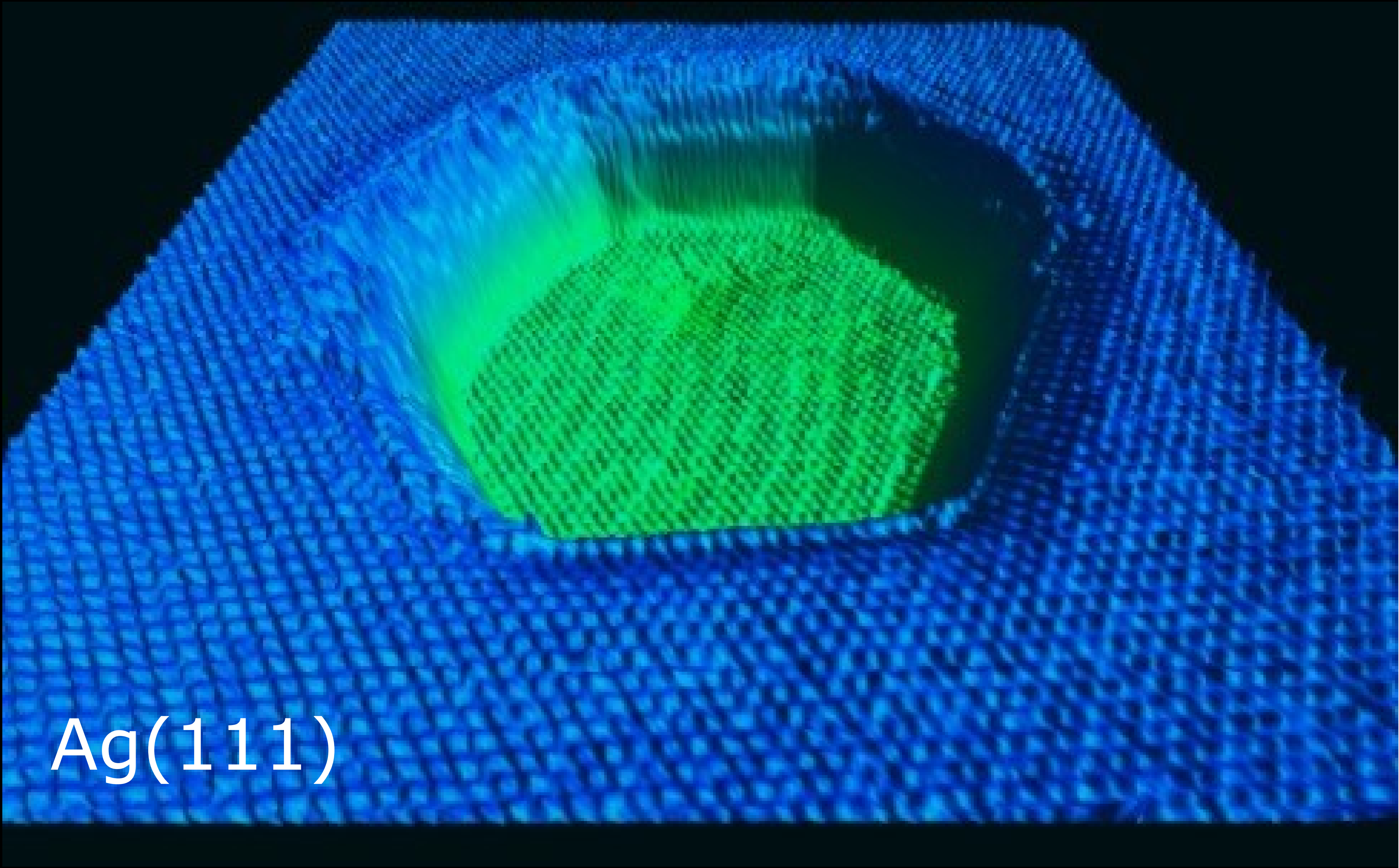
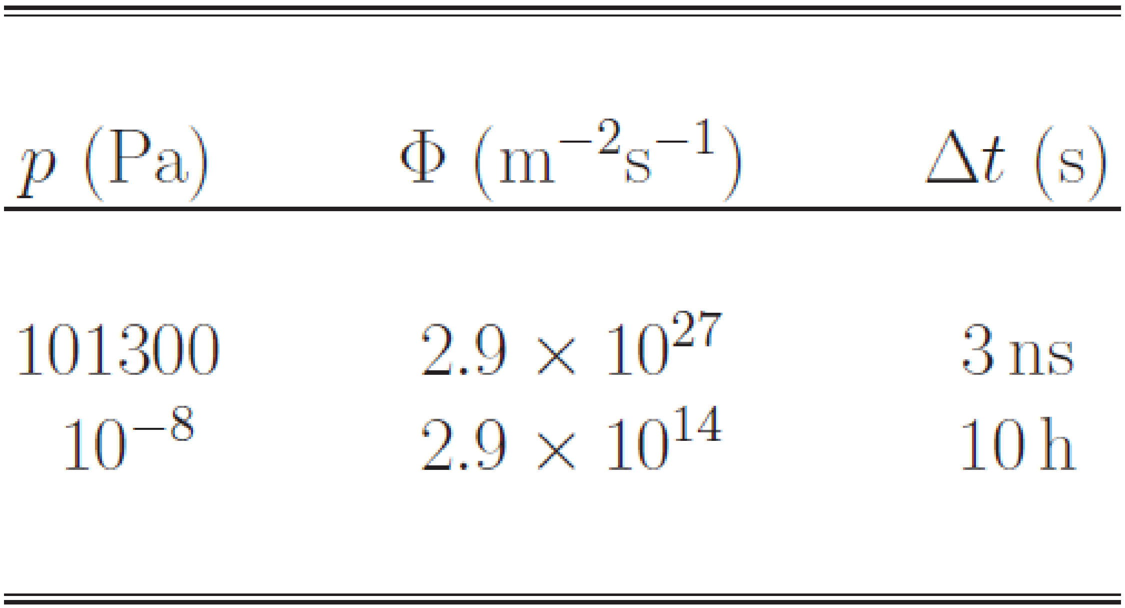
Wie kann eine Oberfläche so sauber sein??



H. Jensen, J. Kröger, R. Berndt, S. Crampin, Phys. Rev. B **71**, 155417 (2005).

Teilchenfluss bei Druck *p* und Temperatur *T*

$$\boxed{\Phi \propto \frac{p}{\sqrt{T}}}$$



p (Pa)	Φ ($\mathrm{m}^{-2}\mathrm{s}^{-1}$)	Δt (s)
101300	2.9×10^{27}	3 ns
10^{-8}	2.9×10^{14}	10 h

Pressure, p, Torr	Molecular density, n, cm^{-3}	Arrival rate, I, cm^{-2}s^{-1}	Mean free path, λ	Monolayer arrival time, τ
760	2×10^{19}	3×10^{23}	700 Å	3 ns
1	3×10^{16}	4×10^{20}	50 µm	2 µs
10^{-3}	3×10^{13}	4×10^{17}	5 cm	2 ms
10^{-6}	3×10^{10}	4×10^{14}	50 m	2 s
10^{-9}	3×10^{7}	4×10^{11}	50 km	1 hour

To convert	Into	Multiply
mbar	Pa	100
mbar	Torr	0.75
Pa	mbar	0.01
Pa	Torr	7.5×10^{-3}
Torr	mbar	1.33
Torr	Pa	133

Vakuum- & Strömungsbereiche

$$\lambda = \frac{1}{\sqrt{2}\, n \pi\, d^2} = \frac{k\,T}{\sqrt{2}\, \pi\, d^2\, p}$$

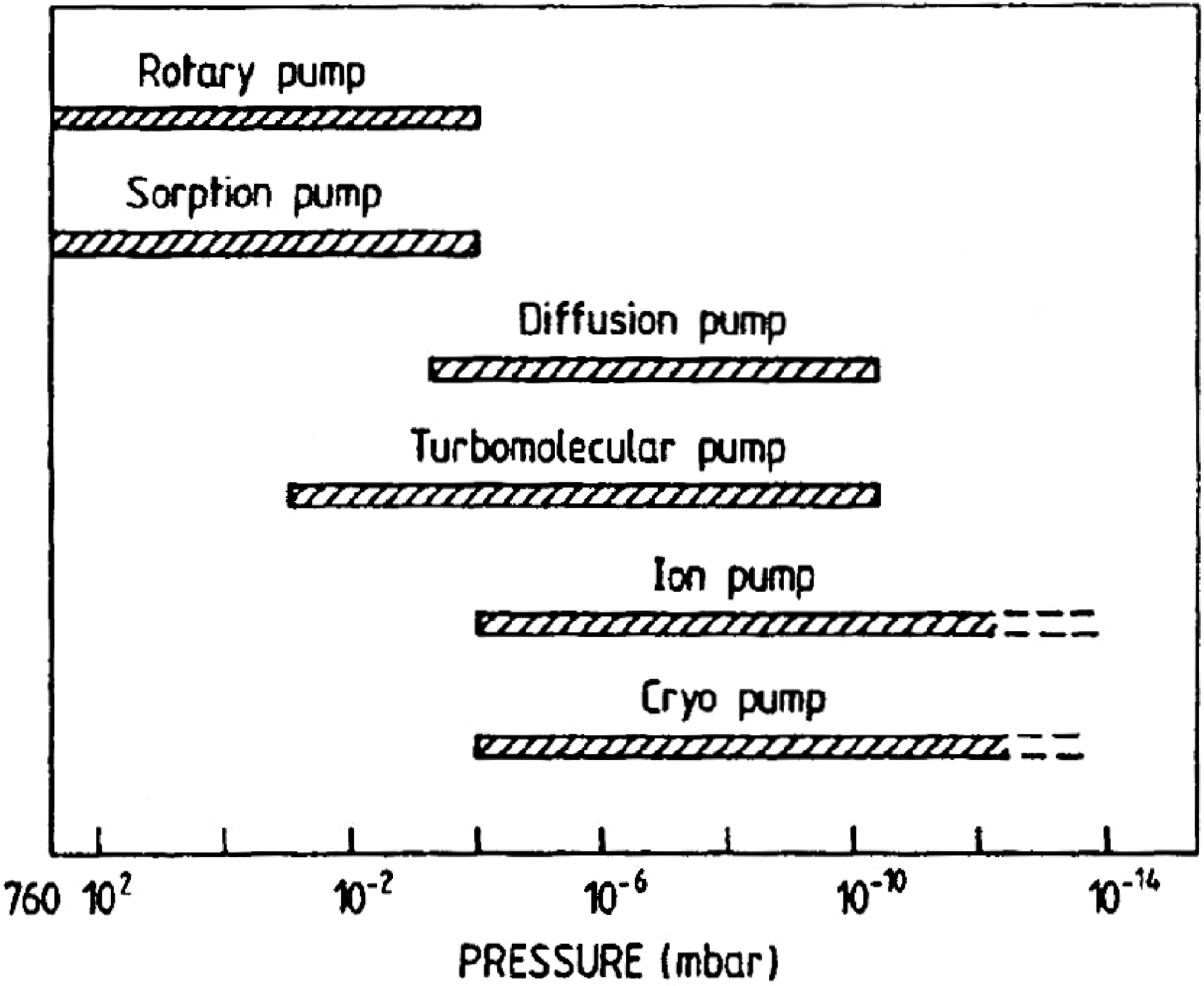
D: Moleküldurchmesser

n: Teilchendichte

Grobvakuum	10^5–100 Pa	viskose Stömung	$\lambda << d$
Feinvakuum	100–0.1 Pa	Knudsen-Strömung	$\lambda \approx d$
Hochvakuum (HV)	0.1–10^{-5} Pa	Molekularströmung	$\lambda >> d$
Ultrahochvak. (UHV)	10^{-5}–10^{-14} Pa		
extrem hohes V. (XHV)	$<10^{-14}$ Pa		$\lambda > 10^8$ m

