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Leak Detection

When you have completed this chapter, you will be able to:

1. Tell outgassing and virtual leak problems from real leak problems.
2. Be familiar with the sizes of leaks that affect vacuum systems and product life.
3. Identify the principal methods of leak detection.
4. Identify the major components of two of the major types of helium leak detectors.
5. Understand how helium mass spectrometer leak detectors work.
6. Be familiar with the type of calibrated leak commonly used to tune and calibrate a helium leak detector.
7. Identify some welding practices that can make leak detection difficult.

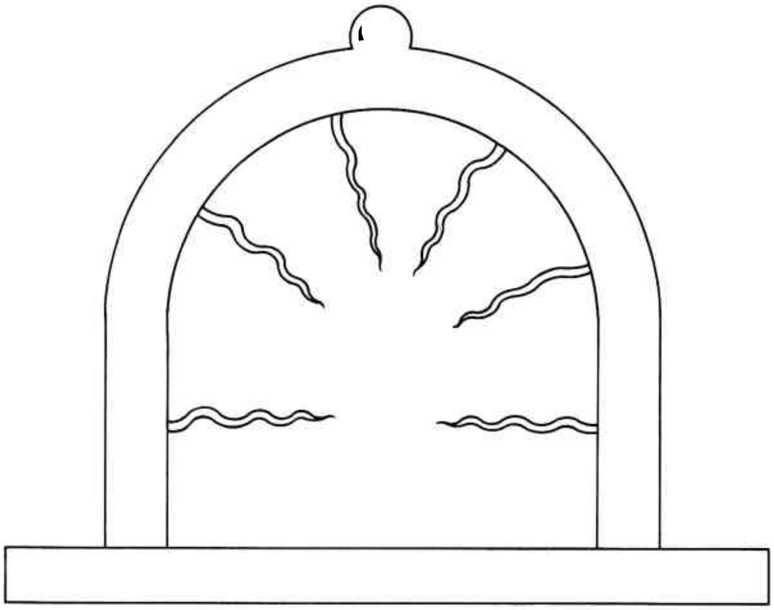
Introduction

In this section, we will consider types of leaks, leak rates, detector principles, and leak detection techniques. Many instruments can be used for leak detection, including simple pressure gauges. Here, however, we will concentrate on the use of the helium mass spectrometer leak detector and its techniques.

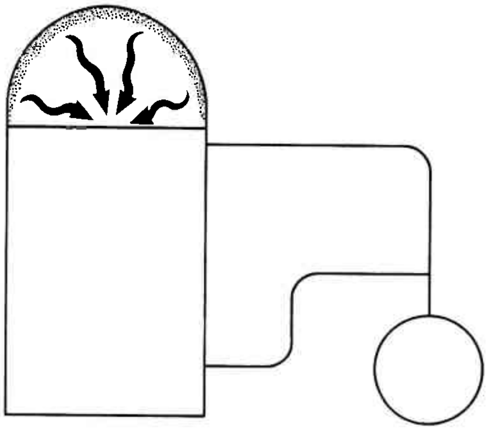
To begin with, everything leaks. It's simply a matter of how much. In some cases, the leaks are so small that they do not hurt the vacuum system process. In other cases, problems occur in vacuum systems that appear to be caused by leaks, but are not. Let's first try to separate real leaks from other types of problems (which themselves are very real).

Problems That Appear to Be Leaks

Outgassing



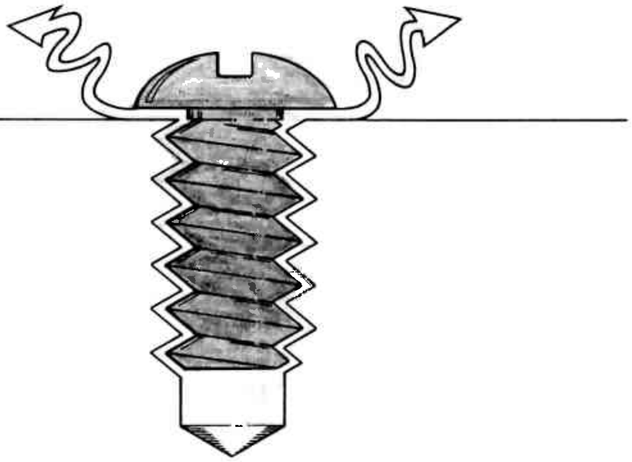
Outgassing can keep a system from reaching satisfactory pressure. Outgassing can be caused by techniques or materials that never should be used with vacuum. These can be improper handling, such as using bare hands in the vacuum system and excessive use of greases. They also include using too many materials which in small amounts might actually be all right to use with vacuum. Your process may cause deposits to form on the walls of the chamber. These deposits may contribute to the outgassing load.



