Ciência e Tecnologia do Vácuo

430323

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2 INTRODUCTION (CH. 1)

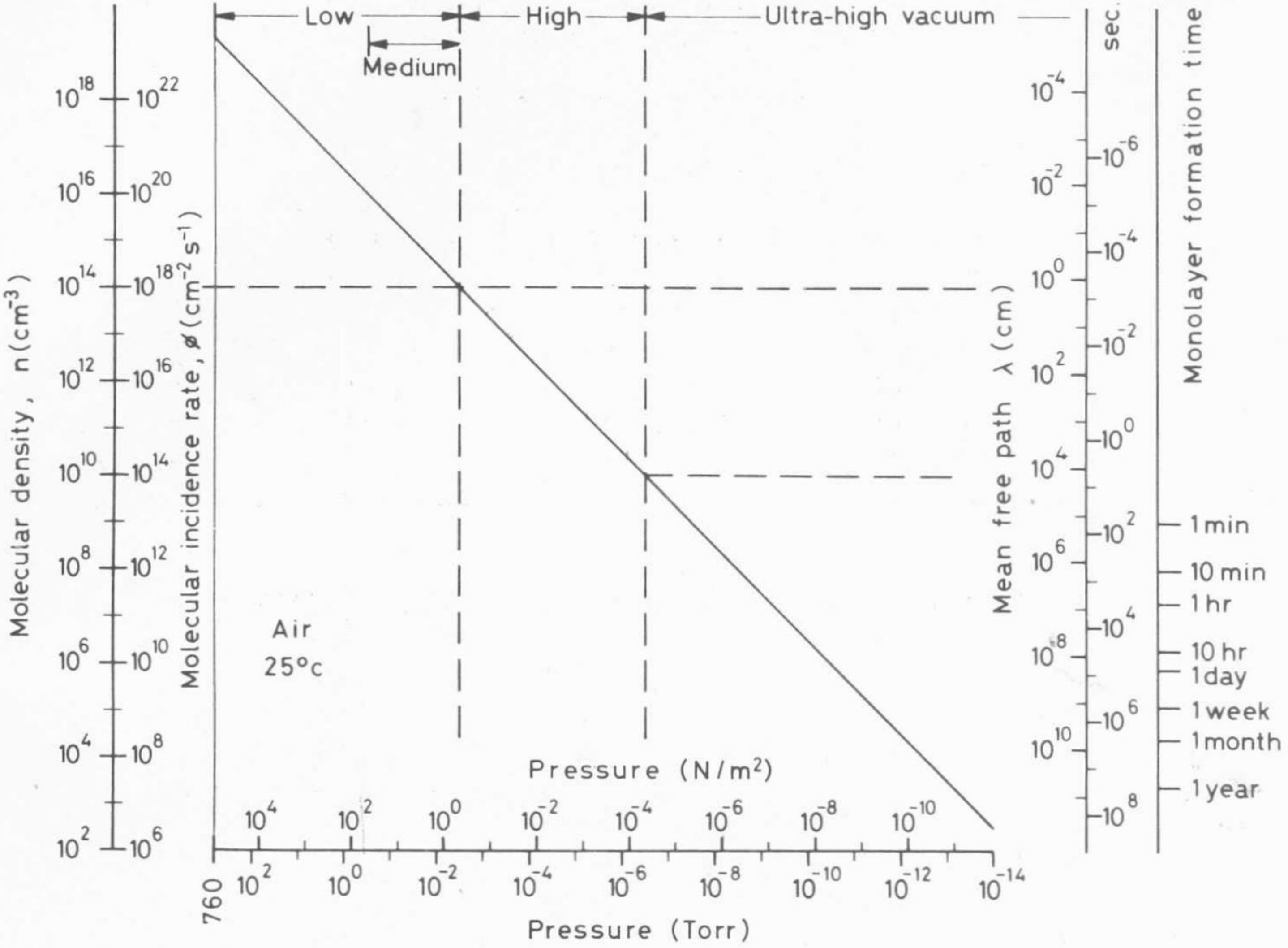


Fig. 1.1 Relationship of several concepts defining the degree of vacuum.

Vacuum Technology – A. Roth, 1990, 3a edição, North-Holland

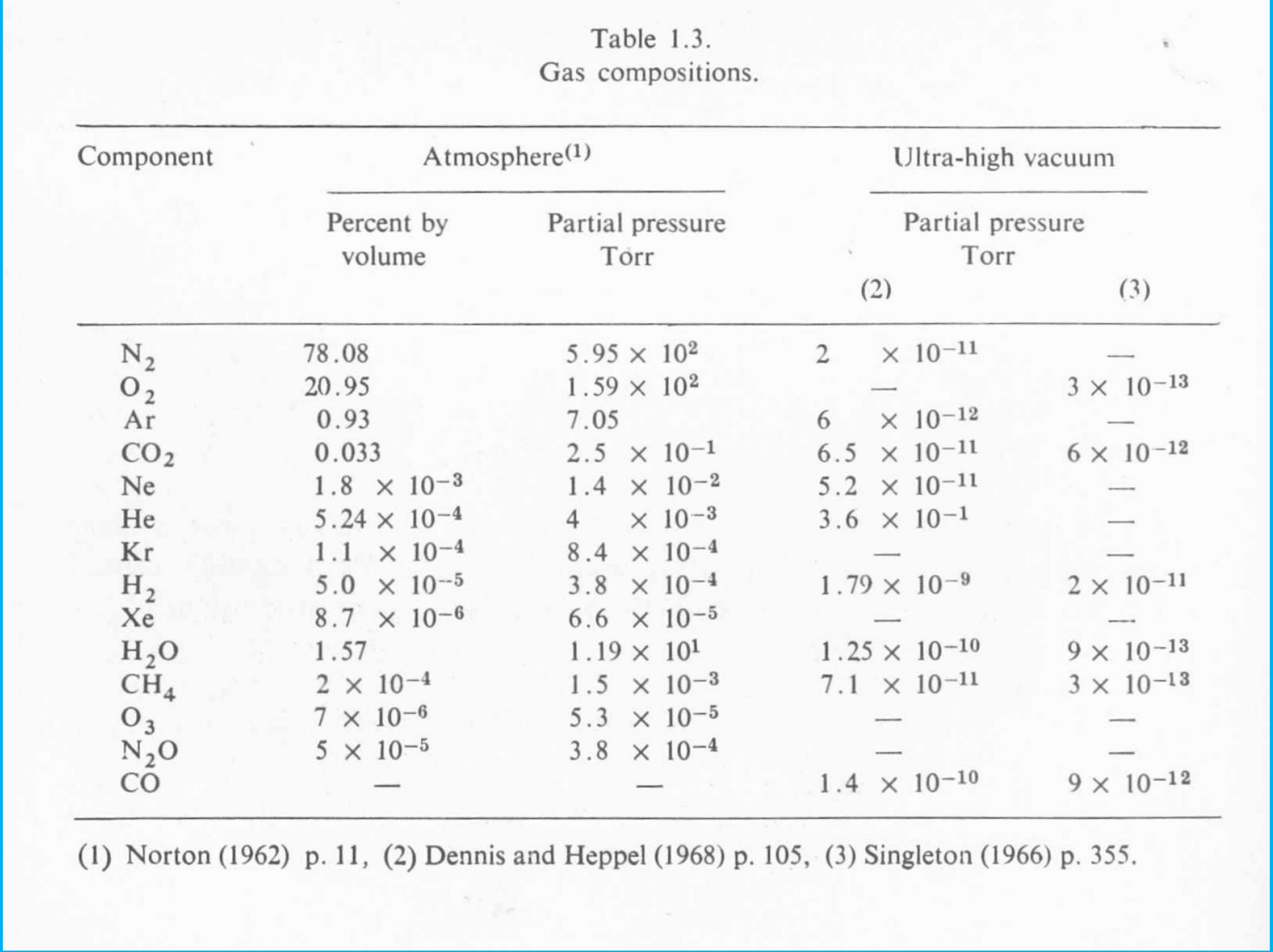
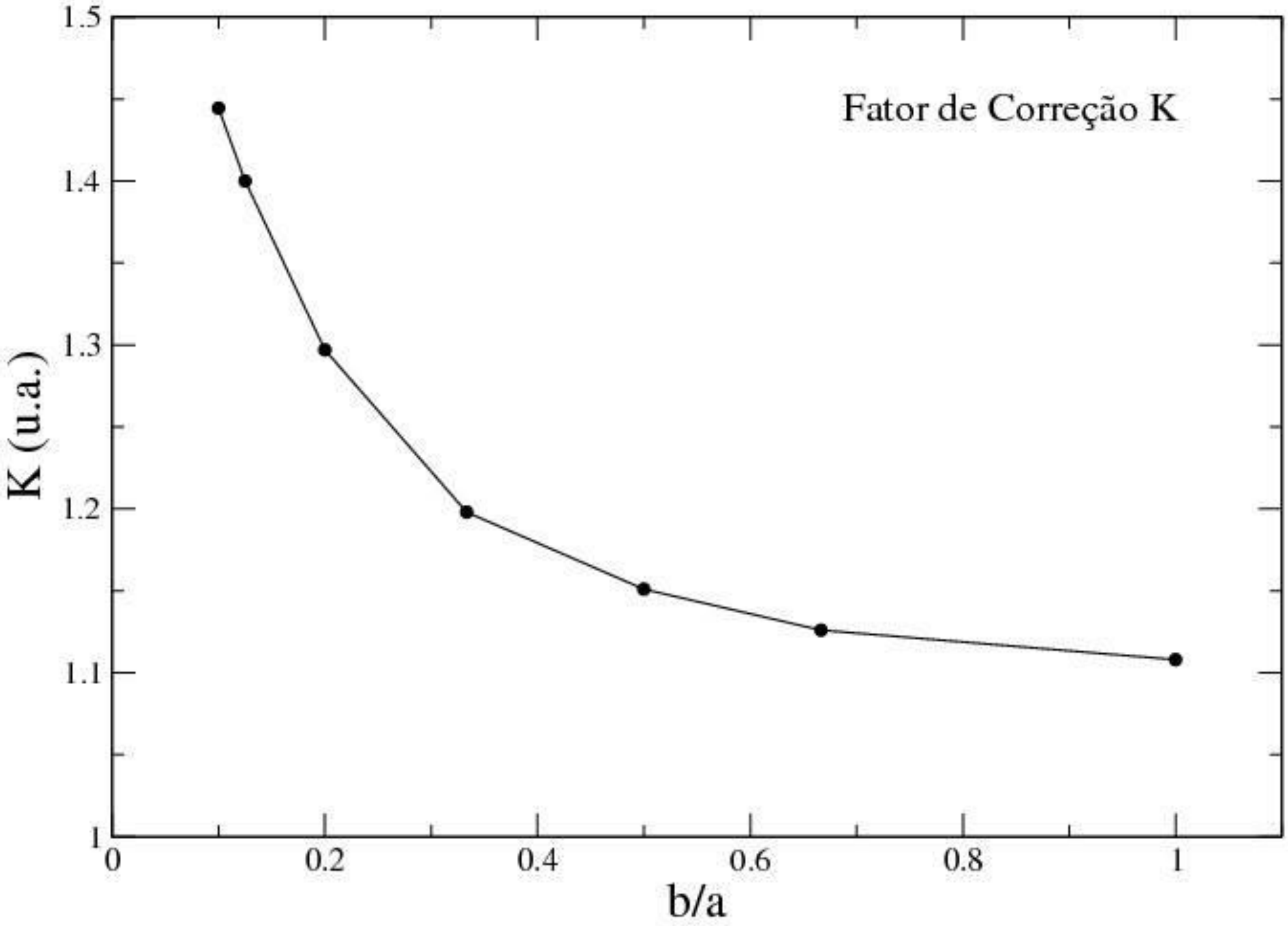


Table 1.3.
Gas compositions.

Component	Atmosphere⁽¹⁾		Ultra-high vacuum	
	Percent by volume	Partial pressure Torr	Partial pressure Torr	
			(2)	(3)
N_2	78.08	5.95×10^{2}	2×10^{-11}	—
O_2	20.95	1.59×10^{2}	—	3×10^{-13}
Ar	0.93	7.05	6×10^{-12}	—
CO_2	0.033	2.5×10^{-1}	6.5×10^{-11}	6×10^{-12}
Ne	1.8×10^{-3}	1.4×10^{-2}	5.2×10^{-11}	—
He	5.24×10^{-4}	4×10^{-3}	3.6×10^{-1}	—
Kr	1.1×10^{-4}	8.4×10^{-4}	—	—
H_2	5.0×10^{-5}	3.8×10^{-4}	1.79×10^{-9}	2×10^{-11}
Xe	8.7×10^{-6}	6.6×10^{-5}	—	—
H_2O	1.57	1.19×10^{1}	1.25×10^{-10}	9×10^{-13}
CH_4	2×10^{-4}	1.5×10^{-3}	7.1×10^{-11}	3×10^{-13}
O_3	7×10^{-6}	5.3×10^{-5}	—	—
N_2O	5×10^{-5}	3.8×10^{-4}	—	—
CO	—	—	1.4×10^{-10}	9×10^{-12}

(1) Norton (1962) p. 11, (2) Dennis and Heppel (1968) p. 105, (3) Singleton (1966) p. 355.

Vacuum Technology – A. Roth, 1990, 3a edição, North-Holland


Fator de Correção K
K (u.a.)
b/a
1.5
1.4
1.3
1.2
1.1
1
0
0.2
0.4
0.6
0.8
1

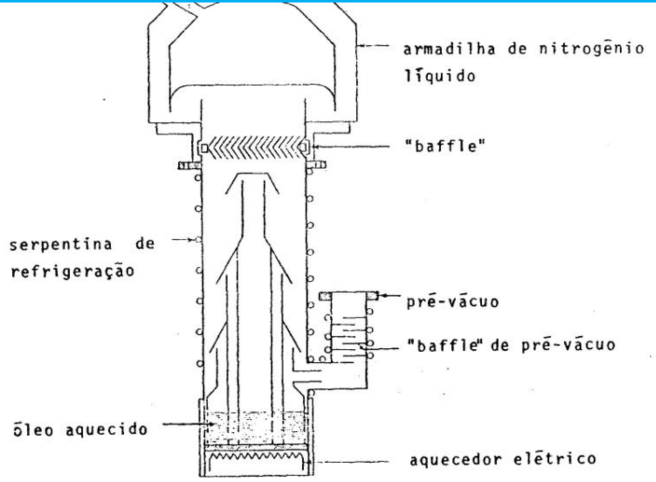
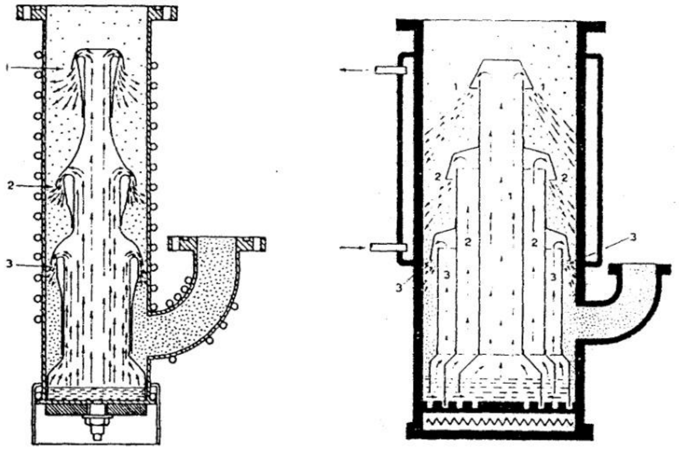


Fig. 29 - Bomba de Difusão com "baffle" chevron e armadilha de nitrogênio líquido ("cold trap")



(a) (b)

Fig. 30 - Esquemas de Bombas de Difusão de três estágios

a) desenho mais antigo; o óleo aquecido não sofre nenhum precesso de purificação

b) com tubos concêntricos permitindo a purificação do óleo por - destilação fracionada, durante o funcionamento (o vapor de óleo mais aquecido e limpo sai pelo chapéu ("nozzle") 1.

Bomba de Difusão

Jato de vapor empurra as moléculas da câmara criando um gradiente de pressão.

