x-rays are created when electrons strike the grid. They are always being produced. Those x-rays that strike the collector release photoelectrons and cause a constant error signal. This x-ray current is insignificant until about 10^{-10} torr. There, the value of pressure-related ion current approaches the x-ray current. To read low pressures, we must make a correction for the x-ray current. Doing this makes it possible to read pressures below 10^{-11} torr.

If you look at the manual for your ion gauge, you will find a table of correction factors. Some modern gauges allow you to put a correction factor or two into the control unit. These correction factors have to do with the fact that some molecules are easier to ionize than others. They will therefore give an incorrect pressure reading. The gauge unit is calibrated using nitrogen gas (or perhaps air). If you now use a different gas in your vacuum system, you should apply the proper correction factor to get "correct" pressure readings. You can, of course, do as many people do and "use the pressure that works."

Maintenance

Ion gauges can sometimes be cleaned using appropriate solvents, though we do not advise it. Most people will use the degas control as a cleaning procedure. The degas heats up the grid so that it bakes the walls of the gauge tube. This baking drives any molecules collected on the walls back into the vacuum system where they may be pumped away. Degassing a tube that is contaminated with silicone-based pump oils permanently affects it.

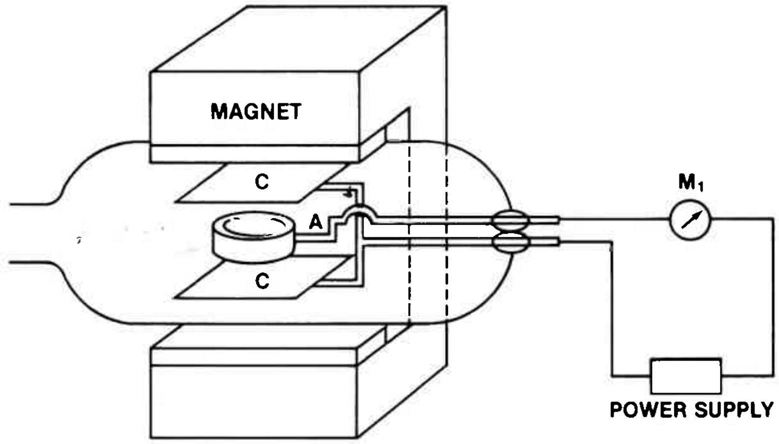
Attempts to clean a gauge tube are not always successful. But if you choose to clean your gauge head with solvents, be certain to thoroughly clean and dry the gauge before installing it. Operating the degas function, which heats the grid, can cause enough outgassing of volatile solvents to create a plasma discharge. The resulting "short" could cause severe electrical shock or death if the system and controller are not adequately grounded. Be sure the gauge has thoroughly dried before reinstallation and subsequent operation.

The ion gauge will need periodic adjustments of the control unit. Refer to the manual for your specific gauge as to how to carry out the procedure. The gauge unit in some installations will require calibration. This involves checking the gauge head and control unit versus a standard or known gauge. The gauge is adjusted to indicate the same pressure as the standard. It is then typically "certified." The National Institute of Standards and Technology will now provide this service for a fee.

Cold Cathode Gauge

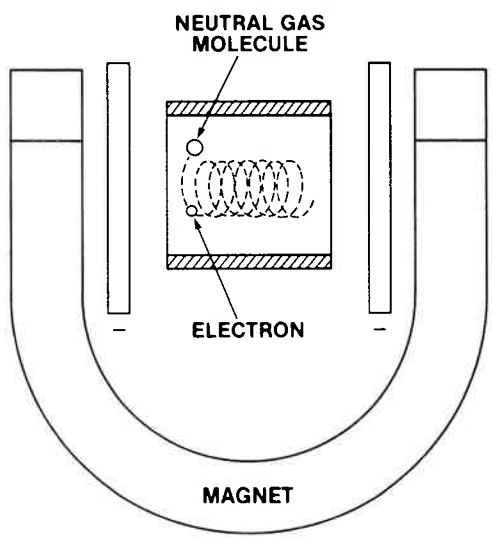
cold cathode ionization gauge

Another high vacuum gauge is the *cold cathode ionization gauge.* It also depends on the ability to ionize molecules.

