Perfect Gas law

Objectives

a. To find the value of absolute zero temperature (0K).
b. To find the value of universal gas constant (R)

Apparatus Required

			
Gas bulb		**Computer Interface**	**Pressure-Temp Sersors**
			
Heater	**stand**	**Beaker**	**water**

Introduction

When a gas is heated, it tends to expand. But if it is restricted to a fixed volume the expansion manifest in the form of pressure. Therefore, the equation for change in pressure can be expressed in the similar manner as the expansion of solid,

$$\Delta \boldsymbol{P} \propto \boldsymbol{P_0} \Delta \boldsymbol{t}.$$

$$\Delta \boldsymbol{P} = \boldsymbol{\beta} \boldsymbol{P_0} \Delta \boldsymbol{t} \qquad \textbf{(1)}$$

Where, β is coefficient of proportionality, ΔP is change in pressure and Δt is change in temperature in ^{0}C or ^{0}F. **[Please see appendix for why the temperature unit must be in ^{0}C or ^{0}F]**

We can expand equations (1) as,

$$P - P_0 = P_0\beta(t - t_0).$$

Where, P_o = pressure at initial temperature t_o and P is arbitrary pressure at arbitrary temperature t.

If we consider initial temperature, t_o = 0°C,

$$P = P_0 + P_0\beta t. \quad \textbf{(2)}$$

Absolute Zero:

The gas pressure is created by continuous bombardment of gas molecules on the wall of the container. That is, the pressure is created by kinetic energy. But the temperature of a gas is a measure of its internal energy which is different form of kinetic energies ($E = \frac{f}{2}nRT$). At any point if pressure of a gas is zero it means the gas molecules are completely at rest or they have zero kinetic energy. Zero kinetic energy literally means zero temperature.

Therefore, absolute zero is a temperature at which the pressure of a gas is zero.

Experiment Procedure:

In this experiment, you will heat up a gas contained in a fixed-volume-metallic-bulb and observe the variation of pressure with temperature. Through data analysis, you will obtain the value of absolute zero and compare it with standard value. You will also find the value of molar gas constant and compare it with the standard value.

1. Fill half of a beaker with water.
2. Put the beaker over the electrical heater.
3. Fix the gas bulb neck in a tripod stand.
4. Insert the gas bulb inside the beaker so that the bulb is **completely immerged** inside the water.
5. Adjust the position of the bulb neck in the stand and **make sure the bulb is not teaching any surface of the beaker and it is completely submerged inside the water**. You can add more water if necessary.
6. Pressure and Temperature sensors are inbuilt in the bulb. Connect these sensors to computer via interface. Make sure the sensor box is not hanging and it is in the relaxed position.
7. Start data studio software and open its graph. Choose pressure in the y-axis and temperature in the x-axis of the graph. **Don't Run the Program yet!**

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8. Make sure the electrical wires are in safe distance from the heater.

9. Turn on the electrical heater. Heat moderately! For moderate heating, you need to put the heater nub somewhere in the middle. **Don't use maximum power of the heater ever**!

10. Run Data Studio software in the computer where the sensors are connected. Choose new experiment. Double click (or drag and drop) graph mode from the left hand side. You can change the pressure range and temperature range according to your data size as data progresses. Example: Pressure 90 kPa to 120 kPa and temperature 20^{o}C to 70^{o}C.

11. The computer will take data automatically and it may take time. As data progresses read rest of the write up. Start writing report.

12. Once you get a nice straight line in the graph stop data studio. Usually you can get a straight line for temperature range 20 ^{o}C to 30 ^{o}C. Example: if you have started to take data from 25^{o}C you can stop around 50^{o}C to 60^{o}C.

13. **Turn off the heater and unplug it.**

14. **Disconnect the sensors and computer interface. Take off the gas bulb from the water and from the stand. Throw the water in the sink**.

Data Analysis Part 1:

1. Best fit the graph and find x-intercept. You might have to change the range of Pressure and Temperature axes. You need intercept for pressure axis. Therefore, start pressure range from some negative value like -5.0kPa. You need x-intercept which will be close to -273^{o}C. Therefore, choose x-axis from the value smaller than -273^{o}C such as -300^{o}C.

2. Since the absolute zero is a temperature at which pressure of a gas is zero; it happens at the intercept of temperature axis. Find the value of absolute zero from the intercept of temperature axis.

At absolute zero, P = 0, and the equation (2) turns to be:

$$\boldsymbol{t = -\frac{1}{\beta}} \tag{3}$$

3. Find the value of $\boldsymbol{\beta}$ from slope of the graph and with the help of equation (2)

4. Find the value of absolute zero temperature in ^{0}C, according to equation (3).

5. Find the average value of absolute zero from step 2 and 4. The average value should be closer to the theoretical value -273^{o}C.

6. Compare it with the theoretical value (find % error).

Data Analysis Part II:

Considering t = $-1/\beta$ ^{0}C as zero, you can start a new system of temperature measurement *T*, and its relationship with *t* in ^{0}C is given by,

$$T = 1/\beta + t. \quad (4)$$

Here, *T* = 0 for *t* = $-1/\beta$ ^{o}C. Thus, *T* = 0 or *t* = $-1/\beta$ ^{o}C is the lowest possible temperature and is called absolute zero temperature. ***T*** is called absolute temperate because of its scientific origin and is measured in Kelvin unit, after Lord Kelvin, who first discovered it. Unlike ^{0}C and ^{0}F, which are based on assumptions, Kelvin is derived from scientific facts. Hence it is a scientific system.

Combining equations (2) and (4) you can get,

$$P = P_0\beta T. \quad (5)$$

From perfect gas law equation,

$$P = \frac{nR}{V}T. \quad (6)$$

Both equations look similar. If we compare them we will find.

$$R = \left(\frac{V}{n}\right)P_0\beta \quad (7)$$

7. Find the value of R from equation (7) provided that n/V = 40.89 moles/ m^3 and P_0 is the pressure at temperature 0^{0}C that you can get from the intercept of pressure axis.

8. You can also find the value of the $\boldsymbol{R}$ from the graph. Since, $T = -\frac{1}{\beta} + t,$ the slope of P with "t" and "T" will be the same. Hence,

$$Slope = \frac{nR}{V} \quad (8)$$

9. Find the value of R from equation (8)

10. Find the average value of R from 7 and 9.

11. Compare it (find % error) with the standard value i.e. 8.3 J/mole K

Appendix: (These questions can be used for report)

1. Why the temperature needs to be in ^{0}C or ^{0}F?

Answer: It is because at this point you don't know the Kelvin unit of temperature. You will be discovering Kelvin unit in this experiment. You are repeating the experiment done by Lord Kelvin himself.

2. How can you get equation (3) from equation (2) and for what condition?
3. Find equation (5) from equations (2) and (4).