 atm

NSRRC accident

Roots blower

P_{in}



P_{out}

to rotary pump

Large pumping speed

Low compression ratio ~ 10

Compression ratio $K = \dfrac{P_{out}^{eq}}{P_{in}^{eq}} \quad @Q_{net} = 0$

Net throughput

$$Q_{net} = P_{in} S_{for} - P_{out} S_{back}$$

If P_{out} is high, Q_{net} can be reduced to 0

Here P_{out}/P_{in} is at maximum and

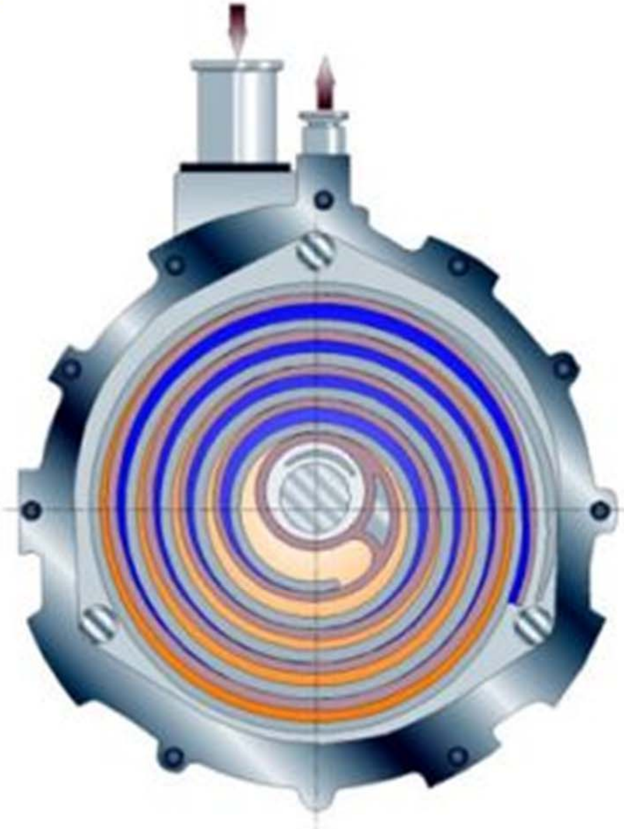
$$K = P_{out}/P_{in} = S_{for}/S_{back}$$

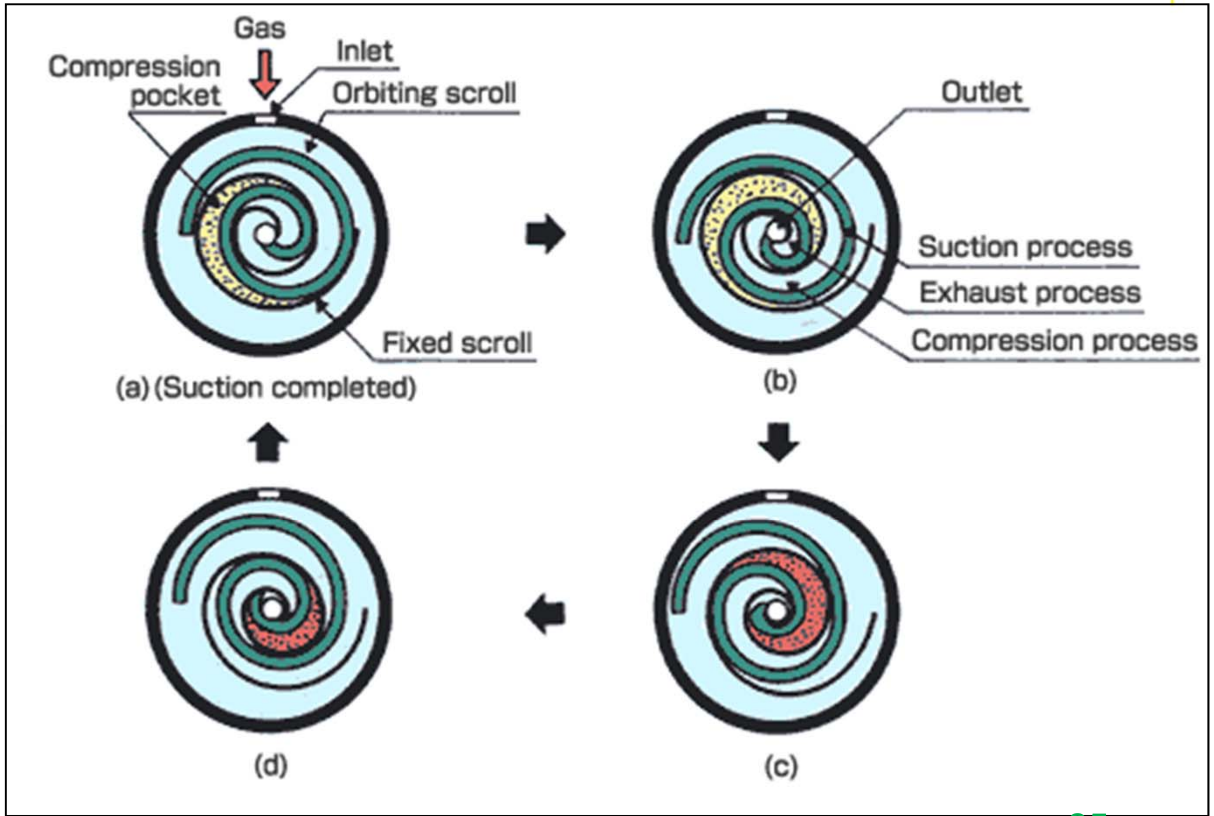
Scroll pump Dry (24hr/day) (365day/yr) = 8760 hr/yr

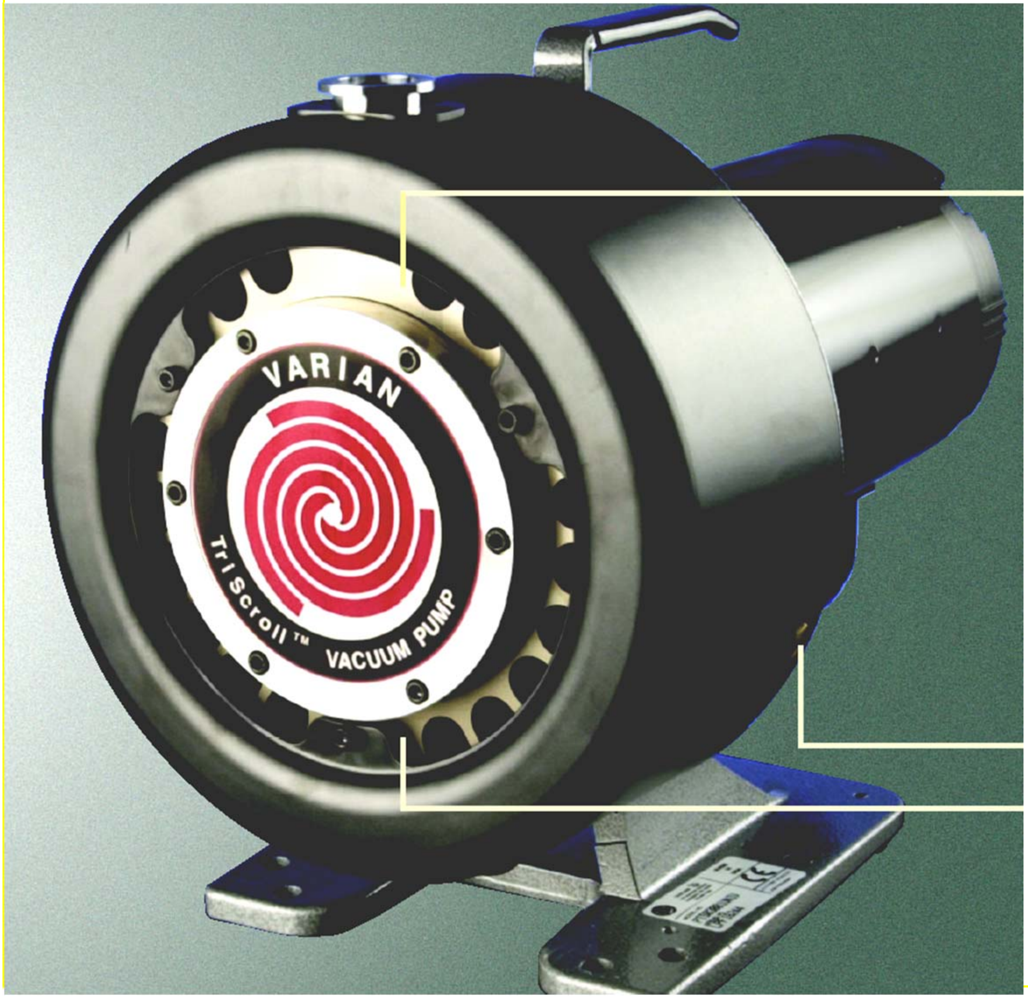
Shorter maintenance interval (5000 hrs)

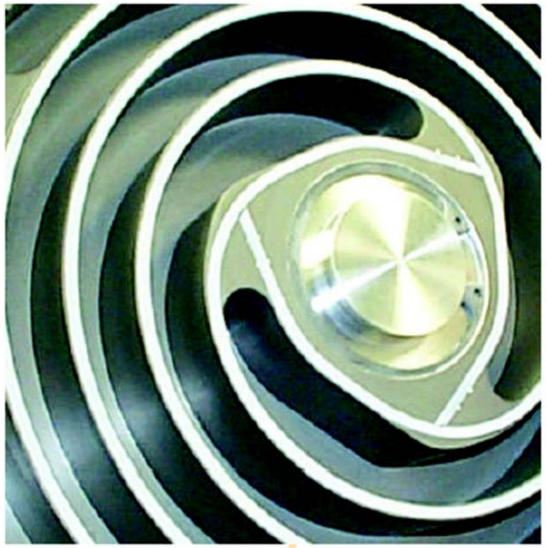
Poorer corrosive resistance

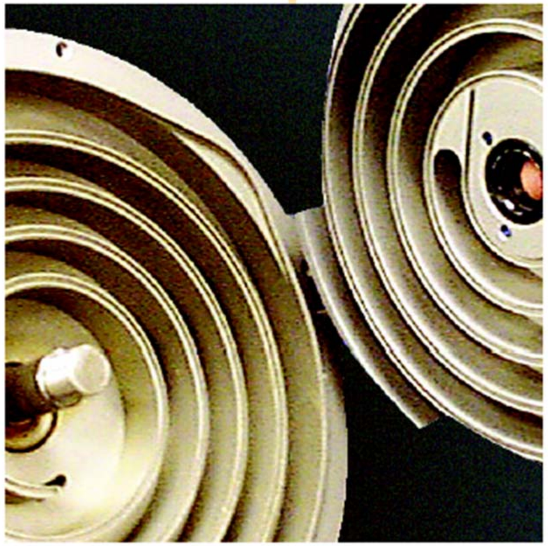
Inlet pressure: 10^{-3} torr ~ torr ~ atm Outlet pressure: 1 atm ~ 1.1 atm

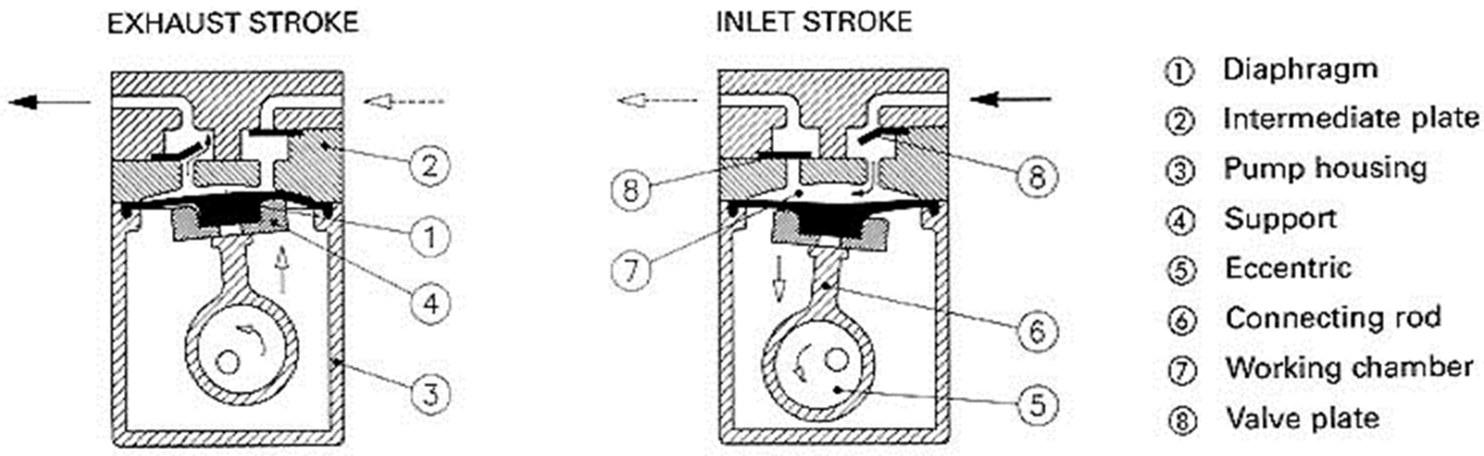


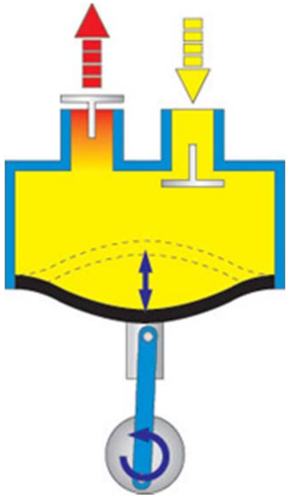



VARIAN
TriScroll™ VACUUM PUMP









Dry; Small; Low power consumption

Low pumping speed

Low compression ratio

Poor ultimate pressure: ~ torr

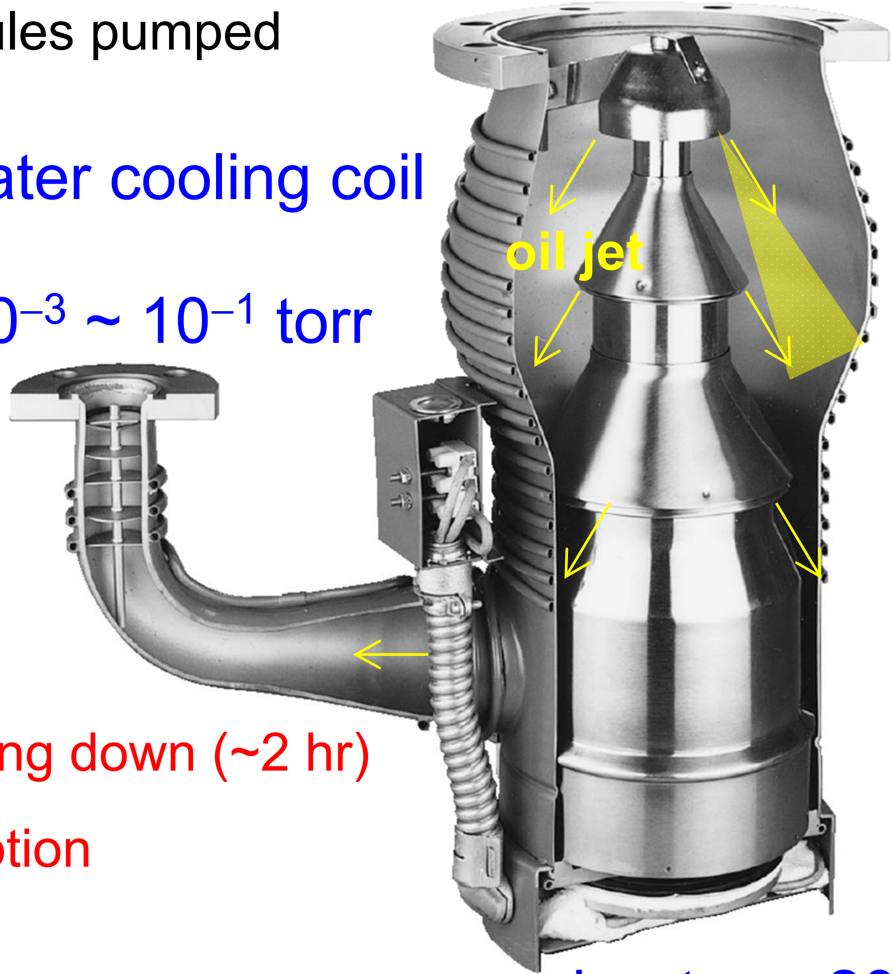
Diaphragm outgas

Diaphragm crack

1–4 stages are available

Oil diffusion pump

mechanism:
momentum of oil molecules
>> momentum of gas molecules pumped



Cheap, Robust

Oil back stream

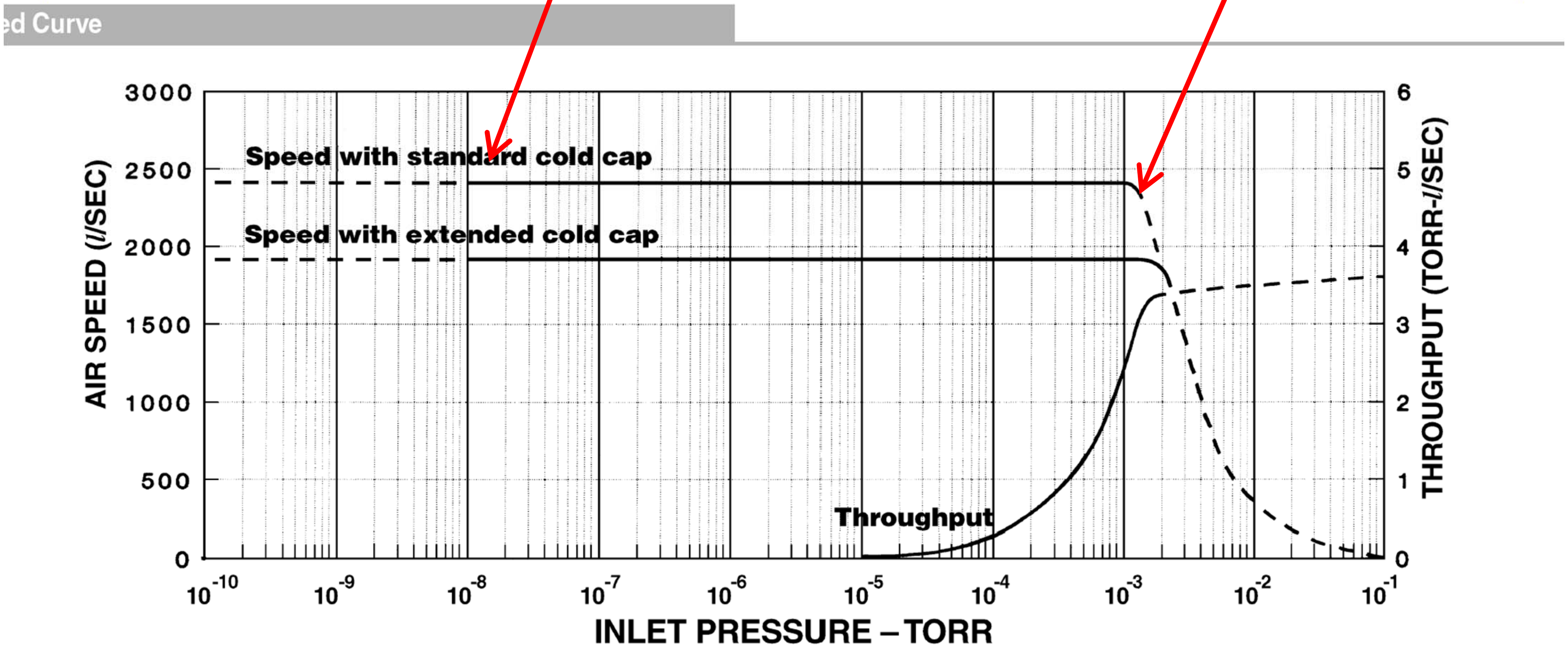
Slow heat up (~0.5 hr) & cooling down (~2 hr)

Large electric power consumption

mean free path ~ 5 cm at inlet
even shorter at outlet

Oil vapor

Load too high



Refer to page 50 for a description of speed test.