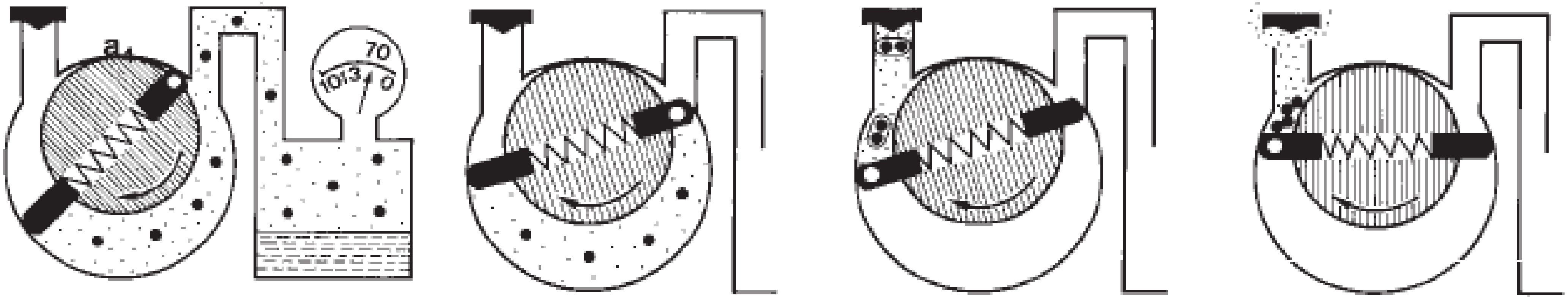
Faustformel: $p\lambda$ = const., 7 cm bei 10^{-3} mbar

Evakuiere Rezipient von 10^5 auf 10^{-9} Pa!



Drehschieberpumpe

Grob- und Feinvakuum



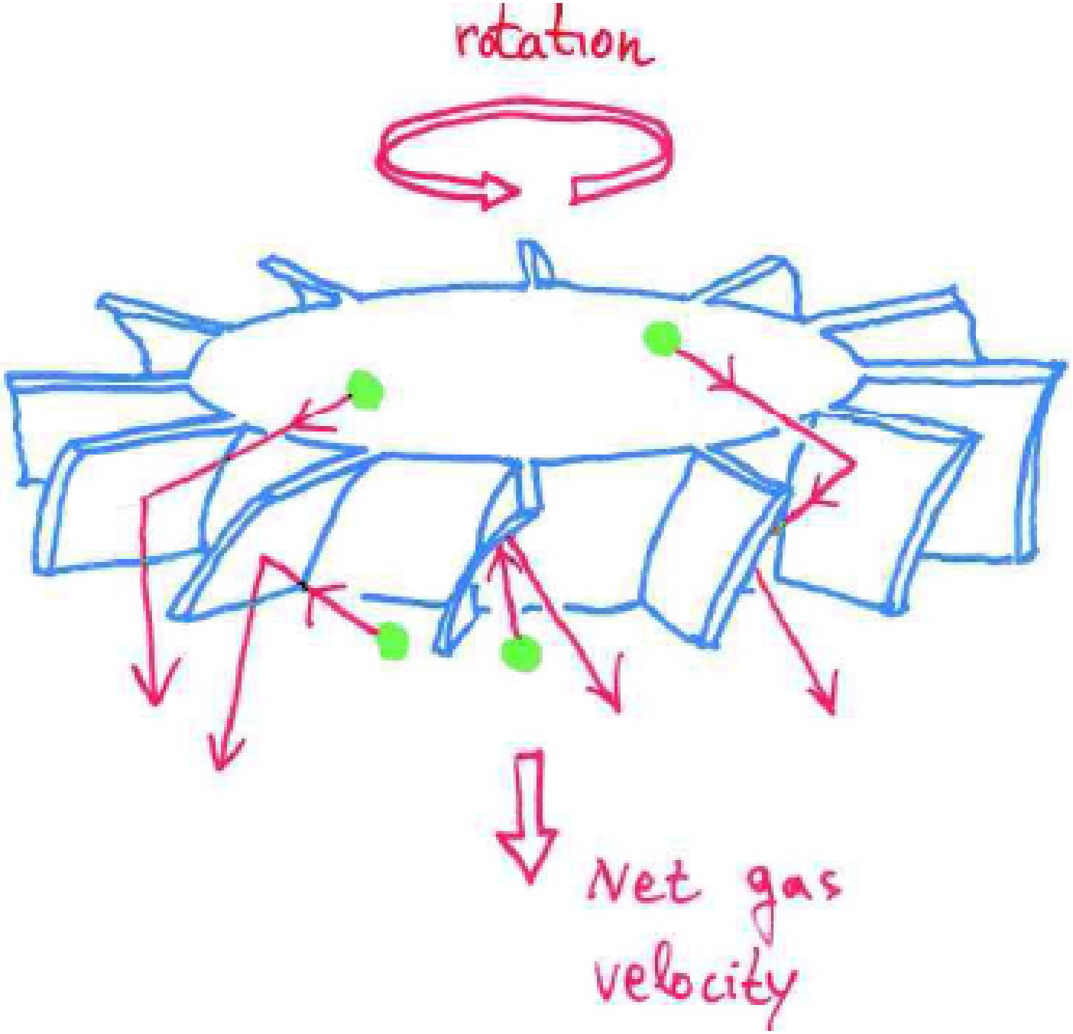
I II III IV

Evakuierung des Rezipienten bis ≈ 0.1 Pa.

Weitere Aufgabe:
Vorvakuum für Turbo – Molekularpumpe

Aus: W. Umrath, *Grundlagen der Vakuumtechnik* (Leybold, Köln, 1997).

