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Determining the density of carbon dioxide gas through measurement of mass and volume preceding and following a chemical reaction

Introduction:

Carbon dioxide is a naturally occurring chemical compound that is found when two oxygen atoms are double bonded to one carbon atom. At room temperature, carbon dioxide takes the form of a gas. Initially discovered in the seventeenth century by chemist Jan Baptiste van Helmont, CO_2 has grown to be one of the most widely known gases. For the purposes of this lab, carbon dioxide is released when a chemical reaction occurs between an effervescent tablet, such as Alka-Seltzer, and water. This reaction is illustrated through the following equation: $3NaHCO_{3(s)} + H_3C_6H_5O_{7(s)} + H_2O_{(l)} \rightarrow Na_3C_6H_5O_{7(aq)} + 4H_2O_{(l)} + 3CO_{2\,(g)}$. This states that three molecules of sodium bicarbonate (baking soda), plus one molecule of citric acid, plus one molecule of water will transform into one molecule of sodium citrate dissolved in water, four molecules of water, and three molecules of carbon dioxide gas. The known density of carbon dioxide gas is 0.00196 g/cm_3.

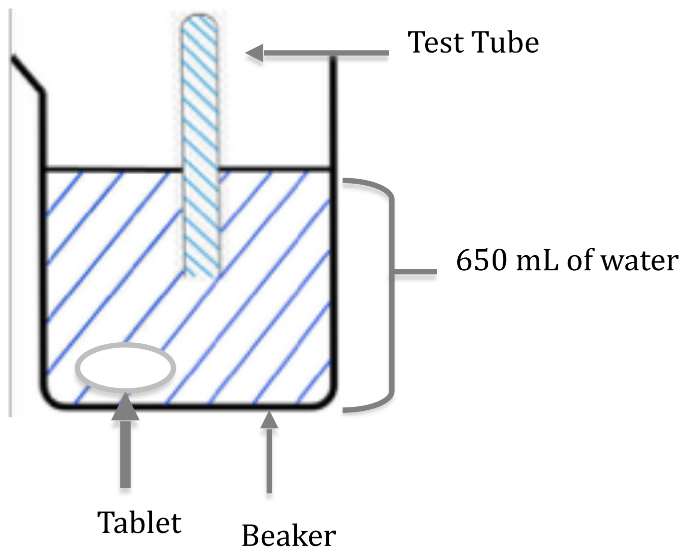
The concept of density (the mass of an object divided by the volume of an object) was first discovered by Archimedes around 250 BC after he noticed that he displaced water when he got into his bathtub. Given that density is intrinsic (independent of the amount of material) and unique to each specific element, it is expected that the density of CO_2 can be determined after the mass and volume of the gas are found.

Methods and Materials:

Preceding any lab activity, it is important to take appropriate safety precautions. Goggles were worn at all times while in the laboratory and all glass instruments were handled with care.

In order to determine the density of carbon dioxide, we first had to find the mass and volume of a specific amount of the gas. For the first trial, we elected to fill an 18x150 mm test tube with CO_2. Our first step was to use a balance to weigh the empty test tube including the rubber stopper in order to calculate the change in mass once the carbon dioxide was collected. Once this mass was found, we filled the test tube with water and emptied the contents of the test tube into a 25mL graduated cylinder to find the volume of the container. After the initial measurements had been taken, a 1000mL beaker was filled with 650 mL of water. The test tube was then refilled with water and a thumb was placed over the mouth of the test tube, sealing the water inside, before the filled test tube was inverted and submerged in the water inside of the beaker. One effervescent tablet was then dropped into the beaker. As the chemical reaction took place, we held the opening of the test tube directly over the carbon dioxide emissions, test tube resting on the effervescent tablet (Figure 1). As the bubbles rose, they entered the test tube, expelling the denser water into the beaker. It was found that one effervescent tablet did not have a sufficient reaction so as to completely fill the test tube with carbon dioxide. The test tube was removed from the beaker, the instruments were cleaned, and the experiment was reset.

Figure 1: Setup of experiment including placement of tablet and test tube in beaker



As the 18x150mm test tube proved to be too large in Trial One, we replaced it with a 15x125mm beaker for Trial Two. The empty test tube with the rubber stopper was once again weighed to determine mass and subsequently filled with water, which was then poured into the 25mL graduated cylinder to measure its volume. The procedure of Trial One was repeated with the smaller test tube, with the exception of the final two steps. After the test tube was entirely filled with carbon dioxide, tongs were used to place the rubber stopper into the opening of the test tube while it was still underwater in order to prevent any CO_2 from escaping. The test tube was removed from the beaker and weighed. The new weight of the test tube was found, and the initial mass was subtracted from the new mass measurement to find the weight of only the CO_2 in the test tube. This mass was divided by the volume measurement that was previously found, giving us the density.

