UCRL - 334
c2

UNIVERSITY OF CALIFORNIA

Radiation Laboratory

TWO-WEEK LOAN COPY

This is a Library Circulating Copy which may be borrowed for two weeks. For a personal retention copy, call Tech. Info. Division, Ext. 5545

BERKELEY, CALIFORNIA

UCRL-334
c.2

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

UNIVERSITY OF CALIFORNIA

Radiation Laboratory

LABORATORY VACUUM MANUAL

compiled by

A. Guthrie and R. Loevinger

(Extracted from Vol. I Div. I of the N.N.E.S.)

April 20, 1949

Berkeley, California

TABLE OF CONTENTS

I Summary of formulae useful in vacuum design.

II Table of some convenient constants and conversion factors.

III Composition of the atmosphere.

IV Properties of some common gases.

V. Mechanical pump oils.

VI Diffusion pump oils.

VII Cold trap data.

VIII Effectiveness of drying agents

IX Vacuum greases and cements.

X Solders, brazing alloys and fluxes.

XI Properties of some liquids used in vacuum practice.

XII Properties of substances commonly used in vacuum practice.

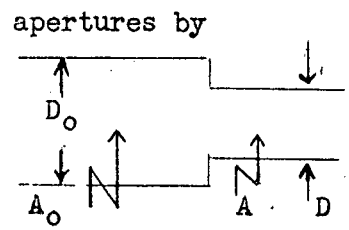
XIII Relations between various units of pressure.

XIV Bibliography

I. Summary of Formulae Useful in Vacuum Design

The formulae most frequently used in vacuum design work are presented here. They are given in two types of units, chosen because they are convenient and frequently used.

		Metric Lab Units	Mixed English and Metric Lab Units
a, b	- length of side of rectangle	cms	inches
A	- cross-sectional area	cm^2	$inches^2$
C	- conductance	liters/sec	liters/sec
$\mathfrak{G}$	- mass of gas in volume V	grams	grams
L	- length of a pipe	cms	feet
D	- diameter of a circular pipe or aperture	cms	inches
λ	- mean free path	cms	inches
M	- molecular weight of gas	atomic weight units	atomic weight units
V	- volume of vessel	liters	liters
V'	- volumetric flow	liters/sec	liters/sec
P	- pressure	μ (microns)	μ
Q = PV'	at constant T, flow	μ - liters/sec	μ - liters/sec
t	- time	seconds	seconds
S	- pumping speed	liters/sec	liters/sec
Z	- impedance	secs/liter	secs/liter

	Metric Lab Units	Mixed English and Metric Lab Units
Mass of gas at 20°C	$\gamma = 5.44 \times 10^{-8}$ M P V grams For air $\gamma = 1.56 \times 10^{-6}$ grams/μ- liter	
Mean free path for air at 20°C	$\lambda = \frac{4.86}{P}$ cms	$\frac{1.91}{P}$ inches
Impedance and conductance, definition	$\frac{1}{Z} = C = \frac{Q}{P_1 - P_2}$ liters/sec P_1 is upstream pressure P_2 is downstream pressure	
Pumping speed, definition	$S = Q/P$ liters/sec	
Series impedances	$Z = \sum Z_i$, $\frac{1}{C} = \sum \frac{1}{C_i}$	
Parallel impedances	$\frac{1}{Z} = \sum \frac{1}{Z_i}$, $C = \sum C_i$	
Pumping speed through an impedance Z of a pump with speed S_p	$\frac{1}{S} = Z + \frac{1}{S_p} = \frac{1}{C} + \frac{1}{S_p}$	
Viscous conductance of a thin, small aperture; air at 20°C $P_2/P_1 \leq .1$	$C = 20A$ liters/sec or $C = 16\ D^2$ liters/sec	129 A liters/sec 100 D^2 liters/sec
Molecular conductance of a thin, small aperture. $\lambda >>$ aperture size	$C = 11.6$ A liters/sec or $C = 9.1\ D^2$ liters/sec	75 A liters/sec 59 D^2 liters/sec
Aperture pumping speed	$S = C\ (1 - P_2/P_1)$ $S = C$ for $P_2/P_1 < 0.1$ P_1 and P_2 are the upstream and downstream pressures respectively.	
Molecular flow through a large aperture	Multiply preceding formulae for small apertures by $\frac{A_o}{A_o - A}$ or by $\frac{D_o^2}{D_o^2 - D^2}$ for circular aperture.	

