Optimization of Charles Gay-Lussac's law experiment with temperature correction at the capillary pipe and fixed volume to improve the accuracy of experimental data in Polban applied physics laboratory

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Abstract. The results of Charles Gay-Lussac's law experimental tools at Politeknik Negeri Bandung (Polban) Applied Physics Laboratory show the pressure value of $1.027 \times 10^5$ Pa with relative uncertainty value of 11.1% and the number of moles in a flask of 12.47 mmole with relative uncertainty value of 24.3%. The experimental data has relatively low accuracy. In this study, Charles's Law experimental tools were optimized by a measured temperature correction on the capillary pipe using the conduction concept. The heat distribution equation that occurs in capillary pipe was solved by numerical solutions using the finite difference method. The modification of Gay-Lussac’s Law experimental tools to get fixed volume was located on the manometer integrated with a glass flask. Data collection techniques were carried out in two different circumstances, namely when the system is experiencing heating and cooling, then compared. After temperature correction, it was obtained that pressure value $0.977 \times 10^5$ Pa with relative uncertainty of 5.7%. After using integrated manometer and data collection techniques when cooling, the number of moles in the flask was 21.5 mmole with relative uncertainty value of 6.2%. With the correction of temperature in the capillary pipe and the volume maintained provides more accurate experimental results.

1. Introduction

There are thermodynamic Charles Gay-Lussac's Law experimental tools available at Polban Applied Physics Laboratory with a complete variation of observational variables including pressure, temperature, number of moles, and volume. The experimental tools consist of two different tool settings, the Charles's Law experimental tool for measuring air pressure and the Gay-Lussac's Law experimental tool for measuring the number of moles in a flask. Physics practicum based learning significantly more integrated [1]. By carrying the dependent and independent variables in this experiment, it can be observed that all macroscopic quantities contained in Charles Gay-Lussac's law equation.

In the writing of Muldiani, the results of the Charles's Law experiment results show a pressure value of $1.027 \times 105$ Pa equal to a relative uncertainty value of 11.1% and the results of the Gay-Lussac's Law experiment results showed the number of moles in the flask was 12.47 mmoles with a value of relative
uncertainty of 24.3% [2]. According to Yulkifli, the measurement of air pressure in theory is by height correction following the equation [3]: \( P = P_0 - 0.116 P_0 h \). The height of the place affects the amount of air pressure at that place. The higher the position of a place above sea level, the smaller the air pressure. The pressure value on Charles’s law experiments is greater than 1 atm. This is not possible if the experiment is carried out at Polban Applied Physics Laboratory which is located on a highland where the air pressure should be measured below 1 atm.

Data from Charles Gay-Lussac's Law experiments at Polban Applied Physics Laboratory have relatively low experimental data accuracy. This is indicated by the relative uncertainty value above 10%. The experimental data has a good precision value but still has a low accuracy value. According to Kerlinger, scientific research also means a systematic, controlled, empirical, and critical investigation of natural phenomena, guided by theories and hypotheses about relationships that are thought to exist between these phenomena. Rationally tested and empirical means that the results of experimental data must be logically accepted by reason that relies on observing the reality of conditions that can be observed directly or based on theoretical references [4].

Based on these conditions, further research is needed as a correction and refinement in the development of thermodynamic experimental tools of Charles Gay-Lussac's Law in order to obtain more accurate and proven truth of experimental data. For this purpose, this study will be optimized in the Charles Gay-Lussac's Law experiment with measured temperature corrections in capillary pipes using the concept of heat transfer and refinement of measurements with a fixed volume.

2. Method

2.1. Charles’s law experiment
Mercury droplets is added into the capillary pipe so that there is air/gas trapped in the capillary pipe. The end of the mouth of the capillary pipe is left open so that the gas trapped in the capillary pipe get a constant chamber pressure. The capillary pipe is inserted into a vessel filled with heated water as shown in figure 1. The increase in gas temperature causes a change in the volume of the gas column marked by an increase in mercury droplets. The purpose of Charles's Law experiment was to determine the room air pressure at the Applied Physics Laboratory.