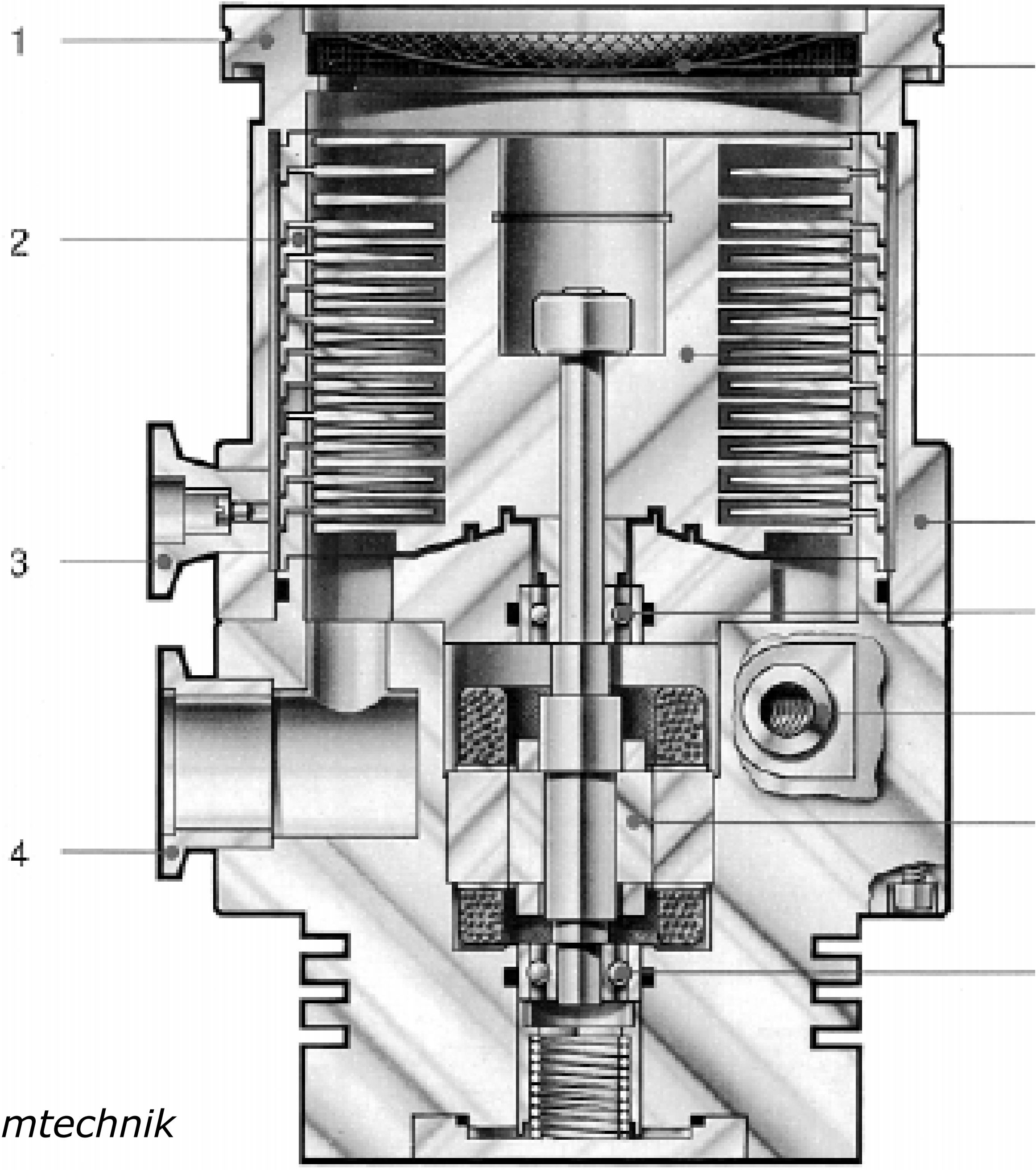
Schnelle Rotation eines Schaufelrades



1956, W. Becker bei der Firma Pfeiffer Vacuum

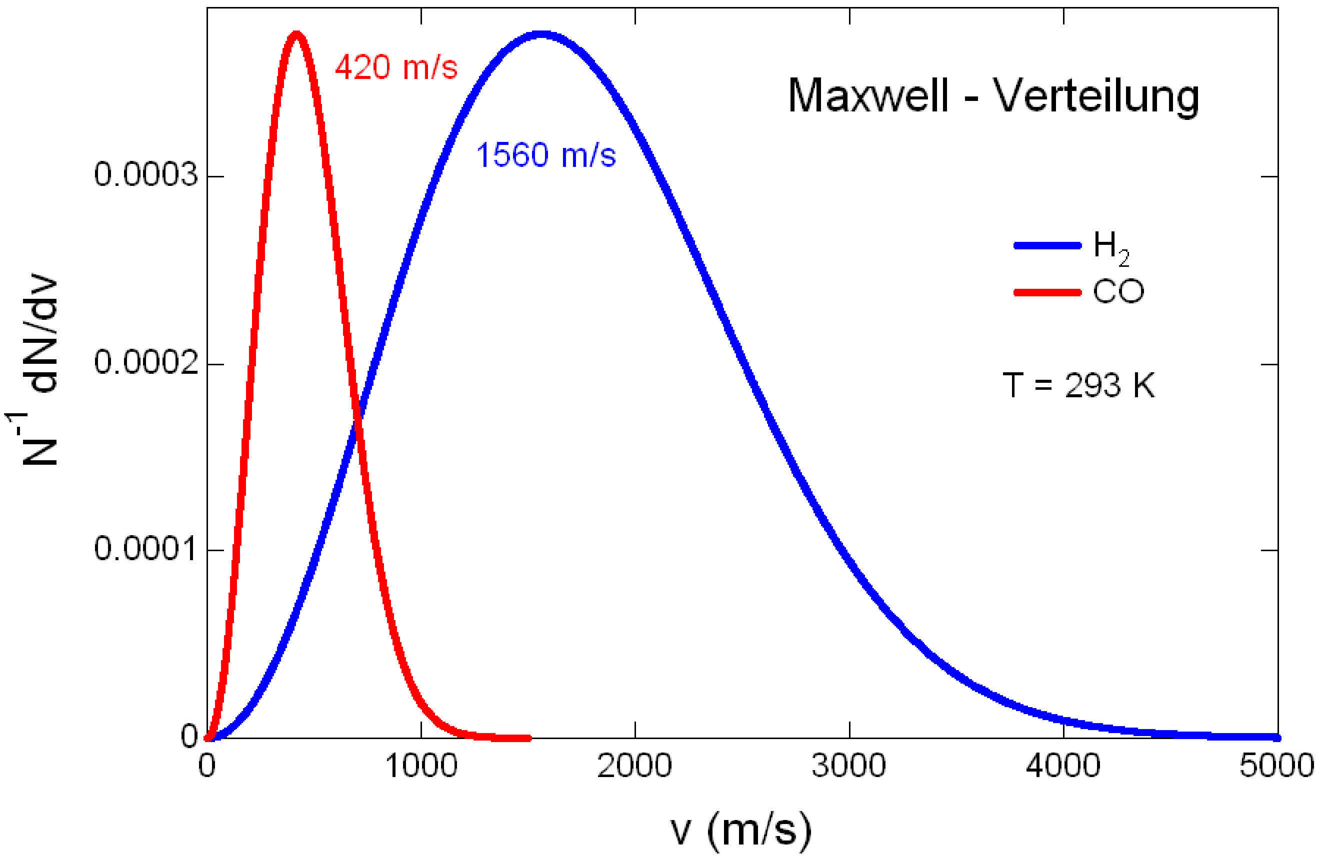
Turbomolekularpumpe

Hoch- und Ultrahochvakuum



Aus: W. Umrath, *Grundlagen der Vakuumtechnik* (Leybold, Köln, 1997).

Rotationsfrequenz ?



Durchmesser des Schaufelrades ≈ 10 cm

Rotationsfrequenz ≈ 1500 Hz

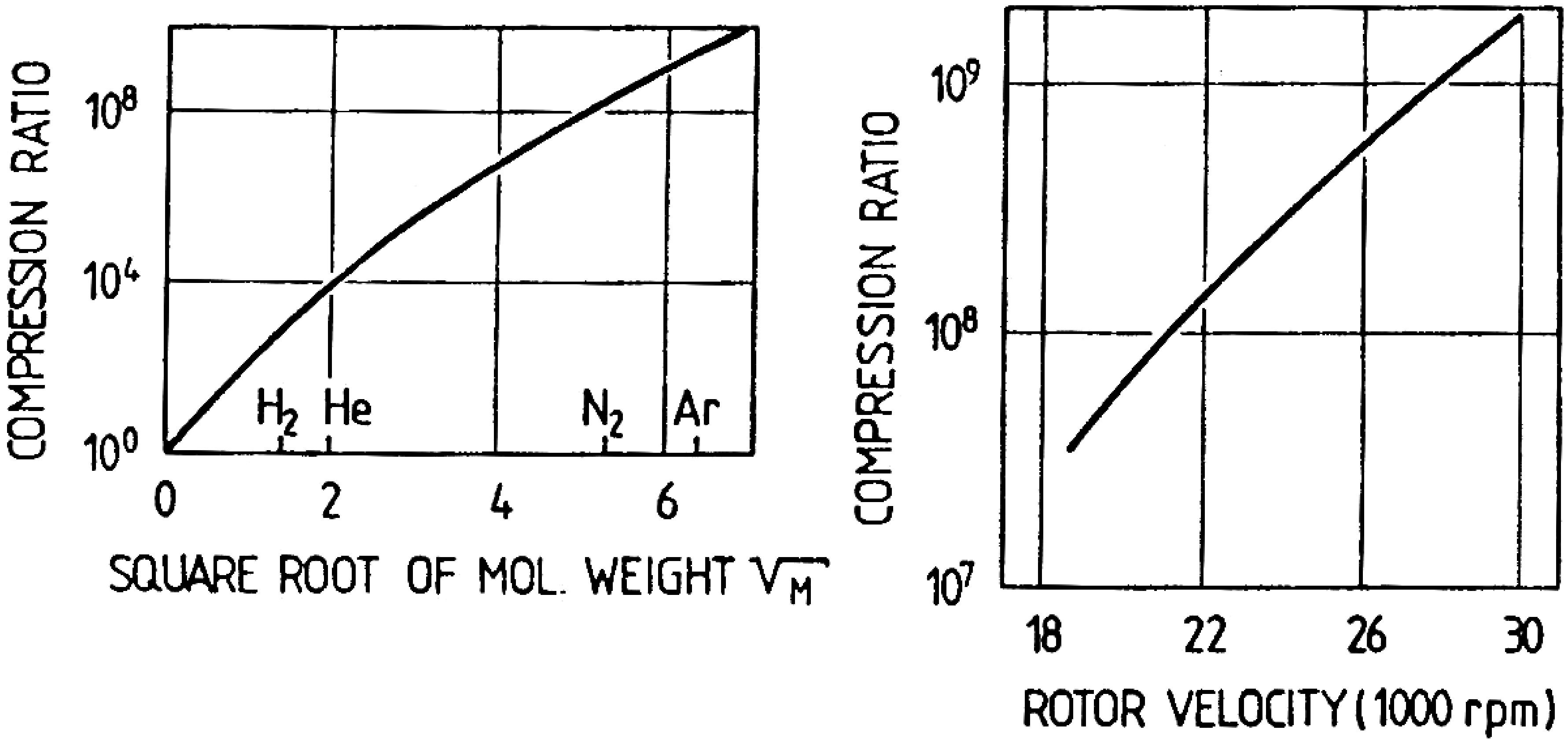


Fig. I.6. Compression ratio of a turbomolecular pump as a function of molecular weight M of the molecules pumped (left) and of the rotor velocity (right).

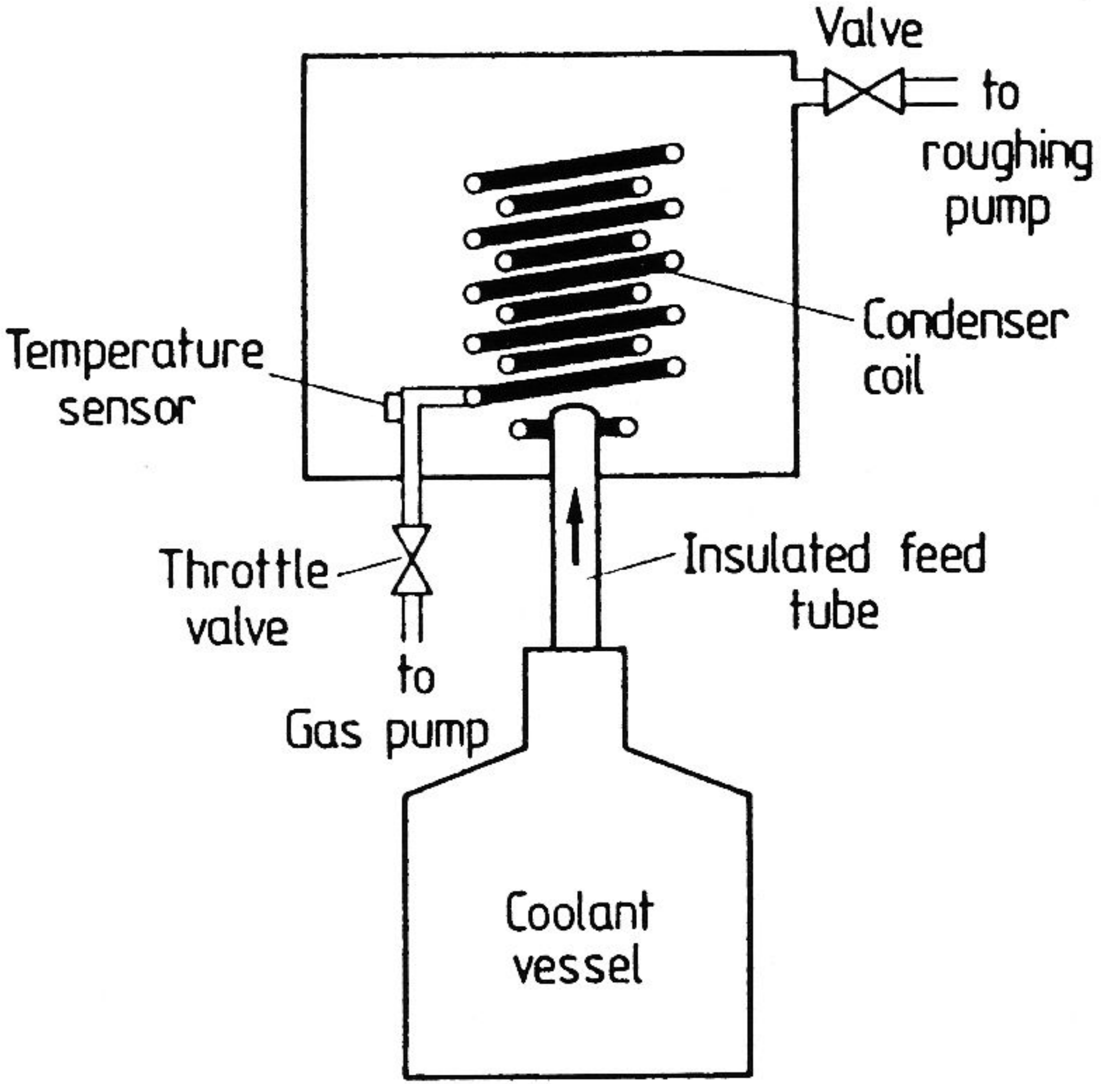


Fig. I.9. Schematic diagram of a cryopump. (After Leybold Heraeus GmbH)