	Metric Lab Units	Mixed English and Metric Lab Units
Reynold's number	$Re = Dv\rho/\eta$ ρ is gas density, η = coefficient of viscosity, v is velocity of gas stream	
Reynold's number for air at 20°C; circular pipe	$Re = \frac{Q}{89D}$	$\frac{Q}{226D}$
Turbulent to viscous transition; air at 20°C	Flow is turbulent if $Q > 2 \times 10^5 D$ Flow is viscous if $Q < 10^5 D$	$Q > 5 \times 10^5 D$ $Q < 2.5 \times 10^5 D$
Viscous to molecular transition; air at 20°C (Gives conductances accurate to 10%)	The flow is viscous if $\bar{P}D > 500\ \mu$-cm, $\lambda < \frac{D}{100}$ The flow is molecular if $\bar{P}D < 15\ \mu$-cm, $\lambda > \frac{D}{3}$ $\bar{P}$ is average pressure.	$\bar{P}D > 200\ \mu$-in, $\lambda < \frac{D}{100}$ $\bar{P}D < 6\ \mu$-in, $\lambda > \frac{D}{3}$
Viscous conductance if a long circular pipe; air at 20°C	$C = 0.182 \frac{D^4}{L} \bar{P}$ liters/sec $\bar{P}$ is average pressure	$0.25 \frac{D^4}{L} \bar{P}$ liters/sec
Viscous volume flow in a long circular pipe; air at 20°C	$V' = 0.182\ D^4 \frac{(P_1 - P_2)}{L}$ liters/sec $= 0.182\ D^4$ liters/sec/unit of pressure gradient	$0.25\ D^4 \frac{(P_1 - P_2)}{L}$ liters/sec $0.25\ D^4$ liters/sec/unit pressure gradient
Viscous conductance if a long rectangular duct; air at room temperature	$C = 0.26 \frac{a^2b^2}{L} \bar{P}\ Y$ liters/sec Y is correction factor given in Table 1	$0.36 \frac{a^2b^2}{L} \bar{P}\ Y$ liters/sec
Viscous volume flow in a long rectangular duct; air at room temperature	$V' = 0.26\ a^2b^2\ Y \frac{(P_1 - P_2)}{L}$ liters/sec $= 0.26\ a^2b^2\ Y$ liters/sec/unit of pressure gradient Y given in Table 1	$0.36\ a^2b^2 Y \frac{(P_1 - P_2)}{L}$ liters/sec $= 0.36\ a^2b^2 Y$ liters/sec/unit pressure gradient
Impedance of any short pipe	Add impedance of aperture to impedance of pipe computed from long pipe formula	
Molecular conductance of a long circular pipe; air at 20°C	$C = 12.1 \frac{D^3}{L}$ liters/sec	$6.5 \frac{D^3}{L}$ liters/sec
Molecular conductance of a short circular pipe; air at 20°C	$C = 12.1 \frac{D^3}{L} \alpha$ liters/sec α given in Table 2	$6.5 \frac{D^3}{L}$ liters/sec

