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 hand-on activities during courses utilizing Agilent’s fully-equipped labs.

Courses are offered at Agilent training facilities in Palo Alto, CA and Lexington, MA (USA), at regional locations throughout North America, and at Agilent training facilities in Torino (Italy), Darmstadt (Germany), Orsay (France), and Surrey (England), 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, and at our factory locations through our Custom On-Request Training program.

Please visit our website at www.agilent.com/chem/vacuumtraining/

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 course, or through our On-Request and On-Site Training programs.
Small Class Sizes
Limited course enrollment enhances student-trainer interaction and promotes participation by students.

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

Course Material
Comprehensive course manuals provide an excellent source of theoretical and practical information.

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 and On-Request courses are held at Agilent locations in the US and Europe. On-Site courses are also available for customers’ convenience.

www.agilent.com/chem/vacuumtraining/
Agilent Vacuum and Leak Detection

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 manual, 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
  – Cryppumps
  – 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

In North America Call 1 800 882 7426   In Europe Call  00 800 234 234 00
Leak Rate Test and Measurement: BVP-Companion (LRTM-BC)  

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 rate-leak 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

www.agilent.com/chem/vacuumtraining/
Agilent Vacuum and Leak Detection

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 leakrate specifications, and measuring and locating leaks in pressurized system 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

<table>
<thead>
<tr>
<th>Day 1</th>
<th>Introduction to Leak Detection</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Why leak test?</td>
</tr>
<tr>
<td></td>
<td>Leak detection operations</td>
</tr>
<tr>
<td></td>
<td>Understanding leak rate</td>
</tr>
<tr>
<td></td>
<td>Leak detection methods</td>
</tr>
<tr>
<td>Vacuum Fundamentals for Leak Detection:</td>
<td></td>
</tr>
<tr>
<td>Working with numbers and temperature scales</td>
<td></td>
</tr>
<tr>
<td>Understanding matter, pressure, gas properties</td>
<td></td>
</tr>
<tr>
<td>Vapor pressure, outgassing, gas flow, conductance.</td>
<td></td>
</tr>
<tr>
<td>Pumping speed and throughput</td>
<td></td>
</tr>
<tr>
<td>Introduction to Rough Vacuum Systems</td>
<td></td>
</tr>
<tr>
<td>Operating pressure range and gauging</td>
<td></td>
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<tr>
<td>Wet and dry pump operations</td>
<td></td>
</tr>
<tr>
<td>System operation</td>
<td></td>
</tr>
<tr>
<td>Demo Lab: Roughing pumpdown</td>
<td></td>
</tr>
<tr>
<td>Introduction to High Vacuum Systems</td>
<td></td>
</tr>
<tr>
<td>Operating pressure range and gauging</td>
<td></td>
</tr>
<tr>
<td>Turbo pump and system operation</td>
<td></td>
</tr>
<tr>
<td>Helium Leak Detector Fundamentals</td>
<td></td>
</tr>
<tr>
<td>System components</td>
<td></td>
</tr>
<tr>
<td>Vacuum system architecture</td>
<td></td>
</tr>
<tr>
<td>Spectrometer: operation, tuning, zeroing, calibration</td>
<td></td>
</tr>
<tr>
<td>Demo Lab: Tuning, zeroing, and calibration</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Day 2</th>
<th>HMSLD performance considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Response/appearance time</td>
</tr>
<tr>
<td></td>
<td>Cleanup time (disappearance)</td>
</tr>
</tbody>
</table>

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

In North America Call 1 800 882 7426  In Europe Call 00 800 234 234 00
Advanced Vacuum Practice (AVP)  

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

www.agilent.com/chem/vacuumtraining/
Agilent Vacuum Equipment Maintenance

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. Scheduled training is available for the following Agilent models: 959, 979, and VS Series. Training for other Agilent leak detector models is available through our On-Site Training Program.