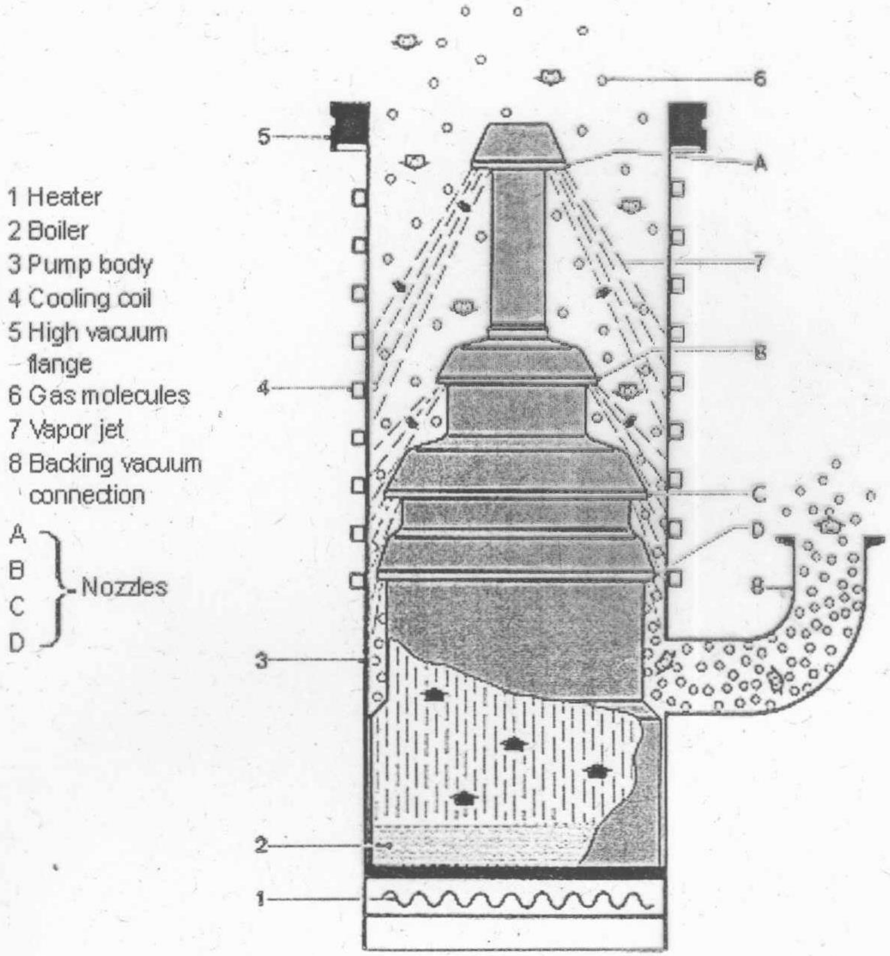


Fig. 2.44
Mode of operation of a diffusion pump

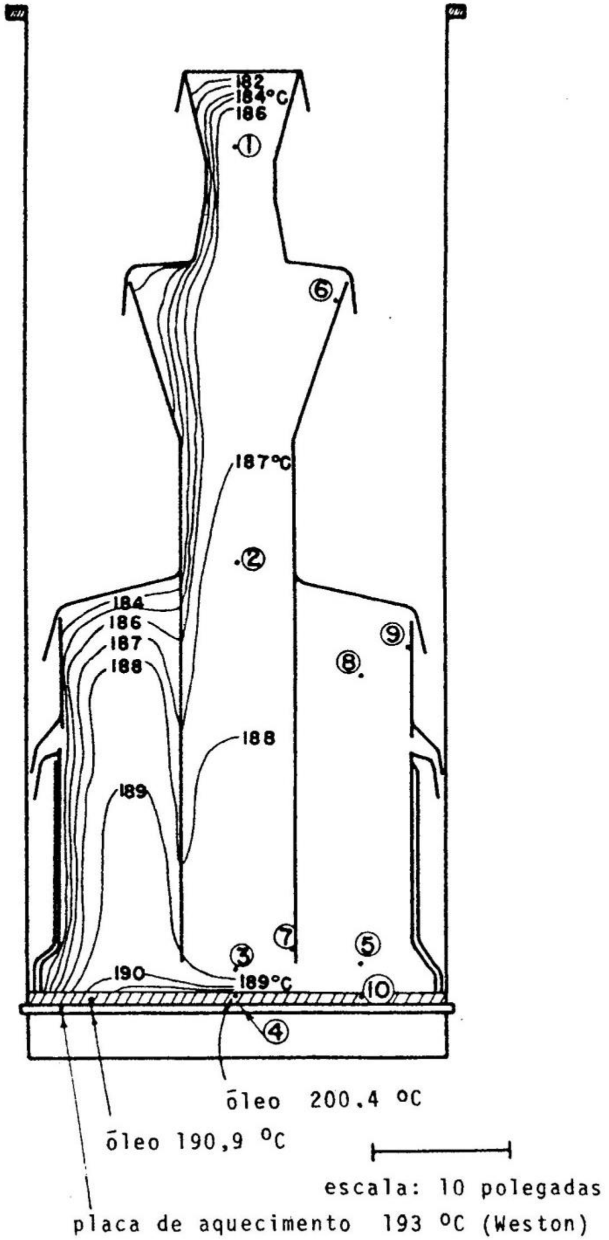
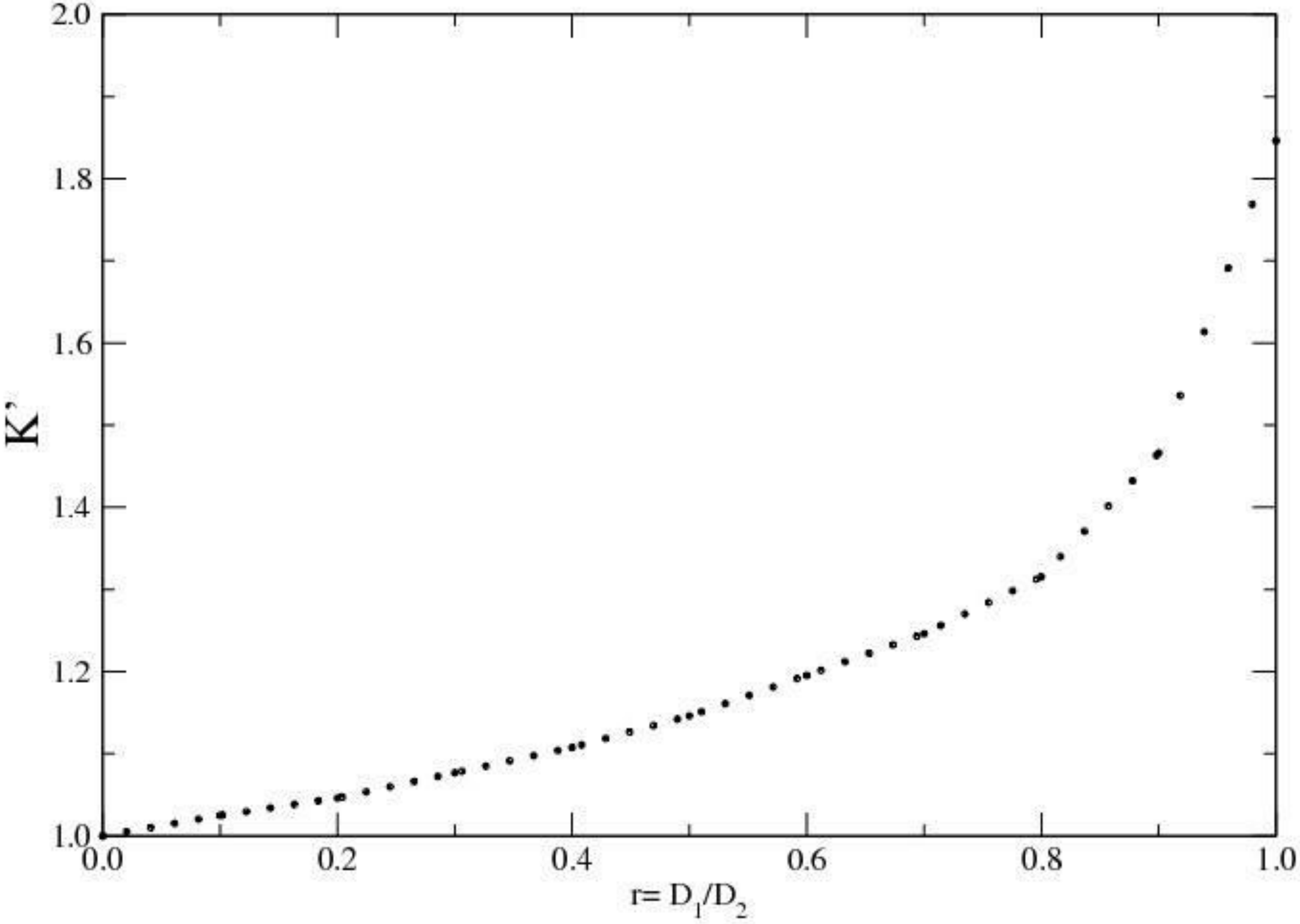
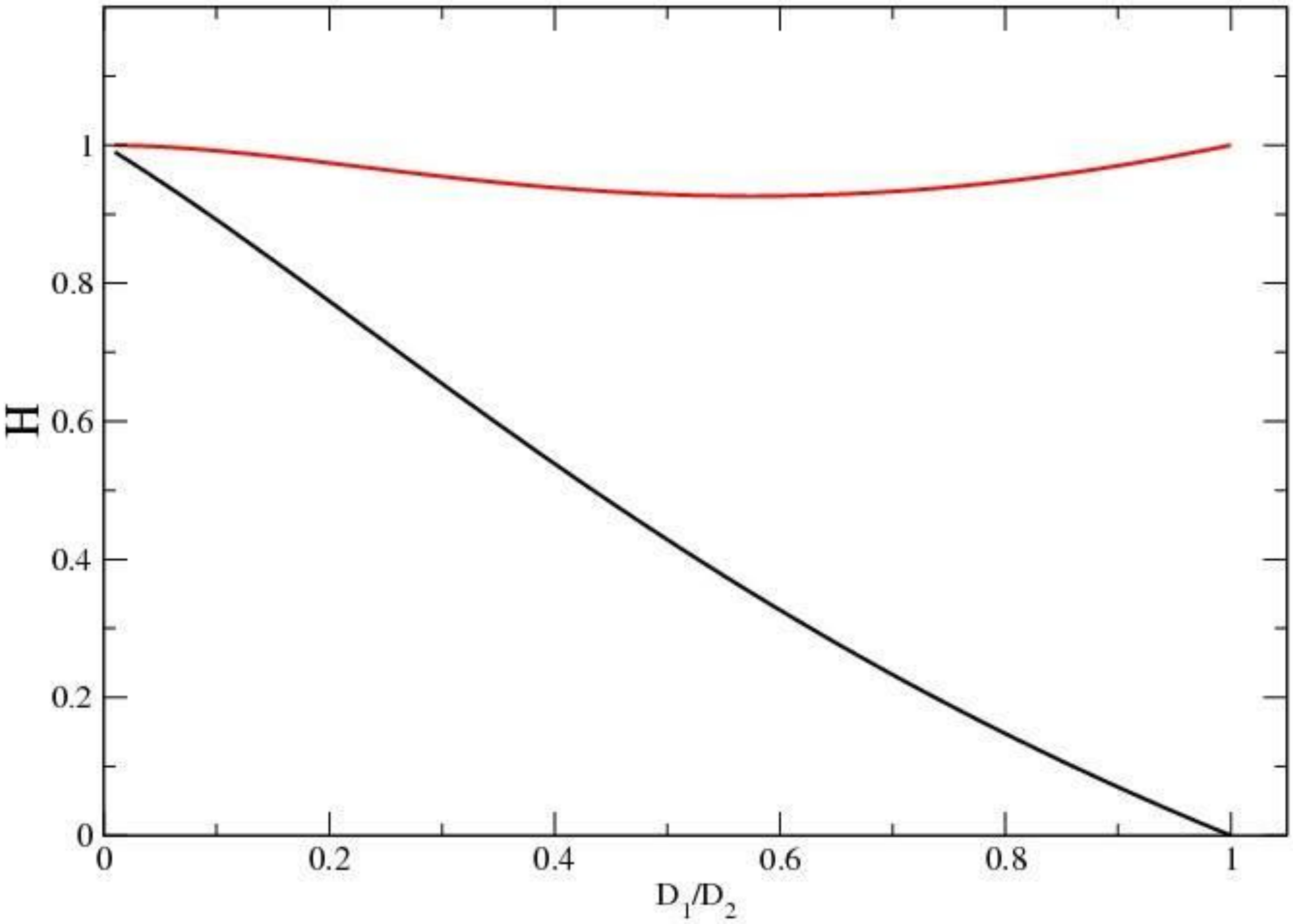


Fig. 31 - Diagrama isotérmico de uma Bomba de Difusão de 32". Os pontos numerados representam a localização dos termopares utilizados nas medições das temperaturas.


2.0
1.8
1.6
1.4
1.2
1.0
K'
0.0
0.2
0.4
0.6
0.8
1.0
r= D_1/D_2


H
0
0.2
0.4
0.6
0.8
1
0
0.2
0.4
0.6
0.8
1
D_1/D_2

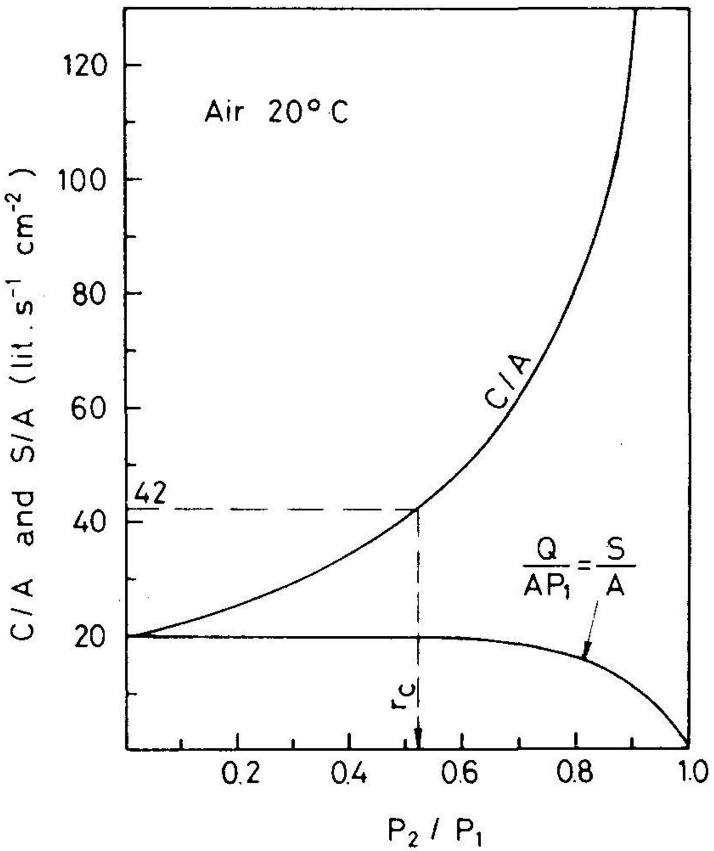


Fig. 3.6 Conductance *C* and pumping speed *S* of apertures (viscous flow). *A* is the cross section area of the aperture.

This equation is plotted for air in fig. 3.36, by using as a parameter the value

$$D^4/L = (128/\pi)\ \eta\ E$$

and considering $P_i = 10^6$ dyne/cm² (760 Torr), and $P = 10^2$ dyne/cm² (7.6×10^{-2} Torr), i.e. the pressure range in which usually the flow is viscous. If a volume of $V = 100$ liter is evacuated by a pump of $S_p = 2$ lit/sec through a pipe $D = 2$ cm and $L = 200$ cm, then $D^4/L = 8 \times 10^{-2}$. On the curve 8×10^{-2}, for $S_p = 2$, it results $t/V = 6$ sec/liter. Thus the time required for 100 liter is $t = 600$ sec. If the volume is connected directly to the pump, the line $D^4/L = \infty$ gives $t/V = 4.5$ sec/liter, thus $t = 450$ sec.

It is interesting to mention that if the pump is connected directly to the vessel, $L = 0$, thus $E = \infty$, eq. (3.252) becomes

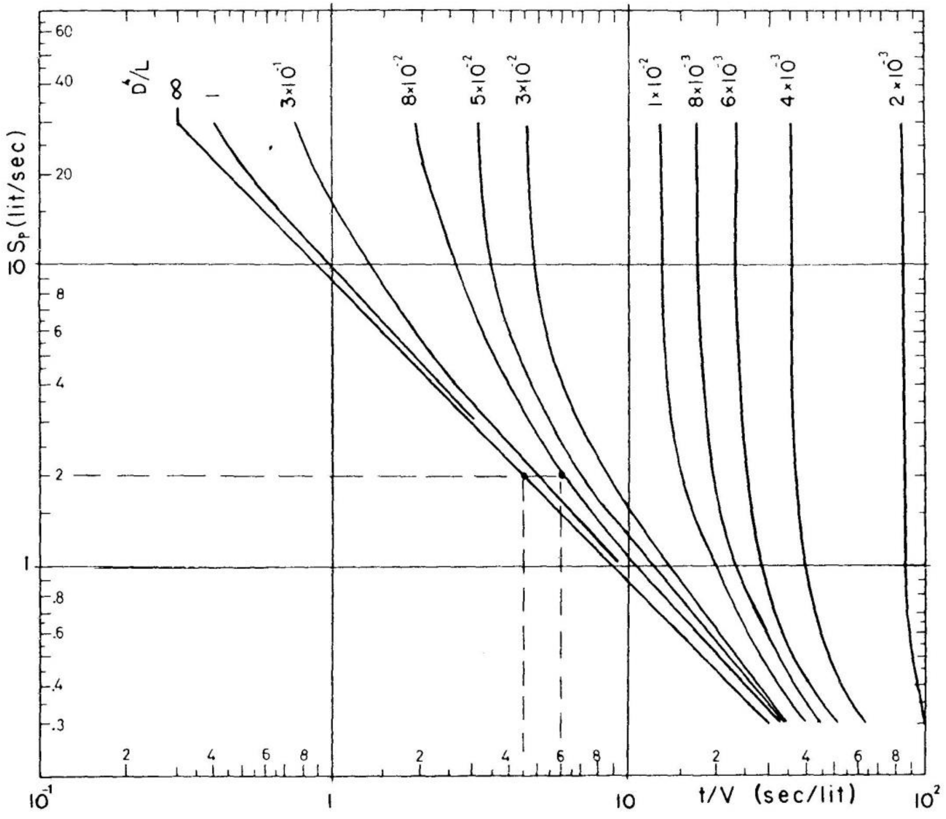


Fig. 3.36 Time required to decrease the pressure from 760 Torr to 7.6×10^{-2} Torr in a volume $V(l)$, connected by a pipe of diameter D(cm) and length L(cm) to a pump of pumping speed $S_p(l/s)$. After Delafosse and Mongodin (1961).

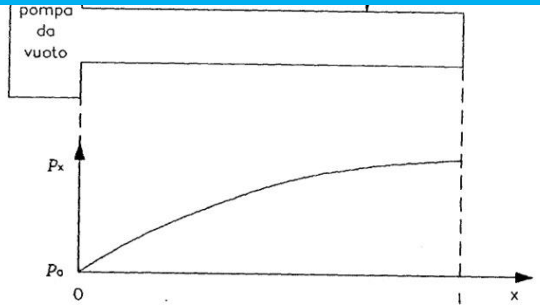


Figura 4.2 - Andamento della pressione in una camera da vuoto tubolare, chiusa ad una estremità e collegata con una pompa all'altra.