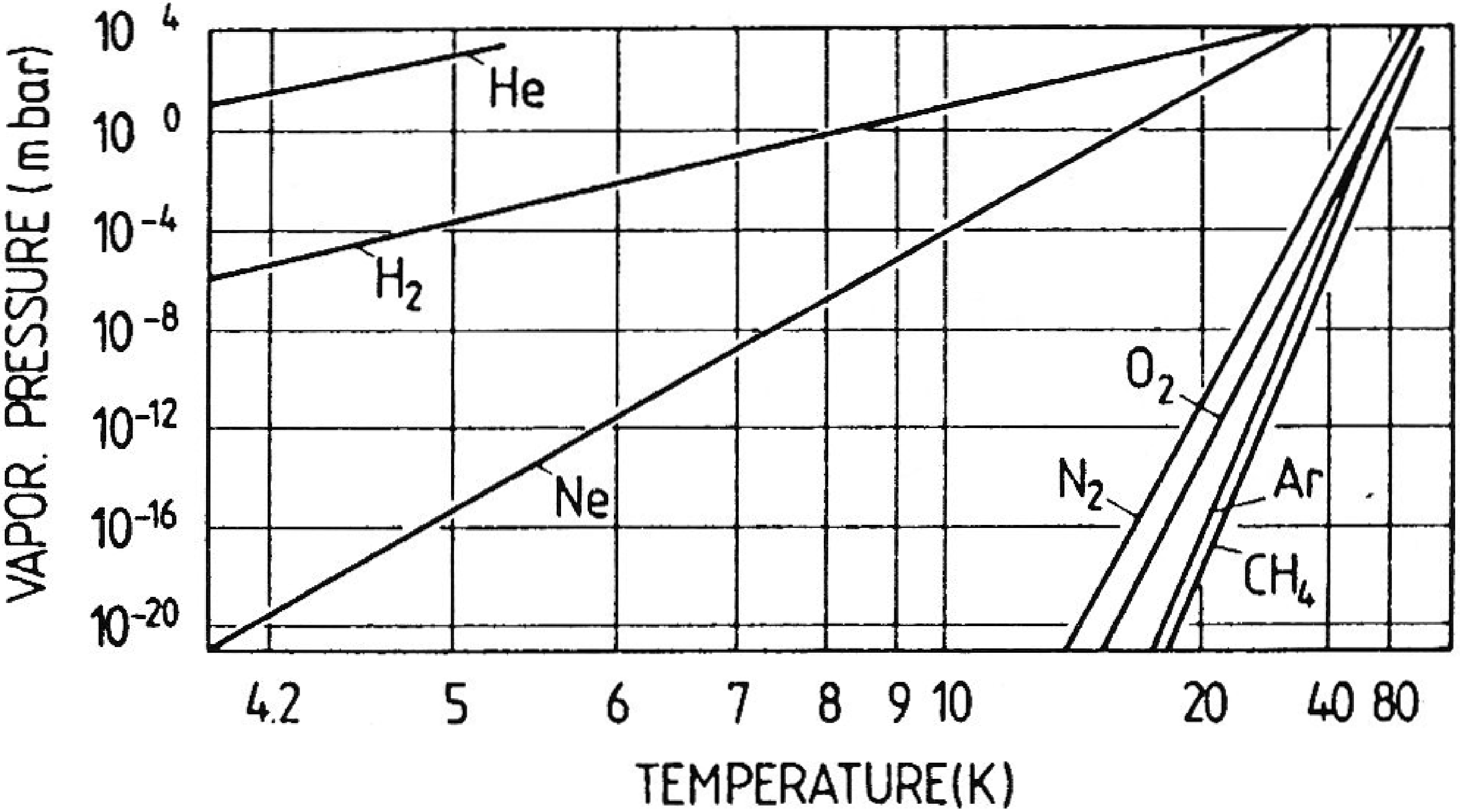
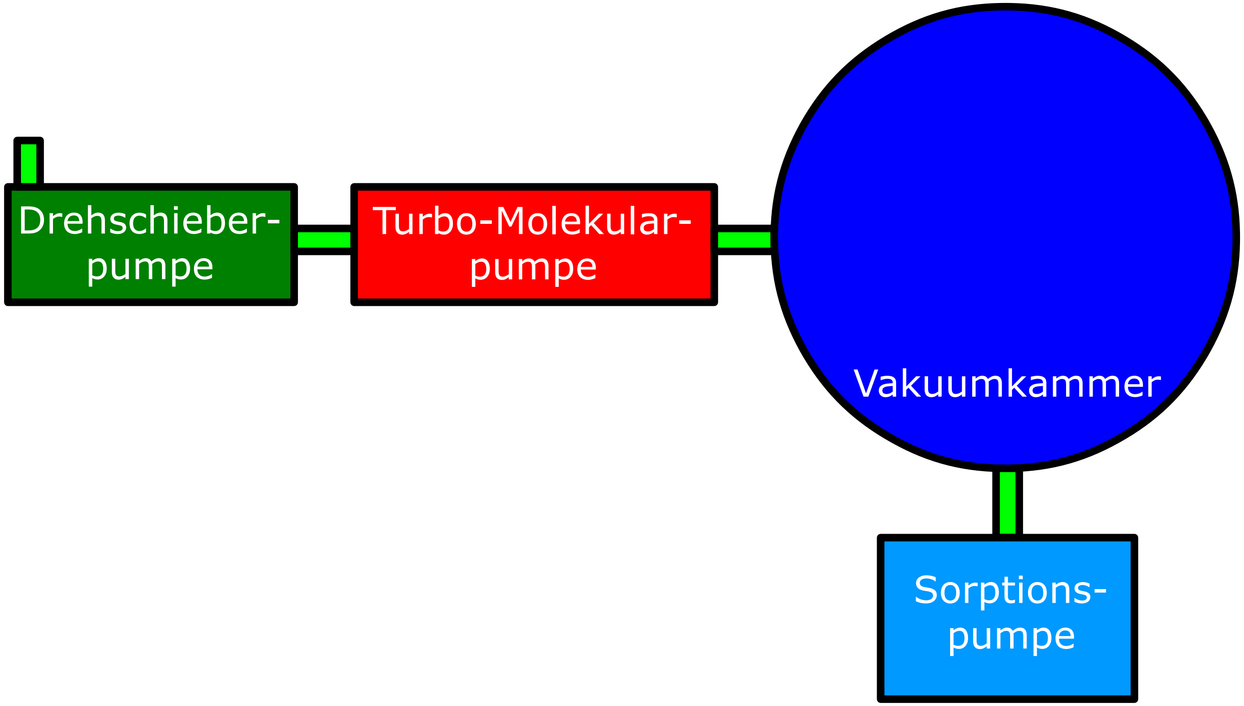


Fig. I.10. Saturation vapor pressures of various coolant materials



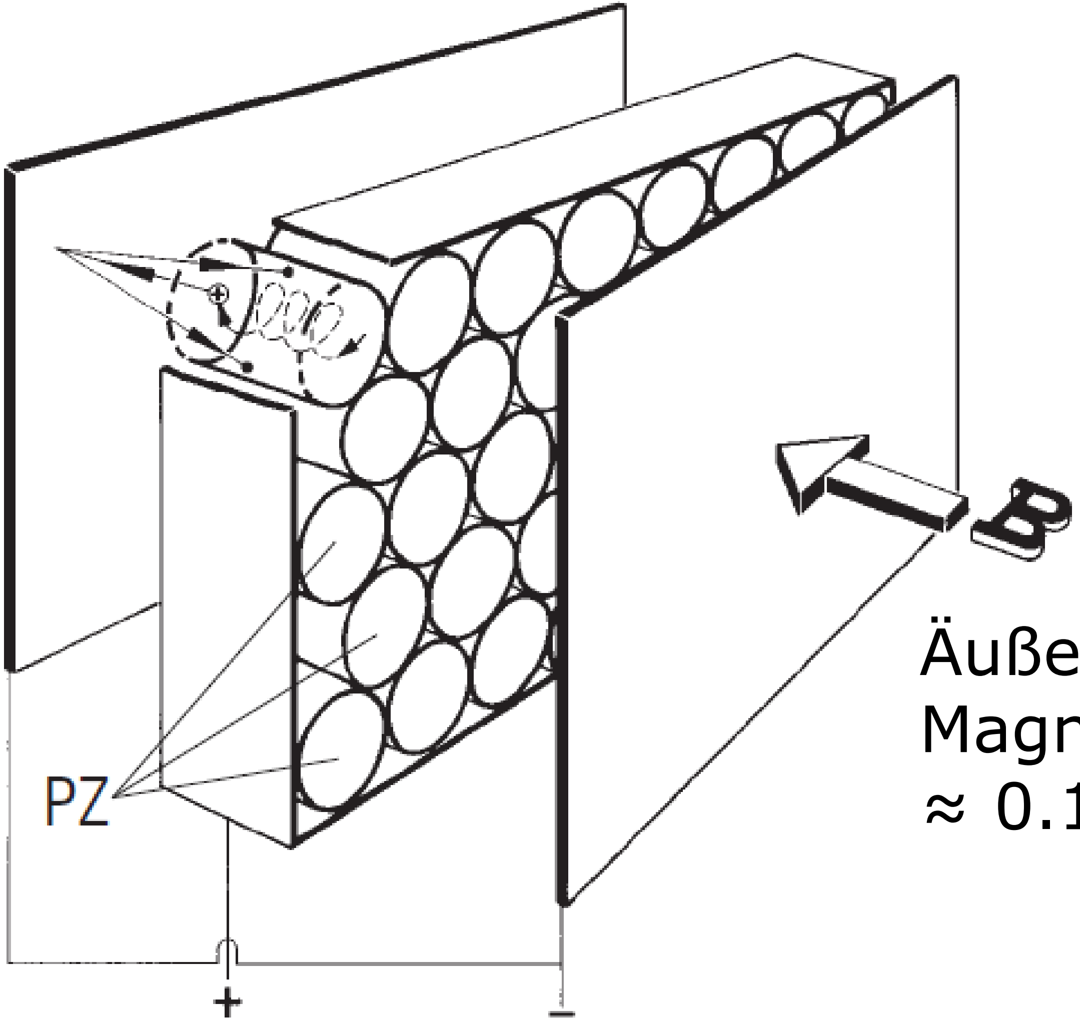
Sorptionspumpe

Bindung von Restgasteilchen an Sorptionsmittel

geräuschlos, keine Vibrationen, 10^{-9} Pa

z. B. Ionen–Zerstäuberpumpe

Funktionsprinzip der Ionen – Zerstäuberpumpe

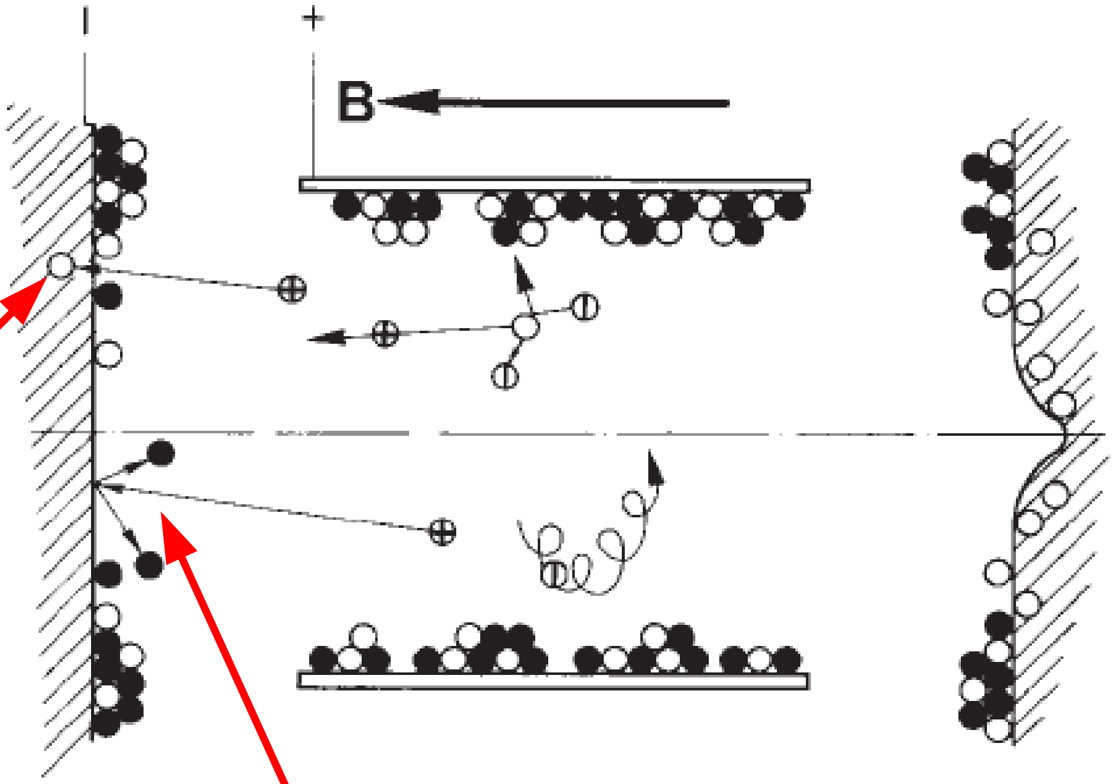


Kathoden
mit kV-Potenzial
gegen Anode

Äußeres
Magnetfeld
≈ 0.1 T

Aus: W. Umrath, *Grundlagen der Vakuumtechnik* (Leybold, Köln, 1997).