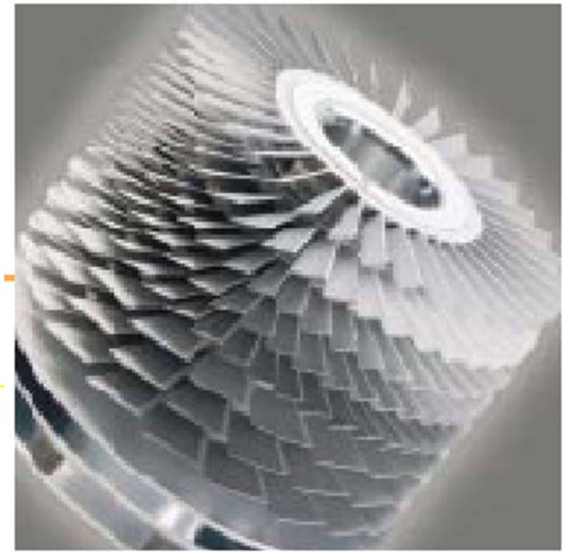
Turbo Molecular Pump

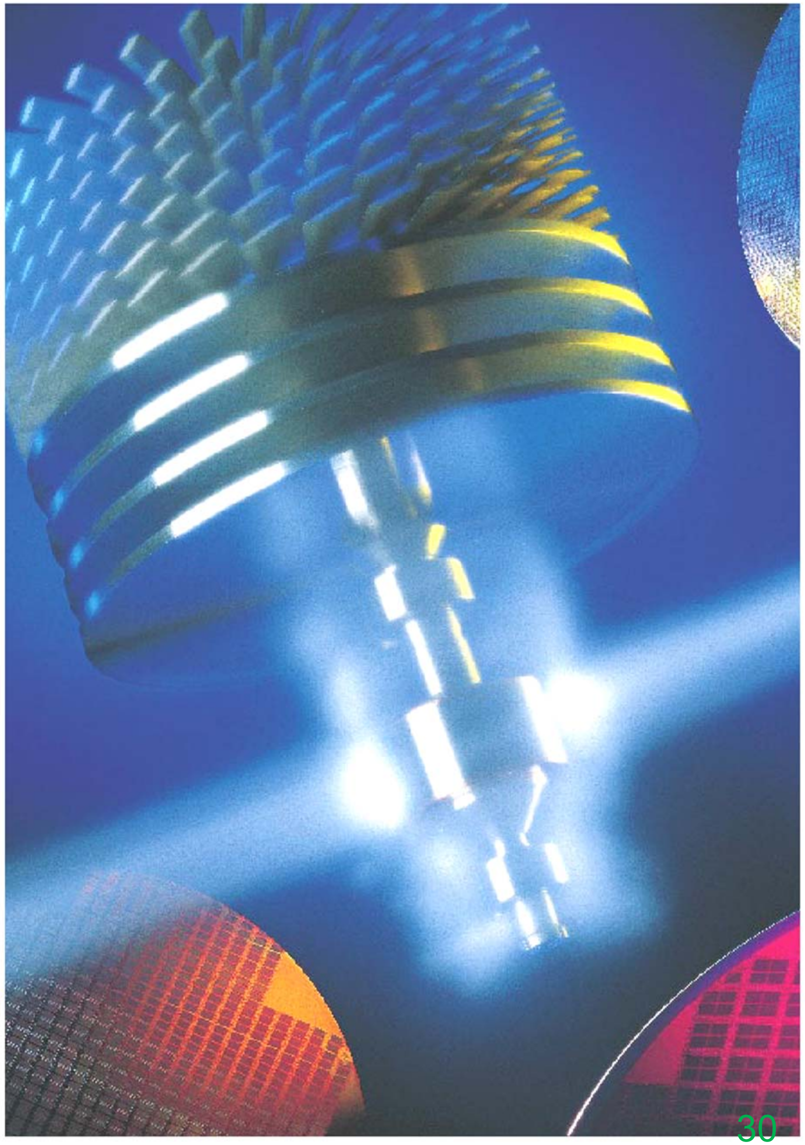
There are stators to block bouncing back (not shown)

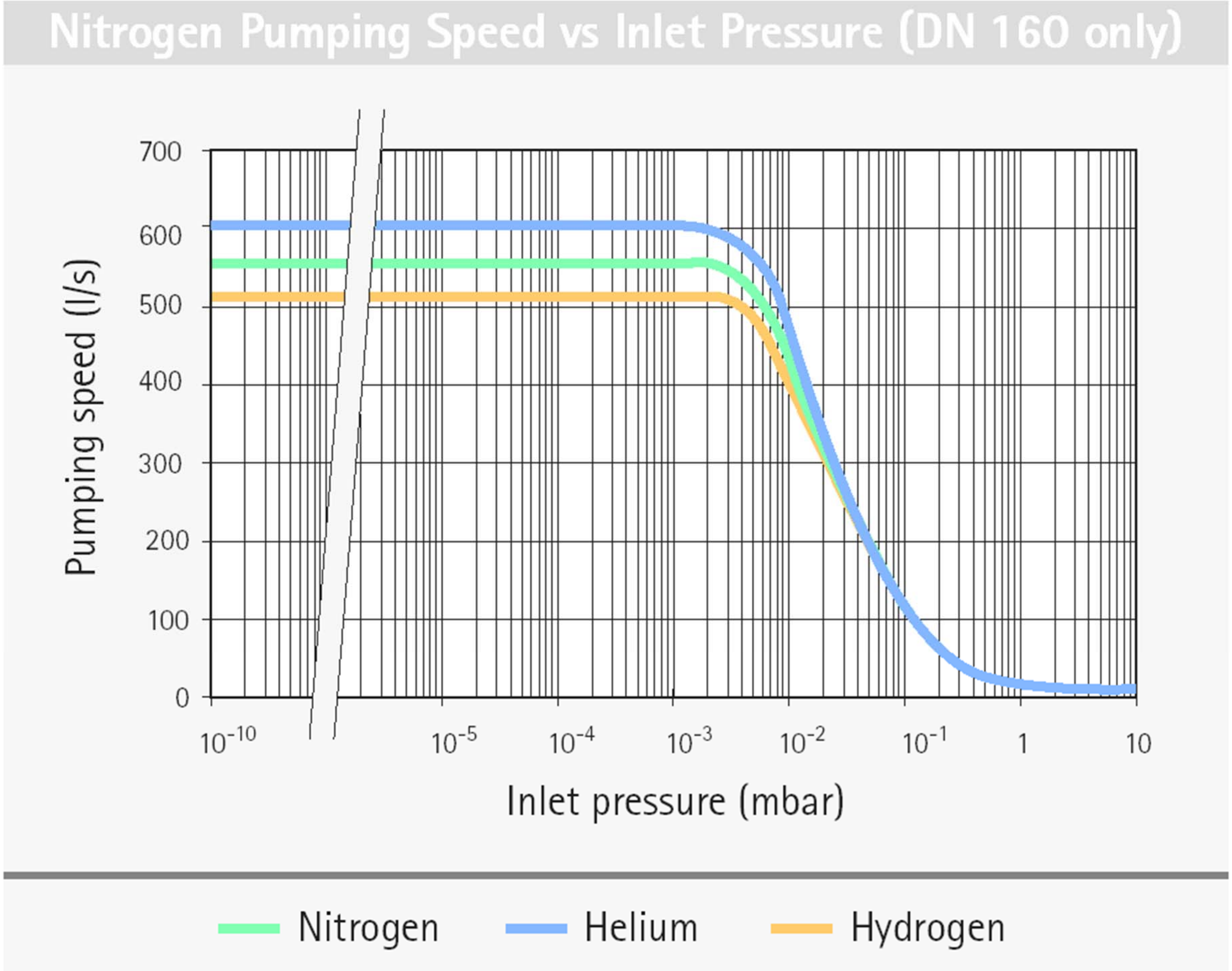
- High Speed Fan (rotor)
- momentum transfer
- blade speed ~ molecular speed

$$\bar{v} = \sqrt{\frac{8kT}{\pi m}} = 500\,{}^{m}\!/_{s}\ for\,air$$

$$2000\,{}^{m}\!/_{s}\ for\,H_2$$



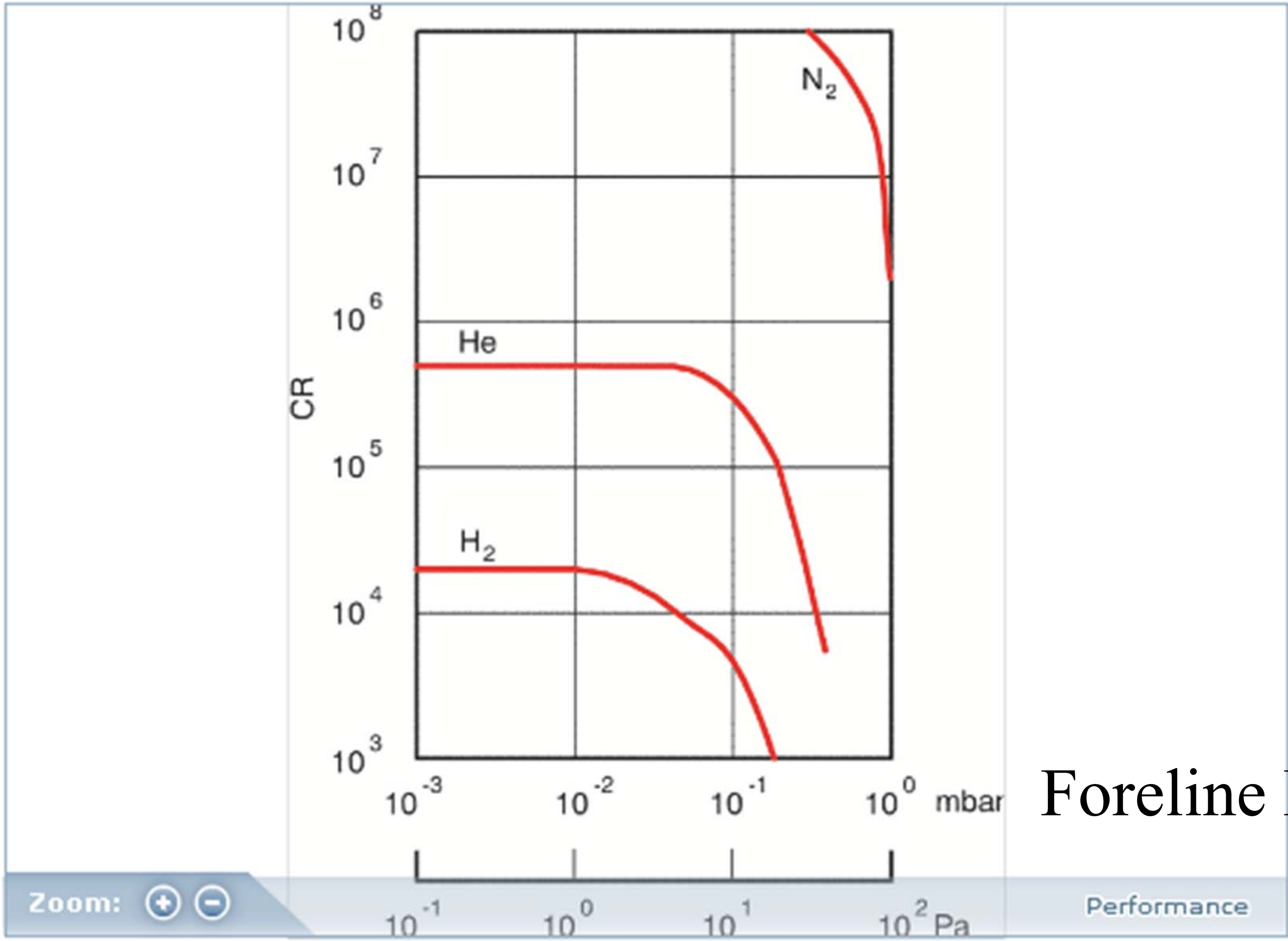




Nitrogen Pumping Speed vs Inlet Pressure (DN 160 only)
700
600
500
400
300
200
100
0
Pumping speed (l/s)
10-10
10-5
10-4
10-3
10-2
10-1
1
10
Inlet pressure (mbar)
Nitrogen
Helium
Hydrogen

Small compression ratio for H_2

Compression ratio $K = \frac{P_{out}}{P_{in}} \quad @Q_{net} = 0$



Foreline Pressure

Turbo	Convenient, reliable now, small size

Bakable to 125 ^{o}C

Low compression ratio for H_2, $10^3 \sim 10^5$

Outgas from lubricant and wires

magnetic bearing	maintenance free

Corrosive resistant

Foreline Pressure determines its load.

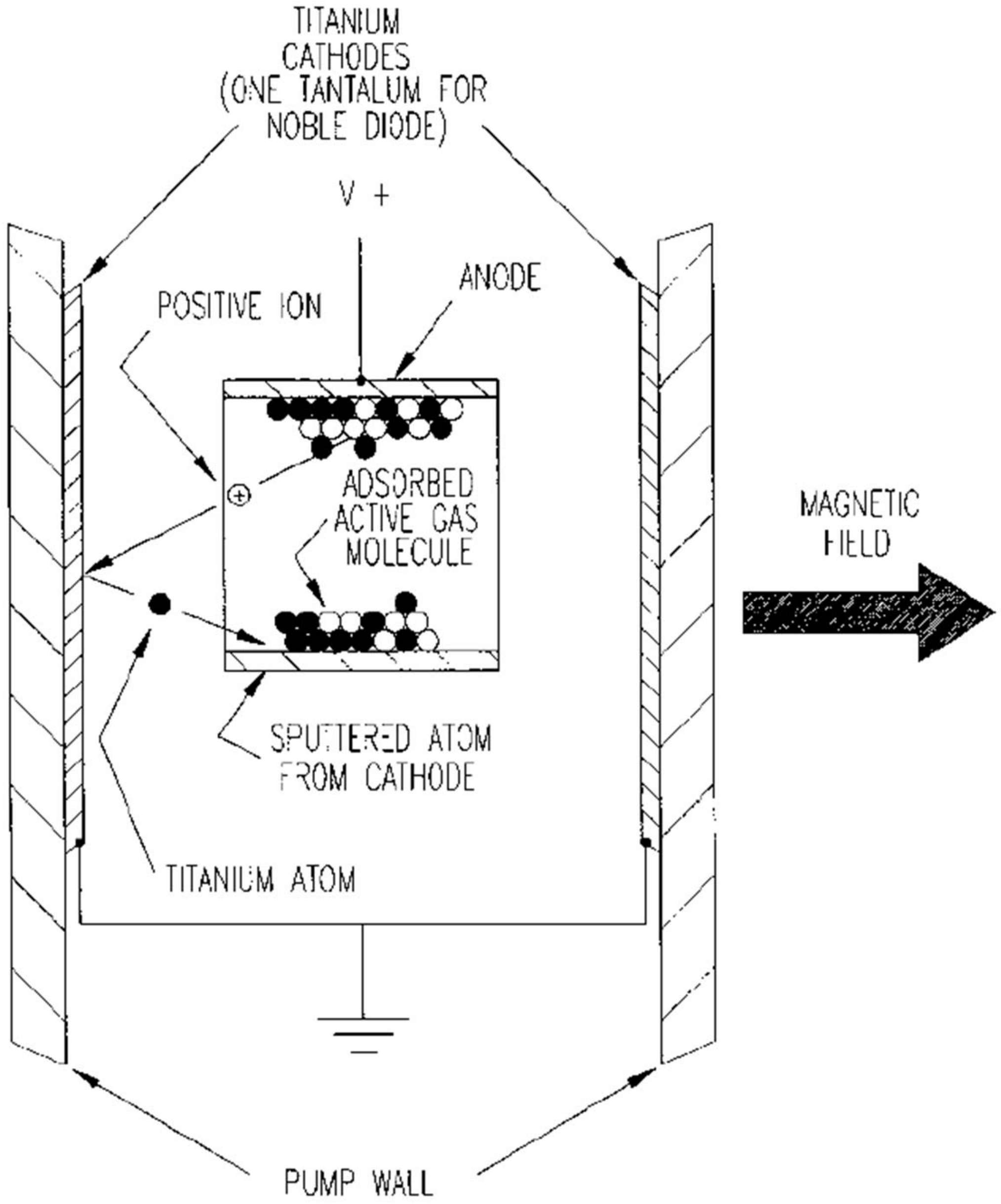
Ion Pump

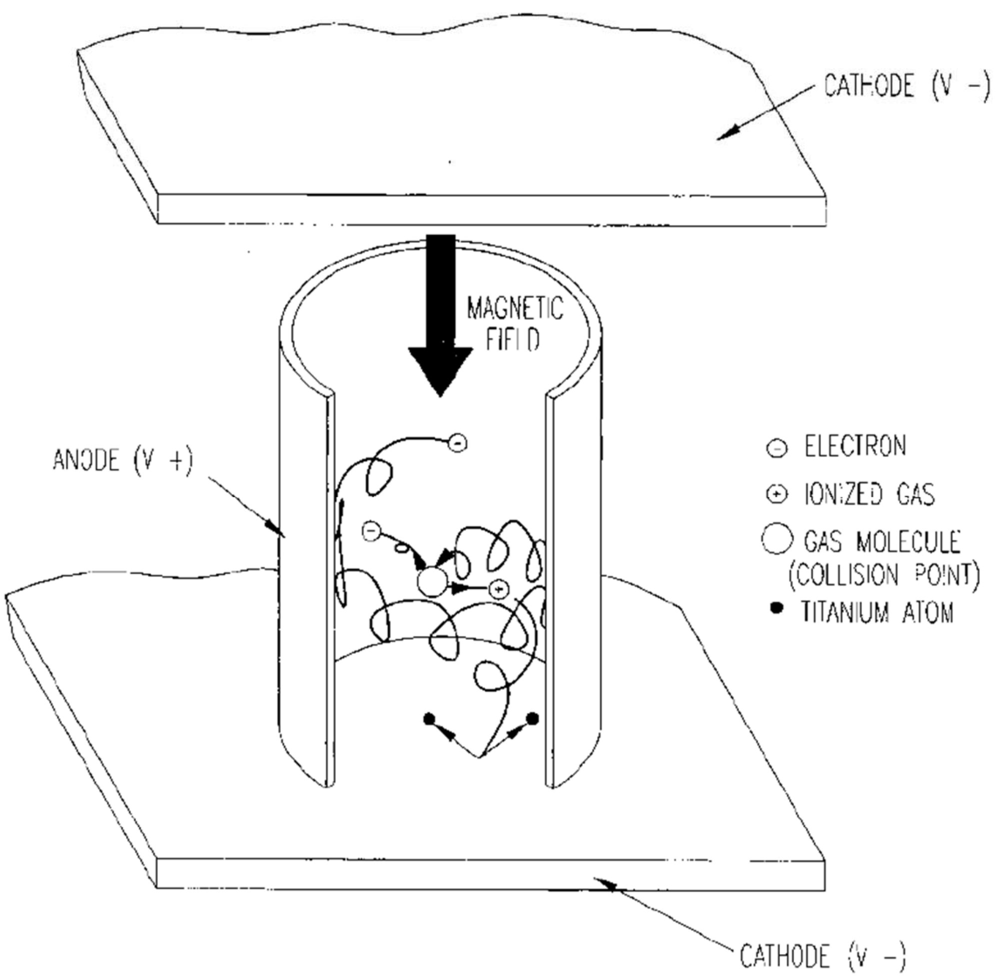
gas ionization by e^-

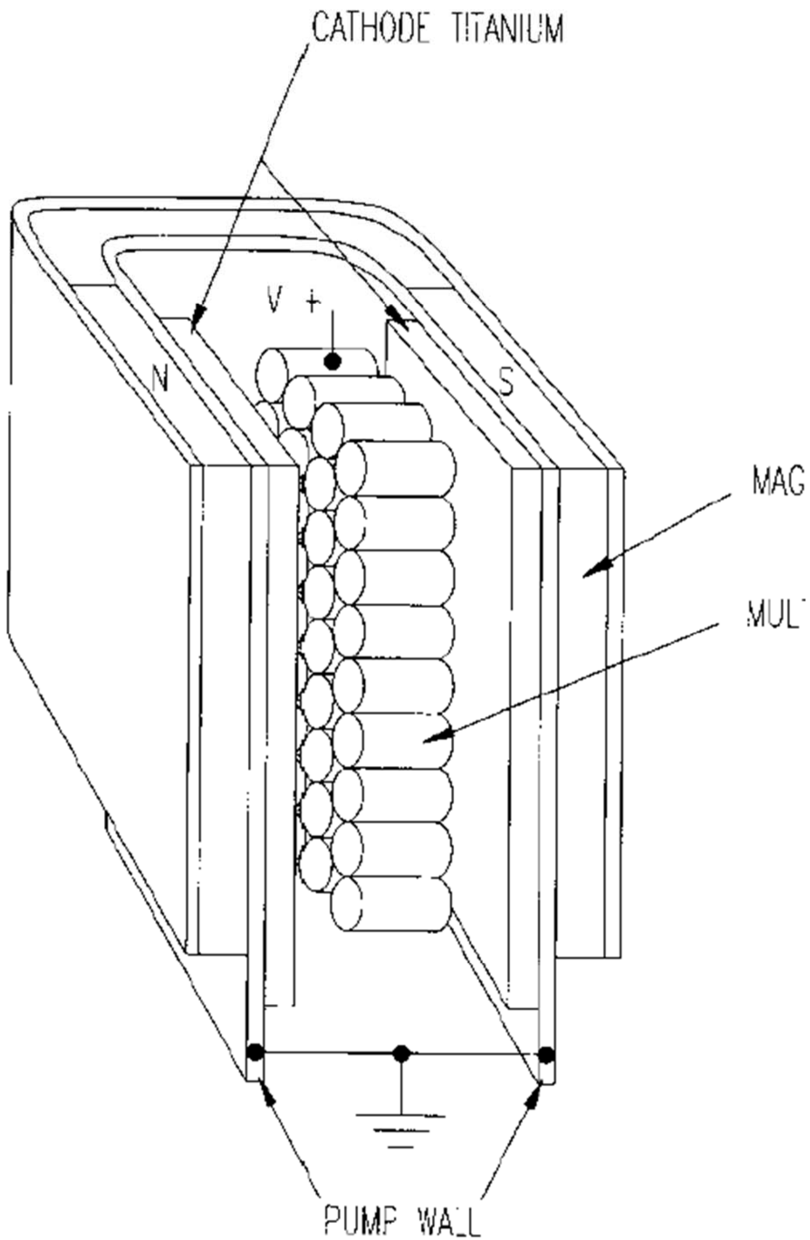
implantation

Ti sputtering

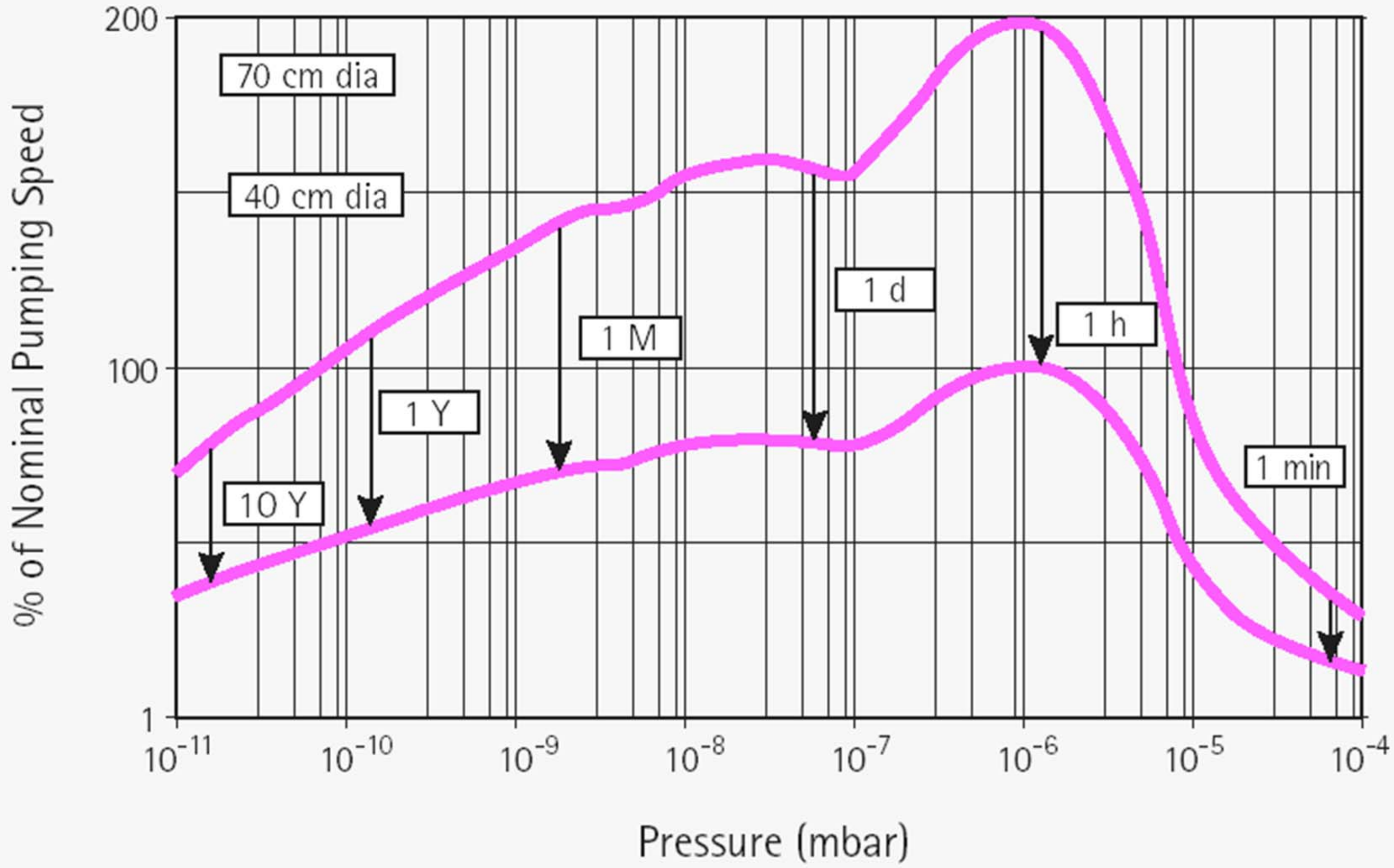
gas absorption on Ti




CATHODE (V -)
MAGNETIC
FIELD
ANODE (V +)
ELECTRON
IONIZED GAS
GAS MOLECULE
(COLLISION POINT)
TITANIUM ATOM
CATHODE (V -)


CATHODE TITANIUM
V +
N
S
MAG
MUL
PUMP WALL

Saturation Effect



Ion Pump and Ti Sublimation Pump

No foreline needed

Ti sorption pumping when electric

power is off

Robust

Saturation effect, only for very small load

Memory effect, outgas

Gas species dependent

Cryopump

Gas condensation on ultracold surfaces

< 20K activated carbon to absorb H_2, Ar, N_2, O_2, etc

< 80K metal surface to absorb H_2O, etc

Large pumping speed for condensing gases

No fore line needed

Corrosive resist

Gas species dependent: No pumping for He, Ne

Saturation effect, Memory effect
Huge outgas when warm
} gate valve recommended

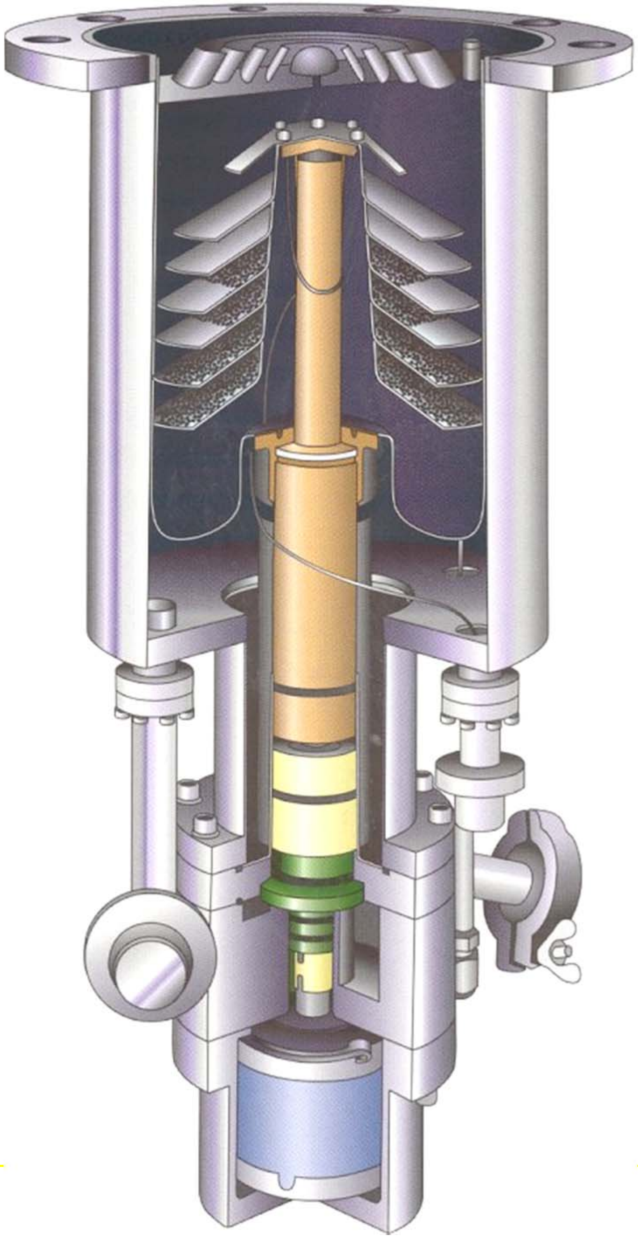
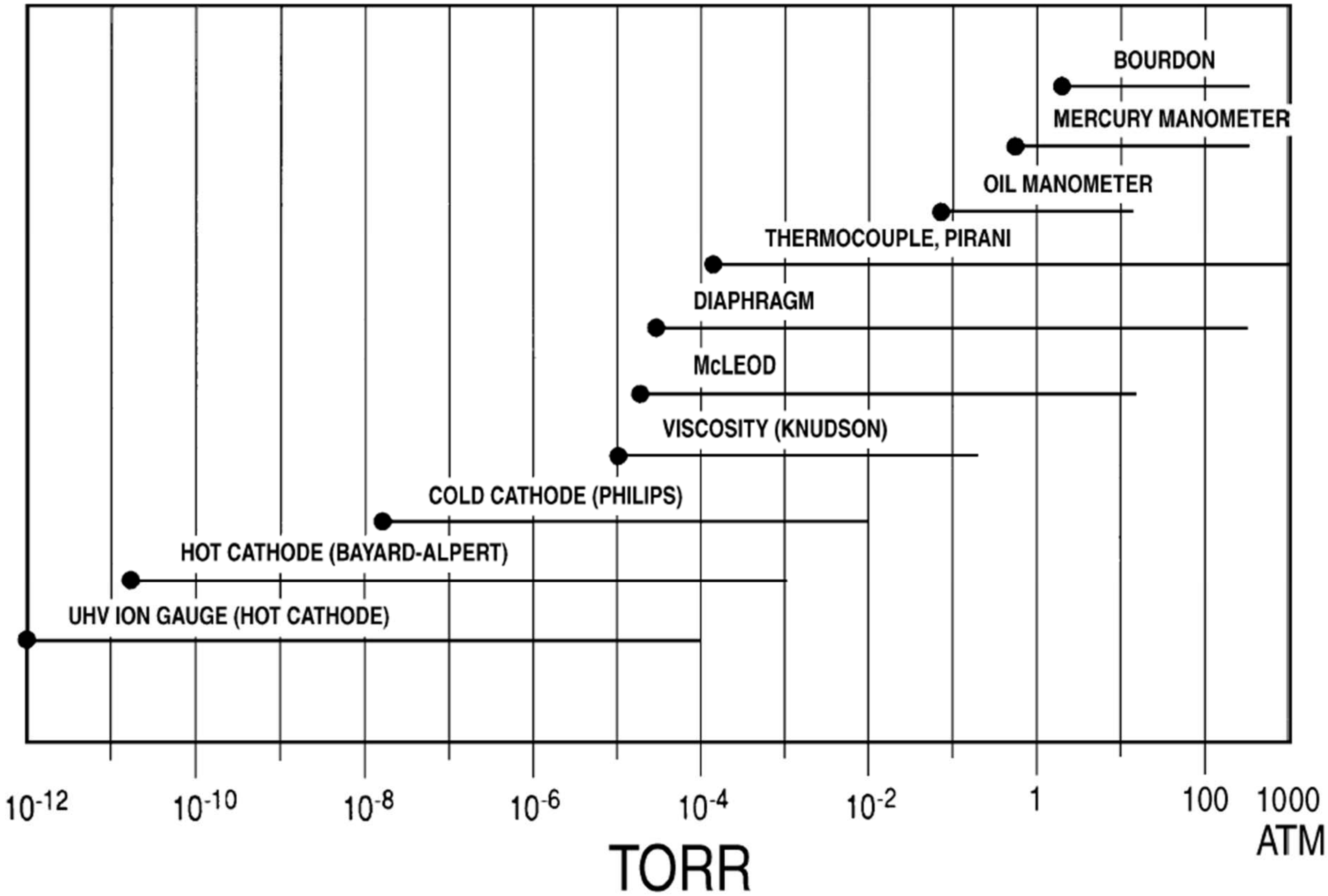


Figure 4 Pressure Ranges of Various Vacuum Gauges



Gauge types

Mechanical: liquid column, diaphragm, etc

psig Vs. *psia*

Real pressure from force measurement

Thermal Conductance: Thermal Couple (TC)

thermo resister (Pirani)

convection

cheap, wide range 10^6

nonlinear sensitivity

zero point is not absolute

species dependent

Ionization: $e^- + M \rightarrow M^+ + 2e^-$

hot cathode: hot filament, W or Th on Ir

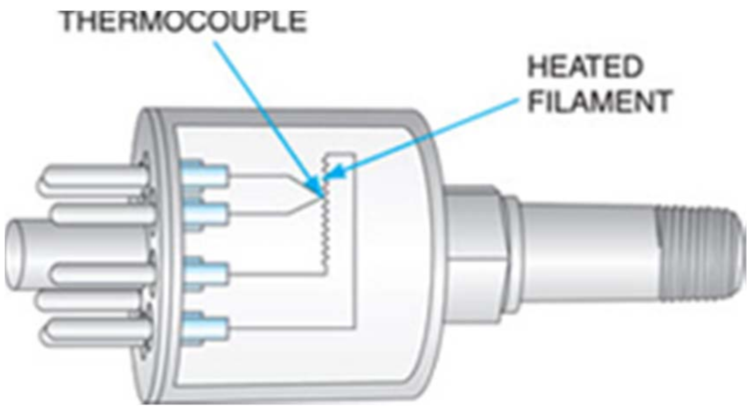
cold cathode, discharge (ion pump current)

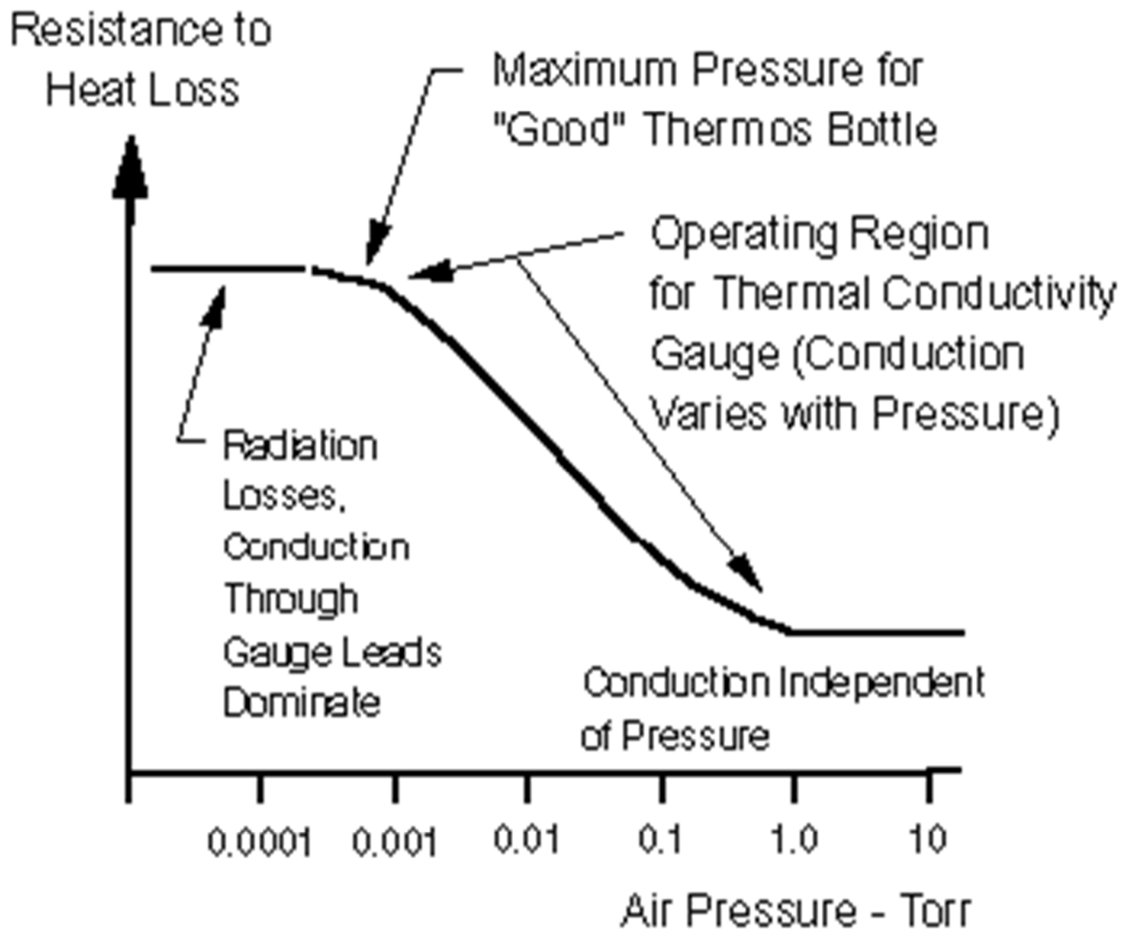
linear sensitivity

absolute zero point

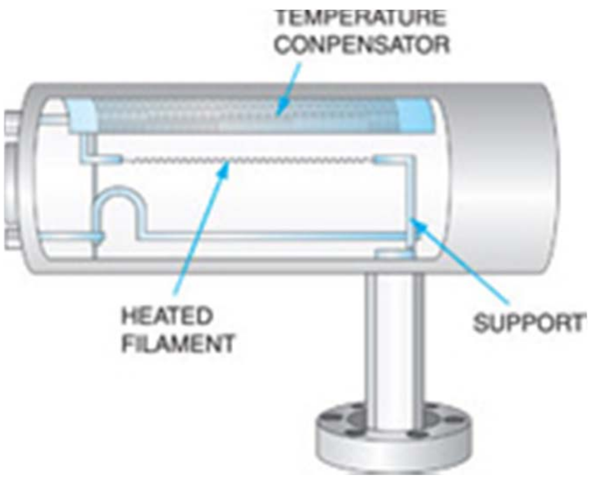
species dependent

Principle of the Thermal Conductivity Gauge





GP 275 Convectron Gauges



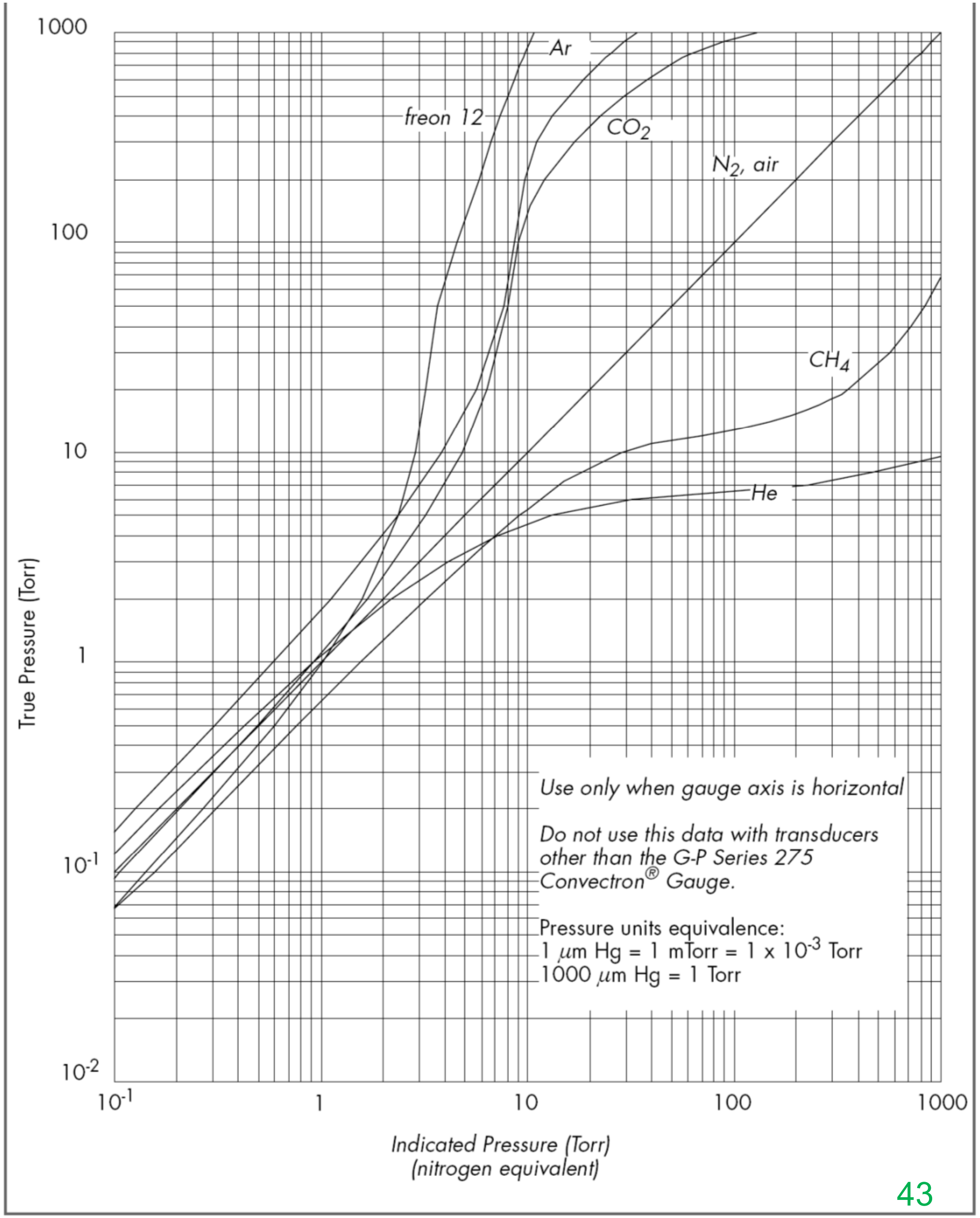
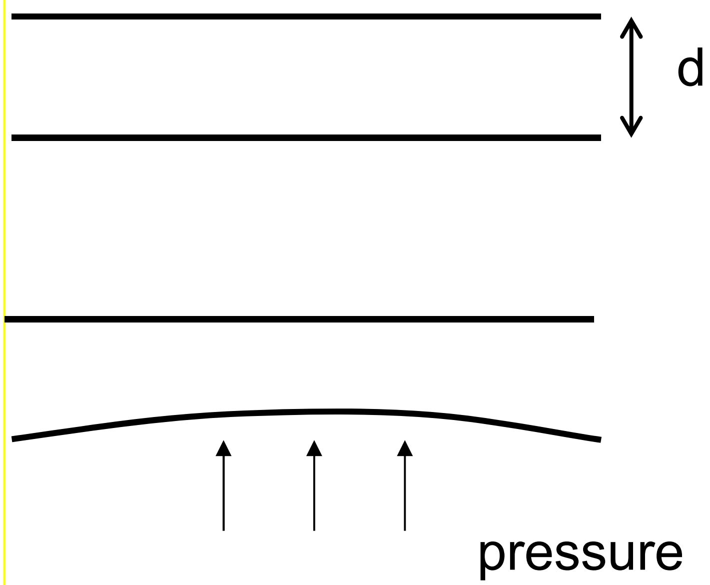
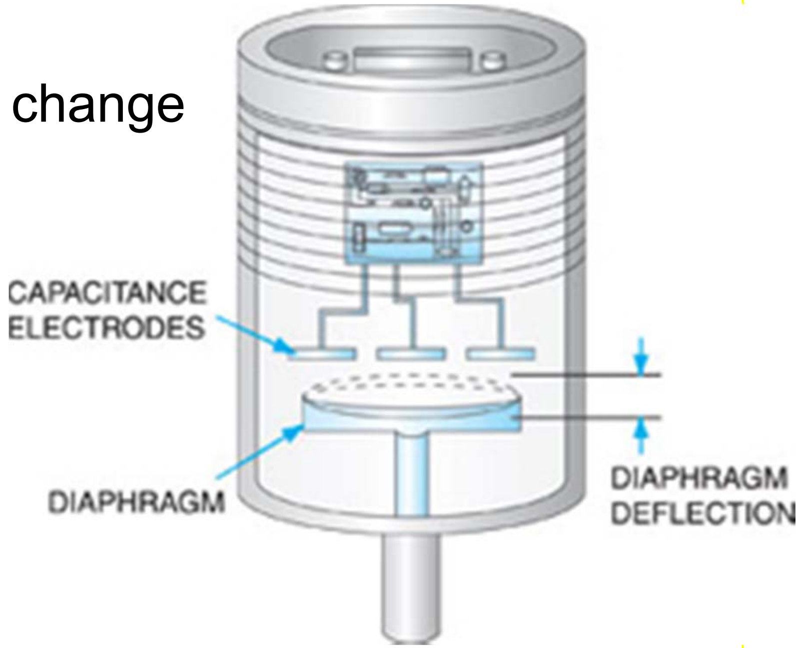


Figure 3-3 *Convectron Gauge Indicated vs. True Pressure Curve; 10^{-1} to 1000 Torr.*

Capacitance (diaphragm) gauge:
measure diaphragm bending by capacitance change



$$C = \varepsilon \frac{A}{d}$$



Absolute pressure
reference to a vacuum cell

real species independent

linear, accurate

zero point is not absolute

Full range: 0.02 torr, 1 torr, 1000 torr,

10000 torr

Accuracy ~ 0.1 %

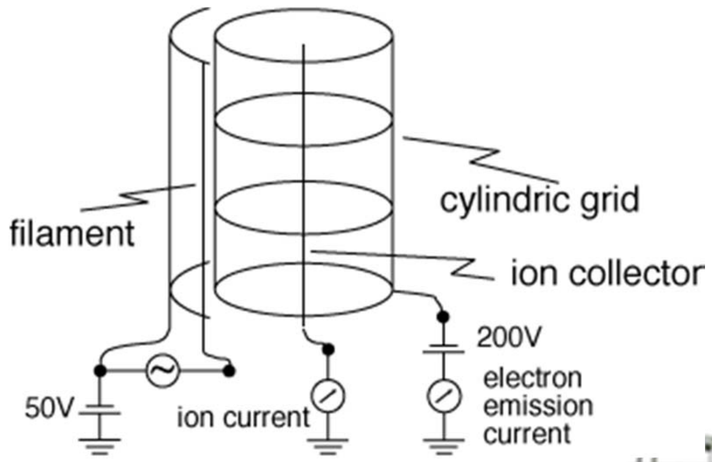
hot cathode: hot filament, W or Th on Ir

$10^{-11} \sim 10^{-3}$ torr

linear sensitivity

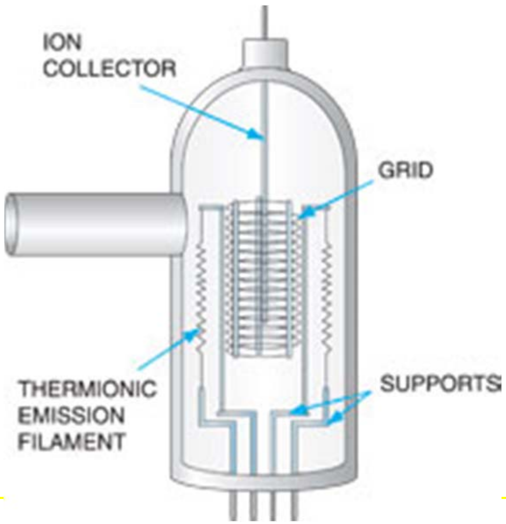
absolute zero point

species dependent



Th on Ir has a lower work function,

so works at a lower temperature



sensitivity

$\propto$ ionization cross section

air, N_2, O_2	1.0
He	0.15
Ne	0.3
H_2	0.4
CH_4	1.4

cold cathode, discharge (ion pump current)

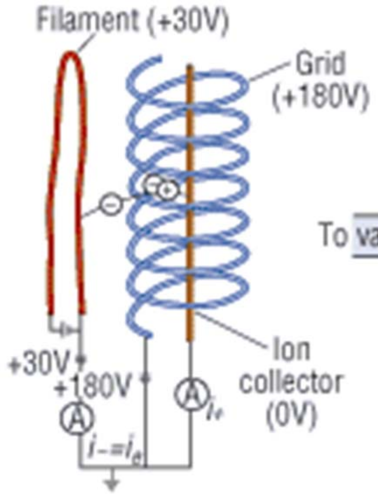
similar to hot cathode ion gauge

more robust

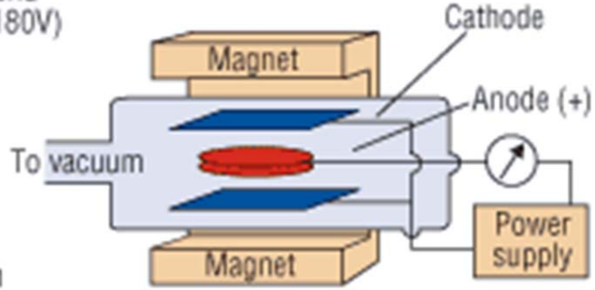
less accurate

hard to ignite at low pressure

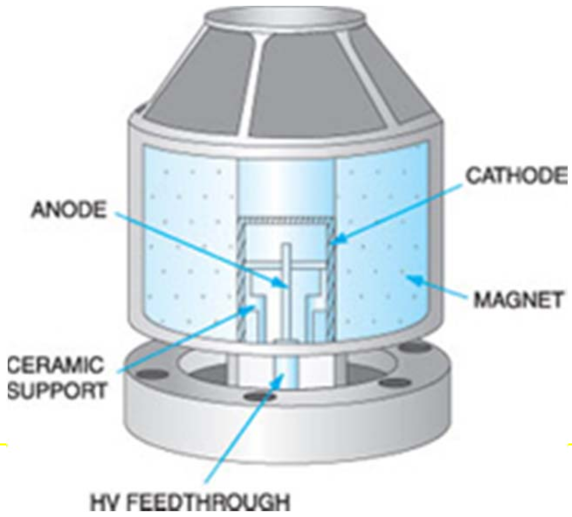
magnet



Hot

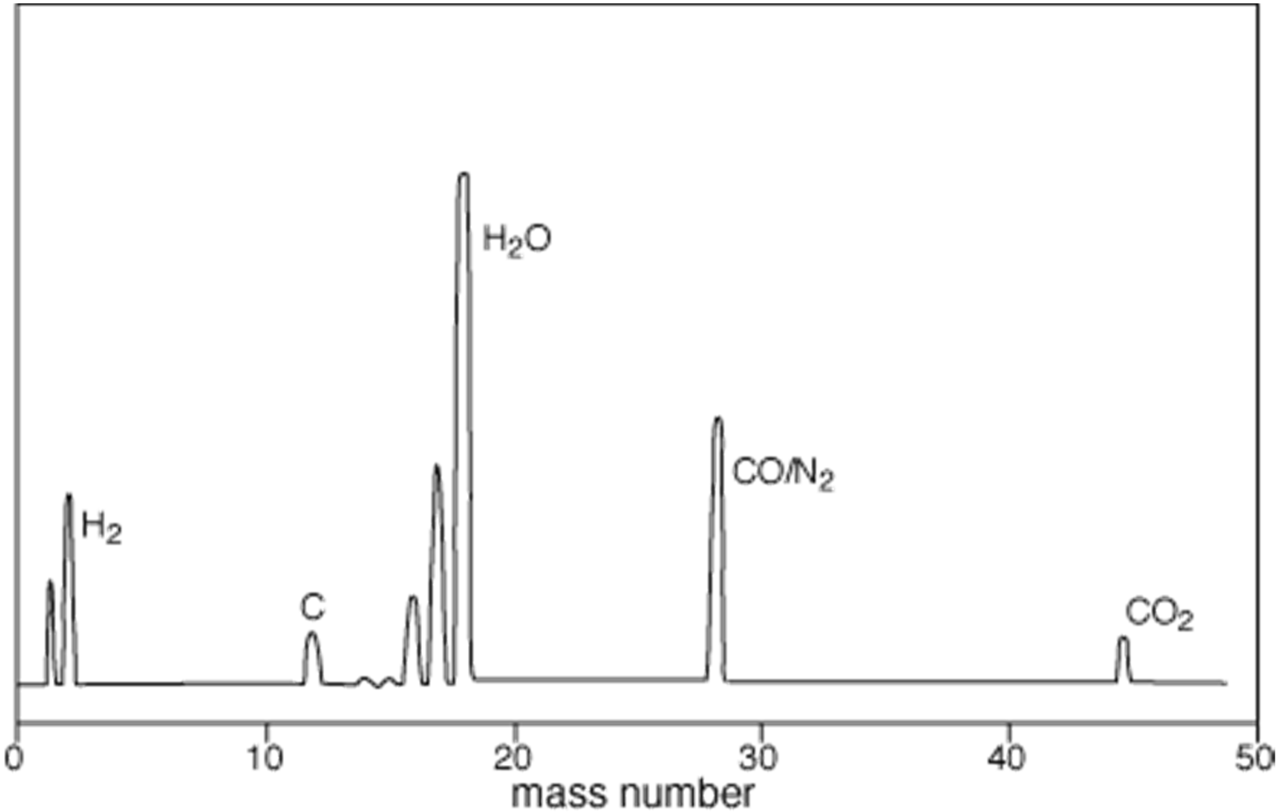


Cold



Residue Gas Analyzer (RGA)

A small quadrupole mass analyzer with an electron impact ionizer



with electron multiplier, sensitivity ~ 10^{-15} torr

A mixture of 10% C_3H_8 in He flows into a vacuum chamber which is pumped by a turbo pump. The Ion Gauge reading is $1x10^{-5}$ torr.

