Wash Bottle Laboratory Exercises: Mass of $NaHCO_3$ in an Alka-Seltzer Tablet, Molar Mass of CO_2, and the Ideal Gas Law Constant

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The determination of the ideal gas constant can be performed with one of three methods: (i) A water displacement setup is used to determine the volume of a gas produced by a reaction at atmospheric pressure *(1)*. (ii) The pressure increase in a gas-producing reaction is measured at constant volume *(2, 3)*. (iii) A known mass of a volatile liquid is injected into an evacuated flask maintained at a temperature above the boiling point of the volatile liquid and the pressure is measured *(4)*. In each of these methods, the procedure is such that the pressure, volume, temperature, and amount of gas are measured or determined. The ideal gas constant, R, is calculated according to the formula

$$R = \frac{PV}{nT} \tag{1}$$

where P is the pressure, V is the volume, T is the temperature, and n is the amount of gas.

The determination of the molar mass, M, of a volatile liquid is a common general chemistry laboratory experiment. The determination is based on the measurement of the density of the vapor (the Dumas method). The equation is

$$M = \frac{dRT}{P} \tag{2}$$

where d is the density of the volatilized liquid, R is the gas constant, P is the pressure, and T is the temperature. The most common approach is based on total vaporization of a volatile solvent in a flask with a pinhole, condensing the vapor and performing weighing operations that provide the mass of the condensed liquid *(1)*. A less common approach is based on the injection of known mass of a volatile liquid into an evacuated flask maintained at a temperature higher than the boiling point of the volatile liquid *(4)*.

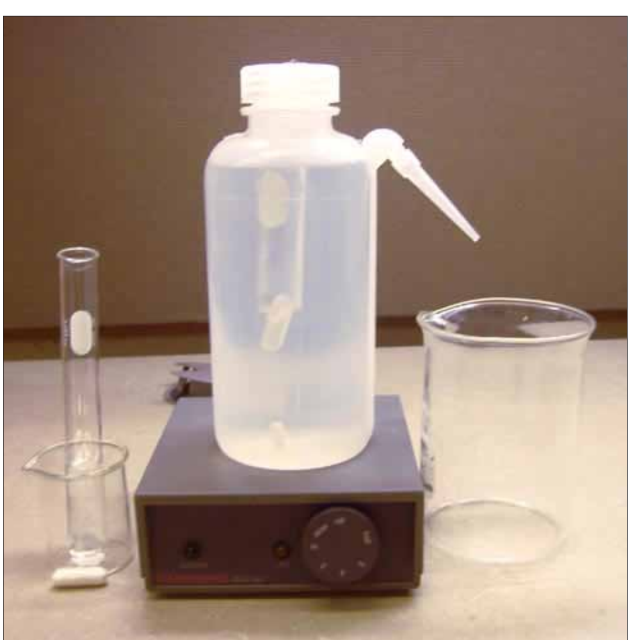

Figure 1. Wash bottle water displacement setup.

We report a wash bottle water displacement setup in which the density of CO_2, the molar mass of CO_2, and the ideal gas law constant are determined from a single experiment (Figure 1). We use a sample from a powdered Alka-Seltzer tablet to generate CO_2(g) and, in so doing, the mass of $NaHCO_3$ in the Alka-Seltzer tablet is also determined. The determination of the mass of $NaHCO_3$ in Alka-Seltzer tablets via the generation of CO_2(g) has been reported *(5)*. Our procedure uses a gelatin capsule, a test tube, a wash bottle, and 4 M HCl(aq). The gelatin capsule holds a powdered Alka-Seltzer sample and this is placed in a test tube with 4 M HCl(aq). The gelatin capsule takes 5–7 minutes to dissolve in 4 M HCl(aq). This is sufficient time to perform weighing operations, place the test tube in the water-filled wash bottle, and close the lid prior to any reaction. The CO_2(g) generated displaces water from the wash bottle. After the reaction is completed, the lid is opened slightly and a temperature measurement device is lowered into the CO_2(g) in the wash bottle and the temperature is measured. The outside of the reaction test tube is dried and the test tube is weighed. The difference in mass is equal to the mass of carbon dioxide produced and the volume of the CO_2(g) is equal to the water displaced from the wash bottle. In addition to these measurements, the atmospheric pressure is measured.

We are not the first to suggest a wash bottle water displacement procedure. A water displacement procedure has been used to determine the kinetics of hydrogen peroxide decomposition reaction *(6)*.

Calculations

The mass of $NaHCO_3$ in the tablet is calculated from the mass of CO_2(g). The reaction is

$$NaHCO_3(aq) + HCl(aq) \rightarrow CO_2(g) + NaCl(aq) + H_2O(l)$$

As it is a weak acid, the citric acid component of the Alka-Seltzer tablet does not react with $NaHCO_3$ in the presence of excess HCl(aq). The mass of $NaHCO_3$ that generated the CO_2 is calculated and thereafter, the percent $NaHCO_3$ in the sample and the mass of $NaHCO_3$ in a whole tablet are calculated.