Dioden – Ionen – Zerstäuberpumpe



- ● Titan
- ○ Gasteilchen
- ⊕ Ion
- ⊖ Elektron

Implantation der Gasteilchen

Zerstäuben des Titanfilms

Aus: W. Umrath, *Grundlagen der Vakuumtechnik* (Leybold, Köln, 1997).

Diffusionspumpe (Gaede)

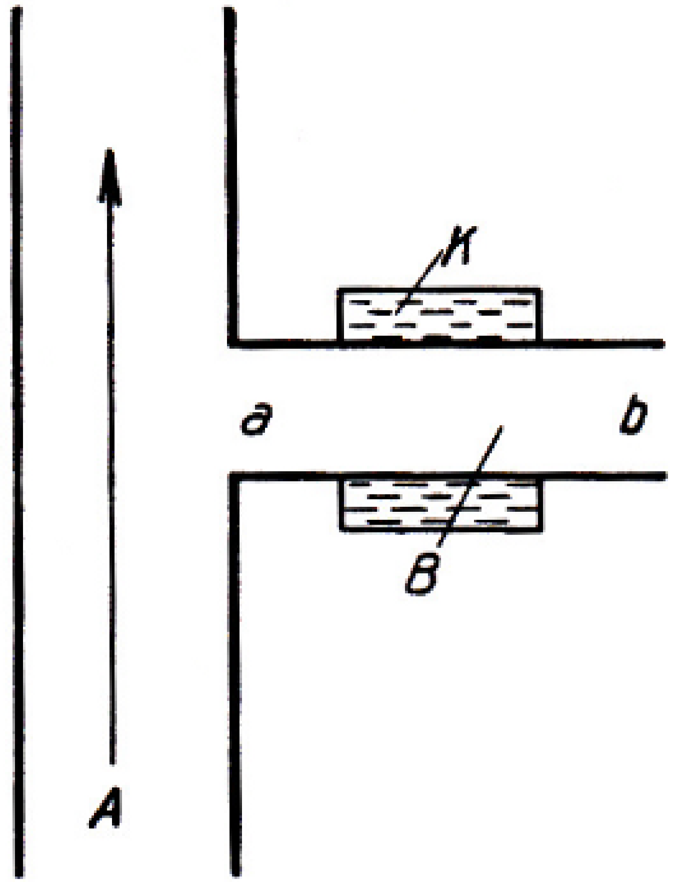


Abb. VII, 79. Zur Wirkung der Diffusionspumpe

A: Hg-Gasstrom – luftfrei
K: Kondensator

a→b: Hg-Diffusion
a←b: Luftdiffusion

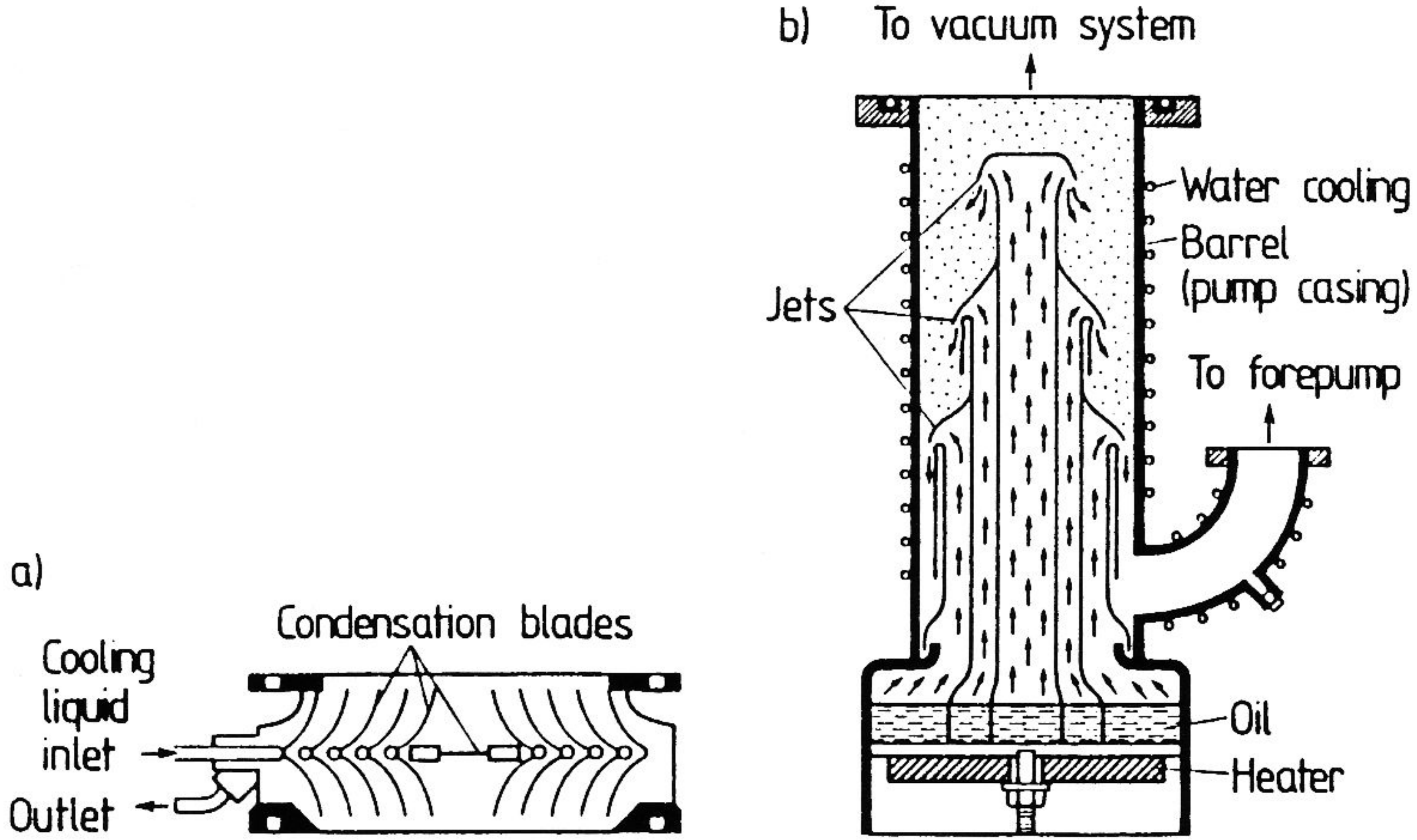
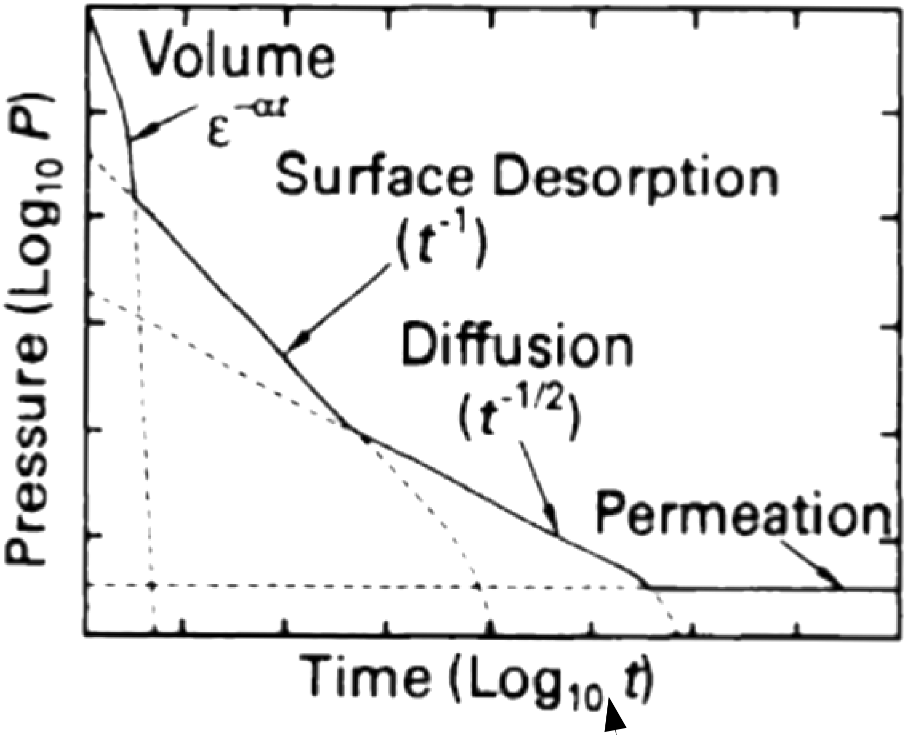


Fig. I.8. Simplified representation of a vapor (diffusion) pump (**b**) together with a baffle or cold trap (**a**) on the high vacuum side. Baffle (**a**) and pump (**b**) are arranged one on top of the other in a pumping station



10000 a

J. F. O'Hanlon: *A User's Guide to Vacuum Technology*

Magdeburger Halbkugeln, Otto von Guericke (1648)

wikipedia

"1 kg/cm^2"