To be sure of accuracy, the experiment was once again reset. The same size of instruments was used in Trial Three as in Trial Two (the used test tube from Trial Two was replaced with a new test tube of the same size for Trial Three). Trial Three was conducted in the same manner as Trial Two, with the exception of the placement of the test tube as it was held over the reaction of the effervescent tablet. In this trial, the test tube was held near the surface of the water as opposed to directly on top of the effervescent tablet so as not to get any stray particles from the tablet into the test tube. Once the final effervescent tablet had completed the chemical reaction and the rubber stopper had been inserted into the opening of the test tube, it was found that there was not as much CO_2 in the test tube as there had been in the previous trial; there was approximately one-half mL of water remaining. To account for this extra weight, the test tube was first weighed as it was (with the combination of carbon dioxide and water), before we removed the rubber stopper and tilted the test tube at an angle slightly less severe than 90° to allow the carbon dioxide to escape, being sure to not allow the water to spill. After one minute being held at an angle, the rubber stopper was once again inserted into the test tube. The test tube was weighed again and the results were recorded. This mass was subtracted from the mass of the test tube with carbon dioxide and water to determine the weight of the gas. The new weight was recorded and divided by the volume of the test tube to determine the density.

Results:

As the purpose of the lab was to determine the density of carbon dioxide gas, we needed to measure both the mass and the volume of the gas. When Trial One was conducted with the 18 x 150 mm test tube, the initial mass was found to be 26.116 g and the volume was measured at 27 mL. No other measurements were recorded for Trial One, as the test tube was deemed too large.

For Trial Two, the initial mass of the 15 x 125 mm test tube was recorded, along with the volume (Table 1). Following the collection of CO_2, the mass was found to be 17.325 g. The initial mass was taken from the post-reaction mass to find the weight of only the gas. This figure, along with the earlier recorded volume measurement, was plugged into the equation

$$p=m/v$$

to determine the density, where "m" is the mass of the object and "v" is the volume of the object. In this case, m=0.094 g and v=13.5 mL, so the equation was p=0.094 g / 13.5 mL. This gave us our final density of 0.00696 g/mL for Trial Two. After the density was determined, we calculated our percent error using the following equation:

$$\%\ \text{error} = \frac{|\text{Accepted} - \text{Measured}|}{\text{Accepted}} \times 100$$

The density of carbon dioxide gas is 0.00196 g/mL. Using this number as "accepted" and our density of 0.00696 g/mL as "measured," the equation was first worked out as (*absolute value)* (0.00196 g/mL / 0.00696 g/mL). This was found to be 0.005. This number was then divided by 0.00196 g/mL, giving us 2.55, and then multiplied by 100 to give us our final percent error of 255%.

During Trial Three, the initial mass and volume of the test tube were once again recorded (Table 1). As there was a small amount of water left in the test tube after the collection of CO_2 in Trial Three, two masses were recorded: the post-reaction mass of carbon dioxide and water, found to be 18.559 g, and the mass of the test tube with the presence of water and absence of CO_2, measured at 18.533 g. The second mass was taken from the first mass, giving us the weight of only the carbon dioxide gas (Table 1). Once again, the weight of the gas (0.026 g) was divided by the volume (13.5 mL), which gave us the final density of 0.00193 g/mL. Percent error was once again calculated using the same equation as in Trial Two, except the "measured" value of density in Trial Two (0.00696 g/mL), was replaced by the density found in Trial Three of 0.00193 g/mL. The final percent error of Trial Three was found to be 1.50%.

Between Trials Two and Three, the measured densities showed a difference of 0.00503 g/mL (from 0.00696 g/mL to 0.00193 g/mL), and the percent error was reduced by 253.5%.

Table 1: Volume, mass, density, and percent error calculations for Trials 1-3

	Volume (mL)	$Mass_{initial}$ (g)	$Mass_{post\text{-}reaction}$ (g)	$Mass_{water}$ (g)	$Mass_{carbon\ dioxide}$ (g)	Final Density (g/mL)	Percent Error (%)
Trial 1	27 mL	26.116 g	N/A	N/A	N/A	N/A	N/A
Trial 2	13.5 mL	17.231 g	17.325 g	N/A	.094 g	0.00696 g/mL	255%
Trial 3	13.5 mL	17.524 g	18.559 g	18.533 g	.026 g	0.00193 g/mL	1.50%