(a) What is the true pressure?

(b) What is the pressure reading for a 30% C_3H_8 in He mixture under the same flow rate?

(c) What is the pressure reading for a 30% C_4H_{10} (butane, not on the table) in He mixture under the same flow rate?

(d) What pressure gauge is independent on the gas species? How does it work?

Nominal Gas Correction Factors

Gas	R_g
He	.18
Ne	.30
D_2	.35
H_2	.46
N_2	**1.00**
Air	1.0
O_2	1.01
CO	1.05
H_2O	1.12
NO	1.15
NH_3	1.23
Ar	1.29
CO_2	1.42
CH_4 (methane)	1.4
Kr	1.94
SF_6	2.2
C_2H_6 (ethane)	2.6
Xe	2.87
Hg	3.64
C_3H_8 (Propane)	4.2

Where to get information?

Wiki, Google, ...

Manufacturer: catalog, manual, ..

Experienced users: ... (salesman?)

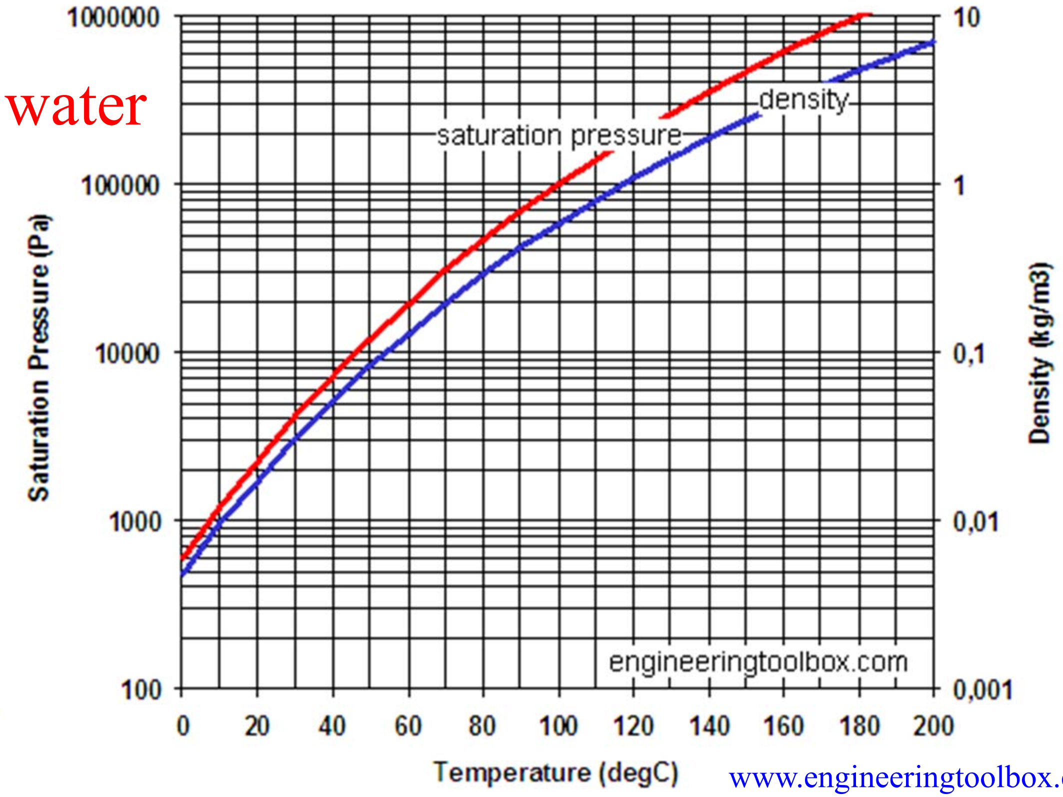
Thinking: operation principle, ...

Chamber: 方 or 圓

Surface Outgas Concern

For a normal vacuum chamber that has no leak, it is known that water outgas from the surface is the major source of residue gases at a pressure range of 10^{-9} – 10^{-6} torr.

Vapor pressure of Liquid water



www.engineeringtoolbox.com/

Temperature (˚C)	Vapour pressure (kPa)	Vapour pressure (mmHg)
0	0.6	4.5
3	0.8	6.0
5	0.9	6.8
8	1.1	8.3
10	1.2	9.0
12	1.4	10.5
14	1.6	12.0
16	1.8	13.5
18	2.1	15.8
19	2.2	16.5
20	2.3	17.3
21	2.5	18.8
22	2.6	19.5
23	2.8	21.0
24	3.0	22.5
25	3.2	24.0
26	3.4	25.5
27	3.6	27.0
28	3.8	28.5
29	4.0	30.0
30	4.2	31.5
32	4.8	36.0
35	5.6	42.0
40	7.4	55.5
50	12.3	92.3
60	19.9	149.3
70	31.2	234.1
80	47.3	354.9
90	70.1	525.9
100	101.3	760.0

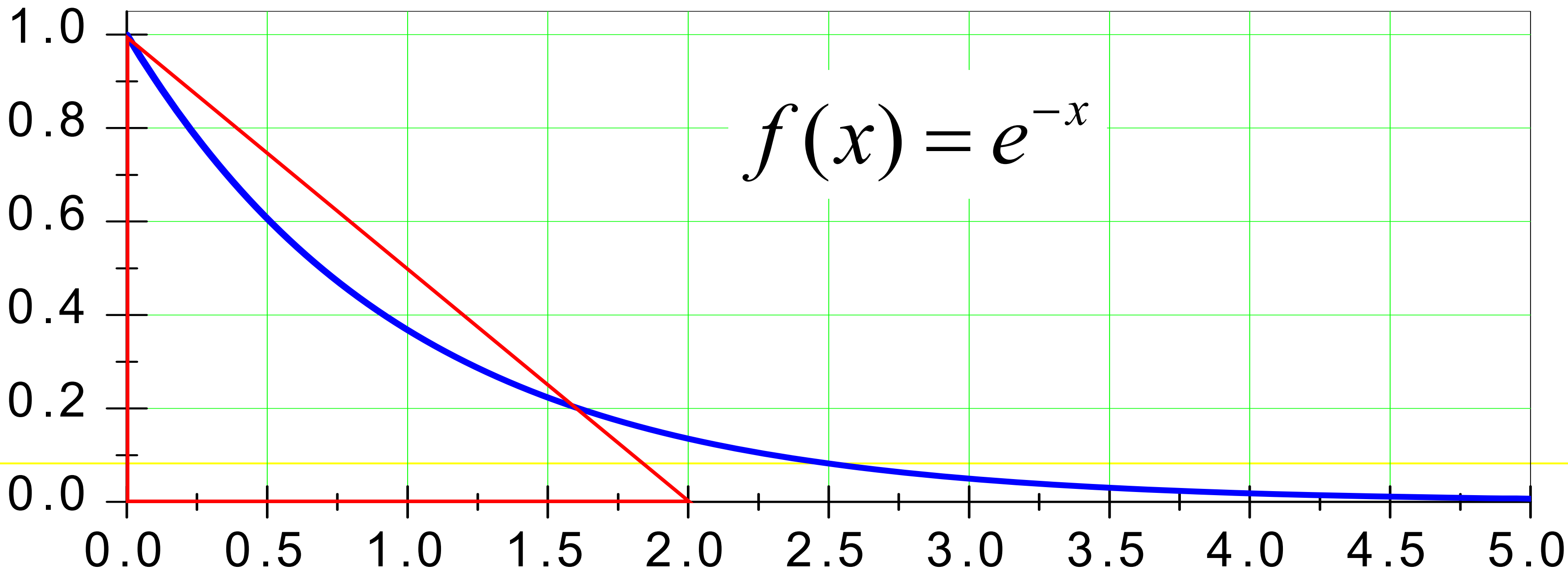
27	3.6	27.0
28	3.8	28.5
29	4.0	30.0
30	4.2	31.5
32	4.8	36.0

en.wikipedia.org/

If the water outgas pressure is 1×10^{-7} torr and it takes a week to pump down to 1×10^{-8} torr when the pumping speed is 1000 L/s, how much water has been pumped out?

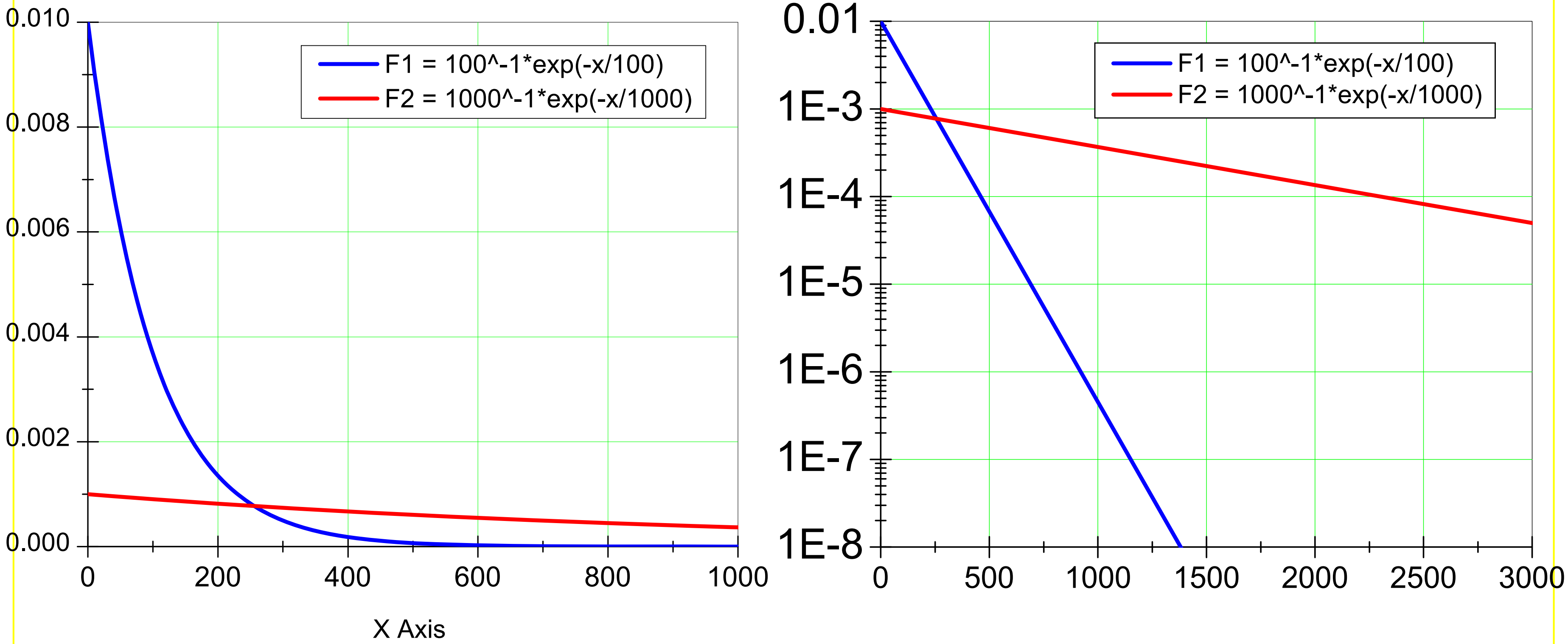
Assume an exponential decay of the water outgas.

$$\frac{dA}{dt} = -\frac{1}{\tau}A \qquad A(t) = A_0 e^{-t/\tau} \qquad \int_0^\infty A_0 e^{-t/\tau} dt = A_0 \tau$$



$$\tau = \frac{\int_0^\infty A_0 e^{-t/\tau}\,dt}{A_0} = \frac{total\ amount}{initial\ rate}$$

example of exponential decay
same area under both curves



$$\frac{dP}{dt} = -\frac{1}{\tau}P \qquad P = P_0\,e^{-t/\tau}$$

$$Q = PS; \quad \frac{dQ}{dt} = -\frac{1}{\tau}Q; \quad Q = Q_0 e^{-t/\tau}$$

$$\Delta Q = \int_{t1}^{t2} Q_0 e^{-t/\tau} dt = Q_0 \tau [e^{-t/\tau}]_{t2}^{t1} = \tau [Q_1 - Q_2]$$

$$= \tau S [P_1 - P_2]$$

If $P_1 = 10P_2$, $\tau = \Delta t/\ln 10 = (7\times24\times3600\ \mathrm{s})/2.3 = 2.6\times10^5\ \mathrm{s}$

$\Delta Q = \tau S[P_1 - 0.1P_1] \cong 26$ torr L $= 1.4\times10^{-3}$ mol $= 0.02$ g

A story about a rainy evening.

Pump out time constant = τ

$$\tau = \frac{\text{total amount}}{\text{initial rate}} = \frac{26\ \text{torr}\ L}{(10^{-7}\ \text{torr})(1000 L/\text{s})} = 26\times10^{4}\ \text{s} = 72\ \text{hr} = 3\ \text{days}$$

Often this is the case for a chamber with big surface area

Big chamber ≠ big surface area

How to minimize surface area

Oxide could be porous

Remove thick surface oxide:

- electro polish SUS chamber and parts
- basic wash (NaOH solution) Al alloy
- acid wash copper/brass parts
- sand blast

Dirty surface is thicker

Cleaning   Strong detergent is much more efficient than solvent

Estimate the effect of Baking

$$k(T) = Ae^{-E_a/RT}$$

When temperature rises to 100 °C, outgas rate rises by roughly two orders of magnitude, i.e., 10^{-5} torr instead of 10^{-7} torr

Initial pumping throughput is 10^{-5} torr * 1000 L/s = 10^{-2} torr L/s

$$\tau = \frac{2.6\times10^{1}\,\text{torr}\,L}{10^{-2}\,\text{torr}\,L/\text{s}} = 2.6\times10^{3}\,\text{s} = 0.72\,\text{hr}$$

to P = 10^{-10} torr, $P_0/P = 10^5$

$$\Delta t = \tau \ln\frac{P_0}{P} = 11.5\,\tau = 8.3\,\text{hr}$$

Practically, it takes a little bit longer (≲100 hr)

∵ Single exponential delay is only an approximation

Deeper water has smaller outgas rate, thus longer τ

bake uniformly is important to avoid distortion

Aluminum foil on SUS chamber, heating tape on the aluminum foil, another layer of aluminum foil to reduce heat loss

Degas ion gauge during baking

Clean ion gauge and its surrounding by excess heating

Don’t bake oily surface. oil → tar

Estimate the effect of using plastic parts

plastic may absorb H_2O to 1~2 % w/w

Assume 100 g plastic can absorb ~1.8 g H_2O = 0.1 mol

If the initial outgas pressure is 10^{-7} torr, τ = 5000 hr

If the initial outgas pressure is 10^{-6} torr, τ = 500 hr

@1000 L/s

more troublesome is that most plastics cannot be baked

Use only:

Inert material: Teflon, PE, PP, Kel-F, Viton,

Teflon insulated wire

Less absorption

$$<\approx \frac{1}{10} normal\ plastic$$

High temperature material : polyimide (Vespel, Kapton),

Kalrez perfluoro elastomer (O-ring)

Bakable to $200^{o}C$

Material outgas (volume outgas)

It lasts forever! More than your life!

SUS: H_2 & CO.