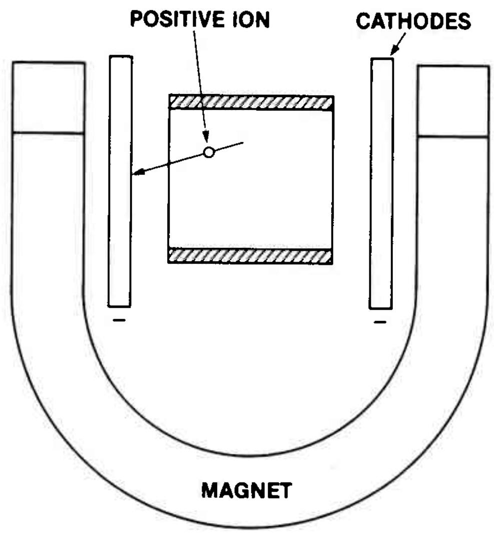


A cold cathode gauge consists of a gauge tube and control unit. The gauge tube has a central anode and two cathodes or a cylindrical cathode. A strong permanent magnet surrounds these elements. Its accuracy is approximately ±50% of the true pressure.

How the Gauge Works



A dc voltage of about 2,000 volts attracts electrons in the gauge tube to the positively charged anode. The magnetic field forces the electrons into long helical paths. This increases the probability of electron-molecular collisions. The collisions produce ions. This, in turn, produces a glow discharge.



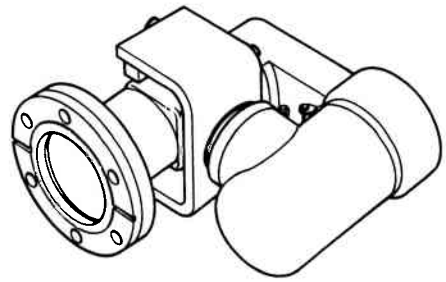
The positive gas ions are now attracted to the negatively charged cathode. The resulting ion current is measured and calibrated in units of pressure. (Note the similarity between this gauge and the ion pump—the cold cathode gauge is an ion pump with non-gettering cathode material.)

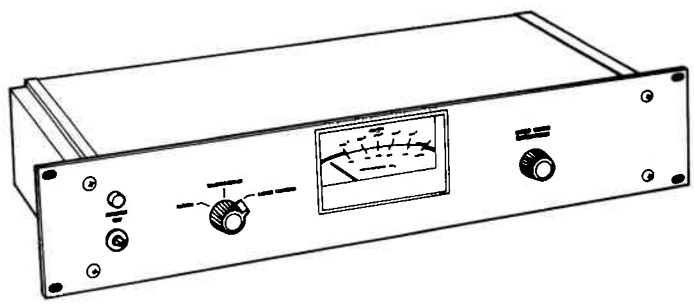
The gauge extinguishes when the pressure (gas density) gets too high (about 10^2 torr) to support a gas discharge. It also extinguishes when the pressure gets too low (about 10^{-8} torr) to support a discharge. Most cold cathode gauges are constructed so that they may be taken apart for cleaning. An advantage of this gauge is that there is no filament to burn out. This makes it a more rugged gauge that takes more abuse but is less accurate.

Maintenance

The cold cathode gauge usually does not need calibration or adjustment. It depends completely on the ion current being proportional to the pressure. It is quite rugged because of its all-metal construction. An adaptation of the cold cathode gauge is the residual nitrogen analyzer, which we'll look at next.