	Metric Lab Units	Mixed English and Metric Lab Units
Molecular conductance of a long circular annulus; air at 20°C	$C = 12.1 \frac{(D_1-D_2)^2 (D_1+D_2)}{L}$ K liters/sec $D_1 > D_2$. K is given in Table 3	$6.5 \frac{(D_1-D_2)^2(D_1+D_2)}{L}$ K liters/sec
Molecular conductance of a long rectangular duct; air at 20°C	$C = 30.9 \frac{a^2b^2}{(a+b)L}$ K liters/sec K is given in Table 4	$16.6 \frac{a^2b^2}{(a+b)L}$ K liters/sec
Molecular conductance of a long equilateral triangular duct; air at 20°C	$C = 4.79 \frac{a^3}{L}$ liters/sec	$2.58 \frac{a^3}{L}$ liters/sec
Molecular conductance of a thin, slit-like tube; air at 20°C	$C = 27 \frac{ab^2}{L} \log \frac{L}{b}$ liters/sec $L/b > 10$	$C = 14.4 \frac{ab^2}{L} \log \frac{12L}{b}$ $12L/b > 10$
Molecular flow at bends and elbows. For each bend allow for an effective length in the range indicated by the inequality	$L_{axial} < L_{eff} < L_{axial} + 1.33\ D$	$L_{axial} < L_{eff} < L_{axial} + 0.11\ D$
Pumping speed of pump of speed S_p through an impedance Z	$\frac{1}{S} = Z + \frac{1}{S_p}$ sec/liter	
Pumping speed of pump of speed S_p near base pressure P_o	$S = S_p \left(1 - \frac{P_o}{P}\right)$ liters/sec	
Pump speed formula, metered leak method	$S_p = 760 \frac{V'}{\Delta P}$ liters/sec	V' is leak in cc/sec of free air ΔP is pressure rise in μ
Pump speed formula, rate of rise method	$S_p = \frac{P'_2 - P'_1}{P_2 - P_1} V$ liters/sec	V is volume of vessel P'_1 and P'_2 are the rates of rise corresponding to operating pressures P_1 and P_2 respectively.
Evacuation rate; time to fall to 1/2 pressure	$t_{\frac{1}{2}} = 0.7 \frac{V}{S_p}$	V is volume of system S_p is pump speed

TABLE 1

a/b	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
Y	1.00	0.99	0.98	0.95	0.90	0.82	0.71	0.58	0.42	0.23

TABLE 2

L/D	0.05	0.08	0.1	0.2	0.4	0.6	0.8	1.0	2.0	4.0	6.0	8.0	10.0	20.0	40.0
α	0.036	0.055	0.068	0.13	0.21	0.28	0.30	0.38	0.54	0.70	0.77	0.81	0.84	0.91	0.95

L/D	60.0	80.0	$\geq$100.0
α	0.97	0.98	1.0

TABLE 3

D_2/D_1	0	0.259	0.500	0.707	0.866	0.966
K	1.000	1.072	1.154	1.254	1.430	1.675

TABLE 4

b/a	1.00	0.667	0.500	0.333	0.200	0.125	0.100
K	1.108	1.126	1.151	1.198	1.297	1.400	1.444

II. Table of Some Convenient Constants and Conversion Factors

Number of molecules in a mole $\cong 6.06 \times 10^{23}$

$k \cong 1.381 \times 10^{-16}$ dyne-cms/deg. Boltzmann's constant

1 atomic weight unit $\cong 1.660 \times 10^{-24}$ grams

1 atmosphere $\cong$ 760 mm Hg at sea level $\cong$ 760,000 μ

1 μ (micron) $\cong 10^{-3}$ mm Hg

1 microbar $\cong$ 1 dyne/cm^2 $\cong$ 0.745 μ Hg

1 poise $\cong$ 1 gm/cm/sec (c.g.s. unit of viscosity)

1 liter/sec $\cong$ 2.12 ft^3/min $\cong$ 2.12 c.f.m.

1 cc/sec at atmospheric pressure $\cong$ 760 μ-liters/sec

1 liter $\cong$ 61.0 in^3 = 0.0353 ft^3

III. Composition of the Atmosphere

Dry air at sea level, % by volume

N_2	O_2	A	CO_2	H_2	N_3	He
78.03	20.99	0.94	0.03	0.01	.0012	.0004

IV. Properties of Some Common Gases

GAS	M, molecular weight in atomic weight units	m, mass of a molecule in 10^{-24} grams	$\bar{v}$, average velocity of a molecule in km/sec at 15°C	λ, mean free path at 15°C and 1 μ pressure, in cms	σ, diameter of a molecule in 10^{-8} cms	κ, thermal conductivity in 10^{-3} cal/cm/sec/deg, at 0°C	η, viscosity in micropoises, at 15°C	Relative diffusion into air, arbitrary scale
H_2	2.02	3.35	1.74	8.97	2.74	0.416	87	1.0
He	4.00	6.64	1.23	14.1	2.18	0.344	194	0.87
CH_4	16.0	26.6	0.616	3.92	4.14	0.072	108	0.29
NH_3	17.0	28.2	0.597	3.42	4.43	0.051	97	0.27
H_2O vapor	18.0	29.9	0.582	3.18	4.60	0.055 at 100°C	93	0.25
Ne	20.2	33.5	0.550	10.0	2.59	0.110	310	0.42
N_2	28.0	46.5	0.467	4.77	3.75	0.057	173	0.28
Air	(28.7)	(47.6)	0.459	4.86	3.72	0.057	180	0.27
O_2	32.0	53.1	0.437	5.15	3.61	0.057	200	0.28
HCl	36.5	60.6	0.409	3.38	4.46	---	140	0.21
A	39.9	66.2	0.391	5.06	3.64	0.039	220	0.25
CO_2	44.0	73.0	0.372	3.18	4.59	0.034	145	0.20
Hg	201	334	0.174	---	4.26	---	---	0.18
electron	5.5×10^{-4}	9.1×10^{-4}	105	---	---	---	---	---