SUS316L can be vacuum fired at 1000 °C to remove deeper contaminants

Al alloy: less H_2 & CO. Bakable to 120 °C

Zn & Cd alloy have high vapor pressure

High temperature increase outgas @ bake out

Cooling can reduce outgas @ use

Sealing Concern:

Metal seal: copper gasket & ConFlat flange are preferred

100% seal
low outgas
bakable

two surfaces may fuse together
use silver plated screws in SUS taps

O-ring seal: Viton O-ring bakable to 100 ^{o}C
15 ~ 18 % compression to seal
volume compression is not allowed

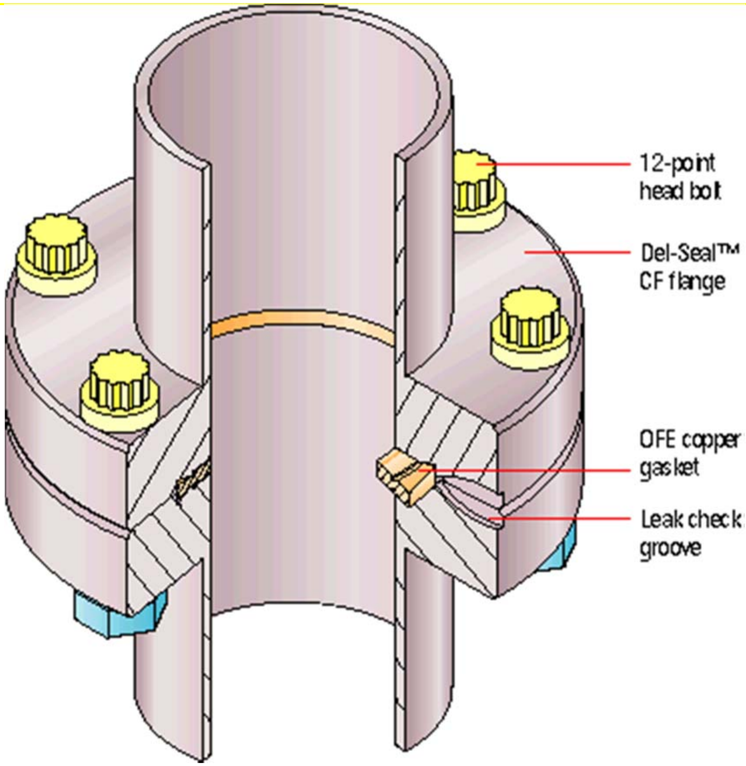
convenient
non-consuming

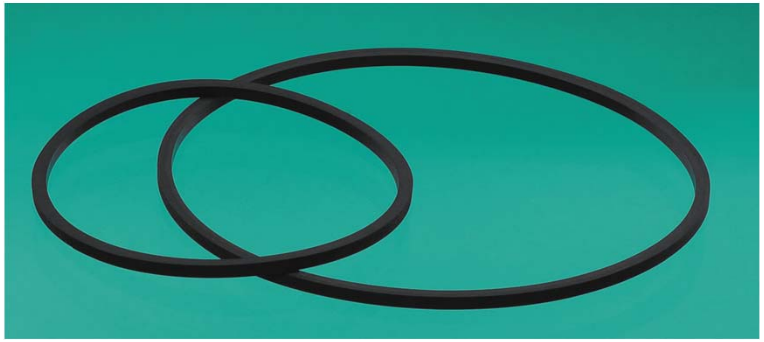
sealing surface polish is important
small leak is possible
(***Hard*** to find small leaks)

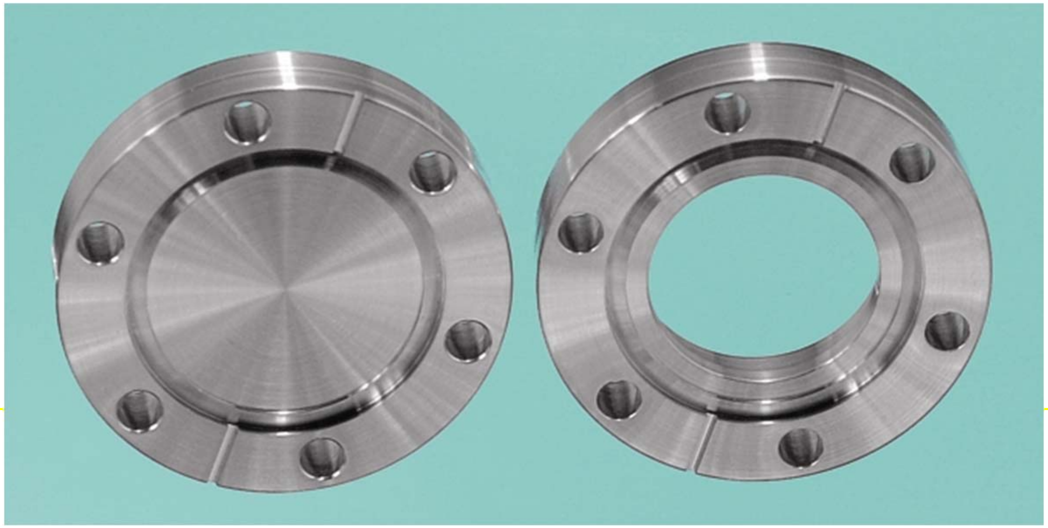
Careful to use viton gasket on conflat flanges

not cheap

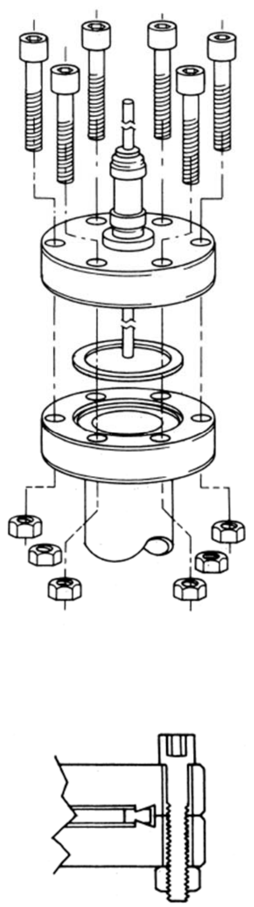
very easy to leak
for size larger than
4.5” O.D.

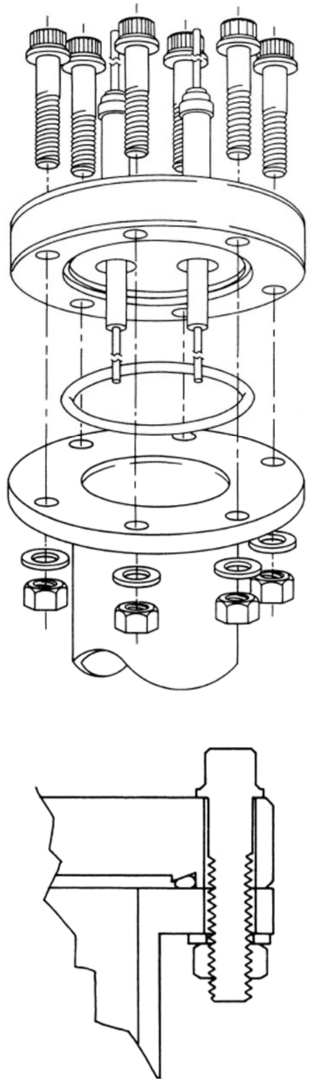

12-point
head bolt
Del-Seal™
CF flange
OFE copper
gasket
Leak check
groove





CONFLAT FLANGE





Viton O-Ring Seal Flange to Flange

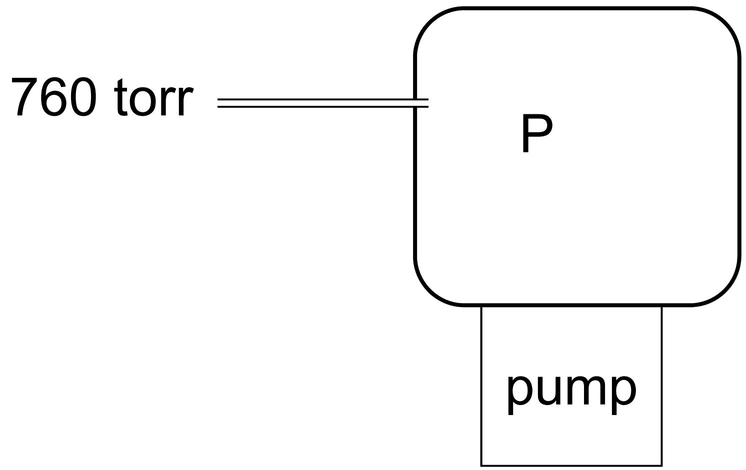
（美規）

Flange Dia.	O-Ring Cross Section	Parker O-Ring Cat. No.
1.33	.103 Dia.	2-114
2.75	.139 Dia.	2-223
3.38	.139 Dia.	2-227
4.50	.139 Dia.	2-234
6.00	.139 Dia.	2-246
8.00	.139 Dia.	2-260
10.00	.139 Dia.	2-268

Viton O-Ring Seal Flange to Flat Plate

Flange Dia.	O-Ring Cross Section	Parker O-Ring Cat. No.
1.33	.070 Dia.	2-17
2.75	.103 Dia.	2-130
3.38	.103 Dia.	2-139
4.50	.103 Dia.	2-151
6.00	.103 Dia.	2-157
8.00	.103 Dia.	2-165
10.00	.103 Dia.	2-173

Leak Rate is similar to ***Conductance***



Through put = (760 – P)*L_k, L_k=leak rate, P<<760 torr

Caution: water leak is very dangerous!

Number density of liquid water is 10^3 times that of air

$$V(water) = 18\,cc/mol \quad V(air) = 25\,L/mol$$

That is, a small liquid leak is a huge gas leak.

Dynamic Seal

with differential pumping

760 torr * L_k = P_2 (0.1 L/s)

P_2 = 1 x10^{-3} torr

P_2*L_k = P_3 (1000 L/s)

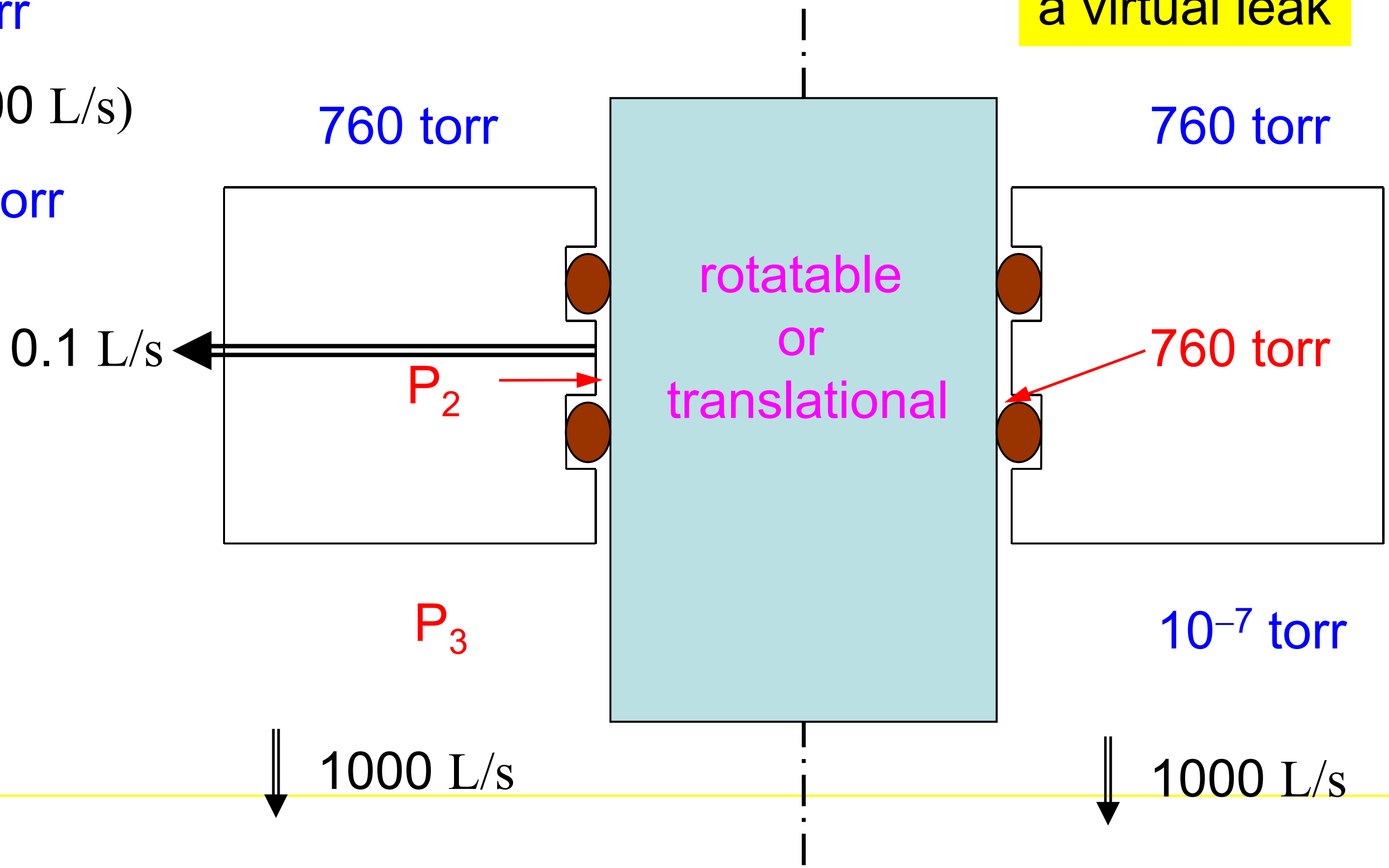
P_3= 1.3x10^{-13} torr

without differential pumping

760 torr * L_k = (10^{-7} torr) (1000 L/s)

Leak rate L_k = 1.3 x10^{-7} L/s

a virtual leak



O-ring may trap gas & water ⇒ small Virtual leak

O-ring seal is cheaper and easily being machined

O-ring: 15 ± 2 % compression + Grease

+ well polished surfaces to have the above leak rate

Careless work makes 10^1-10^2 worse

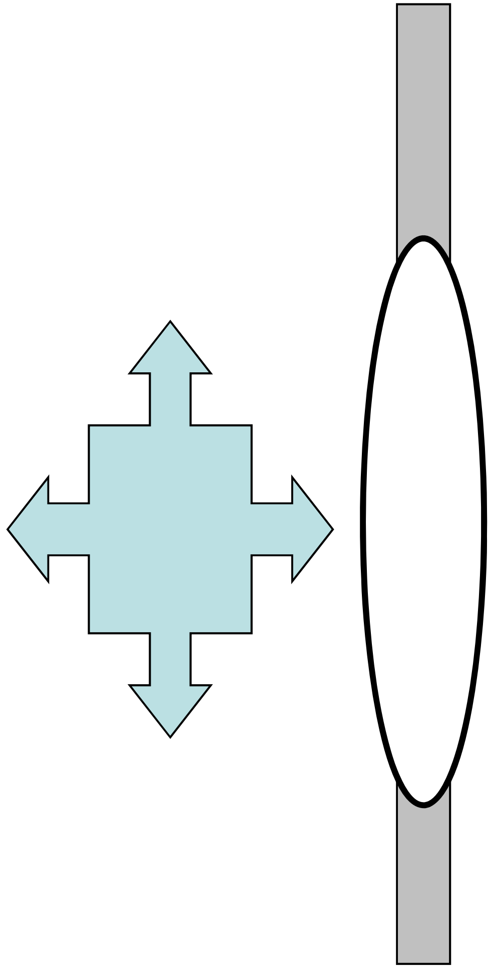
	Elasticity	Inertness	Price
NBR	↑	↓	↓
Viton			
Kalrez			

Conductance of an Aperture or short tube

where A is the area in cm^2. In the molecular-flow region, the conductance of an aperture for a gas of molecular weight M is:

$$C = 3.7\left(\frac{T}{M}\right)^{1/2} A \text{ L s}^{-1} \tag{3.25}$$

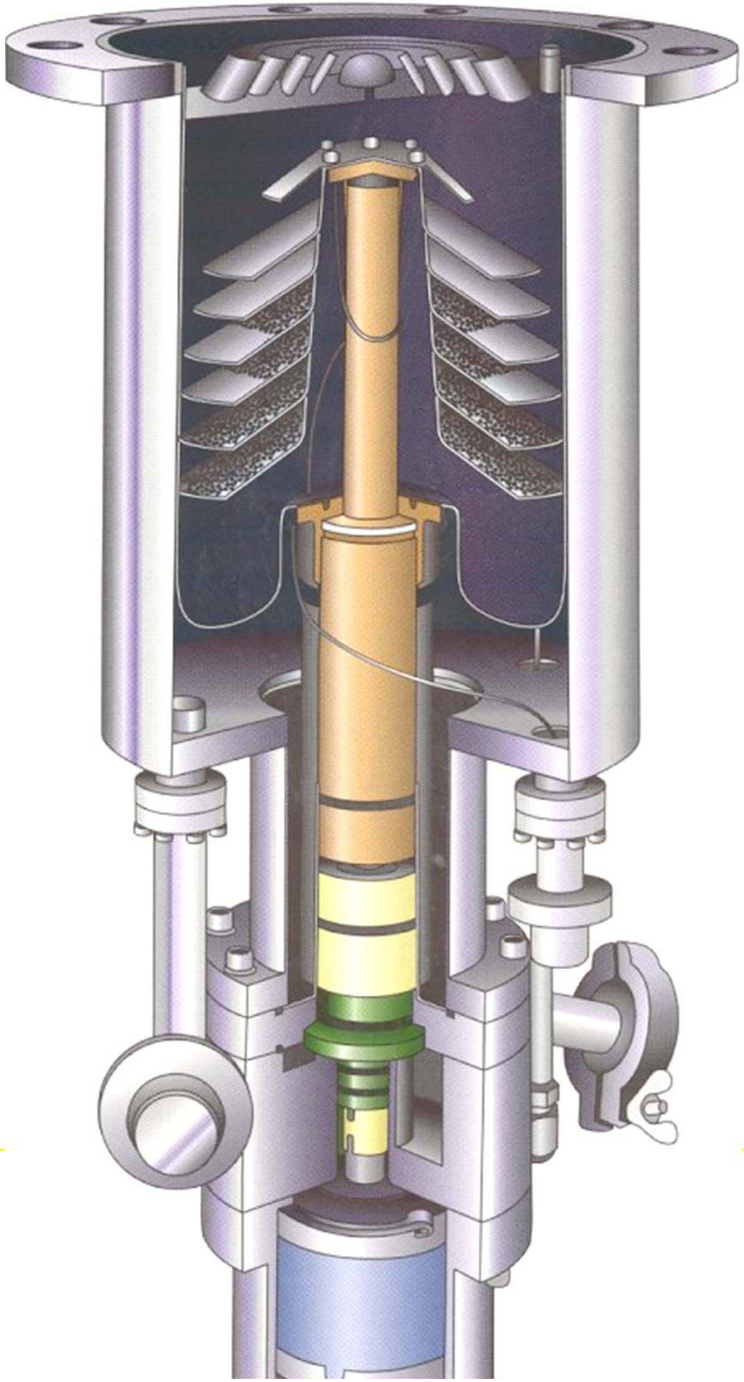
where A is the area in cm^2. These equations are useful for determining the rate of gas flow into a vacuum chamber through an aperture in a gas-filled collision chamber or ion source.