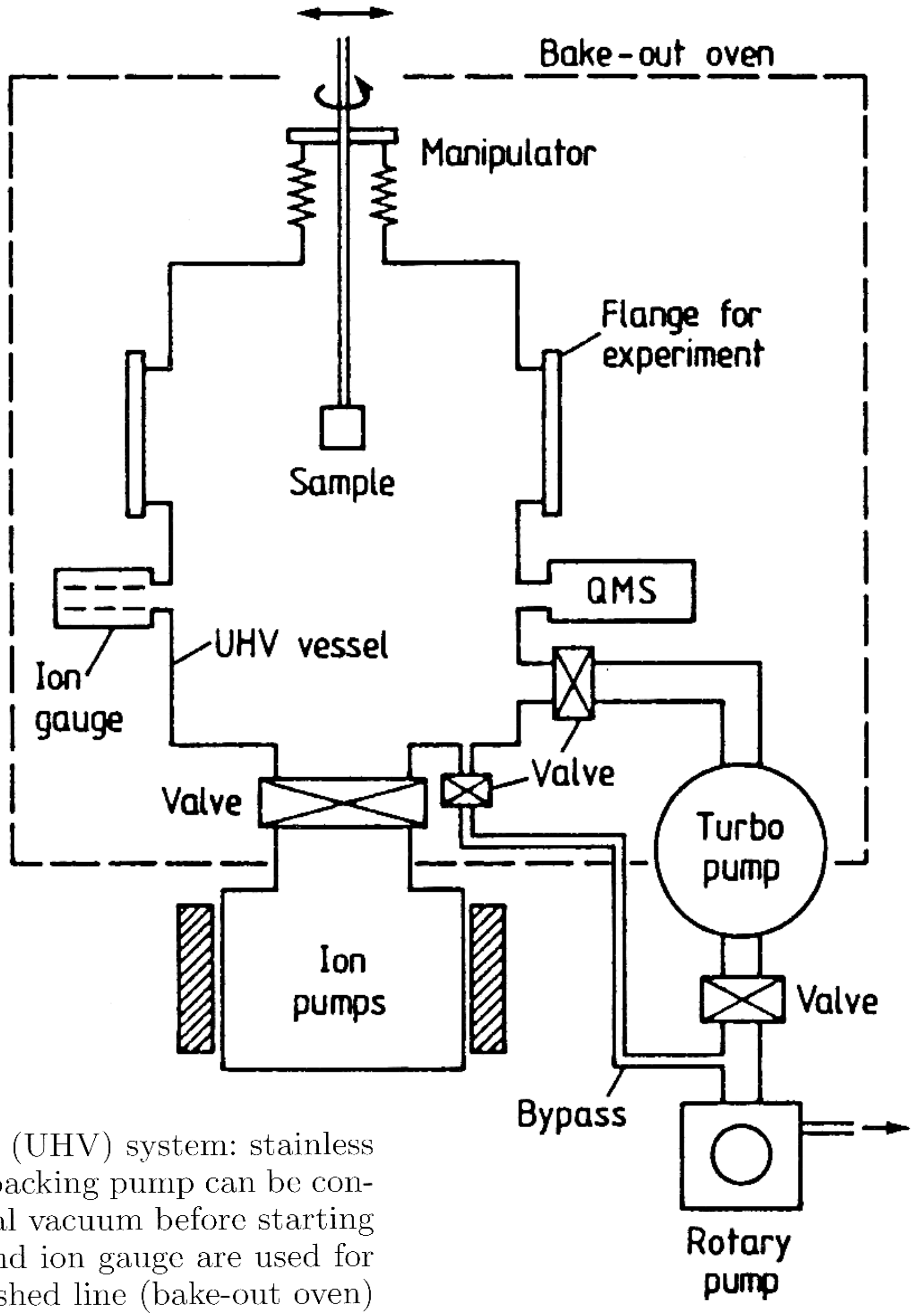
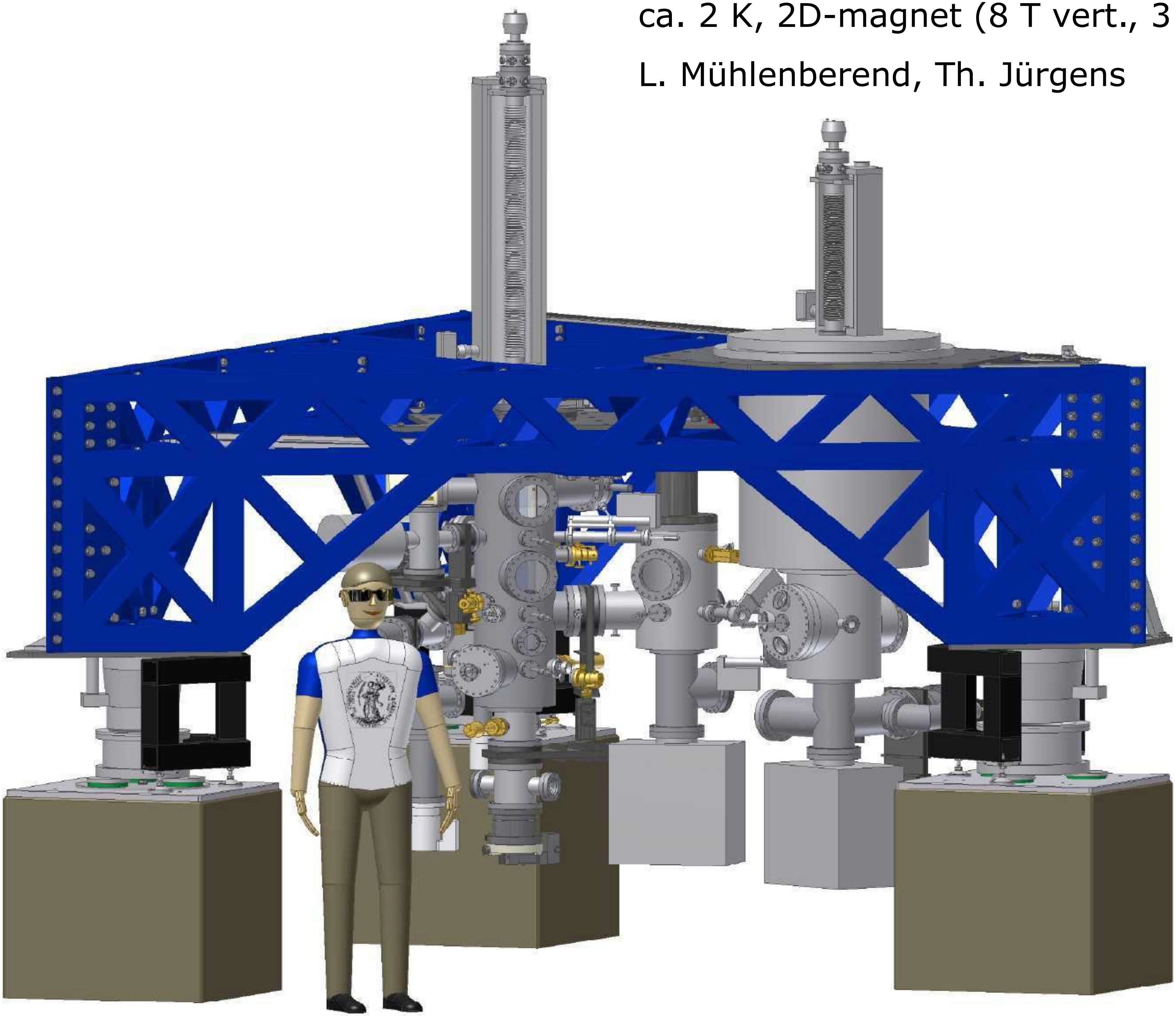


Fig. I.1. Schematic view of an Ultrahigh High Vacuum (UHV) system: stainless steel UHV vessel pumped by different pumps; the rotary backing pump can be connected to the main chamber in order to establish an initial vacuum before starting the ion pumps. Quadrupole mass spectrometer (QMS) and ion gauge are used for monitoring the residual gas. All parts enclosed by the dashed line (bake-out oven) must be baked in order to achieve UHV conditions Rotary pump ca. 2 K, 2D-magnet (8 T vert., 3 T hor.)

L. Mühlenberend, Th. Jürgens



Materialien

niedriger Dampfdruck & heizbar

nicht permeabel

Glas

Edelstahl (H_2), Aluminium(XHV)

W, Ta, Mo

Al_2O_3, Saphir (tiefe T)

Macor, Vespel

Teflon, Viton

Au (low T)