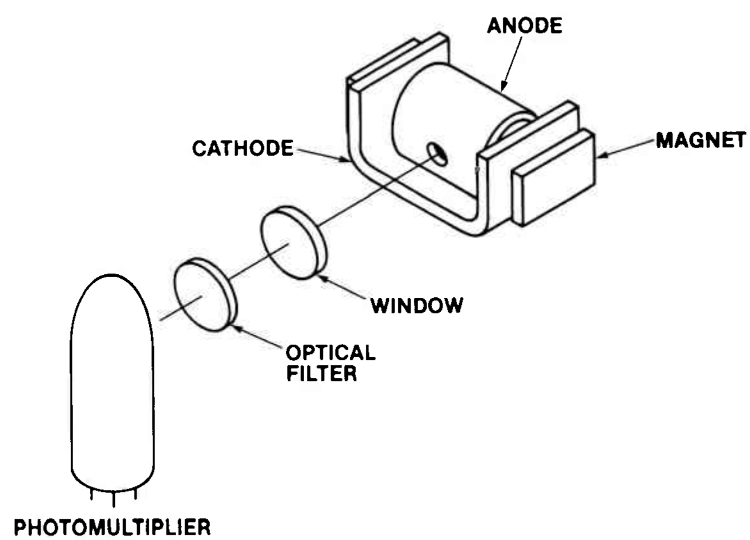
Residual Nitrogen Analyzer





The residual nitrogen analyzer (RNA) reads the total pressure and the nitrogen partial pressure. It operates in the high vacuum range.

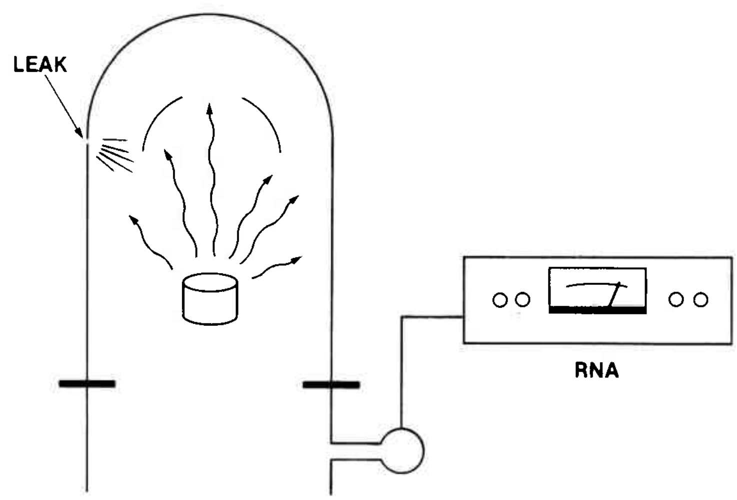
How the RNA Works



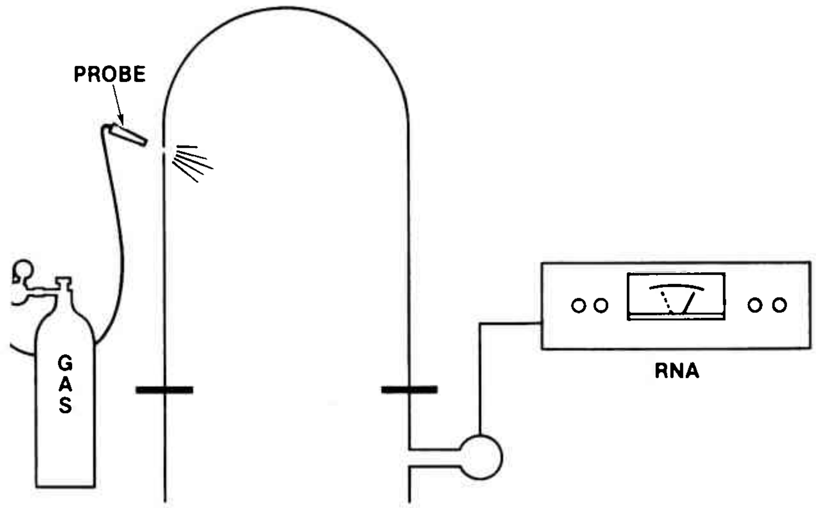
The RNA is a cold cathode gauge that also includes a window, an optical filter, and photomultiplier tube. Ionization produces light. This light has various colors, depending on the gases producing it. The filter passes nitrogen light and blocks the light from other ionized gases. Thus, the gauge reads only the nitrogen pressure. In the "normal" mode, this cold cathode gauge also reads the total pressure. We can use this to help us in determining the condition of our vacuum system.

