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Progress Report
Technique of High Vacuum &
Vacuum Gauges

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Progress Report on the Renovation of the
Westinghouse Mercury Diffusion Pump

Outline

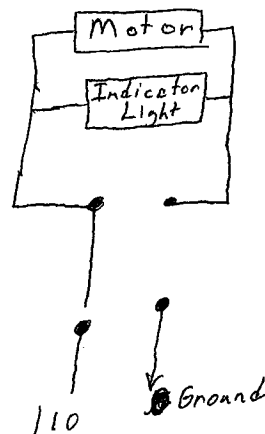
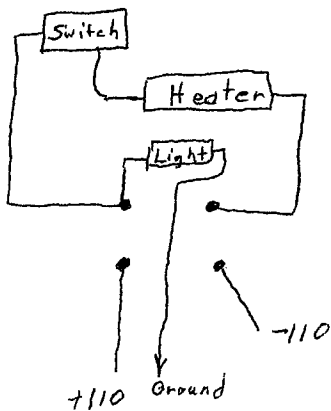
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Progress Report on the Renovation
of the Westinghouse Mercury Diffusion Pump

The first part of the semester was spent removing rust from between each stage of the pump and checking the gaskets. These gaskets were coated with vacuum wax and then put back together. The connection pipe was threaded and several connections were made to fit it. They include one for glass, one for rubber tubing, and one for shutting off system.

The last part of the semester was spent trying to figure out the resistance of the heater and switches in order to get the wiring done properly. The heater's rating is 220 volts, and 720 watts. I found the resistance of the heater to be about 70 ohms and for the switch it was 44 ohms. I wired them in series to get a combined resistance of 114 ohms. Assuming this is for 220 volts, the heater would have a current of 2 amps. This wattage checked out.

I made a switch box and wired the oil pump motor and heater inside it to prevent confusion due to there being so many different wires. The motor runs on 110 volts where the heater on 220 volts. Since 220 volts was not available we set up a system for getting the 220 volts from two sides of the 110 volts. The diagrams of the wiring are below. The pump should be ready for test runs after a check of the heater wiring then making the connections solid.



Technique of High Vacuum

Technique of High Vacuum

Some of the equations from the kinetic theory are important in the design, construction, and operation of vacuum apparatus. Accordingly, I will begin my treatment of the technique of high vacuum with a discussion of them. The derivations of these equations are omitted, since we are interested only in their applications.

The laws of ideal gases are represented, mathematically, by Equations 1 and 2.

$$(1) \quad P_1 = \frac{w_1}{M_1} R \frac{T}{V}$$

$$(2) \quad P_T = P_1 + P_2 + \dots + P_n$$

P_1 represents the total pressure exerted on the walls of a vessel containing w_1 grams of a gas of molecular weight M_1 , when this vessel has a volume V and is maintained at an absolute temperature T . If more than one gas is present, for example, if the vessel contains w_1 grams of one gas of molecular weight M_1 , w_2 grams of a second gas of molecular weight M_2 , and so forth, the partial pressure exerted by each gas is given by Eq. 1.

The total pressure, given by Eq. 2, is the sum of these partial pressures. The value of the constant R , the so-called universal gas constant, is independent of the molecular weight of the gas, but its value does depend on the units in which the pressure and volume are expressed. In vacuum work the pressure is usually expressed in millimeters of mercury and the volume in cubic centimeters, in which case R has the value of 62,370.

Eqs. 1 and 2 are based on the assumptions, first, that the molecules are infinitely small and, ~~second, that no inter-~~
~~molecules are infinitely small and~~, second, that no inter-molecular forces exist. Neither assumption is valid for real gases. Nevertheless, the equations describe the behavior of real gases, especially hydrogen and helium, with sufficient accuracy for our purposes here. Although the equations break down at elevated pressures (pressures greater than 1 atmosphere), they become increasingly precise if the pressure is reduced. And, at pressures encountered in vacuum work, Eqs. 1 and 2 not only apply to the description of the behavior of

gases but describe the behavior of many unsaturated vapors as well.

The mean free path is the average distance transversed by molecules between successive intermolecular collisions. The magnitude of this quantity is determined by the size of the molecules and is given by the formula

$$\lambda = \frac{1}{\sqrt{2} \pi n \sigma^2} \quad (3)$$

σ represents the molecular diameters and n the number of molecules per cubic centimeter.

