A Study On How Gas Volumes Differ When Measured At Standard Temperature and Pressure (STP)

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Block D - Topic 8

Introduction

The researchers experimented with small samples of gases to determine their molar volumes. Three gases were used during experimentation, air, argon (Ar), and carbon dioxide (CO_2). The researchers attempted to conduct the experiment in conditions where the gases were most ideal. In order for a gas to be ideal it must agree with the five main postulates from the kinetic theory of gases.

The first postulate is that gas particles have no definite volume, but do have a defined mass (Sevini & Cooley, 2023). There are no gases that completely agree with this statement because all gas particles have some volume. This means that there are no perfectly ideal gases. Even though there are no gas particles without a defined volume, some gas particles have a very small volume; making them the most ideal. The volume of a particle is directly proportional to its atomic radius, which means that the most ideal gases will be made of particles with the smallest atomic radii. Noble gases have the smallest atomic radii which would make them the most ideal.

The second postulate in the kinetic theory of gases is that gas particles have no potential energy. This means that the total energy is equal to the sum of the kinetic energies (Sevini & Cooley, 2023). Just like the first statement, this is almost never true. There will always be repulsive and attractive forces between particles. However, in most cases, these forces are negligible and can be ignored.

The third and fourth postulates are that gas particles are in continuous random motion and that collisions between particles are perfectly elastic (Sevini & Cooley, 2023). When at high temperatures and low pressures, gas particles more closely agree with the third postulate. However, these conditions result in many collisions between gas particles. These collisions will cause a small loss of kinetic energy. This loss shows that the collisions are not perfectly elastic; meaning that the gas is not perfectly ideal. The fifth and final postulate says that at a given temperature, the average kinetic energy of all gases will be the same (Sevini & Cooley, 2023). This statement has a negligible effect on the researcher's experiment.

The researchers have hypothesised that the molar volume of all three gases is 22.4L/mol. The experimentation will be done at standard temperature and pressure(STP). This will make the gases very ideal; allowing the researchers to use the ideal gas law ($PV = nRT$). This law states that the pressure in atmospheres, multiplied by the volume of the gas in litres, is equal to the amount of gas in moles, multiplied by the temperature in kelvin, multiplied by the ideal gas constant($0.08205\frac{Latm}{molK}$). The researchers solved the equation for volume by using the conditions at STP and one mol of gas. The researchers calculated that for one mol of gas at STP, the gas would have a volume of 22.4L.

Materials

- 2 Towels
- 1 Eudiometer
- 1 Gas Canister
- 0.5m Clear Tubing
- 1 roll of Masking Tape
- 1 WD40 Straw
- 1g Argon
- 1g Air
- 1g CO_2
- 1 Scale (0.0001g)
- 1 Thermometer
- 1 400 mL Beaker
- 5L Liquid Water
- 3L Ice

Procedure

1. Completely fill a 400mL beaker with water and ice

2. Place the beaker onto a small stack of towels to absorb any spilt water
3. Use a thermometer to measure the temperature of the water until it reaches 0℃
4. Completely fill the eudiometer with water and feed in the plastic tubing until 10cm of the tubing is left outside the eudiometer
5. Firmly press on the open end of the eudiometer so as to cover it and flip it upside down into the beaker with water
6. If any air was let into the eudiometer during step 5, repeat steps 4-5 until no air is let into the eudiometer
7. Ensure nothing is on the scale, close the doors, and zero the scale by pressing the labelled button
8. Fill a gas canister with Argon gas and record the mass using the scale
9. Place the WD40 straw halfway into the plastic tubing and seal with masking tape
10. Connect the gas canister to the WD40 straw using the cap on the gas canister
11. Slowly begin spraying the Argon gas into the canister until the water level in the eudiometer is level with the water level in the beaker
12. Record the water level in the eudiometer
13. Disconnect the gas canister from the WD40 straw and record the mass using the scale
14. Repeat steps 1-13 nine more times until ten trials have been recorded with Argon
15. Repeat all steps using CO2 then repeat again using Air

