Gas Laws and Absolute Zero

**Purpose:**
**Part I:** To examine the relationship between the temperature and pressure of a constant volume of gas (air) in order to determine experimentally the value of absolute zero.

**Part II:** To examine the relationship between pressure & kinetic energy of a confined gas.

**Equipment:** Absolute zero demonstrator device (hollow sphere attached to a pressure gauge), several water baths at different temperatures from boiling to freezing, and thermometers.

**Discussion Part 1:** The behavior of a confined gas (primes represent after the change)

Charles’ Law: \( \frac{V}{T} = \frac{V'}{T'} \) (constant pressure)

Boyle’s Law: \( PV = P'V' \) (constant temperature)

Combined Law: \( \frac{PV}{T} = \frac{P'V'}{T'} \)

When the quantity of gas is a consideration, the combined law is applied to one mole of gas, \(.0224\text{m}^3\) at STP (Standard Temperature, 273K and Pressure, 101,000Pa):

\[
\frac{PV}{T} = 8.31 \frac{J}{\text{mole} \cdot \text{K}} = R \quad \text{for any number of moles of gas;} \quad \frac{PV}{T} = nR
\]

rearranging gives the ideal gas law:

\[
PV = nRT \quad \text{(Ideal Gas Law)}
\]

\( P = \text{pressure in N/m}^2 = \text{Pascals(Pa)} \)

\( V = \text{volume in m}^3 \)

\( T = \text{temperature in Kelvins(K)} \)

\( n = \text{number of moles} \)

\( R = \text{gas constant in the above units(N·m/mole·K)=J/mole·K} \)

A **mole** of any substance is its gram molecular weight and contains the SAME NUMBER OF MOLECULES, Avogadro’s number (6.022x10^{23}). For example, one mole of water (H\textsubscript{2}O) has a mass of 18 grams, while one mole of oxygen gas (O\textsubscript{2}) has a mass of 32 grams.

The gas used during this lab exercise is air, while not an ideal gas, its behavior, like that of most real gases, is very closely approximated by equation (1). Remember: Whenever dealing with gas laws, the temperature must be in Kelvins.
Procedure Part I:

1. Using the absolute zero demonstrator device, measure and record five different temperatures and pressures for the air contained in your sphere. Begin with freezing OR boiling, but increase or decrease bath temperatures IN ORDER (Don’t go from hot to cold to warm to cool, etc.). During each immersion, make sure the sphere is completely submerged and leave it there long enough to obtain an accurate final reading. Tap the gauge lightly to ensure no sticking of the needle. Read to the nearest kPa.

2. After recording the fifth and final temperature / pressure change of your first run (when the sphere will be very hot or very cold), change the amount of gas in the sphere by activating the pin valve with a ballpoint pen or similar to equalize the pressure between the room and the sphere. This will change the number of air molecules in the sphere. Repeat the procedure.

3. **Plot the pressure (kPa) as a function of temperature (°C) for both runs.** By extrapolation, determine for each run the temperature at which the pressure goes to zero. Average these two values to arrive at your experimental answer for absolute zero, which defines the starting point of the Kelvin absolute temperature scale. Compare your result to the actual value of $-273.15 \, ^\circ \text{C}$. Determine percent error.

Results for part 1: Average value of absolute zero for both runs and % relative error.

Discussion Part 2: You have seen that as the temperature of a gas increases, so does the pressure. The increase in pressure is an indication of the increase in kinetic energy based on the average speed of the air molecules themselves. The kinetic energy of the molecules of an enclosed gas is given by the Boltzman Law.

$$KE = \frac{3}{2} kTN \quad \text{(for gases having one atom per molecule)}$$

or

$$KE = \frac{5}{2} kTN \quad \text{(for gases having two or more atoms per molecule)}$$

Since air is mainly composed of nitrogen and oxygen, both of which exist as diatomic molecules, we will use the latter equation today. In the equations above, “$k$” is Boltzman’s constant, and equals $1.38 \times 10^{-23} \, \text{J/K}$. T is the temperature of the gas in kelvins, and N is the number of molecules.
Procedure Part II:

1. Before you begin Part I, run 1, the pressure in your sphere was equalized at room pressure while at room temperature, so you will use run 1 data to calculate kinetic energy.

2. The volume of the sphere is 525 cm$^3$ which must be converted to MKS units of cubic meters.

3. Determine the number of molecules, “N”, in the sphere, by using the ideal gas law to find “n” the number of moles. “N”, is just “n” times Avo’s number. Find “n” using the ideal gas law. The volume of the sphere is 525 cm$^3$.

4. Convert Celsius degrees to Kelvins (273+C) for the run 1 temperatures, and calculate the kinetic energy of the gas for each temperature.

5. Plot the pressure as a function of kinetic energy. (pressure on the y axis)

The result of part 2 is a discussion of the relationship between pressure and average kinetic energy as determined by the graph.

Questions (write questions and show all work)

1. If the temperature of 2.0L of gas at constant pressure drops from 100$^0$C to 50$^0$C, determine the new volume.

2. 5.0L of gas is held at constant temperature while the pressure is increased from 1.0atm to 4.0atm. Find the new volume.

3. A .50 m$^3$ metal cylinder is filled with an unknown gas to a pressure of 1000kPa. If the temperature of the gas is 25$^0$C, how many molecules are in the cylinder?