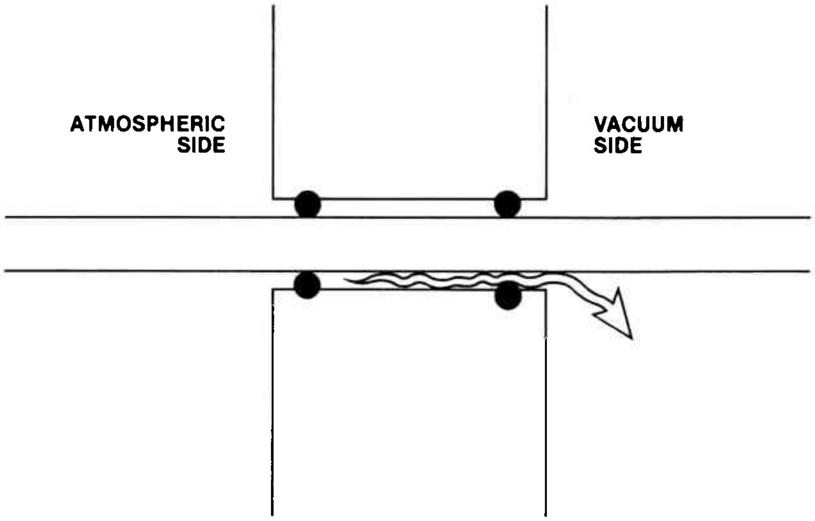
virtual leaks

Contaminated systems can outgas to the point that they make it impossible to reach satisfactory pressure. Such a problem can appear to be the result of real leaks. We often call these ***virtual leaks.*** Virtual leaks are any source of gas that is already inside the vacuum system. Two examples are outgassing and trapped volumes.

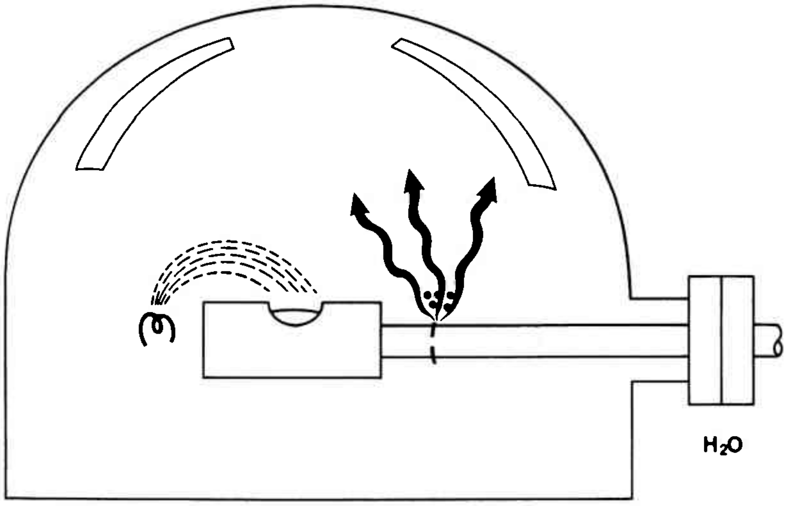
Trapped Volumes



Trapped volumes, also called virtual leaks, are sources of gases that are inside the vacuum system but which are released very slowly into the system. For example, water vapor on the walls, solvent residues, and trapped volumes can release gases into the system over a long period of time. This can make it impossible to reach satisfactory pressures until all of the gas is completely released.



Virtual leaks can also result from double O-ring-sealed shafts.

