AGILENT TRAINING

IngenieríaAnalítica

Chromatography & Spectrometry

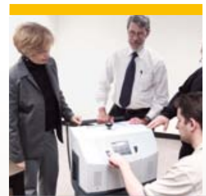
Agilent Technologies

FEATURES AND BENEFITS

Since our invention of the VacIon ultra-high vacuum pump over 40 years ago, Varian, now Agilent, has maintained a leadership position in vacuum and leak detection technology for industrial and scientific applications.
Agilent's highly-regarded training program is staffed by dedicated professional trainers with the expertise and experience to provide comprehensive and thorough instruction on a broad range of vacuum and leak detection technologies. Limited enrollment ensures attendees have ample opportunity to interact with instructors, and to participate in demonstration activities during courses utilizing Agilent's fully-equipped labs.
Courses are offered at Agilent training facilities in Santa Clara, CA and Lexington, MA (USA), at regional locations throughout North America, and at Agilent training facilities in Europe, and at customer locations world-wide.
Agilent's Training Department develops cost-effective customized vacuum and leak detection training programs tailored to meet specific training requirements for course content and duration. Agilent's professional trainers deliver custom training programs at customer locations world-wide through our Custom On-Site Training program.

Please visit our website at
www.agilent.com/chem/vacuum
Open the Training & Events tab,
Select "Training Courses"
In the Product Line box at left, select "Vacuum Technologies".

for training dates, locations, prices and registration forms, or contact Agilent toll free in the United States at
1 (800) 882 7426, or Toll Free in Europe at 00 (800) 234 234 00.

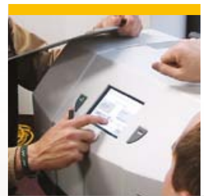


Trainer's Expertise
Agilent's dedicated training professionals bring years of experience in a wide range of vacuum and leak detection applications to the classroom.

Course Offering
Agilent offers a broad range of Vacuum, Leak Detection and Equipment Operation & Maintenance courses to suit every customer's need, with regularly scheduled courses, or through our On-Site Training programs.

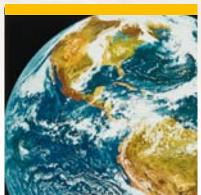
Small Class Sizes
Limited course enrollment enhances student-trainer interaction and promotes participation by students.

Vacuum Demo Labs
Fully equipped laboratory facilities provide access to a variety of vacuum pumps, gauges and components.



Methodology
A combination of theory and hands-on activities are used to facilitate and reinforce the learning process.

Local languages
Courses held in Europe are taught in English, French, German and Italian, using training materials in the native language, and taught by instructors fluent in the native language.



Locations
Regularly scheduled courses are held at Agilent locations in the US and Europe. On-Site courses are also available for customers' convenience.

Basic Vacuum Practice (BVP) — 3 Days

Course Description

This course provides practical information on vacuum system operation, performance, and maintenance, as well as a comprehensive treatment of vacuum technology. In addition, the process of using a Helium Mass Spectrometer Leak Detector (HMSLD) to locate vacuum system leaks is thoroughly covered. Gain the practical knowledge to properly characterize, operate, and maintain your vacuum system for maximum uptime. Lab equipment, including a turbo-pumped high vacuum system and an HMSLD, is provided for instructor-led demonstrations. Participants will receive the Basic Vacuum Practice Workbook, an excellent source of practical information.

Basic Vacuum Practice is the required prerequisite for Leak Rate Test and Measurement (LRTM-BC) and Advanced Vacuum Practice (AVP).

Who Should Attend?

Technicians, engineers, and scientists who use vacuum technology in their work environment and who need to acquire a detailed understanding of the underlying principles, as well as become proficient at operating and maintaining vacuum systems.

Course Goals and Objectives

After completing this course, participants will be able to:

- Describe gas properties and laws
- Properly pump-down and cycle vacuum systems
- Identify advantages and disadvantages of available pumping methods
- Select appropriate gauging and materials at different vacuum levels
- Describe routine maintenance requirements for pumps and components
- Characterize vacuum system performance
- Describe HMSLD principles of operation
- Properly operate, tune, and calibrate a HMSLD
- Troubleshoot and locate vacuum system leaks

Course Outline

Day 1

Introduction to Vacuum Applications and Fundamentals

- Working with numbers and temperature scales
- Understanding matter, pressure, gas properties
- Vapor pressure and outgassing
- Gas flow and conductance
- Pumping speed and throughput
- Overview of vacuum pumping methods
- Rough Vacuum Systems
  - Gauges
  - Wet and dry mechanical pumps
  - Traps and filters
  - Sorption (entrapment) pump
  - Pump comparison
  - *Demo Lab*: Rough vacuum system operation

Day 2

High & Ultra High Vacuum Systems

- High Vacuum
  - Gauges
  - Turbo pumps/controllers and diffusion pumps
  - Baffles and traps
  - Cryopumps
  - Pump comparison
  - System configurations and operation
  - Demo Lab: High vacuum system assembly and operation
- Ultra High Vacuum
  - Outgassing issues
  - Gauges
  - Ion pumps
  - Non-evaporative getter pumps
  - Titanium sublimation pumps
  - System configurations and operation

Day 3

Vacuum Materials and Hardware

- Material selections
- Joining techniques
- Fittings, feedthroughs, and valves
- Vacuum system performance and troubleshooting
- Characterizing the system
- Problems and sources
- Methods, techniques, and tools
- Helium Leak Detector
  - Principles of operation
  - Tuning and calibration procedures
  - Vacuum system leak-checking techniques
  - Demo Lab: System performance troubleshooting and leak detection

Leak Rate Test and Measurement: BVP-Companion (LRTM-BC) — 1 Day

Course Description

Basic Vacuum Practice is the required prerequisite and scheduled to immediately precede LRTM-BC. This course is a "companion" to the BVP course: building on the vacuum and Helium Mass Spectrometer Leak Detector (HMSLD) fundamentals learned in BVP, it provides an introduction to production testing of parts against leak-rate specifications, and measuring and locating leaks in pressurized systems/ components, using an HMSLD. Leak testing methods designed to solve various problems are discussed and demonstrated.

Excellent for product/manufacturing engineers and equipment operators, this intensive program addresses the advantages and limitations of various leak-testing techniques and explores ways to get the best performance from an HMSLD. Lab equipment, including popular helium mass spectrometer leak detectors and various application test fixtures, is provided for instructor-led demonstrations.

Who Should Attend?

Engineers and operators who are responsible for quality control of production parts and assemblies. Also, technicians responsible for the maintenance of pressurized and evacuated systems such as those found in power generation facilities, process gas delivery, and refrigeration, etc.

Course Goals and Objectives

After completing this course, participants will be able to:

- Identify advantages and disadvantages of various leak testing methods
- Describe leak rate specifications and helium conversions.
- Select, setup, and perform the proper leak test technique for a given application

Course Outline

Introduction to Leak Detection
- Why leak test?
- Leak detection operations
- Understanding leak rate
- Leak detection methods

Leak Rate Specification Conversions
- Specification leak rate vs. std cc/sec
- Specification pressure vs. test pressure
- The helium leak rate

Locating Leaks
- Spray and sniffer probe techniques
- *Demo Lab*: Find leaks in evacuated and pressurized parts

Measuring Leak Rate
- Leak rate testing software overview
- Hard vacuum: Inside-out testing (pressurized part)
- Hard vacuum: Outside-in testing (evacuated part)
- Bombing
- Accumulation testing
- *Demo Lab*: Measure leak rates

Application Specific Leak Rate Testing Examples
- Hermetically sealed parts
- Pressurized parts: accumulation method (joints/welds/ crimps, AC lines, brake lines, valves)
- Pre-pressurized parts in large vacuum chamber (compressor, heater core, wheel, gas tank, transmission, torque converter)
- Parts with pressure differential intolerance (gas tanks, gas caps, filler necks)
- Small part/high sensitivity
- Long narrow tubes
- Process gas components and systems

Leak Rate Test and Measurement: Stand-Alone (LRTM-SA) — 2 Days

Course Description

This "Stand-Alone" course provides an all inclusive introduction to production testing of parts against leak rate specifications, and measuring and locating leaks in pressurized systems and components, using a Helium Mass Spectrometer Leak Detector (HMSLD). Principles of operation of the spectrometer and underlying vacuum fundamentals are presented in a classroom setting. Operation, tuning, and calibration of the leak detector are covered in practical demonstration/laboratory sessions. Leak testing methods designed to solve various problems are discussed and demonstrated.

Excellent for product/manufacturing engineers and equipment operators, this intensive program addresses the advantages and limitations of various leak-testing techniques and explores ways to get the best performance from an HMSLD. Lab equipment, including popular helium mass spectrometer leak detectors and various application test fixtures, is provided for instructor-led demonstrations.

Who Should Attend?

Engineers and operators who are responsible for quality control of production parts and assemblies. Also, technicians responsible for the maintenance of pressurized and evacuated systems such as those found in power generation facilities, process gas delivery, and refrigeration, etc.

Course Goals and Objectives

After completing this course, participants will be able to:

- Describe gas properties and laws
- Identify advantages and disadvantages of various leak testing methods
- Explain vacuum fundamentals and concepts essential to the operation of an HMSLD
- Describe principles of operation of a mass spectrometer
- Properly operate, tune, and calibrate an HMSLD
- Describe rate-leak specifications and helium conversions
- Select, setup, and perform the proper leak test technique for a given application

Course Outline

Day 1

Introduction to Leak Detection
- Why leak test?
- Leak detection operations
- Understanding leak rate
- Leak detection methods

Vacuum Fundamentals for Leak Detection:
- Working with numbers and temperature scales
- Understanding matter, pressure, gas properties
- Vapor pressure, outgassing, gas flow, conductance.
- Pumping speed and throughput

Introduction to Rough Vacuum Systems
- Operating pressure range and gauging
- Wet and dry pump operations
- System operation
- *Demo Lab*: Roughing pumpdown

Introduction to High Vacuum Systems
- Operating pressure range and gauging
- Turbo pump and system operation

Helium Leak Detector Fundamentals
- System components
- Vacuum system architecture
- Spectrometer: operation, tuning, zeroing, calibration
- *Demo Lab*: Tuning, zeroing, and calibration

Day 2

HMSLD performance considerations
- Response/appearance time
- Cleanup time (disappearance)

Leak-Rate Specification Conversions
- Specification leak rate vs. standard cc/second
- Specification pressure vs. test pressure
- The helium leak rate locating leaks
- Spray and sniffer probe techniques
- *Demo Lab*: Find leaks in evacuated and pressurized parts

Measuring Leak Rate
- Leak-rate testing software overview
- Hard vacuum: Inside-out testing (pressurized part)
- Hard vacuum: Outside-in testing (evacuated part)
- Bombing
- Accumulation testing
- Demo Lab: Measure leak rates

Application-Specific Leak-Rate Testing examples
- Hermetically sealed parts
- Pressurized parts: accumulation method (joints/welds/crimps, AC lines, brake lines, valves)
- Pre-pressurized parts in large vacuum chamber (compressor, heater core, wheel, gas tank, transmission, torque converter)
- Parts with pressure-differential intolerance (gas tanks, gas caps, filler necks)
- Small part/high sensitivity
- Long narrow tubes
- Process gas components and systems

Advanced Vacuum Practice (AVP)

3 Days

Course Description

Basic Vacuum Practice is the required prerequisite. Building on Basic Vacuum Practice (BVP), this course begins with a short review of vacuum theory and moves on to calculations for building and characterizing a vacuum system designed to perform at specified pressures. Participants use lab facilities to build and test vacuum system designs. Knowledge gained from this class will be extremely valuable for vacuum applications in the semiconductor, R&D, and manufacturing sectors.

Who Should Attend?

Lab technicians, engineers, university students, professors, and research scientists who use vacuum technology in their work environment and who need to specify and configure vacuum systems that meet various application performance requirements.

Course Goals and Objectives

After completing this course, participants will be able to:

- Evaluate vacuum system performance
- Comprehensively describe effects of outgassing, permeation, and leaks
- Select proper materials to minimize gas load
- Perform calculations to estimate gas load, pumping speed, and pumpdown time
- Calculate conductance values
- Select appropriate pumps and gauging
- Design, build, and evaluate an elementary vacuum system

Course Outline

Day 1

Gas and Surface Physics

- Macroscopic properties
- Microscopic properties
- Surface effects
- Vapor Pressure review vacuum technology
- Gas flow
- Speed calculations
- Chamber pumpdown
- Working with Q=SP

Rough Vacuum

- Vacuum system design criteria
- Rough vacuum pump and gauge selection
  – Criteria, pumps, specifications, comparisons
  – Pumpdown calculations
  – Load lock dilution pressure
- *Hands-On Lab*: Calculate roughing system pumpdown; assemble and measure