M is taken from Handbook of Chemistry and Physics, 29th Edition.
m is computed using $m = 1.660 \times 10^{-24}$ M.
$\bar{v}$ is from Ref 1, p 26.
λ is from Ref 1, p 149, the values there being reduced to 1 μ here.
σ, κ, and η are from Ref 1, p 149, except κ for air which is from the Handbook of Chemistry and Physics.
Relative diffusion computed from equation (1.14) Vol I Div I of the National Nuclear Energy Series.

V. Mechanical Pump Oils

Brand of Oil	Type of Oil	Approx. Price Per Gal.	Viscosity S. U. at 100°C	Viscosity S. U. at 210°F	Type of Hydrocarbon	Resistance to (a)Cl_2 (b)HCl (c)Moisture Clouding
Caloil Deturbo Medium	Turbine					
Gulf Crest B	Turbine	$0.63	209	48	Paraffin	Good for (a) and (b); Poor for (c).
Gulf Crest C	Vacuum	0.65	311	55	Paraffin	Good for (a) and (b); Very Poor for (c)
Gulf Mechanism E	Machine	0.48	205	45	Naphthalene	Good for (a) and (b)
Gulf Harmony E	Turbine	0.46	603	64	Paraffin	Fair for (a) and (b)
MacMillan Vacuum Pump	Vacuum	0.68	350	50	Mixed	Poor for (a) and (b)
Shell Turbo 41	Turbine					
Socony Vacuum Pump	Vacuum	0.71			Paraffin	
Socony D.T.E. Light	Turbine	0.71	155	43	Paraffin	Poor for (a) and (b)
Texaco Regal B	Turbine	0.43	196	45	Paraffin	
Texaco Regal C	Turbine	0.45	325	49	Paraffin	
Texaco URSA P-10 (Navy Symbol 2110)	Turbine	0.32	165	45	Paraffin	Fair for (a) and (b); Good for (c)

VI. Diffusion Pump Oils

Oil	Refined from	Ult. Vac. at 25°C (mm. Hg)	Approx. List Price per Gal.	Resistance to Oxidation
Apiezon A		10^{-5}		
Apiezon B	Petroleum	10^{-7}		Fair
Butyl Phthalate		10^{-3}		
Butyl Sebacate		10^{-5}		
Amdil	N-Amyl Phthalate	7×10^{-6}	$60.00	Poor
Amdil-X	N-Amyl Sebacate	2×10^{-6}	$95.00	Poor
Litton C	Petroleum	2×10^{-6}	$40.00	Fair
Octoil	Di-ethyl hexyl Phthalate	2×10^{-7}	$135.00	Poor
Octoil-S	Di-ethyl hexyl Sebacate	5×10^{-8}	$160.00	Poor

VII. Cold Trap Data

Type	Temp. °C	Vapor Pressure of Water	Latent Heat Col. per gm.	Specific Gravity	Approx. Cost
Solid CO_2	-78	0.6μ	45	1.56	3¢ / lb.
Liquid O_2	-183	$\sim 10^{-18}\mu$	3.3	1.14	--
Liquid Air	-187	$\sim 10^{-18}\mu$	--	--	17.5¢ / liter
Liquid N_2	-196	$\sim 10^{-18}\mu$	6.1	0.81	--