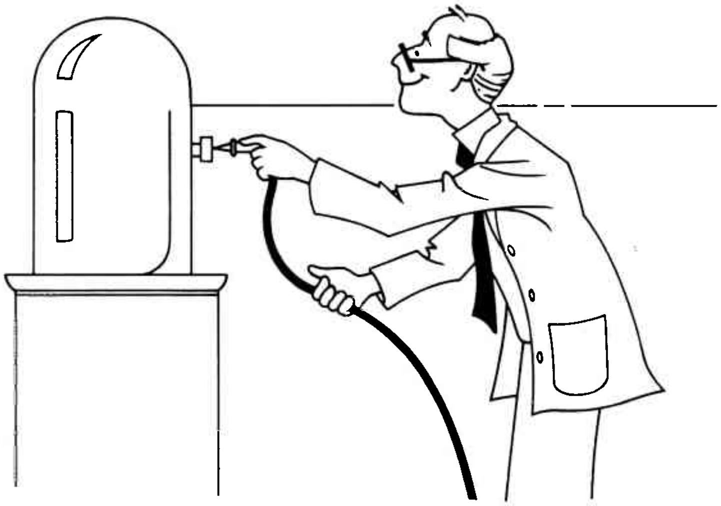


There are real leaks which act like virtual leaks. An example is a cooling line leak which "looks" like a virtual leak because it is not directly connected to the outside.

Permeation Leaks

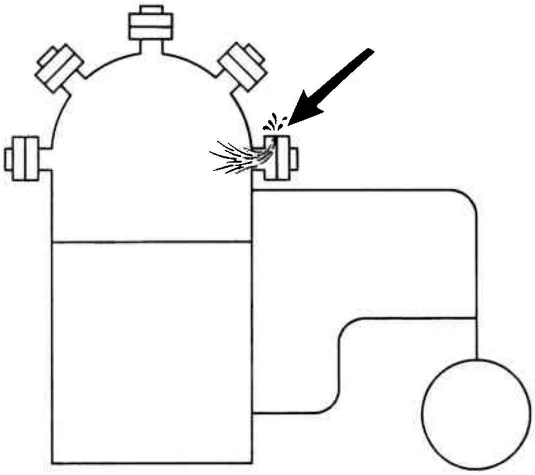
Gases may penetrate through some "solid" materials such as elastomers (O-rings). We call these permeation leaks. These are different than real leaks because the only way to prevent or stop them is to change to a less permeable material.

Real Leaks



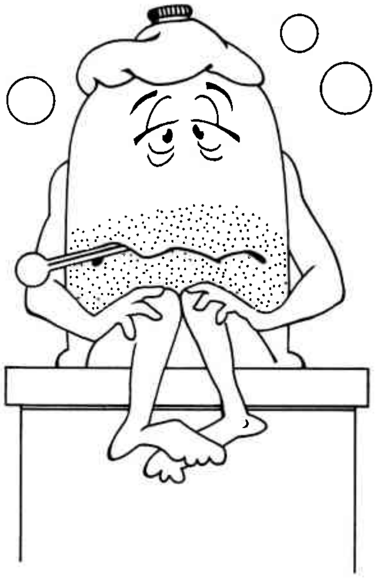
Real leaks (cracks and holes) are the types of problems that can be relatively easy to solve by leak detection techniques. These are the types we will concentrate on in this section. We often refer to real leaks as *air leaks*.

Sizes of Leaks



In modern industrial vacuum systems containing many feedthroughs, there are many opportunities for leaks to occur. You can see an example of a leaky flange in the illustration above.

Vacuum-related leaks are small. The types of leaks that we will consider are not gaping holes. Instead they are tiny fissures that can develop at joints, welds, seals, or even in the materials that make up the system.

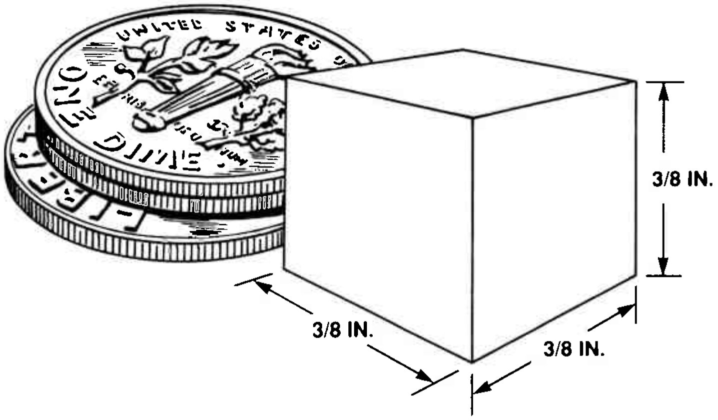


Even tiny leaks can have a negative effect on the productivity of a system or cause it to become useless.