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
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 Standard Course. 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/vacuumtraining/
Appendix - Formulas and Tables

Common Physics Values

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceleration gravity g</td>
<td>9.806 m sec⁻² (32.174 Ft sec⁻²)</td>
</tr>
<tr>
<td>Atomic Mass Unit AMU</td>
<td>1.6605 x 10⁻²⁴ grams</td>
</tr>
<tr>
<td>Angstrom unit Å</td>
<td>10⁻10 m = 0.1 nm</td>
</tr>
<tr>
<td>Avogadro’s number n</td>
<td>6.0221353 x 10⁻²³ mol⁻¹</td>
</tr>
<tr>
<td>Molar volume</td>
<td>22.41 liters at 1 atm and 273 °K</td>
</tr>
<tr>
<td>Boltzmann’s constant k</td>
<td>1.38 x 10⁻¹⁶ ergs deg⁻¹ molecule⁻¹</td>
</tr>
<tr>
<td>Plank’s constant h</td>
<td>6.6256 x 10⁻³⁴ J sec</td>
</tr>
<tr>
<td>Equivalent of heat J</td>
<td>4.185 x 10³ Joules K cal⁻¹</td>
</tr>
<tr>
<td>Natural log base e</td>
<td>2.7183</td>
</tr>
<tr>
<td>Velocity of light c</td>
<td>2.9979 x 10⁸ m sec⁻¹</td>
</tr>
<tr>
<td>Velocity of sound s</td>
<td>330 m sec⁻¹</td>
</tr>
<tr>
<td>Standard pressure p</td>
<td>101.325 Pa = 1013 mbar</td>
</tr>
<tr>
<td>(at 45° north and 0 °C)</td>
<td></td>
</tr>
<tr>
<td>Magnetic flux density T</td>
<td>Tesla (1 gauss G = 10⁻⁴ Vs m⁻² = 10⁻⁴ T)</td>
</tr>
</tbody>
</table>

Physical Properties of some Gases

<table>
<thead>
<tr>
<th>Gas</th>
<th>Chemical formula</th>
<th>Molecular weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>H₂</td>
<td>2.016</td>
</tr>
<tr>
<td>Helium</td>
<td>He</td>
<td>4.002</td>
</tr>
<tr>
<td>Deuterium</td>
<td>D₂</td>
<td>4.028</td>
</tr>
<tr>
<td>Methane</td>
<td>CH₄</td>
<td>16.04</td>
</tr>
<tr>
<td>Ammonia</td>
<td>NH₃</td>
<td>17.03</td>
</tr>
<tr>
<td>Water (vapour)</td>
<td>H₂O</td>
<td>18.02</td>
</tr>
<tr>
<td>Neon</td>
<td>Ne</td>
<td>20.18</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>N₂</td>
<td>28.01</td>
</tr>
<tr>
<td>Oxygen</td>
<td>O₂</td>
<td>31.99</td>
</tr>
<tr>
<td>Argon</td>
<td>Ar</td>
<td>39.84</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>CO₂</td>
<td>44.01</td>
</tr>
<tr>
<td>Krypton</td>
<td>Kr</td>
<td>83.80</td>
</tr>
<tr>
<td>Xeno</td>
<td>Xe</td>
<td>131.30</td>
</tr>
<tr>
<td>Mercury</td>
<td>Hg</td>
<td>200.59</td>
</tr>
</tbody>
</table>

Ideal Gas Equation

\[ PV = nR_0T \] or \[ PV = n kT \]

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>pressure in Torr</td>
<td>P = pressure in dynes</td>
</tr>
<tr>
<td>V</td>
<td>volume in liters</td>
<td>V = volume in cc</td>
</tr>
<tr>
<td>n</td>
<td>numbers of Moles</td>
<td>n = numbers of Moles</td>
</tr>
<tr>
<td>R₀</td>
<td>molar gas constant</td>
<td>k = Boltzmann’s constant</td>
</tr>
<tr>
<td>T</td>
<td>degrees Kelvin</td>
<td>T = degrees Kelvin</td>
</tr>
</tbody>
</table>

Temperature Scale

<table>
<thead>
<tr>
<th>°F</th>
<th>°C</th>
<th>°K</th>
</tr>
</thead>
<tbody>
<tr>
<td>212</td>
<td>100</td>
<td>373</td>
</tr>
<tr>
<td>32</td>
<td>0</td>
<td>273</td>
</tr>
<tr>
<td>-321</td>
<td>-196</td>
<td>77</td>
</tr>
<tr>
<td>-459</td>
<td>-273</td>
<td>0</td>
</tr>
</tbody>
</table>

Conversion factors:

\[ °C = \frac{5}{9} (F - 32) \]
\[ °K = °C + 273 \]
\[ °F = \frac{9}{5} °C + 32 \]

\[ °C = \text{Celsius} \]
\[ °K = \text{Kelvin} \]
\[ °F = \text{Fahrenheit} \]
Some Molecular Relationships (at 273 °K)

