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Vacuum and Leak Detection Reference

Formulas, Properties, and Glossary

Training Guide

Help from the Vacuum Experts at Agilent

This reference allows you to keep important properties, formulas, and terms at your fingertips.

Talk with a vacuum expert

Visit our vacuum products or services sites for a wealth of technical information. Or use the ChatNow function from any page to get fast, helpful answers to all your vacuum questions.

www.agilent.com/en/product/vacuum-technologies

www.agilent.com/en/service/vacuum-product-leak-detector-services

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Formulas and Tables

Common physics values

Acceleration Gravity	g = 9.8066 m sec2 (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 = 6.02214076 x 10^{23} mol^{-1} (number of particles per mol)
Molar Volume	= 22.41 liters (at 1 atm and 273 K)
Boltzmann's Constant	1.38064852 × 10^{-23} m^2 kg s^{-2} K^{-1}
Plank's Constant	h = 6.62607 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 10^8 m sec^{-1}
Velocity Of Sound	s = 343 m sec^{-1} (at 20°C and 1 atm)
Standard Pressure	p = 101325 Pa = 1013 mbar (at sea level and 0 °C)
Magnetic Flux Density	T = Tesla (1 gauss G= 10^{-4} Vs m^{-2} = 10^{-4} T)

Ideal Gas Equation

PV = nRT	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
R = molar gas constant		k = Boltzmann's constant
T = Kelvin		T = Kelvin

P	**V**	**T**	**R**
Pascal (N/m^2)	m^3	K	8.314 Joule / K mole
dyne / cm^2	cm^3	K	8.314 • 10^7 erg / K mole
Torr	cm^3	K	6.236 • 10^4 Torr cm^3 / K mole
Torr	liters	K	62.364 Torr liters /K mole
atm	cm^3	K	82.057 atm cm^3 / K mole

Physical properties of gases

Gas	Chemical formula	Molecular weight
Hydrogen	H_2	2.016
Helium	He	4.002
Deuterium	^2H	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
Krypton	Kr	83.80
Xenon	Xe	131.30
Mercury	Hg	200.59

Temperature Scale – Conversion Table

° F	° C	Kelvin	Significance
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

Pressure conversion table

	Torr	mbar	Pa	micron	psi	atm
1 Torr	1	1.33	133	1000	$1.9 \cdot 10^{-2}$	$1.32 \cdot 10^{-3}$
1 mbar	0.751	1	100	750	$1.4 \cdot 10^{-2}$	$9 \cdot 10^{-4}$
1 Pa	$7.51 \cdot 10^{-3}$	$1 \cdot 10^{-2}$	1	7.5	$1.4 \cdot 10^{-4}$	$9 \cdot 10^{-6}$
1 micron (mTorr)	$1 \cdot 10^{-3}$	$1.3 \cdot 10^{-3}$	$1.3 \cdot 10^{-1}$	1	$1.9 \cdot 10^{-5}$	$1.3 \cdot 10^{-6}$
1 psi (a)	51.72	68.96	$6.89 \cdot 10^{3}$	$5.17 \cdot 10^{4}$	1	$7 \cdot 10^{-2}$
1 atm	760	10^{13}	$1.01 \cdot 10^{5}$	$7.6 \cdot 10^{5}$	14.7	1

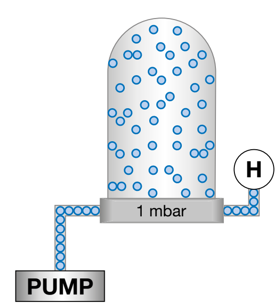
Note: Pressures on vacuum instruments are always considered absolute pressure.

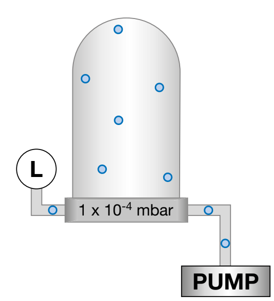
Some molecular relationships (at 273 K)

Pressure	Molecular Density	Molecular Collision	Mean Free Path	Monolayer Formation
Torr	molec./cm^3	molec./cm^2 • sec	cm	time (sec)
760	$3.25 \cdot 10^{19}$	$3.78 \cdot 10^{23}$	$5.1 \cdot 10^{-6}$	$2.2 \cdot 10^{-9}$
10^{-3}	$3.25 \cdot 10^{1}$	$3.78 \cdot 10^{17}$	5.1	$2.2 \cdot 10^{-3}$
10^{-6}	$3.25 \cdot 10^{10}$	$3.78 \cdot 10^{14}$	5100	2.2
10^{-9}	$3.25 \cdot 10^{7}$	$3.78 \cdot 10^{11}$	$5.1 \cdot 10^{6}$	2200
10^{-12}	$3.25 \cdot 10^{4}$	$3.78 \cdot 10^{8}$	$5.1 \cdot 10^{9}$	$2.2 \cdot 10^{6}$

Gas flow characteristics

Viscous Flow	The distance between molecules is small, collisions between molecules dominate, the flow is through momentum transfer, P is generally greater than 1 millibar.	
	$\bar{p} \cdot D > 0.7$ (mbar cm);	$\lambda < D/100$
	Pressure (millibar) x Diameter (centimeters) ≥ 0.7	
Transition Flow	Region between viscous and molecular flow	
	$1.3 \cdot 10^{-2} < \bar{p} \cdot D < 0.7$ (mbar cm);	$D/100 < \lambda < D/2$
Molecular Flow	The distance between molecules is large, collisions between molecules and wall dominate, the flow is through random motion; P is generally 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.	
	$\bar{p} \cdot D < 1.3 \cdot 10^{-2}$ (mbar cm);	$\lambda < D/2$
	Pressure (millibar) x Diameter (centimeters) ≤ 0.013	





Formulas and Tables

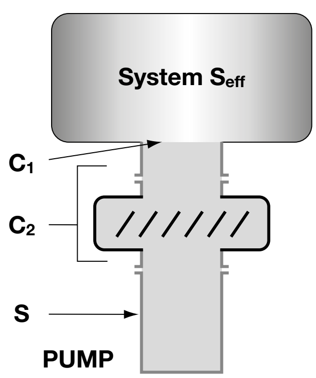
Conductance - Viscous flow formulas

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



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

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

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

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

where:

S_{eff} = Effective pumping speed (l/s)
S = Nominal pumping speed (l/s)
C = Conductance (l/s)

Pumping speed - Conversion table

Pressure	L/s	L/min	m^3/h	Cubic Feet per Minute
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 foot per minute	0.472	28.32	1.70	1

Pump Down calculation (Viscous flow)

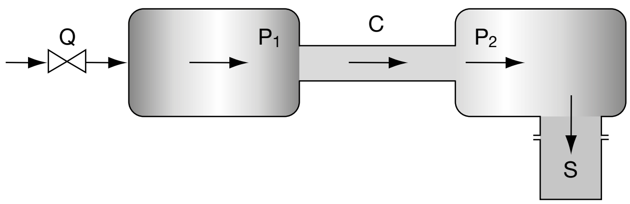
This equation is accurate from start to approximately 1 mbar.
At lower pressures outgassing can become significant.

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

t = Pump down time (sec)
S = Pumping speed (L/sec)
V = Chamber volume (L)
P_o = Beginning pressure mbar
P_f = Final pressure

multiply by:
1.5 for pressure to 0.5 mbar
2 to 5 • 10^{-2} mbar
4 to 1 • 10^{-3} mbar
(ln = 2.3 $\log_{10}$)

Throughput



Throughput: quantity of gas per unit time,

$$Q = C \cdot (P_1 - P_2) = P_2 \cdot S$$

$$\text{or: } Q = \frac{V}{t} P = SP$$

Throughput = Conductance x Pressure = Pressure x Pump Speed

Throughput is expressed in mbar liters/sec, Torr liters/sec, standard cc's/min.

Unit of throughput - flow - leak rate - conversion table

Flow or leak rate	STD (cc/s) atm (cc/s) mbar (L/s)	molecules/s (at 0 °C)	Torr (L/s)	Pa (m³/s)	sccm
	L/s	L/min	m³/h	Cubic Feet per Minute	
1 STD cc/sec – 1 atm cc/sec – 1 mbar l/sec	1	$2.687 \cdot 10^{19}$	0.76	0.1	60
1 molecule/s	$3.72 \cdot 10^{-20}$	1	$2.86 \cdot 10^{-20}$	$3.72 \cdot 10^{-21}$	$2.23 \cdot 10^{-18}$
1 Torr l/sec	1.3	$3.493 \cdot 10^{19}$	1	0.13	80
1 Pa m³/sec	10	$2.687 \cdot 10^{20}$	7.5	1	600
1 sccm	0.016	$4.299 \cdot 10^{17}$	0.0125	0.016	1

Pump down calculation (Molecular flow)

Where gas load is dependent upon outgassing, the final pressure depends on the property of the surface and time necessary to reach the working pressure may be calculated by the following relation:

Where

t = time (hours) necessary to reach the working pressure

Q_{outgas} = gas load referred to time t_0 (generally 1hour)

A = internal area exposed to vacuum

P_{work} = working pressure

S_{eff} = effective pumping speed

Outgassing rate per unit area

Qoutgas	1 h	10 h	100 h
Viton A – Dry	2×10^{-6}	1×10^{-7}	1×10^{-9}
Aluminum – Cleaned	1×10^{-8}	1×10^{-9}	2×10^{-10}
Stainless – Degreased	2×10^{-9}	2×10^{-10}	2×10^{-11}
Stainless – Cleaned	3×10^{-9}	1.5×10^{-10}	2×10^{-11}
Stainless – 24 h baked at 150 °C	4×10^{-12}	4×10^{-12}	4×10^{-12}

$$t = \frac{Q_{outgas} \times A \times t_0}{S_{eff} \times P_{work}}$$

Ultimate pressure

The ultimate pressure of the vacuum system is determined by the pumping speed and the limiting compression for various gases, where Q_i is the gas load from a gas $type_i$, and S_i is the pumping speed for that gas. P_{2i} is the outlet pressure for gas $type_i$ and K_i is the compression ratio of the pump for gas type.

$$P_1 = \left(\Sigma \frac{Q_i}{S_i}\right)_{ext} + \left(\Sigma \frac{Q_i}{S_i}\right)_{int} + \Sigma \frac{P_{2i}}{K_i}$$

Formulas and Tables

Vacuum technology standards

Number	Title
DIN 28400	Vacuum Technology; Designations and Definitions
DIN 28401	Graphic Symbols in Vacuum Technology
DIN 28402	Vacuum Technology: Variables, Symbols, Units - Overview
DIN 28403 ISO 1609 PNEUROP 6606	Vacuum Technology; Quick Connections, Small Flange Connections
DIN 28404 ISO 1609 PNEUROP 6606	Vacuum Technology: Flanges, Dimensions
DIN 28410	Vacuum Technology; Mass Spectrometer Partial Pressure Gauges, Definitions
DIN 28411 ISO 3530.2	Mass Spectrometer type Leak Detector Calibration
DIN 28416	Calibration of Vacuum Gauges – General Method
DIN 28417	Measurement of Throughput by Volumetric Method
DIN 28418 ISO/DIS 3567	Vacuum Gauges – Calibration by Direct Comparison
DIN 28426, part I, II ISO 1607 / 1,2 PNEUROP 6602	Positive Displacement Vacuum Pumps- Measurement of Performance Characteristics. Measurement of Ultimate Pressure
DIN 28427 ISO 1608 / 1,2 PNEUROP 5607	Vapor Vacuum Pumps - Measurement of Performance Characteristics. Measurement of Critical Backing Pressure
DIN 28428 PNEUROP 5608	Vacuum Technology; Acceptance Specifications for Turbo Molecular Pumps
DIN 28429 PNEUROP 5615	Vacuum Technology; Acceptance Specifications for Getter Pumps
DIN 28430 PNEUROP 6601	Measurement of Performance of Ejector Vacuum Pumps and Ejector Compressors
ISO 1314	Pressure; Basic Definitions, Units
ISO 3529 I,II,III	Vacuum Technology Vocabulary
ISO/DIS 3556 / 1	Sputter Ion Pumps - Measurement of Performance Characteristics.
ISO/DIS 3568	Ionization Vacuum Gauges – Calibration by direct comparison
ISO/DIS 3570 / 1	Vacuum Gauges – Standard Methods for Calibration
ISO/DIS 3669	Bakeable Flange Dimensions
PN5ASR CC/5	Vacuum Pumps, Acceptance Specifications Refrigerator Cooled Cryopumps

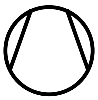
ISO - International Standardization Organization – Switzerland

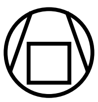
DIN - Deutsches Institut fuer Normung - Germany

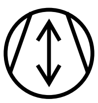
PNEUROP – European Committee of Manufacturers of Compressors, Vacuum Technology, Pneumatic Tools, Air Treatment Equipment and Condensate Treatment Equipment - England

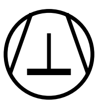
Graphic Symbols in Vacuum Technology DIN28401

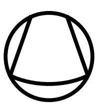
Vacuum pumps

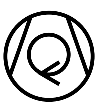
 Vacuum pump, general

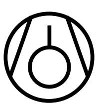
 Positive displacement pump

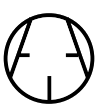
 Positive displacement pump, oscillating

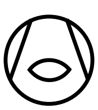
 Piston vacuum pump

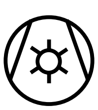
 Diaphragm vacuum pump

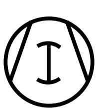
 Rotary positive displacement pump

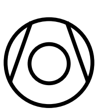
 Rotary plunger vacuum pump

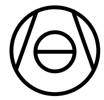
 Sliding vane rotary vacuum pump

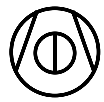
 Rotary piston vacuum pump

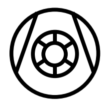
 Liquid ring vacuum pump

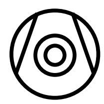
 Roots vacuum pump

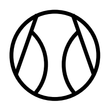
 Turbine vacuum pump, general

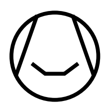
 Radial flow pump

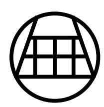
 Axial flow pump

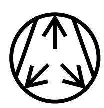
 Gas ring vacuum pump

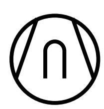
 Turbomolecular pump

 Ejector vacuum pump

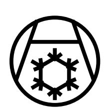
 Diffusion pump

 Adsorption pump

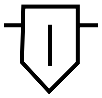
 Getter pump

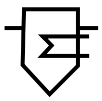
 Sublimation (evaporation) pump

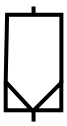
 Sputter ion pump

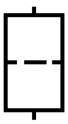
 Cryopump

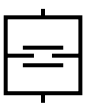
Vacuum pump accessories

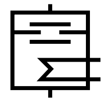

Condensate trap, general

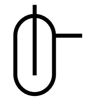

Condensate trap whit heat exchange (e.g., cooled)

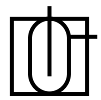

Gas filter, general

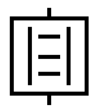

Filtering apparatus, general


Baffle, general

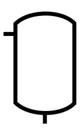

Cooled baffle

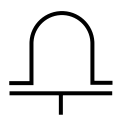

Cold trap, general


Cold trap with coolant reservoir

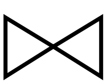

Sorption trap

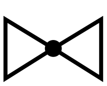
Vacuum chambers

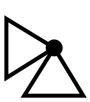

Vacuum chamber

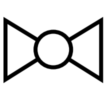

Vacuum bell jar

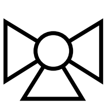
Isolation devices

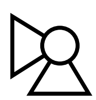

Shut-off device, general

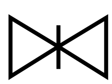

Isolating valve

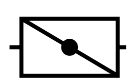

Right angle valve

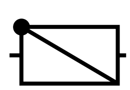

Stop cock

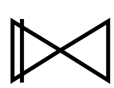

Three-way stop cock


Right-angle stop cock

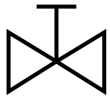

Gate valve

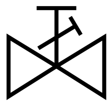

Butterfly valve

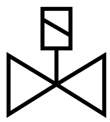

Non-return valve

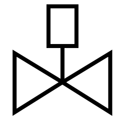

Safety shut-off device

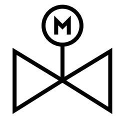
Valve mode of operation


Manual operation

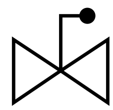

Variable leak valve


Electromagnetic operation

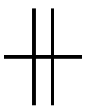

Hydraulic or pneumatic operation

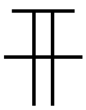


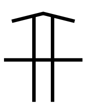
Electric motor operation

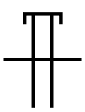

Weight-operated

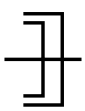
Connections and tubes

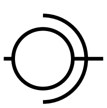

Vacuum pump, general

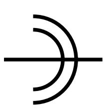

Positive displacement pump

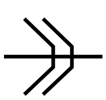

Positive displacement pump, oscillating


Piston vacuum pump

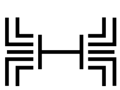

Diaphragm vacuum pump

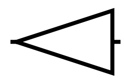

Rotary positive displacement pump


Rotary plunger vacuum pump

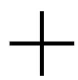

Sliding vane rotary vacuum pump

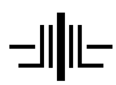

Rotary piston vacuum pump


Rotary piston vacuum pump

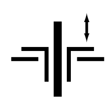

Change in the cross section of a duct

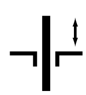

Intersection of two ducts with connection

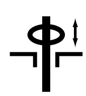

Crossover of two ducts without connection

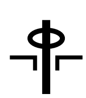

Electric current leadthrough


Flexible connection
(e.g., bellows, flexible tubing)

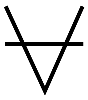

Linear motion leadthrough, flange-mounted


Linear motion leadthrough, without flange


Leadthrough for transmission of rotary and linear motion


Rotary transmission leadthrough

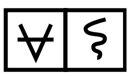
Vacuum gauges



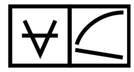
General symbol for vacuum

Vacuum measurement, gauge head

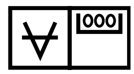
Vacuum gauge, gauge control unit



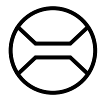
Vacuum gauge, control unit recording



Vacuum gauge control unit with dial indicator



Vacuum gauge control unit with digital indicator



Measurement of throughput

Glossary of Vacuum Terminology

Absolute pressure — See pressure, absolute.

Absolute temperature — The temperature scale that starts at "true" or absolute zero. It is often called the Kelvin scale.

Absorption — The binding of a gas in the interior of a solid or liquid.

Adsorption — The condensing of a gas on the surface of a solid.

Atmosphere, standard — See standard atmosphere.

Atom — The smallest identifiable part of an element. An atom has a nucleus with particles called protons and neutrons. Under normal conditions, it is surrounded by a number of electrons equal to the number of protons. Neutrons are neutral, protons are positively charged, and electrons are negatively charged.

Atom mass unit — A way of classifying atoms according to their weight, or mass. Atoms of the different elements have different weights, or masses.

Avogadro's Law — The gas law that states that one mole of any gas has 6.023×10^{23} particles, and under standard conditions occupies 22.4 liters.

Backing pump — See forepump.

Backstreaming — The small amount of pump fluid vapor that moves in the wrong direction, i.e., toward the work chamber.

Bakeout — The degassing of a vacuum system by heating during the pumping process.

Bar — Unit of pressure measurement. There are 1.010 bar in one standard atmosphere. One bar equals 1 x 106 dynes per square centimeter.

Base pressure — That pressure which is typically reached with your system when it is clean, empty, and dry.

Blower pump — A type of vacuum pump which functions from 10 Torr to 0.0001 Torr. Also called a booster or Roots pump.

Body — That part of a valve which contains the external openings for entrance and exit of the controlled fluid.

Bomb test

A method of helium leak testing where sealed parts are enclosed in a container that is pressurized with helium. Parts that have a leak will then have helium forced into them. This process is known as bombing. Afterwards, parts are removed from the pressurized bombing container and then checked with a helium leak detector to detect if any helium is leaking from the parts, thus indicating a leaking part.

Bonnet

In general, that part of the valve through which the stem enters the valve, and which is rigidly attached to the valve body.

Bourdon gauge

A roughing gauge that responds to the physical forces that a gas exerts on a surface.

Boyle's law

The gas law that states $P_{1V1} = P_{2V2}$, or original pressure times original volume equals new pressure times new volume. This equation predicts new pressure or new volume whenever the other is changed by any amount (providing that the temperature is unchanged).

Calibrated leak

An external reference standard that permits calibration of a helium leak detector.

Capacitance manometer

A vacuum gauge which senses pressure by the change in capacitance between a diaphragm and an electrode.

Charles' law

The gas law that describes what happens to the volume of gas as the temperature is changed. As a gas is cooled, its volume gets smaller. As a gas is heated, its volume increases (at constant pressure).

Chemisorption

The binding of a gas on or in a solid by chemical action. (See gettering.)

Closed-loop refrigeration system

A refrigeration system in which the coolant is recycled continuously.

Cold cap

A component mounted on top of the jet assembly in a diffusion pump. This cap helps to keep pump fluid vapor out of the work chamber.

Cold cathode discharge

A visible glow caused by the recombination of electrons and ions. The color is characteristic of the gas species present.

Cold cathode gauge

See ionization gauge.

Cold trap

See cryotrap.

Condensatíon

The process of a gas turning back into a liquid.

Conductance

A term used to indicate the speed with which atoms and molecules can flow through a particular region such as an orifice or pipe.

Conductance limited

The inability to make use of the rated speed of a pump due to the use of an opening or pipe smaller than the inlet diameter of the pump.

Conduction — The transfer of energy (heat, light, etc.) by direct contact. In the case of gaseous conduction, the transfer of energy by molecules directly contacting surfaces and other molecules.

Convection — The transfer of heat from one place to another by the circulation of currents of heated gas or other fluid.

Critical forepressure — See maximum tolerable foreline pressure.

Crossover — The pressure at which a vacuum chamber is changed from being pumped by a roughing pump to being pumped by a high vacuum pump.

Cryocondensation — The pumping of gases that are condensed at cold temperatures. For example, water vapor on a liquid nitrogen trap at -196 °C undergoes cryocondensation.

Cryosorption — The pumping of gases that are not readily condensed (or pumped) at cold temperatures, by the process of sticking onto a cold surface.

Cryotrap — A device usually placed before the inlet of a high vacuum pump to “trap” or freeze out gases such as pump oil vapor and water vapor. Cryotraps commonly use liquid nitrogen as the coolant. Also called cold trap or liquid nitrogen trap.

Degassing — The removal of gas from a material, usually by application of heat under high vacuum. (See bakeout.)

Desorption — See outgassing.

Diffusion

1. The flow of one substance through another by random molecular motion.
2. The process by which molecules intermingle as a result of their thermal motion.

Diffusion pump — A vapor pump having boiler pressures of a few Torr and capable of pumping gas continuously at intake pressures. These do not exceed about 2 mTorr, and discharge pressures (forepressures) do not exceed about 500 mTorr.
The term diffusion should be applied only to pumps in which the pumping action of each vapor jet occurs as follows: The gas molecules diffuse through the low-density scattered vapor into the denser, forward-moving core of the freely expanding vapor jet. Most of the gas molecules are then driven at an acute angle toward the wall and on into the fore vacuum.

Dynamic seal — A seal that moves. (See static seal.)

Electron — A negatively charged particle. (See atom.)

Evaporation — The process that happens when a liquid or solid becomes a gas.

Feedthrough — A device used to allow some sort of utility service to go from the outside world to the inside of a vacuum system, while maintaining the integrity of the vacuum. An example is an electrical feedthrough.

Foreline — The section of a pump through which the gases leave. The exhaust line of a pump.

Foreline valve — A vacuum valve placed in the foreline to permit isolation of the pump from the forepump.

Forepump — The pump which is used to exhaust another pump, which is incapable of discharging gases at atmospheric pressure. Also called the backing pump.

Fractionation — A process that helps to purify the condensed fluid in a diffusion pump. This process removes contaminants produced by decomposition of pump fluid.

Gas — A state of matter where the individual particles are free to move in any direction and tend to expand uniformly to the confines of a container.

Gas ballast — A method used with any oil-sealed rotary pump which allows a quantity of air to be admitted during the compression cycle to prevent condensation of water vapor. The amount of air admitted is regulated by the gas ballast valve. The use of the gas ballast raises the ultimate pressure of the pump.

Gas density — The number of molecules per unit of volume.

Gas load — See pressure, gauge.

Gay-lussac's law — The gas law that states that if the temperature of a volume of gas at 0 °C is changed by 1 °C, the volume will change (plus or minus, as appropriate) by 1/273 of its original value.

General gas law — The gas law that covers pressure, volume, and temperature in one single equation, or $P_1V_1T_2 = P_2V_2T_1$.

Gettering — A method of pumping gases through chemical reaction of a material with gas molecules. The material usually used is an active element such as titanium. (see chemisorption.)

Helium mass spectrometer leak detector (hmsld) — See mass spectrometer leak detector.

High vacuum — Pressure which ranges from about 10^{-4} Torr (0.0001 Torr) to approximately 10^{-8} Torr (0.00000001 Torr).

High vacuum pump — A vacuum pump which will function in the high vacuum range. Common examples are the diffusion pump and the mechanical cryopump.

High vacuum valve — A large diameter valve usually placed between the vacuum chamber and the vacuum pumps. It is used to isolate the vacuum chamber from the pumps when it is necessary to work on something in the chamber. Also called hi-vac valve, gate valve, or trap valve.

Implosion — In vacuum work, the inward collapse of the walls of a vacuum system, caused by external pressure.

Ion

A charged particle consisting of an atom or molecule which has an excess of positive or negative charges. Typically produced by knocking an electron(s) out of an atom or molecule to produce a net positive charge.

Ionization

The process of creating ions. (See ion.)

Ionization gauge

A vacuum gauge that has a means of ionizing the gas molecules, electrodes to enable the collection of the ions formed, and a means of indicating the amount of the collected ion current. Various types of ionization gauges are identified according to the method of producing the ionization. The common types are:

1. Hot cathode ionization gauge. The ions are produced by collisions of gas molecules with electrons emitted from a hot filament (or cathode) and accelerated by an electric field. Also called hot-filament ionization gauge, or simply ion gauge.
2. Cold cathode ionization gauge. The ions are produced by a cold cathode discharge, usually in the presence of a magnetic field, which lengthens the path of the electrons.

Ion pump

An electrical device for pumping gas. The ion pump includes a means for ionizing the gas with a system of electrodes at suitable potentials, and also a magnetic field. The ions formed move toward a cathode or a surface on which they are reflected, buried, or cause sputtering of cathode material.

Jet assembly

A nozzle assembly that directs oil vapors in a diffusion pump.

Leak

Leaks may be of three different types:

1. A real leak, which is a crack or hole allowing gases to pass through;
2. A virtual leak, which is caused by outgassing of some volatile material inside a vacuum system or trapped volume;
3. A permeation leak, which consists of atomic-scale holes throughout the material of construction (For example, O-rings are quite permeable).

Leak detector

A device for detecting, locating, and/or measuring leakage.

Leak rate

Mass flow through an orifice per unit time. Vacuum system leakage rates are typically measured in atm-cc per second or Torr-liters per second.

Liquid nitrogen trap

See cryotrap.

Mass

A fundamental characteristic of matter which is most closely related to the unit of weight.

Mass spectrometer (ms)

An instrument that is capable of separating ionized molecules of different mass/charge ratios and measuring the respective ion currents. The mass spectrometer may be used as a vacuum gauge that measures the partial pressure of a specified gas, as a leak detector sensitive to a particular tracer gas, or as an analytical instrument to determine the percentage composition of a gas mixture.

Mass spectrometer Leak detector
A mass spectrometer adjusted to respond only to the tracer gas. Helium is commonly used as the tracer gas, and thus the instrument is normally referred to as a helium leak detector.

Maximum tolerable Foreline pressure
A measure of the ability of the diffusion pump to pump gases against a certain discharge pressure. Also called critical forepressure.

Mean free path
The average distance between molecular collisions. Of importance for vacuum systems is where one is interested in getting a particular type of particle from a source to a surface. Examples include ion implanters, coaters, or television tubes.

Micron
Unit of length equal to one millionth of a meter.

Millibar
Unit of pressure measurement, equal to 1/1000 bar.

Millimeter of mercury
See Torr.

Millitorr
Unit of pressure measurement, equal to 1/1000 Torr.

Mole
The number of particles in equal volumes of gases under the same conditions of temperature and pressure. One mole of any gas has $6.023 \cdot 10^{23}$ particles.

Molecular density
The number of molecules in a unit of volume such as a cubic centimeter. There are approximately $3 \cdot 10^{19}$ molecules per cc at one standard atmosphere.

Molecular flow
The type of flow that occurs in the range of pressures in which gas molecules are fewer and spread far apart. Fewer collisions occur, the mean free path is longer, and molecules tend to act independently of each other.

Molecular sieve
A very porous material used to contain the pumped gases in sorption pumps. May also be used in a foreline trap to contain oil molecules.

Molecular sieve trap
A device used to collect oil vapors backstreaming from oil-sealed mechanical pumps.

Molecular weight
A way of classifying molecules according to their weight, or mass. Molecular weight or mass is the sum of the individual atomic weights that make up the molecule.

Molecule
One atom, or two or more atoms joined together and having definite chemical and physical characteristics.

Neutron
A particle located in the nucleus of an atom which has no electrical charge but does have mass. (see atom.)

Neutron
The dense center portion of an atom containing protons and neutrons. (see atom.)

Open-loop refrigeration system
A refrigeration system in which the coolant vents to atmosphere.

Outgassing

The process in which a gas particle leaves a surface and moves into the volume of a vacuum chamber. This adds to the gas load and may or may not be desirable. In extreme cases, it prevents pumping down a vacuum system to the specified pressure. The system is then said to be outgassing, also called desorption or virtual leak.

Outside-in leak detection Technique

A leak detection technique where the leak detector senses a tracer gas that passes from the outside of the container to the inside of the container. May be used to determine the size and/or the location of a leak.

Partial pressure

See pressure, partial.

Pascal

Unit of pressure measurement. There are 101,325 pascals in one standard atmosphere. A pascal equals one newton per square meter.

Permeation leak

Molecular-scale holes through a material of construction. (see leak.)

Pirani gauge

A vacuum gauge used to measure pressure in the rough vacuum range.

Powers of ten

A convenient way of describing very large and very small numbers.
A number is written as some value from 1 and up to 10 (but not including 10). Then, it is multiplied by either a positive or negative power of ten. Also called exponential notation or scientific notation.

Pressure

Force per unit area. The force is created when atoms, molecules, or particles strike the walls of their container. Common pressure units for vacuum work are Torr, pounds per square inch relative (psig), inches of mercury, millimeters of mercury, bar, millibar, and pascal.

Pressure, absolute

Pressure above zero pressure (corresponding to totally empty space) as distinguished from gauge pressure. In vacuum technology, pressure is always measured from zero pressure, not atmospheric pressure, and therefore the term absolute pressure is not required.

Pressure, gauge

The difference between absolute pressure and atmospheric pressure. The most common unit is psig.

Pressure measurement

A measurement of the pressure (the number and intensity of particle impacts) on a given unit of area. There are several different scales for pressure measurement: for example, Torr, milliTorr, bar, millibar, and pascal. These scales may be used as absolute or relative scales.

Pressure, partial

A measurement of the pressure of one particular gas in a mixture of gases. For example, the partial pressure of oxygen in air is about 160 Torr.

Pressure, relative

See pressure, gauge.

Pressure, total

The sum of all of the partial pressures of every gaseous species. The force exerted by all the gas molecules in any mixture of gases. We commonly assume that a pressure gauge reads total pressure.

Pressure, vapor — The pressure exerted by molecules after they have escaped from a liquid or solid and formed a vapor (gas). One tries, in general, to put substances of low vapor pressure into a vacuum system so as to decrease the gas load on the vacuum pumps.

Pressure, vapor — The pressure exerted by molecules after they have escaped from a liquid or solid and formed a vapor (gas). One tries, in general, to put substances of low vapor pressure into a vacuum system so as to decrease the gas load on the vacuum pumps.

Probe — A tube having a fine opening at one end, used for directing or collecting a stream of tracer gas.

Probe test — A leak test in which the tracer gas is applied by means of a probe so that the area covered by a tracer gas allows the tracer gas to enter and locate the leak.

Proton — A positively charged particle. (See atom.)

Psia — Pounds per square inch absolute, a unit of pressure measurement.
There are 14.69 psia in one standard atmosphere.

Psig — Pounds per square inch gauge, a unit of pressure measurement. Gauge pressure is the difference between absolute pressure and atmospheric pressure. One standard atmosphere equals 0 psig.

Pump-down curve — A graphic plot of pressure versus time as a vacuum system is being pumped. Usually plotted on graph paper. Can be used to distinguish real leaks from virtual leaks.

Pumping speed — A measure of the ability of a vacuum pump to remove gases. It is typically measured in liters per second, cubic feet per minute, or cubic meters per hour.

Radiation — Heat transfer by energy from infrared light. Radiated heat is the only way to transfer heat inside of a vacuum system at high vacuum.

Rate of rise — The rate of pressure increase versus time when a vacuum system is suddenly isolated from the pump by a valve. The volume and temperature of the system are held constant during the rate-of-rise measurement.

Rate-of-rise test — A method of determining whether a leak is present in a system, or of obtaining an estimate of the magnitude of a leak, by observing the rate of rise of pressure in the evacuated system when the system is isolated from the pump. This method also can determine if leakage is real or virtual.

Real leak A crack or hole that allows gases to pass through in both directions. (See leak.)

Regeneration Some vacuum pumps and traps fill up from usage (containment pumps) and must be emptied periodically. The process of emptying the pump is called regeneration.

Residual gas analyser A gauge that measures partial pressure.

Roots blower See blower pump.

Roughing The initial evacuation of a vacuum system.

Rough pump A vacuum pump which will function in the rough vacuum range. A roughing pump is often used to "rough" a vacuum chamber. Typical examples of rough pumps are the mechanical pump and the sorption pump.

Rough vacuum Pressure which ranges from just below atmospheric pressure to about 10^{-3} Torr (0.001 Torr).

Sniffer probe See probe. (Also called a detector probe.)

Sputtering The release of one or more molecules from a cathode surface when that surface is struck by a high-energy ion.

Standard atmosphere At 45° N latitude, at sea level, and 0 °C, the average pressure exerted on the earth's surface. This average pressure is 14.69 pounds per square inch (absolute), or 14.69 psia.

Standard cubic centimeter The quantity of gas in a volume of 1 cc at standard temperature and pressure (0 °C, 760 Torr).

Static seal A seal that does not move. (See dynamic seal).

Sublimation The process in which a substance can go directly from the solid state to the vapor state, without passing through a liquid state.

Sublimes Changes directly from a solid to a vapor state.

Tc gauge See thermocouple gauge.

Temperature A qualitative measurement of energy. The hotter something is, the more energy it contains, thus its temperature is higher.

Thermal expansion rate Materials change in size as their temperature changes. This size-to-temperature relationship of the material is called its thermal expansion rate.

Thermocouple gauge A vacuum gauge used to measure pressure in the rough vacuum range.

Throughput Pumping speed times pressure, used to express the quantity of gas per unit of time flowing through a vacuum system or component, such as a pump. Typical unit of measure is Torr-liters per second. It is a unit of power; 5.70 Torr-liters/sec = 1 watt.

Torr Unit of pressure measurement, equal to the force per unit area exerted by a column of mercury one millimeter high. There are 760 Torr in one standard atmosphere.

Tracer gas A gas which, passing through a leak, can be detected by a specific leak detector and thus reveal the presence of a leak.

Transfer pressure See crossover pressure.

Transition range A range of pressure that cannot be defined as either a viscous flow condition or molecular flow condition.

Trap A device which will hold selected molecules and not let them pass. Two common types are the molecular sieve trap and the liquid nitrogen trap.

Tubulation A pipe or hose used in a vacuum system.

Ultimate pressure The lowest pressure a vacuum pump or vacuum system can reach when clean and empty. Is dependent upon the particular gas species being pumped.

Ultrahigh vacuum Pressure which ranges from about 10^{-8} Torr (0.00000001 Torr) to less than 10^{-14} Torr.

Ultrahigh vacuum pump A vacuum pump which will function in the ultrahigh vacuum range. Typical examples are the ion pump and the TSP (titanium sublimation pump).

Useful operating range The pressure range of a vacuum pump between the higher pressure limit where it will begin pumping, and the base (or ultimate) pressure, which is the pump's lower operating limit.

Vacuum Any pressure lower than atmospheric pressure.

Vacuum pump A type of pump which is capable of removing the gases in an enclosed volume such as a vacuum chamber.
Vacuum pumps are typically divided into three broad categories:

1. roughing pumps,
2. high vacuum pumps,
3. ultrahigh vacuum pumps.

Vapor The gas produced as a result of evaporation.

Vapor pressure See pressure, vapor.

Vent valve A valve used for letting atmospheric air or other gas into a vacuum system. Also called a back-to-air valve.

Virtual leak An apparent leak that is caused by release of gas from a trapped volume or outgassing of some volatile material or trapped gas inside a vacuum system. (see leak.)

Viscous flow

The type of flow which occurs when gas molecules are packed closely together and collide with each other quite frequently.

Work chamber

A contained volume from which some of the air and other gases have been removed. The work chamber separates the vacuum from the outside world. The portion of a vacuum system where the process is performed. (See bell jar.)

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