![Figure 1. Charles's law experimental tools.](image)

The temperature \( T \) of the gas in the capillary pipe cannot be measured directly, so the temperature of the water as a heating medium is assumed to be the same as the temperature of the gas in the capillary pipe. However, this is what causes inaccuracies in the experimental data. For this reason, heat transfer must be considered from the outer surface of the capillary pipe to the inside of the capillary pipe, so that the true temperature value inside the capillary pipe can be determined.

The calculation of heat transfer (conduction) in a capillary pipe meet the following partial differential equation [5]:
\[ \frac{\partial T}{\partial t} = \alpha \frac{\partial^2 T}{\partial x^2} \]  \hspace{1cm} (1)

With \( \alpha = \frac{k}{\rho c} \) is diffusion coefficient \((m^2/s)\), \( k \) is material conductivity \((W/m K)\), \( \rho \) is material density \((kg/m^3)\), \( c \) heat material capacity \((J/kg K)\). To solve equation (1) can be used finite difference method [6]:

\[ \frac{\partial T}{\partial t} = \frac{T^{n+1}_i - T^n_i}{\Delta t} \quad \text{and} \quad \frac{\partial^2 T}{\partial x^2} = \frac{T^n_{i-1} - 2T^n_i + T^n_{i+1}}{\Delta x^2} \]  \hspace{1cm} (2)

To determine the temperature correction by solving the one-dimensional diffusion equation in equation (1) the finite difference method is used, so that equation (1) can be changed to:

\[ T^{n+1}_i = T^n_i + \frac{\alpha \Delta t}{\Delta x^2} (T^n_{i-1} - 2T^n_i + T^n_{i+1}) \]  \hspace{1cm} (3)

Schematic calculation of temperature distribution using finite difference and capillary 1 pipeline model can be seen in figure 2.

Figure 2. Capillary pipe model with finite difference method.

Conduction transfers heat from the outer surface of the capillary pipe to the inside of the gas filled pipe. The first assumption is that the external surface temperature of the capillary pipe \((x = 0 \text{ and } x = d)\) is the same as the water temperature measured on the thermometer and is a boundary condition in the calculation of finite difference.

\[ T(0, t) = T(d, t) = T_{air} (t) \]

The second assumption at \( t = 0 \) the temperature distribution in each section of the capillary pipe is the same as the initial water temperature

\[ T(0, x) = T_{air}(0) \]

The following parameters are used in the calculation of finite difference:

| Table 1. Finite difference calculation parameters. |
|---------------------------------------------------|
| Initial water temperature \( (T_{water} (0)) \) | 22,5°C |
| Pipe diameter \( (d) \) | 8.0 mm |
| Glass width | 3.0 mm |
| Glass coefficient diffusion \( (\alpha_{glass}) \) | \( 3.4 \times 10^{-7} \) m²/s |
| Gas coefficient diffusion \( (\alpha_{gas}) \) | \( 2.1 \times 10^{-5} \) m²/s |
| Step-size \( (\Delta x) \) | 0.1 mm |
| Step-size \( (\Delta t) \) | 1 s |

2.2. Gay Lussac’s law experiment

Flask containing air / gas at a fixed volume, heated by inserting it into a vessel filled with water as shown in figure 3 and then cooled. Changes in gas pressure due to increasing or decreasing temperature of the gas. The purpose of the Gay-Lussac's law experiment is to determine how many moles of gas are in a closed volume.
Modification of the experiment is located on an integrated manometer with a glass flask to determine the number of moles of gas. Data collection techniques and carried out two different conditions, namely when the system is experiencing heating and cooling. Data collection with the two techniques is then compared to find the best results.

3. Result and discussion

3.1. Charles’s law experiment

Charles’s Law experiment was carried out on the outside air pressure \( P_{\text{measured}} = 0.925 \times 10^5 \) Pa, average indoor temperature = 298 K. Capillary pipe dimension as shown in table 2.

| Capillary pipe dimension                  | Size       |
|-----------------------------------------|------------|
| Overall pipe length                     | 0.215 m    |
| Inside diameter                         | 1.95 \times 10^{-3} m |
| \( L_0 \) (length of initial air column) | 5.8 \times 10^{-2} m |
| \( V_0 \) (Volume of initial air column) | 1.73 \times 10^{-3} m³ |
| The number of moles of air in the column \( n = \frac{P_{\text{measured}} V_0}{RT_{\text{room}}} \) | 6.46 \times 10^{-6} moles |

