MCE380: Measurements and Instrumentation Lab

Chapter 7: Pressure Measurements

Topics:

Absolute Pressure, Gage Pressure and Vacuum

Mechanical Devices for Pressure Measurement

Electrical Devices for Pressure Measurement

Holman, Ch. 6

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Mechanical Engineering

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What is Pressure?

- Pressure is the normal force per unit area exerted by a fluid upon a surface. It has the same units as stress.
- In gases, pressure has a statistical interpretation. The pressure is a measure of the average kinetic energy of molecules impacting the containing walls (see Eq. 6.1 in Holman).
- The SI unit of pressure is the Pascal (Pa), which equals 1N/m^2. In English units, the unit is the psi (pound per square inch).
- Pressure may be measured in *atmospheres*, *bar* or in terms of the height of a liquid column (usually Mercury).
- What is the pressure generated by a 760mm column of Mercury at 20 C? Use the formula

$$P = \rho g h$$

with $\rho = 13579$ kg/m^3. Express the result in kPa, psi, atm and bar.

Absolute, Gage and Vacuum Pressures

The value of the force per unit area on one side of the container wall corresponds to the *absolute pressure*.

If we subtract the atmospheric pressure from the absolute pressure, we get *gage* or *manometric pressure*. So:

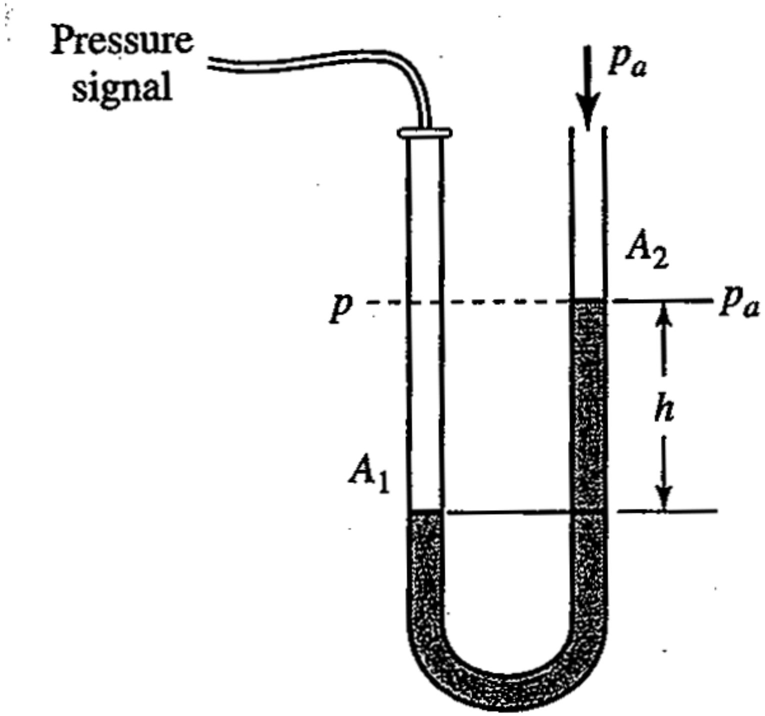
absolute pressure=gage pressure+atmospheric pressure

Many pressure gages have a scale starting at 0: they are called *manometers*. The gage pressure can be negative. In this case, we have a vacuum. The absolute pressure cannot be negative, since zero absolute pressure means no molecules.

This implies that a vacuum pressure lower than the atmospheric pressure can never be obtained. See Fig. 6.1 in Holman.

The U-Tube Manometer

This is the simplest way of measuring pressure.



Pressure balance:

$$p - p_a = \frac{g}{g_c} h(\rho_m - \rho_f)$$

Well-Type Manometer

See Fig. 6.4 in Holman. The well-type manometer is similar to a U-type one, but with one column shorter and wider, usually exposed to atmospheric pressure.