Day 2

Conductance Calculations

- End effects
- Formulas and their usage
- Effective pumping speed
- System case study
- *Hands-On Lab*: Calculate and measure effect of conductance on pump-down gas load analysis
- Outgassing rates and calculations
- Permeation and leak effects

Materials Selection

- Characteristics
- Fabrication techniques

Day 3

High and Ultra-High vacuum

- Characteristics
- Example systems
- HV/UHV pump and gauge selection
- Criteria, pumps, specifications, comparisons
- Systems sizing calculations
- Diffusion pump, turbo, and cryopump
- Backing requirements
- *Hands-On Lab*: Calculate and measure pumping speed, throughput, and outgassing

Vacuum System Performance and Troubleshooting Theory and Application of RGA

- Principles of operation
- Fragmentation patterns
- System interconnections
- *Hands-On Lab*: Analyze existing systems

Leak Detector Maintenance (LDM) — 3 Days

Course Description

This course provides participants with the ability to perform routine maintenance and troubleshooting procedures on supported Agilent leak detectors. Training is normally held at the customer site and covers Agilent VS, 959, 979, and other Leak Detector models.

LDM begins with an introduction to leak detection and vacuum fundamentals then covers the principles of spectrometer operation and the underlying vacuum system in a classroom setting. Leak detector operation, tuning, and calibration, as well as preventative maintenance and troubleshooting procedures, are covered in practical laboratory sessions.

Lab equipment, including Agilent leak detectors and various maintenance consumables, is provided for extensive hands-on lab activities and instructor-led demonstrations. Participants will work with the Agilent leak detector model that they use in their work environment.

Who Should Attend?

This course is for maintenance technicians and personnel responsible for maintaining Agilent leak detectors.

Course Goals and Objectives

After completing this course, participants will be able to:

- Explain vacuum fundamentals and concepts essential to the operation of a leak detector
- Describe principles of operation of a helium mass spectrometer and ContraFlow
- Identify all major leak detector components
- Properly operate, tune, and calibrate the leak detector
- Perform preventative maintenance procedures:
  - Spectrometer cleaning and seal replacement
  - Ion source replacement
  - Valve blocks and manifold cleaning
  - Mechanical and high vacuum pumps
- Troubleshoot routine problems

Course Outline

Day 1

Introduction to Leak Detection
- Why leak test?
- Leak detection basics

Overview of Vacuum for Leak Detectors
- Working with numbers
- Understanding matter, pressure, gas properties
- Vapor pressure and gas flow
- Pumping speed and throughput

Introduction to Rough Vacuum Systems
- Operating pressure range and gauging
- Wet and dry pump operations
- Maintenance issues
- System configuration and operation
- *Hands-On Lab*: Roughing pump-down

Introduction to High Vacuum Systems
- Operating pressure range and gauging
- Turbo pump and controller operation
- Diffusion pump operation
  - Baffles and traps
  - Maintenance issues
- System configuration and operation

Leak Detector Fundamentals
- System components
- Vacuum system architecture
- Contra-flow concepts
- Mass spectrometer principles of operation
- Operating sequence
- *Hands-On Lab*: ID system components

Day 2

Operation of the Leak Detector
- Front panel displays and controls
- Operator interface
- *Hands-On Lab*: Operating the leak detector

Spectrometer Tuning, Zeroing, and Calibration
- Tuning leak
- Background helium signal
- Calibrated leak
- *Hands-On Lab*: Manual tuning, zeroing, and calibration

Spectrometer Maintenance Procedures
- *Hands-On Lab*: Clean spectrometer and replace Ion source

System Electronics
- Block diagram overview
- Test Points and adjustments
- *Hands-On*: ID components and verify test point data

Gauge Maintenance
- Procedures
- *Hands-On Lab*: Calibrate test port and system gauge

Day 3

Valve Block and Manifold Maintenance Procedures
- *Hands-On Lab*: Clean valve block and manifold

Mechanical Pump Maintenance Procedures
- *Hands-On Lab*: RV/TS pump maintenance

High Vacuum Pump Maintenance Procedures
- *Hands-On Lab*: DP/TP pump maintenance

System Troubleshooting
- Symptom: Cause overview
- Procedures
- Hands-On Lab: Troubleshoot common problems

Mechanical Pump Rebuilding — 1 Day

TriScroll Dry Scroll Pump

Course Description

Agilent offers customers the opportunity to service and rebuild Agilent TriScroll dry vacuum pumps. This one-day course, available through Agilent's On-Site program, covers required minor and major service for TriScroll 300 and TriScroll 600 scroll pumps.

Class size is limited to 8 attendees

DS Series Oil-Seal Rotary Vane Pump

Course Description

Agilent offers customers the opportunity to service and rebuild Agilent DS Series oil-sealed rotary vane vacuum pumps. This one-day course, available through Agilent's On-Site program, covers a comprehensive tear down and rebuild of the pump.

Class size is limited to 8 attendees

On-Site Training Programs

Agilent's Training Department can assist customers in meeting their specific training requirements by organizing and sequencing customer-selected content topics from Agilent's standard vacuum practice curriculum. Our professional instructors will deliver this cost-effective training at your facility through our On-Site Training Program. Please contact the Training Department at 800.882.7426 (x5489) for assistance.

On-Site Training Advantages:

- Professional vacuum and leak detection training provided at your facility
- Tailored content from our Standard Courses
- Scheduled when you need the training
- Eliminates employee travel time and expenses
- Cost effective for training groups of employees

Training Registration:

An online registration form can be found on the Agilent training web site:

www.agilent.com/chem/vacuum

Open the Training & Events tab,
Select "Training Courses"
In the Product Line box at left, select "Vacuum Technologies".

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

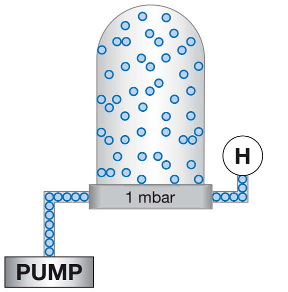
Pressure Conversion Table

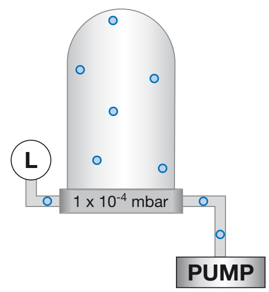
	Torr	mbar	Pa	micron	psi	atm
1 Torr	1	1.33	133	1000	1.9×10^{-2}	1.32×10^{-3}
1 mbar	0.751	1	100	750	1.4×10^{-2}	9×10^{-4}
1 Pa	7.51×10^{-3}	1×10^{-2}	1	7.5	1.4×10^{-4}	9×10^{-6}
1 micron (mTorr)	1×10^{-3}	1.3×10^{-3}	1.3×10^{-1}	1	1.9×10^{-5}	1.3×10^{-6}
1 psi (a)	51.72	68.96	6.89×10^{3}	5.17×10^{4}	1	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.	
	$\bar{p}$ x D > 0.7 (mbar cm);	**λ < D/100**
	Pressure (millibar) x Diameter (centimeters) = > 0.7	
Transition Flow	Region between viscous and molecular flow	
	1.3×10^{-2} < $\bar{p}$ x D < 0.7 (mbar cm);	**D/100 < λ < 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.	
	$\bar{p}$ x D < 1.3×10^{-2} (mbar cm);	**λ < D/2**
	Pressure (millibar) x Diameter (centimeters) = < 0.013	





APPENDIX - FORMULAS AND TABLES

Conductance - Viscous Flow Formulas

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

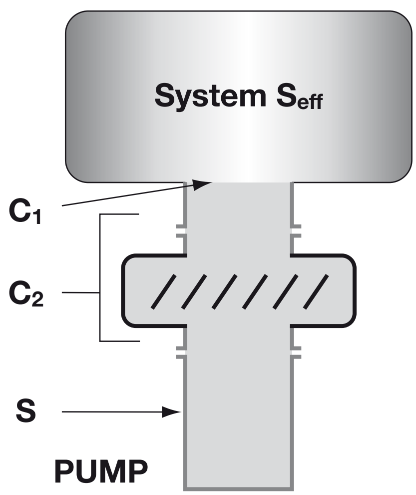
Aperture	$C = 20\,A$	where A = Area, cm^2 C = l/sec
Pipe	$C = \frac{137\,D^4}{L}\,\bar{p}$	D = Diameter, cm P = Pressure, mbar L = Length, cm

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	$C = \frac{12.1\,D^3}{L}$ valid when Length >> Diameter	D = Diameter, cm L = Length, cm
Short pipe	$C = \frac{11.6\,A}{1 + L/D}$ valid when Length < 0.7 times Diameter	D = Diameter, cm L = Length, cm

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)

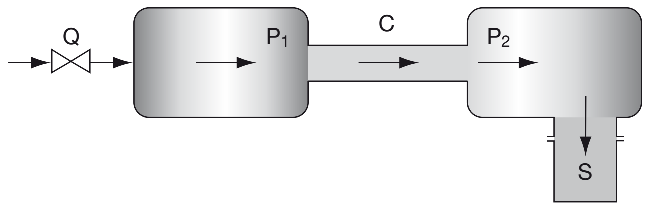
This equation is accurate from start to approximately 1 mbar.
At lower pressures outgassing can become significant.