<table>
<thead>
<tr>
<th>Pressure Torr</th>
<th>Molecular density molec./cm³</th>
<th>Molecular collision molec./cm² x sec</th>
<th>Mean free path cm</th>
<th>Monolayer formation time (sec)</th>
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</thead>
<tbody>
<tr>
<td>760</td>
<td>3.25 x 10¹⁹</td>
<td>3.78 x 10³²</td>
<td>5.1 x 10⁻⁶</td>
<td>2.2 x 10⁻⁹</td>
</tr>
<tr>
<td>10⁻³</td>
<td>3.25 x 10¹³</td>
<td>3.78 x 10¹⁷</td>
<td>5.1</td>
<td>2.2 x 10⁻³</td>
</tr>
<tr>
<td>10⁻⁶</td>
<td>3.25 x 10¹⁰</td>
<td>3.78 x 10¹⁴</td>
<td>5100</td>
<td>2.2</td>
</tr>
<tr>
<td>10⁻⁹</td>
<td>3.25 x 10⁷</td>
<td>3.78 x 10¹¹</td>
<td>5.1 x 10⁶</td>
<td>2200</td>
</tr>
<tr>
<td>10⁻¹²</td>
<td>3.25 x 10⁴</td>
<td>3.78 x 10⁸</td>
<td>5.1 x 10⁹</td>
<td>2.2 x 10⁶</td>
</tr>
</tbody>
</table>

Common Physics Values

Pressure Conversion Table

<table>
<thead>
<tr>
<th>Pressure</th>
<th>Torr</th>
<th>mbar</th>
<th>Pa</th>
<th>micron</th>
<th>psi</th>
<th>atm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Torr</td>
<td>1</td>
<td>1.33</td>
<td>133</td>
<td>1000</td>
<td>1.9 x 10⁻²</td>
<td>1.32 x 10⁻³</td>
</tr>
<tr>
<td>1 mbar</td>
<td>0.751</td>
<td>1</td>
<td>100</td>
<td>750</td>
<td>1.4 x 10⁻²</td>
<td>9 x 10⁻⁴</td>
</tr>
<tr>
<td>1 Pa</td>
<td>7.51 x 10⁻³</td>
<td>1 x 10⁻²</td>
<td>1</td>
<td>7.5</td>
<td>1.4 x 10⁻⁴</td>
<td>9 x 10⁻⁶</td>
</tr>
<tr>
<td>1 micron (mTorr)</td>
<td>1 x 10⁻³</td>
<td>1.3 x 10⁻³</td>
<td>1.3 x 10⁻¹</td>
<td>1</td>
<td>1.9 x 10⁻⁵</td>
<td>1.3 x 10⁻⁶</td>
</tr>
<tr>
<td>1 psi (a)</td>
<td>51.72</td>
<td>68.96</td>
<td>6.89 x 10³</td>
<td>5.17 x 10⁴</td>
<td>1</td>
<td>7 x 10⁻²</td>
</tr>
<tr>
<td>1 atm</td>
<td>760</td>
<td>1013</td>
<td>1.01 x 10⁵</td>
<td>7.6 x 10⁵</td>
<td>14.7</td>
<td>1</td>
</tr>
</tbody>
</table>

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.
- \( p \times D > 0.7 \text{ (mbar cm)} \Rightarrow \lambda < D/100 \)
- \( \text{Pressure (millibar) x Diameter (centimeters)} = > 0.7 \)

**Transition Flow**
- Region between viscous and molecular flow
- \( 1.3 \times 10^{-2} < p \times D < 0.7 \text{ (mbar cm)} \Rightarrow D/100 < \lambda < D/2 \)

**Molecular Flow**
- Distance between molecules is large; collisions between molecules and wall dominate; flow is through random motion; generally P is smaller than 10⁻³ millibar. A system is in molecular flow when the mean free path is longer than the diameter of the tube or chamber.
- \( p \times D < 1.3 \times 10^{-2} \text{ (mbar cm)} \Rightarrow \lambda < D/2 \)
- \( \text{Pressure (millibar) x Diameter (centimeters)} = < 0.013 \)

www.agilent.com/chem/vacuumtraining/
Appendix - Formulas and Tables

Conductance - Viscous Flow Formulas

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

**Aperture**

\[ C = 20A \]

where \( A = \text{Area, cm}^2 \)

\( C = \text{l/sec} \)

**Pipe**

\[ C = \frac{137D^4}{L} \bar{p} \]

\( D = \text{Diameter, cm} \)

\( P = \text{Pressure, mbar} \)

\( L = \text{Length, cm} \)

**Conductance - Molecular Flow Formulas**

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

**Aperture**

\[ C = 11.6A \]

where \( A = \text{Area, cm}^2 \)

\( C = \text{l/sec} \)

**Long pipe**

\[ C = \frac{12.1D^3}{L} \]

valid when Length >> Diameter

**Short pipe**

\[ C = \frac{11.6A}{1 + \frac{L}{D}} \]

valid when Length < 0.7 times Diameter

Series Conductance and Effective Pumping Speed

\[ \frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} \]

\[ C_T = \frac{C_1 \times C_2}{C_1 + C_2} \]

\[ \frac{1}{S_{\text{eff}}} = \frac{1}{S} + \frac{1}{C_T} \]

\[ S_{\text{eff}} = \frac{S \times C_T}{S + C_T} \]

where \( S_{\text{eff}} = \text{Effective pumping speed (l/s)} \)

\( S = \text{Nominal pumping speed (l/s)} \)

\( C = \text{Conductance (l/s)} \)

Pumping Speed - Conversion Table

<table>
<thead>
<tr>
<th>Unit</th>
<th>l/s</th>
<th>l/min</th>
<th>m³/h</th>
<th>CFM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 liter per second</td>
<td>1</td>
<td></td>
<td>3.8</td>
<td>2.19</td>
</tr>
<tr>
<td>1 liter per minute</td>
<td>0.01666</td>
<td>60</td>
<td>0.06</td>
<td>0.589</td>
</tr>
<tr>
<td>1 cubic meter per hour</td>
<td>0.287</td>
<td>16.67</td>
<td>1</td>
<td>0.589</td>
</tr>
<tr>
<td>1 cubic foot per minute</td>
<td>0.472</td>
<td>28.32</td>
<td>1.70</td>
<td>1</td>
</tr>
</tbody>
</table>

Pump Down Calculation (Viscous Flow)

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

\[ t = \frac{V}{S} \ln \frac{P_o}{P_f} \]

where \( t = \text{pump down time (sec)} \)

\( S = \text{pumping speed (l/sec)} \)

\( V = \text{Chamber Volume (l)} \)

\( P_o = \text{beginning pressure mbar} \)

\( P_f = \text{final pressure} \)

\( \ln = 2.3 \log_{10} \)

In North America Call 1 800 882 7426   In Europe Call 00 800 234 234 00
**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

<table>
<thead>
<tr>
<th>Unit</th>
<th>STD cc/sec</th>
<th>atm cc/sec</th>
<th>molecules/s (a 0°C)</th>
<th>Torr l/sec</th>
<th>Pa m³/sec</th>
<th>sccm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 STD cc/sec – 1 atm cc/sec – 1 mbar l/sec</td>
<td>1</td>
<td>2.687 x 10¹⁹</td>
<td>0.76</td>
<td>0.1</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>1 molecule/s</td>
<td>3.72 x 10⁻²⁰</td>
<td>1</td>
<td>2.86 x 10⁻²⁰</td>
<td>3.72 x 10⁻²¹</td>
<td>2.23 x 10⁻¹⁸</td>
<td></td>
</tr>
<tr>
<td>1 Torr l/sec</td>
<td>1.3</td>
<td>3.43 x 10⁻¹⁹</td>
<td>1</td>
<td>0.13</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>1 Pa m³/sec</td>
<td>10</td>
<td>2.687 x 10⁻¹⁰</td>
<td>7.5</td>
<td>1</td>
<td>600</td>
<td></td>
</tr>
<tr>
<td>1 sccm</td>
<td>0.016</td>
<td>4.239 x 10⁻¹⁷</td>
<td>0.0125</td>
<td>0.016</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

**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
- \( Q_{outgas} \) = gas load referred to time \( t_0 \) (generally 1 hour)
- \( A \) = internal area exposed to vacuum
- \( P_{work} \) = working pressure
- \( S_{eff} \) = effective pumping speed

**Ultimate Pressure**

The ultimate pressure of the vacuum system is determined by the pumping speed and the limiting compression for various gases

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

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.
### Vacuum Technology Standards

<table>
<thead>
<tr>
<th>Number</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIN 28400</td>
<td>Vacuum technology; designations and definitions</td>
</tr>
<tr>
<td>DIN 28401</td>
<td>Graphic Symbols in Vacuum Technology</td>
</tr>
<tr>
<td>DIN 28402</td>
<td>Vacuum technology; variables, symbols, units - overview</td>
</tr>
<tr>
<td>DIN 28403</td>
<td>Vacuum technology; quick connections, small flange connections</td>
</tr>
<tr>
<td>ISO 1609</td>
<td>Vacuum technology; flanges, dimensions</td>
</tr>
<tr>
<td>PNEUROP 6606</td>
<td></td>
</tr>
<tr>
<td>DIN 28410</td>
<td>Vacuum technology; mass spectrometer partial pressure gauges, definitions</td>
</tr>
<tr>
<td>ISO 3530.2</td>
<td>Mass Spectrometer type Leak Detector Calibration</td>
</tr>
<tr>
<td>DIN 28416</td>
<td>Calibration of Vacuum Gauges – General method</td>
</tr>
<tr>
<td>DIN 28417</td>
<td>Measurement of Throughput by volumetric method</td>
</tr>
<tr>
<td>DIN 28418</td>
<td>Vacuum Gauges – Calibration by direct comparison</td>
</tr>
<tr>
<td>ISO/DIS 3567</td>
<td></td>
</tr>
<tr>
<td>ISO 1607 / 1,2</td>
<td>Measurement of ultimate pressure</td>
</tr>
<tr>
<td>PNEUROP 6602</td>
<td></td>
</tr>
<tr>
<td>DIN 28427</td>
<td>Vapor Vacuum Pumps - Measurement of performance characteristics.</td>
</tr>
<tr>
<td>ISO 1608 / 1,2</td>
<td>Measurement of critical backing pressure</td>
</tr>
<tr>
<td>PNEUROP 5607</td>
<td></td>
</tr>
<tr>
<td>DIN 28428</td>
<td>Vacuum technology; acceptance specifications for Turbo Molecular Pumps</td>
</tr>
<tr>
<td>PNEUROP 5608</td>
<td></td>
</tr>
<tr>
<td>DIN 28429</td>
<td>Vacuum technology; acceptance specifications for Getter Pumps</td>
</tr>
<tr>
<td>PNEUROP 5615</td>
<td></td>
</tr>
<tr>
<td>DIN 28430</td>
<td>Measurement of performance of ejector vacuum pumps and ejector compressors</td>
</tr>
<tr>
<td>PNEUROP 6601</td>
<td></td>
</tr>
<tr>
<td>ISO 1314</td>
<td>Pressure; basic definitions, units</td>
</tr>
<tr>
<td>ISO 3529 I,II,III</td>
<td>Vacuum Technology Vocabulary</td>
</tr>
<tr>
<td>ISO/DIS 3556 / 1</td>
<td>Sputter Ion Pumps - Measurement of performance characteristics.</td>
</tr>
<tr>
<td>ISO/DIS 3568</td>
<td>Ionization Vacuum Gauges – Calibration by direct comparison</td>
</tr>
<tr>
<td>ISO/DIS 3570 / 1</td>
<td>Vacuum Gauges – Standard Methods for Calibration</td>
</tr>
<tr>
<td>ISO/DIS 3669</td>
<td>Bakeable Flange Dimensions</td>
</tr>
<tr>
<td>PNSASR CC/5</td>
<td>Vacuum pumps, acceptance specifications refrigerator cooled cryopumps</td>
</tr>
</tbody>
</table>

*ISO - International Standardization Organization – Switzerland*
*DIN - Deutsches Institut für Normung – Germany*
*PNEUROP – British compressed air society – England*
## Graphic Symbols in Vacuum Technology DIN28401

