

Seminar Handbook

HIGH AND ULTRA-HIGH VACUUM FOR SCIENCE RESEARCH

The Measure of Confidence





HIGH/ULTRA-HIGH VACUUM

Seminar Outline

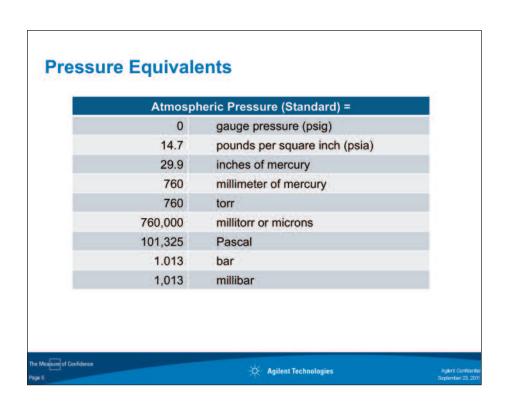
- Vacuum introduction
- Applications of physics
- Materials selection
- System pumping speed
- Vacuum pumps
- UHV applications selection criteria
- Turbo pump comparisons Q & A session
- Compression ratio

- Cryopump
- High vacuum pump comparison
- Gauges
- System operation
- Case studies
- Pumpdown calculations

Vacuum Introduction

Overview

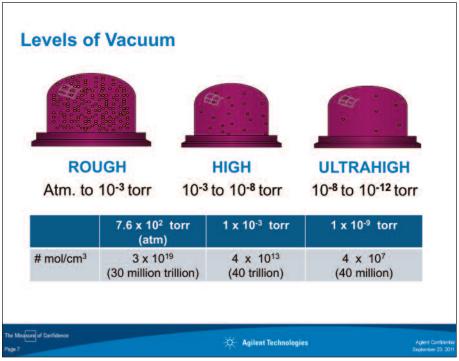
- Pressure
- Levels of vacuum
- · Gas characteristics in vacuum
- Flow regimes: viscous/molecular



Pressure Conversion Table

	Torr	Mbar	Pa	Micron	PSI	ATM
1 Torr	1	1.33	133	1000	1.9x10 ⁻²	1.32x10 ⁻³
1 mbar	0.751	1	100	750	1.4x10 ⁻²	9x10-4
1 Pa	7.51x10 ⁻³	1x10 ⁻²	1	7.5	1.4x10 ⁻⁴	9x10 ⁻⁶
1 micron (mTorr)	1x10 ⁻³	1.3x10 ⁻³	1.3x10 ⁻¹	1	1.9x10 ⁻⁵	1.3x10 ⁻⁶
1 psi (a) (pound per square inch)	51.72	68.96	6.89x10 ³	5.17x10 ⁴	1	7x10 ⁻²
1 atm	760	1013	1.01x10 ⁵	7.6x10 ⁵	14.7	1





Gas Composition					
	Pressure (torr)	Major Gas Load			
	Atm	Wet Air			
Rough	10-3	Water vapor (75% – 85%)			
	10-6	H ₂ O, CO			
High	10-9	H ₂ O, CO, N ₂ , H ₂			
Ultra High	10-10	CO, H ₂			
	10-11	H ₂			
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Characteristics of Rough Vacuum

- Roughing removes original atmosphere
- Gases move in viscous flow
- Chamber volume and pump speed determine pumpdown
- Comparison is same as original environment (80% N₂ : 20% O₂)



Characteristics of High Vacuum

- Gases originate from walls/surfaces
- Gases are in molecular flow
 - MFP > chamber dimensions
 - Gases are at thermal speeds

Particles move randomly

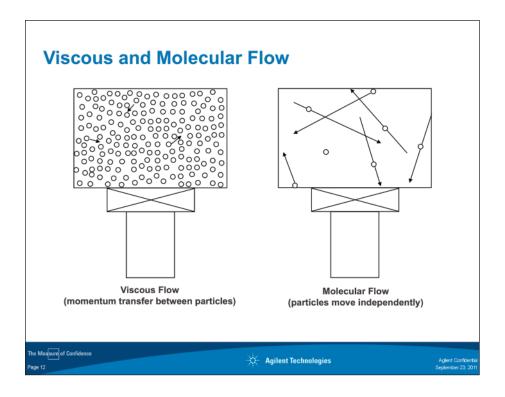
- Surface area, material type and pump speed determne pressure and pumpdown times
- Comparison is constant through high vacuum (80% H₂0 and 20% N₂, CO, H₂, CO₂)



Characteristics of Ultra High Vacuum

- Gases originate from walls/surfaces
 - diffuse out of vessel materials
 - permeate through vessel materials released within UHV pumps
- Gases are in molecular flow
- Surface area, material type, pump speed and temperature determne ultimate pressure and pumpdown times
- Primary source of gas is H₂ (below 1 x 10-10 torr)





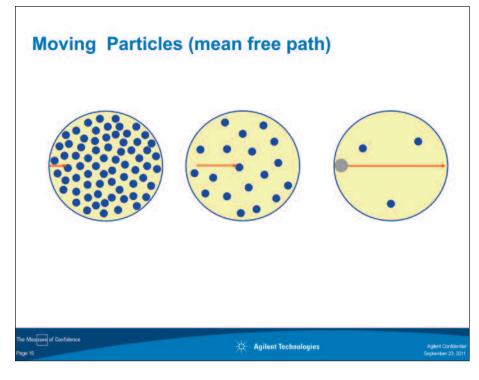
Flow Regimes

- · Viscous flow:
 - Distance between particles is small; collisions between gas particles dominate; flow through momentum transfer; generally P greater than 0.1 torr (100 millitorr)
- Transition Flow:
 - Region between viscous and molecular flow
- Molecular flow:
 - Distance between particles is large; collisions between the gas particles and wall dominate; flow through random motion; generally P smaller than 10-3 torr

Note: A system is in molecular flow when the mean path is larger than the diameter of the tube or chamber.



Flow Regimes Mean Free Path Viscous flow: is less than 0.01 Diameter of Pipe Mean Free Path Transition Flow: is between 0.01 and 1 Diameter of Pipe Mean Free Path Molecular flow: is greater than 1 Diameter of Pipe Agilent Technologies



Moving Particles

We use a vacuum when we want to move a particle through space in a specific way. In a television set cathode ray tube, electrons generated at the back of the tube in the electron gun have to move to a particular spot on the phosphor screen that coats the front of the tube. If there was air in the tube, the electrons would be deflected and blocked from reaching the screen.

A very common application is to deposit a material on a substrate. In a vacuum system, a material is heated and evaporated. The atoms have to move from a source to a substrate over a certain distance. If there was gas in the chamber, the gas particles (atoms and/or molecules) would prevent the evaporated material from reaching the substrate. Also, if the gas in the chamber contains oxygen, it could oxidize the material we are depositing.

Mean Free Path

Mean Free Path is the average distance a gas molecule travels before it collides with another gas molecule

	7.6 x 10 ² torr (atm)	1 x 10 ⁻³ torr	1 x 10 ⁻⁹ torr
MFP	2.5 x 10-6 in	2 inches	31 miles
	6.4 x 10-5 mm	5.1 cm	50 km



Mean Free Path

The average distance traveled between collisions, or average mean free path, depends on the size of the gas particle and the number of particles present (density or pressure).

$$\lambda = \frac{1}{\sqrt{2} \pi d^2 n}$$

where d is the molecular diameter in centimeters, and n is the number of particles per cubic centimeter. For air at room temperature, the mean free path (MFP) can be found from

$$MFP = \frac{5.1 \times 10^{-3}}{P_{torr}} (cm)$$

The range of variation in the mean free path for common gasses is about a factor of 10. (He 2.8x; H₂ 1.8x; H₂O 0.64x)



Notes

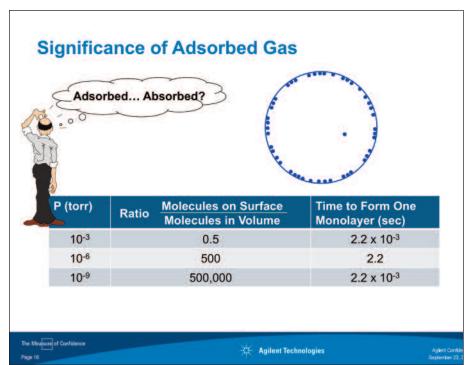
Mean Free Path

As we lower the pressure in the vacuum chamber, the amount of space between the gas molecules increases. The particles bump into each other less frequently. The average distance a molecule moves before it bumps another particle is called the mean free path. At atmosphere, the mean free path is extremely short, about 2.5 millionths (2.5 x 10-6) of an inch. Under vacuum, fewer molecules remain, and the mean free path is longer. Its length depends on the number of molecules present, and therefore on the pressure. When P is expressed in torr, the mean free path for air can be estimated from the relationship:

Mean Free Path =
$$\frac{5 \times 10^{-3}}{P}$$
 (cm)

From this we can see that as the pressure gets lower the mean free path gets longer. Likewise, as the pressure gets lower, there are fewer molecules of gas present, so there is less chance of them striking each other.

In 1 cc of gas at standard conditions (760 torr at 00C), there are about 3×1019 gas molecules and the mean free path is about 2.5×10^{-6} cm (a few millionths of an inch). At 1×10^{-9} torr, there are about 4×10^{7} (ten million!) molecules per cc, and the mean free path is about 31 miles or 50 kilometers. The number of molecules per unit volume (in this example cubic centimeters) is called the gas density or molecular density.



Adsorbed Gas

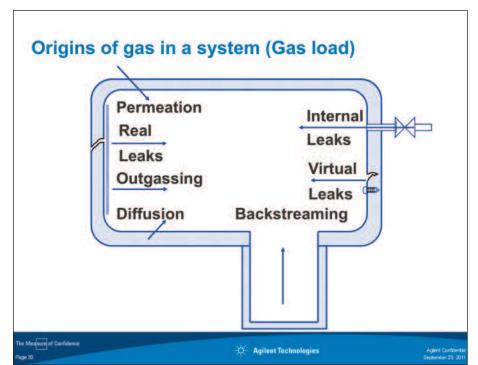
The diagram above illustrates the fact that once the pressure in a high vacuum system has reached high vacuum levels, most gas resides on the walls of the system. At a pressure of 1 x 10-6 torr there are 500 molecules residing on the walls of the system for every molecule moving through the system.

This highlights the fact that at high vacuum and ultra-high vacuum levels, the pressure in the system is determined by the surface gas in the system. The right column in the diagram shows that it only takes 2.2 seconds to coat a perfectly clean system (a system without a single molecule in it!) with a monolayer of gas when it exposed to that gas at a pressure of 1 x 10-6 torr. At 1 x 10-9 torr it will take 2,200 seconds to coat the system with one monolayer. This explains why surface analysis equipment usually operates at ultra-high vacuum pressures.

Vacuum Characteristics

Pressure (torr)	Molecular Density (molecules/cm³)	Molecular Incidence (molecules/cm²/sec)	Mean Free Path (cm)	Monolayer Formation Time (sec)
760	2.47 x 10 ¹⁹	3.14 x 10 ²³	6.7 x 10 ⁻⁶	2.9 x 10 ⁻⁹
1	3.25 x 10 ¹⁶	4.13 x 10 ²⁰	5.1 x 10 ⁻³	2.2 x 10 ⁻⁶
10-3	3.25 x 10 ¹³	4.13 x 10 ¹⁷	5.1	2.2 x 10 ⁻³
10-6	3.25 x 10 ¹⁰	4.13 x 10 ¹⁴	5.1 x 10 ³	2.2
10 ⁻⁹	3.25 x 10 ⁷	4.13 x 10 ¹¹	5.1 x 10 ⁶	2.2 x10 ³ (37 min)
10-12	3.25 x 10 ⁴	4.13 x 10 ⁸	5.1 x 10 ⁹	2.2 x 10 ⁶ (25.5 days)

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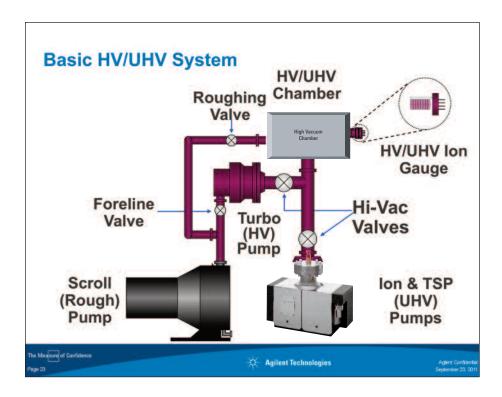
Vacuum system gas load results from:

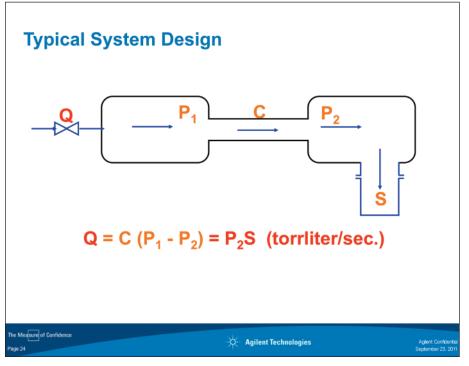
- Surface Condition (outgassing/ desorption)
- System Materials (diffusion and permeation)
- Leaks (real and internal/virtual leaks)
- Pumps (backstreaming)

Practical Application of Physics

Overview

- Processes that use vacuum
- Basic HV/UHV system
- System pressure
- Gas load
- Material permiation





Throughput

Throughput is the actual amount of gas – or the number of atoms and/or molecules - moving through or being removed from a vacuum system. This is the work really being done by a vacuum system. Throughput is expressed by the letter Q.

The flow of gas through a pipe is described as the amount of gas (Q) flowing through a pipe is equal to conductance (C) of the pipe times the pressure (P1 - P2)over the pipe.

Or:
$$Q = C \times (P_1 - P_2)$$

For the case where a pump is removing gas from a chamber at pressure P, we can look at how throughput is related to pumping speed (S) by taking another look at the definition of speed

Pumping Speed: amount of gas flowing into a chamber

pressure in the chamber

or:
$$S = \frac{Q}{P}$$
 (liters/second)

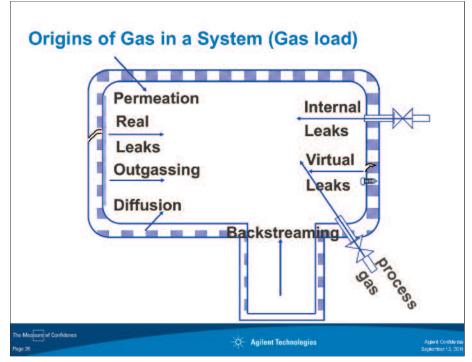
reworking this formula: $Q = P \times S$ (torrliters/second)

Or in words: the amount of gas being pumped from a chamber is equal to the pressure in the chamber multiplied by the speed of the pump attached to the chamber.

Flow Regimes

- Pressure is the force exerted by gas particles on a unit of surface area by momentum transfer during collisions
- Pressure is a measure of the number of gas particles per unit volume (density) at a fixed temperature
 - At constant temperature
 - lower pressure <-> lower density <-> higher vacuum
 - higher pressure <-> higher density <-> lower vacuum
 - At constant pressure
 - higher temperature <-> lower density
 - lower temperature <-> higher density
- Pressure is expressed in units of force per unit area
 - psig, psia, torr, bar, pascal (Pa), in Hg, in H₂O





Vacuum system gas load results from:

- Surface Condition (outgassing/desorption)
- System Materials (diffusion and permeation)
- Leaks (real and internal/virtual leaks)
- Pumps (backstreaming)

Definitions

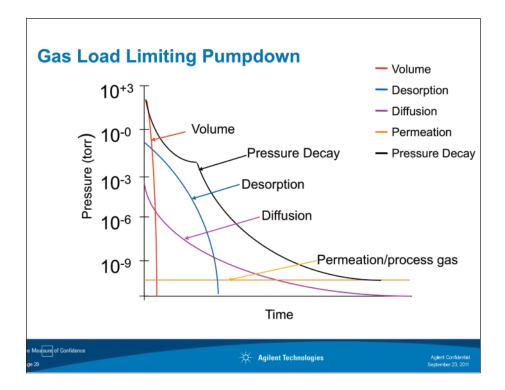
- Outgassing (desorption): Release of gas that has accumulated on system surfaces when they are exposed to atmosphere
- Diffusion: Gas particles present in the vessel walls at the start of (initial) pumpdown and released into the system during operation
- Permeation: Gas migrating into the system through the vessel walls from atmosphere and released into the system during operation
- Outgassing (general): Any gas from the above sources released into the vacuum system during operation
- Process: Gas introduced during process



Gas Load (Q)

- The gas load is the rate gas enters the system volume
 - Gas entering the volume through external and internal leaks
 - Gas entering the volume through external and internal leaks
 - Gas emanating from or passing through materials by diffusion and permeation
- At a known temperature, the gas load is the amount of gas particles entering the system volume per unit time
- · Q (gas load, throughput, leak rate) is expressed in units of pressure • volume/time
 - torr•liters/sec, atm•cc/sec, sccm, mbar•liters/sec, Pa•m3/hr





What Determines System Pressure?

• Equilibrium Pressure (P) in a vacuum system is determined by the total Gas Load (Q) and the System Pumping Speed (S)

$$P = \frac{Q}{S}$$

Or: Q = P x S (torr.liter/second) S = liter/second



Total Gas Load

The total gas load on a vacuum system is comprised of

 $Q_{Total} = Q_{VOLUME} + Q_{LEAK} + Q_{OUTGAS} + Q_{DIFFUSION} + Q_{PERMEATION} + Processgas$

Given limitations on available pumping speed, it is necessary to minimize the total gas load in order to achieve UHV pressures.