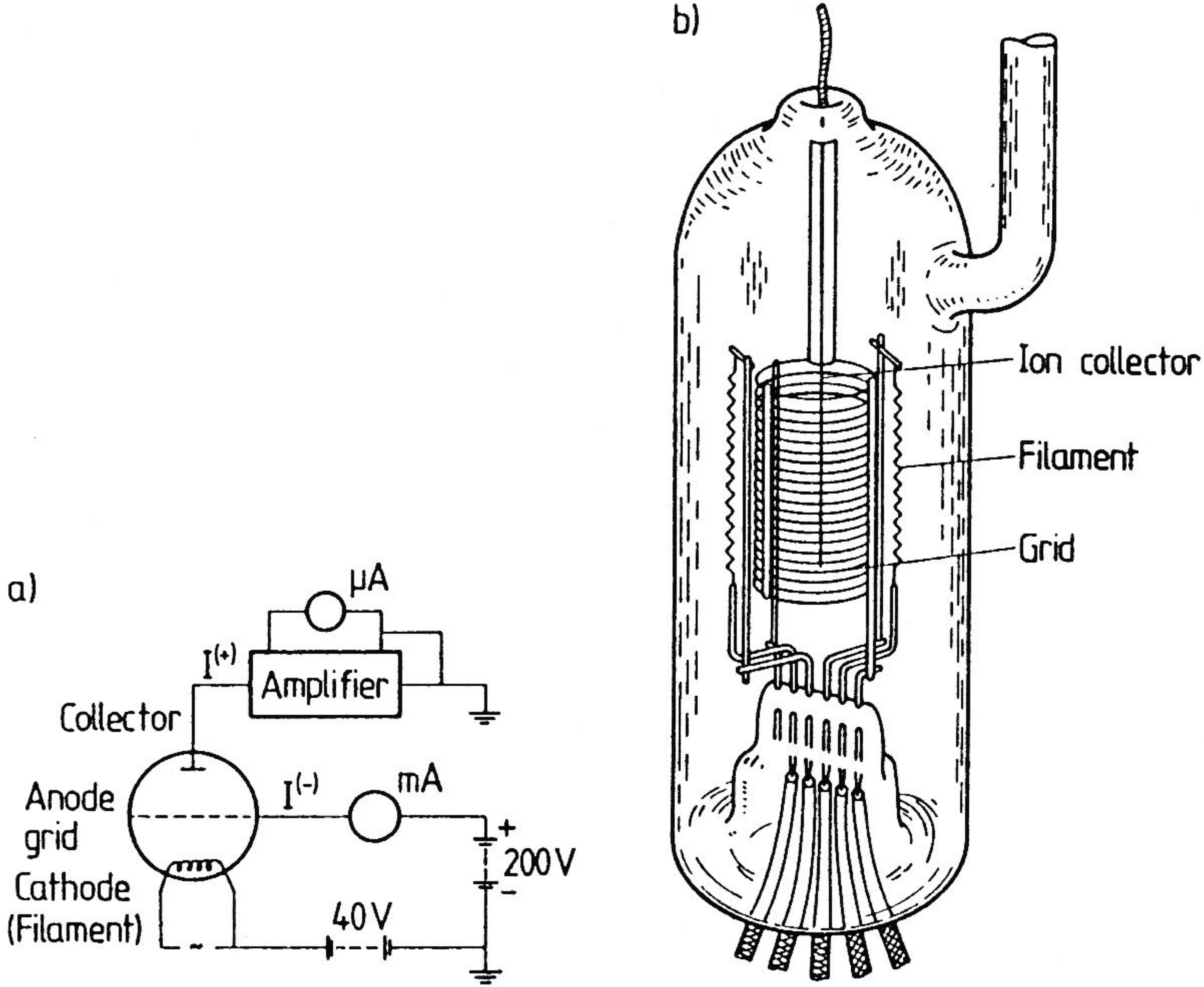
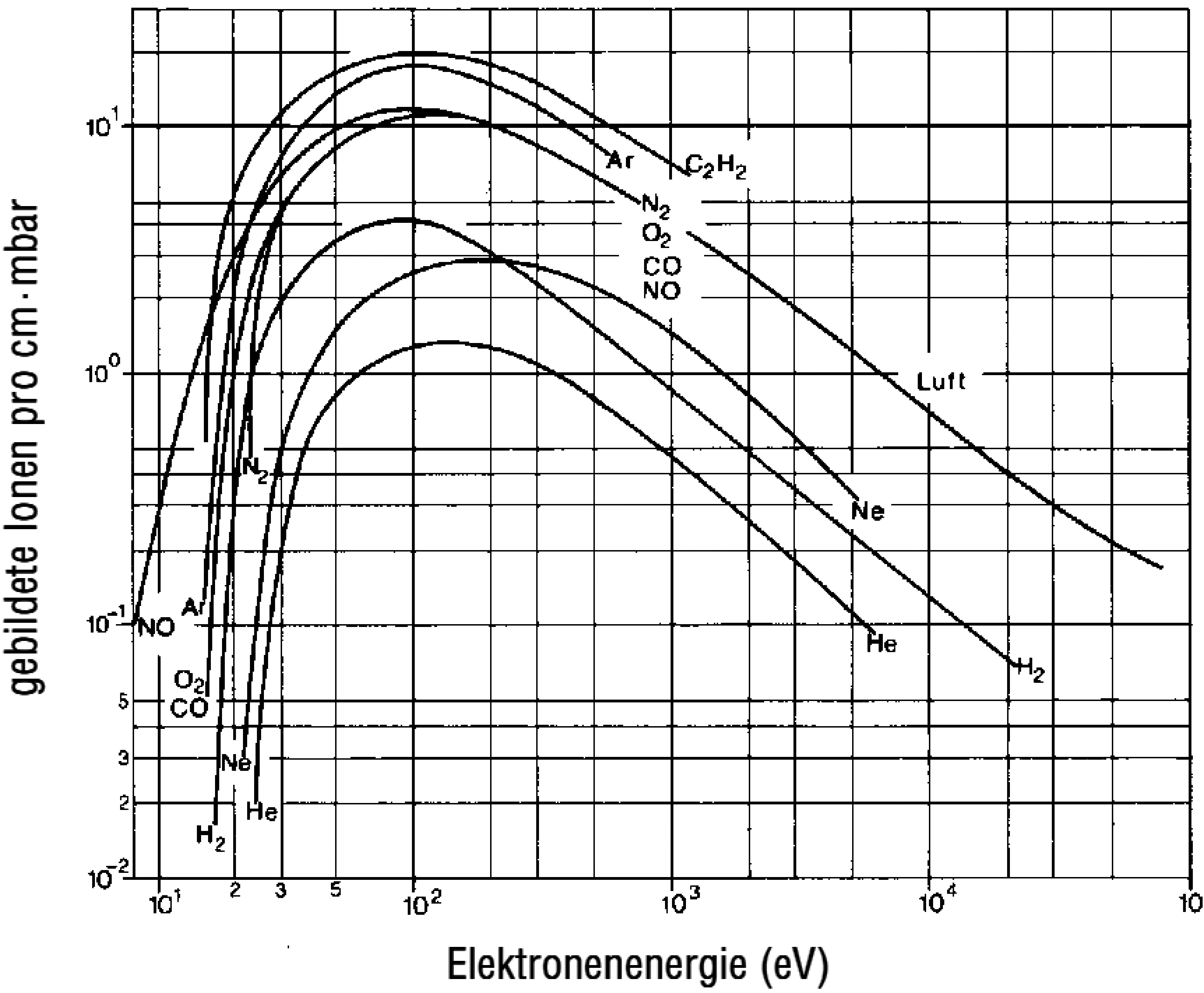
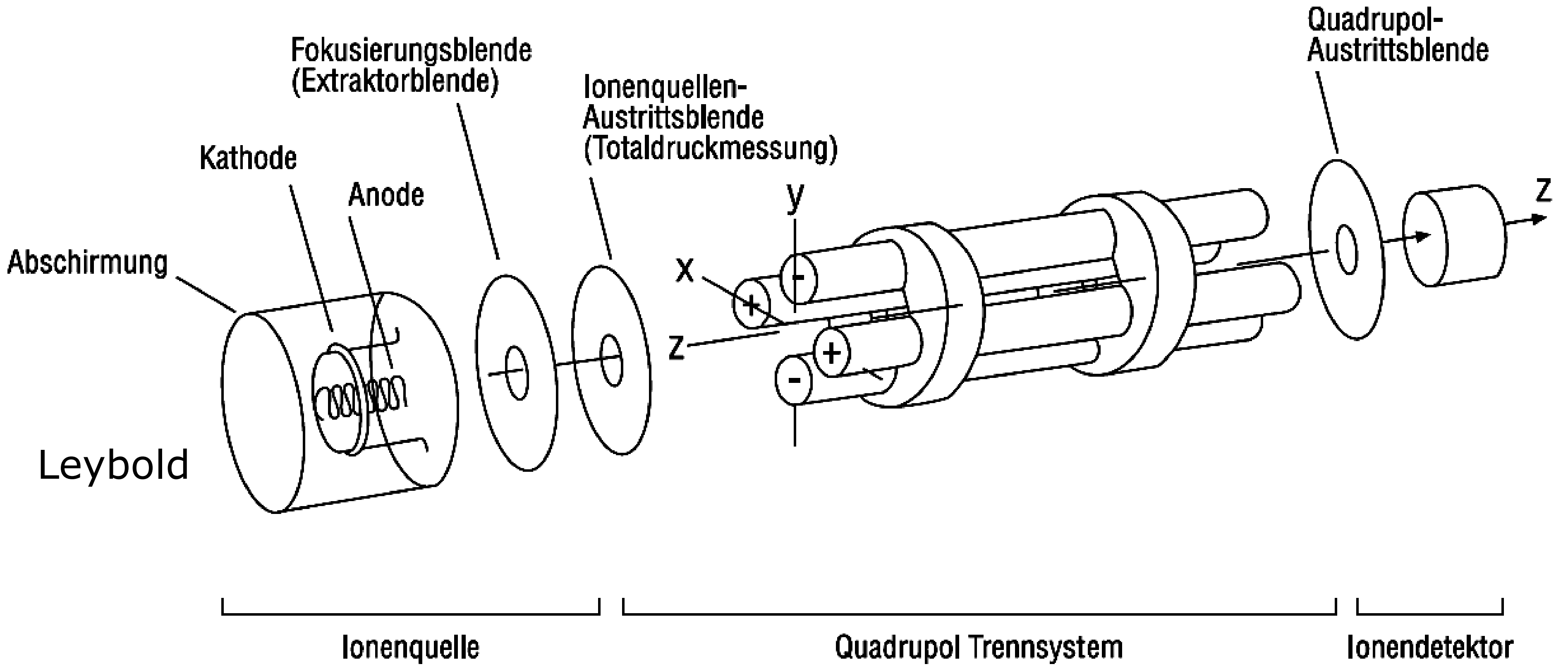


Fig. I.11a,b. Ionization gauge for pressure monitoring between 10^{-4} and 10^{-10} Torr. (**a**) Electric circuit for measuring the electron emission current I^{-} and the ion (collector) current I^{+}. (**b**) Typical construction of a modern Bayard-Alpert type ionization gauge. Cathode filament, anode grid and ion collector are contained in a glass (pyrex) tube which is attached to the UHV chamber. The electrode arrangement can also be put directly into the UHV chamber


gebildete Ionen pro cm · mbar
Elektronenenergie (eV)
10^1
10^0
10^-1
5
3
2
10^-2
10^1
2
3
5
10^2
10^3
10^4
10^5
Ar
C2H2
N2
O2
CO
NO
Luft
Ne
He
H2
NO
Ar
O2
CO
N2
Ne
He
H2

Quadrupolmassenspektrometer (QWS)

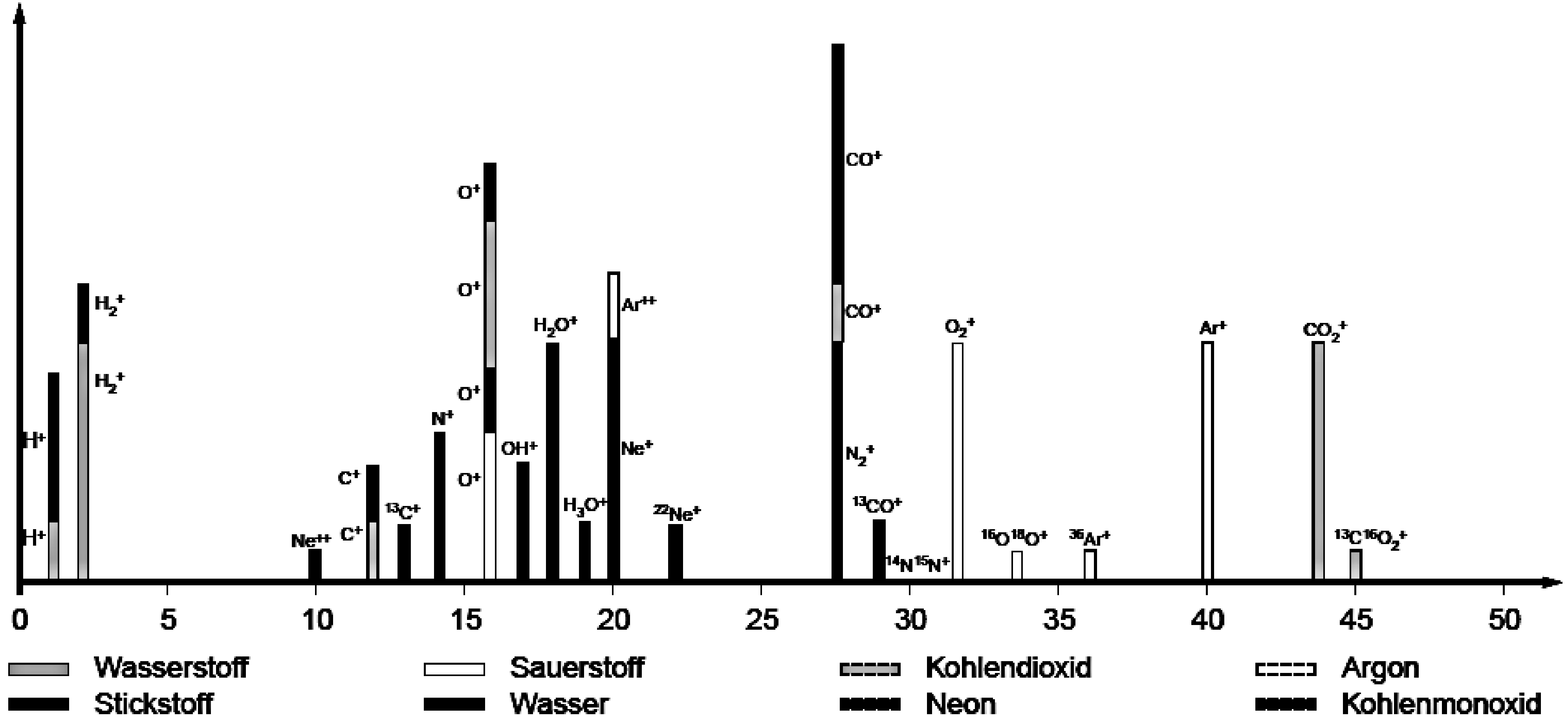
US Patent 2939952   Publication date: 1960-06-07
WOLFGANG PAUL; HELMUT STEINWEDEL
Apparatus for separating charged particles
of different specific charges