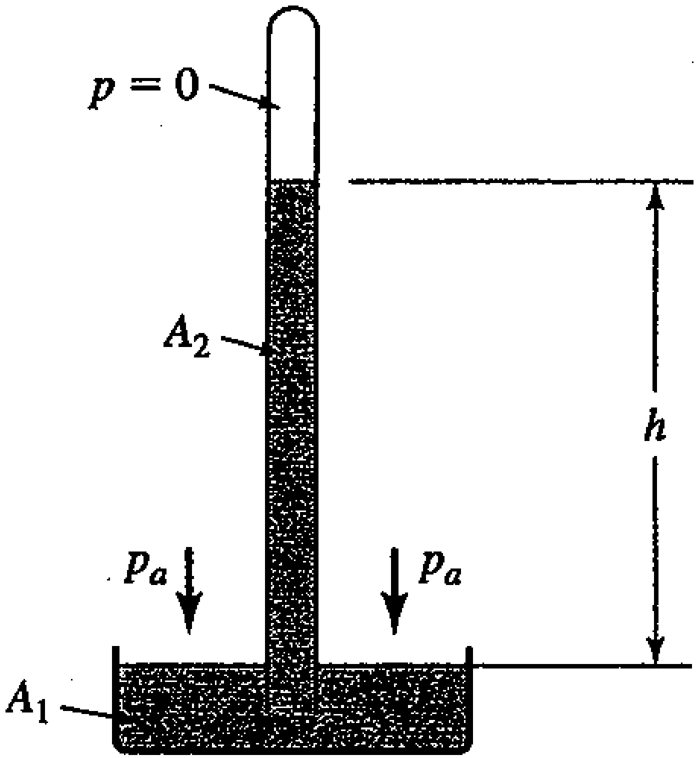
The advantage over the conventional U-tube is that we don't have to take readings at two different places and subtract. In the well-type manometer, the level change is very small at the wide end.

For more precision, the scale on the narrow tube can be corrected (see Eq. 6.13) to account for level drop at the wide end.

Sometimes, the narrow tube is inclined, to magnify the scale and give better accuracy.

Barometers

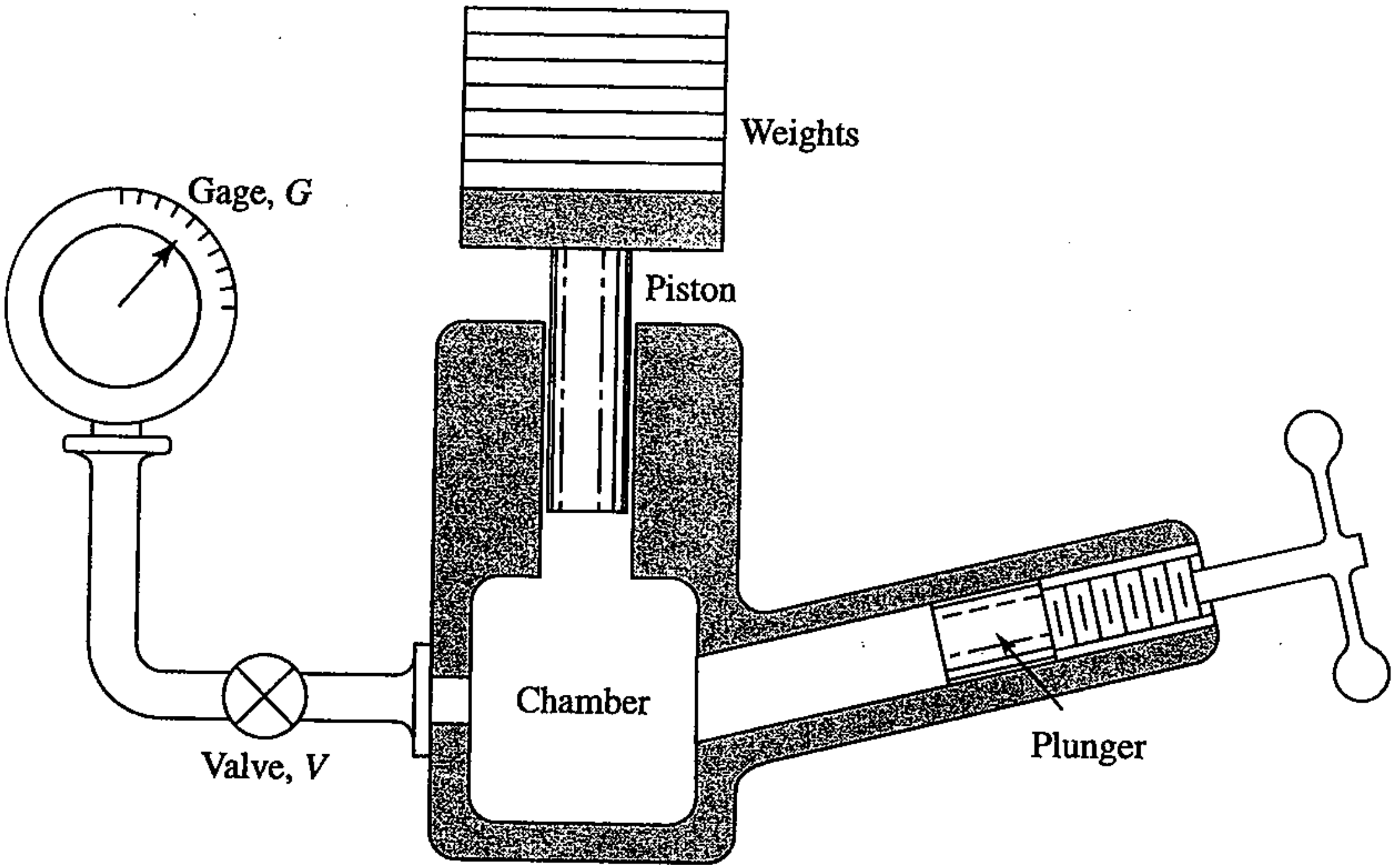
Barometers are designed to measure atmospheric pressure.