Example: To reach 10⁻¹² Torr in a system with 1000 l/s pumping speed, the gas load must be less than 10-9 Torr I/s.

хР = Q $1,000 \text{ ltr/sec} \times 10^{-12} \text{ torr} = 10^{-9} \text{ torr.ltr/sec}.$



Total Gas Load

Q_{VOLUME} is always negligible in UHV

Q_{I FAK} may appear following bakeout, tighten bolts following bakeout. Mass spectrometer indicats peaks at 28, 32 and also 14 and 18 (m/e) with real external leak.

Q_{OUTGAS} can be hastened and QDIFFUSION can be reduced by bakeout, minimuzing time open to atmosphere, and by purging with a dry gas while system is open.

QPERMEATION can only be reduced by using less permeable materials

Q PROCESS = process gas in system



Outgassing

 $Q_{OUTGAS} = q_{OUTGAS} \times A$

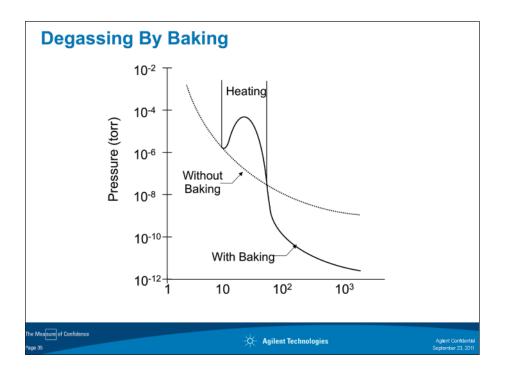
- Where q_{OUTGAS} is the rate of outgassing per unit area and A is the geometric surface area exposed to the vacuum
- Minimize the total microscopic system surface area in order to reduce the total gas load from surface desorption



Outgassing

- Rate of outgassing dependent upon the base material, temperature and time
- General outgassing rates are in torr•liters sec-1 cm-2 or in mbar•liters sec-1 cm-2 at a defined temperature
- Detailed consideratins require the knowledge of the rate for a specific gas species from an understood surface
- Surface state is important
 - Untreated (as received)
 - Machined (cutting oil used, etc...)
 - Degreased (method and solvents)
 - Post fabrication treatment (baking, degassing)

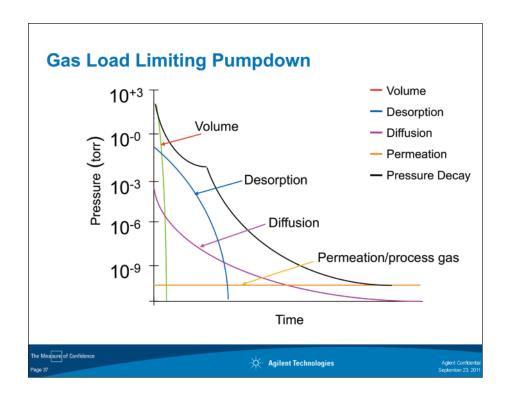




Material Permeation

- Permeation is the ability of a gas to pass through solid materials
- · Materials have permeation rates for different gases specific to that material
 - Examples
 - steels have higher permeation rates with higher carbon content
 - copper has low permeation for all gases
 - aluminum has low permeation for hydrogen
- Polymers are permeable to all gases

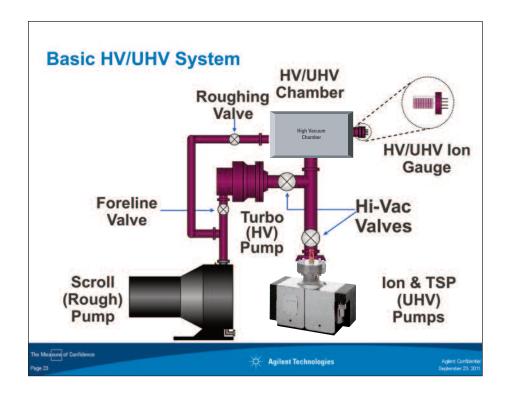


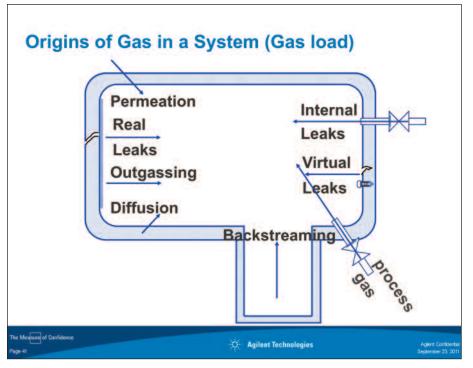


Materials

Overview

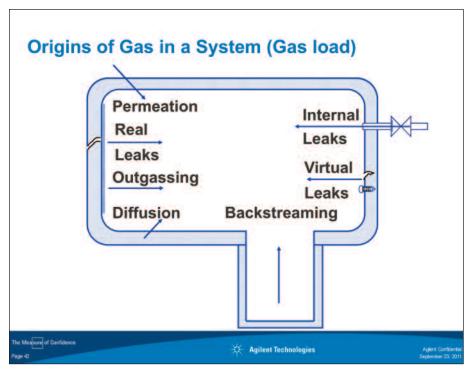
- Basic HV/UHV system
- Origins of gas
- Materials selection
- Surface preparation and cleaning
- Outgassing rates
- Mechanical joining
- Valves and seals





Vacuum system gas load results from:

- Surface Condition (outgassing/desorption)
- System Materials (diffusion and permeation)
- Leaks (real and internal/virtual leaks)
- Pumps (backstreaming)



Vacuum system gas load results from:

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Materials Selection

- General engineering properties
- Fabrication processes available and their influence on the vacuum environment
- Chemical compatibility
- Cost versus performance



Stainless Steel

- Austenitic (AISI 304, 304L, 316, 316L, 316LN)
- Low outgassing rate (5 x 10^{-8} to 3 x 10^{-13} torr.ltr/cm².sec)
- Can be welded
- Corrosion resistant
- · Role of additional alloy elements:
 - Cr Resistance to oxidation
 - Ni Austenitic structure / Anticorrosion
 - Mo Accelerates formation of passivating films
 - W Mechanical resistance at high temperature
 - Ti Stabilizes the austenitic structure
 - N Mechanical characteristics



Copper

- · Used as plates, bars and tubing
- · Most common use is for vacuum lines
- · Joining techniques include
 - Welding
 - Brazing
 - Soldering
- Outgassing rate can be lowered from 8 x 10⁻⁹ to 1 x 10⁻¹² torr.liter/sec cm²
- Some applications require oxygen free high conductivity copper (OFHC)



Aluminum

- · 6061-T6 is the most widely used alloy
- Aluminum gasket flanges are made from A2219-T87 with the knife edges coated with titanium carbide.
 - Al or Cu gaskets can be used with these flanges
- Typical outgassing range from 8 x 10⁻⁷ to 5 x 10⁻¹³ (torr.liter/ sec cm²)



Aluminum (Continued)

- · Aluminum alloys require special attention to both weld design and weld technique
- · The desorption rate of water vapor from the surface of aluminum is slower than stainless which gives it different initial pump down characteristics
- · A common surface treatment is anodizing. This produces a hard inert surface, but outgassing rate is degraded. Total surface area increases significantly



Ceramics

- Alumina (Al₂O₃)
 - Max temperature 1800°C
 - Can be brazed
 - Tensile strength 25k psi (96% density)
- Steatite (MgO-SIO₂)
 - Max temperature (1000°C)
 - Tensile strength 15k psi



Brass (avoid in UHV)

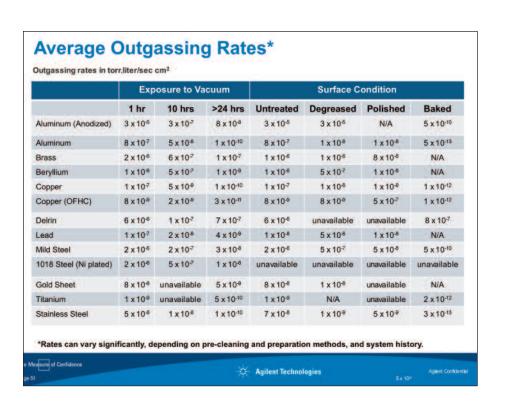
- Commonly used for many components in vacuum chambers and fixtures
- Used in vacuum systems where temperatures above 100°C are found
- Easily machined
- Joining techniques include:
 - Brazing, soldering, welding (not used extensively)
- Outgassing rate ranges from 10-5 to 10-7 torr-liter/sec cm²

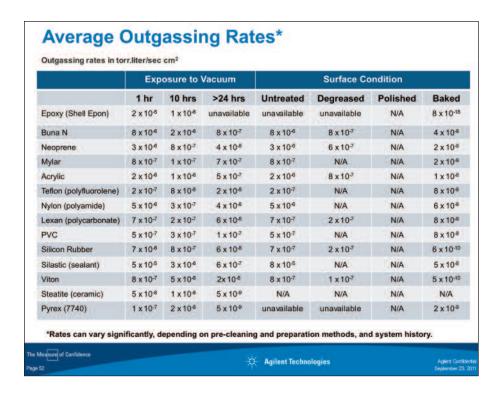


Surface Preparation and Cleaning Techniques

- Techniques
 - Physical wiping/polishing
 - Detergent washing
 - Chemical cleaning (i.e., acids, solvents/degreasers)
 - Sand/bead blasting
 - Ultrasonic bath
 - Electropolishing
 - Nickel plating
- Most manufacturere and labs have devised their own proprietary methods, often combining these methods
- Avoid fingerprints and dust at all times







Mechanical Joining Vacuum Systems

- Demountable; Conflat or wheeler flange
- · Valves: all metal valves
- Cleanliness and roughness of all sealing seats very critical
- Use of proper sealing methods make real leakage negligible
- O-rings: permeation contributes much to the gas load



KF Flange Assemblies В C D 2 **NW 10** 30 12,2 14 **NW 16** 30 17,2 2 20 **NW 25** 40 16.2 2 28 2 **NW 40** 55 41,2 44,5 **NW 50** 75 52,2 3,2 57 Dimensions in mm Agilent Technologies

Notes

KF Flange

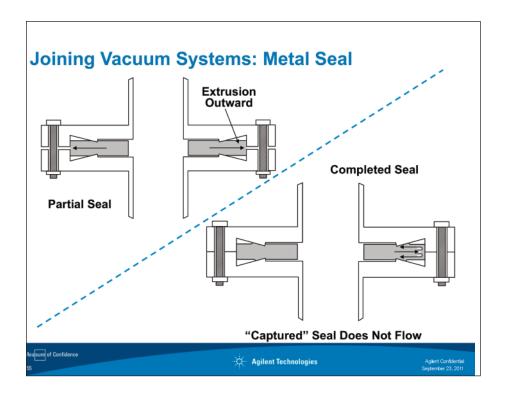
Another popular type of elastomer flange is the KF™ flange, also known as an NW flange.

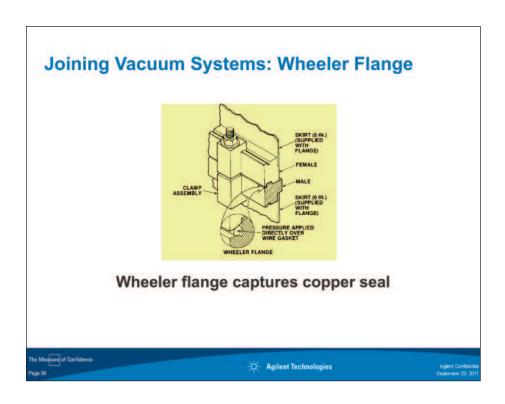
The flange is of standard ISO 2861/1 design consisting of two symmetrical flanges, a center ring to support and position an o-ring, and a clamp that allows assembly without any tools. KF flanges are quite convenient to use in rough and high vacuum systems.

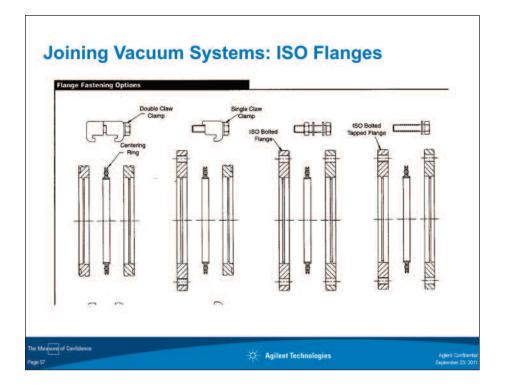
O-Ring Seals

Below are useful suggestions for working with o-rings:

- 1. When preparing to make a flange connection, be sure to clean and dry the groove and the flat mating surfaces. Check the sealing surfaces for scratches that cross the seal area.
- 2. Lightly lubricate the o-ring with a vacuum grease such as Apiezon-LTM, then wipe off most of the grease with lint-free paper before making the connection. Keep in mind that the o-ring makes the seal not the grease. The grease makes the o-ring slip and helps it to conform to its groove.



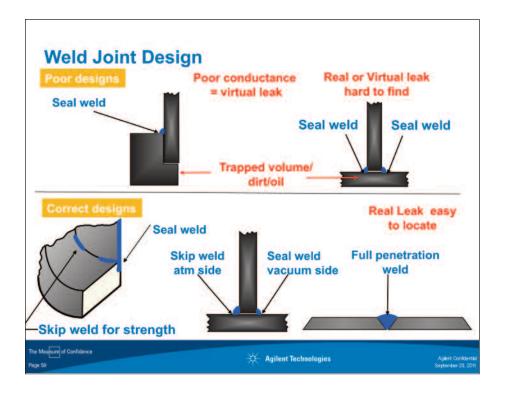




Joining Vacuum Systems: Welding

- Tungsten and metal inert gas welding (TIG & MIG) are the most widely used techniques for vacuum systems
- The most critical component of welding s the design. If design is not done properly, acceptable welds cannot be made
- Critical vacuum systems require the joint be cleaned prior to welding to prevent "baked-on" oil residue from machining. Joint also to be cleaned after welding
- Welding with flux coated rod should be avoided to prevent residual contamination





Joining Vacuum Systems: Soldering and Brazing

- Soldering and brazing of vacuum components is a common and cost effective method of joining
- Both techniques use a flux to prepare the surface. It can be difficult to remove the flux completely
- Soft soldering < 300°C uses filler materials such as lead. tin, zinc, bismuth, which have high vapor pressures and are often not compatible with ultra-high vacuum systems



Joining Vacuum Systems: Soldering and Brazing

- Silver soldering or torch brazing, accomplished at higher temperatures, generally uses copper and silver alloys. these require flux in most cases. Alloys not requiring a wet flux are available.
- In the case of silver soldering where strength is required, joint design is important

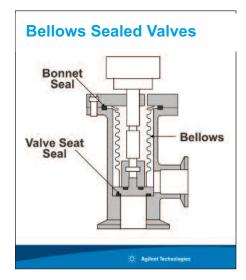




Valves

A variety of valves are manufactured for various vacuum requirements. Each of these takes into consideration factors such as operating vacuum levels, degree of cleanliness needed, need for bakeout, and materials construction. Above, a small right angle block valve made of aluminum and using o-ring seals is used as an illustration.

Valves can be separated into several types based first on whether they are elastomersealed or all-metal; then whether they are small or large valves. Valves also come in hand-operated, pneumatically-operated, and solenoidoperated varieties. Small valves will be defined as valves with inside diameters less than 2 inches. Large valves will be defined as valves with more than 2 inches inside diameter. Valves can also be classified as rightangle, tee, straight-through, back-to-air, variable-leak, gate and slide valves.



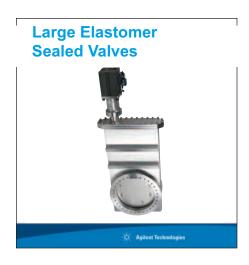
Elastomer-Sealed Small Valves

In an elastomer-sealed bellows valve, all o-ring seals are static seals, meaning that they do not move. These valves are much more reliable than an o-ring shaft-sealed valve.

This type of valve has bellows made of brass, aluminum or stainless steel. The bellows can be formed or welded. The price, of course, varies accordingly. The choice of material depends upon the use of the valve.

The stainless steel bellows is generally used in high and ultrahigh vacuum systems. An example where a stainless steel bellows is not chosen is on valves used with sorption pumps. The hot steam that is produced during regeneration corrodes the stainless steel bellows rather quickly. Inconel bellows are therefore recommended rather than the stainless steel bellows.

Viton is generally the elastomer of choice in valves, although other elastomers are also used. Polyimide finds use in special applications requiring higher temperatures or better chemical resistance.