Sizes of Leaks That Affect Vacuum Systems

leak rates

So, let's next consider *leak rates*, or the sizes of leaks that affect a vacuum system.



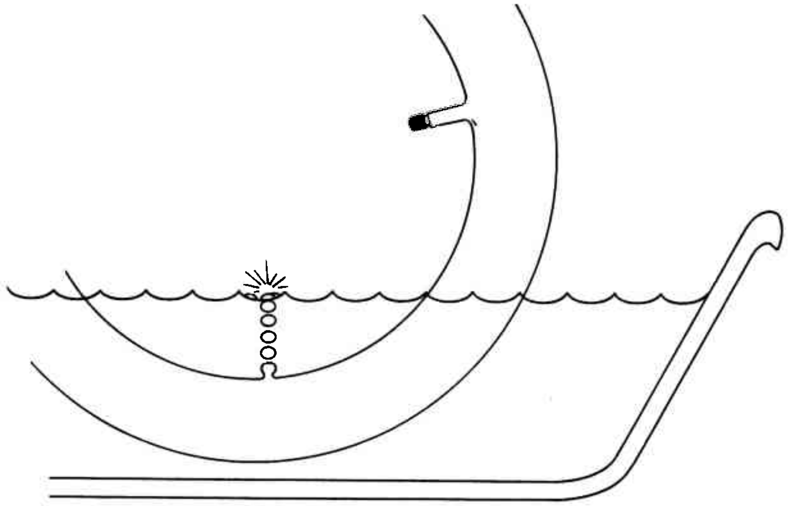
standard cubic centimeter

A one *standard cubic centimeter* per second (std cc/sec) leak rate is equivalent to 1 cc of gas at the standard pressure of 760 torr and temperature of 0°C passing through a leak at a pressure differential of 1 standard atmosphere. Recall that the volume of

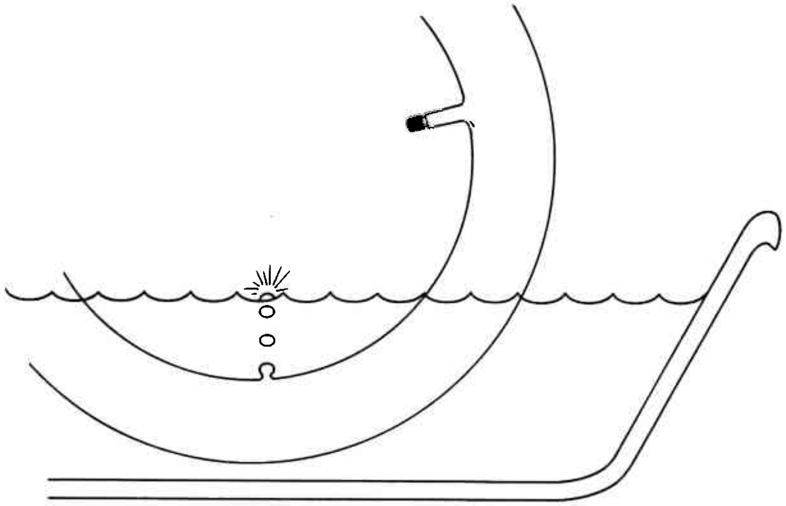
1 cc is equal to a cube approximately three-eighths of an inch on each side, or the volume of three dimes. One standard cc per second can also be expressed as 0.76 torr-ℓ/sec. Let's next look at these leak rates in more familiar terms.

1 std cc/sec = 0.76 torr-ℓ/sec

This flow can occur at any pressure differential. Remember that we are talking about a flow rate here, *not* a pressure reading.



The bubble test is a commonly used method of locating a leak in a bicycle tube. A bicycle inner tube leak that releases a steady stream of very small bubbles releases about 1 std cc of air in 10 seconds. In leak detector terms, this is about equivalent to a 10^{-1} std cc/sec leak rate.