If Hg is used at 20 C, the height of the column at sea level will be 760 mm.

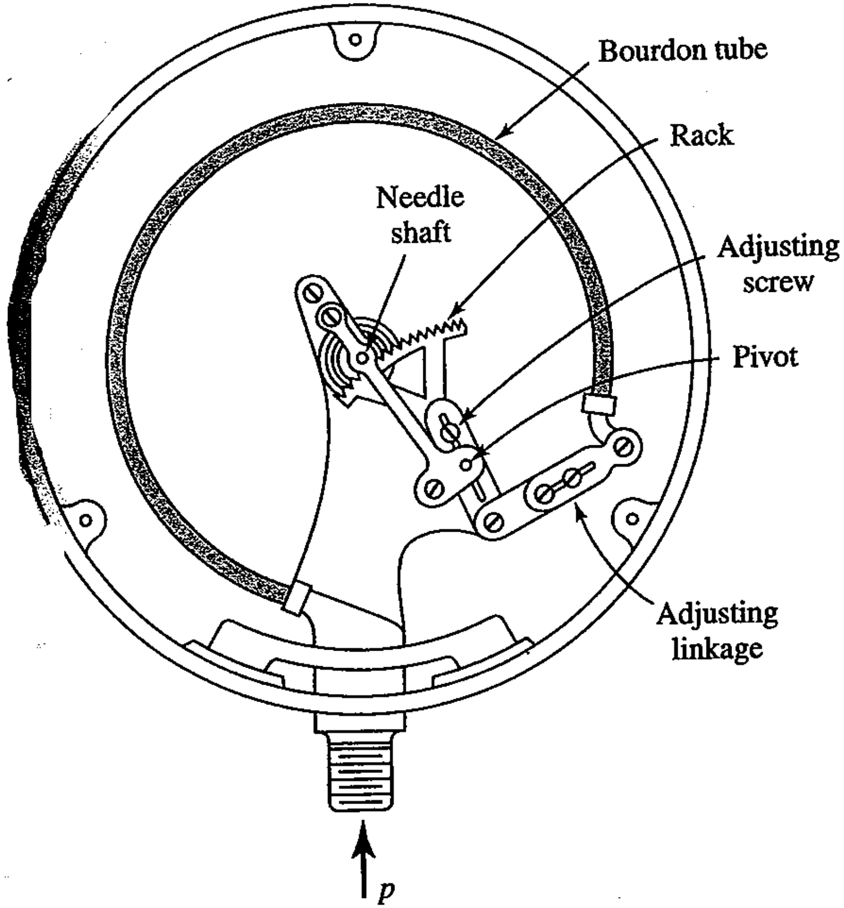
Pressure Meas. by Dead-Weight Testing

This is used for the calibration of gages only.