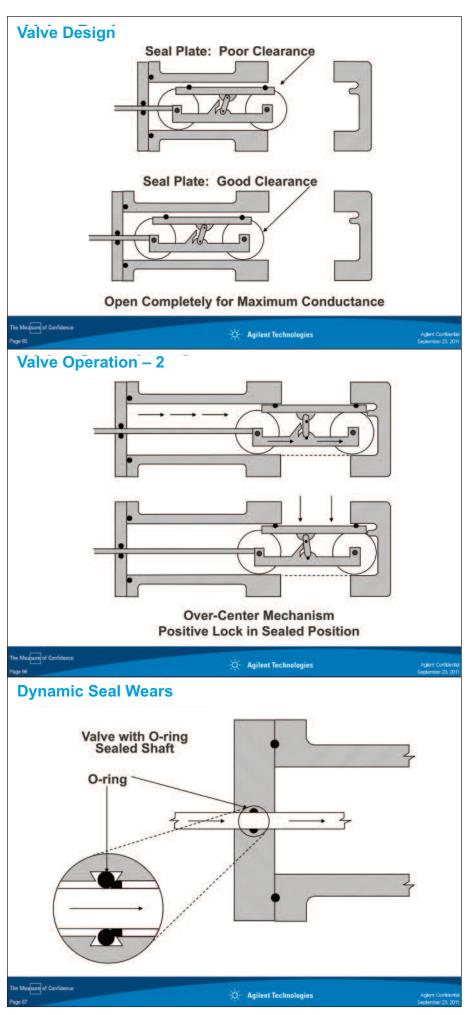


Elastomer-Sealed Large Valves

Most industrial applications require isolation of the work chamber from the system pumps. Many processes require that the chamber be alternately cycled from vacuum to atmosphere. Without a valve between the chamber and pump, the cycle time might be too long, or even physical damage to the pump or system components might result.

Valves for these uses are usually of the sliding gate or swing gate design. Typical port diameters of this type are 4, 6, or 8 inches, although much larger valves are available for specialized pumps and applications.

Since the seals in these valves are usually made of Viton o-rings, heat ranges and operating pressures are about the same as those for small elastomer-sealed valves. The valve bodies are usually made of cast aluminum or stainless steel.



Valve Design

The valve seal plate opens and closes as with a gate. That is, the seal plate drops and retracts from the port. In some designs, the plate does not fully clear the port and, therefore, does not give maximum conductance.

Also, debris can fall on the seal and cause leaks.

Valve Operation

After forward motion stops, further driving motion moves the seal plate up into the sealed position.

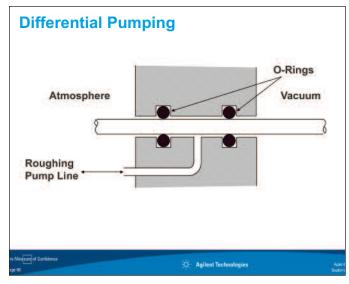
The over-center mechanism and second mechanical stop insure that the seal plate is positively locked in the sealed position.

Valves are often air-operated and close with considerable speed and force. It is important to remember to disconnect both air and electricity when maintenance has to be done.

O-Ring Seals

In a valve having an o-ring-sealed shaft, the seal is usually quickly rolled and scuffed. This seriously reduces its life. The o-ring must be lubricated in order to minimize wear.

Valves with this type of design should be one of the first items to check when troubleshooting a vacuum system.





Double O-Ring Seals

The shaft in an o-ring sealed valve is often equipped with a double o-ring seal. This double seal provides better separation between the vacuum chamber and atmosphere. However, it also creates a trapped volume which may result in a virtual leak.

The volume between the two o-rings may also be connected to a roughing pump. This is to improve vacuum separation of the work chamber even further. The driving pressure over the o-ring on the vacuum side of the seal will be significantly reduced. Instead of 760 torr forcing gas through the o-ring, a force of only several hundred millitorr will be driving the gas through the seal. This will reduce the leakage rate by a factor of 1,000 or more!

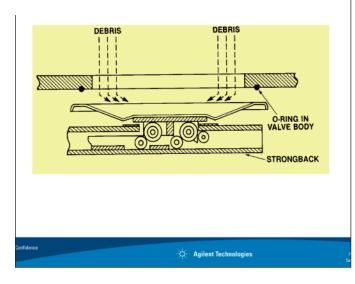
When leak checking a double shaft seal, the line to the rough pump is disconnected. Then both the outer and inner seal can be checked by inserting helium into the space between the o-rings.

Bellows Sealed Swing Gate Valve

To eliminate contamination problems of the sliding gate valve design, bellows made of brass or stainless steel are often used.

An 8-inch "swing gate" valve is shown as illustration above. The main flanges are sealed with Conflat flanges, but an o-ring seal is used on the seal plate. All seals are static seals.

Debris Is Kept Away from Seal Area



Elastomer-Sealed Large Valve

The conical shape of the seal plate causes process debris to fall away from the seal area. Also, the seal is located in the valve body instead of in the seal plate. This location further minimizes the possibility of seal leaks.

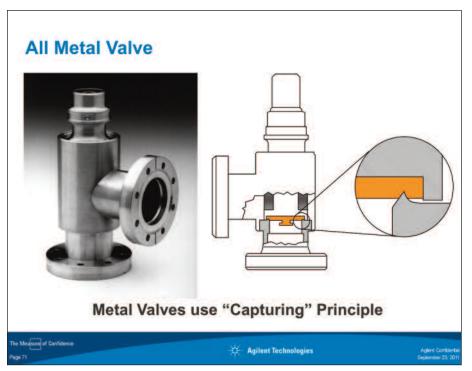
Maintenance

The valve should be in the open position for maintenance and cleaning. Air and electrical lines should then be removed. Next, remove the whole actuator sealing-plate assembly by taking off the body flange and its o-ring.

The body flange o-ring is held in its position over a large, rectangular o-ring retainer. Re-assembly of this flange can be time-consuming if the o-ring continues to slip off its retainer during the bolt-on process. Bolting on is made much easier by using a seal positioning tool.

Once out of the valve body the mechanism can be cleaned, adjusted, or repaired. Full removal of the valve and valve body from the vacuum system is usually required to perform proper cleaning and refurbishing. See instruction manual for proper maintenance procedures.

The cleaning procedure is similar to the small elastomer-sealed valves. Do not attempt to spray cleaning solutions or solvents into the valve body or port area while the valve is on the vacuum system. Serious pump or system contamination could result.



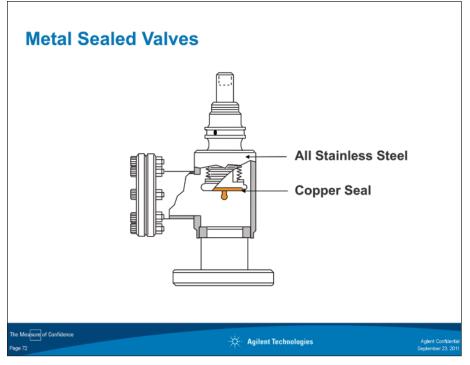
Notes Small Metal-Sealed Valves

Small valves are ¾4 in. to 2½ in. in diameter. The construction of the valves is entirely metal. There are no elastomers used. The seal is accomplished using a copper gasket. Therefore, metal-sealed valves provide reliable seals under repeated bakeout conditions.

A cross-section of an all-metal valve, made entirely of stainless steel and copper is shown above.

The sealing surface inside the valve has a knife edge which cuts into the copper button to seal the valve closed. The same capturing principle is used as described previously.

This type of valve can be baked to 450°C, if necessary.



All Metal Valves

All metal valves use the gasket-capturing design discussed in the flange section. This insures that the gasket material will not flow away from the seal area, even under bakeout temperatures of 450°C.

Metal-sealed valves are used in ultrahigh vacuum systems or for high-purity gas systems. Because of the UHV requirements, these valves are baked. The temperature at which they keep their sealing integrity is usually related to their size and seal design.

These valves, when operated at room temperature, will perform well up to 100 cycles. When baked out to maximum temperatures, however, valve seal life is about one order of magnitude less. The sealing torque must also be increased after each bakeout.

The drive mechanisms (outside the vacuum system) must be lubricated with an appropriate high-temperature grease after each bakeout. This prevents galling of the threads and early wear of the valve components.

Pressure ranges of these valves are usually from about atmosphere to 10-11 torr. Typical leak rates are less than 10-10 std cc/sec.

Closure Repeatability is a Must **Groove From Groove From** Leak! One Closing Another Closing Agilent Technologies

Thin Light Weight Conical Plate Reduces Force Ramp Roller Agilent Technologies

Notes

Sealing Torque

Knife edge grooves can produce vacuum leaks where the grooves crisscross if the sealplate position is not exactly maintained. If the grooves do crisscross, a leak can be avoided by using greater sealing pressure each time a closure is made. This limits the life of the gasket, however. The torque used to seal the valve must be increased with each closing as closing repeatability has some slight tolerance. The initial sealing torque ranges from about 1 to 13 ft-lbs to a maximum of 6 to 46 ft-lbs, again depending on valve size.

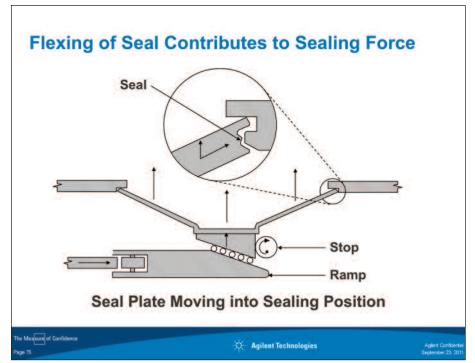
Maintenance

Some maintenance suggestions for all-metal valves are outlined below:

- 1. Metal sealed valves require more sealing force than elastomer valves. When the valve is opened or closed, support the valve so the attached plumbing is not bent or kinked.
- 2. After baking at high temperatures, the threads on the valve need to be lubricated to prevent galling. Use a suitable high-temperature lubricant such as Fel-Pro™ C-100.
- 3. A new seal needs to be installed after a maximum of 300 closures. While the procedure is guite simple, it might be necessary to remove the valve from the vacuum system to carry out the seal change. The valves require a torque wrench to increase the torque by about ½ ft-lb per closure.
- 4. Keep a closure log!

Conical Plate

Another solution to the sealing force requirement is to use a thin lightweight conical plate. The basic design resembles the elastomer-sealed gate design described earlier. The seal plate in this valve is also conical, thin and lightweight. These characteristics are used to good advantage.



Seal Flexing

When moving into the sealing position, the seal plate drives against a stop built into the valve body. When this occurs, further upward force spreads the plate outward. This flexing of the seal plate actually multiplies the driving force. It also reduces the load on the drive mechanism. A goldplated ridge machined into the seal-plate edge makes a tight leak-free seal when the plate flattens out against the seat.

The other two ridges protect the center or sealing ridge against mechanical damage. This valve is bakeable in the open or closed position. Perhaps the greatest advantage of this metal-seal design is that it isn't at all sensitive to position repeatability. That is, there is no possibility of indenting eccentric circles into the seat and causing leaks as in the case of other metal seals.

Maintenance

Maintenance should be carried out according to the manufacturer's instructions. The exact dimensional tolerances needed in reassembly require specialized tools and proper training whenever possible.

Cleaning of the valve body and actuator assembly is usually the same as discussed earlier in this chapter. Again, UHV usage demands that good vacuum practice be strictly followed. Lint, grease and cleaning residue can cause excessively long pumpdown time. This is related to the outgassing load produced by contaminants in the system.

System Pumping Speed

Overview

- Definition
- Ohms Law correlation
- Delivered (net) speed
- Throughput vs pressure
- Effect of conductance

Typical System Design: Q = P*S $Q = C (P_1 - P_2) = P_2S \text{ (torrliter/sec.)}$ The Medicard of Confidence Agiftent Technologies Agiftent Technologies

System Pumping Speed (S)

- System pumping speed is a measure of:
 - the rate system pressure decreases in time with no gas load, or
 - the change in system pressure per change in throughput
- System base pressure (when S_{net} = 0) is determined by:
 - limiting compressin ratio of the pump with no gas load, or
 - the minimum achievable gas load (permeation)
- Pumping speed is expressed in units of volume/time
 - liters/sec, liters/min, m³/hr, cfm



Notes

Throughput

Throughput is the actual amount of gas, or the number of atoms and/or molecules, moving through or being removed from a vacuum system. This is the work really being done by a vacuum system. Throughput is expressed by the letter Q.

The flow of gas through a pipe is described as the amount of gas (Ω) flowing through a pipe is equal to conductance (C) of the pipe times the pressure ($P_1 - P_2$) over the pipe.

Or:
$$Q = C \times (P_1 - P_2)$$

In the case where a pump is removing gas from a chamber at pressure P, we can look at how throughput is related to pumping speed (S) by taking another look at the definition of speed

Pumping Speed: amount of gas flowing into a chamber

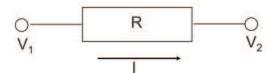
Pressure in the chamber

or:
$$S = \underline{Q}_{P}$$
 (liters/second)

reworking this formula: $Q = P \times S$ (torrliters/sec.)

Or in words: the amount of gas being pumped from a chamber is equal to the pressure in the chamber multiplied by the speed of the pump attached to the chamber.

Ohm's Law In Vacuum (conductance)



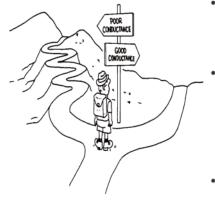
Ohm's Law: $I \times R = V1 - Vs) = V$

Or: $I = 1/R \times (V1 - V2) = C \times (V1 - V2)$

Vacuum Systems = Q - C x (P1 - P2) torr.liter/sec

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Conductance



- The speed with which molecules flow through a region like an orifice or pipe
- The term "conductance" is assigned to passive components of a system and it is the reciprocal of the resistance to gas flow.
- Conductance is expressed in volume units per unit time (L/s)

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When we talk about moving a gas through an opening or tube, we use the term conductance (C). Conductance is the ability of an opening or tube to allow a given volume of gas to pass through in a given time. It is expressed in such units as liters per second, cubic feet per minute or cubic meters per hour.

A good conductance path is wide and short. It has few turns, thus allowing free gas flow. This is important for molecular flow. In viscous flow, these conditions for good conductance are not so important. This is because the molecules tend to push one another along under the influence of a pressure difference.

Conductance is also defined as the amount of gas per unit time (Q) that flows through an orifice or tube divided by the pressure over the tube $(P_1 - P_2)$, or:

Conductance: gas flowing through an opening or tube

pressure over the opening/tube

Or: C =
$$\frac{.0 \text{ (liters per second)}}{P_1 - P_2}$$

This formula is usually expressed as follows: $Q = C (P_1 - P_2)$ (torrliters per second)

System Pumping Speed

To achieve the best possible vacuum or lowest system pressure with a given pump, it is necessary to maximize effective pumping speed at the chamber while minimizing gas load.

$$S_{EFF} = \frac{S \times C_{T}}{S + C_{T}} = \frac{S}{1 + S/C_{T}}$$

$$C_{T} >> S$$

$$C_{T} = S$$

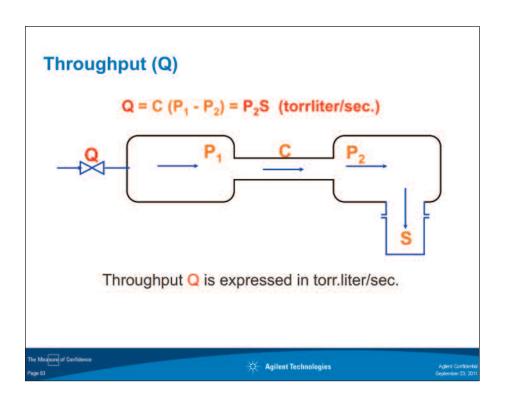
$$C_{T} << S$$

$$S_{EFF} = S/2$$

$$S_{EFF} = C_{T}$$

For N2 at 295K, the maximum theoretical pumping speed SEFF into a 12" diameter chamber is about 8000 liter / sec

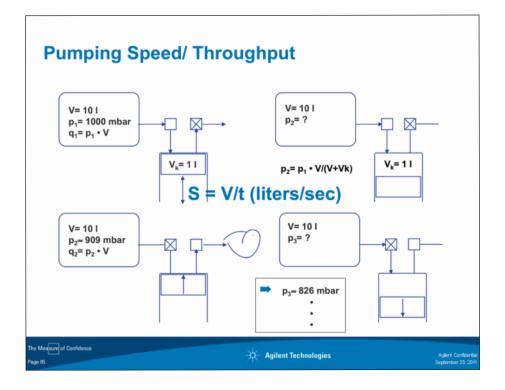


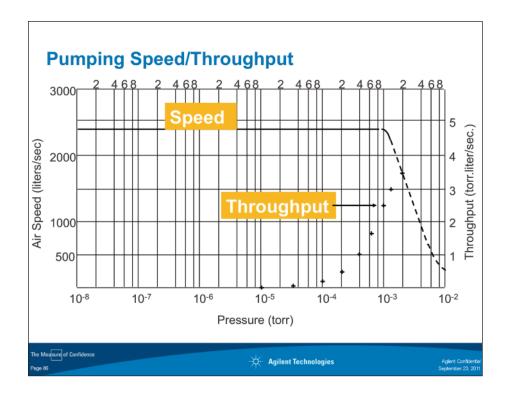


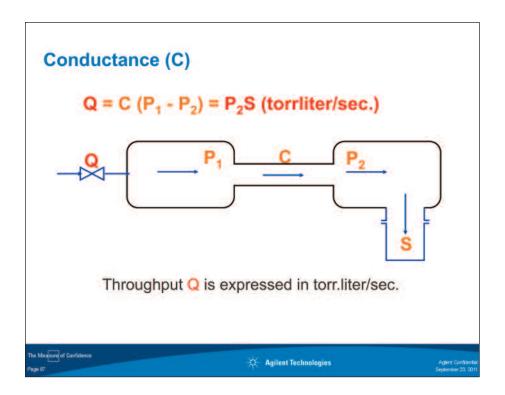
Pumping Parameters

- · Pumping speed of the pump
- Net pumping speed of the system
- Throughput of the system

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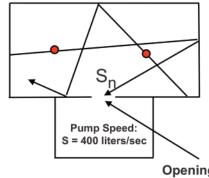






Example: Conductance Limitation

Orifice



$$R_T = R_1 + R_2$$

$$\frac{1}{C_T} = \frac{1}{S_N} = \frac{1}{C} + \frac{1}{S}$$

$$S_n = \frac{C \times S}{C + S}$$

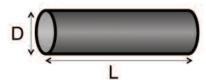
 $S_n = 63 \text{ ltr/sec}$

Opening: 1 in² C = 75 liters/sec





Conductance in Viscous Flow



- · Under viscous flow conditions doubling the pipe diameter (D) increases the conductance sixteen times
- The conductance is INVERSELY related to the pipe length (L)





Conductance in Molecular Flow



- · Under molecular flow conditions doubling the pipe diameter (D) increases the conductance eight times
- The conductance is INVERSELY related to the pipe length (L)



Addendum B Conductance Formulas

Conductance In Molecular Flow (Orifice)

$$C = 3.64 \times A \times \sqrt{\frac{T}{M}}$$
 (1/sec)

A = Area of orifice in cm²

T = Temperature in Kelvin

M = Atomic Mass Unit (A.M.U.)

