J. Phys.: Theor. Appl. Vol. 2 No.02 (2018) 53-63 doi: 10.20961/jphystheor-appl.v2i2.30666

Optimization of the amount of gas moles determination through Boyle's law and Gay-Lussac's law experiments

Kunlestiowati Hadiningrum, Ratu Fenny Muldani

Politeknik Negeri Bandung

kunlestiowati@polban.ac.id, ratu.fenny@polban.ac.id

Received 16 August 2018, Revised 14 September 2018, Published 30 September 2018

Abstract: Boyle's Law describes the inverse relationship between absolute pressure and air volume, if the temperature is constant in a closed system. Gay Lussac's Law states that the pressure of a gas mass is directly proportional to the absolute temperature of the gas, when the volume is held constant. The macroscopic quantity associated with both laws includes the number of moles of gas. The purpose of the study is to calculate the number of moles of gas through Boyle's Law and Gay Lussac's Law experiments. The experimental results were confirmed by calculating the number of moles theoretically, so that it can be concluded that the experimental device settings which the closest to the theoretical results. The Boyle's Law experimental results with a pipe cross-sectional area of 54.08 mm^2, at a temperature of 295 K obtained 4.67 x 10^{-4} moles, its relative uncertainty is 7.60%, at a temperature of 299.1 K obtained 3.97 x 10- 4 moles, the relative uncertainty value is 0.51%, and at a temperature of 299.5 K obtained 5.20 x 10^{-4} moles, the relative uncertainty value is 12.56%. The average relative uncertainty value of the three experiments is 6.89%. The results of the Gay Lussac's Law experiment, at a gas volume of 0.578 x 10^{-3} m^3, obtained the number of moles in a row of 1.38 x 10^{-2} moles, 1.83 x 10^{-2} moles and 1.33x 10^{-2} moles, theoretical calculation of 2.14 x 10^{-2} moles. The average value of the relative uncertainty of the three experiments is 24.3%. Based on these results, it can be concluded that the results of calculating the number of moles through Boyle's Law experiments are closest to theoretical calculations.

Keyword: Number of moles of gas, Boyle's Law, Gay Lussac's Law

1. Introduction

Gas is one of the three form of substances and it is an inseparable part of chemical studies. The physical properties of an ideal gas depend on the structure of its molecules and the chemical properties of gas also depend on its structure. The behavior of gas as a single molecule is a good example for the dependence of the macroscopic properties in the microscopic structure.

Basically, the gas is divided into two types, an ideal gas and a true gas. The simplest gas and approached the simplest properties of true gas is an ideal gas. The ideal gas complies the common gas equation, while the true gas is not always complied with the equation of an ideal gas. Kinetic theory of gas provides a bridge between microscopic and macroscopic gas [2].

The kinetic theory (or the kinetic theory on gas) explain the macroscopic gas properties, such as pressure, temperature, or volume, with regard to molecular composition and its movement. This theory states that the pressure caused by the collision between molecules that move in different velocity. Kinetic theory is known as a molecular-kinetic theory or theory of the collision or the gas kinetic theory.

The word of kinetic came from the assumption that gas molecules are always moving. In the concept of molecules, there is a need for a unit which is in accordance and can be used to describe the size of the atoms and tiny molecules, a unit of as is explained before is mole, mole represent the total amount of particle (atoms, molecules, and ions) in a substance [1]. Amount of moles of usually used as an easy way to state the amount of a reactant and a product of a chemical reaction, because it is a group of atoms or molecules, that can be used to simplify the equation of a reaction as the information about the amount and the type of substance's mole which takes part in a chemical changes [4].

In order to get the number of moles can be obtained through the ideal gas equation. The kinetic theory of ideal gas applied the Gay Lussac and Boyle's Law, which is explain the relation between macroscopics unit of its various kinds of processes and its formulation. Boyle's Law states that pressure inversely proportional with the volume on a mass with constant temperature. and Gay Lusaac's Law states that the volume of gas is in a closed vessel maintained constant [5], the gas pressure will be proportional with the temperature. The aim of this study is to measure the number of moles using both of the laws. The results then compare with the calculation results, and the value of uncertainty (KSR) will be count.

The laws of an ideal gas which are Boyle's Law, Charles's Law, and Gay Lusaac's Law. Kinetic theory of gas provides a bridge between microscopic and macroscopic gas. The laws of gas like Boyle's Law, Charles's Law, and Gay Lusaac's Law, showing the relation between macroscopic units of various kinds of processes and formulation. The word "kinetic" came from the assumption that gas molecules are always moving [3,6,7]

The general ideal gas equation is:

$$\frac{PV}{T} = nR \qquad (1)$$

P = Pressure
V = Volume
T= Temperature
n = Mole
R= Common Gas Constants (8.314 J/mol K)

1.1. Boyle's Law

The results of experiments conducted by Boyle, states that if temperature of the gas in a closed vessel maintained constant, the gas pressure will be inversely proportional with its volume. Gas in two different state of equilibrium, and at a constant temperature, obtained the following equation:

$$\frac{PV}{T} = nR \; PV = nRT \text{ or } P_1V_1 = P_2V_2 \quad (2)$$

Equation (3) describes the isothermal process, which occurs in a constant temperature, the equation is called Boyle's Law. Figure (1) describes the graphical form of the relationship between pressure and volume of gas at the constant temperature. Figure (1) then called as an isothermal curve.

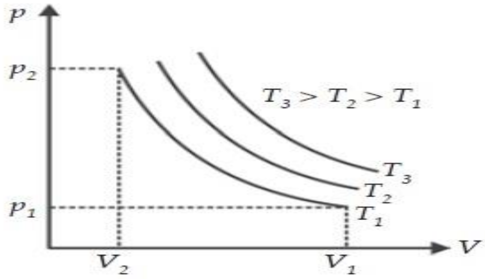

Figure 1. Isothermal Curve

1.2. Gay-Lussac's Law

Gay-Lusaac's Law stated that if the volume of gas in a closed vessel maintained constant, gas pressure will be proportional with its absolute temperature. Gas in two different state of equilibrium, and at a constant volume, obtained the following equation:

$$\frac{P}{T} = \frac{nR}{V} \text{ or } \frac{P_1}{T_1} = \frac{P_2}{T_2} \quad (3)$$

Equation (3) describes the isochoric process, called as a Gay-Lussac's Law. Figure (2) describes the graphical form of the relationship between pressure and volume.

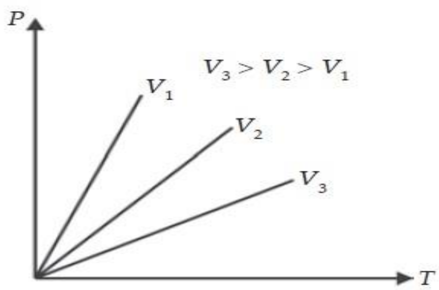

Figure 2. Isochoric Curve

2. Method

The methodology that was used to conduct this research is laboratory experimental that has been conducted in Applied Physics Laboratory in Politeknik Negeri Bandung. The data was measured through the testing and the results will be analyzed to obtain the relationship between investigated variables.

For the Boyle's Law, pressure and volume at the constant temperature will be the measured variables, and the measurement conducted 3 times with 3 different constant temperatures. While for the Gay Lusaac's Law, pressure and temperature at the constant volume will be the measured variables, and the measurement conducted 3 times with 3 different constant volume.

The results then confirmed using theoretical calculation, and it can be concluded from both experiments results, which most closely resembled the theory.

3. Result and Discussion

3.1. Boyle's Law

In Boyle's Law experiment, two cylindrical glass pipes were connected through an elastic tube. These pipes filled with mercury, on the top of left pipes, filled with air (can be closed with a tap of glass), and on the top of the right pipes left fenceless, shown in Figure 3.

Figure 3. Boyle's Law Experimental Tools

In this experiment, pressure and gas volume are the parameters. Figure 3 shows the instrumentation which used to measure Boyle's Law testing data.

For data acquisition, constant temperature has been used, then the length of air column L repeatedly change by changing the height of mercury on the pipes h. Data then used for this equation.

$$h = M\left(\frac{1}{L}\right) - N \tag{4}$$

The value of variable M and N in figure 4 are:

$$M = \frac{C}{\rho g A} \quad \text{and} \quad N = \frac{Bar}{\rho g} \tag{5}$$

With ρ is a density of mercury, g is gravitational acceleration, A is the cross-sectional area of the left pipes, and Bar is the pressure of external air. If the equation 5 get subtituted to equation 4, it will be the ideal gas equation (equation 1)

The positive value of h (pressure increase) and negative value of h (pressure decrease) obtained from observation shown in figure 4.

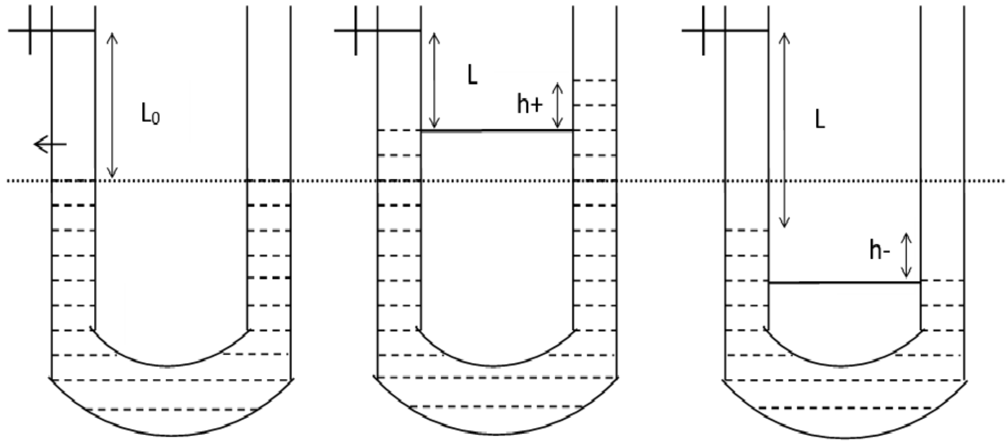

Figure 4. Measure the value of h+ and h-

Equation 4 and 5 has been used to calculate the value of moles by testing method. These are the result of Boyle's Law testing on the constant temperature of 299.5 K

Table 1. Test 1

L (cm)	1/L (1/cm)	h (cm)
20,5	0,0488	3
20,2	0,0495	6
19	0,0526	10,6
17,8	0,0562	14,5
22,9	0,0437	-4,5
24	0,0417	-7,3
25,8	0,0388	-12
27,1	0,0369	-15,5

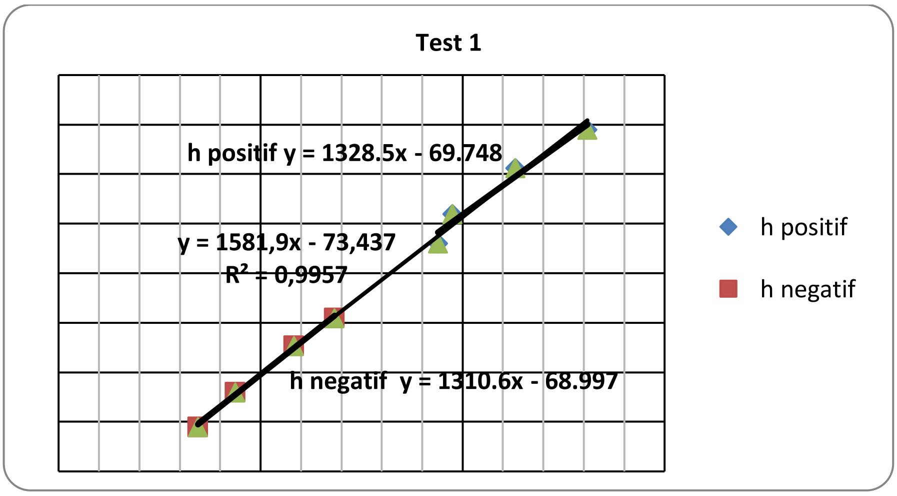

Figure 4. Boyle's Law Test 1 Graph

Using the same methodology, the test 2 conducted in constant temperature of 299.1 K, and test 3 conducted in constant temperature of 295 K. The result of test 2 and test 3 graph shown in figure 6

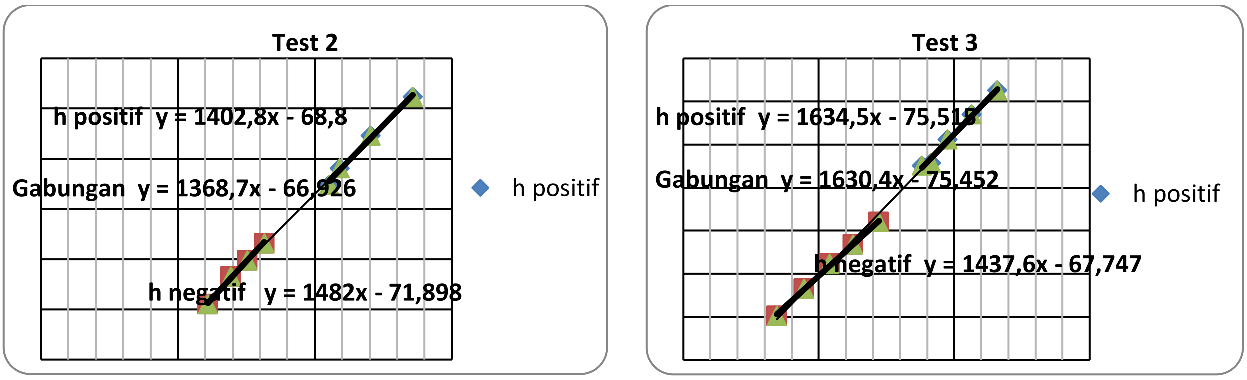

Figure 6. Boyle's Law Test 2 and Test 3 Graph

The result from the three test using the cross-section area of 54.08 mm2 shown in table 4. The relative uncertainty value obtained using equation 6.

$$KSR = \frac{Jumlah\,mol_{teori} - Jumlah\,mol_{pengujian}}{Jumlah\,mol_{teoritis}} \quad (6)$$

The theoritical value of mole (n) obtained using equation $PV = nRT$

P = External air pressure

T = Room temperature

V = Air Volume

R= Gas constants (8,314 J/mole K)

The testing value of mole using equation 3 and 4 shown in detail in table 2

Table 2. Boyle's Law test result

Test	Temperature	Moles	Relative uncertainity(KSR)
1	295 K	4,67 x 10^{-4} moles	7,60 %,
2	299,1 K	3,97 x 10^{-4} moles	0,51 %,
3	299,5 K	5,20 x 10^{-4} moles	6,89%.

3.2. Gay-Lussac's Law

In In the Gay-Lussac test using a heated vessel to vary the temperature of the system, and the pressure that changes every change in temperature with a fixed air volume. Tests are carried out repeatedly three times to obtain optimal results. The tool used for Gay Lussac's Legal Testing as in Figure 5. For three times the test uses data as in table 3.

Table 3. Gay Lussac's Law testing condition

Experiment data	Size
External air pressure (P_{Ukur})	92.500 Pa
Average room temperature (T_{Ruang})	297,6 K
Air volume of flask (V)	0,578 x 10^{-3} m^3

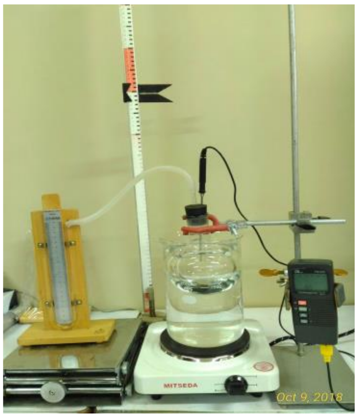

Figure 8. Gay Lusaac's Law Experimental tools

Testing data shown in table 4 below.

Table 4. Variety of pressure on temperature increase (Test 1)

Temperature (^{0}C)	Pressure Difference ΔP (Pa)
24.6	98
24.8	147
25,0	196
25.2	245
25.3	294
25.5	343
25.7	392
25.9	441
26.3	490
26.5	539
26.8	588
27.3	686
27.8	735

Figure 9 shows the test result in graph, y-axis represent the pressure difference, and the x-axis represent the temperature.

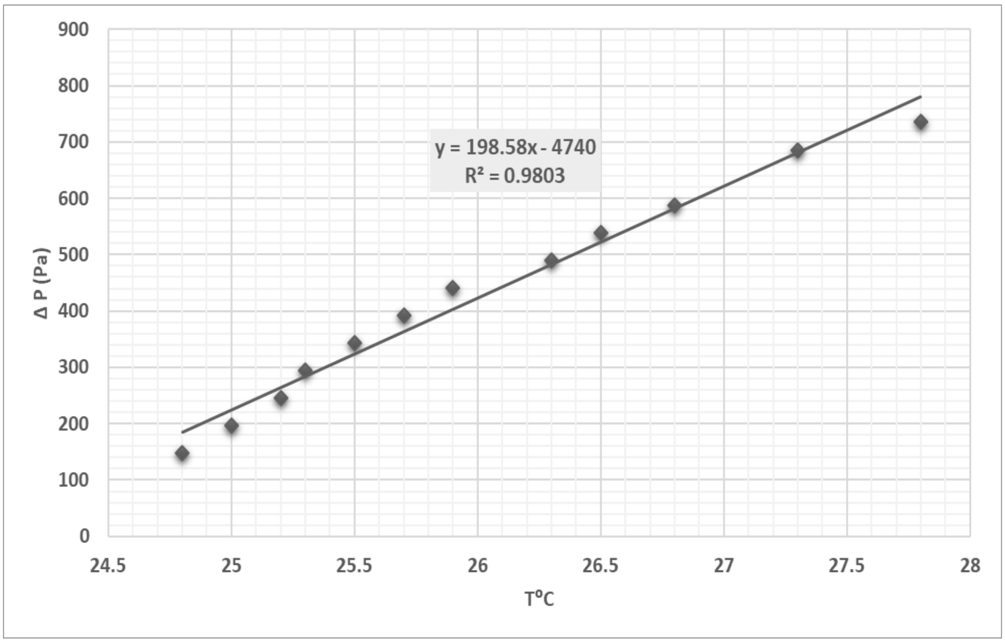

Figure 9. Gay Lusaac Law Test 1 graph resault

In the same way, tests 2 and 3 are carried out, graphs as in Figure 10 and Figure 11.

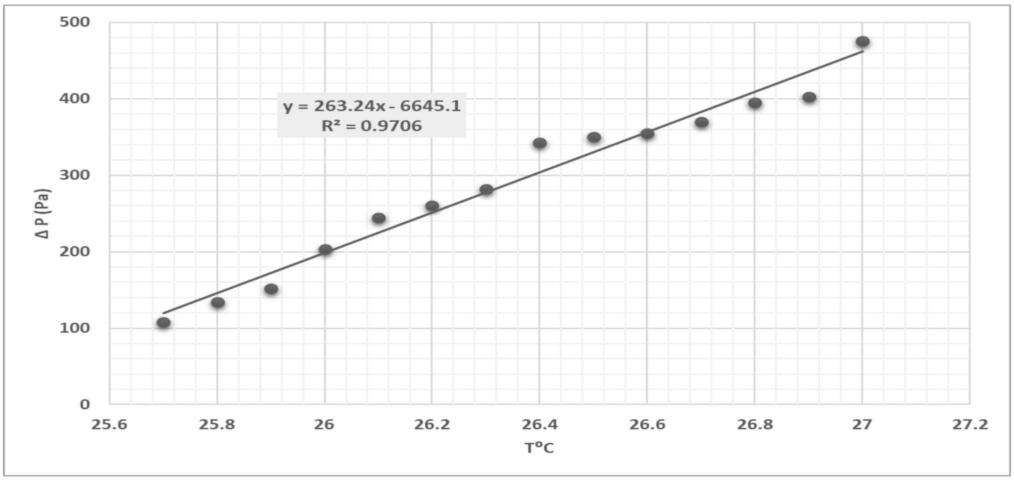

Figure 10. Gay Lusaac's Law test 2 result graph

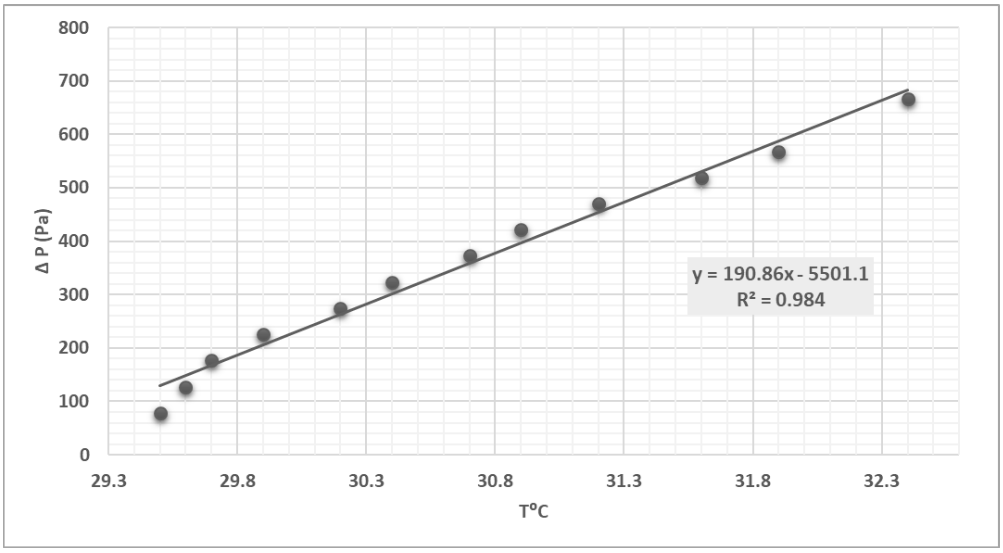

Figure 11. Gay Lusaac's Law test 3 result graph

From the three test above, and using the liniear regression method, then these equation obtained:

1) Test 1

$\Delta P = (198.58\,T - 4740)\ Pa$, with gradient B is 198.58 Pa/K. The amount of air mole n can be calculated using equation.

$$\boldsymbol{n} = \frac{V\,B}{R} = \frac{(0.578 \text{ x } 10^{-3}\text{ m}^3)(\text{ }198.58\text{ Pa/K})}{(8.314472\,\frac{Joule}{mol\ K})} = \mathbf{13.8}\ \boldsymbol{mmol}$$

2) Test 2

$\Delta P = (198.58\,T - 4740)\ Pa$, with gradient B is 263.2 Pa/K. The amount of air mole n can be calculated using equation.

$$n = \frac{VB}{R} = \frac{\left(0.578x10^{-3}m^3\right)\left(263.2Pa/K\right)}{8.314472\frac{J}{molK}} = 18.3\,mmol$$

3) Test 3

$\Delta P = (198.58\,T - 4740)\ Pa$, with gradient B is 198.58 Pa/K. The amount of air mole n can be calculated using equation.

$$\boldsymbol{n} = \frac{V\,B}{R} = \frac{(0.578 \text{ x } 10^{-3}\text{ m}^3)(\text{ }190.86\text{ Pa/K})}{(8.314472\,\frac{Joule}{mol\ K})} = \mathbf{13.3}\ \boldsymbol{mmol}$$

Table 5 shows the calculation result of mole on closed vassel for Gay-Lusaac Law Experiment

Table 5. Gay Lusaac's Law test result

Test	Air moles (moles)	KSR
1	1,38 x 10^{-2}	31%
2	1,83 x 10^{-2}	8,5%
3	1,33x 10^{-2}	33,5%

While, the theoretical calculation of mole's amount using pressure, temperature, and volume data (table 3), using the equation 1 generate the 10^{-2} mole. The calculation result is $\frac{92,500}{297,6} = \frac{n.(8,314)}{0,578x10^{-3}}$, then, n = 2,14 x 10^{-2} mol.

4. Conclusion

The resultse of the Boyle's Law experiment using a 54.08 mm^2 pipe, on 295K obtained 4,67 x 10^{-4} mol, with its relative uncertainty value 7,60 %, on 299.1K obtained 3,97 x 10^{-4} mol and its relative uncertainty value 0.51%, and on 299.5K obtained 5,20 x 10^{-4} mol, with the relative uncertainty value 12,56%. The average value of relative uncertainty on Boyle's Law is 6.89%. The outcome of the Gay Lusaac's Law experiment on 0,578 x 10^{-3} m^3 of gas volume, obtained 1,38 x 10^{-2} mole, 1,83 x 10^{-2} mole and 1,33x 10^{-2} mole, and theoretical calculation result is 2,14 x 10^{-2} mol. The average value of relative uncertainty from three experiment is 24.3%. Based on that result, it can be concluded that the calculation of mole amount using Boyle's Law experiment results is the closest compare to theoretical calculation

5. Suggestion

The resultse of the Boyle's Law experiment using a 54.08 mm^2 pipe, on 295K obtained 4,67 x 10^{-4} mol, with its relative uncertainty value 7,60 %, on 299.1K obtained 3,97 x 10^{-4} mol and its

References

Ahmad, D. (2019, February 2). Pengertian Reaktan dan Produk dalam Reaksi Kimia. Retrieved from https://www.sridianti.com/

Davidzon M.Y. (2018). The First Law of Thermodynamics in Vector Form and Convective Heat Transfer, *American Journal of Physics and Applications. Vol. 6, No. 6*, 2018, pp. 147-153. doi: https://doi.org/10.11648/j.ajpa.20180606.12

Halliday, R, Walker. (2010). Physics, 7th extended edition (terjemahan). Jakarta: Erlangga.

Nofitri. *et al*. (2013). Pembuktian Hukum Boyle pada Gas Ideal Berbantuan Data Studio Software dalam Praktikum Termodinamika Prosiding Simposium Nasional Inovasi dan Pembelajaran Sains 2013 (SNIPS 2013), Bandung, Indonesia.

Shin Y.S. (2019) The Average Energy and Molar Specific Heat at Constant Volume of an Einstein Solid Measured by an Observer with Fluctuating Frame of Reference, *American Journal of Physics and Applications*. *Vol. 7, No. 1*, 2019, pp. 21-26. doi: https://doi.org/10.11648/j.ajpa.20190701.14

Serway, R.A, Jawett, J.W. (2009). Fisika untuk Sains dan Teknik. Jakarta: Salemba Teknika

Tipler, P. A. (2005). Fisika untuk Sains dan Teknik. Jakarta, Indonesia: Erlangga.