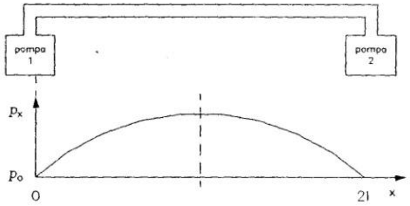


Figura 4.3 - Andamento della pressione in una camera da vuoto tubolare pompata ad entrambe le estremità.

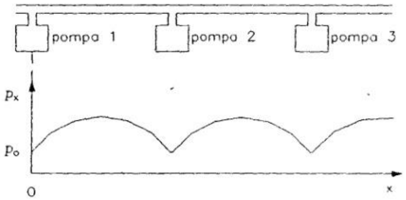


Figura 4.4 - Andamento della pressione in una camera da vuoto tubolare pompata con una serie di pompe disposte ad intervalli regolari di spazio e di uguali caratteristiche.

Bruno Ferrario

Introduzione alla tecnologia del VUOTO

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ANITA CALCATELLI

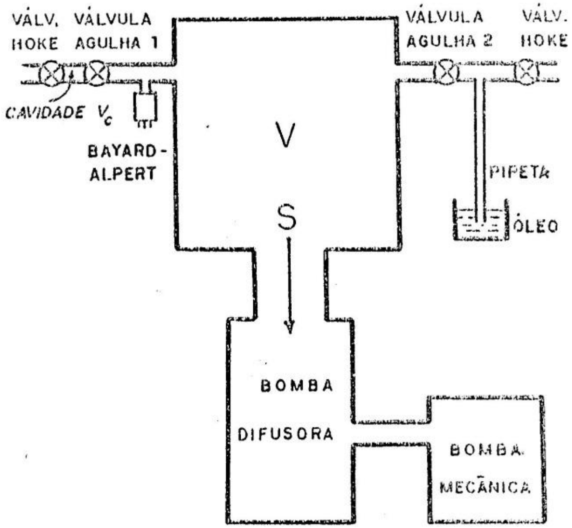


Fig. 4 - Esquema de montagem para simulação de vazamentos reais e virtuais.

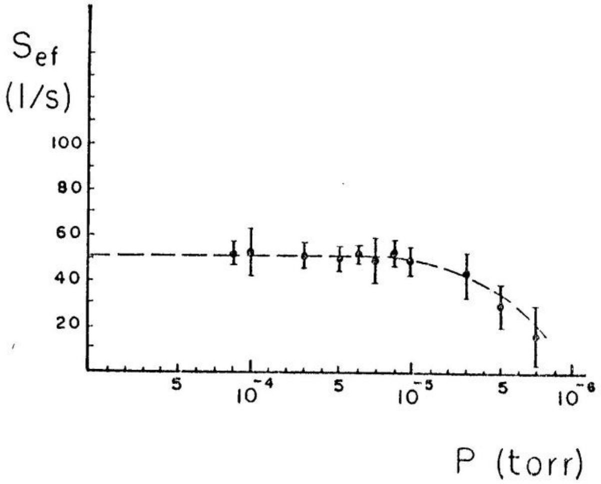


Fig. 6 - Velocidade Efetiva da Bomba Difusora.

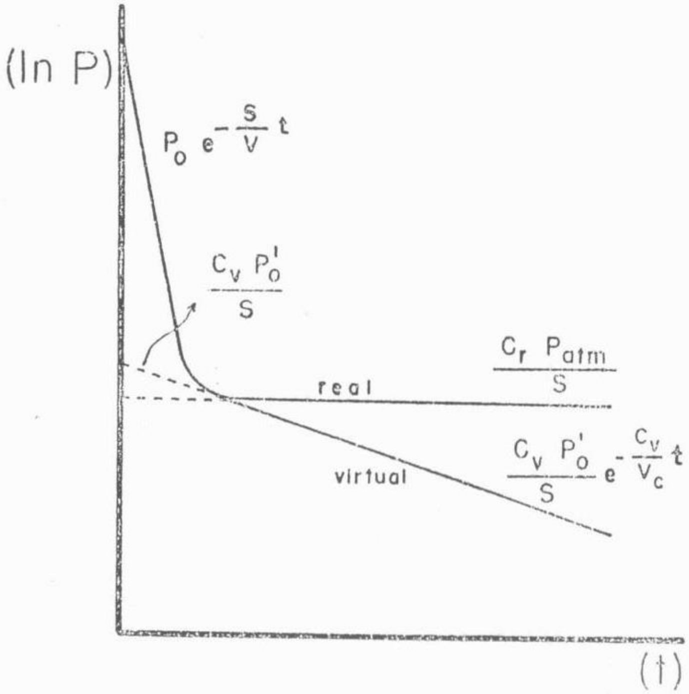


Fig. 2 - Vazamentos: real e virtual.

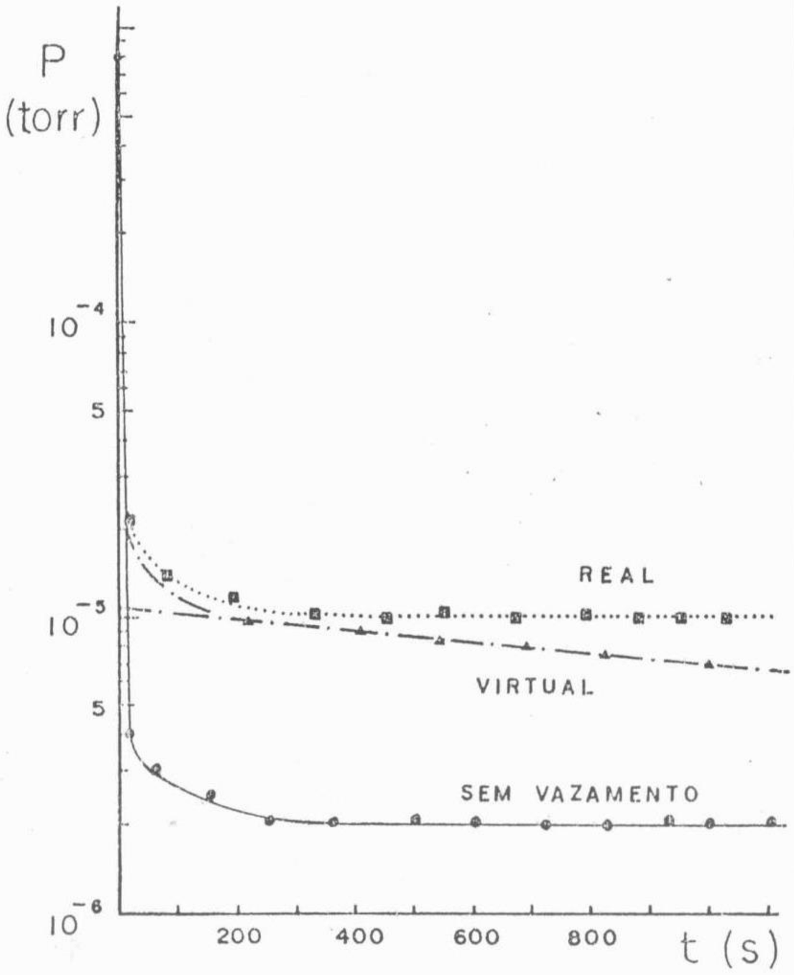


Fig. 5 - Medidas de Simulação de Vazamentos.

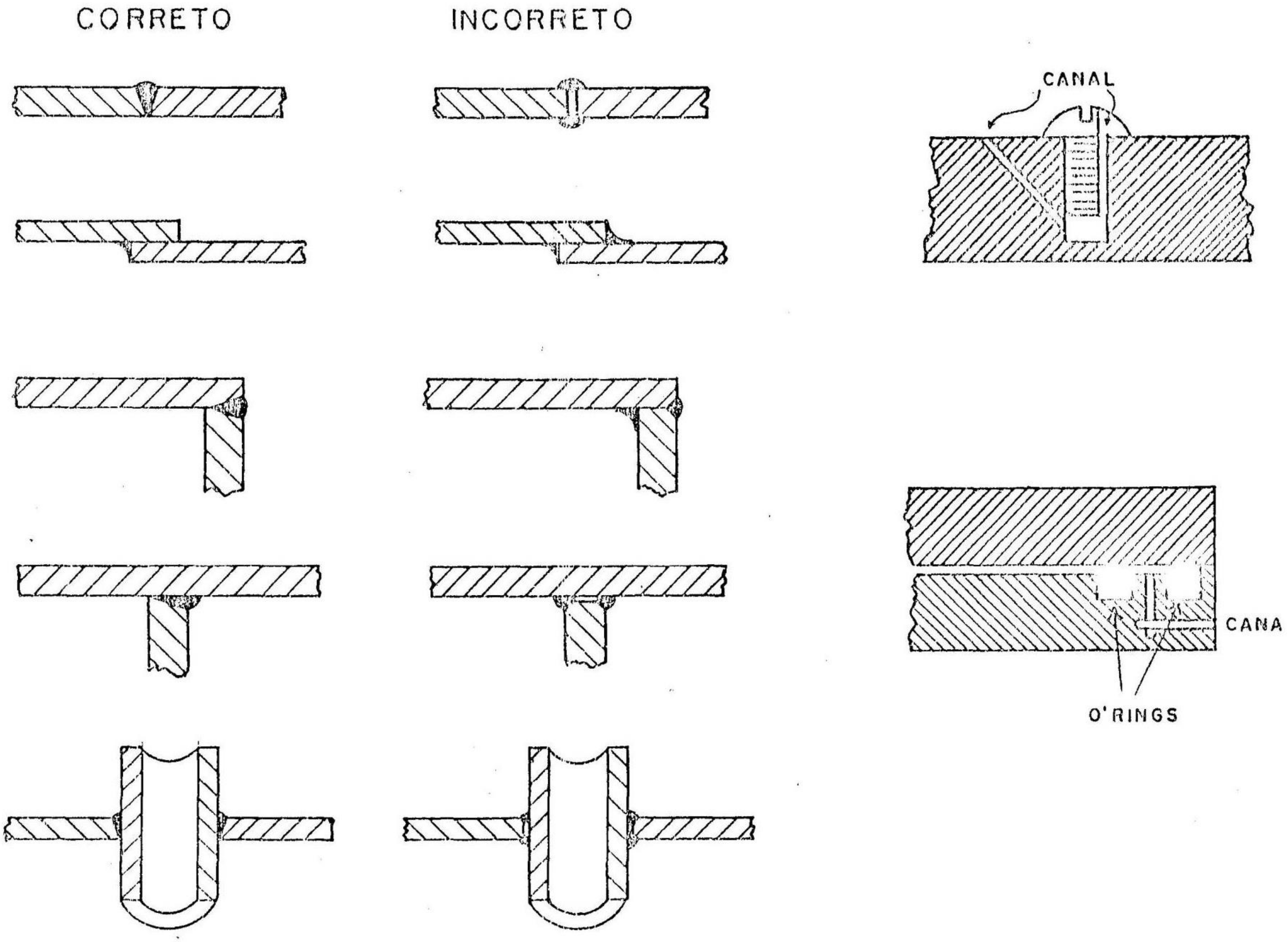
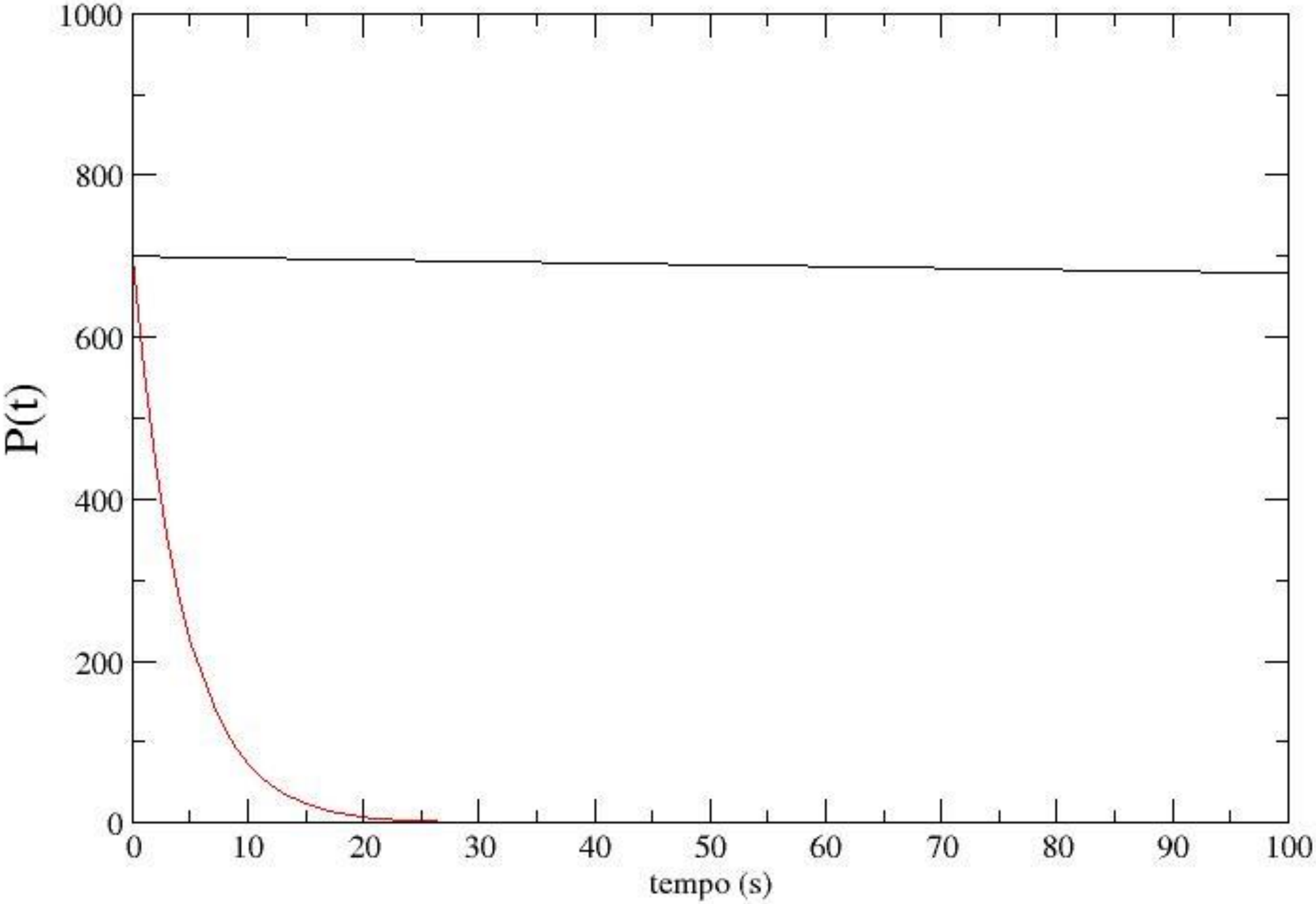
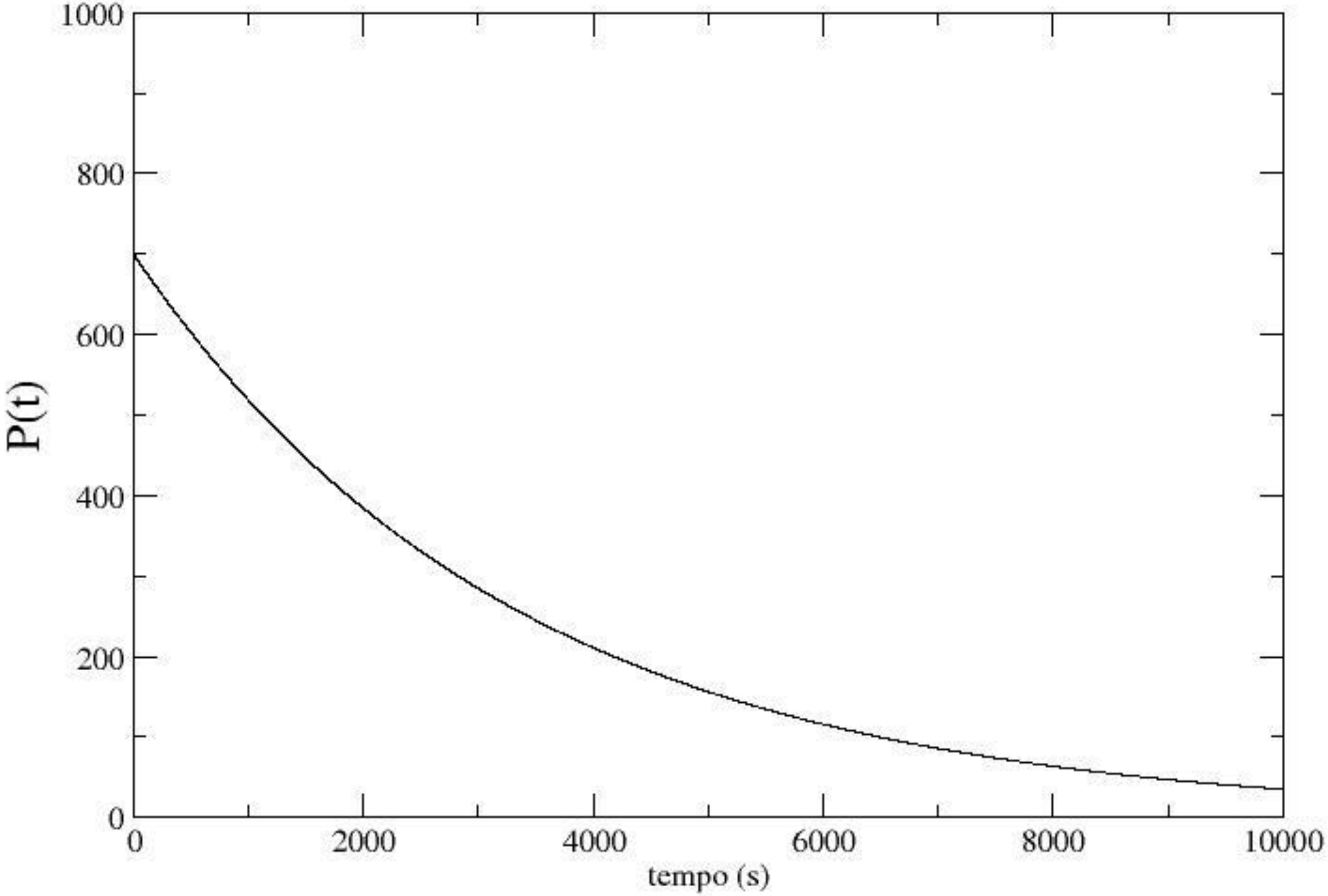


Fig. 8 - Exemplos de Vazamentos Virtuais e suas correções.