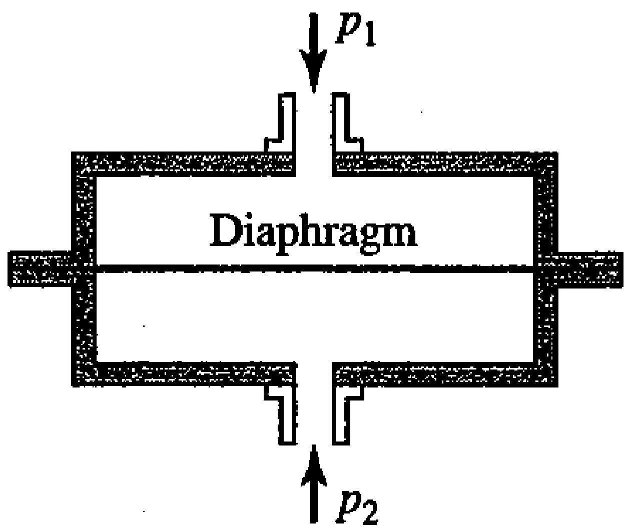
Bourdon Tube Gage

This is the most common type of pressure gage.



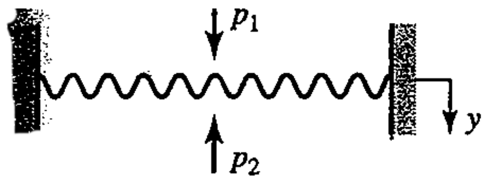
Diaphragm Gages

These devices require the measurement of strain by electrical means. Resistance foil strain gages are commonly used. We have this kind of pressure transducer in the lab.

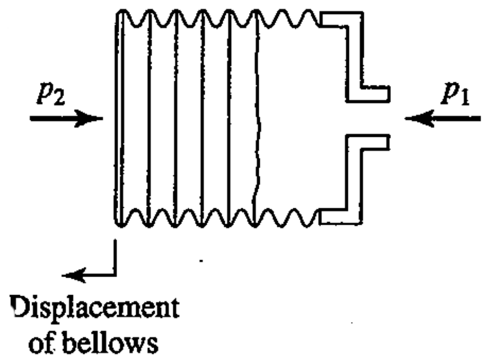


These devices are linear when the deflection is less than a third of the membrane thickness. See also Fig. 6.9.

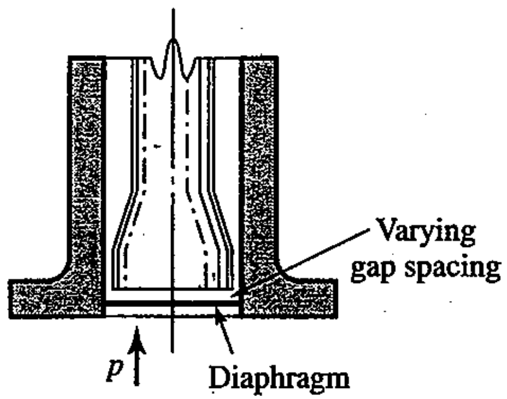
Bellows and Capacitance Gages



Corrugated-disk diaphragm.