Data from Charles’s law experiments without temperature correction on capillary pipes are plotted on a graph with volume as the y axis and temperature as the x axis, as shown in Figure 4.

\[
\Delta V = 0.0052T + 1.6124
\]

\( R^2 = 0.9974 \)

Data from Charles’s law experiments without temperature correction on capillary pipes are plotted on a graph with volume as the y axis and temperature as the x axis, as shown in Figure 4.
the capillary pipe from position $x = 0$ to $x = d$. Then the temperature at the center of the capillary pipe is taken as the temperature of the $T$ gas in the capillary pipe. Changes in the volume of the gas column as a function of the corrected temperature are then plotted again, as in figure 5b.

Experimental data with temperature correction when approached with the least square method obtained the equation $(0.0055T + 1.6132) \times 10^{-7} \text{ m}^3$, with a gradient of $5.5 \times 10^{-10} \text{ m}^3 / \text{ K}$. From this equation we can calculate outside air pressure (P experiment) is $0.977 \times 10^5 \text{ Pa}$. With a relative uncertainty value of 5.7%.

![Figure 5](image)

**Figure 5.** (a) Temperature distribution finite difference calculation and (b) Graph $V$ vs $T$ Charles’s Law experiment after temperature correction.

Before the temperature correction was carried out on the capillary pipe, $P_{\text{experiment}} = 1,027 \times 10^5 \text{ Pa}$ was obtained with a relative uncertainty of 11.1%. After the temperature correction is obtained $P_{\text{experiment}} = 0.977 \times 10^5 \text{ Pa}$ with a relative uncertainty of 5.7% closer to the measured outside air pressure of $0.925 \times 10^5 \text{ Pa}$. Referring to the reference [2], the air pressure value of $0.977 \times 10^5 \text{ Pa}$ in the Laboratory of Applied Physics of the Polban has accordingly followed the equation: $P = P_0 - 0.116 P_0 h$. That the pressure obtained must be below 1 atm $\approx 1.013 \times 10^5 \text{ Pa}$.

3.2. Gay-Lussac’s Law experiment

The Gay-Lussac's Law experiment was carried out at the outside air pressure $P$ measured $= 0.925 \times 10^5 \text{ Pa}$, average $T$ room temperature $= 296.9 \text{ K}$, and flask air volume $V = 619 \text{ ml}$. In flasks containing air / gas with a fixed volume, such as Figure 3, temperature changes and gas pressure changes are measured. The measurement data is then plotted on the graph of pressure change $\Delta P$ as a function of temperature $T$ as in figure 6.

![Figure 6](image)

**Figure 6.** (a) Graph $\Delta P$ vs $T$ Gay-Lussac’s Law experiment with heating and (b) cooling process.
The two experimental data for the heating and cooling process were approached using the least squares method. For the heating process obtained $\Delta P = (379.01T - 8804.9) \text{ Pa}$, with a gradient $B = 379.01 \text{ Pa/K}$, so we can calculate the number of moles of gas in the flask is 28.2 mmol. The number of moles of gas in the flask if calculated in theory is 23.2 mmol, then for the heating process the relative uncertainty value is 21.6%.

In the same way, for the cooling process obtained $\Delta P = (288.86T - 11001) \text{ Pa}$, with a gradient $B = 288.86 \text{ Pa/K}$, so we can calculate the number of moles $n = 21.5 \text{ mmol}$ with a relative uncertainty value of 6.2%.

Based on the results obtained, using the tool settings as shown in Figure 3, there has been a decrease in the relative uncertainty value. This happens because the volume in the flask has been conditioned to remain [9]. Likewise, the data collection techniques performed when the cooling process gives better results than during the heating process. This is because pressure changes as a function of temperature are more stable during the cooling process, the gas pressure that occurs is not affected by the movement of gas molecules which is relatively faster as occurs during the heating process [10].

4. Conclusion

The value of space pressure is based on the results of Charles's law experiment by considering the heat transfer process in capillary pipes shows better results with a relative uncertainty of 5.7% below 10%. Whereas in the Gay-Lussac's law experiment, the number of moles of gas in the modified flask integrated with the manometer measurement data taken during the cooling process showed better results with a relative uncertainty of 6.2% compared to the heating process.

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