If there is a "black-hole" pump,

$$\frac{S_{\lim}}{L/s} = 3.7\sqrt{\frac{T/K}{M/amu}}\frac{A}{cm^2}$$

For pumping port ϕ=20 cm, A=314 cm^2, $S_{\lim}$(air)=3750 L/s



Specification		CP-8
Gas Pumping speeds (liters/second)	Water	4000
	Air	1500
	Hydrogen	2200
	Argon	1200
Gas capacities (standard liters @ $5x10^{-6}$ Torr)	Hydrogen	12
	Argon	1000
Throughput	Argon	700 sccm
Crossover	Torr-liters	150
Cool down time	60 Hertz	90 min
Cryopump measurements	Height	7.03"
	Length	22.6"
	Weight	42 lbs
Inlet flange		ANSI/ISO/CF

S_{lim}	S/S_{lim}
4743	84% ~ 1
3750	40% ~ 1/2
14229	15% < 1/2
3182	38% ~ 1/2

Leak Check, ***not a trivial Job!***

Spread CH_3OH or C_2H_5OH on a possible leak to see if pressure rises

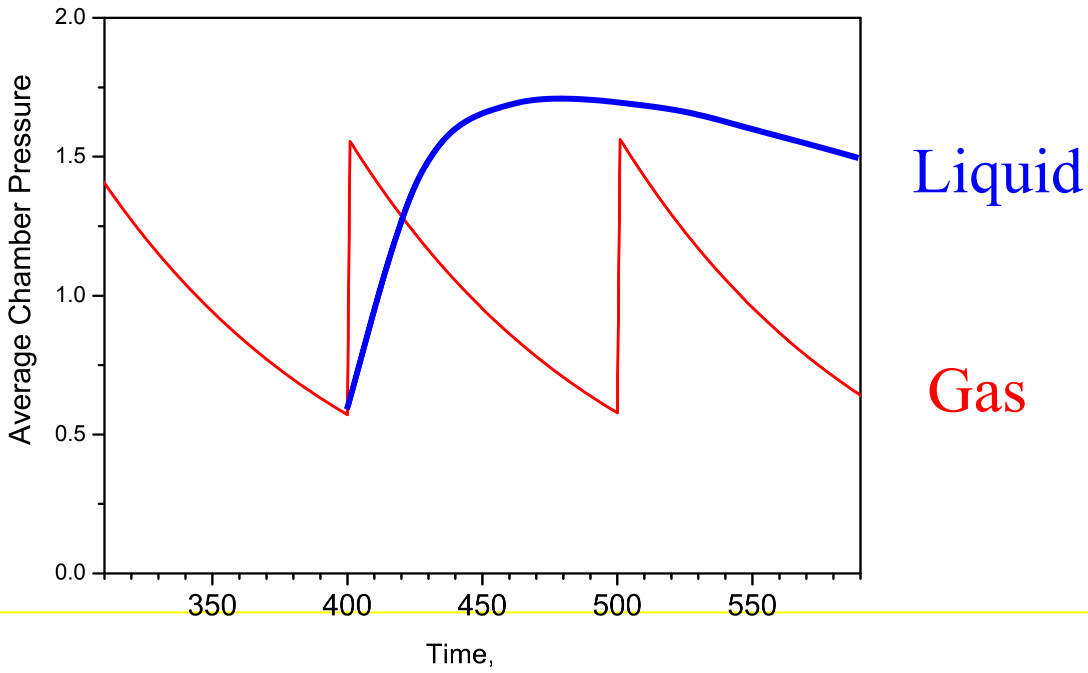
Acetone is OK for metal, bad for O-ring, bad for health

Response rise time ~ few seconds, Don't move too fast.

It takes very long to dry out the solvent. ***Very long fall time !!***

From lower spots to higher spots.

few hours is possible



Helium leak check:

Spread He to see if P_{He} rises

MASS is required. RGA (Residue Gas Analyzer) or He leak detector

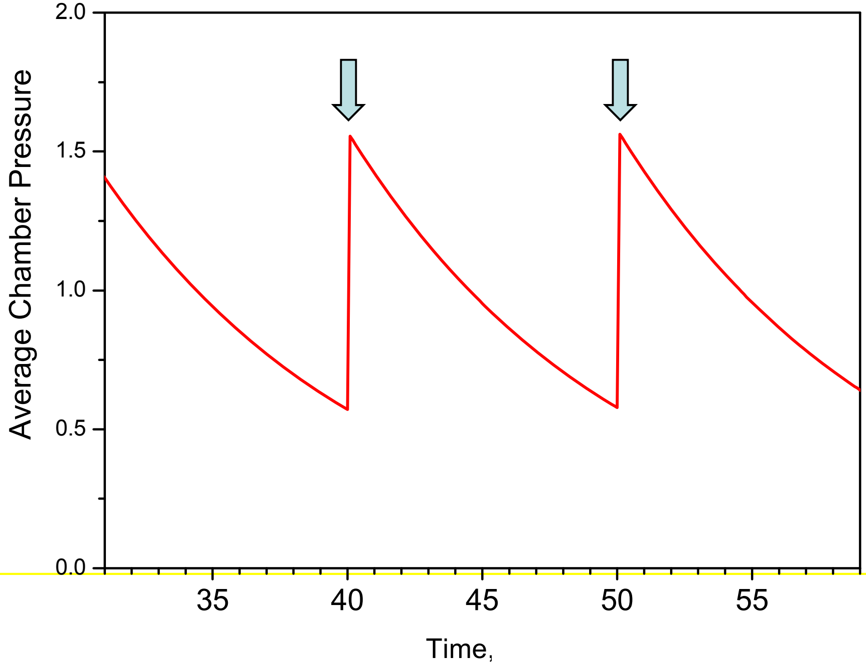
fast $\lesssim$ 1 sec $\because$ light mass $\therefore$ fast speed

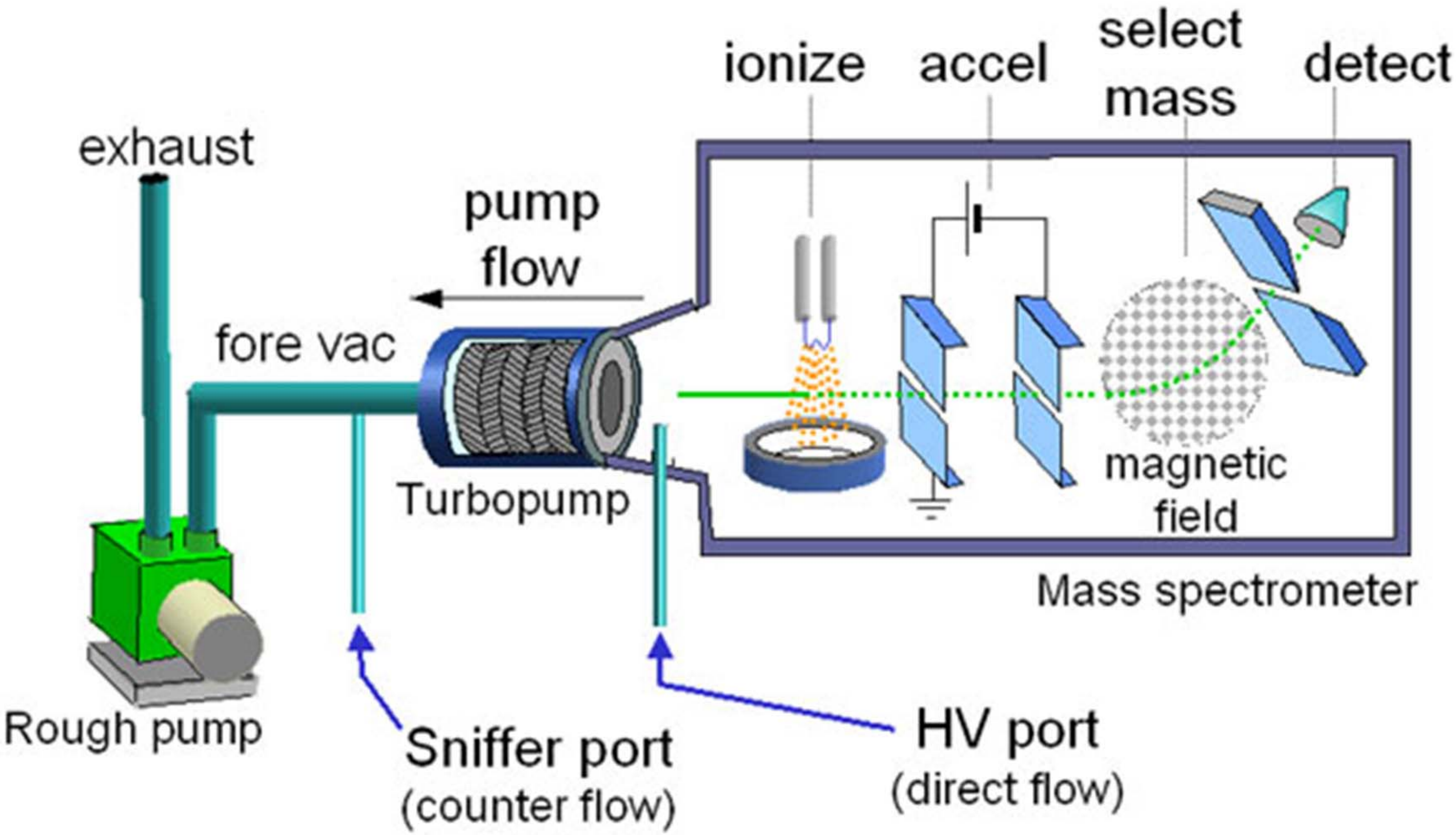
He is fast to escape, fast to pump down

low background, inert

from higher spots to lower spots

He is easy to reach a nearby (even 1 m away) spot. ⇒ isolation




ionize
accel
select
mass
detect
exhaust
pump
flow
fore vac
Turbopump
magnetic
field
Mass spectrometer
Rough pump
Sniffer port
(counter flow)
HV port
(direct flow)

Residue Gas Analyzer (RGA) provide very important information

high m28/m32 (4:1) indicate air leak

daughter ion is useful. CO^+ / C^+ , O^+ Vs. N_2^+ / N^+

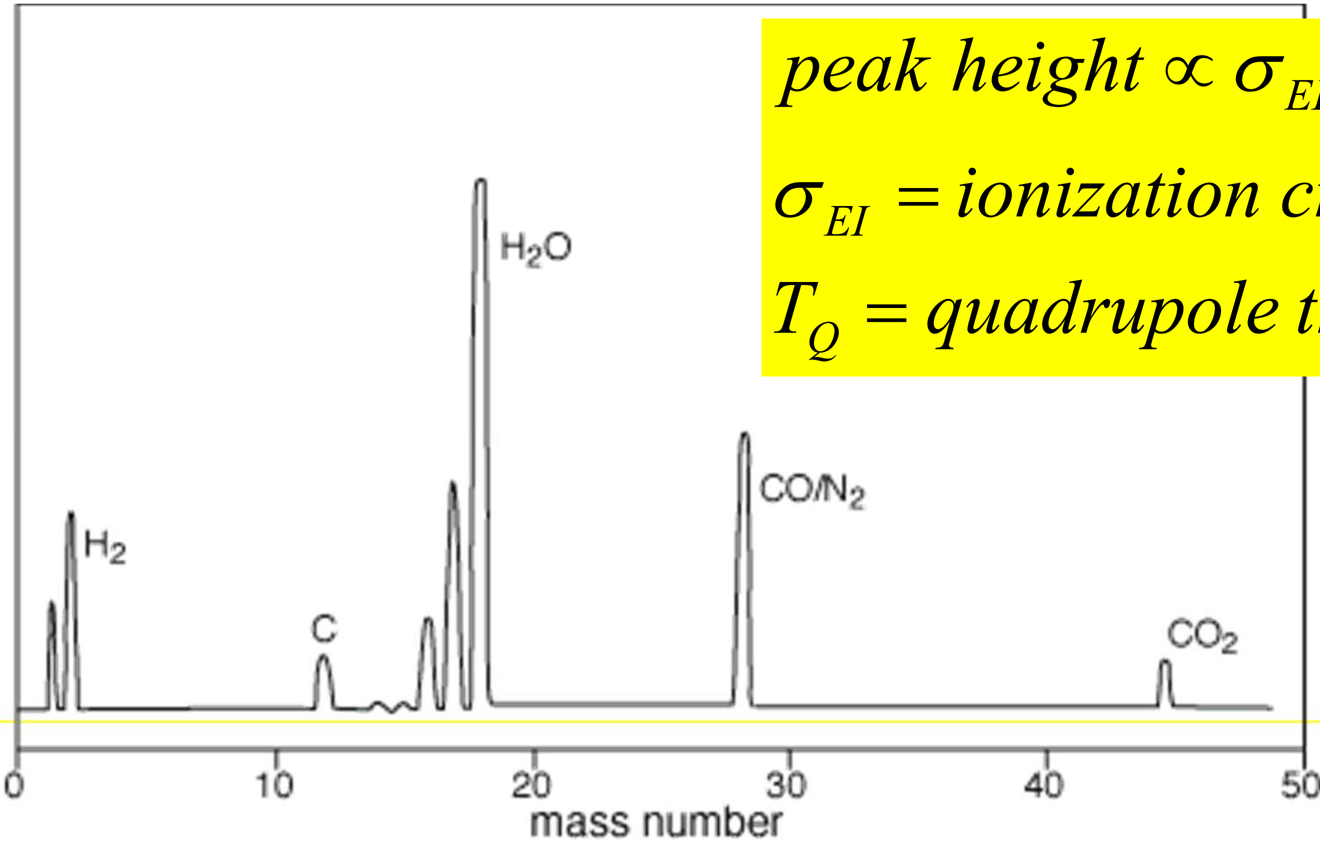
H_2O is very common

Don't make vacuum chamber wet, especially at a rainy day

$$peak\ height \propto \sigma_{EI} T_Q$$

$$\sigma_{EI} = ionization\ cross\ section$$

$$T_Q = quadrupole\ transmission$$



Good vacuum practices

No leak

Clean: traps for oil pumps: **molecular sieve, LN2**

Metal & non-porous ceramic is excellent

Plastic and grease: as less as possible

Confident sealing. Finding a leak is very labor-consuming.

Bakable for 10^{-10} torr or better

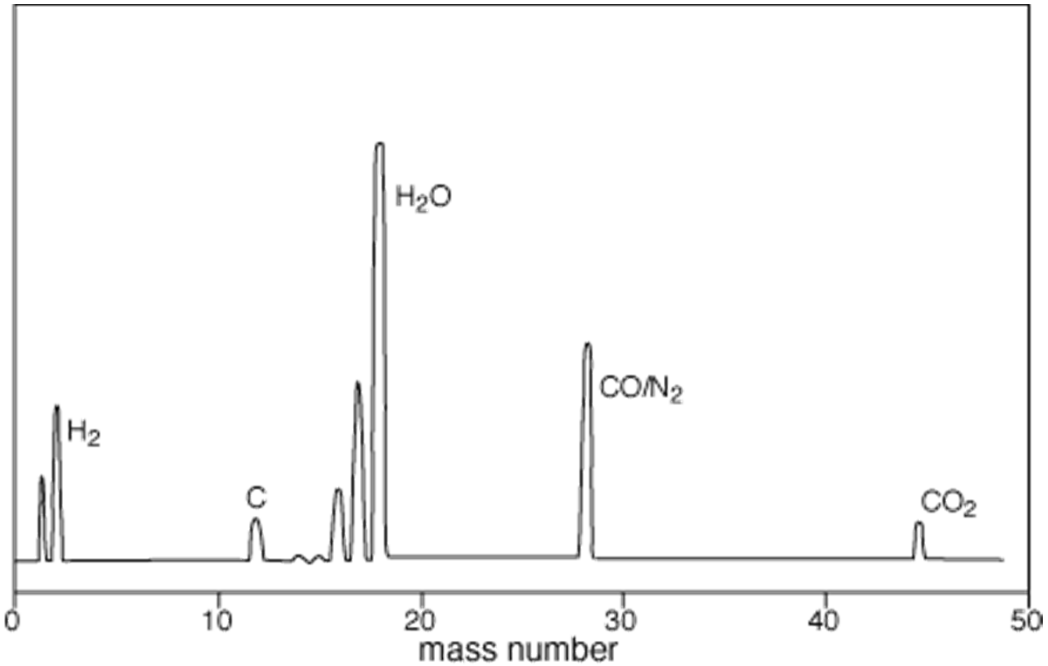
Good ***Local Conductance*** for pumping speed concern.

Gas composition (partial pressure) is often more important than the total pressure, as most vacuum parameters are species dependent. e.g. surface laser burn, background masses

RGA is very nice to have (it is cheap now)

Take home message:

Partial Pressures is more important than the total pressure.