VIII. Effectiveness of Drying Agents*

Drying Agent		Milligrams of Residual Water Vapor per Liter of Gas Dried at 25°C
Phosphorus pentoxide	P_2O_5	2.0×10^{-5}
Magnesium perchlorate	$Mg(ClO_4)_2$	5.0×10^{-4}
Melted caustic potash	KOH	2.0×10^{-3}
Aluminum oxide	Al_2O_3	3.0×10^{-3}
Sulphuric acid	H_2SO_4	3.0×10^{-3}
Sulphuric acid 95.1%	H_2SO_4, 95.1%	0.3
Calcium oxide	CaO	0.2
Calcium chloride (gran.)	$CaCl_2$ (gran.)	0.14 to 0.25
Calcium chloride (fused)	$CaCl_2$ (fused)	0.36
Copper sulphate	$CuSO_4$	1.4
Zinc chloride	$ZnCl_2$	0.8
Sodium hydroxide	NaOH (fused)	0.16

* International Critical Tables, Vol. III, p. 385, (1928). McGraw - Hill Book Co., New York

IX. Vacuum Greases and Cements

Trade Name	Supplier	M.P. °C.	V.P. in mm. Hg at 20°C	Solubility	General
Lubriseal	Arthur H. Thomas Co.	40	$<10^{-5}$	---	Grease
Vacuseal Light	Central Scientific Co.	50	10^{-5}	---	Grease
Vacuseal Heavy	Central Scientific Co.	60	10^{-5}	---	Grease
Celvacene Light	Distillation Products, Inc.	90	10^{-6}	---	Grease
Celvacene Medium	Distillation Products, Inc.	120	$<10^{-6}$	---	Grease
Celvacene Heavy	Distillation Products, Inc.	130	$<10^{-6}$	---	Grease
Stop-Cock Grease	Dow-Corning Chemical Co.	215	$<10^{-5}$	---	Grease
Apiezon "L"	James G. Biddle Co.	Probably <50	10^{-3} at 300°C (10^{-11} at 20°C)	---	Grease. Should be kept free from contact with air when not in use.
Apiezon "M"	James G Biddle Co.	Probably <50	10^{-3} at 200°C 6×10^{-7} at	---	Grease. More viscous than "L". Should be kept free from contact with air when not in use.
Apiezon "Q"	James G. Biddle Co.	---	10^{-4}	---	Plasticene-like substance. Graphite mixed with low V.P. residues of paraffin oil distillation products.
Apiezon "W"	James G. Biddle Co.	Softening point 60-70	$<10^{-8}$	Soluble in zylene	Hard substance, supplied in sticks
Picein	Central Scientific Co.	80, 105 (2 grades)	10^{-8} 3-10 at 50°C	Inert to usual organic liquids and inorganic acids	Hard black wax.
de Khotinsky Cement	Central Scientific Co.	Softens at 50	$\sim 10^{-3}$	Comparatively insoluble in usual organic liquids and common acids	Mixture of shellac and pitch. Useful for seals below 40°C
Dennison's Sealing Wax	James G. Biddle Co.	Softens 60-80	$\sim 10^{-5}$	Soluble in alcohol	Hard wax
Shellac	Various	---	---	Soluble in alcohol and butyl phthalate	Usually used mixed with beeswax.
Silver Chloride	Various	455	---	Soluble in sodium thiosulphate	Applied at 450°C. Useful sealant to stand high temperature.
Beeswax	Various	60	---	Soluble in CCl_4 & alcohol	Mixture of beeswax and resin (melted together)
Bakelite Cement	---	80	---	Soluble in methylated spirits	Widely used in radio tube industry

X. Solders, Brazing Alloy and Fluxes

Soft and Intermediate Solders

Solder	Composition, Percent	M.P. °C
Wood metal	Bi 50, Cd 12.5, Pb 25, Sn 12.5	61
Soft solder (high strength)	Pb 34, Sn 66	180
Half and half	Pb 50, Sn 50	205
Intermediate	Ag 20, Cu 3, Zn 2, Sn 75	400

Hard Solder and Brazing Alloy

Solder	Composition, Percent	M.P. °C
Silver solder	Ag 45, Cu 30, Zn 25	720
Brazing compound	Cu 54, Zn 46	875

Fluxes for Soft and Intermediate Solders

Flux	Composition (% by wt.)
Liquid flux	40 $ZnCl_2$, 20 NH_4Cl, 40 H_2O
Flux paste	90 paste of petroleum, 10 NH_4Cl
Spirit of rosin	A solution of rosin in alcohol

Fluxes for Hard Soldering

Flux	Composition
Borax-boracic acid paste	A thin paste of 10 parts powdered borax, 1 part boracic acid in water
Borax	Dry borax