Leybold

Fragmentierung

Gas	Symbol	1 = 100	2	3	4	5
Azeton	$(CH_3)_2CO$	43/100	15/42	58/20	14/10	27/19
Luft		28/100	32/27	14/6	16/3	40/1

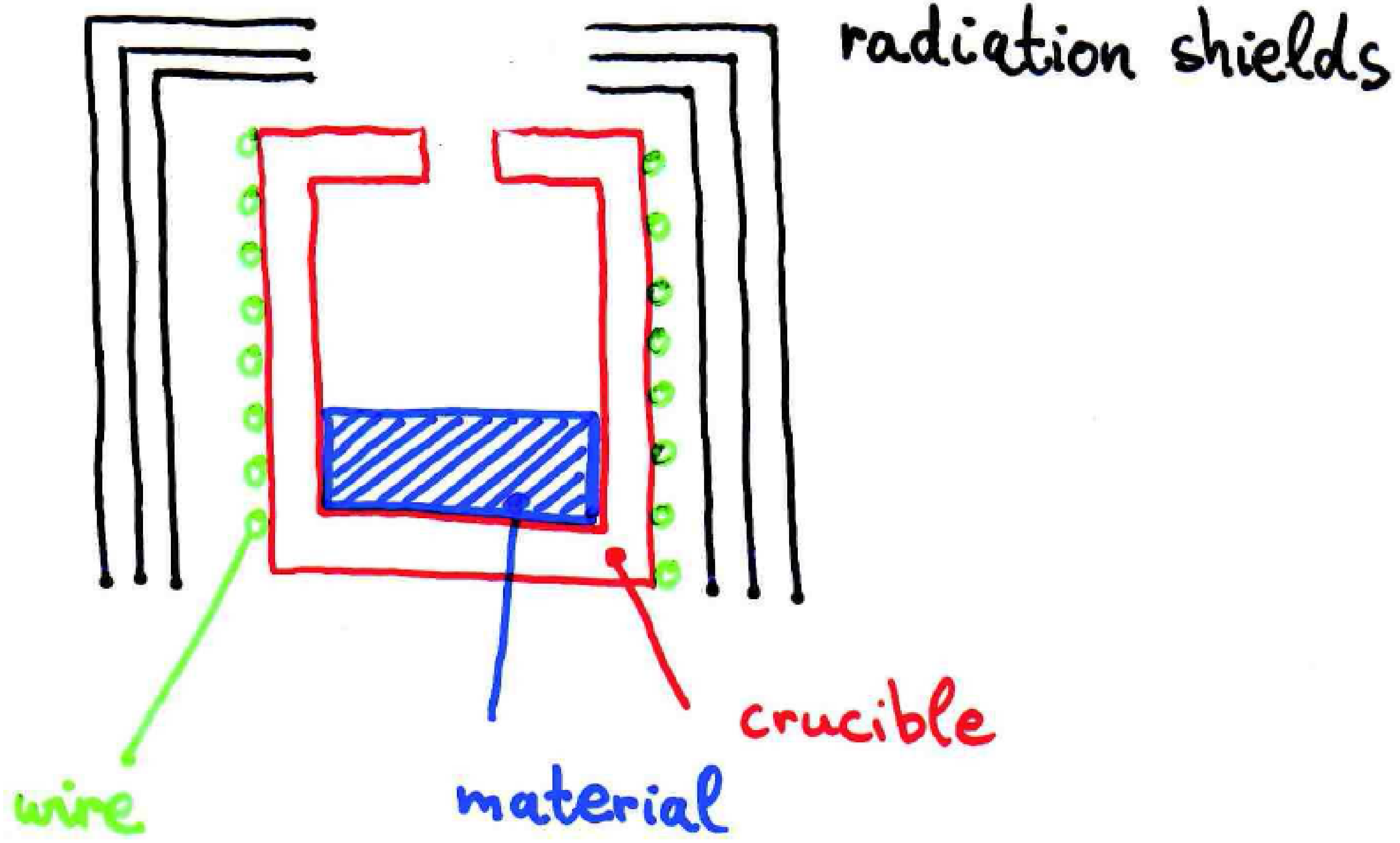


Auswertungsprobleme: Beispielsweise kann der Peak bei Masse 28 aus Sauerstoff-Fragmenten von O_2, H_2O, CO_2 und CO stammen; der Peak bei Masse 28 von Beiträgen aus N_2 sowie CO und CO als Fragment von CO_2; der Peak bei Masse 20 kann von einfach ionisiertem Ne und zweifach ionisiertem Ar stammen.

Leybold

a: Hochleistungs-Sensor mit Channeltron,
b: Kompakt-Sensor mit Micro-Channelplate,
c: Hochleistungs-Sensor mit Faraday-Cup

Knudsen cell



Dampfdrücke

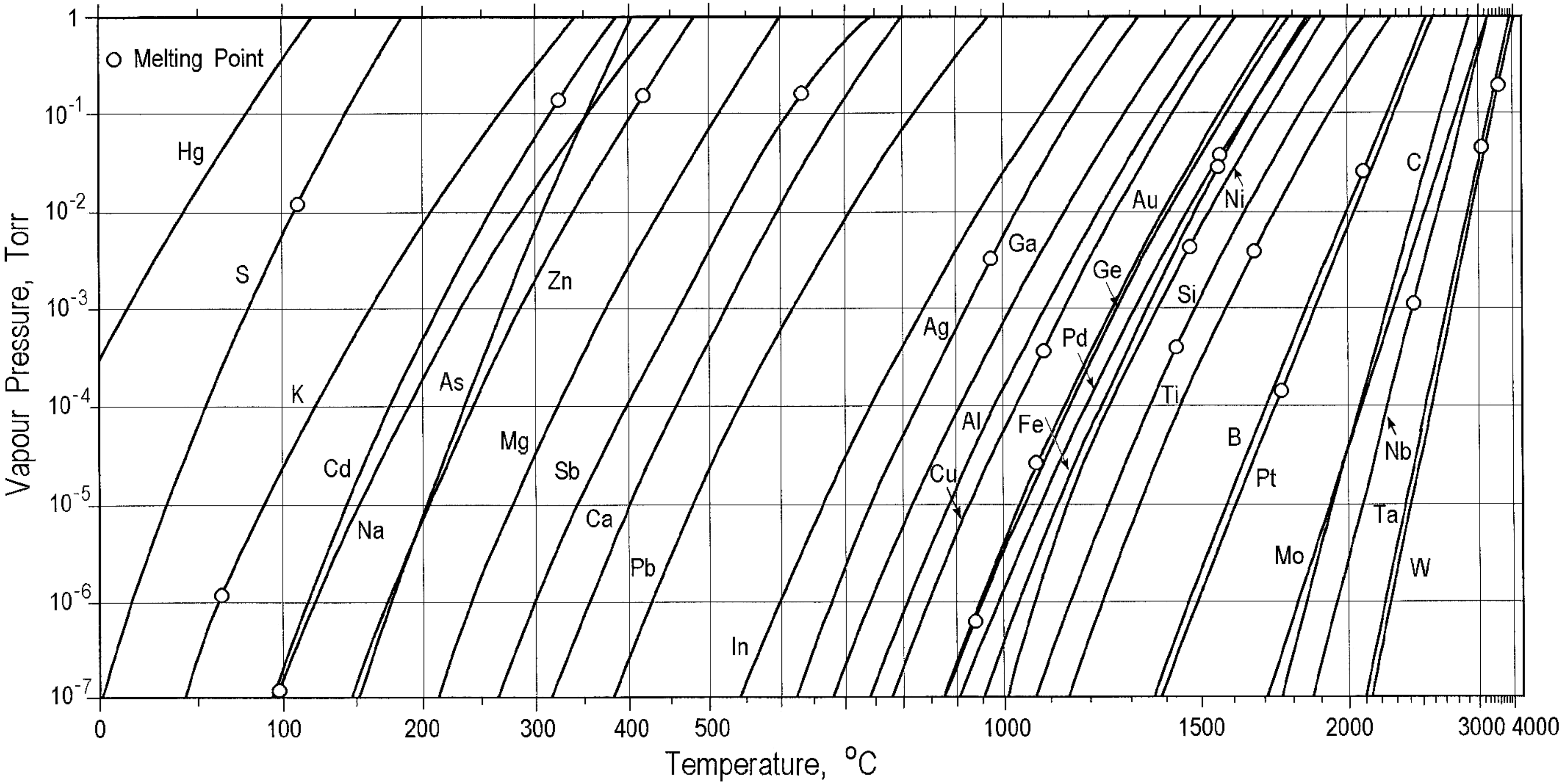


Fig. 3.17

Material	Symbol	MP, °C	Temperature °C for a given vapor pressure Torr		
			10^{-8}	10^{-6}	10^{-4}
Aluminum	Al	660	685	812	972
Antimony	Sb	630	279	345	425
Arsenic	As	817	104	150	204
Bismuth	Bi	271	347	409	517
Boron	B	2300	1282	1467	1707
Cadmium	Cd	321	74	119	177
Carbon	C	3652	1657	1867	2137
Copper	Cu	1083	722	852	1027
Gallium	Ga	30	619	742	907
Germanium	Ge	937	812	947	1137
Gold	Au	1064	807	947	1132
Indium	In	157	488	597	742
Iron	Fe	1535	892	1032	1227
Magnesium	Mg	649	185	246	327
Mercury	Hg	−39	−72	−44	7
Molybdenum	Mo	2610	1592	1822	2117
Nickel	Ni	1455	927	1072	1262
Platinum	Pt	1772	1292	1492	1747
Potassium	K	63	21	65	123
Silicon	Si	1410	992	1147	1337
Silver	Ag	962	547	685	832
Sodium	Na	98	74	123	193
Tantalum	Ta	2996	1957	2237	2587
Tin	Sn	232	682	807	997
Titanium	Ti	1660	1062	1227	1442
Tungsten	W	3410	2117	2407	2757

Präparation durch Spalten

… gibt Spaltflächen

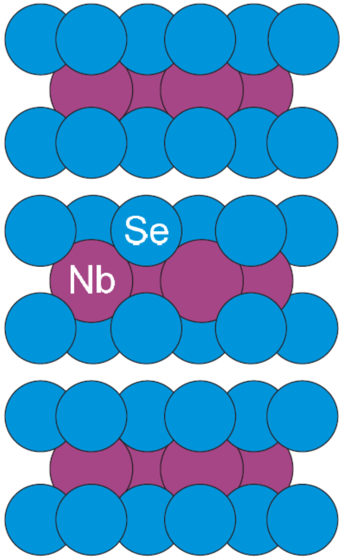
Oxide, z. B. ZnO, TiO_2, SnO_2

Alkalihalide, z. B. NaCl, KCl

Halbleiter, z. B. Si, Ge, GaAs, InP, GaP

Metalldichalcogenide

Kupratsupraleiter



2H - $NbSe_2$

Präparation durch Heizen

resistiv

per Strahlung

per Elektronenstoß

Präparation durch chemische Reaktionen

z. B. Mo, W in O_2 (~ 10^{-6} Pa) heizen (~ 1400 K)

C reagiert zu CO

desorbiert bei ~ 2200 K

Präparation durch ''sputtering'' (Ne+, Ar+ Beschuss)