Practically

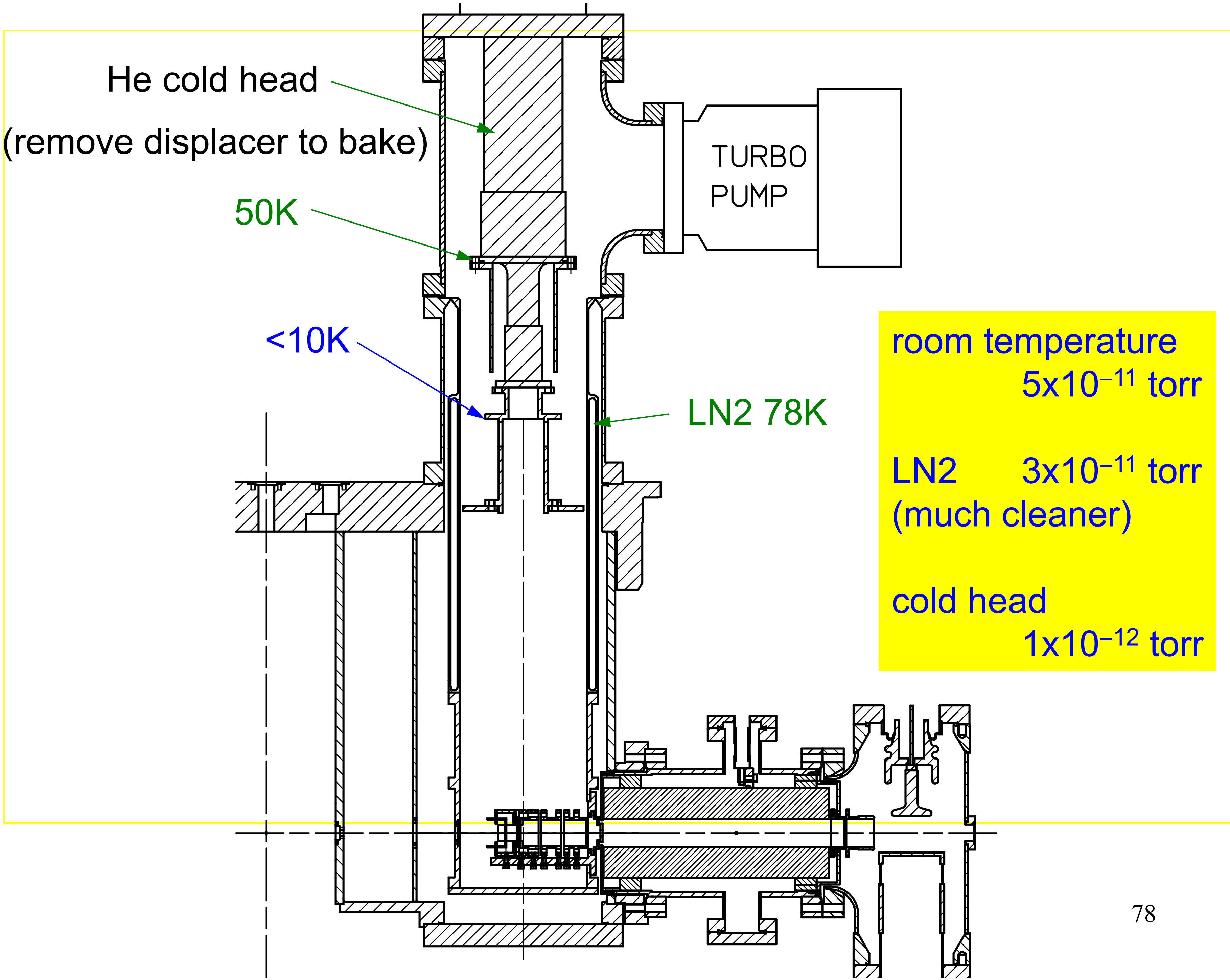
clean chamber, turbo pump, not baked, 10^{-9} torr

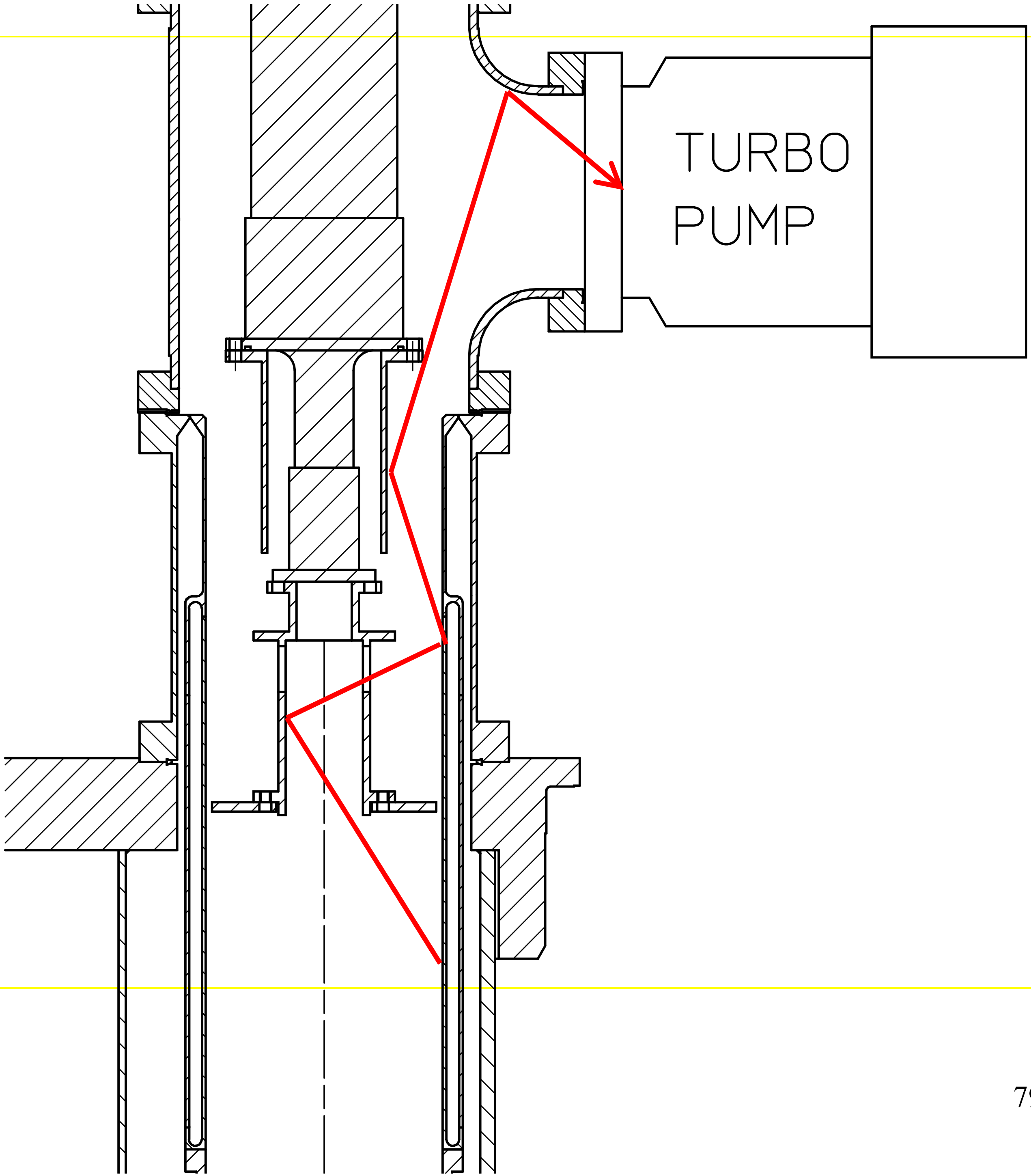
clean chamber, 2 serial turbo pumps, baked, 10^{-11} torr

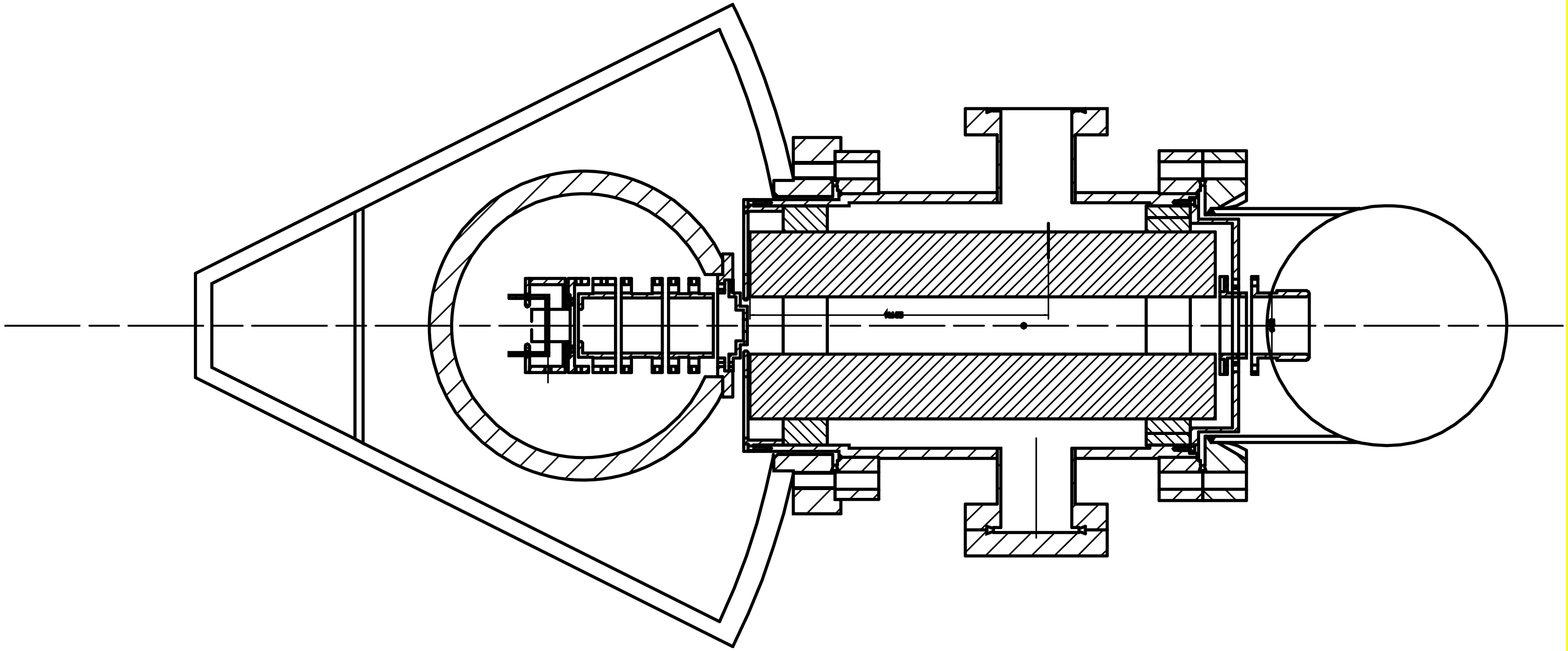
(compression ratio for H_2)

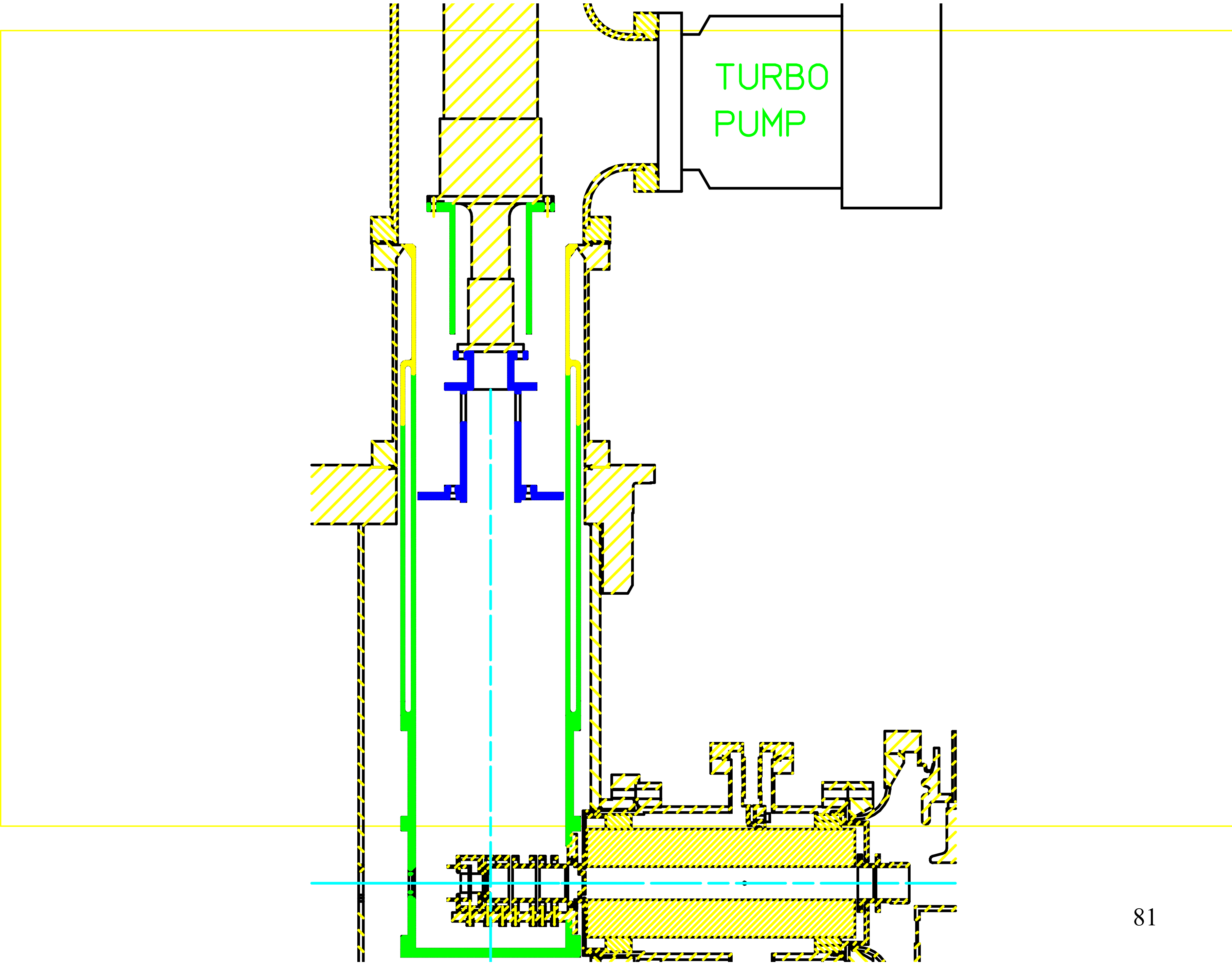
Untra High Vacuum < 1×10^{-10} torr

Example of 1×10^{-12} torr


He cold head
(remove displacer to bake)
50K
<10K
LN2 78K
TURBO
PUMP
room temperature
5x10^{-11} torr
LN2 3x10^{-11} torr
(much cleaner)
cold head
1x10^{-12} torr


TURBO
PUMP




TURBO
PUMP

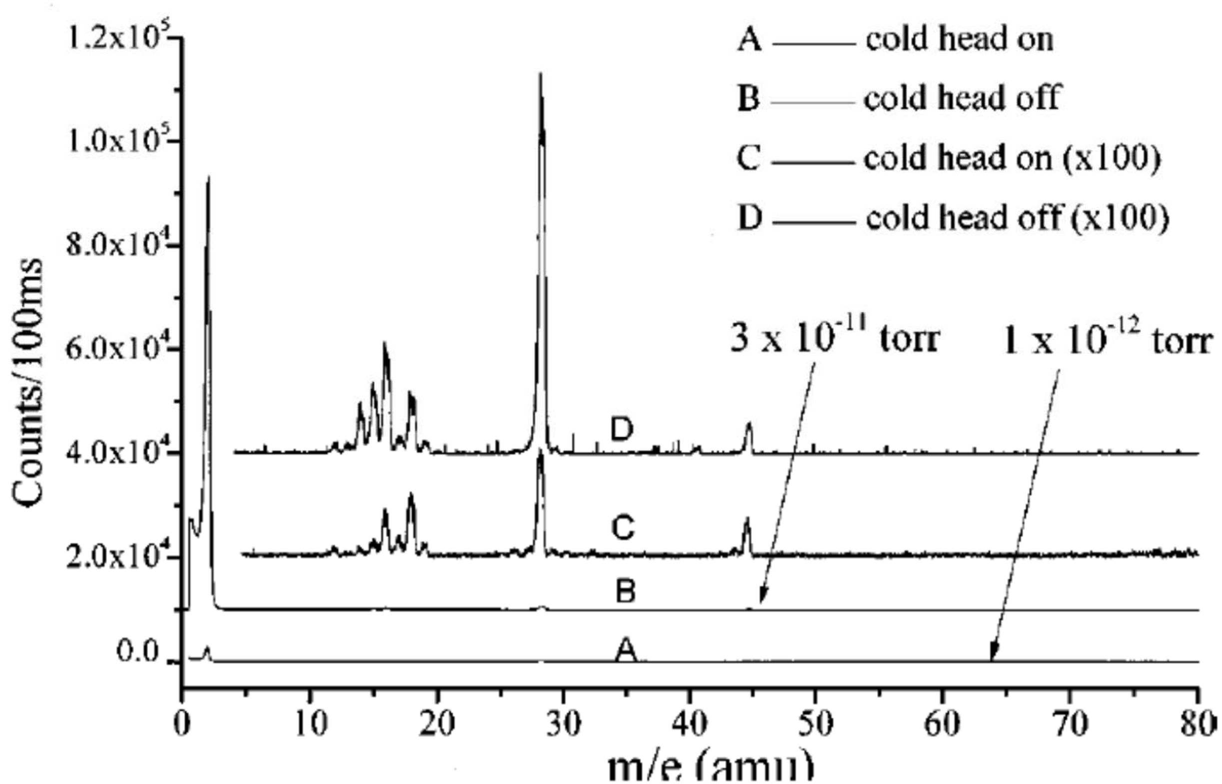


FIG. 3. Detector residual gas mass spectra before and after the cryogenic He cold head cryopump starts to pump.

How to make Ultra High Vacuum (UHV): Outgas rate = pumping speed x pressure

100 l/s x 10^{-11} torr

Ultimate pressure of pumps

- 2 serial Turbo Pumps: 10^{-11} torr, H_2 compression ratio
- Ion Pumps : 10^{-11} torr, small pumping speed, memory effect
- Getter Pumps: Titanium Sublimation pump, Non-evaporative getter
- Cryopump: 10^{-10} torr, not-bakable, memory effect

Outgas rate

- Materials: Stainless Steel, Al alloy, OFHC copper, ceramic, *Teflon, Kapton*
- Surfaces: mechanical polish (glue on sand paper!), electro polish, acid, base
- Bake & Contamination: Firing, porous oxides, oil→tar→charcoal
- Low temperature: LN2, cryohead

Effective pumping speed

$S^{-1} = S_1^{-1} + S_2^{-1}$

Virtual Leaks

Turbo pumps: 400 L/s, 600 L/s

compression ratio: 10^2-10^4 for H_2, 10^6 for He, 10^9 for N_2

<125°C

Oil, grease, or magnetic bearing and **insulated wires**

Fore line back stream when Electric shutdown

Getter pumps: Ion, Ti, NEG

No foreline needed, no continuous electricity needed

250°C, 400°C

Not for every gas, memory effect

Low maintenances for low load systems

Cryopumps: >1500 ℓ/s,

bake to 70°C only,

Not for every gas, memory effect

Outgas due to activated carbon absorber

Electric shutdown

Cryopump + turbo pump: Very high pumping speed even for H_2 at 10^{-9} torr

Bakable Cryohead without absorber: high pumping speed for H_2 at $<10^{-11}$ torr

Low outgas $\Rightarrow 10^{-12}$ torr

SUS304, SUS304L: Cr 18%, Ni 10%, Fe, C<0.2 % or Low carbon < 0.08%

SUS316, SUS316L: Cr 18%, Ni 10%, Mo 2-3%, std and Low carbon

Sand ballasting, basic detergent, Acid dip, Electro polish, DI water

Easy to be welded,

Bake to 250^{o}C, SUS316L: Fire at 1000^{o}C at 10^{-8} torr

Major outgas: H_2, CO

Al alloy 6061-T6, and others

Low H_2, CO outgas

Welding at outside, must clean before welding

NaOH(aq), HNO_3(aq),

Al_2O_3 is porous. Mirror finish parts is available (Japan)

120^{o}C, high temperature will change tempering condition

Oxygen Free High Conductance copper, Beryllium copper

Brass and bronze could be dirty (zinc, phosphor)

Special (strong) acid brightening

Plastic: gas/water permittivity is high

Teflon absorb water 10 times less than usual plastics, but still too much for UHV

Teflon, PE, PP, might be OK for 10^{-8} torr, others are only good to 10^{-6} torr. No PVC

polyimide (Kapton) is bakable, 10^{-10} torr

Ceramic could be porous

Al_2O_3 (alumina) (thermal conductance better than SUS)

Vacuum firing

Thank You for Your Attention