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

t = pump down time (sec)
S = pumping speed (l/sec)
V = Chamber Volume (l)
Po = beginning pressure mbar
Pf = Final pressure

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

Throughput



Throughput: quantity of gas per unit time,

$$Q = C \times (P_1 - P_2) = P_2 \times S \quad \text{or:} \quad Q = \frac{V}{t} P = SP$$

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

	STD cc/sec atm cc/sec mbar l/sec	molecoles/s (a 0°C)	Torr l/sec	Pa m³/sec	sccm
1 STD cc/sec – 1 atm cc/sec – 1 mbar l/sec	1	2.687×10^{19}	0.76	0.1	60
1 molecole/s	3.72×10^{-20}	1	2.86×10^{-20}	3.72×10^{-21}	2.23×10^{-18}
1 Torr l/sec	1.3	3.493×10^{19}	1	0,13	80
1 Pa m³/sec	10	2.687×10^{20}	7.5	1	600
1 sccm	0.016	4.299×10^{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:

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

Where
t = time (hours) necessary to reach the working pressure
Qoutgas = gas load referred to time t_0 (generally 1hour)
A = internal area exposed to vacuum
Pwork = working pressure
Seff = effective pumping speed

Outgassing Rate per Unit Area

Qoutgas $\frac{\text{Torr liter}}{\text{sec cm}^2}$	1h	10h	100h
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}

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 typei and S_i is the pumping speed for that gas. P_{2i} is the outlet pressure for gas typei and K_i is the compression ratio of the pump for gas type.

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

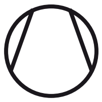
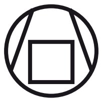
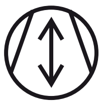
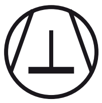
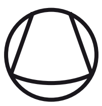
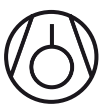
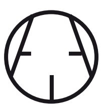
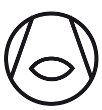
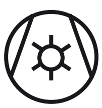
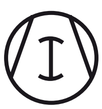
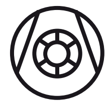
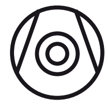
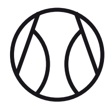
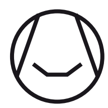
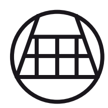
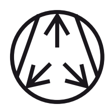
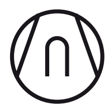
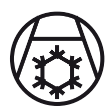
Vacuum Technology Standards

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

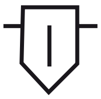
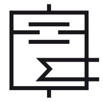
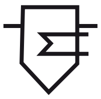
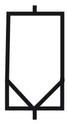
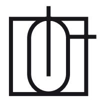
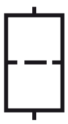
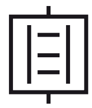
ISO - International Standardization Organization – Switzerland
DIN - Deutsches Institut fur Normung - Germany
PNEUROP – British compressed air society - England

Graphic Symbols in Vacuum Technology DIN28401

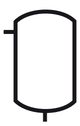
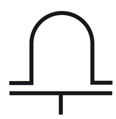
Vacuum Pumps

	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

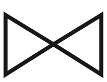
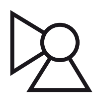
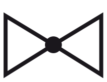
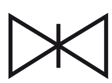
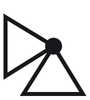
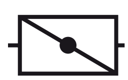
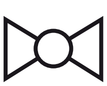
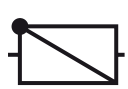
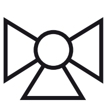
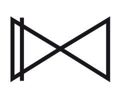
Vacuum Pump Accessories

	Condensate trap, general		Cooled baffle
	Condensate trap whit heat exchange (e.g., cooled)		Cold trap, general
	Gas filter, general		Cold trap with coolant reservoir
	Filtering apparatus, general		Sorption trap
	Baffle, general		