A bicycle tube leak that releases one bubble per second will release a total of 3 cc of air per hour. In leak detector terms, this is about a leak rate of 10^{-3} std cc/sec. A leak rate of 10^{-4} std cc/sec releases 1 cc every 3 hours, or one bubble in 10 seconds. Smaller leaks than this cannot be detected by the bubble technique.

Although the bubble test is used in many industries, we will not discuss this technique further in this section. Looking at leak rates in terms of bubbles helps to get a feel for the leak sizes that we will consider.

LEAK RATES

10^{-1} std cc/sec — 1cc/10 sec
10^{-3} std cc/sec — 3cc/hour
10^{-5} std cc/sec — 1cc/day
10^{-6} std cc/sec — 1cc/2 weeks
10^{-7} std cc/sec — 3cc/year
10^{-9} std cc/sec — 1cc/30 years

A leak rate of 10^{-5} std cc/sec releases a volume of gas equal to 1 std cc every 24 hours. A leak rate of 10^{-6} std cc/sec releases 1 std cc in a 2-week period.

For a vacuum system, the gas for the most part is not released from the system, but instead is admitted into the system from the atmosphere. A 10^{-7} std cc/sec leak rate admits 3 std cc of air into the system per year, and a 10^{-9} std cc/sec leak rate admits 1 std cc of air into the system in 30 years!

This last example, of course, doesn't sound like a very serious leak rate because it is so tiny. Indeed, in many processes, a leak rate this small can be ignored. However, in UHV systems this might be a serious leak.

Sizes of Leaks That Affect Product Life

This leads us to consider the sizes of leaks that affect product life. Of course, the maximum acceptable leak rate for a given product depends on what the product is. In general, static sealed systems require stricter specifications than other systems. In any case, if a tiny leak does not negatively affect a product, there is no need to worry about it or test for it. To do so would be very uneconomical, both with time and money.

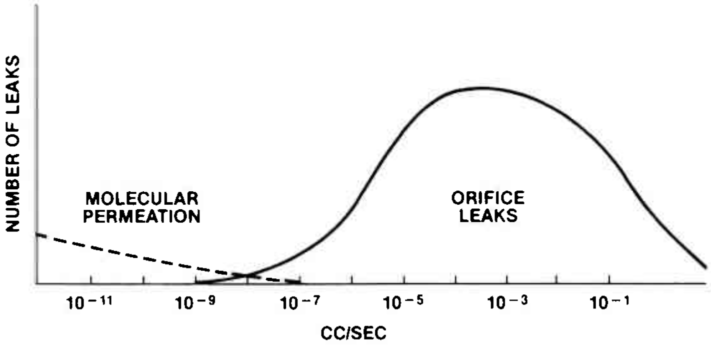
Product or System	**Leak Rate Specification**
Chemical Process Equipment	10^{-1} to 1 atm cc/sec
Torque Converter	10^{-3} to 10^{-4} atm cc/sec
Beverage Can End	10^{-5} to 10^{-6} atm cc/sec
Vacuum Process System	10^{-6} to 10^{-7} atm cc/sec
IC Package	10^{-7} to 10^{-8} atm cc/sec
Pacemaker	10^{-9} atm cc/sec

This table lists the suggested leak rate specifications for different types of products. It can be seen that the range is quite wide. For example, a leak in a torque converter greater than that specified as acceptable shows up as a fluid leak.

The leaky beverage can pull-tab lid shows up as a can of very flat beverage if it leaks at a greater rate than the specified limit. Another way to look at an acceptable leak rate in a beverage pull-tab lid is to consider that the beverage should retain its carbonation over a three-month shelf life.

Helium mass spectrometer leak detectors are commonly used for testing can lids, damaged vacuum process systems, IC packages, and pacemakers, as well as many other industrial and consumer products.

