Ideal Gas Law, Absolute Zero

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Objective:

To demonstrate the relationship between change in Temperature and change in Pressure.

Description:

- The pressure gauge: This was made of a steel bulb filled with air that could be calibrated to room pressure by opening a valve. This sets the 1 atm pressure mark to room pressure and the pressure calculated hereafter would be relative pressure rather than absolute (unless absolute room pressure is 1 atm in which case the absolute and relative pressures will remain the same)
- There were 2 thermometers: 1 to measure low temperatures (-100° to 50° C) and another to measure higher temperatures like that of boiling water (-10° to 110° C).
- There was an insulating flask with alcohol in order to keep the alcohol after the addition of dry ice (The alcohol was cooled down to -78°C, while room temperature was measured to be ~22°C, lack of insulation would have led to rapid temperature rise, alcohol was used instead of water due to its significantly lower freezing point)
- There was another insulating flask with liquid Nitrogen that was assumed to be at -196°C although this could not be corroborated experimentally because the thermometers in the lab were not suitable to measure temperatures as low.
- Bunsen burner: this was used to heat the water to boiling point in order to measure the change in Pressure of water with change in its temperature.

Theory:

The ideal Gas Equation states that:

$$PV = Nk_BT$$

Where

P – Pressure of the Gas

V – Volume of the Gas

N – Number of molecules

k_B – Boltzmann's constant = 1.38 J/molecule•K

T – Absolute temperature of the Gas

When measuring Pressure, the volume of air inside the Pressure Gauge remains restricted, which means that only Pressure and the Temperature inside the pressure gauge bulb are variable. This gives us the equation:

$$\frac{P_0}{T_0} = \frac{P_1}{T_1} = \frac{Nk_B}{V}$$

Or the direct relation that the Pressure of a gas is directly proportional to its absolute temperature

This equation was rearranged as suggested in the lab manual as:

$$P = mT + b$$

And then to:

$$T = \frac{P}{m} - \frac{b}{m}$$

Where P represents pressure and T represents Celsius temperature. Here the b represents the intercept of the P vs T graph and the m represents the slope. The values of these constants are known (m = Nk_B and $\frac{b}{m} = 273.15$, the difference between Kelvin and Celsius temperatures)

These values are to be verified in this experiment.

Procedure:

- We initially calibrated the pressure gauge to room pressure in order to set it to 1 atm at room temperature and measured room temperature.
- For the first part of the experiment we heated water to a boil and measured the temperature at which point the thermometer read 91° C, the pressure at this point was measured, but the water was left to heat further to ensure it had reached its boiling point.
- For the next part, we used a bucket of water with ice in it. The temperature and pressure were recorded.
- The pressure gauge was removed from the ice water and allowed to cool before checking room pressure again to ensure there was no leakage.
- We added dry ice pieces to the alcohol thermos, to avoid splashing and heavy effervescence the process of adding dry ice cubes to the alcohol had to be carried out slowly. The temperature and pressure were measured and recorded twice during the process and once again finally when the boiling of dry ice reached equilibrium.
- For the last part of the experiment the Temperature and Pressure were recorded for the flask of liquid nitrogen, these values were found to be the lowest so far.

Data & Analysis:

	Liquid Nitrogen	**Alcohol + Dry Ice**	**Ice + Water**	**Room Temperature**	**Boiling Water**
Pressure (atm)	0.27±0.01	0.72±0.01	0.96±0.01	1.00±0.01	1.26±0.01
Temperature (℃)	-196±1	-78±4	-1±1	21±1	92±9

Uncertainty in the fitted slope is:

1.83311127737 ≅ 1.83

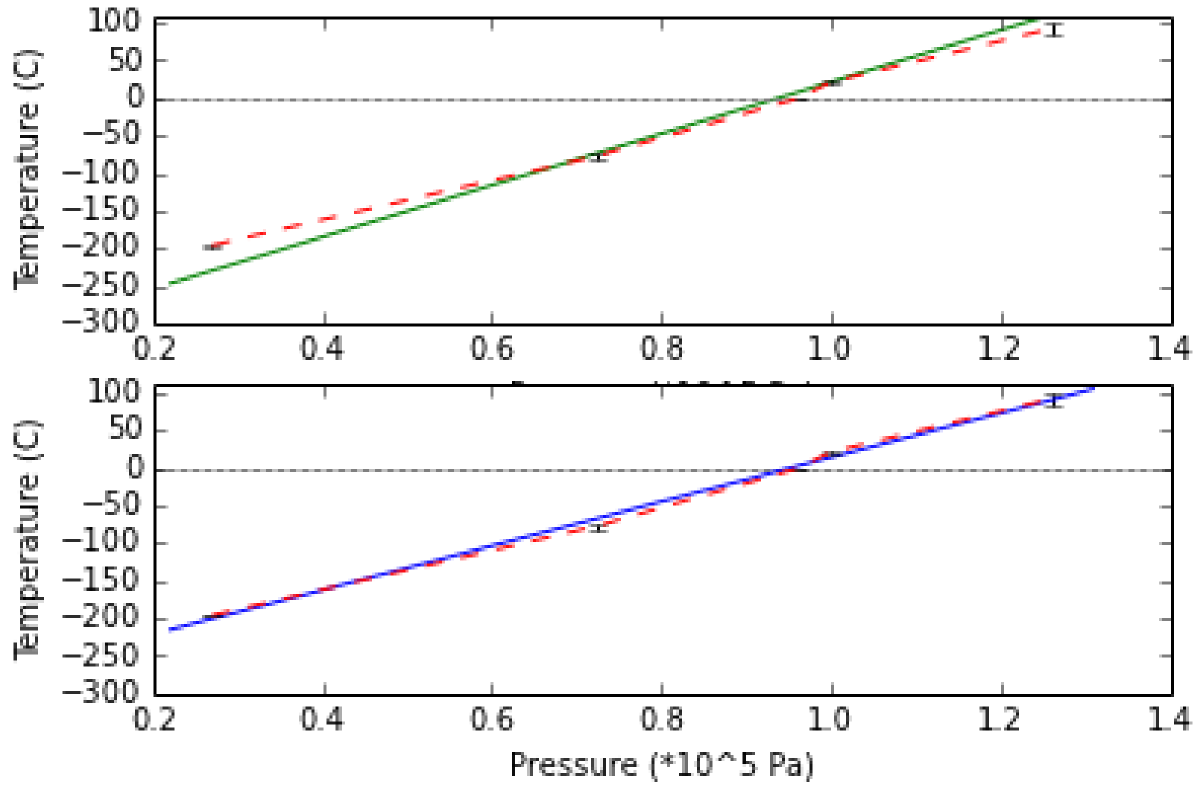
Uncertainty in the fitted y intercept is:

1.51419561737 ≅1.51

The y intercept (-b/m) for LinearFit is -322.42 and the y intercept for Weighted LinearFit is -279.92

The slope for Linear fit was 343.65 and the slope for the weighted fit was 293.86

From the slopes we can see that the 'm' for Linearfit was 0.003 and the 'm' for Weighted fit was 0.003



The data can be fitted to a line, but this is helped by the large changes in temperature values on the graph which make it hard to resolve the inconsistencies visually.

We can see, however, that the line of fit seems to align better with the experimental data values, as well as with the expected theoretical result when the uncertainties in the measurements are taken into account.

The value of (b/m) from this weighted fit is 279.92 which is reasonably close (within 2.4%) to 273.15, our theoretical result.

- Temperature has the dimensions of $\frac{PV}{Nk_B}$
- And m therefore has the dimensions of $\frac{V}{Nk_B}$
- b/m has the dimensions of Temperature so, b must have the dimensions of P

Results

- The data fits a line well within reasonable error.
- The value for absolute zero, in Celsius is 279.92
- The $\frac{N}{V}$ value can be calculated using the fact that $m = \frac{Nk_B}{V}$ which gives us that $\frac{m}{k_B} = \frac{N}{V} = \frac{0.003}{1.38*10^{-23}} = 2.17 * 10^{20}$ molecules.
- Diameter of bulb = 10cm → radius = 5cm = 0.05m
- Volume of bulb = 0.05^3m^3
- Number of moles = $\frac{2.17*10^{20}}{6.022*10\text{^}23} = 0.36 * 10^{-3}$ moles of air
- The density of the air will not remain constant if there is any leakage from the pressure gauge to the outside (which will result in higher experimental pressure values for the low temperature experiments and lower values for the boiling water) In this case, the experimental errors would increase the slope, thereby lowering the y-intercept (as is evident in the experiment)

- A large enough difference in pressure between the inside of the bulb and the outside could cause the bulb to deflate under pressure in which case the volume would decrease and the density of the air would increase. This too would give the same result.
- Given a large enough change in temperature, the metal of the bulb might contract and shrink the bulb causing the density to increase once again resulting in a lower intercept.
- In addition to this, the uncertainties in the measurements of temperature may have been larger than recorded seeing as the thermometer consistently read 92℃ for the boiling water

Original Experiment:

As an experiment to ensure that the behavior of the gases is close enough to ideal throughout the experiment, we submerged the bulb of the pressure gauge in the alcohol-dry ice mixture (the temperature of the alcohol was recorded again) and the pressure gauge was calibrated to read this pressure as 1 atm.

As long as the ideal gas law holds,

$$\frac{P_1}{P_2} = \frac{T_1}{T_2}$$

This means that given a constant volume, i.e. a pressure gauge without leakage, the relative pressures should be equal to the relative absolute temperatures. This experiment verified the ideal behavior of the gas inside the pressure gauge (air) at the temperatures of the room, as well as at the temperatures of liquid Nitrogen and dry ice.

	Pressure	**Temp** $(\pm 1K)$	**T(DryIce)/T**	$\frac{T(DryIce)}{T} * P$	**P(DryIce)**
Dry Ice	1.00	-79°C = 194.15 K	194.15/194.15 = 1.00	1.00*1.00 = 1.00	1.00
Room	1.38	21°C = 294.15K	194.15/294.15 = 0.66	0.66*1.38 = 0.91	1.00
Liquid Nitrogen	0.40	-196°C = 77.15K	194.15/77.15 = 2.52	2.52*0.40 = 1.01	1.00

These measurements are consistent with the ideal gas equation and therefore demonstrate that air can be thought of as an ideal gas with a reasonable degree of accuracy.