The density of the CO_2(g) is determined from the mass of the CO_2 and the volume of the water displaced from the wash bottle and with this the molar mass is calculated according to eq 2. The ideal gas constant is calculated according to eq 1.

Experimental

Materials and Equipment

Wash bottles (500 mL with spout on the side, 3 per pair of students), 0.9 mL gelatin capsules (Parr Instrument Co.), Alka-Seltzer tablets (powdered and whole tablets), 6 in. test tubes, 4 M HCl(aq), milligram mass balance, temperature measurement device, room pressure measurement device, stir bars, and stirrers.

Procedure

Vacuum grease is applied to the mouth of a 500 mL wash bottle and the wash bottle is filled with tap water to the fill line on the bottle. An empty gelatin capsule is weighed, loaded with the powdered Alka-Seltzer sample, and reweighed. A small stir bar is added to a 6 in. test tube and 7–10 mL 4 M HCl is added. The gelatin capsule is added to the test tube and the test tube is weighed. (The filled test tube is referred to as the reaction system.) The test tube is placed upright in the wash bottle[1] and the lid is secured. A beaker is placed to catch the water displaced from the wash bottle. After the reaction appears to be complete (no more water washing out), the wash bottle is placed on a stirrer and the test tube contents stirred to flush out remaining CO_2(g). The wash bottle is opened just enough to allow measurement of the temperature of CO_2(g). Thereafter, the test tube is removed from the wash bottle, the outside of the test tube is dried, and the test tube and contents are weighed. The volume of the water displaced from the wash bottle, which is also the volume of CO_2(g) generated, is measured using a graduated cylinder. The room atmospheric pressure is also measured.

Hazards

Hydrochloric acid is corrosive. Contact can cause severe burns to skin and eyes.

Results and Discussion

The data and results reported by a student are shown in Table 1. The students are required to perform the experiment a minimum of 5 times. Based on the results in Table 1, the 95% confidence intervals of the mean ($N = 5$) are

Mass $NaHCO_3$ in tablet: 1.9 ± 0.1 g

Molar Mass of CO_2: 44.4 ± 0.7 g/mol

Gas Constant R: 0.082 ± 0.001 L atm/(K mol)

Table 1. Data and Results as Reported by a Student

Quantity	Experimental Data				
Mass of empty gelatin capsule/g	0.113	0.123	0.113	0.114	0.123
Mass of whole Alka-Seltzer tablet/g	3.272	3.231	3.272	3.283	3.231
Mass of capsule + Alka-Seltzer sample/g	1.015	0.971	0.902	1.089	0.94
Reaction system mass before reaction/g	26.042	25.72	26.042	25.708	25.719
Reaction system mass after reaction/g	25.783	25.479	25.783	25.428	25.467
Temperature of CO_2(g)/°C	20.6	21.6	20.7	20.6	20.6
Room pressure/kPa	99.0	98.5	99.0	99.0	98.5
Volume of CO_2(g)/mL	144	135	143	154	139
	Calculated Data				
Mass of Alka-Seltzer in capsule/g	0.902	0.848	0.789	0.975	0.817
Mass of CO_2(g)/g	0.259	0.241	0.259	0.28	0.252
Mass of $NaHCO_3$ in sample/g	0.495	0.460	0.495	0.535	0.481
Mass percent of $NaHCO_3$ in sample (%)	54.8	54.3	62.7	54.8	58.9
Mass of $NaHCO_3$ in tablet/g	1.79	1.75	2.05	1.80	1.90
Temperature of CO_2(g)/K	293.7	294.7	293.8	293.7	293.7
Pressure of CO_2(g)/atm	0.977	0.972	0.977	0.977	0.972
Amount of CO_2(g)/mol	0.00589	0.00548	0.00589	0.00636	0.00573
Volume of CO_2(g)/L	0.144	0.135	0.143	0.154	0.144
Density of CO_2(g)/(g/L)	1.80	1.79	1.81	1.82	1.75
Gas constant, R/[L atm/(K mol)]	0.0814	0.0813	0.0808	0.0805	0.0832
Molar Mass of CO_2/(g/mol)	44.4	44.4	44.7	44.9	43.4

Conclusion

Our students perform this lab midway through the general chemistry lab curriculum after studying the chapter on gases. This experiment is recommended for the following reasons:

1. It combines three labs into one: stoichiometry and analysis, molar mass by the Dumas method, and determination of ideal gas constant.

2. The quick and easy setup allows multiple trials to be performed and the 95% confidence intervals of the mean can be calculated.

3. The experiment uses equipment that is readily available.

4. Students' results are precise and accurate.

Note

1. The test tube is held upright by resting on the neck of the wash bottle.

Literature Cited

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Supplement

Instructions for the students, including pre- and in-laboratory questions

Notes for the instructor