Schematic of a bellows pressure gage



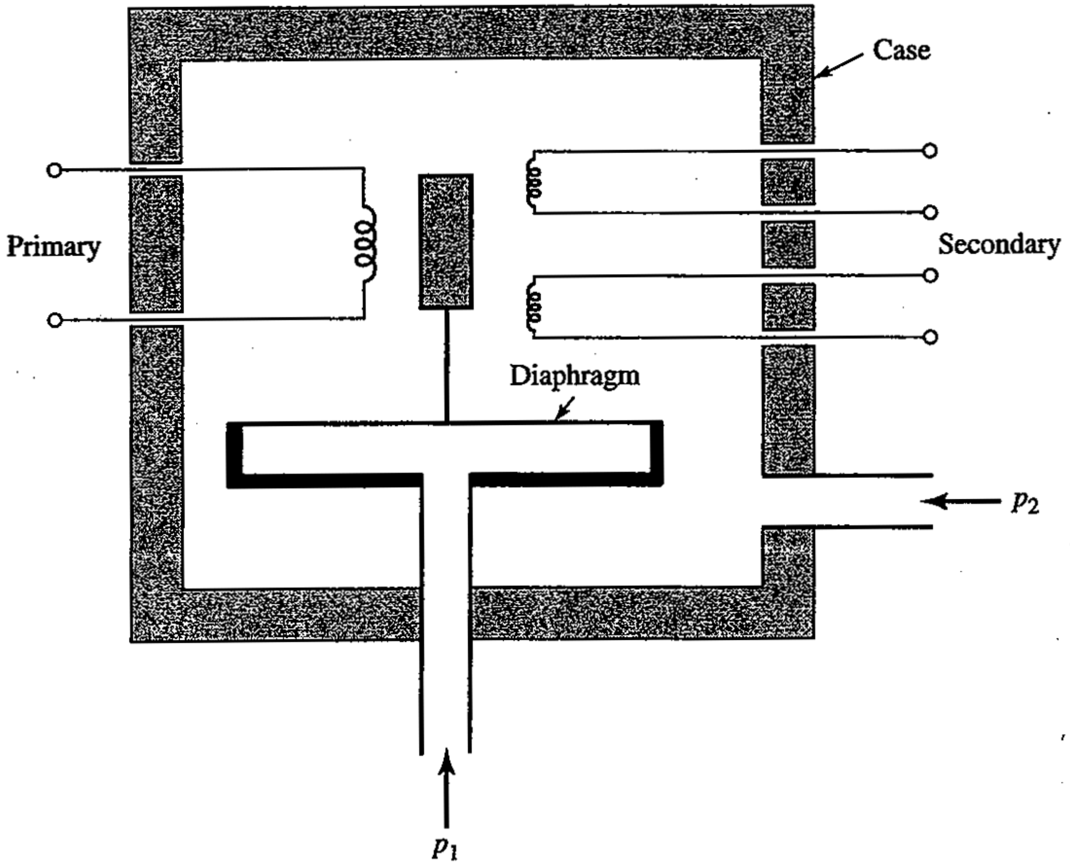
Bellows and Capacitance Gages

These gages allow for larger pressure differentials than the membrane types.
Due to the corrugated shape, mechanical amplification is used instead of strain gages to produce the measurement readout.
Due to the large mass of the bellows, these devices are slow-responding and not suitable for transient measurements.

The variable gap created by a moving diaphragm can be used as a capacitance sensor, but it requires special electronics.

Diaphragm+LVDT Gages

The motion of the diaphragm is sensed by a LVDT (linear variable differential transformer), which we'll study later (we have several in the lab).



The Bridgman Gage

If a fine wire is subjected to hydrostatic (surrounding) pressure, its resistance will change according to:

$$R = R_1(1 + b\Delta p)$$

where R_1 is the resistance at 1 atm, b is the pressure coefficient of resistance and Δp is the gage pressure.
This can be used to measure pressures as high as 100000 atm. Wires are made of Manganin (84% Cu, 12% Mn, 4% Ni), which has $b = 2.5 \times 10^{-11}$ Pa^{-1}.