XI. Properties of Some Liquids Used in Vacuum Practice*

Vapor Pressure of Liquids in mm. Hg at 20°C

Liquid	Vapor Pressure
Acetone C_3H_6O	184.8
Benzene C_6H_6	74.65
Carbon Disulphide CS_2	298.0
Carbon Tetrachloride CCl_4	90.99
Chloroform $CHCl_3$	159.6
Ethyl Alcohol C_2H_6O	43.9
Methyl Alcohol CH_4O	96.0
Ethyl Ether $C_4H_{10}O$	442.2
Ethyl Bromide C_2H_5Br	387.0
Turpentine $C_{10}H_6$	4.4
Water H_2O	17.535
Mercury Hg	0.001201

* Taken from Handbook of Chemistry and Physics, 30th Edition, Chemical Rubber Publishing Co., Cleveland, Ohio

XII. Properties of Substances Commonly Used in Vacuum Practice*

Substance	Composition	M.P. °C	Specific Gravity	V.P. mm. Hg	Resistivity μ-ohm cms.	General
Aluminum	--	658	2.70	10^{-8} at 680°C 10^{-2} at 1200°C	2.82	Used in aluminizing mirrors, in electrodes
Asbestos	--	1150 Hornblende 1550 Serpentine	2.5-3.5	--	--	Used as heat insulator - diffusion pump lagging, etc. Thermal cond. cals. per cm. per sec. per °C: Fiber = 0.00019 (500°C), Paper = 0.0006.
Bakelite	Urea formaldehyde	--	1.44-1.55	--	--	Good electrical insulator. Not used inside vacuum system (V.P. high above 30°C).
Barium	--	850	3.50	10^{-8} at 300°C 1.0 at 1000°C	--	Primarily used as a getter.
Beryllium	--	1280	1.84	1.0 at 1550°C	--	Very hard. Used for reflecting coating, windows in X-ray tubes. Be-Cu used in vacuum gauges etc. (springs).
Brass	Cu-Zn alloy	930-1030	8.5	--	6.4-8.4	Widely used in vacuum practice. Easy to machine, solder.
Bronze	Cu-Sn alloy	1000-1050	8.8	--	~18	Used for castings in vacuum apparatus prone to airleaks.
Cadmium	--	321	8.65	.001 at 219°C 1.0 at 392°C	~7.5 at 18°C	Used in photocells, nuclear studies.
Caesium	--	27	1.87	10^{-6} at 27°C 1.0 at 290°C	19.0 at 0°C	Oxidizes rapidly at A.P. Used for photo sensitive surfaces.
Carbon	--	--	2.22(graph) 3.51(diam)	10^{-8} at 2000°C 10^{-1} at 3000°C	2700 at 500°C 900 at 2500°C	Used for gas absorption, electrodes. Difficult to outgas. Aquadog is colloidal suspension of graphite in water - used as conductor.

Substance	Composition	M.P. °C	Specific Gravity	V.P. mm. Hg	Resistivity μ-ohm cms.	General
Copper	--	1083	8.89	10^{-8} at 800°C 10^{-1} at 1400°C	1.72	Good electrical and heat conductor. Used widely in vacuum practice. Can be sealed to glass, easily soldered.
Gold	--	1063	19.3	.001 at 1292°C 1.0 at 1768°C	1.42	Easily sputtered or evaporated in vacua. Used as conductor in instruments.
Iron (steels)	-- steel=Fe+C alloyed with Cr, Ni, Cu, etc.	1530 (pure) 1400-1550 for steels	7.80 (pure) 7.7to 7.9 for steels	10^{-8} at 750°C 0.3 at 1000°C	9.8 at 20°C 20-120 for common steels at 20°C	Constructional material for large vacuum systems -not attacked by Hg (mild steel commonly used). Highly magnetic. Special steels also used, such as stainless, duraloy, etc.
Lead	--	327	11.34	0.001 at 636°C 1.0 at 985°C	22 at 20°C	Used for gaskets in vacuum practice (elevated temperatures).
Mercury	--	-38.9°C	13.546 at 20°C	$3x10^{-9}$ at -78°C $3x10^{-2}$ at 60°C	94 at 0°C	Widely used in diffusion pumps, manometers, switches, protective devices. Poisonous. Forms amalgams with many metals.
Mica	Na-Al-Si compound	--	2.7-3.0	--	Very large	Electrical insulator in vacuum practice. Thin windows in G.M. tubes.
Molybdenum	--	2470	10.1	.001 at 2293°C	5.7 at 20°C	Seals to Pyrex glass. Spot-welds to Fe and Ni. Readily absorbs O_2 at 1000°C. Used for filaments.
Nickel	--	1452	8.8	10^{-8} at 1100°C 10^{-2} at 1700°C	7.24 at 20°C	Used for electrode. Ferro-magnetic alloys: Nichrome(heaters), Invar(low coeff. of exp.).
Palladium	--	1555	12.2	--	11 at 20°C	Used as getter. Absorbs H_2 strongly.
Platinum	--	1773	21.45	--	10 at 20°C	Seals readily to glass. Commonly used where minimum corrosion desirable. Very ductile.
Silica	Amorphous SiO_2	--	2.1-2.2	--	Very large	Chemically inert. Used in insulators, to transmit UV light, and where low coeff. of exp. is desired.
Silver	--	960.5	10.5-10.6	.001 at 837°C 1.0 at 1218°C	1.63 at 18°C	Easily sputtered and evaporated in vacua. Used as conductor, for reflecting coatings.
Tantalum	--	2996	16.6	--	15.5 at 20°C	Used for filaments, electrodes. Can be spot-welded to other metals.