### Vacuum Pumps

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Vacuum pump, general" /></td>
<td>Vacuum pump, general</td>
</tr>
<tr>
<td><img src="image" alt="Radial flow pump" /></td>
<td>Radial flow pump</td>
</tr>
<tr>
<td><img src="image" alt="Positive displacement pump" /></td>
<td>Positive displacement pump</td>
</tr>
<tr>
<td><img src="image" alt="Axial flow pump" /></td>
<td>Axial flow pump</td>
</tr>
<tr>
<td><img src="image" alt="Positive displacement pump, oscillating" /></td>
<td>Positive displacement pump, oscillating</td>
</tr>
<tr>
<td><img src="image" alt="Gas ring vacuum pump" /></td>
<td>Gas ring vacuum pump</td>
</tr>
<tr>
<td><img src="image" alt="Piston vacuum pump" /></td>
<td>Piston vacuum pump</td>
</tr>
<tr>
<td><img src="image" alt="Turbomolecular pump" /></td>
<td>Turbomolecular pump</td>
</tr>
<tr>
<td><img src="image" alt="Diaphragm vacuum pump" /></td>
<td>Diaphragm vacuum pump</td>
</tr>
<tr>
<td><img src="image" alt="Ejector vacuum pump" /></td>
<td>Ejector vacuum pump</td>
</tr>
<tr>
<td><img src="image" alt="Rotary positive displacement pump" /></td>
<td>Rotary positive displacement pump</td>
</tr>
<tr>
<td><img src="image" alt="Diffusion pump" /></td>
<td>Diffusion pump</td>
</tr>
<tr>
<td><img src="image" alt="Rotary plunger vacuum pump" /></td>
<td>Rotary plunger vacuum pump</td>
</tr>
<tr>
<td><img src="image" alt="Adsorption pump" /></td>
<td>Adsorption pump</td>
</tr>
<tr>
<td><img src="image" alt="Sliding vane rotary vacuum pump" /></td>
<td>Sliding vane rotary vacuum pump</td>
</tr>
<tr>
<td><img src="image" alt="Getter pump" /></td>
<td>Getter pump</td>
</tr>
<tr>
<td><img src="image" alt="Rotary piston vacuum pump" /></td>
<td>Rotary piston vacuum pump</td>
</tr>
<tr>
<td><img src="image" alt="Sublimation (evaporation) pump" /></td>
<td>Sublimation (evaporation) pump</td>
</tr>
<tr>
<td><img src="image" alt="Liquid ring vacuum pump" /></td>
<td>Liquid ring vacuum pump</td>
</tr>
<tr>
<td><img src="image" alt="Sputter ion pump" /></td>
<td>Sputter ion pump</td>
</tr>
<tr>
<td><img src="image" alt="Roots vacuum pump" /></td>
<td>Roots vacuum pump</td>
</tr>
<tr>
<td><img src="image" alt="Cryopump" /></td>
<td>Cryopump</td>
</tr>
<tr>
<td><img src="image" alt="Turbine vacuum pump, general" /></td>
<td>Turbine vacuum pump, general</td>
</tr>
</tbody>
</table>

## Appendix - Formulas and Tables

### Vacuum Pump Accessories

<table>
<thead>
<tr>
<th>Icon</th>
<th>Description</th>
<th>Icon</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="icon.png" alt="Condensate trap, general" /></td>
<td>Condensate trap, general</td>
<td><img src="icon.png" alt="Cooled baffle" /></td>
<td>Cooled baffle</td>
</tr>
<tr>
<td><img src="icon.png" alt="Condensate trap with heat exchange (e.g., cooled)" /></td>
<td>Condensate trap with heat exchange (e.g., cooled)</td>
<td><img src="icon.png" alt="Cold trap, general" /></td>
<td>Cold trap, general</td>
</tr>
<tr>
<td><img src="icon.png" alt="Gas filter, general" /></td>
<td>Gas filter, general</td>
<td><img src="icon.png" alt="Cold trap with coolant reservoir" /></td>
<td>Cold trap with coolant reservoir</td>
</tr>
<tr>
<td><img src="icon.png" alt="Filtering apparatus, general" /></td>
<td>Filtering apparatus, general</td>
<td><img src="icon.png" alt="Sorption trap" /></td>
<td>Sorption trap</td>
</tr>
<tr>
<td><img src="icon.png" alt="Baffle, general" /></td>
<td>Baffle, general</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Vacuum Chambers

<table>
<thead>
<tr>
<th>Icon</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="icon.png" alt="Vacuum chamber" /></td>
<td>Vacuum chamber</td>
</tr>
<tr>
<td><img src="icon.png" alt="Vacuum bell jar" /></td>
<td>Vacuum bell jar</td>
</tr>
</tbody>
</table>