Gases are pumped at different rates. Nitrogen is relatively easy to pump, so its percentage in a pumped-out system is lower than it is at atmosphere. A leak, on the other hand, admits an abundance of nitrogen. The RNA, which is tuned to nitrogen, senses this abnormality, and identifies an air leak.

For example, the percentage of nitrogen remaining in a normal evacuated leak-free system at 5×10^{-6} torr may be about 10%. An air leak can change this percentage to about 80%. A low nitrogen reading upsets the normal balance in the other direction, and is a good indication of outgassing or an internal leak in the system. The gauge is a simple way to diagnose a system problem. It answers a very important diagnostic question— does the system have a real leak or a virtual leak?



For example, coating material builds up with time, outgasses and raises the pressure. The RNA can tell the difference between outgassing, which may be still within acceptable limits, and an air leak, which is not.



The RNA also can be used to pinpoint the location of a leak. When a gas probe using any gas except nitrogen passes over the leak, the percentage of nitrogen is again changed. This change can be used to establish the location of the leak.

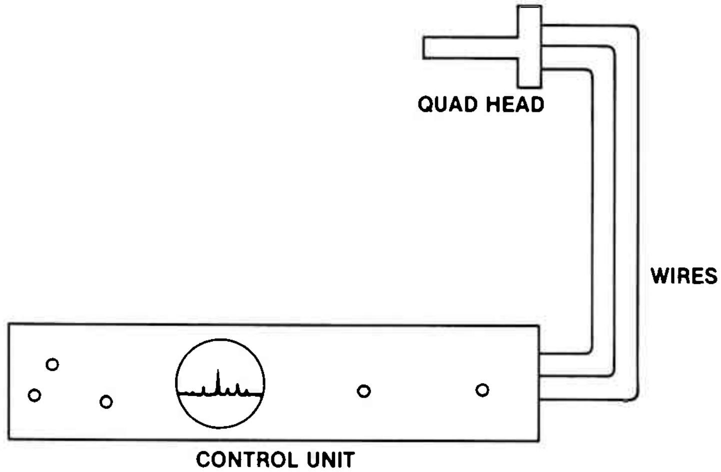
Maintenance

The RNA, being essentially a cold cathode gauge, requires the same maintenance. In addition, the window, filter and photo tube assembly may need attention periodically.

Residual Gas Analyzer

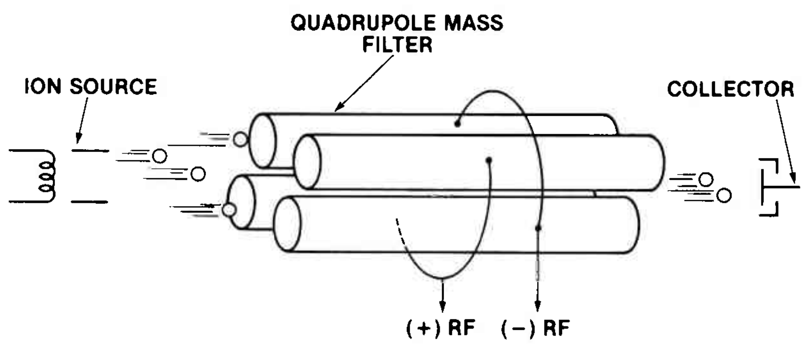
partial pressure

Another gauge that measures *partial pressure* is the RGA, or the residual gas analyzer. This instrument measures the partial pressure of each gas present in the vacuum system as well as the total pressure. It operates in the high and ultrahigh vacuum ranges. It is sometimes used to sample gases at higher pressure (above 10^{-4} torr), but the gauge head must operate at high vacuum.