Data Analysis

During the experiment, the researchers collected several different types of data. The first two pieces of data collected were the initial and final canister mass. The initial mass was measured directly after filling the canister with gas. The final mass was measured directly after the gas was sprayed into the eudiometer. The mass was measured in grams using a scale that was precise to 0.0001g. This extreme precision was required because the researchers only used a small amount of gas in each trial. The researchers also measured the volume of the gas used in each trial. The gas volume was measured directly after measuring the final canister mass. The volume was measured in mL using a eudiometer that was precise to 0.1 mL. While the researchers did not measure temperature, they did ensure that the water had reached 273.15K before starting each trial. Each datum was collected ten times for each of the three gases that the researchers used.

After collecting all the data, the researchers calculated the molar volume of each gas. To do this, the researchers started by finding the mass of the gas used. This was done by subtracting the final canister mass from the initial canister mass. The next step was to convert the mass of each gas into the number of moles of the gas. This was done by dividing the mass in grams, by the molar mass in grams per mole. After this, the researchers converted the volume from mL to litres. To do this, the volume in mL was divided by one thousand. The final calculation was to find the molar volume. This was done by dividing the volume in litres by the amount of the gas in moles.

Example Calculation:

Initial Canister Mass = 200. 2116g

Final Canister Mass = 200.1253g

Gas volume = 48.2 mL

1. Initial Canister Mass - Final Canister Mass →200.2116g - 200.1253g = 0.08630000g
2. Mass/Molar Mass →0.08630000g / 39.948g/mol = 0.0021603 mols
3. Volume (mL)/1000 = Volume (L) →48.2/1000 = 0.0482L
4. Volume (L)/amount of gas (moles) →0.0482/0.0021603 = 22.3L/mol

Figures 1-3 display the experimental molar volume for each gas. These graphs also include a line of average and an expected value line. All three graphs show that the average experimental molar volume was higher than the expected value of 22.4 L/mol. The researchers calculated that carbon dioxide had the lowest error of 10.27%. The next lowest error was compressed air, having an error of 12.50%. Argon had the highest error with an error of 12.95%.

Problems Encountered

The researchers encountered several problems and obstacles during experimentation. The first major obstacle encountered was a flawed experimental process. Instead of pumping gas into the eudiometer until it reached the same water level as the beaker, the researchers pumped an arbitrary amount. This gave flawed results which were five to ten times smaller than the predicted results. At this point, twenty trials had already been completed. However, by restarting, the researchers were able to make the experiment more accurate in a variety of ways. The researchers put a cap on the canister to prevent any leakage. The cap was only removed when filling the canister with gas. Next, the researchers paid close attention to the temperature and waited until the temperature was 0℃ before starting the experiment. The researchers also used a stronger tape to connect the WD40 straw to the tubing. This prevented any gas from leaking out of the tube, as this was an issue before the experiment was redesigned. Finally, the researchers were able to improve their process of placing the eudiometer in the beaker. Often air would leak into the eudiometer when the researchers flipped it into the water beaker. Instead of ignoring this and proceeding with the experiment, the researchers reset the experiment such that there were no air bubbles in the eudiometer. This maximised the accuracy of the eudiometer reading.

However, there were some issues that the researchers were unable to fix. The first problem encountered involved the scale the researchers used. The scale was able to measure down to 0.0001 grams, making it very precise. However, it continuously fluctuated between numbers making it difficult to get an accurate measurement. Another problem that the researchers encountered was reading the eudiometer. The researchers failed to determine a standard of where along the water curve the true water level was. This led to discrepancies of about 0.0001 litres which had a minor, but slightly evident effect. Finally, the pressure was not always at 1 atm and sometimes was slightly higher or lower. This had minimal effects.