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Molecular Flow (Orifice)

Aperture conductance at room temperature

C = 11.6A where $A = Area, cm^2$

C= L / sec

Nitrogen, 20°C

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Molecular Flow

Short pipe at room temperature

$$C = \frac{11.6A}{1 + L/D}$$

$$L = Length, cm$$

$$D = Diameter, cm$$
Nitrogen, 20°C

Valid when length < 1.5 times diameter

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Molecular Flow

Short round tube at room temperature

Combine orifice and tube conductance Method 1:

$$C_{\text{total}} = \frac{C_{\text{orifice}} \times C_{\text{tube}}}{C_{\text{orifice}} + C_{\text{tube}}}$$

Use computer generated Mont Carlo Method 2:

calculations to determine the transmi

coefficient α

$$C_{total} = \alpha \times C_{total}$$



Molecular Flow

Short round tube at room temperature

 α is the ratio between particles exiting the tube after the *first* entrance into the tube and the total number of particles entering the tube

For short tube: $\alpha = \frac{1}{1 + 31/4d}$

For tube length towards 0 (orifice) $\alpha \longrightarrow 1$

For tube length >> tube diameter (long tube): $\alpha \longrightarrow 31/4d^*$

*Dushman, Scientific Foundations of Vacuum Techniques, 2nd ed., Wiley, New York, 1949, Ch.2





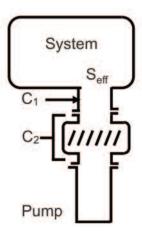
Series Conductance

Tube (C₁): 200 l/s

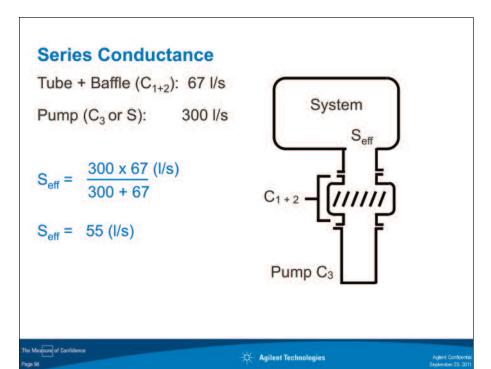
Baffle (C2): 100 l/s

$$C_T = \frac{200 \times 100}{200 + 100} (I/s)$$

$$C_T = 67 (I/s)$$







Conductance in Molecular Flow

Long round tube

$$C = 3.81 \times \frac{d^3}{I} \times \sqrt{\frac{T}{M}}$$
 (I/sec)

d = diameter of tube in cm

I = length of tube in cm

t = temperature (k)

m = A.M.U.



Molecular Flow

Long pipe at room temperature

$$C = \frac{12.1 \text{ D}^3}{\text{L}}$$

$$L = \text{Length, cm}$$

$$D = \text{Diameter, cm}$$

$$\text{Nitrogen, 20}^{\circ}\text{C}$$

Valid when length > 5.0 times diameter

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Viscous vs. Molecular Flow

Example: 4 cm diameter, 100 cm tube, N2, 295 K

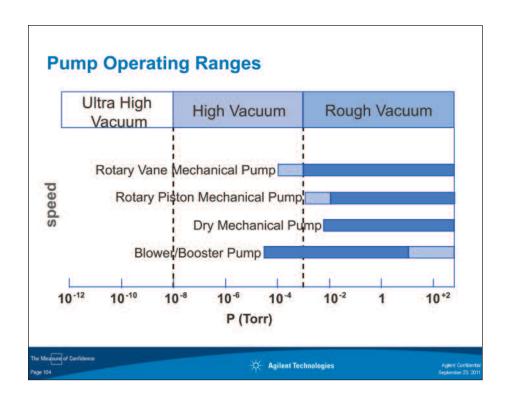
- •Viscous Conductance = 530 l/s
 - -d4/I
 - pressure dependent
- •Molecular Conductance ~ 8 l/s
 - -d3/I
 - temperature and mass dependent

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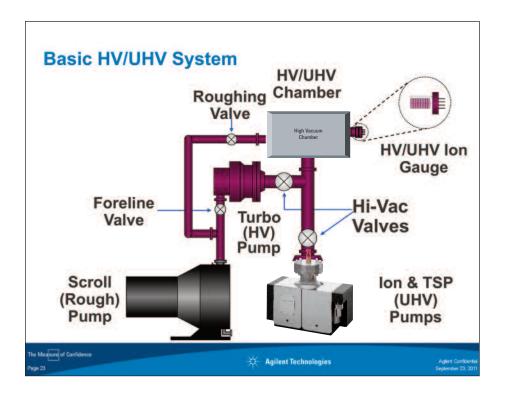
Vacuum Pumps

Overview

- Operating ranges
- Rough pumps
- Scroll pumps
- Diaphragn pumps
- Blower/booster pumps
- Screw pumps
- Pump performance
- Pump precautions
- Pump comparison







Roughing Pump Uses for HV/UHV

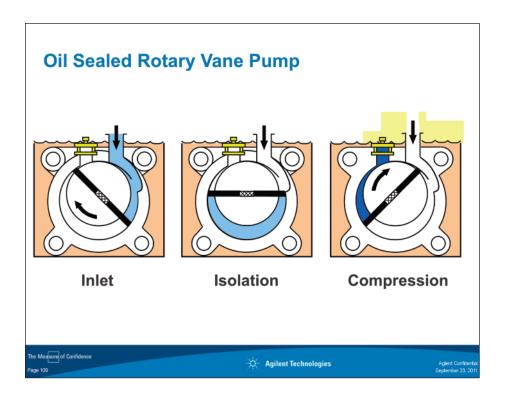
- Remove volume gas (air) from chamber(s)
- Keep foreline of high vacuum pump at acceptable pressure level



Oil Sealed Rotary Vane Pump







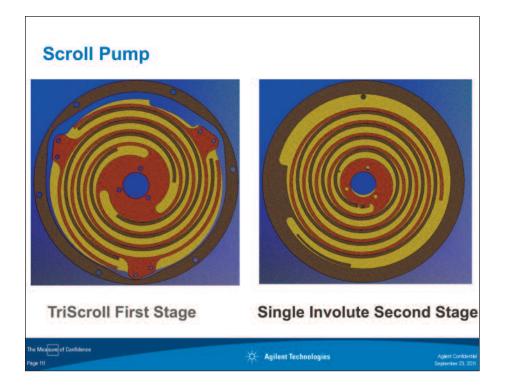
Scroll Pumps

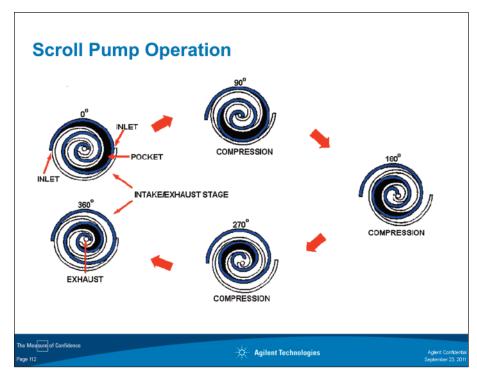
- Dry (no oil in vacuum portion of pump)
- High pump speed
- Compact size
- Base pressure low mtorr



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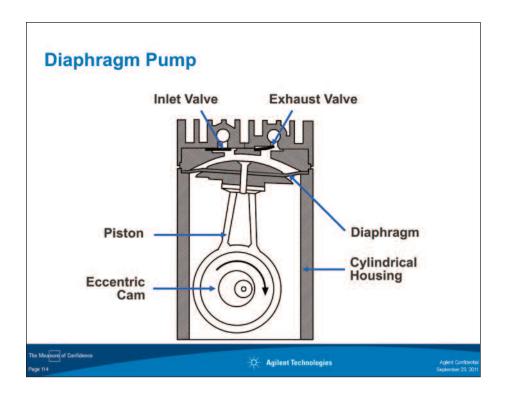


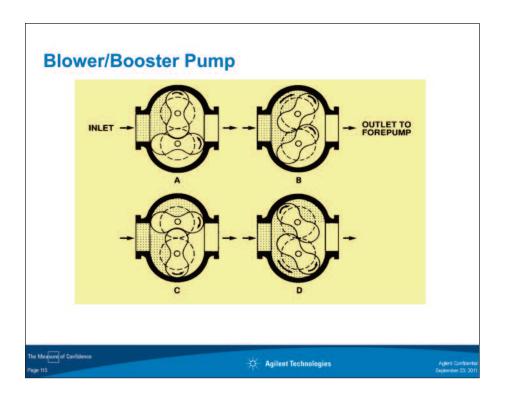


Principle of Operation

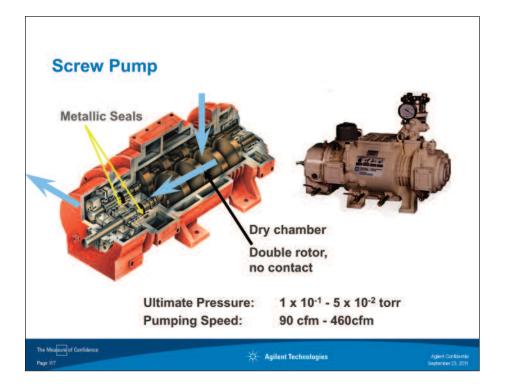
Gas is transferred through the pump in three phases similar to gas transfer occurring in other types of mechanical pumps shown before. The circular motion of the orbiting scroll forms crescent shaped spaces into which the gas enters (1 left) and becomes isolated (2,3 and 4). The orbiting motion moves the gas towards the center. The volume of the gas becomes smaller and the pressure increases. Finally the crescent is connected to the exhaust port (5 left) and moved to the second set of scrolls. The gas is then compressed in an identical way and exhausted from the the pump

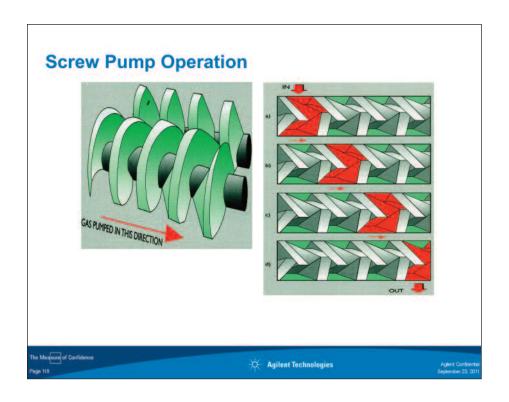


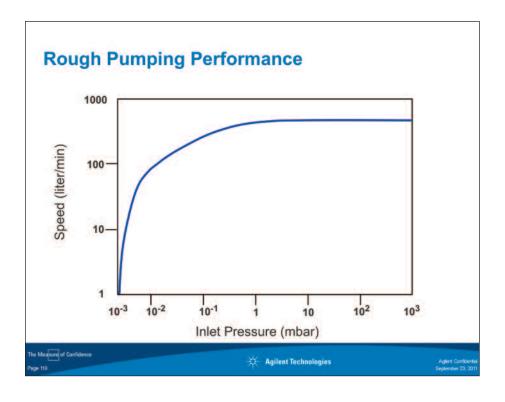












Roughing Pump Precautions Dry pumps prevent oil backstreaming Proper system design is required to prevent particulate contamination VPI valve is a must Turbo Pump SCROLL Pump Agilent Technologies Agilent Technologies

Rough Pump Comparison Disadvantages Advantages Type Low ultimate pressure Rotary Vane Backstreams oil Produces hazard. Waste Low cost Synthetic oil Long pump life High volume Rotary Piston Safety valve Noisy Vibration Low cost No backstreaming Roots lobe Expensive Low ultimate pressure Hook and Claw Frequent maintenance Requires purge gas Scroll Limited bearing life Low "dry" ultimate pressure Permeable to light gases Clean applications only Diaphragm Low pumping speed Quiet Easily Serviced High ultimate pressure Frequent service required No Moving Parts Venturi Limited ultimate pressure Unlimited pumping Low cost No moving parts Sorption Requires regeneration Limited pump capacity Clean pumping Agilent Technologies

Rough Pump Comparison

An overview of rough pump advantages and disadvantages is shown above. Wet pumps tend to be reliable, have long life and are relatively inexpensive. Their major disadvantage is that fluids used in the pump can backstream into the vacuum system.

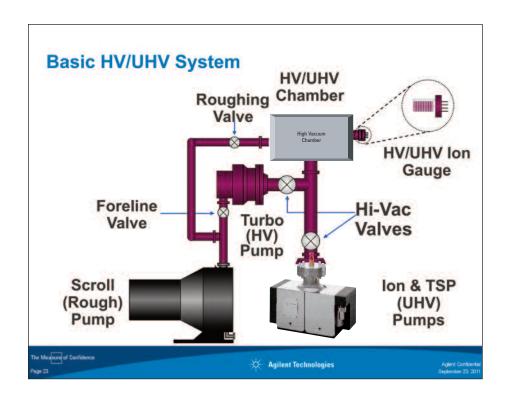
Dry pumps are clean. They are used in applications where backstreaming of pump fluid can not be tolerated. They are more complex and expensive than the equivalent wet pump. Also, in many cases preventative maintenance has to be performed more frequently.

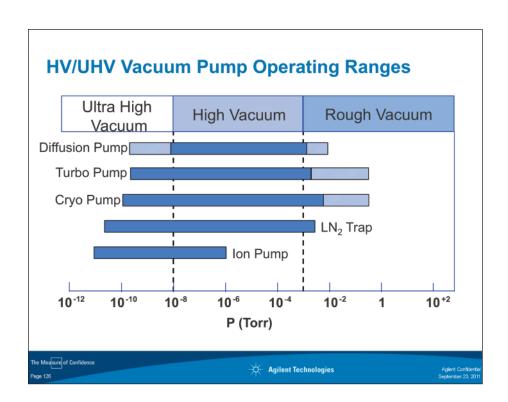
High Vacuum Pumps



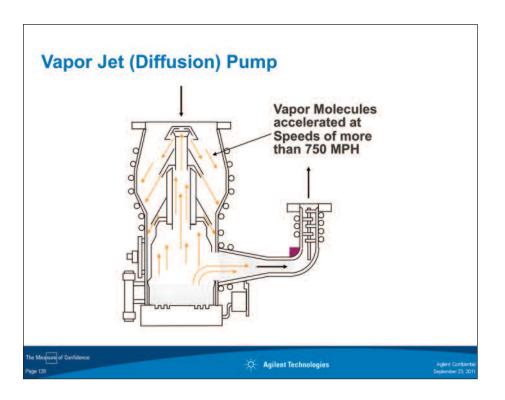
Overview

- Basic system
- Operating ranges
- Vapor jet pumps
- Molecular pumps
- Historical perspective
- Commercial solutions
- Turbo pump comparisons
- Compression ratio
- Cryo pump
- High vacuum pump comparison

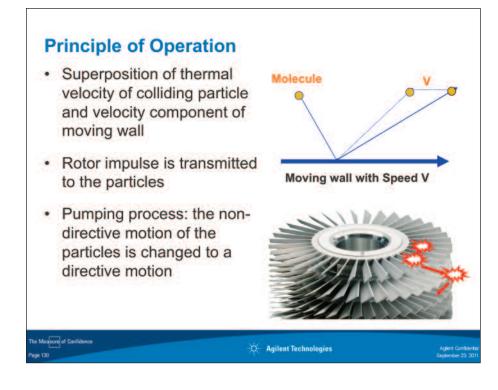


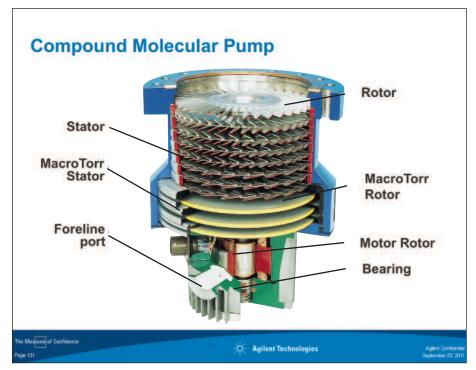






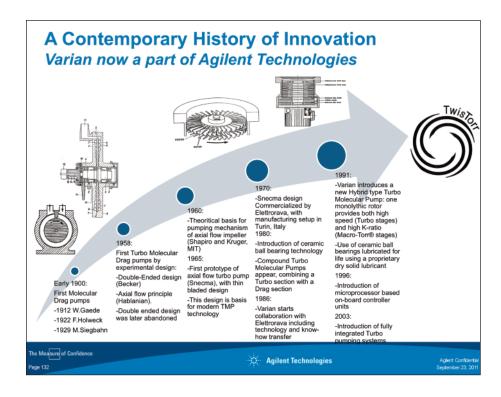
Turbomolecular Pumps Agilent Technologies

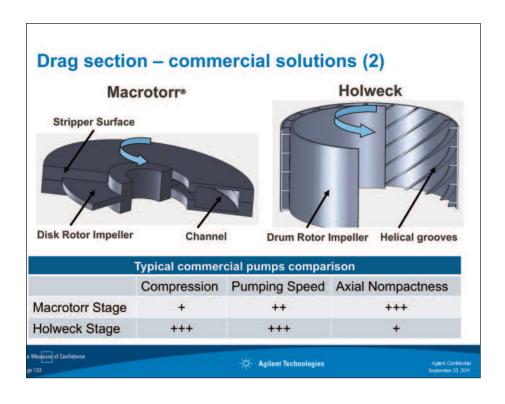


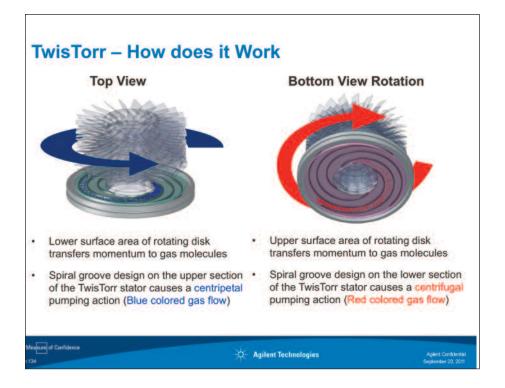


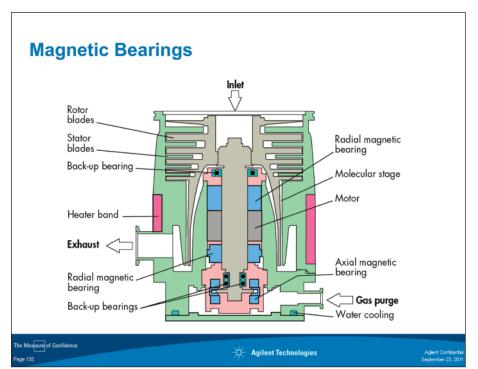
While turbomolecular pumps achieve high pumping speeds, drag pumps have high compression ratios (especially for light gases) and can therefore discharge against pressures of up to several torr. A compound pump design provides both capabilities from a single pump. The Agilent compound pump (Macrotorr) configuration is shown. It consists of 8 to 10 turbomolecular stages (Rotor/Stator) followed by several drag stages (MacroTorr Rotor/Stator) combined in a single rotor-stator assembly.