### Isolation Devices

<table>
<thead>
<tr>
<th>Icon</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="icon.png" alt="Shut-off device, general" /></td>
<td>Shut-off device, general</td>
</tr>
<tr>
<td><img src="icon.png" alt="Right-angle stop cock" /></td>
<td>Right-angle stop cock</td>
</tr>
<tr>
<td><img src="icon.png" alt="Isolating valve" /></td>
<td>Isolating valve</td>
</tr>
<tr>
<td><img src="icon.png" alt="Gate valve" /></td>
<td>Gate valve</td>
</tr>
<tr>
<td><img src="icon.png" alt="Right angle valve" /></td>
<td>Right angle valve</td>
</tr>
<tr>
<td><img src="icon.png" alt="Butterfly valve" /></td>
<td>Butterfly valve</td>
</tr>
<tr>
<td><img src="icon.png" alt="Stop cock" /></td>
<td>Stop cock</td>
</tr>
<tr>
<td><img src="icon.png" alt="Non-return valve" /></td>
<td>Non-return valve</td>
</tr>
<tr>
<td><img src="icon.png" alt="Three-way stop cock" /></td>
<td>Three-way stop cock</td>
</tr>
<tr>
<td><img src="icon.png" alt="Safety shut-off device" /></td>
<td>Safety shut-off device</td>
</tr>
</tbody>
</table>
### Valve Mode of Operation

<table>
<thead>
<tr>
<th>Operation</th>
<th>Icon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manual operation</td>
<td>![Manual icon]</td>
</tr>
<tr>
<td>Hydraulic or pneumatic operation</td>
<td>![Hydraulic icon]</td>
</tr>
<tr>
<td>Variable leak valve</td>
<td>![Variable leak icon]</td>
</tr>
<tr>
<td>Electric motor operation</td>
<td>![Electric motor icon]</td>
</tr>
<tr>
<td>Electromagnetic operation</td>
<td>![Electromagnetic icon]</td>
</tr>
<tr>
<td>Weight-operated</td>
<td>![Weight-operated icon]</td>
</tr>
</tbody>
</table>

### Connections and Tubes

<table>
<thead>
<tr>
<th>Connection Type</th>
<th>Icon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flange connection, general</td>
<td>![Flange general icon]</td>
</tr>
<tr>
<td>Change in the cross section of a duct</td>
<td>![Change icon]</td>
</tr>
<tr>
<td>Bolted flange connection</td>
<td>![Bolted flange icon]</td>
</tr>
<tr>
<td>Intersection of two ducts with connection</td>
<td>![Intersection icon]</td>
</tr>
<tr>
<td>Small flange connection</td>
<td>![Small flange icon]</td>
</tr>
<tr>
<td>Crossover of two ducts without connection</td>
<td>![Crossover icon]</td>
</tr>
<tr>
<td>Clamped flange connection</td>
<td>![Clamped flange icon]</td>
</tr>
<tr>
<td>Electric current leadthrough</td>
<td>![Electric current icon]</td>
</tr>
<tr>
<td>Threaded tube connection</td>
<td>![Threaded tube icon]</td>
</tr>
<tr>
<td>Flexible connection (e.g., bellows, flexible tubing)</td>
<td>![Flexible connection icon]</td>
</tr>
<tr>
<td>Ball-and-socket joint</td>
<td>![Ball-and-socket icon]</td>
</tr>
<tr>
<td>Linear motion leadthrough, flange-mounted</td>
<td>![Linear motion flange icon]</td>
</tr>
<tr>
<td>Spigot-and-socket joint</td>
<td>![Spigot-and-socket icon]</td>
</tr>
<tr>
<td>Linear motion leadthrough, without flange</td>
<td>![Linear motion icon]</td>
</tr>
<tr>
<td>Connection by taper ground joint</td>
<td>![Connection taper icon]</td>
</tr>
<tr>
<td>Leadthrough for transmission of rotary and linear motion</td>
<td>![Leadthrough icon]</td>
</tr>
<tr>
<td>Branch-off point</td>
<td>![Branch-off icon]</td>
</tr>
<tr>
<td>Collection of ducts</td>
<td>![Collection of ducts icon]</td>
</tr>
<tr>
<td>Rotary transmission leadthrough</td>
<td>![Rotary transmission icon]</td>
</tr>
</tbody>
</table>
## Vacuum Gauges