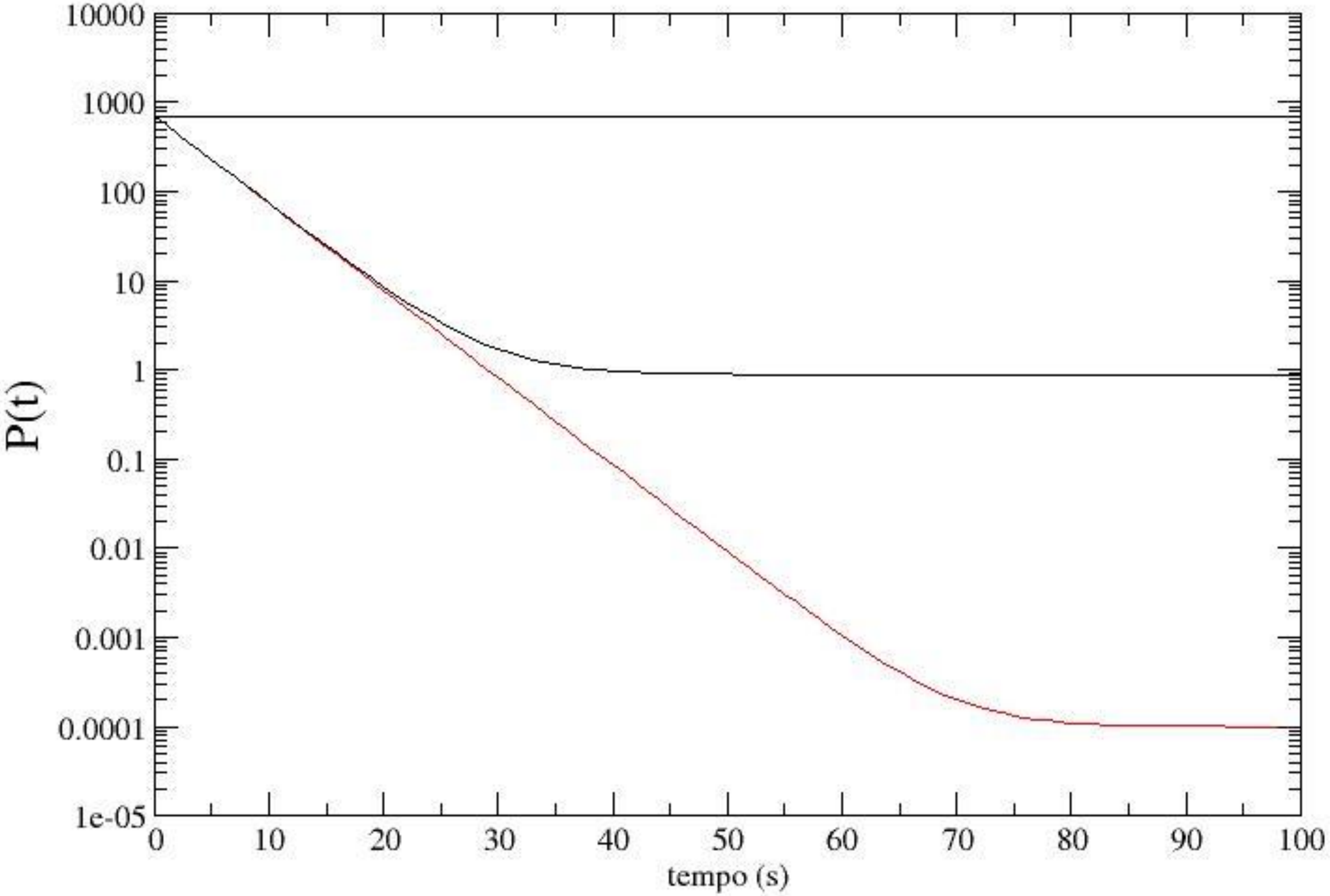
P1



P2

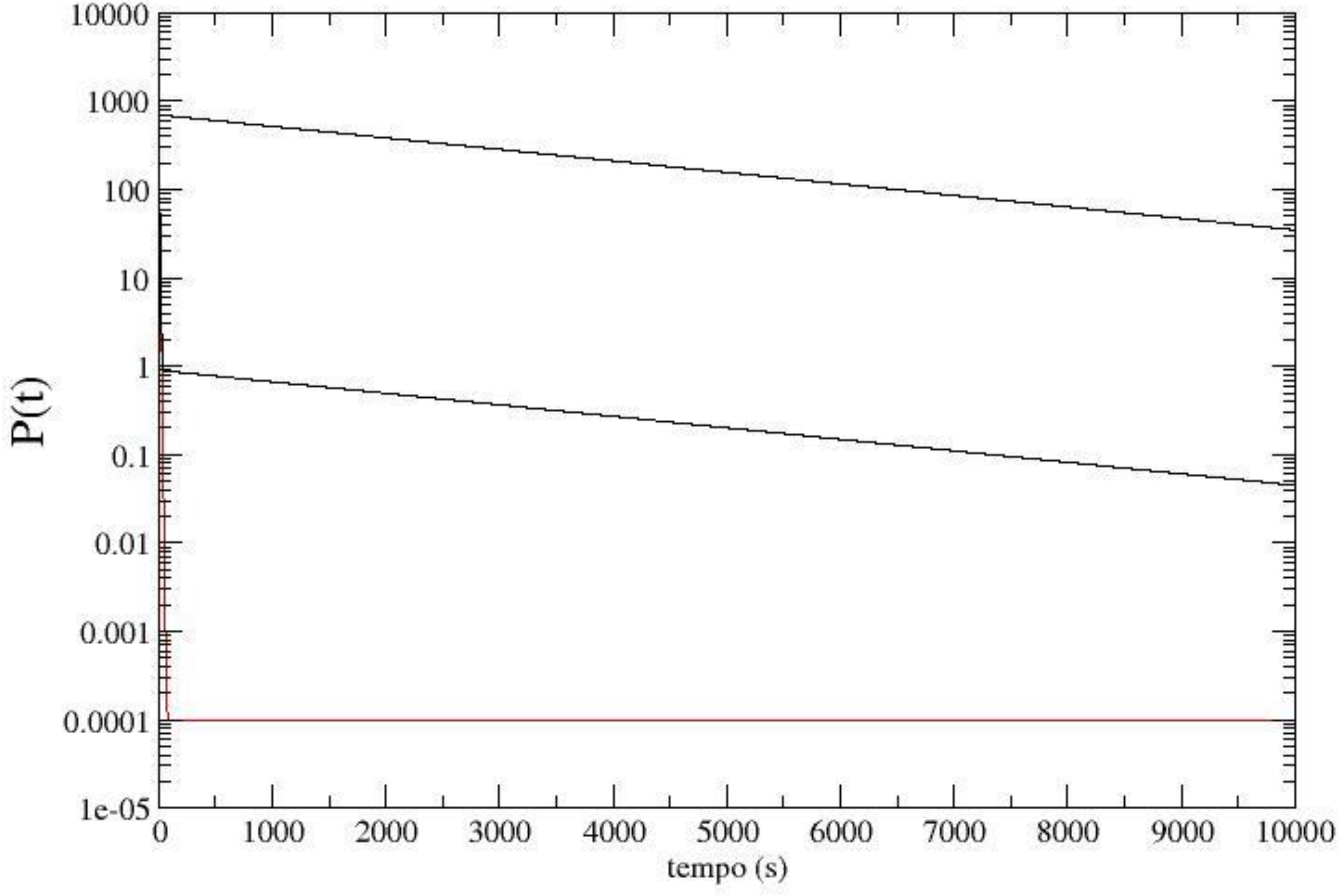


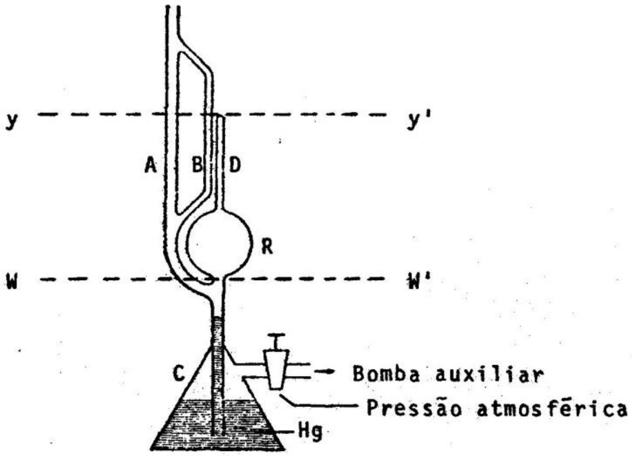
P1P2

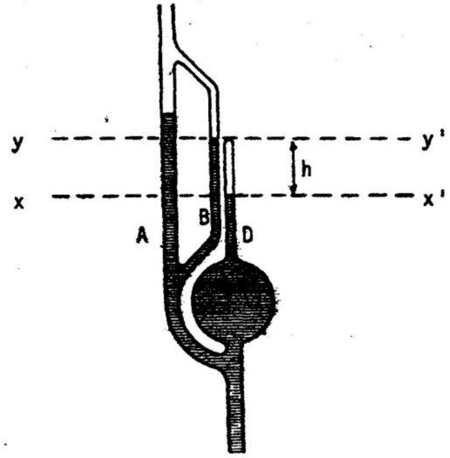


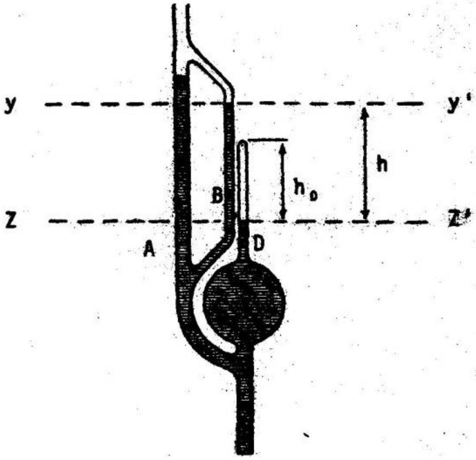
P(t)
10000
1000
100
10
1
0.1
0.01
0.001
0.0001
1e-05
0
10
20
30
40
50
60
70
80
90
100
tempo (s)

P1P2

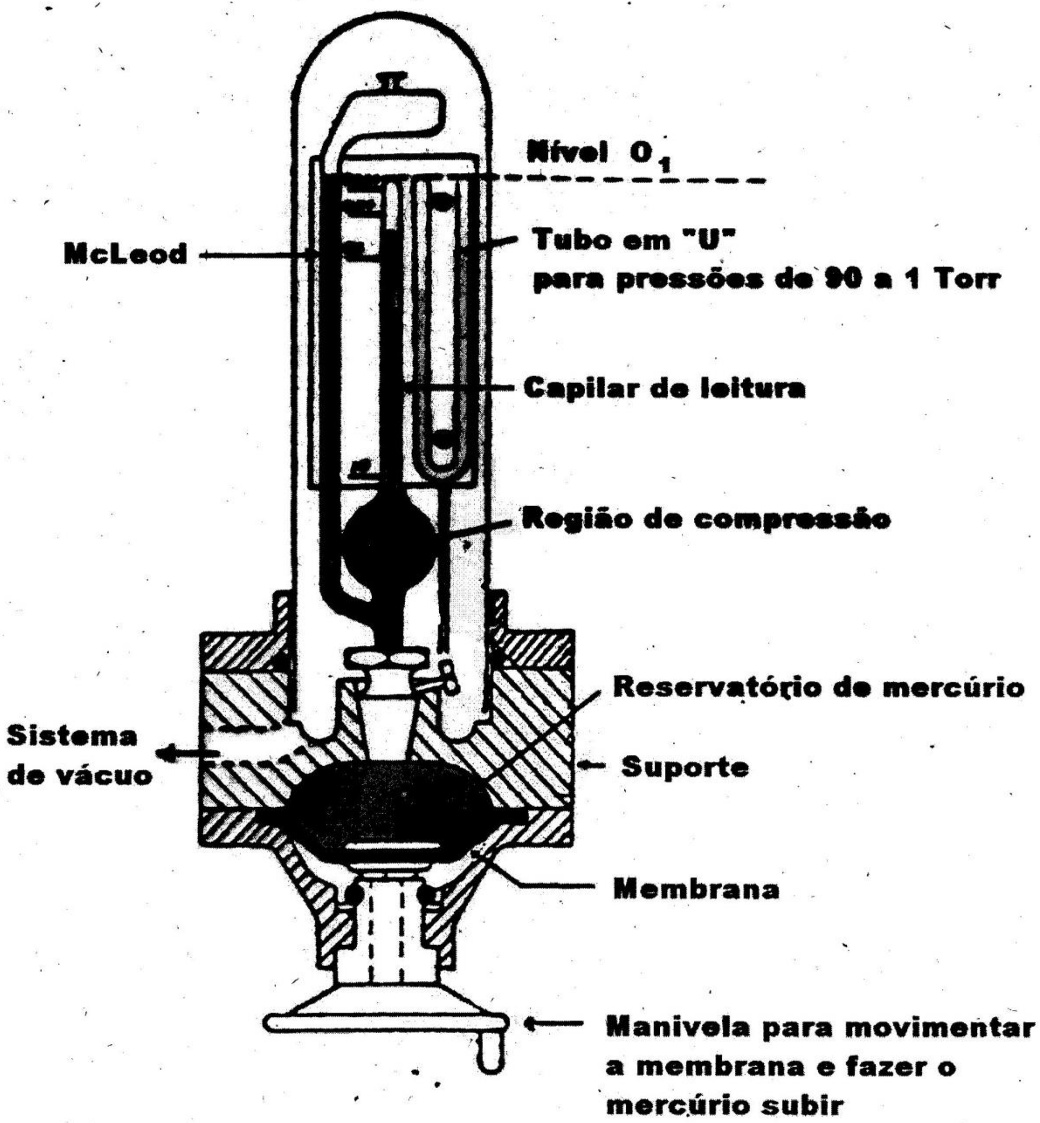

10000
1000
100
10
1
0.1
0.01
0.001
0.0001
1e-05
P(t)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
tempo (s)


y
y'
A
B
D
R
W
W'
C
Bomba auxiliar
Pressão atmosférica
Hg


y
y'
h
x
x'
A
B
D


y
y'
h
h_o
B
Z
Z'
A
D

Kammerer (McLeod)



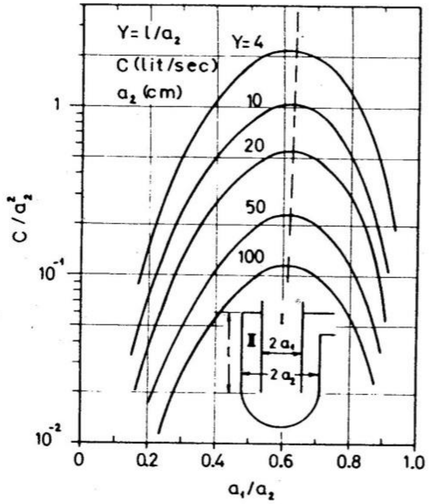
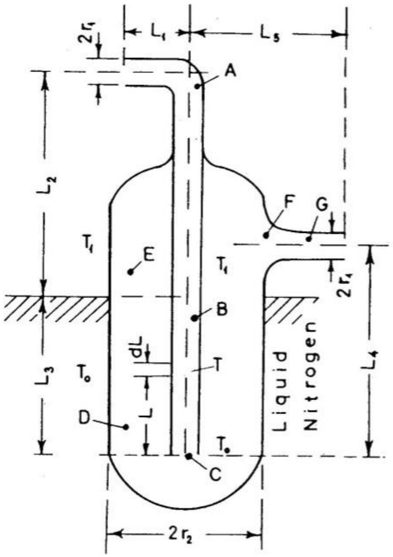


Fig. 3.12 Conductance of traps, for air, 25°C. From Dushman and Lafferty (1962), by permission of J. Wiley & Sons Inc., New York.



ig. 3.13 Parts of a liquid nitrogen trap, for calculating its conductance. After Henry (1971).