The turbo rotor-stator blade combinations at the low-pressure side (inlet) of the compound pump have compressed the gas. So the volume of gas being moved at the high-pressure side (foreline) of the pump has become much smaller, and high pumping speed is no longer needed. Due to the increased compression ratio provided by the drag stages of a compound pump, the discharge pressure against which it can operate is higher than that of a traditional turbomolecular pump. Compound pump can overlap the pressure range of dry roughing pumps, such as a scroll or a diaphragm pump, allowing for a totally dry vacuum system to be built.

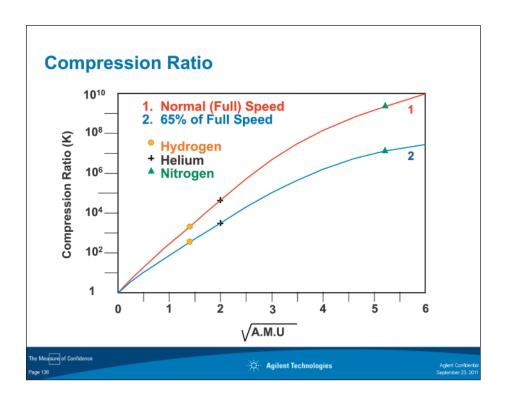


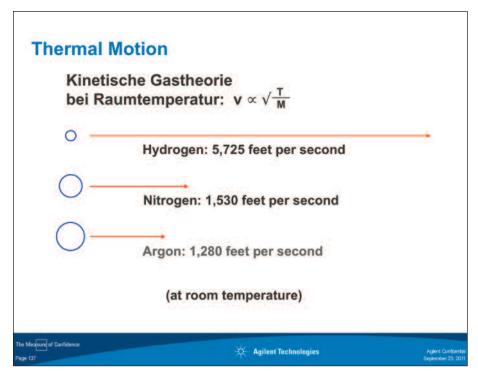






Some manufacturers have developed magnetic bearings for rotor suspension. Magnetic bearings use electromagnets to lift the rotor and hold it in place during operation. Sensors detect any off-center movement of the rotor and, through feedback circuitry, the magnetic fields are adjusted to recenter the rotor. A so-called crash bearing is used to handle inadvertent contact between rotor and stator during power failures or when the pump is accidentally vented to atmosphere ("dumped").





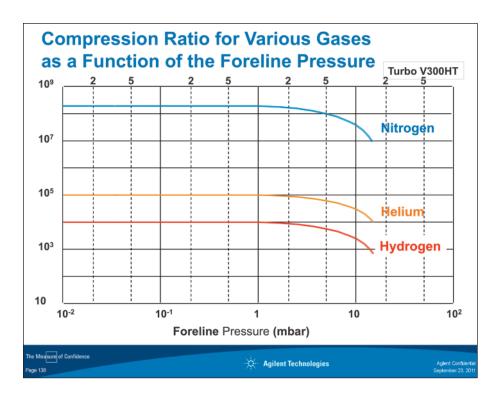
The atoms and molecules in a gas are in constant high-speed, straight-line motion in random directions. This is called thermal motion (or the Kinetic Energy of Motion) and is associated with the temperature of the molecules. The higher the temperature, the higher the speed. Thermal motion will tend to move molecules away from each other until they collide with something, usual the walls of the container and with one another. For a given amount of thermal energy (temperature), the speed of an atom will depend upon its Mass (or weight) - lighter elements will travel faster than heavier elements.

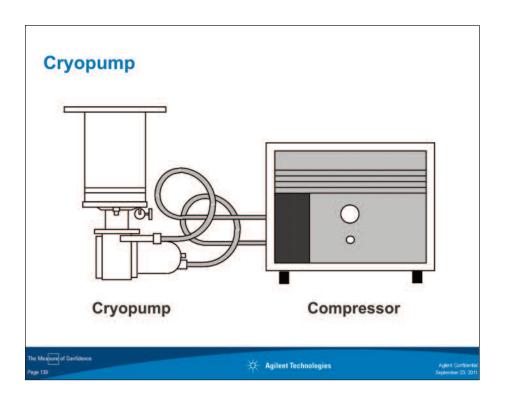
The atomic motion can be "seen" (we cannot really see atoms move) by watching the collective effect of atoms colliding with a dust particle, that is, we may watch the dust particle move and extrapolate what the surrounding atoms must have been doing. The balance between the electrical dispersion forces holding molecules together and the thermal motion which tends to move molecules apart, is very important in a vacuum system. If the dispersion forces are strong, as they are with some molecules, the molecule will stick to a wall when it collides with it. With weak dispersion forces, the molecule will stay on the wall for a very short period.

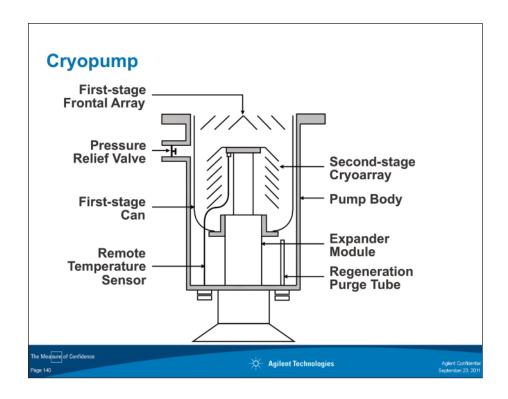
A water molecule is surrounded by strong dispersion forces. When it collides against a wall, it will stick and its movement through the system will be delayed.

Gases such as helium, nitrogen and oxygen have relatively weak dispersion forces. When they move through a vacuum system and periodically collide against a wall, they will not stick and there will essentially be no delay in their movement through the system. This results in helium, nitrogen and oxygen being pumped away much faster than water.

The balance between thermal motion and dispersion forces can be changed by changing the temperature of the vacuum system, For instance, in order to speed up removal of water, vacuum systems are often heated or baked. This increases the energy of thermal motion, resulting in shorter dwell time of the water molecule on a wall.



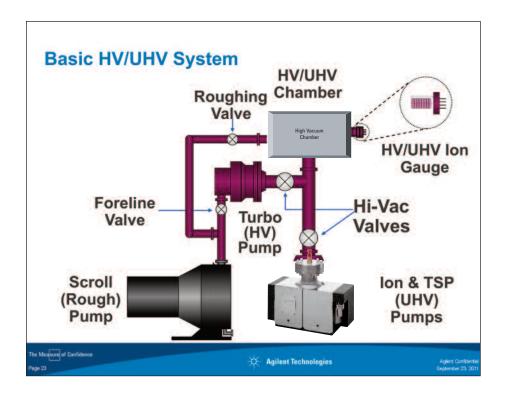


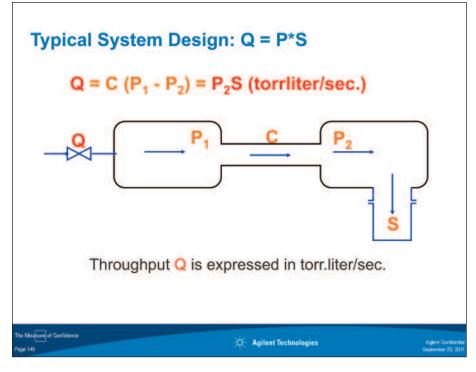


Comparison High Vacuum Pumps Advantages Disadvantages Type Low cost Backstreams Vapor Jet No moving parts **Diffusion** No pressure tolerance Low Maintenance May require coldtrap Continuous pumping **Turbo** Mechanical bearing Clean Vibration High pressure Cost High H₂O pumping speed Regeneration required Cryo Mounts any position Affected by heat Some vibration Clean The Measure of Confidence Agilent Technologies

Ultra-High Vacuum Pumps







Throughput

Throughput is the actual amount of gas — or the number of atoms and/or molecules — moving through or being removed from a vacuum system. This is the work really being done by a vacuum system. Throughput is expressed by the letter $\mathbb Q$.

The flow of gas through a pipe is described as the amount of gas (Q) flowing through a pipe is equal to conductance (C) of the pipe times the pressure $(P_1 - P_2)$ over the pipe.

Or:
$$Q = C \times (P_1 - P_2)$$

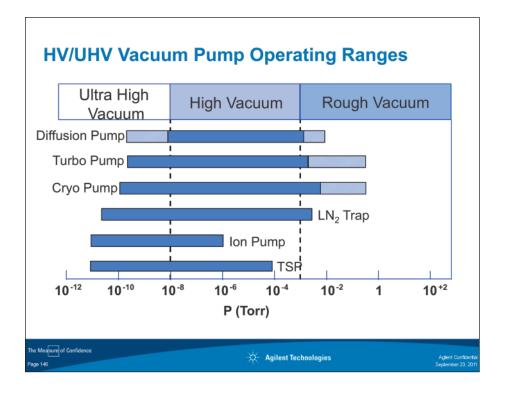
In the case where a pump is removing gas from a chamber at pressure P, we can look at how throughput is related to pumping speed (S) by taking another look at the definition of speed

Pumping Speed: amount of gas flowing into a chamber

Pressure in the chamber

or:
$$S = \frac{Q}{R}$$
 (liters/second)

reworking this formula: $Q = P \times S$ (torrliters/sec.) Or in words: the amount of gas being pumped from a chamber is equal to the pressure in the chamber multiplied by the speed of the pump attached to the chamber.



Overview

- Theory of Ion Pumps
 - Basic pumping mechanism
 - Pumping elements
 - TSP
 - How to choose a pump
- Ion Pump Controller
 - Variable voltage
 - The ion pump as a gauge
- **Best Practice**
 - Bakeout procedure
 - High potting

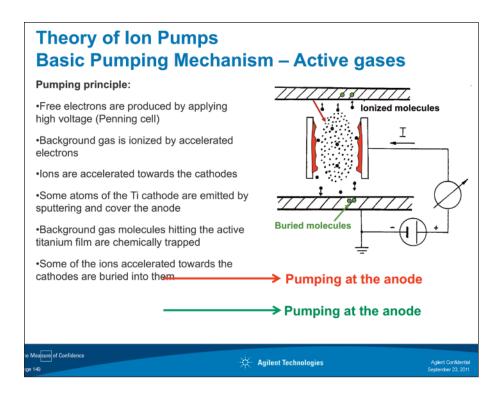


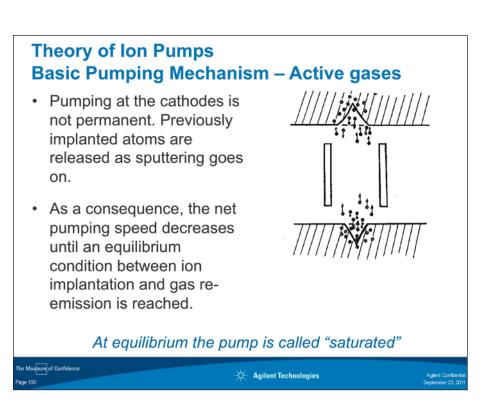
Theory of Ion Pumps Basic Pumping Mechanism

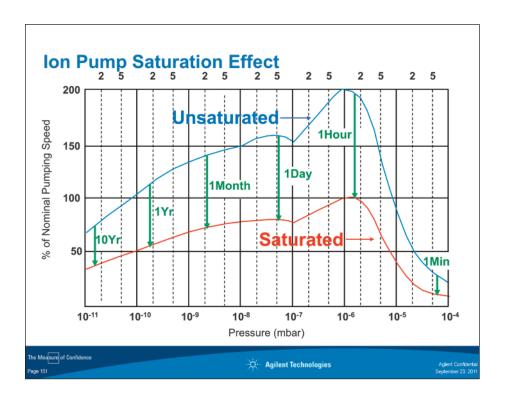
There are three (3) cases to be considered:

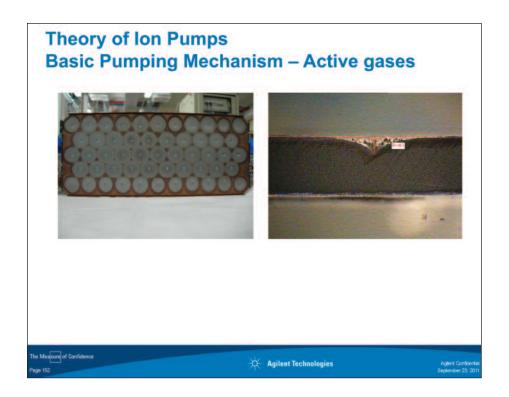
- 1. Chemically active gases
- 2. Hydrogen
- 3. Noble gases





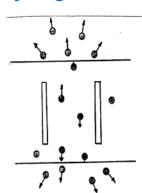






Theory of Ion Pumps Basic Pumping Mechanism - Hydrogen

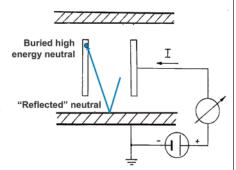
- Hydrogen is chemically reactive so it is pumped by the titanium film.
- Hydrogen has a high solubility in titanium
- -> diffusion into cathode after implementation
- Titanium sputtering yield for hydrogen is very low, so only a small quantity of hydrogen is re-emitted by the cathode
- Present of heavy gases can improve the pumping speed of Hydrogen, as there is more active Titanium available
- In general the Hydrogen pumping speed is ca. 180 - 200% of the nominal pumping speed





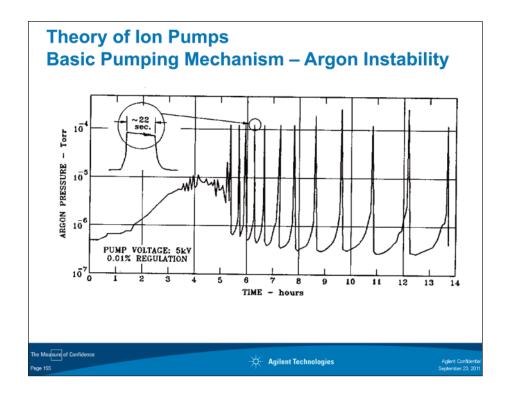
Theory of Ion Pumps Basic Pumping Mechanism - Noble Gases

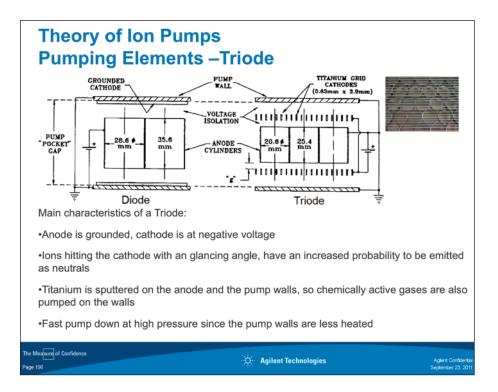
- · They are implanted into the cathode but this type of pumping is not stable
- -> argon / noble gas instability
- After saturation, the pumping speed decreases to only to 1-2 % of N2 pumping speed.
- Noble gases are not chemically active and they are not chemisorbed by the titanium film -> there is no chemical pumping at the anode
- -> only physisorption at anode is stable