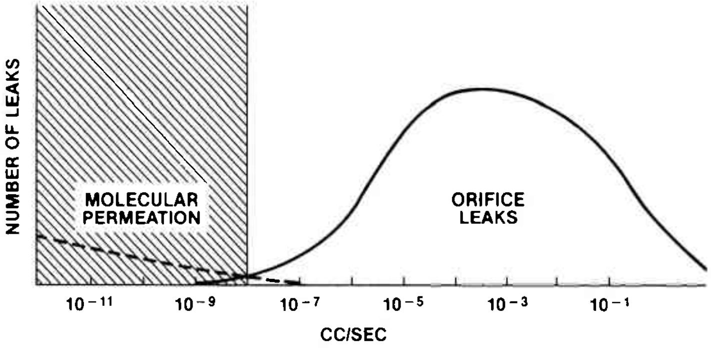
Distribution of Leaks by Size



DISTRIBUTION OF LEAKS BY SIZE

Next, let's look at the distribution of leaks by size. Long experience has shown us that leaks that affect vacuum equipment occur in different sizes. We have also learned that some sizes of leaks occur more often than others. For example, there are relatively few very large leaks above 10^{-1} std cc/sec or very small leaks below 10^{-7} std cc/sec. Instead, the greatest number of leaks occur at a rate that ranges from 10^{-2} std cc/sec on the high side, to 10^{-5} std cc/sec on the low side.

This curve shows that medium-size leaks occur most often. Both very large leaks and very small leaks occur much less often. Note also that most of the leaks represented by the large hump in the curve are orifice leaks. That is, they are holes or cracks or splits between joints such as welds, brazes, and seals. We also commonly call these *air leaks*.

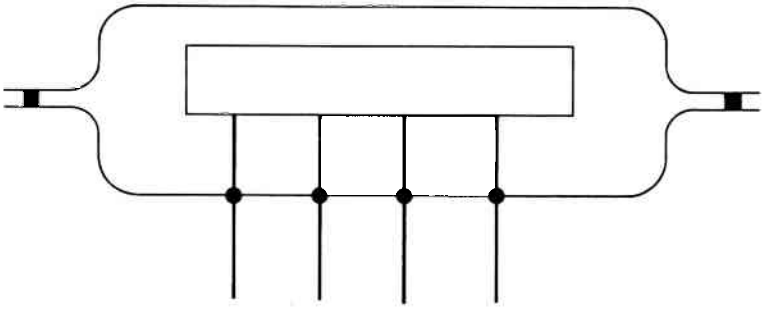


DISTRIBUTION OF LEAKS BY SIZE

Leaks below 10^{-8} std cc/sec may occur through molecular permeation. That is, they occur because gases actually penetrate through the material. This illustrates the need to select materials that are correct for vacuum work, and materials which have been properly made. (We saw earlier how voids can be elongated to create leak paths.) Products having leak rates in the 10^{-8} to the 10^{-9} range generally will have a five-year "leak-free" life.

It may not be economically feasible to 100% leak-check large production systems unless a problem is indicated. Such a problem might be that it is impossible to reach satisfactory vacuum levels. On the other hand, some of the individual components used in the system may routinely be 100% tested. These may include the system components such as the feedthroughs.

Some leaks keep happening over and over and occur in definite patterns. For example, special high-speed presses are used to manufacture pull tab lids for beverage cans. The pull tabs may have leaks as a result of worn or misaligned dies in the high-speed presses. Once the machine produces leaky pull tabs, it will continue to do so. It has been found that sample testing after a definite number of pull tabs have been produced detects almost all leakers.



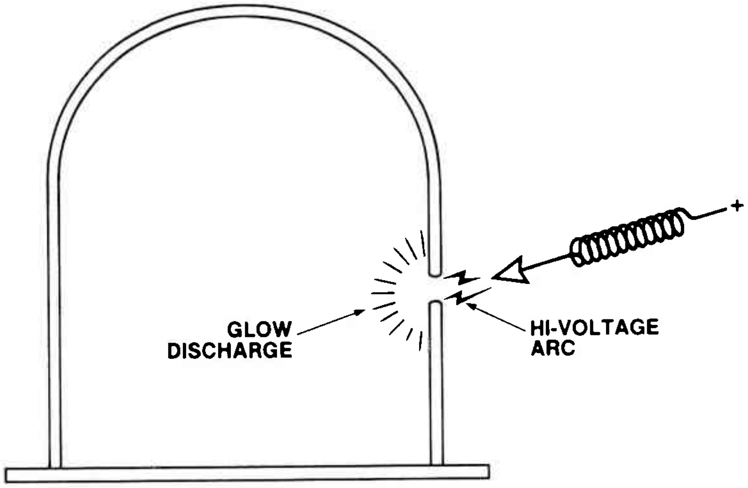
IC PACKAGES

An example of leaks that don't occur in definite patterns can be found in the semiconductor industry. Typically, the average frequency of leakers in production IC packages is 1% to 2% with no observable pattern of size or incidence of leaks.