Substance	Composition	M.P. °C	Specific Gravity	V.P. mm. Hg	Resistivity μ-ohm cms.	General
Tungsten	--	3370	18.6-19.1 2130°C	8×10^{-9} at 2130°C 5×10^{-6} at 2530°C	5.51 at 20°C	Used for filaments, electrodes. Seals to Pyrex and Monax glasses readily.

* Taken from Handbook of Chemistry and Physics, 30th Edition, and High Vacuum Technique by J. Yarwood, John Wiley & Sons, London.

XIII Relations between Various Units of Pressure

	mm Hg	cm Hg	bars	μa	μ (microns) Hg	lbs./in^2	Kg/cm^2	Atmos.
1 mm Hg =	1	.1	1325	10,000	1000	.0193	.00136	.00132
1 cm Hg =	10	1	13250	100,000	10000	.193	.0136	.0132
1 bars (dynes/cm^2) =	7.54×10^{-4}	7.54×10^{-5}	1	7.54	.754	1.45×10^{-5}	1.02×10^{-6}	9.87×10^{-7}
1 μa (UCRL) =	.0001	.00001	.1325	1	.1	1.94×10^{-6}	1.36×10^{-7}	1.32×10^{-7}
1 μ (microns Hg) =	.001	.0001	1.325	10	1	1.94×10^{-5}	1.36×10^{-6}	1.32×10^{-6}
1 lbs./in.^{2} =	51.7	5.17	6.9×10^4	5.17×10^5	5.17×10^4	1	.070	.068
1 Kg./cm^2 =	735.6	73.56	9.8×10^5	7.36×10^6	7.36×10^5	14.2	1	.968
1 atmosphere =	760	76	1.0132×10^6	7.6×10^6	7.6×10^5	14.7	1.0332	1

The bar used here (1 dyne/cm^2) is one-millionth of the bar used in meteorological work. The unit (1 dyne/cm^2) is sometimes called the microbar and is spelled barye. The unit used at UCRL, the μa, is only loosely related to the other more commonly encountered units of pressure.

XIV Bibliography

1. Dunoyer, L., "Vacuum Practice," G. Bill and Sons, London, 1926.

2. Jeans, J. H., "An Introduction to the Kinetic Theory of Gases," Cambridge Univ. Press, Cambridge, 1940.

3. Kaye, G. W. C., "High Vacua," Longmans-Green, London, 1927.

4. Kennard, E. H., "Kinetic Theory of Gases," McGraw-Hill, New York, 1938.

5. Loeb, L. B., "Kinetic Theory of Gases," McGraw-Hill, New York, 1934.

6. Mönch, G., "Vakuumtechnik in Laboratorium," R. Wagner Sohn, Weimar, 1937.

7. Strong, J. D., "Procedures in Experimental Physics," Prentice-Hall, New York, 1939.

8. Yarwood, J., "High Vacuum Technique" (2nd Ed.), Wiley, New York, 1945.