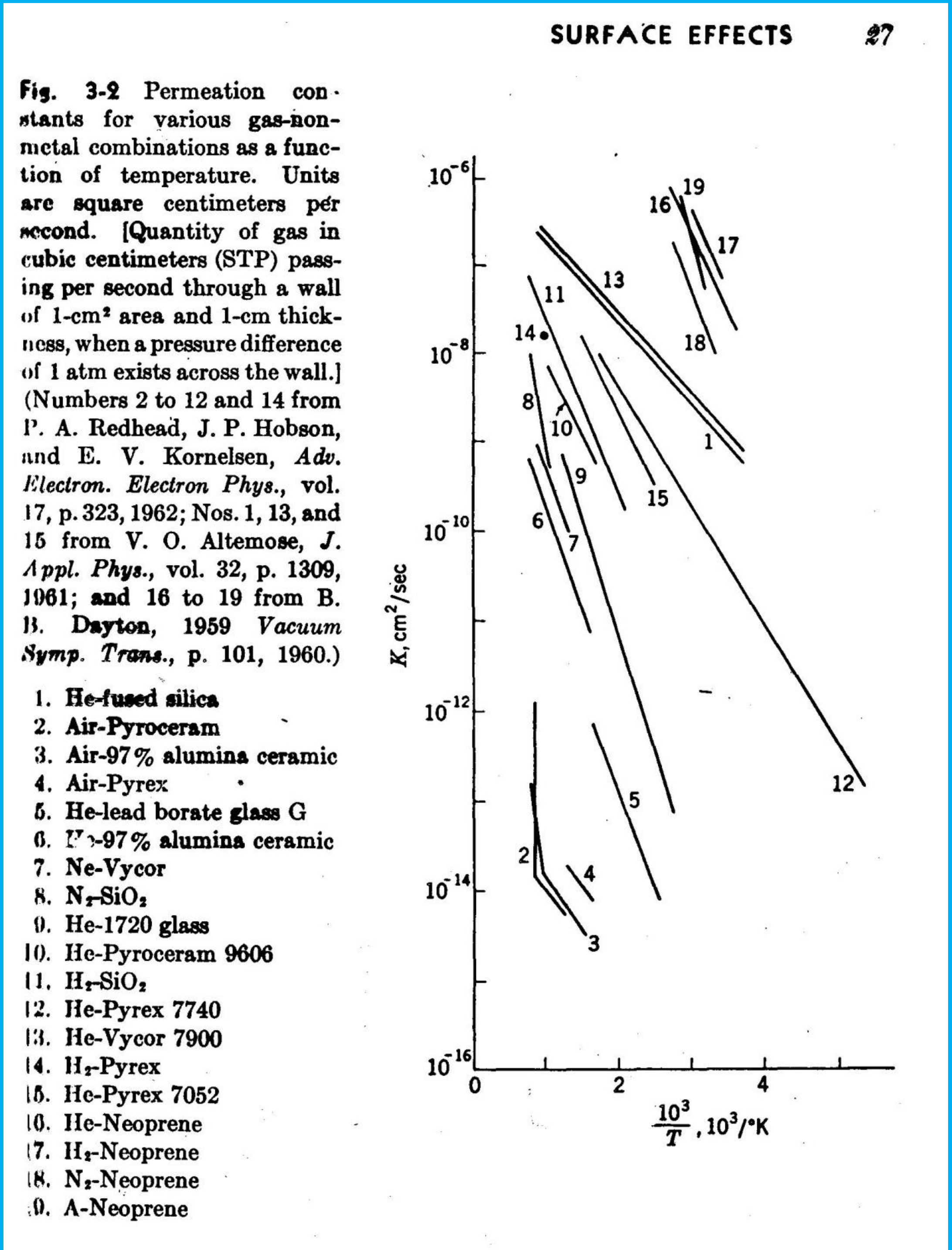


Fig. 3-2 Permeation constants for various gas-nonmetal combinations as a function of temperature. Units are square centimeters per second. [Quantity of gas in cubic centimeters (STP) passing per second through a wall of 1-cm^2 area and 1-cm thickness, when a pressure difference of 1 atm exists across the wall.] (Numbers 2 to 12 and 14 from P. A. Redhead, J. P. Hobson, and E. V. Kornelsen, *Adv. Electron. Electron Phys.*, vol. 17, p. 323, 1962; Nos. 1, 13, and 15 from V. O. Altemose, *J. Appl. Phys.*, vol. 32, p. 1309, 1961; and 16 to 19 from B. B. Dayton, 1959 *Vacuum Symp. Trans.*, p. 101, 1960.)

1. **He-fused silica**
2. **Air-Pyroceram**
3. Air-97% alumina ceramic
4. Air-Pyrex
5. He-lead borate glass G
6. He-97% alumina ceramic
7. Ne-Vycor
8. N_2-SiO_2
9. He-1720 glass
10. He-Pyroceram 9606
11. H_2-SiO_2
12. He-Pyrex 7740
13. He-Vycor 7900
14. H_2-Pyrex
15. He-Pyrex 7052
16. He-Neoprene
17. H_2-Neoprene
18. N_2-Neoprene
19. A-Neoprene

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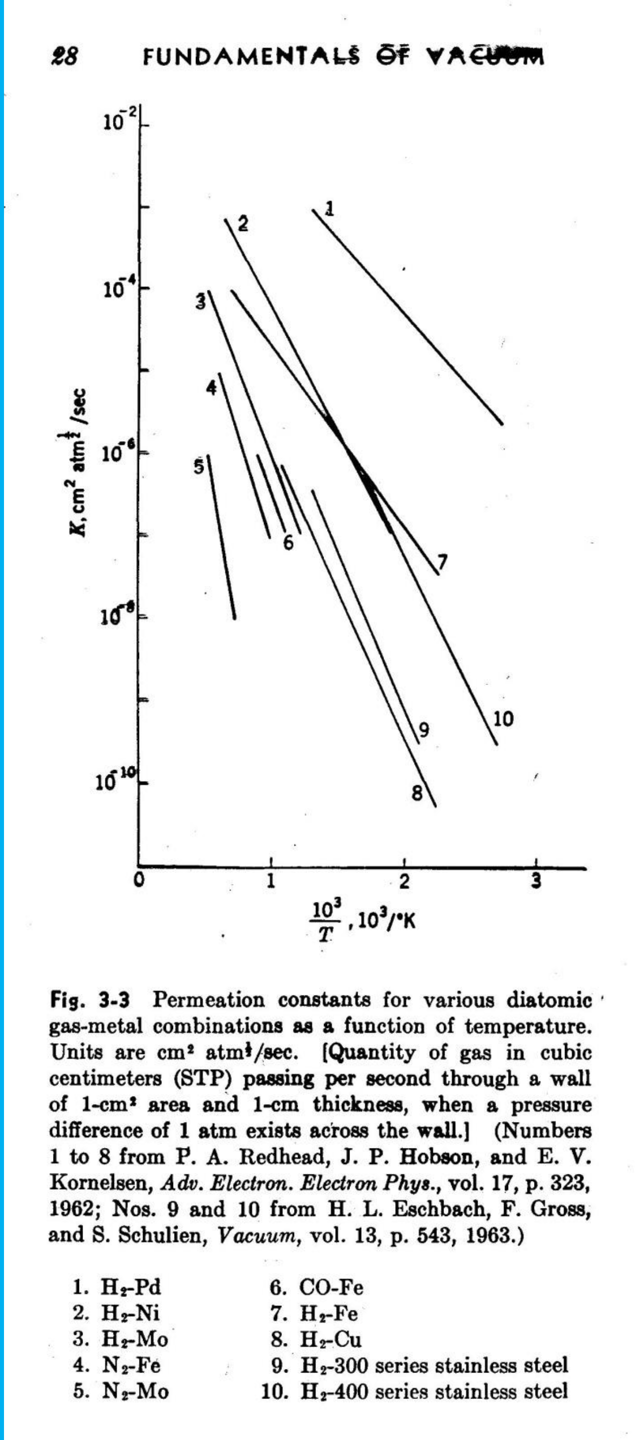

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Fig. 3-3 Permeation constants for various diatomic gas-metal combinations as a function of temperature. Units are $cm^2\ atm^{1/2}$/sec. [Quantity of gas in cubic centimeters (STP) passing per second through a wall of 1-cm^2 area and 1-cm thickness, when a pressure difference of 1 atm exists across the wall.] (Numbers 1 to 8 from P. A. Redhead, J. P. Hobson, and E. V. Kornelsen, *Adv. Electron. Electron Phys.*, vol. 17, p. 323, 1962; Nos. 9 and 10 from H. L. Eschbach, F. Gross, and S. Schulien, *Vacuum*, vol. 13, p. 543, 1963.)

1. H_2-Pd
2. H_2-Ni
3. H_2-Mo
4. N_2-Fe
5. N_2-Mo
6. CO-Fe
7. H_2-Fe
8. H_2-Cu
9. H_2-300 series stainless steel
10. H_2-400 series stainless steel

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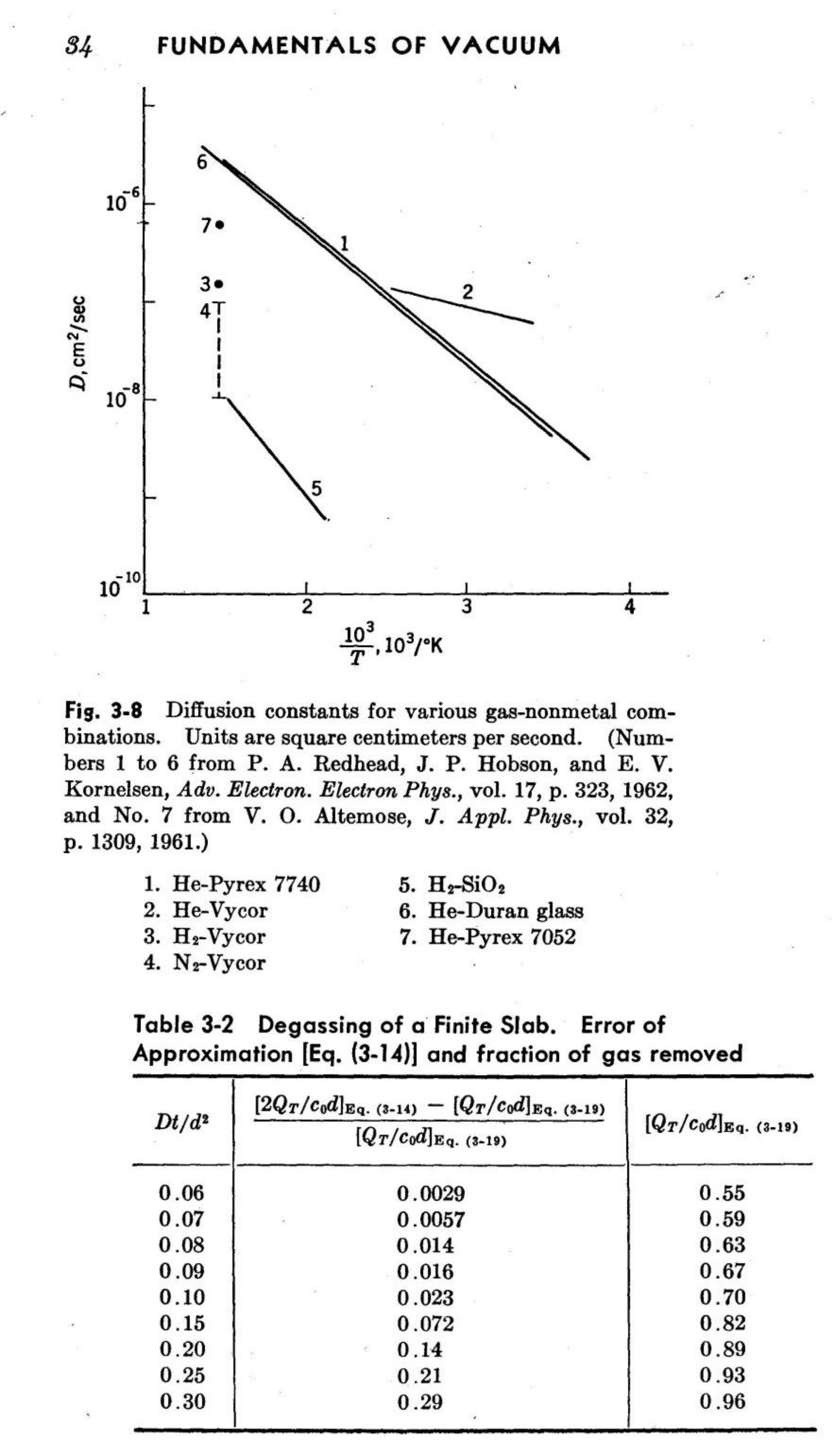

Fig. 3-8 Diffusion constants for various gas-nonmetal combinations. Units are square centimeters per second. (Numbers 1 to 6 from P. A. Redhead, J. P. Hobson, and E. V. Kornelsen, *Adv. Electron. Electron Phys.*, vol. 17, p. 323, 1962, and No. 7 from V. O. Altemose, *J. Appl. Phys.*, vol. 32, p. 1309, 1961.)

1. He-Pyrex 7740
2. He-Vycor
3. H_2-Vycor
4. N_2-Vycor
5. H_2-SiO_2
6. He-Duran glass
7. He-Pyrex 7052

Table 3-2 Degassing of a Finite Slab. Error of Approximation [Eq. (3-14)] and fraction of gas removed

Dt/d^2	$\frac{[2Q_T/c_0d]_{\text{Eq. (3-14)}} - [Q_T/c_0d]_{\text{Eq. (3-19)}}}{[Q_T/c_0d]_{\text{Eq. (3-19)}}}$	$[Q_T/c_0d]_{\text{Eq. (3-19)}}$
0.06	0.0029	0.55
0.07	0.0057	0.59
0.08	0.014	0.63
0.09	0.016	0.67
0.10	0.023	0.70
0.15	0.072	0.82
0.20	0.14	0.89
0.25	0.21	0.93
0.30	0.29	0.96

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70 FUNDAMENTALS OF VACUUM

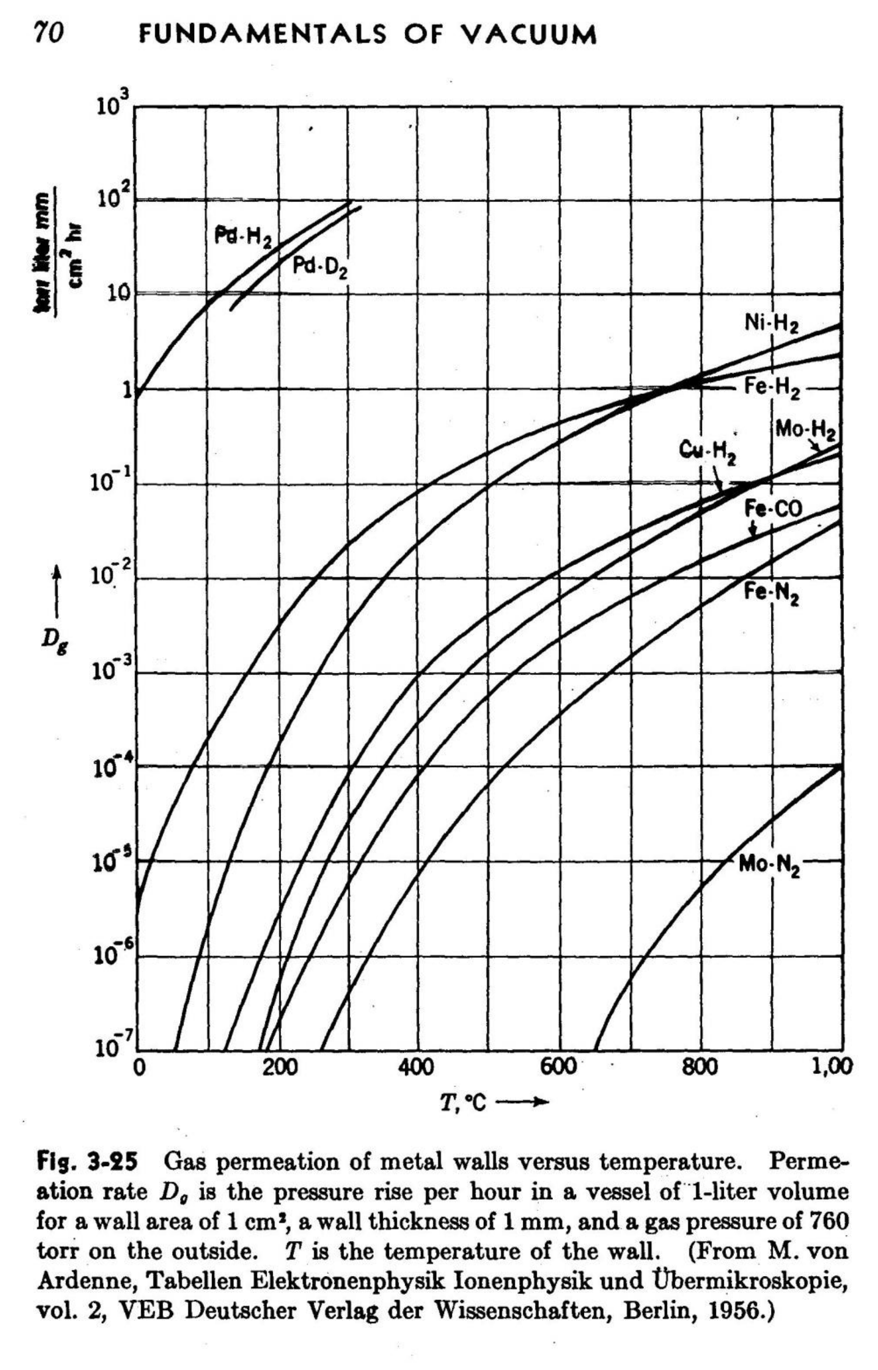

Fig. 3-25 Gas permeation of metal walls versus temperature. Permeation rate D_g is the pressure rise per hour in a vessel of 1-liter volume for a wall area of 1 cm^2, a wall thickness of 1 mm, and a gas pressure of 760 torr on the outside. *T* is the temperature of the wall. (From M. von Ardenne, Tabellen Elektronenphysik Ionenphysik und Übermikroskopie, vol. 2, VEB Deutscher Verlag der Wissenschaften, Berlin, 1956.)