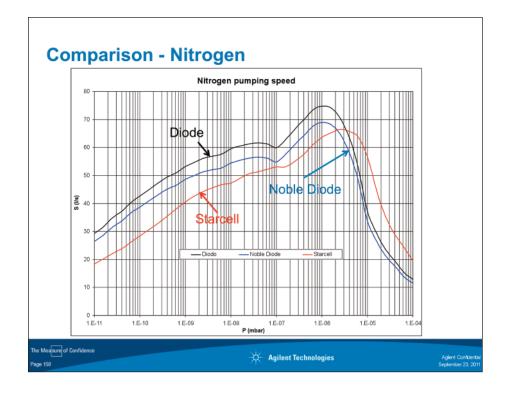
Theory of Ion Pumps Pumping Elements -StarCell

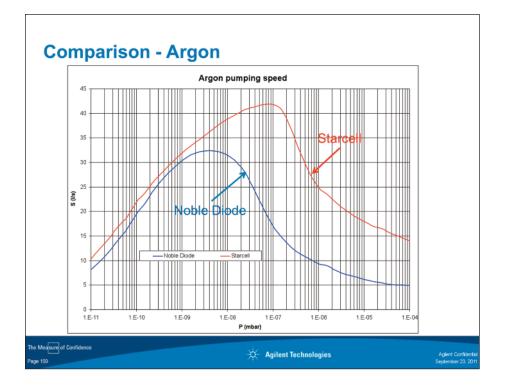
Main characteristics of a StarCell:

- •It is an improved version of the Triode
- ·Longer lifetime than Diode element (titanium consumption is optimized)
- •The shape of the small wings of the stars is optimized in order to maximize the reflection of neutrals (maximum pumping speed for noble gases)
- •Pumping speed for nitrogen is about 75% with respect to the Diode
- •Highest pumping speed and stability for noble gases
- •It can pump larger quantities of hydrogen than the Noble Diode, because both the cathodes are made out of titanium





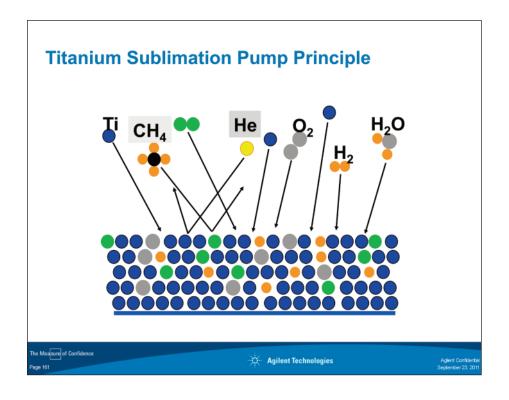


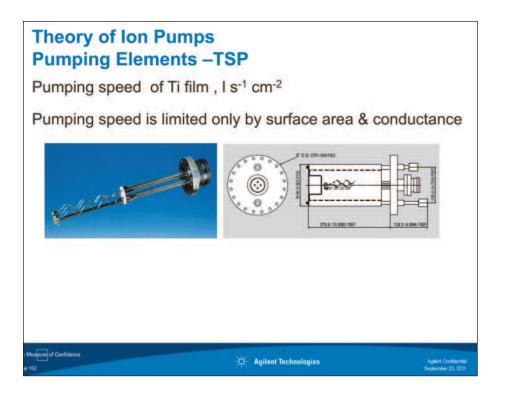


Titamium Sublimation Pumps

- Designed to reach very low pressures
- Provide very high speed at low pressures for all getterable gases
- Zero pumping speed for noble gases and methane
- Limited use (life) at pressure higher than 10-7 mbar







The Titanium Source TI-BALL TI-BALL SOURCE (35 GRAMS) HEATER MINI TI-BALL SOURCE MINI TI-BALL SOURCE (15 GRAMS) **3 FILAMENTS** TITANIUM FILAMENTS Agilent Technologies

TSP Pumping Speed

Typical pumping speed for various gases on sublimed titanium surface (liters per second per square cm)

Surface Temperature	H ₂	N ₂	02	со	CO2	H₂O
20°C	3.1	4.6	9.3	9.3	7.8	3.1
-196°C	10.1	10.1	10.8	10.8	9.3	14.0



Titamium Sublimation Pumps

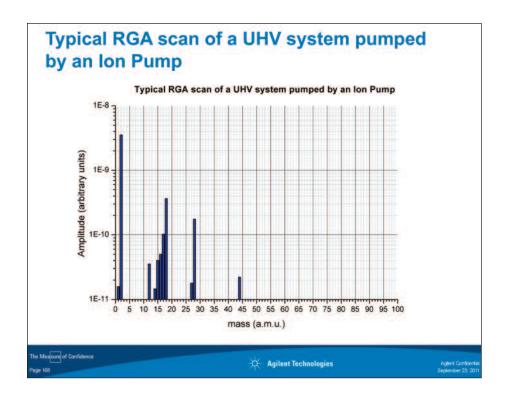
- Designed to reach lower pressures
- Provide very high speed at low pressures for all getterable gases
- Zero pumping speed for noble gases and methane
- Limited use (life) at pressure higher than 10-7 torr



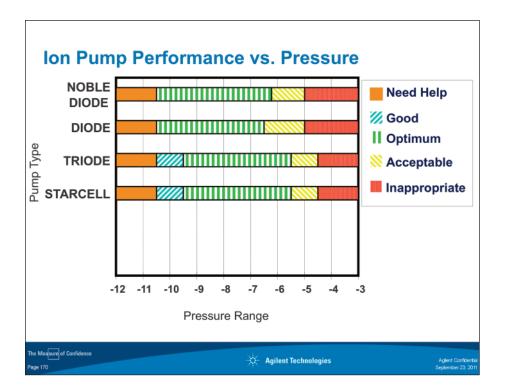
Selection Criteria for UHV Applications

Overview

- RGA scan
- Selection criteria
- Performance vs pressure
- Ion pump selection guide
- Ion pump characteristics
- Leakage
- Baking
- Potting
- Comparison of high vacuum pumps



Selection Criteria TSP Triode Star Cell Diode Noble Diode Hydrogen 3 1 2 3 3 4 Helium 0 1 Water 3 2 2 3 2 Methane 3 3 2 3 0 Nitrogen 3 2 2 3 3 O₂, CO, CO₂ 4 2 2 3 3 Argon 1 0 Null 0 Combination StarCell + TSP is Poor outperforming any other Good 2 combination and can satisfy Excellent nearly any need! Outstanding 4 Agilent Technologies



Summary of Ion Pumps Selection Guidelines

- Diode best for UHV where 98% of gas is hydrogen. Diodes have the highest hydrogen pump speed.
- StarCell good overall performance and best choice for applications with P > E-8 torr. Good H₂ speed, best for pumping noble gas (Ar) or air (air influx, small leaks, frequent vent/pump, air = 1% Ar)
- Nobel Diode compromise of H₂ speed with limited argon stability
- TSP used with ion pump to achieve very low pressures



Diode Ion Pumps Best Used When...

DIODE ION PUMPS: best in UHV applications, where:

- Ion pumps are started below 1 E-6 mbar
- The system is rarely vented to air
- · There ae no air leaks
- The ion pump is used to pump the outgassing of the chamber
- The operating pressure is below 1 E-8 mbar
- Operated @ UHV conditions. Diode ion pumps can work for 20 years before reaching the maximum capacity for Argon



Diode Ion Pumps Characteristics

DIODE ION PUMPS vs others

- Highest pumping speed for all getterable gases $(N_2, O_2, H_2O, CO, CO_2, H_2)$
- Highest pumping speed at low pressures
- Limited speed and stability when pumping noble gases such as Argon and Helium and non-getterable methane
- The only reason to use different and more expensive ion pumps is to improve pumping speed and stability for noble gases



Ion Pumps – Other Selection Factors

Diode ion pumps work great on properly operated UHV systems. However, in real life:

- Air leaks may be present
- · Venting to air may be more frequent than desired
- Working pressures may be higher than design values
- ...then more Argon has to be pumped

Noble gas-stable ion pumps/StarCell ion pumps may offer safer approach when system operating conditions are unknown



StarCell Ion Pump Characteristics

StarCell Ion Pump vs Diode

- Best stability and speed for noble gases
- Lower pumping speed for all getterable gases
- Comparable speed for Hydrogen
- Slightly lower speed at low pressure
- Measured pump current @ UHV might not be the best pressure indicator because of potentially higher leakage current

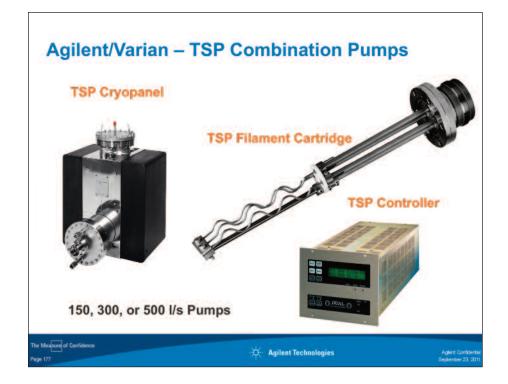


Combipumps

- · lon pump needed mainly to pump Noble gases
- · StarCell (Or Noble Diode) to be used
- · Diode-Based Combipump is very seldom the best choice



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Combination Ion Pumps – TSP Guidelines

Use Ion Pump + TSP combo when a higher pumping speed is needed:

- · At low pressures
- For H₂, CO, CO₂...

Ion Pump + TSP combo benefits:

- TSP provides much higher pumping speed for getterable gas
- Pumping speed independent from pressure
- Ion pump mainly used to pump CH₄ and noble gases



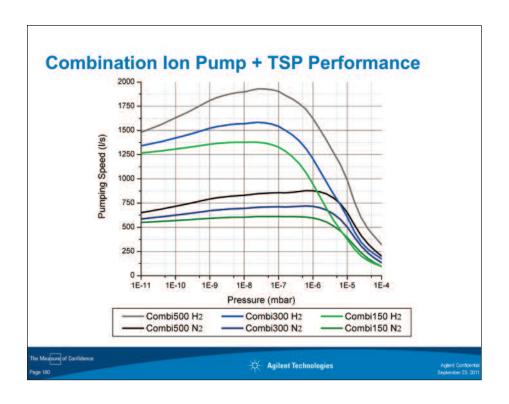
Combination Ion Pump - TSP Performance

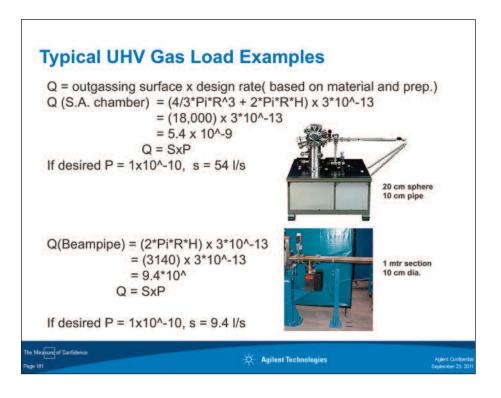
Pumping speed of Ti film, I s-1 cm-2

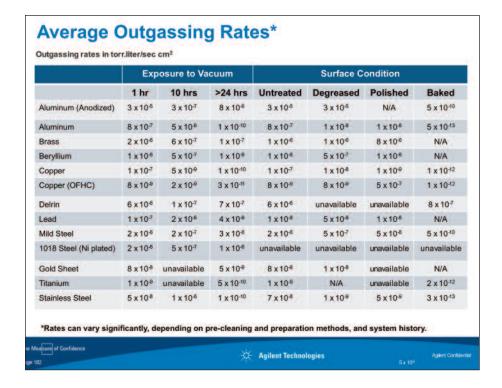
	Gas	H ₂	N ₂	O ₂	со	CO2
Surface	20°C	3.1	4.7	9.3	9.3	7.8
Temp	-195°C	10.1	10.1	10.9	10.9	9.3
	Gas	H₂O	CH₄	Ar	He	
Surface	Gas 20°C	H ₂ O 3.1	CH₄ 0	Ar 0	He 0	

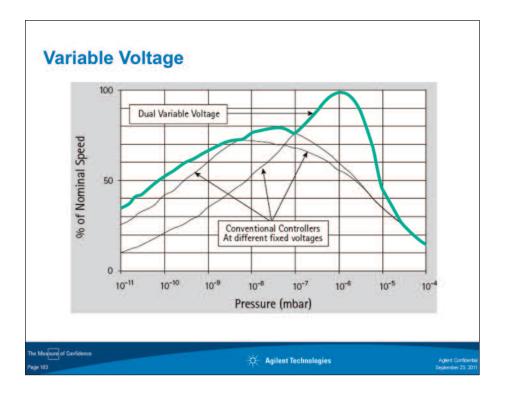
Pumping speed is limited only by surface area and conductance







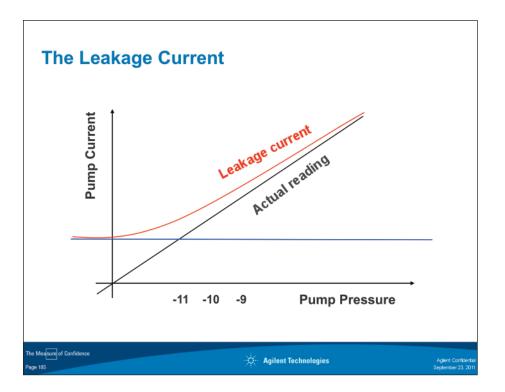


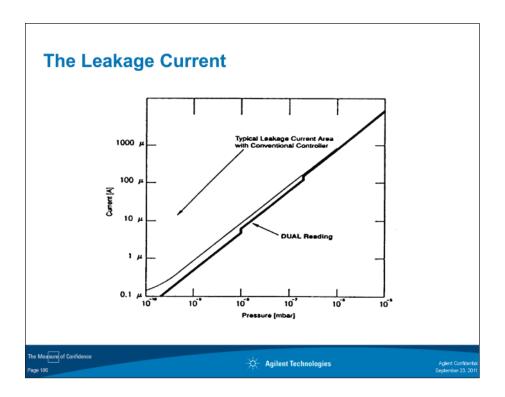


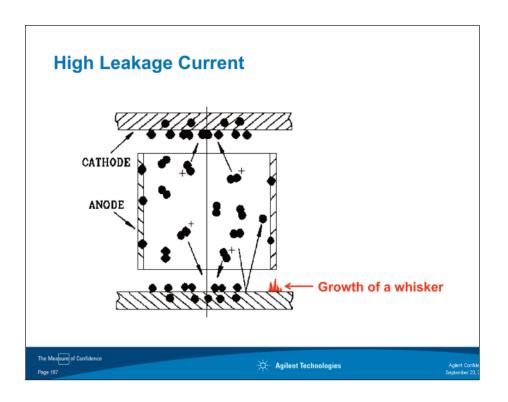
The Ion Pump As A Gauge

- The current in an ion pump is linearly proportioned to the pressure
- The ion pump can so be used as a pressure gauge
- The limitation at low pressures is given by the leakage current

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Baking of an Ion Pump

- Extremely important for pressures less than 10-8 mbar
- Effectively removes water vapor, slowly reduces hydrogen
- Does not remove hydrocarbon contamination, HCs may crack and burn into chamber surface this can ruin the vacuum chamber!
- Result varies with time (linear) and temperature (exponentially)
- Minimum 150°C, best at 300+°C, 200°C is typical
- Heating must be even for all surfaces
- Best results if system is pumped to base pressure before bake
- · Best if each pump is processed following its own outgassing rate-pressure, not time control



Baking of an Ion Pump

- Rough pump system with dry or oil-trapped roughing pump
- Pump to 10-4 or 10-5 mbar with turbo pump
- Best to start bake with ion pump off; use turbo pump to remove gas
- After bake curve approaches flat, start ion pump
- Check that the maximum current of the ion pump doesn't exceed maximum baking current and eventually switch oil heating
- When ion pump reaches full voltage @ stable current close turbo valve
- · When pressure curve is flat, outgas filaments & turn off heat
- Allow system to reach base pressure



When High-Pot?

- When the pump is old (some years)
- When the pump has worked at high pressure for long period (e.g., during a bakeout)
- When we are sure that the leakage current is not coming from the controller or the cable (disconnect the cable from the pump and switch the controller on; read the current on the controller display)
- · When the leakage current is of the same order of magnitude (or higher) of the current the customer runs the pump at



High Potting Procedure?

- The output of an appropriately sized AC transformer may be applied to the pump (preferably without the magnets installed)
- High-potting should be done carefully and in voltage steps since uncontrolled arcing inside the pump can cause permanent damage
- Slowly increase the applied voltage and watch the current meter for indication of arcing inside the pump as whiskers are burned away
- If arcing occurs, wait at this voltage until the current is stable
- Then slowly increase voltage again in steps up to a maximum voltage (depending on the F/T and cables)
- The current should never exceed 50 mA



High potting procedure (2)

Voltage:

Fischer F/T: 8 kV AC max or 11 kV DC max with standard cables

Time:

- •from 0 V to max voltage in at least 30 sec.
- •then stay max 15 sec at max voltage

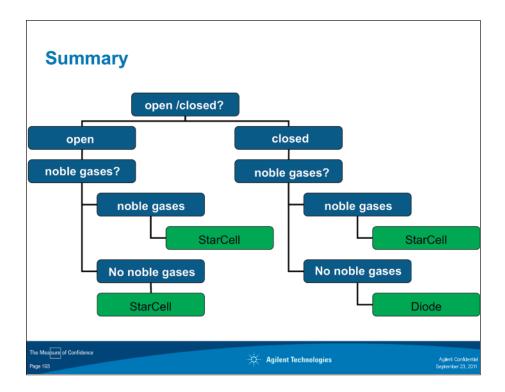
Beware of possible discharges!