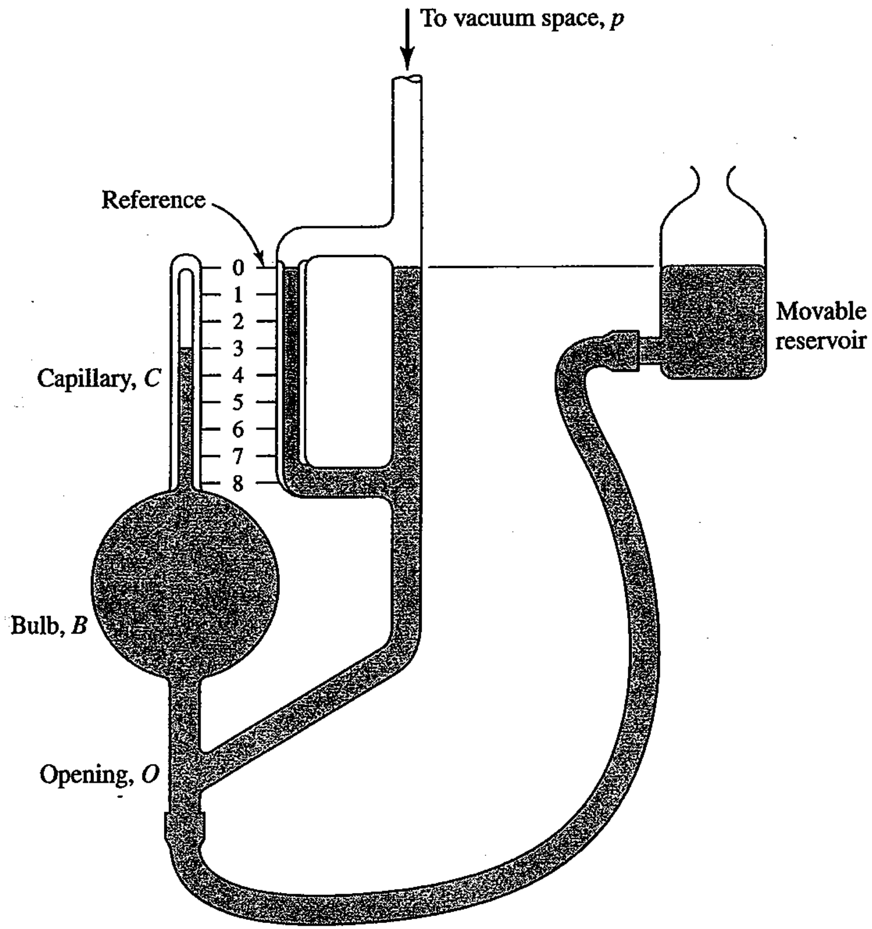
The resistance of a typical length of wire used in a Bridgman gage is 100 Ω. A simple Wheatstone bridge and the above formula can be used to find the pressure.

Example

Solve Prob. 6.12 from Holman.

Vacuum Measurement: McLeod Gage

Moderate vacuum can be measured with conventional gages. Absolute pressures below 1 torr (1 mmHg) require specialized devices.



Operation of McLeod Gage

The idea is to compress part of the gas whose vacuum pressure is being measured.

We measure the pressure of the compressed gas and then use it to find the pressure of the gas before the compression, which is the required vacuum measurement.

Assuming an isothermal compression, we have

$$p_c V_c = p_B V_B$$

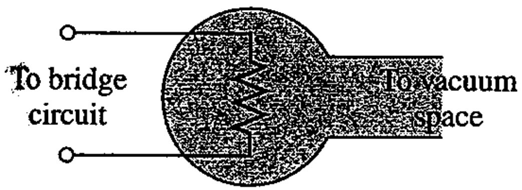
where $_c$ and $_B$ indicate compressed and original conditions, respectively.