Methods of Leak Detection

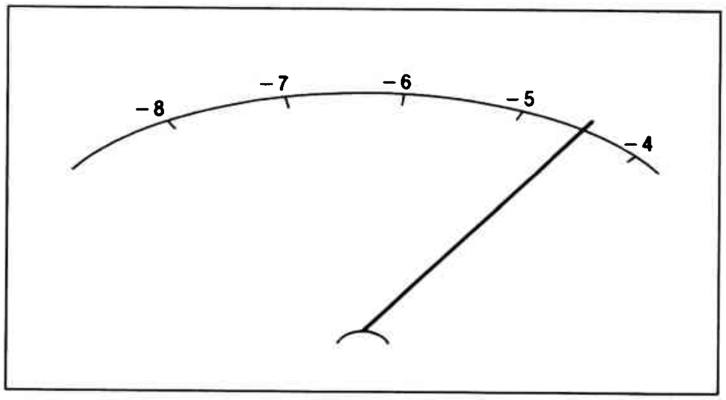
Next, let's look at a few leak detector techniques. Of course, we will concentrate on the helium mass spectrometer leak detector techniques. However, to give us a frame of reference, we will compare this technique with several other leak-check methods.

Spark Coil Technique



The spark coil technique uses a high-voltage or tesla coil to create an arc. This causes the ionization of air at the point where it enters the system. Ionization, of course, creates a glow discharge which is visible in glass systems. This is a simple technique; however, it has a number of drawbacks. First, it can only be used in glass systems. Further, this technique is potentially dangerous. (The high-intensity arc could cause an implosion.)

Pressure Change Method



Another simple technique uses the pressure gauges which are ordinarily used to monitor the system performance. Suspected leak sites can be squirted with a solvent while watching the gauge for a pressure rise that occurs when the solvent enters the leak. This method also has its shortcomings. Solvent entering a leak can actually freeze and plug up the leak. This can result in an inability to pinpoint the leak site. The problem is that the plugging is not permanent and instead will reopen at some later, unpredictable time. This technique also has limited sensitivity. Solvents may also attack vacuum grease and cause O-ring degeneration. Use of solvents for leak checking may require that O-rings be replaced.

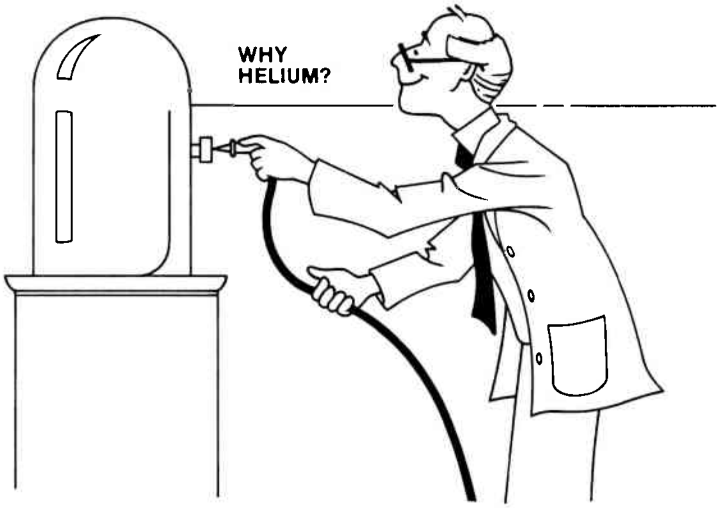
We have also mentioned the residual nitrogen analyzer and the residual gas analyzer in the chapter on gauges. These are also used to detect leaks when the pressure in your vacuum system is between 10^{-4} torr and 10^{-8} torr.