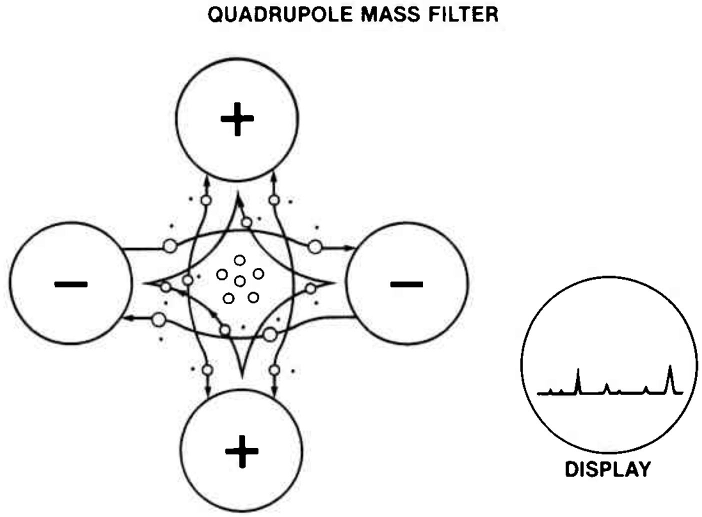
One type of residual gas analyzer includes a quadrupole sensing head and control unit. The control unit has a computer-controlled screen that displays the ion current signals of the gases remaining in the chamber. Some of the older units use an oscilloscope to display the signals.

How the RGA Works

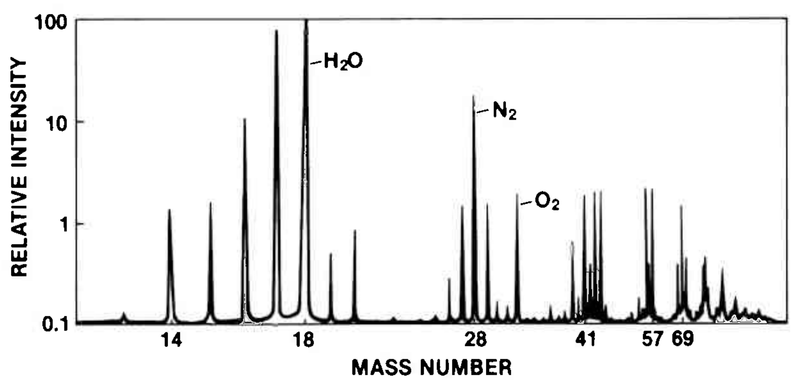


The residual gas analyzer separates, identifies and measures the partial pressures of residual, or remaining, gases in an evacuated chamber. The gases produce peaks in the display. The position of the peaks identifies the gases producing them. The partial pressures of the gases are measured by the heights of the peaks. Total pressure can also be measured.

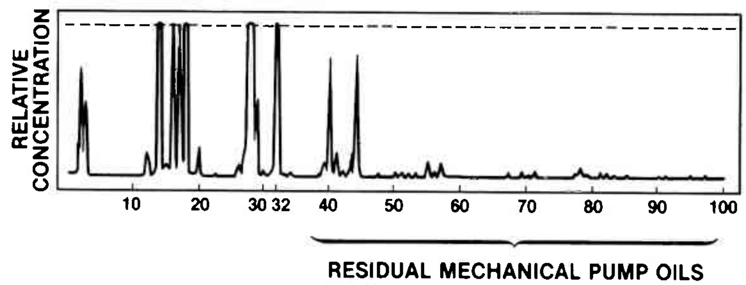
A quadrupole RGA has a sensing head that includes an ion source, quadrupole mass filter, and a Faraday cup collector. Ionized gas molecules are injected into the mass filter. The ions that have the correct mass-to-charge ratio pass through the filter to the Faraday cup collector. These ions produce signals that are in proportion to the number of ions that get through the filter.



The quadrupole mass filter is an array of two pairs of metal rods having equal and opposite rf and dc voltages. For a given set of voltages, only ions of a given atomic weight, or mass, pass through the filter. Ions above and below this mass are grounded on the rods. Then, by progressively changing the voltages on the rods, other ions are allowed through the filter in order. Thus, the various gases are separated and identified. Because this is an electrical process, it can occur quite fast, so that the instrument can display a wide range of masses. Typically, this display capability is 1–100, 200, or 300 mass units.