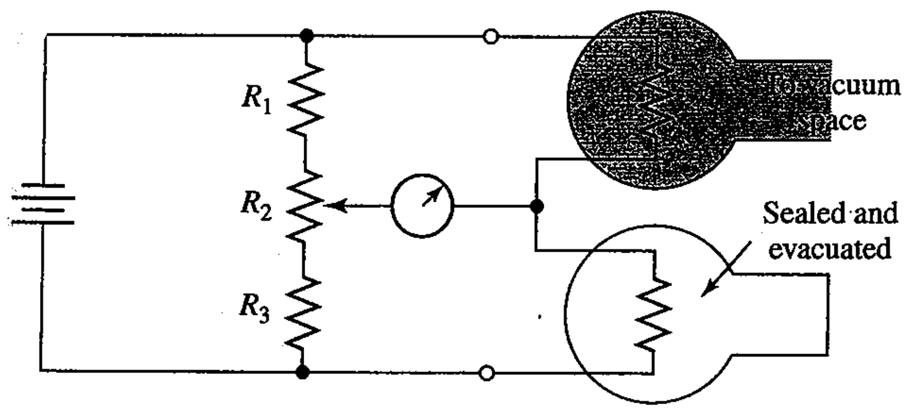
As we can see, V_c and V_B are known from the graduations in the apparatus. The compressed pressure p_c and the required pressure $p_B = p$ can be related as explained in Holman, giving

$$p = \frac{ay^2}{V_B}$$

Vacuum Measurement: Pirani Gage

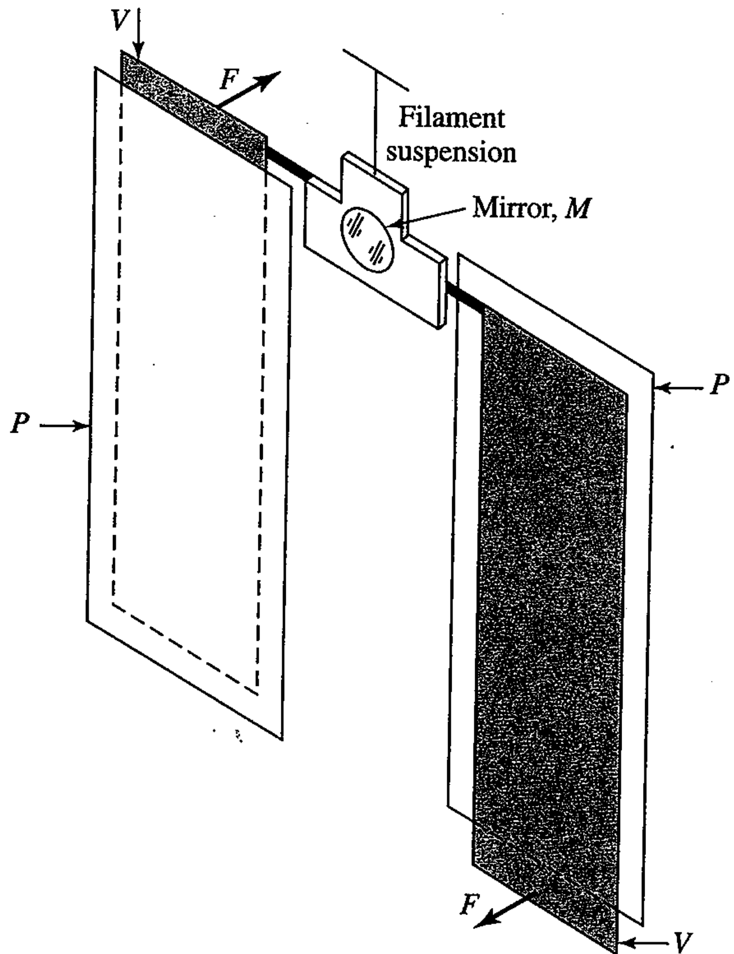
At low pressures, the thermal conductivity of a gas decreases as pressure decreases. Therefore, as pressure decreases, heat transfer from the filaments decrease and they get hotter, resulting in increased electrical resistance. The change in resistance can be measured with a bridge and converted to pressure.





Vacuum Measurement: Knudsen Gage

Gas near the hot plate has a higher temperature than the gas near the colder plate. Therefore the molecules hitting the hot side have a higher momentum. A net momentum makes the assembly rotate. The rotation is amplified by an optical lever (mirror and light beam).



Vacuum Measurement: Ionization Gage

The ratio of plate to grid current is dependent on pressure. See Eq. 6.25.