APPENDIX - FORMULAS AND TABLES

Common Physics Values

Acceleration gravity	g	= 9.806 m sec^2 (32.174 Ft sec^2)
Atomic Mass Unit AMU		= 1.6605 x 10^{-24} grams
Angstrom unit	Å	= 10-10 m = 0.1 nm
Avogadro's number	n	= 6,0221353 x 10^{23} mol^{-1} (number of particles per mol)
Molar volume		= 22.41 liters (at 1 atm and 273 °K)
Boltzmann's constant	k	= 1.38 x 10^{-16} ergs deg^{-1} molecule^{-1}
Plank's constant	h	= 6.6256 x 10^{-34} J sec
Electron charge	q	= 1.602 x 10^{-19} coulomb
Equivalent of heat	J	= 4.185 x 10^3 Joules K cal^{-1}
Natural log base	e	= 2.7183
Velocity of light	c	= 2.9979 x 108 m sec^{-1}
Velocity of sound	s	= 330 m sec^{-1}
Standard pressure	p	= 101.325 Pa = 1013 mbar (at 45°north and 0 °C)
Magnetic flux density	T	= Tesla. (1 gauss G= 10^{-4} Vs m^{-2} = 10^{-4} T)

Physical Properties of some Gases

Gas	Chemical formula	Molecular weight
Hydrogen	H_2	2.016
Helium	He	4.002
Deuterium	D_2	4.028
Methane	CH_4	16.04
Ammonia	NH_3	17.03
Water (vapour)	H_2O	18.02
Neon	Ne	20.18
Nitrogen	N_2	28.01
Oxygen	O_2	31.99
Argon	Ar	39.94
Carbon dioxide	CO_2	44.01
Kripton	Kr	83.80
Xeno	Xe	131.30
Mercury	Hg	200.59

Ideal Gas Equation

PV = nR0T	**or**	**PV = nkT**
P = pressure in Torr		P = pressure in dynes
V = volume in liters		V = volume in cc
n = numbers of Moles		n = numbers of Moles
R0 = molar gas constant		k = Boltzmann's constant
T = degrees Kelvin		T = degrees Kelvin

p	V	T	R0
Newton /m^2	m^3	°K	8.314 Joule / °K g mole
dyne / cm^2	cm^3	°K	8.314 x 10^{-7} erg / °K g mole
Torr	cm^3	°K	6.236 x 10^4 Torr cm^3 / °K g mole
Torr	liters	°K	62.364 Torr liters /°K g mole
atm	cm^3	°K	82.057 atm cm^3 / °K g mole

Temperature Scale

Conversion Table

°F	°C	°K	
212	100	373	Boiling point of water
32	0	273	Freezing point of water
-321	-196	77	Boiling point of LN_2
-459	-273	0	Absolute zero

Conversion factors:

°C = 5/9 (F - 32)	**°K = C + 273**	**°F = 9/5 C + 32**
°C = Celsius	°K = Kelvin	°F = Fahrenheit

Some Molecular Relationships (at 273 °K)

Pressure Torr	**Molecular density** molec./cm^3	**Molecular collision** molec./cm^2 x sec	**Mean free path** cm	**Monolayer formation** time (sec)
760	3.25×10^{19}	3.78×10^{23}	5.1×10^{-6}	2.2×10^{-9}
10^{-3}	3.25×10^{13}	3.78×10^{17}	5.1	2.2×10^{-3}
10^{-6}	3.25×10^{10}	3.78×10^{14}	5100	2.2
10^{-9}	3.25×10^{7}	3.78×10^{11}	5.1×10^{6}	2200
10^{-12}	3.25×10^{4}	3.78×10^{8}	5.1×10^{9}	2.2×10^{6}

Common Physics Values

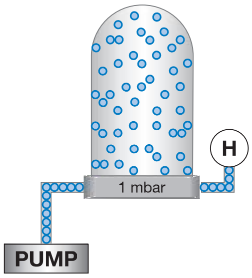
Pressure Conversion Table

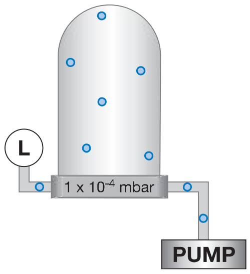
	Torr	**mbar**	**Pa**	**micron**	**psi**	**atm**
1 Torr	1	1.33	133	1000	1.9×10^{-2}	1.32×10^{-3}
1 mbar	0.751	1	100	750	1.4×10^{-2}	9×10^{-4}
1 Pa	7.51×10^{-3}	1×10^{-2}	1	7.5	1.4×10^{-4}	9×10^{-6}
1 micron (mTorr)	1×10^{-3}	1.3×10^{-3}	1.3×10^{-1}	1	1.9×10^{-5}	1.3×10^{-6}
1 psi (a)	51.72	68.96	6.89×10^{3}	5.17×10^{4}	1	7×10^{-2}
1 atm	760	1013	1.01×10^{5}	7.6×10^{5}	14.7	1

Pressure on vacuum technology are always considered absolute pressure.