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Symbol" /></td>
<td>General symbol for vacuum</td>
</tr>
<tr>
<td><img src="image2.png" alt="Symbol" /></td>
<td>Vacuum measurement, gauge head</td>
</tr>
<tr>
<td><img src="image3.png" alt="Symbol" /></td>
<td>Vacuum gauge, gauge control unit</td>
</tr>
<tr>
<td><img src="image4.png" alt="Symbol" /></td>
<td>Vacuum gauge, control unit recording</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image5.png" alt="Symbol" /></td>
<td>Vacuum gauge control unit with dial indicator</td>
</tr>
<tr>
<td><img src="image6.png" alt="Symbol" /></td>
<td>Vacuum gauge control unit with digital indicator</td>
</tr>
<tr>
<td><img src="image7.png" alt="Symbol" /></td>
<td>Measurement of throughput</td>
</tr>
</tbody>
</table>
### Appendix - Glossary

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>absolute pressure</strong></td>
<td>See pressure, absolute.</td>
</tr>
<tr>
<td><strong>absolute temperature</strong></td>
<td>The temperature scale that starts at “true” or absolute zero. It is often called the Kelvin scale.</td>
</tr>
<tr>
<td><strong>absorption</strong></td>
<td>The binding of a gas in the interior of a solid or liquid.</td>
</tr>
<tr>
<td><strong>adsorption</strong></td>
<td>The condensing of a gas on the surface of a solid.</td>
</tr>
<tr>
<td><strong>atmosphere, standard</strong></td>
<td>See standard atmosphere.</td>
</tr>
<tr>
<td><strong>atom</strong></td>
<td>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.</td>
</tr>
<tr>
<td><strong>atomic mass unit</strong></td>
<td>A way of classifying atoms according to their weight, or mass. Atoms of the different elements have different weights, or masses.</td>
</tr>
<tr>
<td><strong>Avogadro’s Law</strong></td>
<td>The gas law that states that one mole of any gas has 6.023 x 10^23 particles and under standard conditions occupies 22.4 liters.</td>
</tr>
<tr>
<td><strong>backing pump</strong></td>
<td>See forepump.</td>
</tr>
<tr>
<td><strong>backstreaming</strong></td>
<td>The small amount of pump fluid vapor that moves in the wrong direction, i.e., toward the work chamber.</td>
</tr>
<tr>
<td><strong>bakeout</strong></td>
<td>The degassing of a vacuum system by heating during the pumping process.</td>
</tr>
<tr>
<td><strong>bar</strong></td>
<td>Unit of pressure measurement. There are 1.010 bar in one standard atmosphere. One bar equals 1 x 10^6 dynes per square centimeter.</td>
</tr>
<tr>
<td><strong>base pressure</strong></td>
<td>That pressure which is typically reached with your system when it is clean, empty, and dry.</td>
</tr>
<tr>
<td><strong>bell jar</strong></td>
<td>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.</td>
</tr>
<tr>
<td><strong>bellows-sealed valve</strong></td>
<td>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.</td>
</tr>
<tr>
<td><strong>blower pump</strong></td>
<td>A type of vacuum pump which functions from 10 Torr to 0.0001 Torr. Also called a booster or Roots pump.</td>
</tr>
<tr>
<td><strong>body</strong></td>
<td>That part of a valve which contains the external openings for entrance and exit of the controlled fluid.</td>
</tr>
<tr>
<td><strong>bomb test</strong></td>
<td>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.</td>
</tr>
<tr>
<td><strong>bonnet</strong></td>
<td>In general, that part of the valve through which the stem enters the valve, and which is rigidly attached to the valve body.</td>
</tr>
<tr>
<td><strong>bourdon gauge</strong></td>
<td>A roughing gauge that responds to the physical forces that a gas exerts on a surface.</td>
</tr>
</tbody>
</table>
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Boyle’s Law

The gas law that states $P_1V_1 = P_2V_2$, 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 ionization gauge.

cold trap

See cryotrap.

condensation

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. Cryotrap 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.
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**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.

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| **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 x 10²³ particles. |
| **molecular density** | The number of molecules in a unit of volume such as a cubic centimeter. There are approximately 3 x 10¹⁹ 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. |
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- **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.

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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.
**train**
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.)