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SURFACE EFFECTS 33

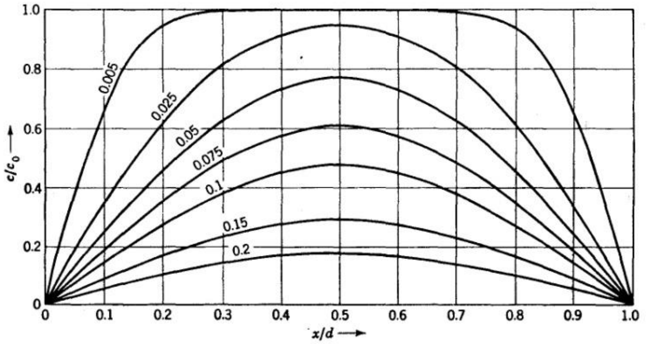

Fig. 3-7 Relative concentration in a finite slab of thickness d for various (dimensionless) times Dt/d^2 as parameter.

SURFACE EFFECTS 35

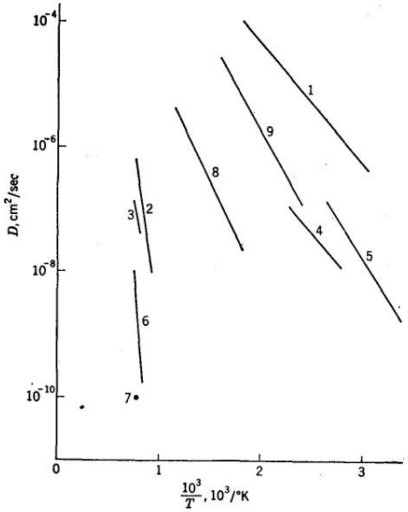

Fig. 3-9 Diffusion constants for various gas-metal combinations. Units are square centimeters per second. (Numbers 1 to 7 from P. A. Redhead, J. P. Hobson, and E. V. Kornelsen, *Adv. Electron. Electron Phys.*, vol. 17, p. 323, 1962; Nos. 8 and 9 from H. L. Eschbach, F. Gross, and S. Schulien, *Vacuum*, vol. 13, p. 543, 1963.)

1. H_2-Pd
2. N_2-Fe
3. CO-Ni
4. H_2-Ni
5. H_2-Fe
6. O_2-Ni
7. O_2-Fe
8. H_2-300 series stainless steel
9. H_2-400 series stainless steel

34 FUNDAMENTALS OF VACUUM

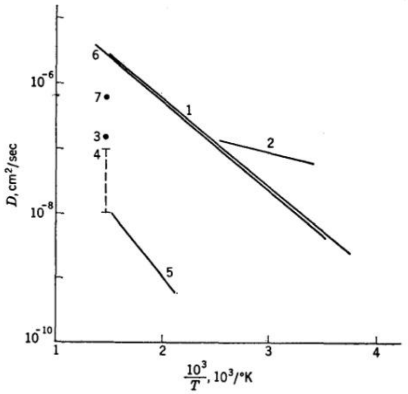

Fig. 3-8 Diffusion constants for various gas-nonmetal combinations. Units are square centimeters per second. (Numbers 1 to 6 from P. A. Redhead, J. P. Hobson, and E. V. Kornelsen, *Adv. Electron. Electron Phys.*, vol. 17, p. 323, 1962, and No. 7 from V. O. Altemose, *J. Appl. Phys.*, vol. 32, p. 1309, 1961.)

1. He-Pyrex 7740
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3. H_2-Vycor
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6. He-Duran glass
7. He-Pyrex 7052

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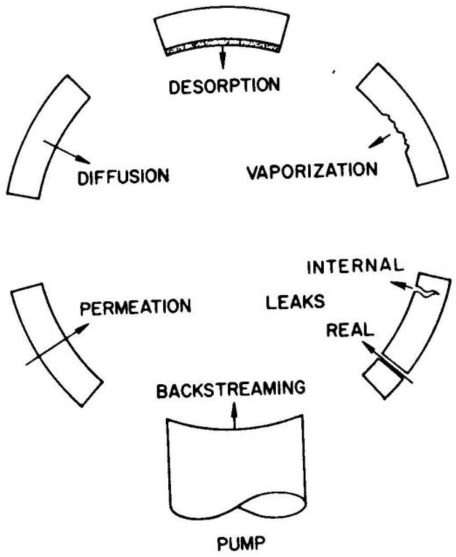

Fig. 4.1 Potential sources of gases and vapors in a vacuum system.

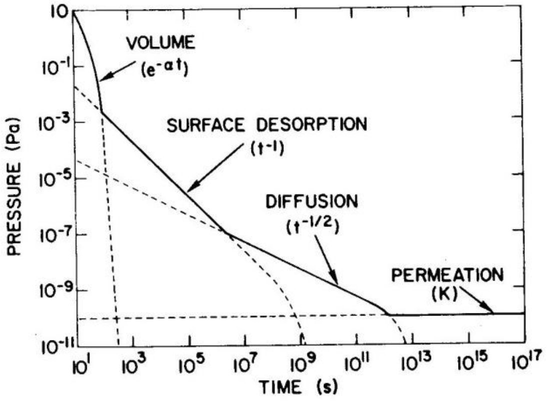

Fig. 4.6 Rate limiting steps during the pumping of a vacuum chamber.

Modelos de Fontes de Gases em um Sistema de Vácuo

Fonte de gás	Característica	Comentário
Volume	$P=P_o e^{\frac{-S}{v}t}$	Pressão cai exponencialmente dependendo de S e V
Vazamento Real	$P_{res}=\frac{Q_{Vr}}{S};Q_{Vr}\approx C_{Vr}P_{atm}$	Fluxo constante. Utilizar detector de vazamentos. Deve ser eliminado
Vazamento Virtual	$Q_{vv}=\frac{C_v}{S}P_o' e^{\frac{-C_v}{V_c}t}$	Cv << Sb Queda da pressão depende de Cv e Vc. Evitar no projeto
Difusão	$Q(t)=c_o\frac{\sqrt{D}}{\sqrt{\pi t}}$	Q(t) é proporcional a $\frac{1}{\sqrt{t}}$
Permeação	$Q=\frac{K(P_e^n-P_i^n)}{d}$	N=1 para não metais; n=1/2 para moléculas diatômicas em metais. Constante de permeação K(T) é proporcional a $10^3/T$
Evaporação	$W=0.058P_v\sqrt{\frac{M}{T}}\frac{g}{cm^2 s}$ Q=WA (g/s) $Q=\frac{\Delta N}{\Delta t}kT\frac{Torrl}{s}$	Crescimento de P_v em função da temperatura é exponencial e por isso mais rápido do que $\frac{1}{\sqrt{T}}$
Desorpção Térmica (desgaseificação)	Primeira ordem: $\frac{dc}{dt}=c_o k_1 e^{-\frac{t}{\tau_{res}}}$ $\frac{1}{k_1}=\tau_{res}=\tau_o e^{\frac{E_d}{N_o kT}}$	Rápido $\tau_{res}=10^{-12}s$
Temperatura (cozimento)	Segunda ordem: $\frac{dc}{dt}=\frac{-k_2C_o^2}{(1+C_oK_2t)^2}$	Cai lentamente A molécula de H_{2s} se dissocia na adsorção e recombina na desorpção
Superfícies Reais	$q_n=\frac{q}{t^\alpha}$ $0.7\leq\alpha\leq2$	Fórmula geral $q_n=qt^{-1}$ Adsorção química Adsorção física

4.6 PRESSURE LIMITS 75

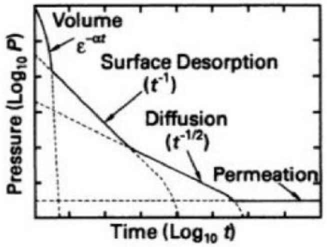

Fig. 4.10 Rate limiting steps during the pumping of a vacuum chamber.

Referência: A user's' guide to vacuum technology – J.F. O'Hanlon

Desorpção Térmica

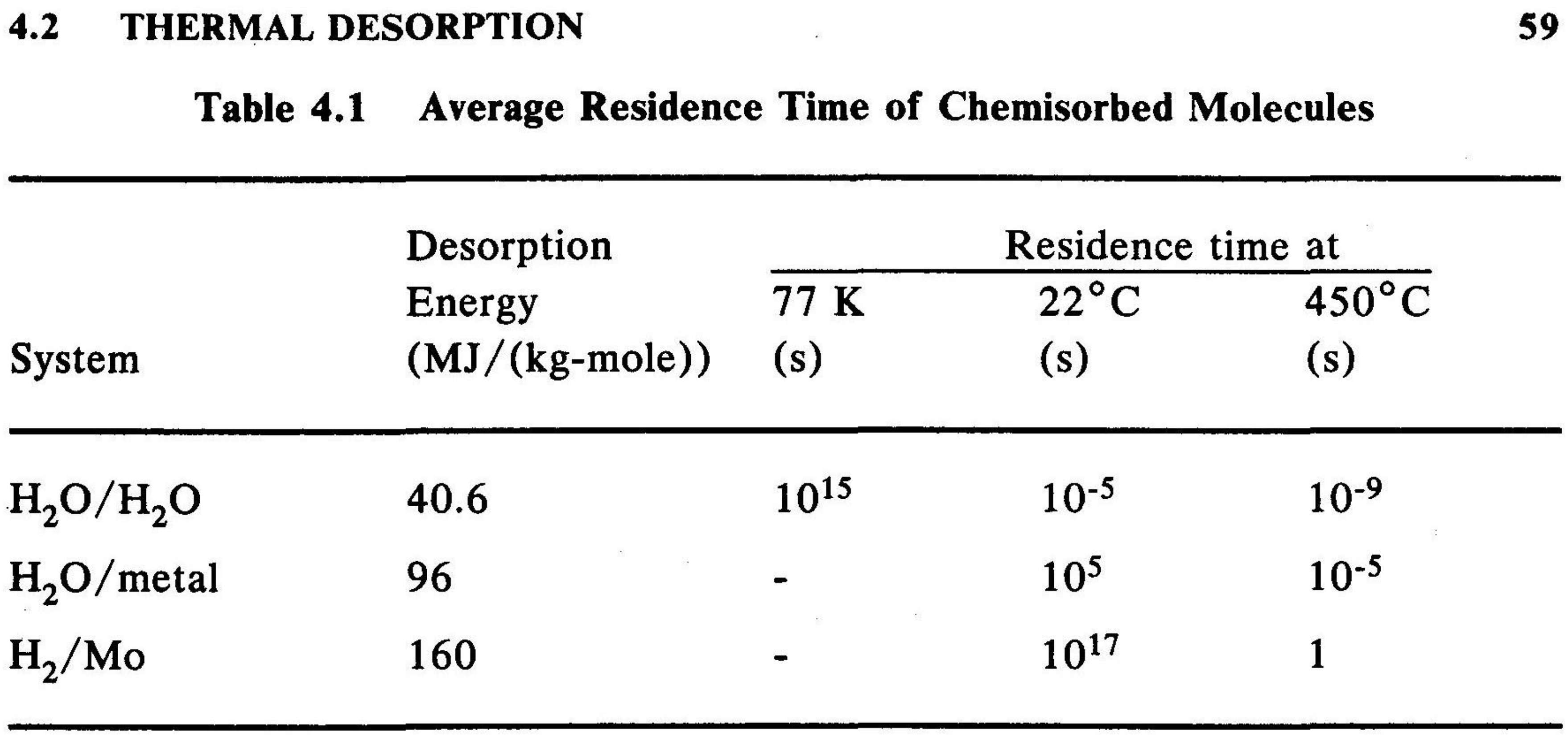

Table 4.1 Average Residence Time of Chemisorbed Molecules

System	Desorption Energy (MJ/(kg-mole))	Residence time at 77 K (s)	Residence time at 22°C (s)	Residence time at 450°C (s)
H_2O/H_2O	40.6	10^{15}	10^{-5}	10^{-9}
H_2O/metal	96	-	10^{5}	10^{-5}
H_2/Mo	160	-	10^{17}	1

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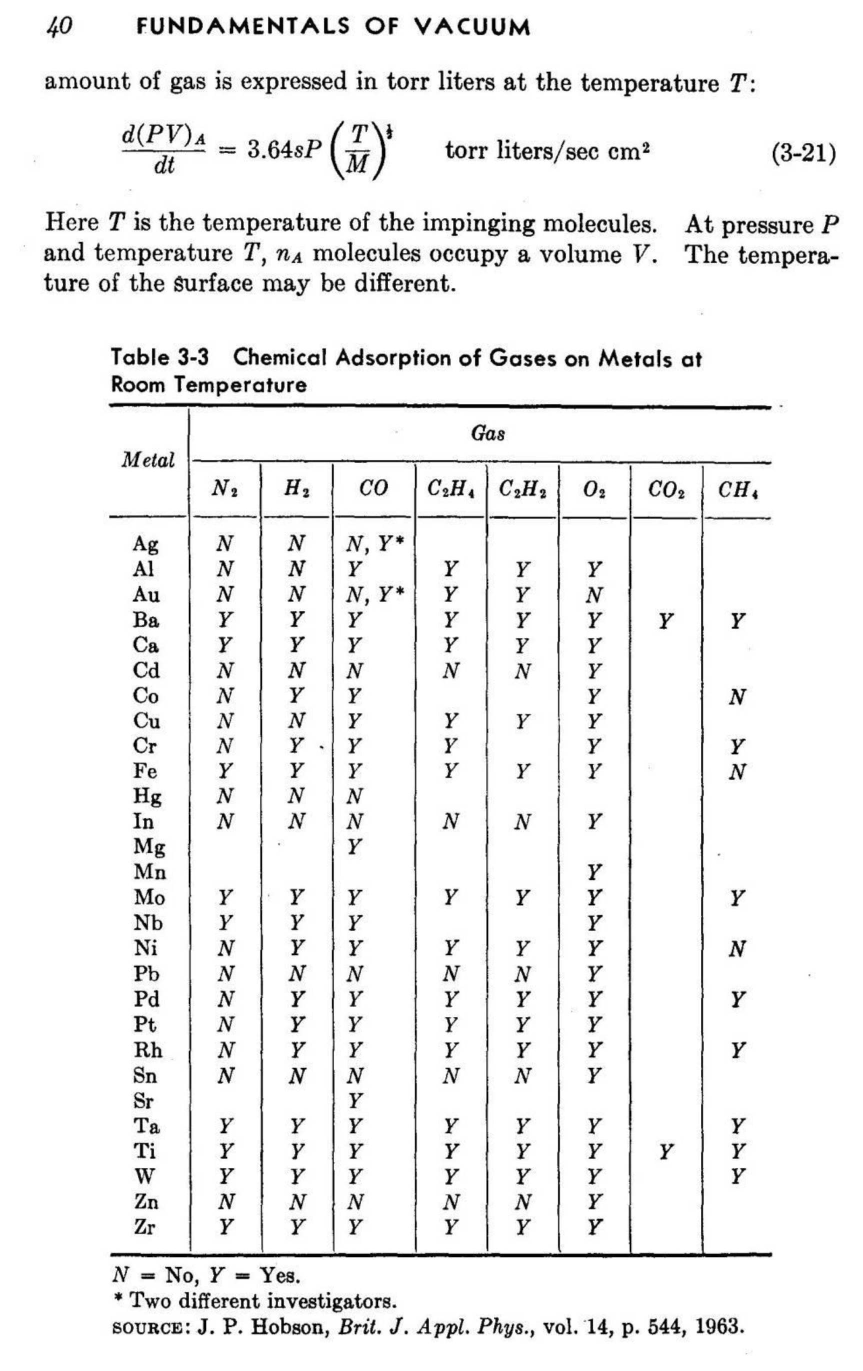


amount of gas is expressed in torr liters at the temperature T:

$$\frac{d(PV)_A}{dt} = 3.64sP\left(\frac{T}{M}\right)^{\frac{1}{2}} \qquad \text{torr liters/sec cm}^2 \qquad (3\text{-}21)$$

Here T is the temperature of the impinging molecules. At pressure P and temperature T, n_A molecules occupy a volume V. The temperature of the surface may be different.

Table 3-3 Chemical Adsorption of Gases on Metals at Room Temperature

Metal	*Gas*							
	N_2	H_2	CO	C_2H_4	C_2H_2	O_2	CO_2	CH_4
Ag	N	N	N, Y*					
Al	N	N	Y	Y	Y	Y		
Au	N	N	N, Y*	Y	Y	N		
Ba	Y	Y	Y	Y	Y	Y	Y	Y
Ca	Y	Y	Y	Y	Y	Y		
Cd	N	N	N	N	N	Y		
Co	N	Y	Y			Y		N
Cu	N	N	Y	Y	Y	Y		
Cr	N	Y	Y	Y		Y		Y
Fe	Y	Y	Y	Y	Y	Y		N
Hg	N	N	N					
In	N	N	N	N	N	Y		
Mg			Y					
Mn						Y		
Mo	Y	Y	Y	Y	Y	Y		Y
Nb	Y	Y	Y			Y		
Ni	N	Y	Y	Y	Y	Y		N
Pb	N	N	N	N	N	Y		
Pd	N	Y	Y	Y	Y	Y		Y
Pt	N	Y	Y	Y	Y	Y		
Rh	N	Y	Y	Y	Y	Y		Y
Sn	N	N	N	N	N	Y		
Sr			Y					
Ta	Y	Y	Y	Y	Y	Y		Y
Ti	Y	Y	Y	Y	Y	Y	Y	Y
W	Y	Y	Y	Y	Y	Y		Y
Zn	N	N	N	N	N	Y		
Zr	Y	Y	Y	Y	Y	Y		

N = No, Y = Yes.

* Two different investigators.

SOURCE: J. P. Hobson, *Brit. J. Appl. Phys.*, vol. 14, p. 544, 1963.