Gas Flow Characteristics

Viscous Flow	Distance between molecules is small; collisions between molecules dominate; flow is through momentum transfer; generally P greater than 1 millibar.	
	$\bar{p} \times D > 0.7$ (mbar cm);	**$\lambda < D/100$**
	Pressure (millibar) x Diameter (centimeters) = > 0.7	
Transition Flow	Region between viscous and molecular flow	
	$1.3 \times 10^{-2} < \bar{p} \times D < 0.7$ (mbar cm);	**$D/100 < \lambda < D/2$**
Molecular Flow	Distance between molecules is large; collisions between molecules and wall dominate; flow is through random motion; generally P is smaller than 10^{-3} millibar. A system is in molecular flow when the mean free path is longer than the diameter of the tube or chamber.	
	$\bar{p} \times D < 1.3 \times 10^{-2}$ (mbar cm);	**$\lambda < D/2$**
	Pressure (millibar) x Diameter (centimeters) = < 0.013	





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Conductance - Viscous Flow Formulas

Conductance changes according to the pressure in the pipe.
For air at 20 °C:

Aperture $C = 20\,A$ where A = Area, cm^2
C = l/sec

Pipe $C = \frac{137\,D^4}{L}\,\bar{p}$
D = Diameter, cm
P = Pressure, mbar
L = Length, cm

Conductance - Molecular Flow Formulas

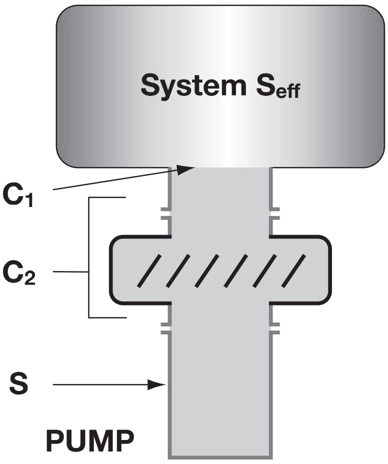
The conductance is independent of the pressure.
For air at 20 °C:

Aperture $C = 11.6\,A$ where A = Area, cm^2
C = l/sec

Long pipe $C = \frac{12.1\,D^3}{L}$
D = Diameter, cm
L = Length, cm
valid when Length >> Diameter

Short pipe $C = \frac{11.6\,A}{1 + L/D}$
D = Diameter, cm
L = Length, cm
valid when Length < 0.7 times Diameter

Series Conductance and Effective Pumping Speed



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

$$C_T = \frac{C_1 \times C_2}{C_1 + C_2}$$

$$\frac{1}{S_{eff}} = \frac{1}{S} + \frac{1}{C_T}$$

$$S_{eff} = \frac{S \times C_T}{S + C_T}$$

where Seff = Effective pumping speed (l/s)
S = Nominal pumping speed (l/s)
C = Conductance (l/s)

Pumping Speed - Conversion Table

		l/s	l/min	m^3/h	CFM
1 liter per second	=	1	60	3.6	2.19
1 liter per minute	=	0.01666	1	0.06	0.0353
1 cubic meter per hour	=	0.287	16.67	1	0.589
1 cubic feet per minute	=	0.472	28.32	1.70	1

Pump Down Calculation (Viscous Flow)

This equation is accurate from start to approximately 1 mbar.
At lower pressures outgassing can become significant.

$$t = \frac{V}{S}\ \ln \frac{Po}{Pf}$$

	multiply by:
t = pump down time (sec)	
S = pumping speed (l/sec)	1.5 for pressure to 0.5 mbar
V = Chamber Volume (l)	2 to 5 x 10^{-2} mbar
Po = beginning pressure mbar	4 to 1 x 10^{-3} mbar
Pf = Final pressure	(ln = 2.3 $\log_{10}$)