Alternative when using StarCell / Triode:

Increase system pressure with pure and dry Argon via leak valve to 1e-5 to 1e-6 mbar for ~ 5 to 10 minutes. After this pump down again and check the leakage current. If necessary repeat this procedure. The introduced Argon will sputter the surfaces of the ion pump clean.

This procedure must not be used on Diode or Nobel Diode pumps!



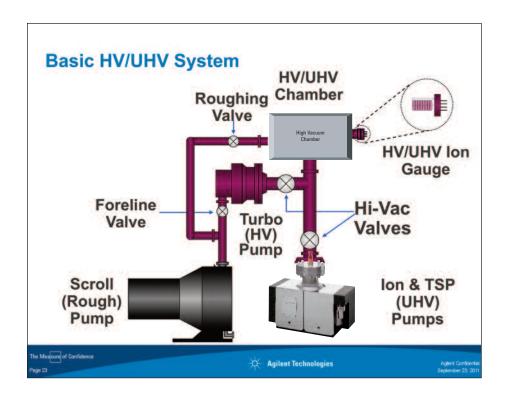


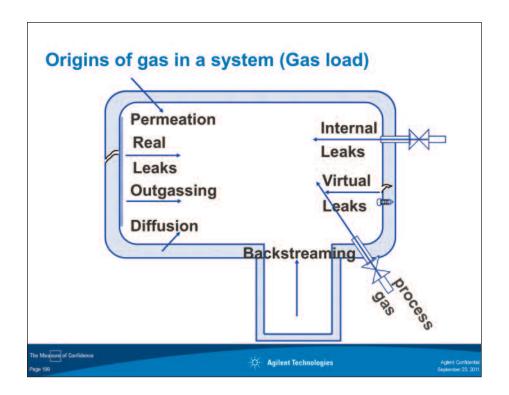
Comparison High Vacuum Pumps Advantages Disadvantages Type Low cost Vapor Jet Backstreams No moving parts **Diffusion** No pressure tolerance Low Maintenance May require cold trap Continuous pumping Mechanical bearing **Turbo** Clean Vibration High pressure Cost High H₂O pumping speed Cryo Regeneration required Mounts any position Affected by heat Clean Some vibration Clean Low throughput ION No moving parts No pressure tolerance Needs no attention Finite life he Measure of Confidence Agilent Technologies

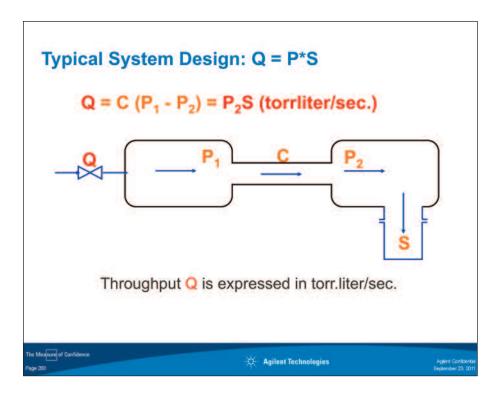
Roughing Systems	High Vacuum Systems	Ultra-High Vacuum Systems
a. Oil-Sealed Mechanical Pump	a. Mechanical Pump b. Baffle or Cryotrap c. Diffusion Pump	a. Dry Pump b. Ion Pump c. Titanium Sublimation Pump d. LN2 Trap
a. Dry Pump	a. Dry Pump b. Cryopump	a. Dry Pump b. Turbo Pump c. Ion Pump
a. Mechanical Pump b. Booster/Blower Pump	a. Dry Pump b. Turbo Pump	

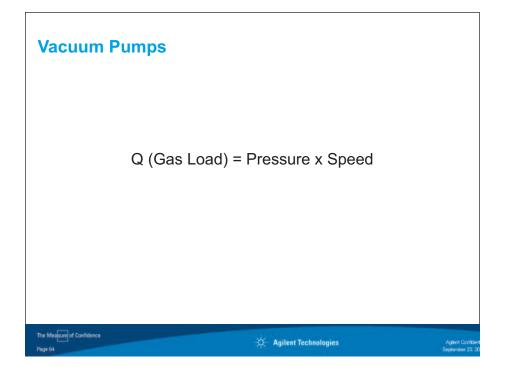
Gauges

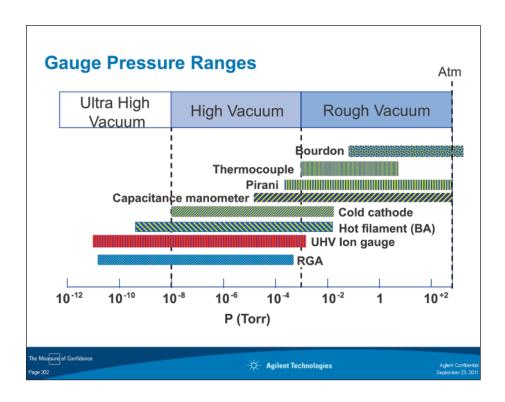
- Basic system design
- Pressure ranges
- Heat transfer gauges
- Pirani transducer
- Capacitance manometer
- Hot filament ion gauge
- Gauge maintenance
- Gauge sensitivity
- UHV ion gauge
- Cold catheter gauge

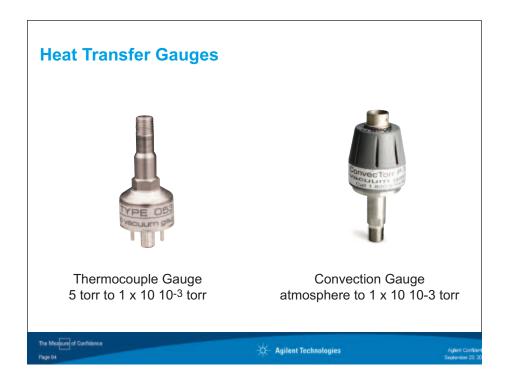


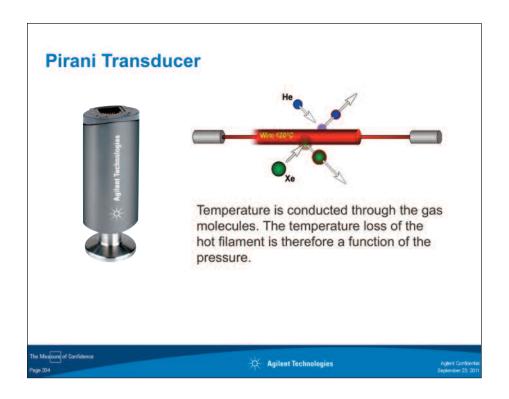


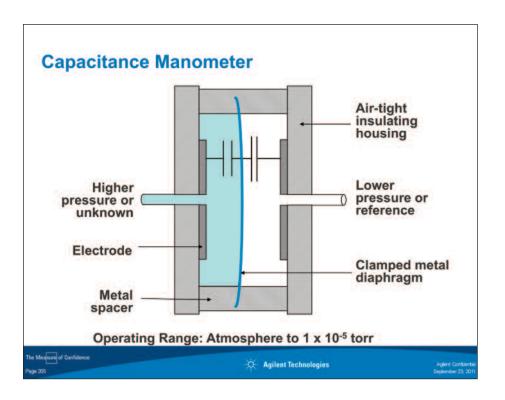


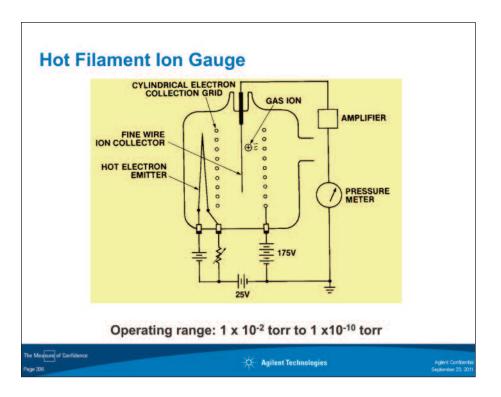












Ionization Gauge Maintenance

- Degas when using below 10-5 torr
- · Degas longer at lower pressure
- Degas more frequently at lower pressure
- Adjust the control unit
- Gauge calibration
- · Check sensitivity of gauge/control unit



Gauge Sensitivity

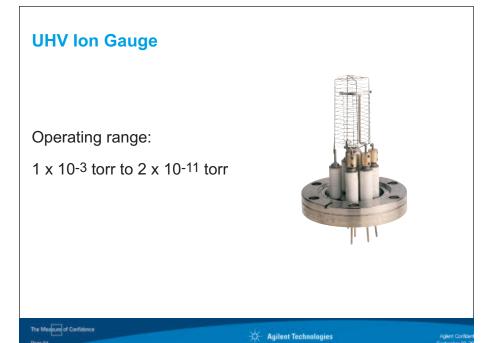
Approximate Gauge Sensitivity of Bayard-Alpert Tubes for Different Gases

Gas	Relative Sensitivity
Α	1.2
СО	1.0 – 1.1
H ₂	0.40 - 0.55
He	0.16
H ₂ 0	0.9 – 1.0
N ₂	1.00
Ne	0.25
O ₂	0.8 - 0.9
Solvents	>> 1

Note: Gauge sensitivity varies depending on manufacturer. Gauge sensitivity must be matched with that of controller used.





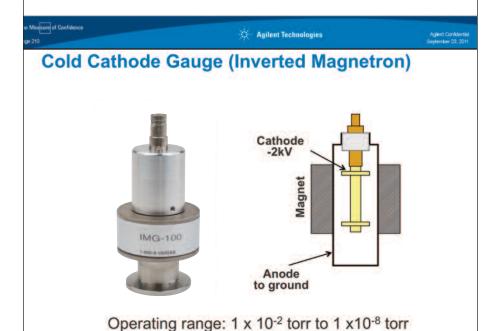


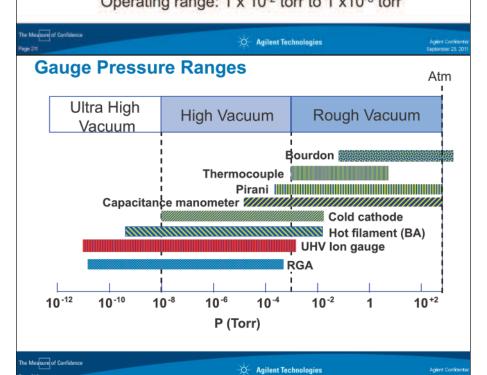
UHV Ion Gauge

Use a nude ion gauge for UHV work.
 For example:

The UHV-24 nude Bayard-Alpert gauge

- 25 amp/torr sensitivity
- x-ray background 2 x 10⁻¹¹ torr
- Bake to 450°C
- · The controller must be able to handle the gauge sensitivity.

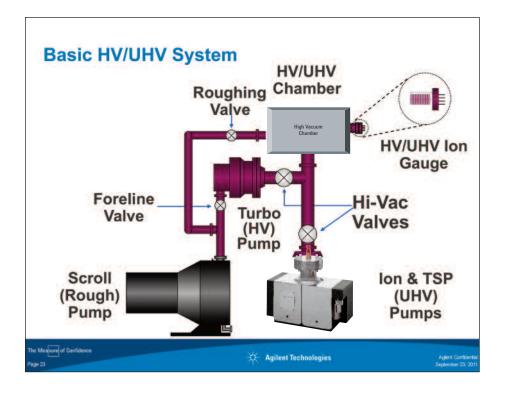




HV/UHV System Operation

Overview

- System operation
- Valve maintenance
- System troubleshooting
- Virtual leaks
- Cleanliness
- Vacuum pumpdown



HV/UHV System Operation

- Pumpdown:
 - Pump through roughing line until gas load from chamber sufficiently low to operate high vacuum pump. Avoid overloading the high (or ultra high) vacuum pump
- Venting:
 - Close high vacuum valve (at pump inlet) and roughing valve before venting chamber

Valve Maintenance

- Inspect seals during valve maintenance
- Lubricate pistons on pneumatically operated valves yearly
- Use recommended lubricants
- Inspect bellows for dents or cracks
- Lubricate O-rings lightly if lubrication is necessary
- Leak check valve before use



HV/UHV System Operation

- All vacuum exposed parts to be kept clean and handled with clean(!) gloves
- · Vent system with dry gas; maintain dry gas flow when system open to atmosphere
- Minimize time open to atmosphere

Notes

Valve maintenance

- 1. Look at the seals whenever maintenance on a valve is done. Inspect the seals to see if they have been warped, or are nicked or scratched.
- 2. The pistons on pneumatically-actuated valves need to be lubricated yearly. Most pneumatically-actuated valves are of the airopen, spring-closed variety. Be careful when disassembling the valve so that it does not come apart during disassembly.
- 3. Lubricate the piston on pneumatic valves with a lubricant recommended for use with compressed-air lines. Please remember that this is not exposed to the vacuum system. This lubricant, which works well for compressedair pistons, will cause problems (high outgassing) if used inside the vacuum system.
- 4. Inspect the bellows for dents or cracks. The brass variety is easy to dent. The dent will cause the bellows to work-harden and crack at that location. It should be replaced while it is disassembled on the bench.
- 5. Only lubricate the o-rings when necessary with a vacuum grease such as Apiezon-L™ or other lubricant. Grease is a contaminant! Remember that only a very thin film is needed.
- 6. The valve should be leak-checked on a helium mass spectrometer leak detector. Do not forget to check the bellows as well as the valve seal and bonnet seal. Leak checking before reinstallation on the system can save a lot of disassembly/re-assembly time should a leak be present.

HV/UHV System Troubleshooting

Expected base pressure not achieved:

- Does the pumping speed match the expected gas load after baking?
- •Was adequate pumpdown time provided?
- •Is the RGA spectrum normal? (Is contamination shown?)
- •Was the bakeout procedure effective? (Water vapor still present?)

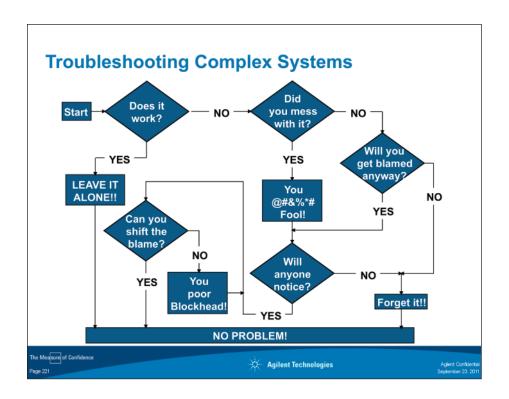


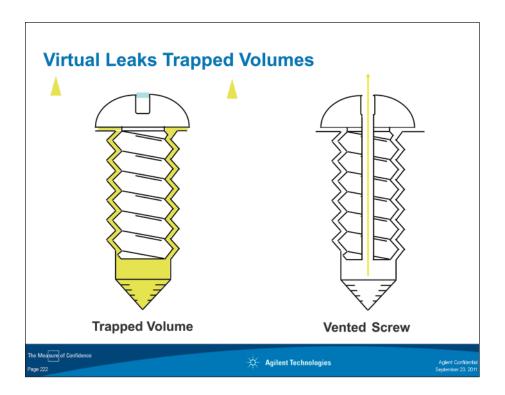
HV/UHV System Troubleshooting

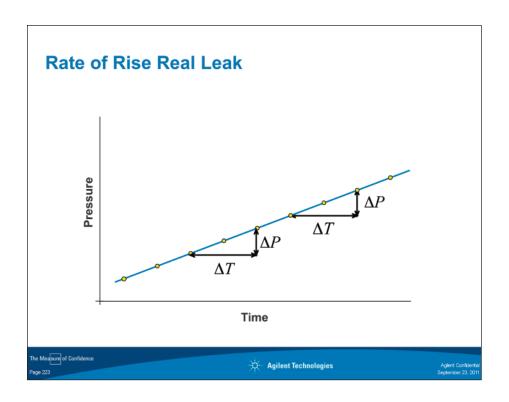
Vacuum leaks:

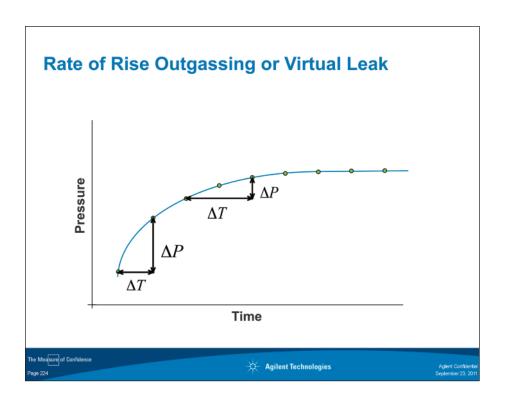
- Quantify the gas load by performing a rate-of-rise test
- Check the system using a helium leak detector
- Check for gauge/pump current fluctuations using helium
- •Check the system by using an RGA







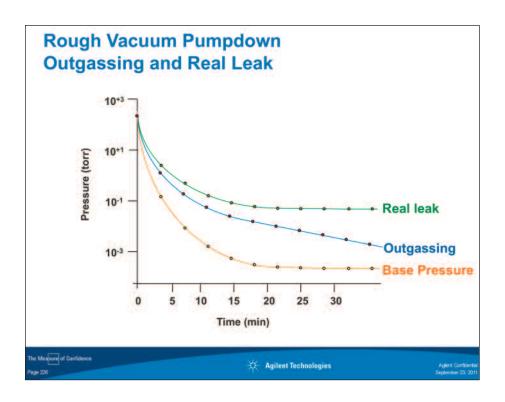


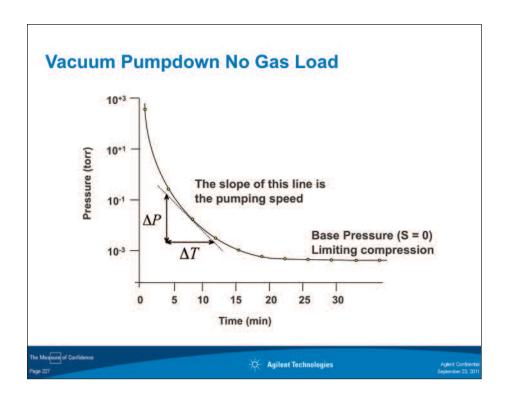


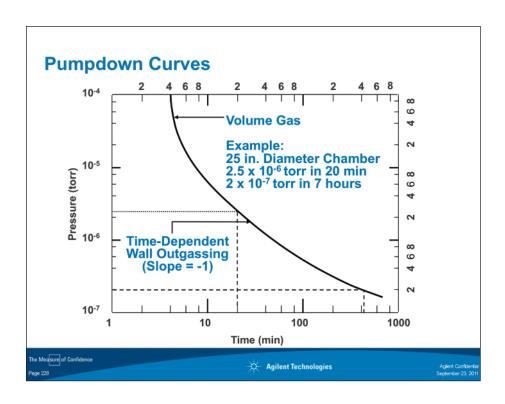
Cleanliness

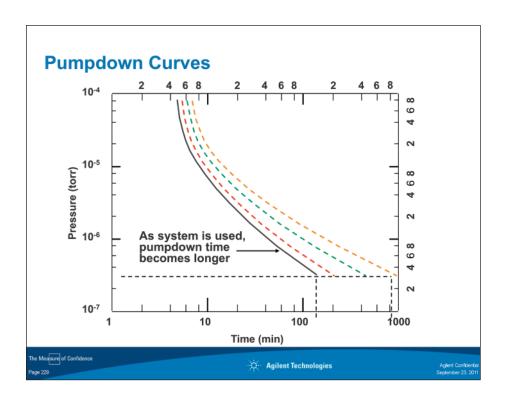
- To reach very low pressures, outgassing is even more important than pumping speed
- · Outgassing from the system and the pump must be minimum
 - Outgassing from:
 - Ion pump body
 - Ion pump element
 - Choice of material
 - Surface treatment

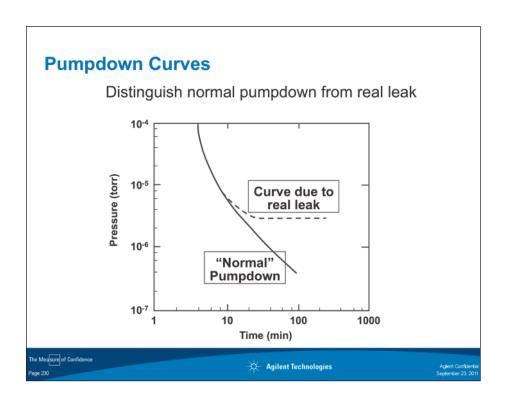








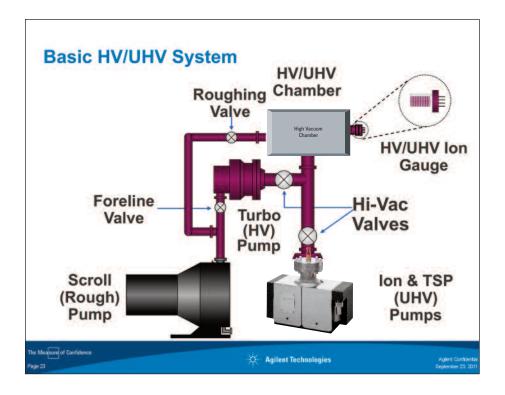




UHV System Operation

Overview

- Basic UHV system design
- UHV system cleanliness
- UHV system operation



UHV System Cleanliness

- · To reach very low pressures, outgassing is even more important than pumping speed
- · Outgassing from the system and the pump must be minimum:
 - Proper choice of material
 - Correct surface treatment
 - Minimize outgassing from:
 - Ion pump body
 - · Ion pump element



UHV System Operation

- · Pumpdown and vent as with HV systems
- · Full bakeout required after each atmospheric exposure (8-24 hours)
- · Do not depend on ion pumps for pressure indication below 10-9 torr
- · Use TSP (sublimation) only as required



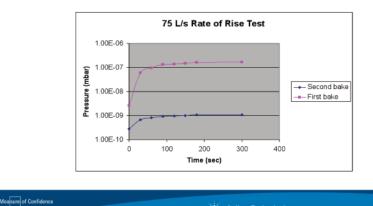
UHV System Operation

- · Use turbo and scroll pumps to rough the chamber(s) to below 1 x 10⁻⁶ torr
- · Bake at the highest allowable temperature for several hours (or overnight)
- Bake at uniform temperature for complete system
- · Valve out the rough pump system as required



UHV System Operation

- First bake was done with no insulation and uneven heating resulting in large water vapor background that limited pressure at 2E-09 mbar.
- Second bake used insulation to improve heating and successfully removed water vapor from system to achieve low pressure.



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This is not a complete compilation. Please consult the references given in the following publications for further sources.

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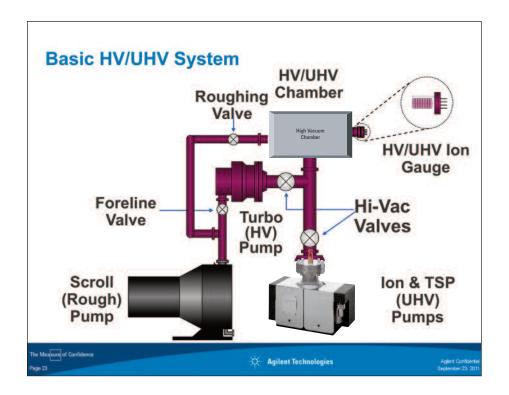


Case Studies

Case Study 1: High/UHV Vacuum Pumpdown

Overview

- Basic system design
- System parameters
- Calculations worksheet
- High vacuum pumpdown
- Outgassing rates stainless steel
- Pumpdown pressure
- Pumpdown calculations



System Parameters

Chamber: stainless steel

Length: 3 feet Diameter: 2 feet Volume: 267 liters

Surface Area: 2.33 x 104 (cm²) Roughing Pump: Scroll Pump

Speed:10 l/sec (atm to 1 torr); 8.5 l/sec at 100 mtorr

High Vacuum Pumps:

- Turbopump with 500 l/sec speed - Ion Pump with 400 l/sec speed

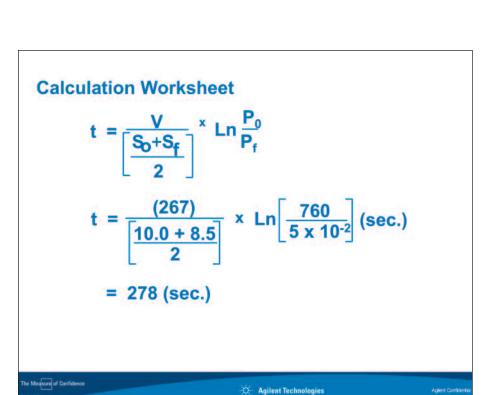


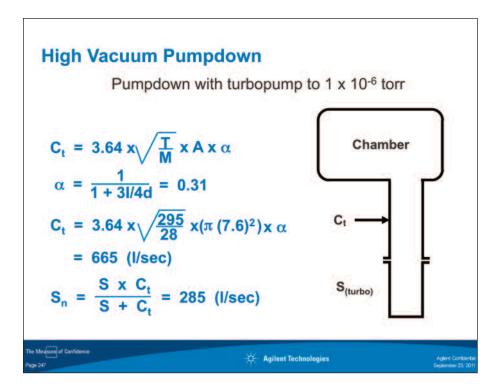
System Parameters

he Measure of Confidence

- Scroll Pump connected to chamber through a 4.0 cm diameter KF-40, 3 feet (91 cm) long line
- · Turbopump and Ion Pump connected to chamber through a 6-inch (15.2 cm) diameter, 18-inch (45.7 cm) long line
- Rough system to 5 x 10⁻² torr with the scroll pump; pump with turbo till 1 x 10⁻⁶ torr, then valve in ion pump. Shut off turbo at 1 x 10⁻⁹ torr?

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High Vacuum Pumpdown

Pumpdown with turbopump to 1 x 10-6 torr:

$$t = \frac{V}{S_t} \times Ln \frac{P_s}{P_f}$$

$$t = \frac{267}{285} \times Ln \left[\frac{5 \times 10^{-2}}{1 \times 10^{-6}} \right] \text{ (sec.)}$$

$$= 8.6 \text{ (sec)}$$



High Vacuum Pumpdown

Pumpdown with turbopump to 1 x 10⁻⁶ torr:

What outgassing rate is needed to achieve 1.0 x10-6 torr?

$$Q = O \times A = Sn \times P$$
, where:

O is the outgassing rate and A the area of the chamber

$$\frac{S_n \times P}{A} = \frac{285 \times 1.0 \times 10^{-6}}{2.33 \times 10^4} = 1.2 \times 10^{-8} \text{ (torrl/sec cm}^2)$$



Outgassing Rates Stainless Steel

Rates are in torrl/sec cm²

	1 Hour	5 Hours	10 Hours	20 Hours	40 Hours
Sandblasted	9.0 x 10 ⁻⁹	1.5 x 10 ⁻⁹	1.0 x 10 ⁻⁹		
Mechanically Polished NS225	4.0x 10 ⁻⁹	9.0 x 10 ⁻⁹	4.0 x 10 ⁻¹⁰	3.0 x 10 ⁻¹⁰	1.2 x 10 ⁻¹⁰
Electropolished NS225	1.7 x 10 ⁻⁹	9.0 x 10 ⁻¹⁰	4.0 x 10 ⁻¹⁰	2.0 x 10 ⁻¹⁰	8.0 x 10 ⁻¹¹
H2 Fired Pipe	2.8 x 10 ⁻¹⁰	1.5 x 10 ⁻¹⁰	1.0 x 10 ⁻¹⁰	8.0 x 10 ⁻¹¹	
Glass bead honed Pipe No. 2	1.2 x 10 ⁻¹⁰	3.0 x 10 ⁻¹¹	2.2 x 10 ⁻¹¹	1.5 x 10 ⁻¹¹	
Chem Cleaned Pipe No. 2	2.0 x 10 ⁻⁹	3.5 x 10 ⁻¹⁰	4.0 x 10 ⁻¹¹	1.2 x 10 ⁻¹¹	
Glass Bead Honed Pipe No. 3	1.5 x 10 ⁻¹⁰	2.5 x 10 ⁻¹¹	1.1 x 10 ⁻¹¹	8.0 x 10 ⁻¹²	3.0 x 10 ⁻¹²

Source: Yale Strausser, Varian Vacuum Report: VR-76



High/UHV Vacuum Pumpdown

Summary:

Pressures in the 10⁻⁸ and 10⁻⁹ torr range are achievable in a reasonable (overnight) pumpdown with the proper pretreatment of the material.

Lower pressures (1 x 10^{-10} 10^{-9} torr) need long pumpdown times and specialcleaning and handling.



Addedum A Pumpdown Calculations

System Pressure - Rough Vacuum

This relation provides approximate pumpdown times in rough vacuum. Outgassing becomes significant at lower pressures and accuracy fails.

$$t = c \frac{V}{S} \ln \left(\frac{P_f}{P_f} \right)$$

t = pumpdown time

S =system pumping speed

V = chamber volume

 P_i = initial pressure

 P_f = final pressure

Correction Factor, C

1.0 between Atm. and 10 Torr

1.5 between 10 Torr and 5 Torr

2.0 between 5 Torr and 50mTorr

4.0 between 50 mTorr and 1 m Torr



System Pressure - Volume Gas

The pressure evolution in a vacuum system of volume V and effective pumping speed S is given by:

$$-V\frac{dP}{dt} = S \cdot P$$

The term on the left represents the rate of mass flow out of the volume (at constant temperature), and the term on the right represents the of mass flow into the pump.





System Pressure - Leaks or Permeability

If Q_∞ represents a constant gas load due to leaks or permeability of the vessel walls then the ultimate pressure is determined by the gas load and system pumping speed rather than a physical limitation of the pump.

$$P_{\infty} = \frac{Q_{\infty}}{S}$$

Thus a term for the constant gas load is added

$$-V\frac{dP}{dt} + Q_{\infty} = S \cdot P$$





System Pressure - Outgassing

For qualitative purposes, the outgassing rate of a surface in high vacuum can be represented as:

$$Q = Q_0 e^{-\frac{t}{\tau}}$$

where Q_0 is the initial outgassing rate, t is the time, and τ is rate outgassing decays with time (assumed to be constant over a reasonable time). For proper matching of experimental outgassing curves, two or more terms are usually required:

$$Q = Ae^{-at} + Be^{-bt}$$





System Pressure - Pumpdown

The solution for pressure decay relative to time that includes the volume gas (1st term), outgassing (2nd term), leaks and permeation (3rd term) is given by:

$$-V\frac{dP}{dt} + Q_0 e^{-\frac{t}{\tau}} + Q_{\infty} = S \cdot P$$





System Pressure - Pumpdown

The solution for pressure decay relative to time is:

$$P = (P_0 - P_{\infty})e^{-\frac{S}{V} \cdot t} + \frac{Q_0}{S - V/\tau} \left(e^{-\frac{t}{\tau}} - e^{-\frac{S}{V} \cdot t}\right) + P_{\infty}$$

This cannot be solved for t, but can be put in the form:

$$t = \frac{V}{S} \ln \frac{(P_0 - P_{\infty}) - Q_0 / (S - V / \tau)}{(P - P_{\infty}) - [Q_0 / (S - V / \tau)] e^{-\frac{t}{\tau}}}$$





System Pressure - Pumpdown

In many common systems, after switching to high vacuum, $P_{\infty} \ll P_0$ and $V/\tau \ll S$ and the solution can be simplified to:

$$P = P_0 e^{-\frac{S}{V} \cdot t} + \frac{Q_0}{S} \cdot \left(e^{-\frac{t}{\tau}} - e^{-\frac{S}{V} \cdot t} \right) + P_{\infty}$$

Usually, after about an hour of pumping in high vacuum, (S/V) $t \ll t/\tau$, and the solution simplifies further to:

$$P = \frac{Q_0}{S} \cdot e^{-\frac{t}{\tau}} + P_{\infty} \Rightarrow t = \tau \ln \frac{Q_0 / S}{P - P}$$





System Pressure - Pumpdown

In a very simplified way, the entire evacuation process can be represented by

$$t = t_1 + t_2 = \alpha \frac{V}{S_{mp}} \ln \frac{P_1}{P_2} + \beta \tau \ln \frac{P_3}{P - P_{\infty}}$$

where S_{mp} is the speed of the roughing pump, α and β are correction factors for a deviation from an exponential relationship, P_1 is the initial pressure, P_2 is the pressure after crossover, τ is the constant associated with outgassing decay and P₃ is the pressure immediately following crossover. P₃ can be estimated by:

$$P_3 = P_2(S_{mp}/S_{hv})$$
 or $P_3 = qA/S_{hv}$





Ultimate Pressure

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

$$P_{1} = \left(\sum \frac{Q_{i}}{S_{i}}\right)_{ext} + \left(\sum \frac{Q_{i}}{S_{i}}\right)_{int} + \sum \frac{P_{2i}}{K_{i}}$$

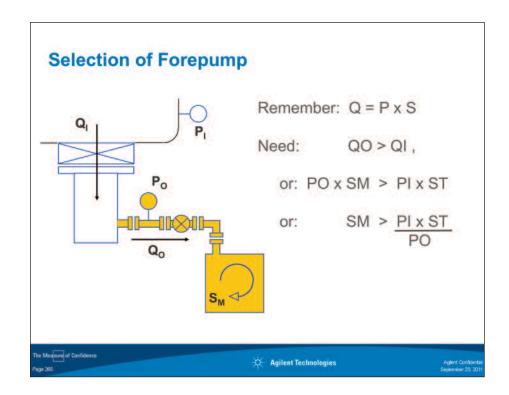
Where Q_i is the gas load from a gas type $_i$ and S_i is the pumping speed for that gas. P_{2i} is the outlet pressure for gas type $_i$ and K_i is the compression ratio of the pump for gas type i.



Case Study 2: Backing Pump

Overview

- Selection of forepump
- System pressure rough vacuum
- Confirmation of ion pump selection/size



Selection of Forepump

Turbo Pump: $S_T = 2,000 \text{ l/s}$

 $P_1(max) = 1 mtorr$

 $MTFP = 400 \text{ mtorr} = P_0(\text{max})$

Size Forepump: ??

$$S_M = P_1 \times S_T = 1 \times 2,000 = 5 (I/s)$$

Speed of 5 l/s converts to: 10.6 cfm

Use pump with at least 150 % safety margin: min 25 cfm

CONDUCTANCES NOT INCLUDED



System Pressure - Rough Vacuum

This relation provides approximate pumpdown times in rough vacuum. Outgassing becomes significant at lower pressures and accuracy fails.

$$t = \frac{V}{S} \ln \left(\frac{P_l}{P_l} \right)$$

t = pumpdown time

S =system pumping speed

V = chamber volume

 P_i = initial pressure

 P_f = final pressure

Note: Pumpdown calculations for outgassing, etc., see Addendum A.



Confirmation of Ion Pump Selection/Size

Given 150 l/sec ion pump, on a 20l chamber, Polished SS chamber, want to achieve e-11 pressure.

Will this work?



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