Overall, the researchers were able to complete all thirty trials (ten trials per gas) with time to spare. These trials were generally accurate, with percent errors as low as 0.45%, and an average percent error of 11.85%.

Discussions

The results show that not all gases have a molar volume of 22.4 L/mol at standard temperature and pressure (STP) which contradicts the hypothesis. Despite being precise, the data was not fully accurate. The average measurement was about 25 L/mol. It is unlikely that the researchers operating at slightly higher pressure and temperature than STP would affect the results to such a significant extent. It is also very unlikely that this error was due to gas leakage. This is because any gas leakage would cause the experimental molar volume to be lower than expected, but the researchers were seeing molar volumes higher than expected. This means that the error most likely came from the fluctuating scale and temperatures higher than 0℃. This would make sense because a higher temperature would also result in a higher molar volume.

These findings are inconsistent with the results of other researchers. Researchers in all other blocks found the molar volume to be lower than the expected 22.4L/mol. The lower results are likely due to gas leakage during the experimental process.

In the future, the researchers hope to experiment with several other gases to collect more data. The researchers would also like to use a more accurate scale and a more precise eudiometer to increase the accuracy of the experiment. If the researchers were to conduct this experiment again, it would be done in a place where the pressure can be regulated. This would allow the gas to be at perfect STP conditions when experimenting; hopefully yielding results closer to the researcher's hypothesis.

Appendices

KEY:

Blue dots - Experimental Values

Orange line - Experimental Average

Turquoise line - Expected Value

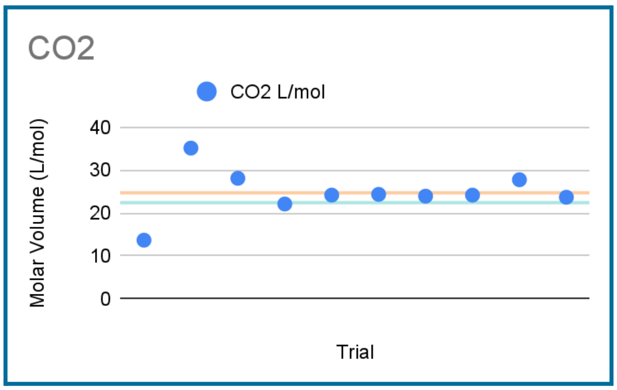

Figure 1. Carbon Dioxide Molar Volume

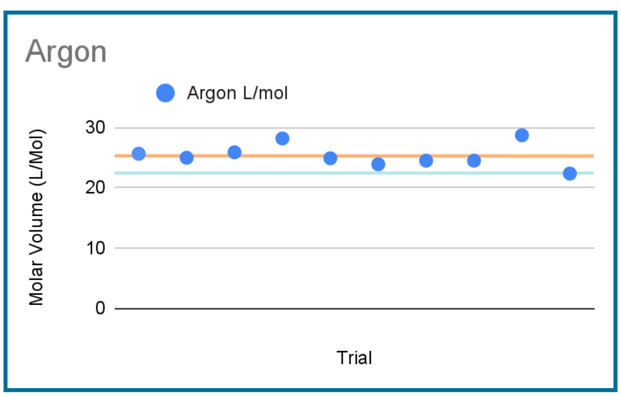

Figure 2. Argon Molar Volume

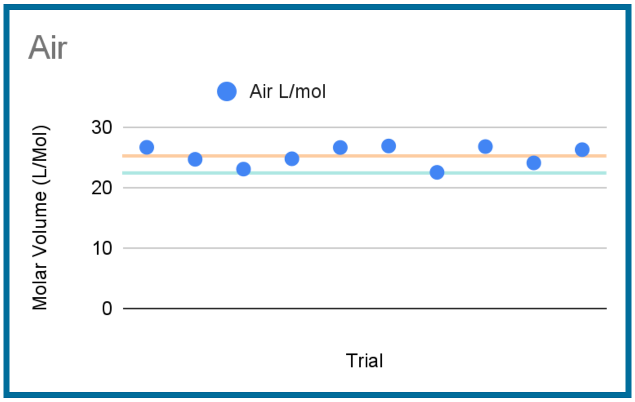

Figure 3. Air Molar Volume

CO_2 Trial	Init. Canister mass (g)	Final canister mass (g)	Mass (g)	Gas volume (mL)	Moles of gas (mol)	Molar Volume (L/mol)
1	202.5738	202.4086	0.1652	51.2	0.003754	13.6
2	202.1101	202.0498	0.0603	48.1	0.001370	35.1
3	201.0808	201.0071	0.0737	47.0	0.001675	28.1
4	201.7319	201.6392	0.0927	46.5	0.002106	22.1
5	202.3156	202.2274	0.0882	48.4	0.002004	24.2
6	203.8705	203.7809	0.0896	49.5	0.002036	24.3
7	203.7808	203.6854	0.0954	51.8	0.002168	23.9
8	203.6861	203.5942	0.0919	50.4	0.002088	24.1
9	203.5696	203.4901	0.0795	50.1	0.001806	27.7
10	203.4144	203.3258	0.0886	47.6	0.002013	23.6

Figure 4. Carbon Dioxide Experimental Data

Argon Trial	Init. Canister mass (g)	Final canister mass (g)	Mass (g)	Gas volume (mL)	Moles of gas (mol)	Molar Volume (L/mol)

1	200.9615	200.8853	0.0762	48.8	0.0019075	25.6
2	200.8857	200.8087	0.0770	48.1	0.0019275	24.9
3	200.8095	200.7337	0.0758	49.0	0.0018975	25.8
4	200.7332	200.6625	0.0707	49.8	0.0017698	28.1
5	200.6609	200.5834	0.0775	48.2	0.0019400	24.9
6	200.5835	200.5081	0.0754	45.0	0.0018875	23.9
7	200.5061	200.4252	0.0809	49.5	0.0020251	24.5
8	200.4069	200.3299	0.0770	47.1	0.0019275	24.5
9	200.2763	200.2107	0.0656	47.1	0.0016421	28.7
10	200.2116	200.1253	0.0863	48.2	0.0021603	22.3

Figure 5. Argon Experimental Data

Compressed Air Trial	Initial canister mass (g)	final canister mass (g)	Mass (g)	Gas Volume (mL)	Moles of gas (mols)	Molar volume (L/mol)
1	200.0336	199.9794	0.0542	0.04986	0.0018715	26.6
2	199.9778	199.9227	0.0551	0.04691	0.0019026	24.7
3	199.9199	199.8608	0.0591	0.04700	0.0020407	23.0
4	199.8715	199.8153	0.0562	0.04802	0.0019406	24.7
5	199.8174	199.7622	0.0552	0.05072	0.0019061	26.6
6	199.7591	199.7068	0.0523	0.04851	0.0018059	26.9
7	199.7025	199.6400	0.0625	0.04855	0.0021581	22.5
8	199.4891	199.4362	0.0529	0.04889	0.0018267	26.8
9	199.3603	199.3007	0.0596	0.04951	0.0020580	24.1
10	199.2987	199.2451	0.0536	0.04859	0.0018508	26.3

Figure 6. Compressed Air Experimental Values

Halpern, J. (Ed.). (2021, August 24). *Chapter 10.7: The kinetic theory of gases*. Chemistry LibreTexts. https://chem.libretexts.org/Courses/Howard_University/General_Chemistry%3A_An_Atoms_First_Approach/Unit_4%3A__Thermochemistry/Chapter_10%3A_Gases/Chapter_10.7%3A_The_Kieory_of_Gases#:~:text=to%20remain%20unchanged.-,Pressure%20of%20Gas%20Mixtures,repulsive%20forces%20on%20one%20another. netic_Th

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