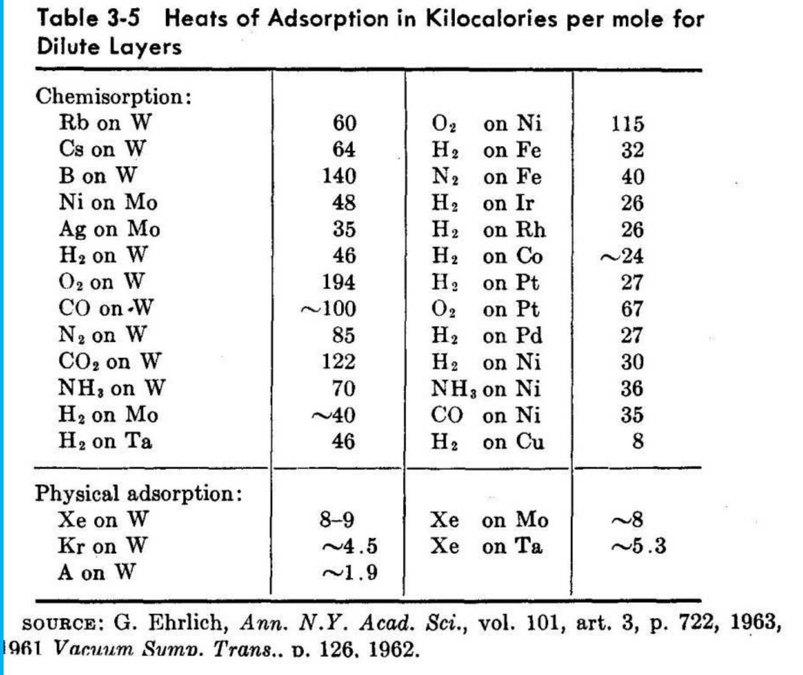


Table 3-5 Heats of Adsorption in Kilocalories per mole for Dilute Layers

Chemisorption:			
Rb on W	60	O_2 on Ni	115
Cs on W	64	H_2 on Fe	32
B on W	140	N_2 on Fe	40
Ni on Mo	48	H_2 on Ir	26
Ag on Mo	35	H_2 on Rh	26
H_2 on W	46	H_2 on Co	~24
O_2 on W	194	H_2 on Pt	27
CO on W	~100	O_2 on Pt	67
N_2 on W	85	H_2 on Pd	27
CO_2 on W	122	H_2 on Ni	30
NH_3 on W	70	NH_3 on Ni	36
H_2 on Mo	~40	CO on Ni	35
H_2 on Ta	46	H_2 on Cu	8
Physical adsorption:			
Xe on W	8–9	Xe on Mo	~8
Kr on W	~4.5	Xe on Ta	~5.3
A on W	~1.9		

SOURCE: G. Ehrlich, *Ann. N.Y. Acad. Sci.*, vol. 101, art. 3, p. 722, 1963, 1961 *Vacuum Symp. Trans.*, p. 126, 1962.

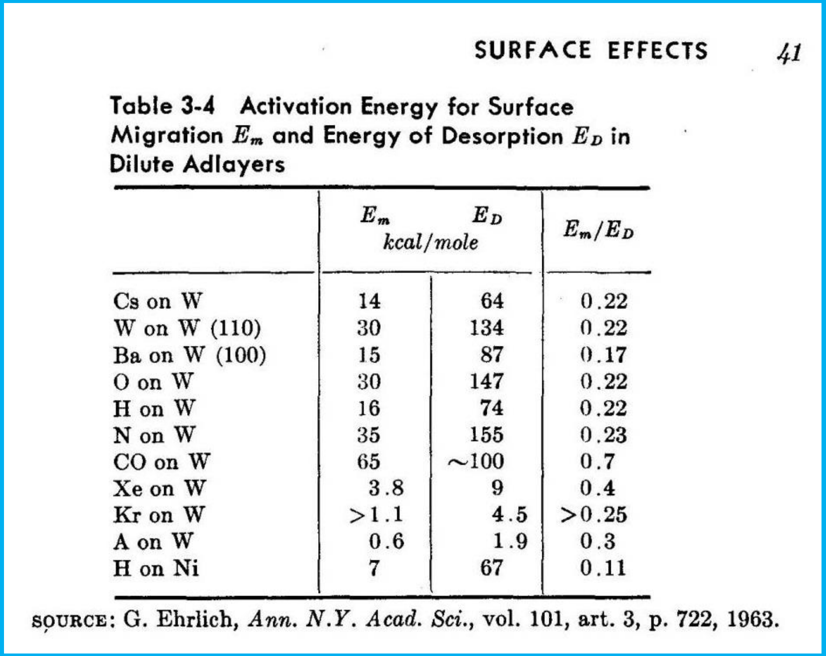
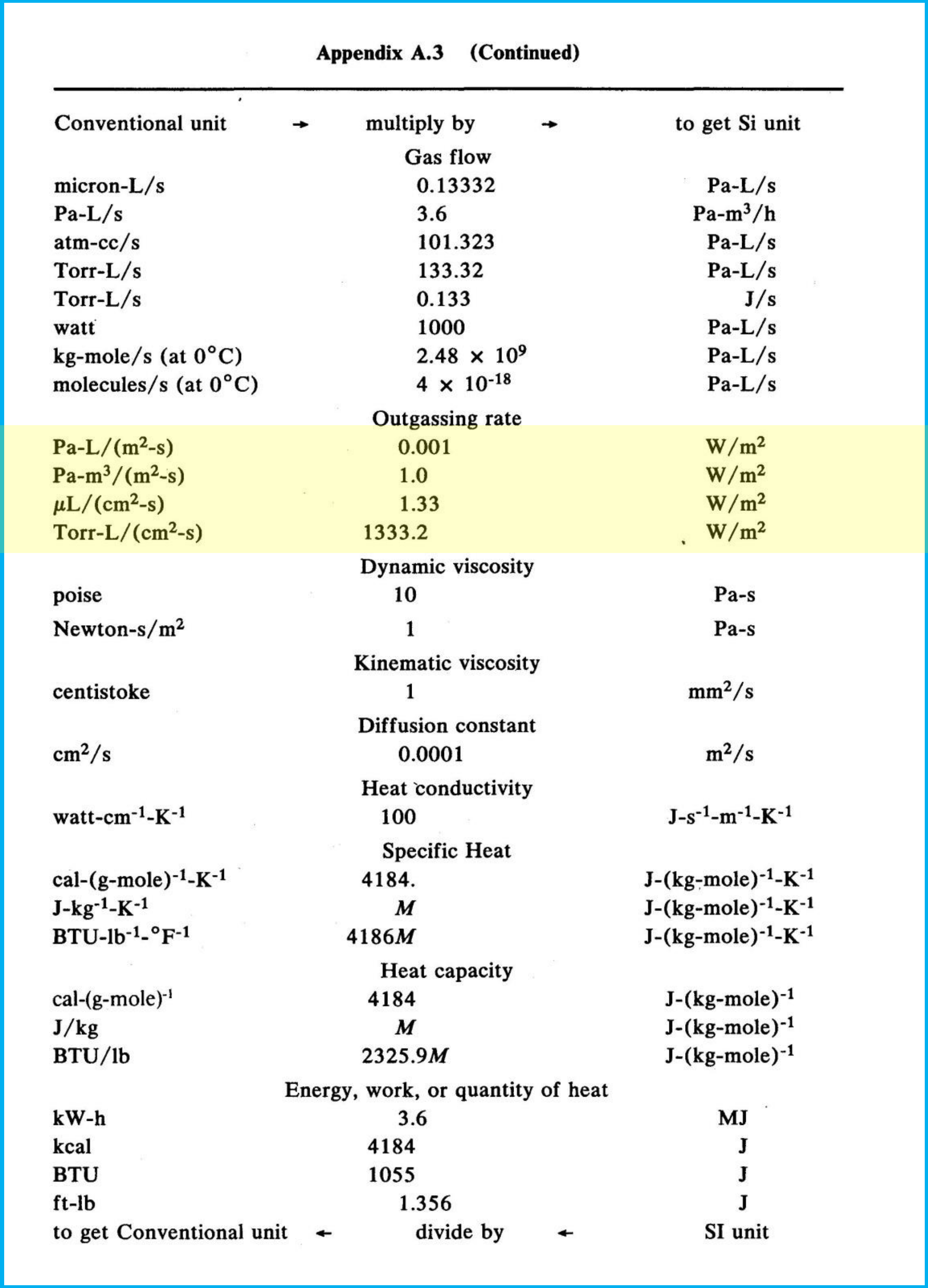


Table 3-4 Activation Energy for Surface Migration E_m and Energy of Desorption E_D in Dilute Adlayers

	E_m	E_D	E_m/E_D
	kcal/mole		
Cs on W	14	64	0.22
W on W (110)	30	134	0.22
Ba on W (100)	15	87	0.17
O on W	30	147	0.22
H on W	16	74	0.22
N on W	35	155	0.23
CO on W	65	~100	0.7
Xe on W	3.8	9	0.4
Kr on W	>1.1	4.5	>0.25
A on W	0.6	1.9	0.3
H on Ni	7	67	0.11

SOURCE: G. Ehrlich, *Ann. N.Y. Acad. Sci.*, vol. 101, art. 3, p. 722, 1963.



Appendix A.3 (Continued)

Conventional unit →	multiply by →	to get Si unit
	Gas flow	
micron-L/s	0.13332	Pa-L/s
Pa-L/s	3.6	Pa-m^3/h
atm-cc/s	101.323	Pa-L/s
Torr-L/s	133.32	Pa-L/s
Torr-L/s	0.133	J/s
watt	1000	Pa-L/s
kg-mole/s (at 0°C)	2.48×10^9	Pa-L/s
molecules/s (at 0°C)	4×10^{-18}	Pa-L/s
	Outgassing rate	
Pa-L/(m^2-s)	0.001	W/m^2
Pa-m^3/(m^2-s)	1.0	W/m^2
μL/(cm^2-s)	1.33	W/m^2
Torr-L/(cm^2-s)	1333.2	W/m^2
	Dynamic viscosity	
poise	10	Pa-s
Newton-s/m^2	1	Pa-s
	Kinematic viscosity	
centistoke	1	mm^2/s
	Diffusion constant	
cm^2/s	0.0001	m^2/s
	Heat conductivity	
watt-cm^{-1}-K^{-1}	100	J-s^{-1}-m^{-1}-K^{-1}
	Specific Heat	
cal-(g-mole)$^{-1}$-K^{-1}	4184.	J-(kg-mole)$^{-1}$-K^{-1}
J-kg^{-1}-K^{-1}	M	J-(kg-mole)$^{-1}$-K^{-1}
BTU-lb^{-1}-°F^{-1}	4186M	J-(kg-mole)$^{-1}$-K^{-1}
	Heat capacity	
cal-(g-mole)$^{-1}$	4184	J-(kg-mole)$^{-1}$
J/kg	M	J-(kg-mole)$^{-1}$
BTU/lb	2325.9M	J-(kg-mole)$^{-1}$
	Energy, work, or quantity of heat	
kW-h	3.6	MJ
kcal	4184	J
BTU	1055	J
ft-lb	1.356	J
to get Conventional unit ←	divide by ←	SI unit

APPENDIX C

Material Properties

Appendix C.1 Outgassing Rates of Vacuum Baked Metals

Material	Treatment	q (10^{-11} W/m^2)
Aluminum[a]	15 h at 250°C	53.0
Aluminum[b]	20 h at 100°C	5.3
6061 Aluminum[c]	glow disch. + 200°C bake	1.3
Copper[b]	20 h at 100°C	146.0
304 Stainless Steel[a]	30 h at 250°C	400.0
Stainless Steel[d]	2 h at 850/900°C vac. furnace	27.0
316L Stainless Steel[e]	2 h at 800°C vac. furnace	46.0
U15C Stainless Steel[f]	3 h vac. furn. 1000°C + 25-h *in situ* vac. bake at 360°C	2.1

Source. Adapted with permission from *Vacuum*, **25**, p. 347, R. J. Elsey. Copyright 1975, Pergamon Press.

[a] J. R. Young, *J. Vac. Sci. Technol.*, **6**, 398 (1969);

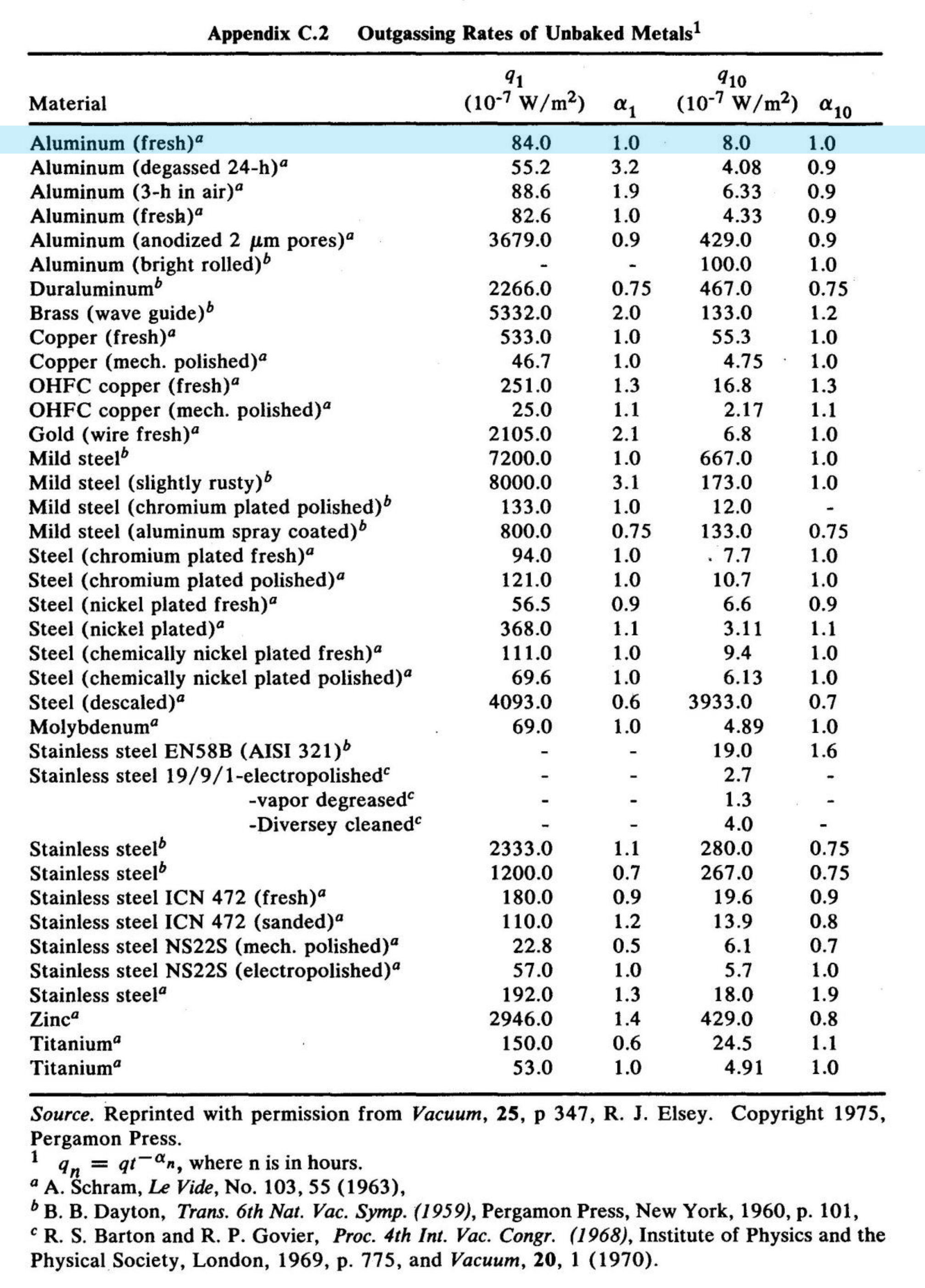
[b] G. Moraw, *Vacuum*, **24**, 125 (1974);

[c] H. J. Halama and J. C. Herrera, *J. Vac. Sci. Technol.*, **13**, 463 (1976);

[d] R. L. Samuel, *Vacuum*, **20**, 295 (1970);

[e] R. Nuvolone, *J. Vac. Sci. Technol.*, **14**, 1210 (1977);

[f] R. Calder and G. Lewin, *Brit. J. Appl. Phys.*, **18**, 1459 (1967).