The viscosity and heat conductivity of a gas, like the mean free path, depend on the molecular diameters. As a result, we have the relationship between the mean free path and the viscosity η ,

$$\eta = \frac{1}{3} \rho v_{av} \lambda, \quad (4)$$

and the relationship between the viscosity and the thermal conductivity K ,

$$K = \eta c_v E. \quad (5)$$

In these equations ρ is the gas density in grams per cubic centimeter, c_v is the heat capacity at constant volume of unit mass of the gas; and E is a constant, being 2.5 for monatomic and 1.9 for diatomic gases. v_{av} is the average velocity of the molecules and is defined by the equation

$$v_{av} = \sqrt{\frac{2.1 \times 10^8 T}{M}} \text{ cm/sec} \quad (6)$$

Substituting PM/RT for ρ and Eq. 3 for λ in Eq. 4, we see that the pressure cancels. In other words, Eq. 4 predicts that the viscosity will be the same at reduced pressure as it is at ordinary pressures. The experimental verification of this prediction by Meyer and Maxwell was a triumph for the kinetic theory. They measured the damping of a torsion pendulum in a bell jar at pressures varying from 1 atmosphere to about 10 mm of mercury. The damping produced by the viscosity of the air was found to be the same at all pressures.

Eq. 5 predicts that the heat conductivity is also independent of the pressure. This was established experi-

mentally by Stefan.

Eqs. 4 and 5 are derived from the assumption that the mean free path is small in comparison with the size of the apparatus. Table I shows the pressures at which this assumption becomes invalid.

If Meyer and Maxwell had reduced the pressure in their bell jar below about 10^{-1} mm, they would have observed a decrease in the damping effect on the torsion pendulum. Likewise, if Stefan had extended his observations, he would have found a decrease in the heat conductivity towards 10^{-1} mm and its complete disappearance below about 10^{-4} mm.

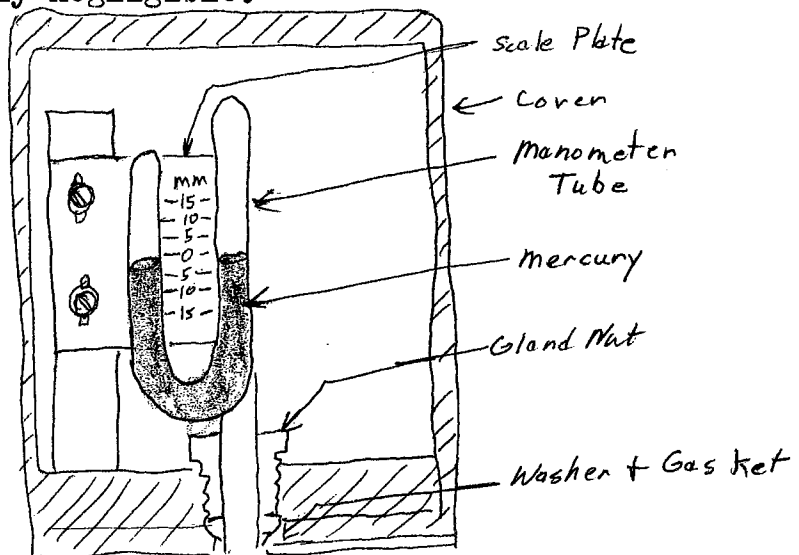
Vacuum Gauges

The Manometer

The manometer provides a check on the operation of the low vacuum pumping system. It is not intended to be an accurate pressure measurement device, but one which will give an indication of faulty operation of the rotary oil pump, or of leaks on the high pressure side of the mercury vapor vacuum pump.

The manometer proper consists of a U shaped glass tube, closed at one end and connected at the other end to the volume whose pressure is to be measured. The tube is evacuated and filled with mercury then sealed off at the factory. After installation in the manometer flange, the tube is broken at the bottom of the flange. Sufficient mercury is used so that with zero pressure at the open end, the columns of mercury in the two legs of the "U" will be at the same height at about half the length of the legs. An adjustable calibrated scale plate is provided so that zero adjustment may be made. The glass tube is sealed to the flange by means of a rubber gasket and gland nut. The whole manometer is covered to protect it from injury.

