DETERMINATION OF THE COMPRESSIBILITY FACTOR

(Last Revision: August 26, 2022)

- ABSTRACT:

The large deviations of real gases from ideal gas behavior is best seen by determining the compressibility factor. The compressibility factor,

$$Z = \frac{P\bar{V}}{RT} \ ,$$

is found in this experiment at a number of pressures and the plot of *Z* versus the pressure gives an excellent picture of the behavior of real gases.

- OTHER REFERENCES:

Dannhauser, Walter, J. Chem. Educ., 49, 563-564(1972).

Burnette, E. S., J. App. Mech., 3, A136(1936).

Baron, J. D. and Watson, G. M., J. Chem. Educ., 31, 74(1954).

- GENERAL DESCRIPTION AND THEORY:

The gas is first allowed to fill volume V_A of the system at the original pressure, P_0. At this point the compressibility is given by:

$$Z_0 = \frac{P_0 V_A}{n_0 RT} \quad .$$

Then the gas is allowed to expand into V_B and the equation is:

$$P_1(V_A + V_B) = n_0 RT Z_1 \quad .$$

Therefore by eliminating RT we obtain:

$$\frac{Z_1}{P_1} = \left(\frac{Z_0}{P_0}\right)\left[\frac{(V_A + V_B)}{V_A}\right] \quad .$$

Then after first evacuating V_B, we get:

$$P_1 V_A = n_1 RT Z_1 \quad ,$$

and after j expansions we have:

$$\frac{Z_0}{P_0} = \left(\frac{Z_j}{P_j}\right)\left[\frac{V_A}{(V_A + V_B)}\right]^j \quad .$$

The constant $\left[\frac{(V_A+V_B)}{V_A}\right]$ which depends on the apparatus is found from:

$$\lim_{P\to 0}\left(\frac{P_{j-1}}{P_j}\right) = \frac{(V_A + V_B)}{V_A}$$

Nitrogen should be used for this extrapolation as it is the closest to ideal behavior.

After the volume ratio has been determined, the value of P_0/Z_0 may be obtained by plotting $\left[\frac{(V_A+V_B)}{V_A}\right]^j$ P_j versus P_j . The intercept will be the value of P_0/Z_0. Then Z_j for each pressure can be determined from:

$$Z_j = \left(\frac{Z_0}{P_0}\right)\left[\frac{(V_A + V_B)}{V_A}\right]^j P_j \quad .$$

Because the volume ratio is raised to a high power, it must be determined carefully to prevent the introduction of large error into the calculation.

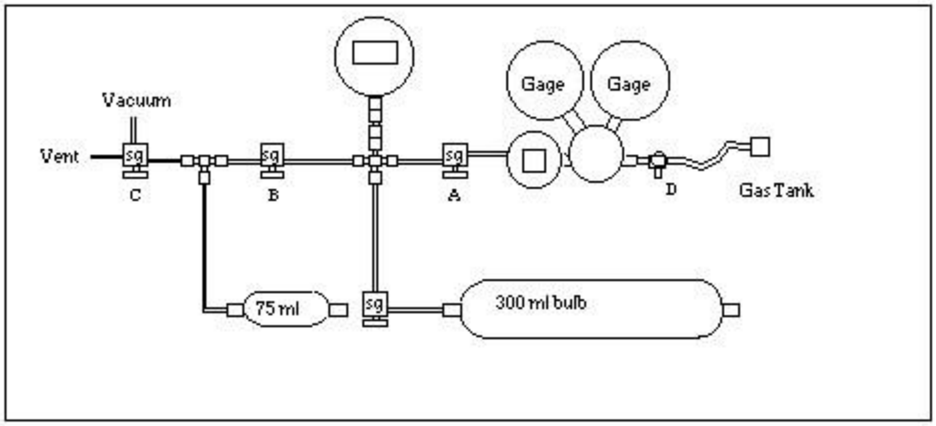
- EQUIPMENT:

The equipment used for this experiment is a high pressure manifold shown in the diagram below. The 300 ml bulb is the VA part of the system and 75 ml bulb is the VB part of the system. (The volumes also include the piping in the system.) Two gas tanks are used, one with nitrogen and the other with helium. They are connected to the system by means of a quick connect connector which is connected by finger pressure - **do not use a wrench**. A vacuum pump is used to evacuate the system through valve C.

- CHEMICALS:

Helium, argon, carbon dioxide and nitrogen are used in the experiment.

- DIAGRAMS:



- LABORATORY PROCEDURE:

Open valves A and B. Close the regulator. The regulator is closed when the center knob (where the gages attach) is turned out until it turns loosely and the left knob is turned in all the way. Turn valve C to the vacuum position and evacuate the system. The digital pressure gage can be turned on by depressing the white button at the top. The digital pressure gage should go to zero under vacuum.
Then close valves C and B. C is closed when the handle is perpendicular to the board.

Then connect the flexible hose to the gas tank being used and bleed the system through valve D by first opening and closing the tank valve and then opening valve D. The gas will come out very quickly at tank pressure. Close D and open the tank valve. Open the left hand knob and then adjust the regulator to fill the system at a pressure of a little over 1000 psi. Then close valve A and the regulator and also the gas tank valve.

Monitor the pressure for a few minutes and when stable record the pressure of P_0. Then open valve B and the gas will expand into V_B. Again after equilibrium, record the pressure as P_1.

Then close valve B, open valve C first to vent V_B and then to evacuate V_B. Then close valve C.

Open valve B and the gas will expand into V_B. When equilibrium is obtained record the pressure as P_2.

Repeat the process of expanding into V_B and evacuating V_B until the pressure drops below 100 psi.

Repeat the whole process for the next gas.

- CALCULATIONS:

First, **for only the run using nitrogen**, plot the ratio (P_{j-1}/P_j) versus P_j and extrapolate to zero pressure. The intercept will be the volume ratio, $(V_A+V_B)/V_A$. This calculation is critical and the results of the experiment will depend on this value for the system. Next, for each of the gases, plot $P_j[(V_A+V_B)/V_A]^j$ versus P_j. The intercept at zero pressure will be P_0/Z_0. Then calculate Z_j at each pressure by using:

$$Z_j = \left(\frac{Z_0}{P_0}\right)\left[\frac{(V_A+V_B)}{V_A}\right]^j P_j \quad .$$

Finally a plot of Z_j versus the pressure should be produced for each of the gases studied in the experiment. Note that for real gases Z should approach unity as the pressure approaches zero.

- LITERATURE VALUES: