

# Determining the Molar Mass of Butane

January 21, 2015  
IB Chemistry HL1

**RESEARCH QUESTION:** "What is the molar mass of butane?"

## ANALYSIS

### Data Collection and Processing

Table 1: Mass of butane lighter before and after gas release

	Mass ( $\pm 0.01$ g)			
	Trial 1	Trial 2	Trial 3	Trial 4
Before	13.70	13.39	14.74	14.39
After	13.40	13.12	14.55	14.16

The uncertainty of the mass measurements is from the instrumental uncertainty of the mass scale.

### Sample Calculations

i. decrease in mass of butane lighter (for trial 1)

$$m_{\text{decrease}} = m_{\text{before}} - m_{\text{after}}$$

$$= 13.70 \text{ g} - 13.40 \text{ g}$$

$$= 0.30 \text{ g}$$

ii. molar mass of butane (for trial 1)

$$PV = nRT$$

$$PV = \frac{m}{M} RT$$

$$M = \frac{RT}{PV} \times m$$

$$M = \frac{(8.31 \frac{\text{J}}{\text{mol} \cdot \text{K}})(297.5 \text{ K})}{(101230 \text{ Pa})(0.00010000 \text{ m}^3)} \times m$$

$$M = \frac{(8.31 \frac{\text{J}}{\text{mol} \cdot \text{K}})(297.5 \text{ K})}{(101230 \text{ Pa})(0.0001 \text{ m}^3)} \times (0.30 \text{ g})$$

$$M = 73.26 \text{ g}$$

$$M = 73 \text{ g/mol}$$

#### Variables used in calculation

- P, barometric pressure (in experiment room):  $101,230 \pm 10$  Pa
- V, volume of (butane) gas:  $0.00010000 \pm 0.00000005 \text{ m}^3$
- R, gas constant:  $8.31 \frac{\text{J}}{\text{mol} \cdot \text{K}}$
- T, temperature of water:  $297.5 \pm 0.5$  K
- n, number of moles (of butane)
- m, mass (of butane gas)
- M, molar mass (of butane)

iii. **uncertainty for molar mass** (for trial 1)

$$\begin{aligned} \text{uncertainty} &= \pm \frac{\max(Mr) - \min(Mr)}{2} \\ &= \pm \frac{\frac{(8.31 \frac{\text{J}}{\text{mol} \cdot \text{K}})(297.5 \text{ K})}{(101230 \text{ Pa})(0.0001 \text{ m}^3)}(0.30 + 0.02 \text{ g}) - \frac{(8.31 \frac{\text{J}}{\text{mol} \cdot \text{K}})(297.5 \text{ K})}{(101230 \text{ Pa})(0.0001 \text{ m}^3)}(0.30 - 0.02 \text{ g})}{2} \\ &= \pm 4.88 \text{ g/mol} \\ &= \pm 5 \text{ g/mol} \end{aligned}$$

iv. **uncertainty for average molar mass** (among all trials)

$$\begin{aligned} \text{procedural uncertainty} = \text{uncertainty} &= \pm \frac{\max(Mr) - \min(Mr)}{2} \\ &= \pm \frac{(73 + 5 \text{ g/mol}) - (46 - 5 \text{ g/mol})}{2} \\ &= \pm 18.5 \text{ g/mol} \\ &= \pm 20 \text{ g/mol} \end{aligned}$$

**Table 2: Decrease in mass of butane lighter due to gas release and molar mass of butane**

	Trial 1	Trial 2	Trial 3	Trial 4	Average (± 20 g/mol)
Decrease in Mass (± 0.02 g)	0.30	0.27	0.19	0.23	
Molar Mass (± 5 g/mol)	73	66	46	56	60

The uncertainty of the decrease in mass values is twice the uncertainty of the mass values. The uncertainty in molar mass is from the largest uncertainty in molar mass due to uncertainty in mass decrease among all trials (from trial 1). The uncertainty in average molar mass is the procedural uncertainty in molar mass among all trials.

A.10

Sample Calculations

v. **percent uncertainty in average molar mass**

$$\% \text{ uncertainty} = \frac{\text{uncertainty in experimental value}}{\text{actual experimental value}} \times 100\%$$

$$\% \text{ uncertainty} = \frac{20 \text{ g/mol}}{60 \text{ g/mol}} \times 100\%$$

$$\% \text{ uncertainty} = 33.3\%$$

vi. **percent error in average molar mass**

$$\% \text{ error} = \left| \frac{\text{theoretical value} - \text{experimental value}}{\text{theoretical value}} \right| \times 100\%$$

$$\% \text{ error} = \left| \frac{58.14 \text{ g/mol} - 60 \text{ g/mol}}{58.14 \text{ g/mol}} \right| \times 100\%$$

$$\% \text{ error} = 3.20\%$$

The theoretical value was determined by using the formula for butane, C<sub>4</sub>H<sub>10</sub>, and the periodic table to calculate the molar mass of butane.

Well organized calculations section

## EVALUATION

### Conclusion

The results of this experiment indicate that the molar mass of butane is:

$$60 \pm 20 \text{ g/mol}$$

The percent uncertainty value for the average molar mass, 33.3%, is very large, indicating extremely low precision in the data and thus the presence of major random errors. However, the percent error in average molar mass, 3.20%, is small, indicating high accuracy and thus the presence of **only** minor systematic errors. Overall, therefore, there is **medium** confidence in the determined molar mass.

Since the molar mass of an element remains the same regardless of its state, the determined molar mass of butane is applicable not only to butane gas, but also to butane in other forms, such as liquid butane.

### Evaluation

An important limitation of the investigation is the assumption that 100% of the liquid contained in the "butane lighter" is butane,  $C_4H_{10}$ . However, it is most likely that the company that manufactured the lighters added proportions of other elements into the lighter liquid as well, for reasons such as to increase effectiveness and safety and to save costs. Therefore, the 100 mL of gas released from the butane lighter into the graduated cylinder was not composed of 100% butane, but included other gases as well. As different elements and compounds have different molar masses, when the mass of the lighter was measured after each trial, the decrease in mass will be different from the mass of 100 mL of pure butane gas (under constant pressure and temperature, as indicated in the Data Collection and Processing section). If those other compounds included in the lighter liquid have an overall higher molar mass than butane, then the decrease in mass of the lighter would be greater than if the liquid were composed entirely of butane, and the experimental value for the molar mass of butane would be greater than its actual value; if those other compounds included in the lighter liquid have an overall lower molar mass than butane, then the decrease in mass of the lighter would be less than if the liquid were composed entirely of butane, and the experimental value for the molar mass of butane would be less than its actual value. Since the experimentally determined molar mass,  $60 \pm 20 \text{ g/mol}$ , is higher than the accepted molar mass of butane,  $58.14 \text{ g/mol}$ , it is most likely that the other gases contained in the lighter liquid have higher molar masses than butane and this systematic error increased the experimental molar mass of butane. However, this direction of the systematic error is not certain, as the precision in the experimental molar mass value is very low. To eliminate this limitation, a gas can that specifically indicates that it contains 100% butane should be used instead of a normal lighter.

Another **limitation in the design of the experiment is the use of the ideal gas equation,  $PV = nRT$ , to calculate the molar mass of butane**.

The use of this equation assumes that the volume of the gas particles is negligible, and that there are no attractive forces between particles. Thus, the equation is accurate when the gas has very low pressure and very high temperature. Because the pressure and temperature of the 100 mL of butane gas in this experiment was approximately room conditions, or  $101,230 \pm 10 \text{ Pa}$  and  $297.5 \pm 0.5 \text{ K}$ , respectively, the behavior of the butane gas particles **deviated considerably from the ideal gas conditions**, and making the experimental value for the molar mass of butane less accurate. To reduce this limitation, experiment conditions must be changed to follow the ideal gas conditions more closely. This can be done in two steps. First, a heating machine should be placed around the graduated cylinder to increase the temperature of the butane gas particles. Second, after 100 mL of gas are collected in the 100 mL graduated cylinder, the gas should be transferred to a larger graduated cylinder (for example, a 2 L graduated cylinder) that is initially in vacuum (holds no gases) to decrease the pressure of the butane gas particles (the pressure is considerably high before this due to the room conditions and the heating of the graduated cylinder).

Consequently, when the pressure and temperature of the butane gas has been adjusted as explained, the pressure and temperature must be measured inside the new graduated cylinder, instead of in the experiment room outside of the graduated cylinder, as the pressure and temperature of the butane gas is now different from those in other areas of the experiment room. **When experiment conditions are closer to ideal gas conditions, the calculated molar mass using the ideal gas equation will be more accurate.**

A problem in the procedure of the experiment is that the calculated change in mass of butane in the lighter for certain trials may actually be the change in mass of butane and water in the lighter. Before each mass measurement, the lighter was submerged in water and then dried off. This is to ensure that the same (controlled) amount of water was collected within the various vents and air channels of the lighter for all the mass measurements, so that the difference in masses in each trial would be the difference in mass of butane in the lighter only, and not include the difference in mass of the water collected in the lighter. However, in this experiment, the degree in which the lighter was dried off after each submersion in water varied. For example, the degree in which the lighter was shaken varied. This results in a random error because the amount of water that is trapped in and thus considered as part of the lighter and butane varied inconsistently across the trials. This resulted in large variation in the calculated decreases in mass

Eval. 5  
Eval. 23

No you know this?

Eval. 24

How do you know this?

Good discussion - but what about using van der Waals equation?

be solved by deciding upon a single, consistent, method of drying the lighter after each submersion in water, such as to not shake the lighter at all, and simply use a new tissue to wipe the water on the outside surface of the lighter after all submersions.

A weakness in the procedure of the experiment was the butane gas escaping from the system of the lighter and graduated cylinder. During certain periods of time, the lighter moved slightly out from being directly under the graduated cylinder (but still remaining in the water) and instead released gas upward into the air outside of the graduated cylinder. This means that during these time intervals, the butane gas released from the lighter was not collected in the graduated cylinder and therefore not recorded as being released. For trials that this happens, the decrease in mass of the butane in the lighter after gas release will be relatively greater than it would be if 100 mL of butane gas were released, resulting in exaggerated values for the decrease in mass of the lighter. This leads to a systematic error, where the experimental value for the molar mass is greater than the actual molar mass of butane in all trials in which gas escaped from the system of the lighter and graduated cylinder. On the other hand, this is also a random error, since in different trials inconsistent amounts of gas escaped from the system. To solve this problem, special care must be taken to ensure that the lighter is directly beneath the graduated cylinder at all times, and that no visible (butane) gas bubbles escape from the lighter and graduated cylinder into the air within the room. Trials in which any gas escapes from the system must be eliminated and redone.

Gas discussion

### Further Research

This experiment can be extended to determine the molar mass of other gases, such as oxygen ( $O_2$ ) and carbon dioxide ( $CO_2$ ), both of which are highly important gases in the atmosphere.

What about finding an unknown MM of gas?