Helium Mass Spectrometer Leak Detector

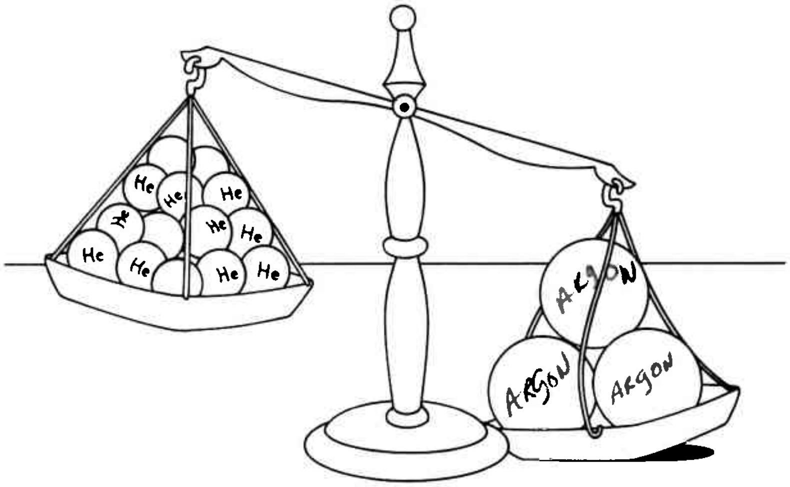
Now, let's concentrate on the helium mass spectrometer leak detector technique. This is one of the most commonly used techniques. It is the most sensitive, and it is very easy to use.

The helium mass spectrometer leak detection technique depends on the ionization, separation, and detection of helium ions. The leak-rate meter displays a value proportional to the helium ion concentration present in the spectrometer tube. Thus, the spectrometer tube is the most important part of the leak detector.

Why Helium Is Used



Why is helium used? Helium has a number of useful characteristics.



Helium Is Very Light

Helium is very light; in fact, it is the lightest and smallest of the inert gas molecules. Therefore, it flows through very small leaks easily. This makes it well suited to high-sensitivity leak detection. Even very small amounts can be readily separated and identified by a relatively simple mass spectrometer.

COMPOSITION OF DRY AIR
AT 760 TORR (SEA LEVEL)

Gas	Percent by Volume	Partial Pressure (Torr)
Nitrogen	78.08	593.40
Oxygen	20.95	159.20
Argon	0.93	7.10
Carbon Dioxide	0.03	0.25
Neon	0.0018	1.38×10^{-2}
Helium	0.0005	4.00×10^{-3}
Krypton	0.0001	8.66×10^{-4}
Hydrogen	0.00005	3.80×10^{-4}
Xenon	0.0000087	6.60×10^{-5}

Another aspect of helium that recommends it for use in mass spectrometer leak detection is that it constitutes only 5 parts per million in the atmosphere. Under most conditions, this makes it easy to distinguish the helium that is deliberately introduced into a leak with a helium probe, from the helium that enters with the atmospheric air. The instrument can be easily calibrated to show a zero response to the natural helium background.

Helium Permits Dynamic Testing

Helium also permits easy testing for leaks while a system is operating (dynamic testing). The system need not be shut down to perform a leak check. Therefore, valuable operating time can be saved. Also, the testing can proceed under the system's normal operating conditions rather than under unrealistic, static conditions.

Helium Permits Nondestructive Testing

The use of the helium probe also permits nondestructive testing. Many systems or products that are shown to have leaks by this technique can be repaired. Those that are rejected are rendered useless by the leak, not by the leak test.

Helium Is Safe

Another useful feature of this technique is that it is nontoxic, inert, and nonreactive. Helium released into the test area presents no personnel safety hazard. Even if a breath is deliberately inhaled, the worst result is that a person will sound rather silly for a few seconds. Helium is also nonhazardous. It is not flammable, nor explosive. We should caution you that breathing a pure helium atmosphere for a period of minutes would cause suffocation.

The Helium Leak Detector System

Helium leak detection systems work as follows: Helium is introduced to a test part that is connected to the leak detector. The helium from the test part leak travels into the leak detector, its partial pressure is measured, and results are displayed on a leak-rate measurement meter as flow rate.

There are two general types of leak detectors— the conventional design and the Contra-Flow™ design.