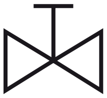
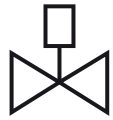
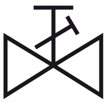
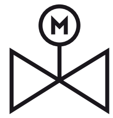
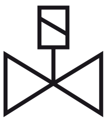
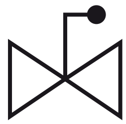
Vacuum Chambers

	Vacuum chamber		Vacuum bell jar

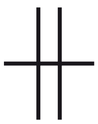
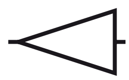
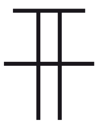
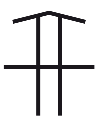
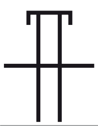
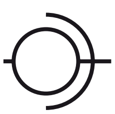
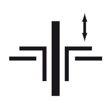
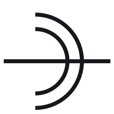
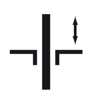
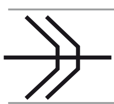
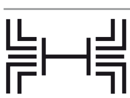
Isolation Devices

	Shut-off device, general		Right-angle stop cock
	Isolating valve		Gate valve
	Right angle valve		Butterfly valve
	Stop cock		Non-return valve
	Three-way stop cock		Safety shut-off device

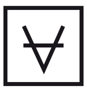
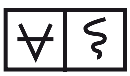
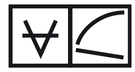
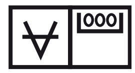
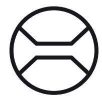
Valve Mode of Operation

	Manual operation		Hydraulic or pneumatic operation
	Variable leak valve		Electric motor operation
	Electromagnetic operation		Weight-operated

Connections and Tubes

	Flange connection, general		Change in the cross section of a duct
	Bolted flange connection		Intersection of two ducts with connection
	Small flange connection		Crossover of two ducts without connection
	Clamped flange connection		Electric current leadthrough
	Threaded tube connection		Flexible connection (e.g., bellows, flexible tubing)
	Ball-and-socket joint		Linear motion leadthrough, flange-mounted
	Spigot-and-socket joint		Linear motion leadthrough, without flange
	Connection by taper ground joint		Leadthrough for transmission of rotary and linear motion
	Branch-off point		Rotary transmission leadthrough
	Collection of ducts		

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

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.

atomic 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 x 1023 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.

bell jar — A container open at the bottom and closed at the top which is used as a vacuum chamber or test vessel. Also called a work chamber.

bellows-sealed valve — A valve type in which the stem seal is accomplished by means of a flexible bellows, one end of which is attached to the sealing disk, the other end to either the bonnet or the body.

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 form of leak test in which enclosures are immersed in a fluid. The fluid is then pressurized to drive it through possible leak passages and thus into the internal cavities. The enclosures are then placed in a leak detector to detect the escaping fluid.

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.

APPENDIX - GLOSSARY

Boyle's Law	The gas law that states $P1V_1 = P_2V_2$, 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 ionizatíon 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.
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 not exceeding about 2 mTorr and discharge pressures (forepressures) not exceeding 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 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; for example, 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 its 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 gas ballast raises the ultimate pressure of the pump.
gas density	The number of molecules per unit of volume.
gas load	The amount of gas being removed from a vacuum chamber by the vacuum pumps. Typically measured in Torr-liters per second, cubic feet per minute, or cubic meters per hour.
gauge pressure	*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.

inside-out leak detection technique A method of leak detection whereby the tracer gas is placed under pressure inside the container to be leak-checked. A detector probe attached to a leak detector is used to locate leaks.

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; and **(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 where one is interested in getting some particular type of particle from a source to a surface. For example, ion implanters, coaters, or television tubes.
micron	Pressure unit equivalent to 1 mTorr.
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 6.023×10^{23} particles.
molecular density	The number of molecules in a unit of volume such as a cubic centimeter. There are approximately 3×10^{19} molecules per cc at one standard atmosphere.
molecular flow	The type of flow which occurs when gas molecules are spread far apart. There are few collisions so that the molecules tend to act independently of other molecules that may be present. The molecular directions are completely random.
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.)*

nucleus 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 "hung up," or 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 probably 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.
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. (More correctly 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 the pressure. It is a term used to measure the quantity of gas per unit of time flowing through a vacuum system or through a component of that system, such as a pump. Typical units are 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 correctly 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, and **(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 BTA or 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.)*