Since the pressure in the sealed off end of the glass tube is practically zero the difference in levels of the two columns of mercury is a measure of the pressure in the reservoir to which the manometer is connected. Under normal operation the rotary oil pump should evacuate the interstage reservoir to the order of a millimeter or less so the difference in level of the two columns of mercury in the manometer should be practically negligible.



The McLeod Gauge

Although many improvements have been made in the McLeod gauge, they have seldom been applied. The gauge as ordinarily used today is essentially the same as it was originally. I will discuss here the simple form of the gauge illustrated. It is made of glass as shown and is mounted on a vertical board. The difference in the heights of the mercury levels in the gauge and in the reservoir is approximately equal to the barometric pressure B . As the reservoir is raised, the mercury level in the gauge comes above the Y-branch, thus isolating a definite volume V_1 of the residual gas. This is isolated at the unknown pressure P_1 , the pressure of the residual gas in the apparatus to which the gauge is connected. As the mercury reservoir is further raised, the isolated residual gas is compressed, and when its volume has been reduced to a volume V_2 , the pressure is great enough to produce a sensible difference in the height of the mercury meniscus in the two capillaries, A and B. At the left the mercury levels are shown at the beginning of a measurement, and at the right they are shown in two different positions corresponding to two methods of making readings. In one, if the meniscus in B is adjusted to the same height as the top of capillary A, the final volume, V_2 , is equal to $\Delta h \times \sigma$, when σ is the cross-section area of the capillary. The decrease in volume from V_1 to V_2 is ordinarily of the order of onehundred-thousandfold, with a corresponding increase of pressure in the capillary over that which obtained originally. The construction of the gauge with the comparison capillary B of identical bore with A eliminates the necessity of making corrections for surface tension. The original product, $P_1 V_1$, is equal to the final product, $P_2 V_2$. From this we get the expression connecting the unknown pressure with the observed manometer difference, Δh :

$$P_1 = \sigma (\Delta h)^2 / V_1$$

V_1 and σ are constants of the gauge determined when it is constructed. σ is obtained by measuring the length of a known volume or weight of mercury in the capillary. V_1 is determined

by filling the gauge with mercury. These original data may be recorded on the board to which the gauge is attached. Here they will not be lost. Values of P_1 determined by the preceding equation are usually laid off on a nonlinear scale, which is mounted behind capillary A in order that pressures may be read directly.

The second procedure of making the observation on V_2 and P_2 is illustrated at the right. The gas is compressed to a definite mark on capillary A at a distance Δh_0 from the top, so that the final volume, V_2 , is the same for every measurement. The final pressure necessary to compress volume V_1 to V_2 is Δh , and the pressure P_1 in the system is determined by these quantities, according to the following equation:

$$P_1 = \sigma \Delta h_0 \Delta h / V_1$$

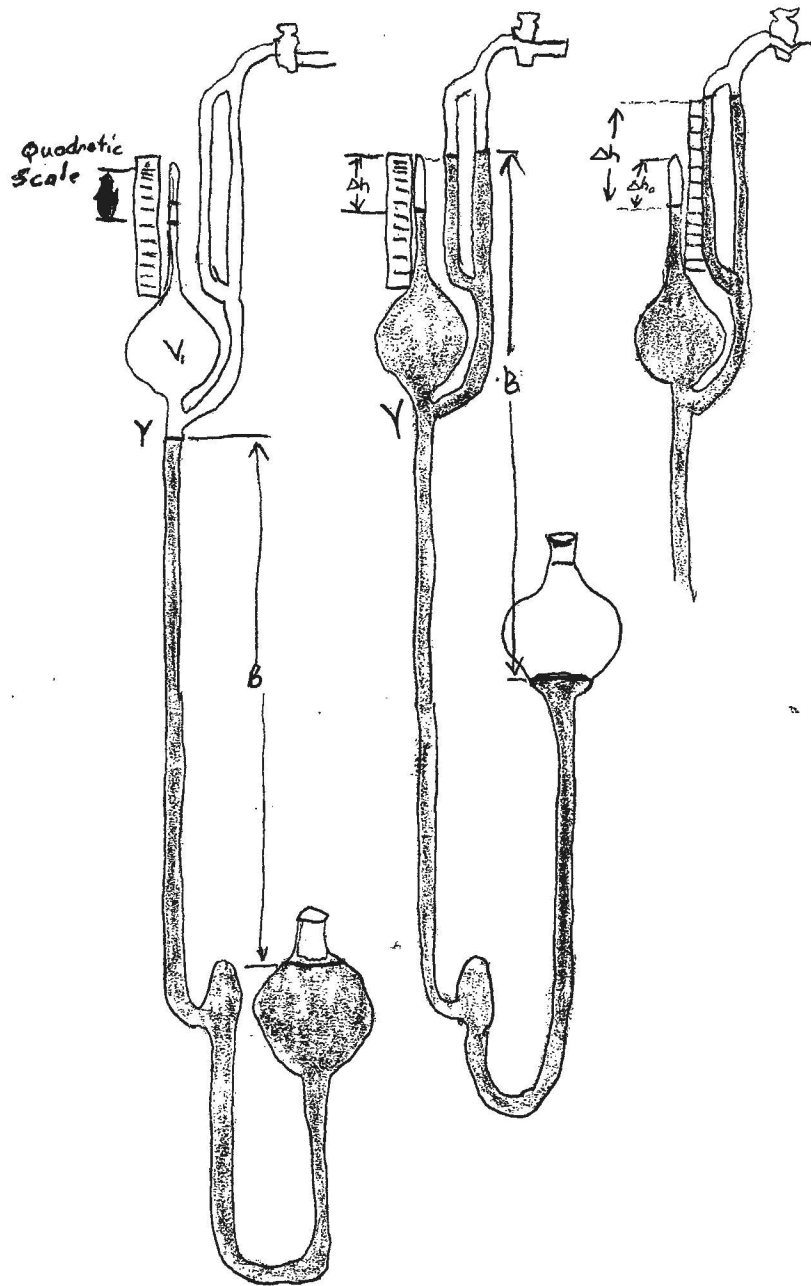
A linear pressure scale computed from this formula is ordinarily mounted behind capillary B.

The McLeod gauge is thoroughly reliable for the permanent gases from 10^{-1} mm to 10^{-4} mm of mercury. It is less reliable to 10^{-5} mm. Below this the indications are only qualitative, and at 10^{-6} mm the mercury often sticks in the top of capillary A.

The gauge is most reliable after it has been outgassed by gently warming it with a soft flame. Three gauges with different values of V_1 are necessary to cover adequately the complete pressure range from 10^{-1} to 10^{-6} mm. The McLeod gauge is fragile. If it breaks, not only is the gauge lost but what is often more serious, mercury may get into the vacuum system. In glass vacuum systems using mercury pumps this is not as serious as it may be in kinetic vacuum systems. These systems, fabricated of brass with soft-soldered joints, are attacked by mercury and the joints are destroyed.

Accidents with this gauge are usually caused by bringing the reservoir up too quickly. Then mercury in V_1 acquires enough momentum to shatter the bulb when the metal surface arrives at the opening of the capillary tube with no cushion of air to soften the shock. Admitting air into the vacuum system can do the same thing. If the mercury gets stuck in the capillary heating it with a soft gas flame will sometimes free it.

McLeod Gauge



The McLeod gauge on the Westinghouse is of the type mentioned first with the nonlinear scale. It uses a bellows to compress the mercury into the capillaries instead of using the reservoir. The gauge seems to have some mercury stuck in it and this might be removed with heating.

The Pirani Gauge

The Pirani gauge consists of a heated filament of platinum, tungsten, or some other metal with a high temperature coefficient of electrical resistance. The filament is exposed to the residual gases and is cooled by the heat conductivity of the residual gas, which, in turn, depends on the pressure. The filament may be operated in several ways. The most satisfactory method is to connect the filament to one arm of a Wheatstone bridge and heat it by a constant current as shown in the figure. If the bridge is balanced at one temperature of the filament, a change of its temperature caused by a change in the heat conductivity of the residual gases will unbalance it. Thus, the deflection of the bridge galvanometer indicates the pressure of the residual gases.

Ordinarily, the filament is mounted in a bulb fitted with a connecting tube and is balanced with an identical compensating filament mounted in an adjacent arm of the bridge. This auxiliary bulb is evacuated and sealed off at a very low pressure. The use of an auxiliary bulb serves to make the gauge insensitive to variations in room temperature. Changes in the over-all temperature of one bulb are the same as changes in the other, so that the galvanometer does not respond to these changes but only to the changes produced by the residual gas in the one bulb.