In this illustration, we can see that the vacuum system has an air leak by the large amount of nitrogen, oxygen and water vapor shown in the display. The instrument can then be used to find the leak by switching to detect helium only, and the system is probed with helium. When the probe is placed near the leak, helium enters the system and is quickly displayed. This pinpoints the location of the leak. Other gases may be used to probe for leaks if the RGA is properly tuned to that gas.



The residual gas analyzer is also useful for determining other types of contamination, such as water leaks or excessive outgassing from dirty components. (Vapors from backstreaming pump oils can also be identified with this instrument.)

Maintenance

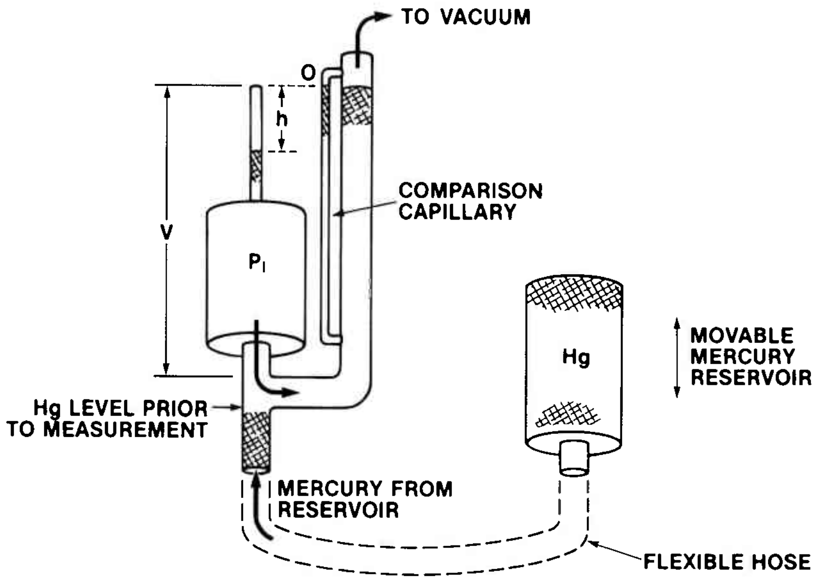
The RGA is a fairly complex and expensive instrument. Please consult your operation manual to determine the required maintenance.

Gauges Used for Calibration

In order to know what the pressure is in your vacuum system, you must measure it. But how do you know that your gauge is correct? Most of us take the manufacturer's word until we are forced to consider that it might be the gauge that is the problem.

To check the accuracy of a gauge, we need a known pressure. We must use an independent gauge to measure the pressure. This independent gauge is usually called a calibration gauge. A calibration gauge may range from one that you keep clean and use as your comparison gauge to a gauge that can be traced to the National Institute of Standards and Technology. Let's look at a few gauges that are used for calibration purposes. We will talk about the McLeod gauge and the spinning rotor gauge.

McLeod Gauge



A McLeod gauge depends upon Boyle's Law for perfect gases. We use a large glass bulb and a small capillary tube with mercury to compress the gas at low pressure into a small volume at a higher pressure. A scale is attached so that we do not have to calculate the pressure from Boyle's Law each time. Because the gauge is made of glass and must use liquid mercury, it is rather fragile. If you had one on your production floor, it's broken by now! They are generally kept on a shelf in the "calibration lab" and used only there. The gauge suffers from several problems:

- It is fragile and is filled with mercury.
- It takes several minutes to get one reading.
- If the vacuum system contains a condensable gas (water vapor, for instance), the gas will condense during compression. The gauge reads incorrectly as a result. Therefore, drying filters must be used, and kept clean in order to get "correct" pressure readings for noncondensable gases.
- The mercury vapor is potentially toxic.
- It cannot measure rapidly changing pressures.

For many years, it has been the best "standard" gauge available, even with its problems.

To use the gauge, you connect it to your system and pump the gauge down. Be careful not to place the mercury bulb so that mercury can go into the vacuum system! When you think the gauge is pumped down (a problem), raise the mercury bulb slowly