Appendix C.2 Outgassing Rates of Unbaked Metals[1]

Material	q_1 (10^{-7} W/m^2)	α_1	q_{10} (10^{-7} W/m^2)	α_{10}
Aluminum (fresh)[a]	84.0	1.0	8.0	1.0
Aluminum (degassed 24-h)[a]	55.2	3.2	4.08	0.9
Aluminum (3-h in air)[a]	88.6	1.9	6.33	0.9
Aluminum (fresh)[a]	82.6	1.0	4.33	0.9
Aluminum (anodized 2 μm pores)[a]	3679.0	0.9	429.0	0.9
Aluminum (bright rolled)[b]	-	-	100.0	1.0
Duraluminum[b]	2266.0	0.75	467.0	0.75
Brass (wave guide)[b]	5332.0	2.0	133.0	1.2
Copper (fresh)[a]	533.0	1.0	55.3	1.0
Copper (mech. polished)[a]	46.7	1.0	4.75	1.0
OHFC copper (fresh)[a]	251.0	1.3	16.8	1.3
OHFC copper (mech. polished)[a]	25.0	1.1	2.17	1.1
Gold (wire fresh)[a]	2105.0	2.1	6.8	1.0
Mild steel[b]	7200.0	1.0	667.0	1.0
Mild steel (slightly rusty)[b]	8000.0	3.1	173.0	1.0
Mild steel (chromium plated polished)[b]	133.0	1.0	12.0	-
Mild steel (aluminum spray coated)[b]	800.0	0.75	133.0	0.75
Steel (chromium plated fresh)[a]	94.0	1.0	7.7	1.0
Steel (chromium plated polished)[a]	121.0	1.0	10.7	1.0
Steel (nickel plated fresh)[a]	56.5	0.9	6.6	0.9
Steel (nickel plated)[a]	368.0	1.1	3.11	1.1
Steel (chemically nickel plated fresh)[a]	111.0	1.0	9.4	1.0
Steel (chemically nickel plated polished)[a]	69.6	1.0	6.13	1.0
Steel (descaled)[a]	4093.0	0.6	3933.0	0.7
Molybdenum[a]	69.0	1.0	4.89	1.0
Stainless steel EN58B (AISI 321)[b]	-	-	19.0	1.6
Stainless steel 19/9/1-electropolished[c]	-	-	2.7	-
-vapor degreased[c]	-	-	1.3	-
-Diversey cleaned[c]	-	-	4.0	-
Stainless steel[b]	2333.0	1.1	280.0	0.75
Stainless steel[b]	1200.0	0.7	267.0	0.75
Stainless steel ICN 472 (fresh)[a]	180.0	0.9	19.6	0.9
Stainless steel ICN 472 (sanded)[a]	110.0	1.2	13.9	0.8
Stainless steel NS22S (mech. polished)[a]	22.8	0.5	6.1	0.7
Stainless steel NS22S (electropolished)[a]	57.0	1.0	5.7	1.0
Stainless steel[a]	192.0	1.3	18.0	1.9
Zinc[a]	2946.0	1.4	429.0	0.8
Titanium[a]	150.0	0.6	24.5	1.1
Titanium[a]	53.0	1.0	4.91	1.0

Source. Reprinted with permission from *Vacuum*, **25**, p 347, R. J. Elsey. Copyright 1975, Pergamon Press.

[1] $q_n = qt^{-\alpha_n}$, where n is in hours.

[a] A. Schram, *Le Vide*, No. 103, 55 (1963),

[b] B. B. Dayton, *Trans. 6th Nat. Vac. Symp. (1959)*, Pergamon Press, New York, 1960, p. 101,

[c] R. S. Barton and R. P. Govier, *Proc. 4th Int. Vac. Congr. (1968)*, Institute of Physics and the Physical Society, London, 1969, p. 775, and *Vacuum*, **20**, 1 (1970).

Appendix C.3 Outgassing Rates of Ceramics and Glasses[1]

Material	q_1 (10^{-7} W/m^2)	α_1	q_{10} (10^{-7} W/m^2)	α_{10}
Steatite[a]	1200.0	1.0	127.0	-
Pyrophyllite[b]	2667.0	1.0	267.0	-
Pyrex (fresh)[c]	98.0	1.1	7.3	-
Pyrex (1 month in air)[c]	15.5	0.9	2.1	-

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[1] $q_n = qt^{-\alpha_n}$, where n is in hours.

[a] R. Geller, *Le Vide*, No. 13, 71 (1958);

[b] R. Jaeckel and F. Schittko, quoted by Elsey;

[c] B. B. Dayton, *Trans. 6th Nat. Symp. Vac. Technol. (1959)*, Pergamon Press, New York, 1960, p. 101.

Appendix C.4 Outgassing Rates of Elastomers[1]

Material	q_1 (10^{-5} W/m^2)	α_1	q_4 (10^{-5} W/m^2)	α_4
Butyl DR41[a]	200.0	0.68	53.0	0.64
Neoprene[a]	4000.0	0.4	2400.0	0.4
Perbunan[a]	467.0	0.3	293.0	0.5
Silicone[b]	930.0	-	267.0	-
Viton A (fresh)[c]	152.0	0.8	-	-
Viton A (bake 12 h at 200°C)[d]	-	-	0.027[e]	-
Polyimide (bake 12 h at 300°C)[d]	-	-	0.005[e]	-

Source. Adapted with permission from *Vacuum*, **25**, p. 347, R. J. Elsey. Copyright 1975, Pergamon Press.

[1] $q_n = qt^{-\alpha_n}$, where n is in hours.

[a] J. Blears, E. J. Greer and J. Nightengale, *Adv. Vac. Sci.Technol.*, **2**, E. Thomas, Ed., Pergamon Press, 1960, p. 473;

[b] D. J. Santeler, et al., *Vacuum Technology and Space Simulation*, NASA SP-105, National Aeronautics and Space Administration, Washington, DC, 1966, p. 219;

[c] A. Schram, *Le Vide*, No. 103, 55 (1963);

[d] P. Hait, *Vacuum*, **17**, 547 (1967);

[e] Pumping time is 12 h.

Appendix C.7 Outgassing Rates of Polymers[1]

Material	q_1 (10^{-5} W/m^2)	α_1	q_{10} (10^{-5} W/m^2)	α_{10}
Araldite (molded)[a]	155.0	0.8	47.0	0.8
Araldite D[b]	253.0	0.3	167.0	0.5
Araldite F[b]	200.0	0.5	97.0	0.5
Kel-F[c]	5.0	0.57	2.3	0.53
Methyl Methacrylate[d]	560.0	0.9	187.0	0.57
Mylar (24-h at 95 RH)[e]	307.0	0.75	53.0	-
Nylon[f]	1600.0	0.5	800.0	0.5
Plexiglas[g]	961.0	0.44	36.0	0.44
Plexiglas[b]	413.0	0.4	240.0	0.4
Polyester-glass Laminate[c]	333.0	0.84	107.0	0.81
Polystyrene[c]	2667.0	1.6	267.0	1.6
PTFE[h]	40.0	0.45	26.0	0.56
PVC (24-h at 95 RH)[e]	113.0	1.0	2.7	-
Teflon[g]	8.7	0.5	3.3	0.2

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[1] $q_n = qt^{-\alpha_n}$, where n is in hours.

[a] A. Schram, *Le Vide*, No. 103, 55 (1963);

[b] R. Geller, *Le Vide*, No.13, 71 (1958);

[c] B. B. Dayton, CVC Technical Report;

[d] J. Blears, E. J. Greer and J. Nightengale, *Adv. Vac. Sci. Technol.*, **2**, E. Thomas, Ed., Pergamon Press, 1960, p. 473;

[e] D. J. Santeler, *Trans. 5th Symp. Vac. Tech. (1958)*, Pergamon Press, New York, 1959, p. 1;

[f] B. D. Power and D. J. Crawley, *Adv. Vac. Sci. Technol.*, **1**, E. Thomas, Ed., Pergamon Press, New York, 1960, p. 207;

[g] G. Thieme, *Vacuum*, **13**, 55 (1963);

[h] B. B. Dayton, *Trans. 6th Nat. Vac. Symp. Vac. Technol. (1959)*, Pergamon Press, New York, 1960, p.101.

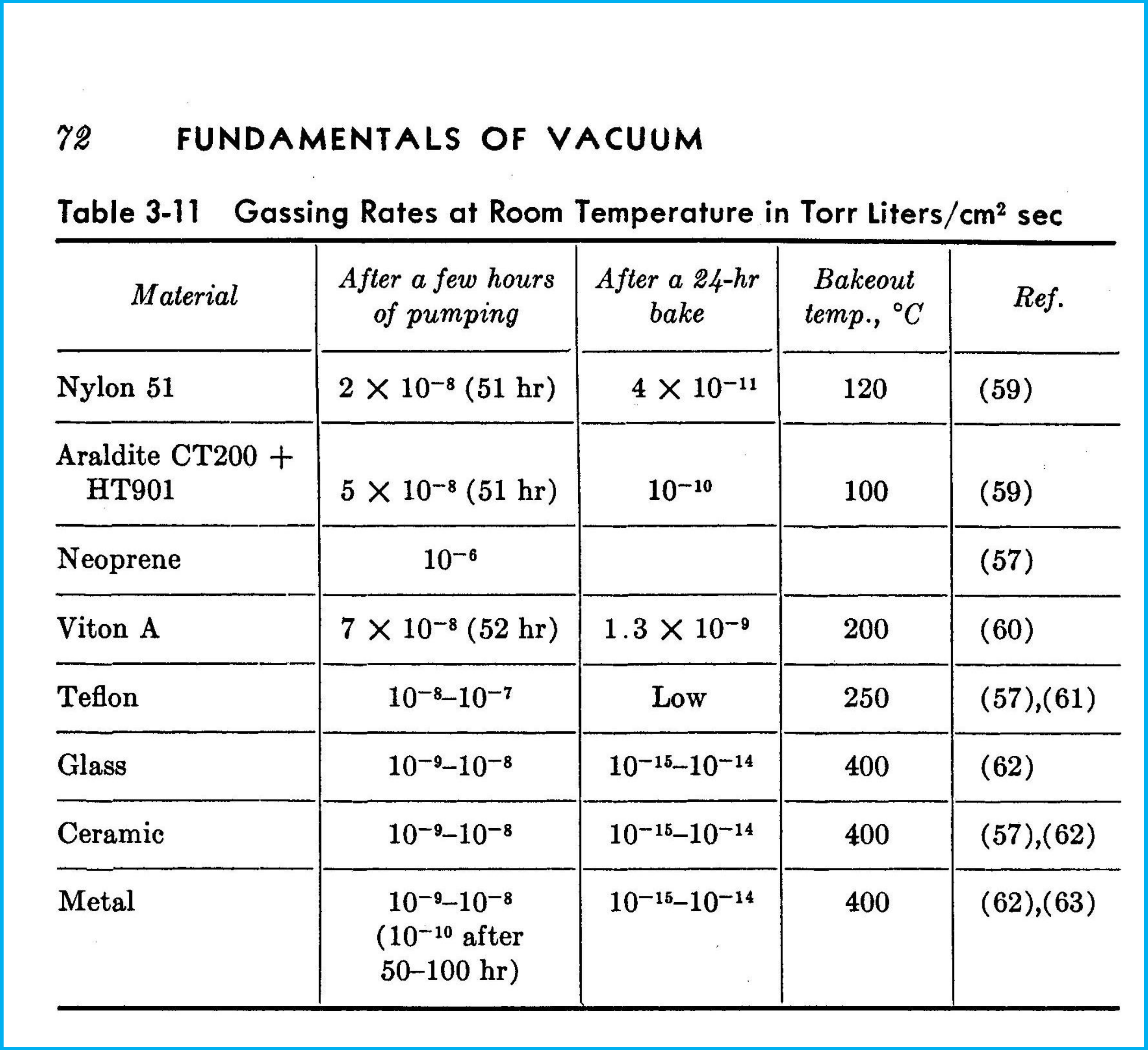
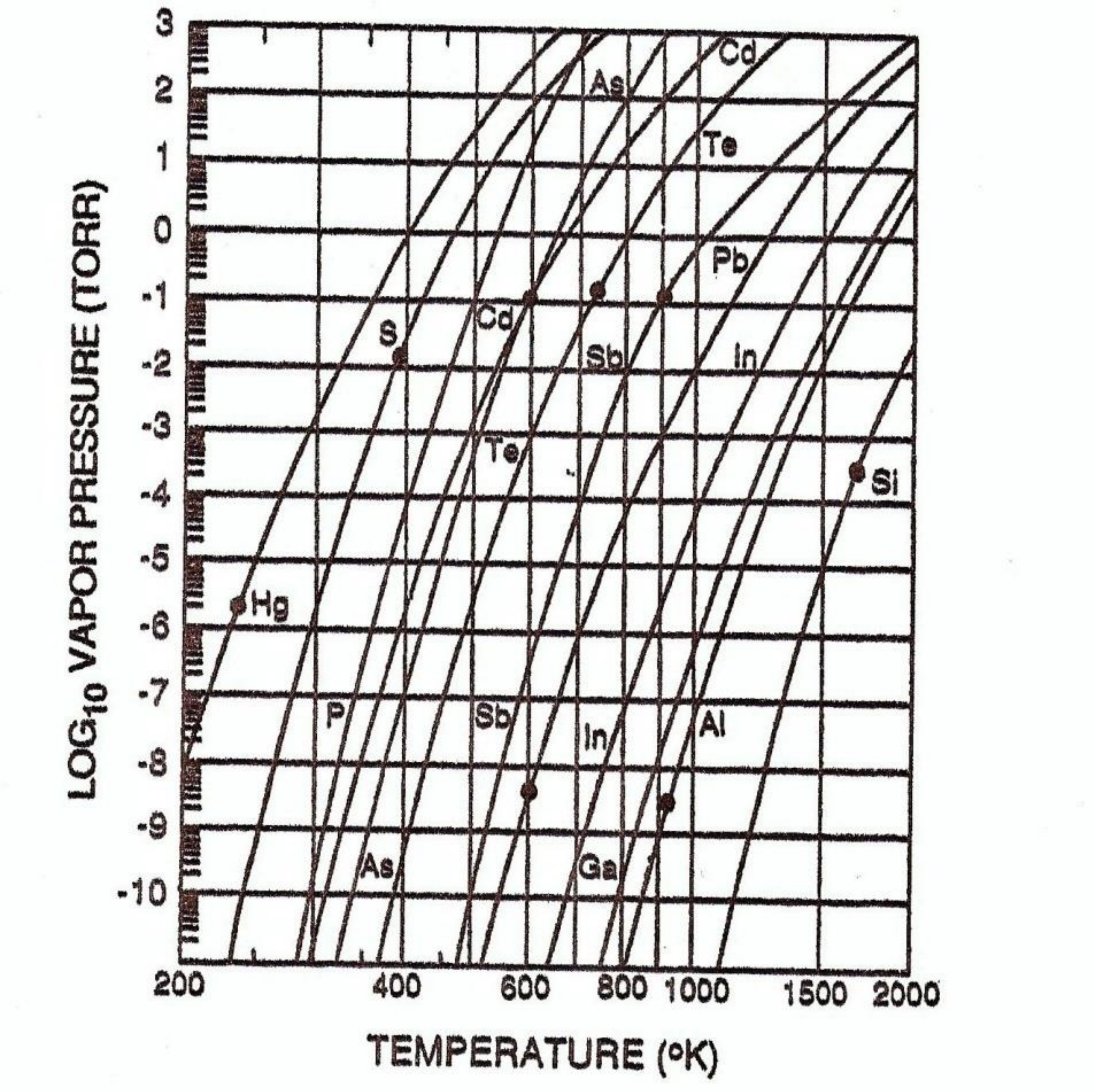


Table 3-11 Gassing Rates at Room Temperature in Torr Liters/cm² sec

Material	*After a few hours of pumping*	*After a 24-hr bake*	*Bakeout temp., °C*	*Ref.*
Nylon 51	2×10^{-8} (51 hr)	4×10^{-11}	120	(59)
Araldite CT200 + HT901	5×10^{-8} (51 hr)	10^{-10}	100	(59)
Neoprene	10^{-6}			(57)
Viton A	7×10^{-8} (52 hr)	1.3×10^{-9}	200	(60)
Teflon	10^{-8}–10^{-7}	Low	250	(57),(61)
Glass	10^{-9}–10^{-8}	10^{-15}–10^{-14}	400	(62)
Ceramic	10^{-9}–10^{-8}	10^{-15}–10^{-14}	400	(57),(62)
Metal	10^{-9}–10^{-8} (10^{-10} after 50–100 hr)	10^{-15}–10^{-14}	400	(62),(63)

Pressão de Vapor em função da Temperatura



Modelos de Fontes de Gases em um Sistema de Vácuo

Fonte de gás	Característica	Comentário
Volume	$P=P_o e^{\frac{-S}{V}t}$	Pressão cai exponencialmente dependendo de S e V
Vazamento Real	$P_{res}=\frac{Q_{Vr}}{S};Q_{Vr}\approx C_{Vr}P_{atm}$	Fluxo constante. Utilizar detector de vazamentos. Deve ser eliminado
Vazamento Virtual	$Q_{vv}=\frac{C_v}{S}P_o'e^{\frac{-C_v}{V_c}t}$	Cv << Sb Queda da pressão depende de Cv e Vc. Evitar no projeto
Difusão	$Q(t)=c_o\frac{\sqrt{D}}{\sqrt{\pi t}}$	Q(t) é proporcional a $\frac{1}{\sqrt{t}}$
Permeação	$Q=\frac{K(P_e^n-P_i^n)}{d}$	N=1 para não metais; n=1/2 para moléculas diatômicas em metais. Constante de permeação K(T) é proporcional a 10^3/T
Evaporação	$W=0.058\,P_v\sqrt{\frac{M}{T}}\frac{g}{cm^2 s}$ Q=WA (g/s) $Q=\frac{\Delta N}{\Delta t}kT\frac{Torrl}{s}$	Crescimento de P_v em função da temperatura é exponencial e por isso mais rápido do que $\frac{1}{\sqrt{T}}$
Desorpção Térmica (desgaseificação)	Primeira ordem: $\frac{dc}{dt}=c_o k_1 e^{-\frac{t}{\tau_{res}}}$ $\frac{1}{k_1}=\tau_{res}=\tau_o e^{\frac{E_d}{N_o kT}}$	Rápido $\tau_{res}=10^{-12}s$
Temperatura (cozimento)	Segunda ordem: $\frac{dc}{dt}=\frac{-k_2 C_o^2}{(1+C_o K_2 t)^2}$	Cai lentamente A molécula de H_{2s} se dissocia na adsorção e recombina na desorpção
Superfícies Reais	$q_n=\frac{q}{t^\alpha}$ $0.7\leq\alpha\leq 2$	Fórmula geral $q_n=qt^{-1}$ Adsorção química Adsorção física

4.6 PRESSURE LIMITS 75

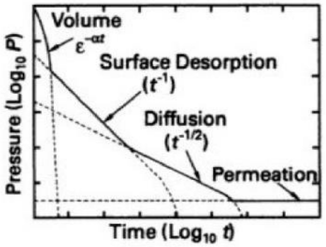


Fig. 4.10 Rate limiting steps during the pumping of a vacuum chamber.

Referência: A user's' guide to vacuum technology – J.F. O'Hanlon