November 22, 2014

Laws of Conservation of Mass and Definite Proportions[1,2]

Principles:

"The mass of the products of a chemical reaction are equal to the mass of the reactants," Antoine Lavoisier, ~ 1775

"A pure compound contains the same elements in the same proportion by mass," J.L. Proust, 1799.

Abstract:

The reaction between sodium bicarbonate ("baking soda") and acetic acid ("vinegar") produces sodium acetate, water and carbon dioxide. A demonstration with a rigid bottle containing the reactants on a triple beam balance, shows that the mass does not change after the reaction is complete. In a second demonstration, a balloon is fitted over the mouth of a bottle containing the reactants on a triple beam balance. The carbon dioxide produced fills the balloon and the mass is reduced slightly because of a buoyant force acting upward. But, by measuring the circumference of the filled balloon, the volume and mass of carbon dioxide can be calculated. This result is compared with the mass of carbon dioxide calculated from the chemical formulas using the law of definite proportions.

Key Concepts:

- Products
- Reactants
- Conservation of Mass
- Buoyant force

Materials & Equipment

- Apron or lab coat
- Erlenmeyer flask (graduated) with capacity of 250 ml
- Balloons, size 12 (12-inch diameter when inflated)
- Small plastic or paper cup (about 50 ml capacity)
- Eye protection
- Gloves (disposable)
- Cloth tape measure with metric markings
- Baking Soda (10 g of sodium bicarbonate) - 100 g for 5 classes
- Vinegar (300 ml of 5% acetic acid solution) - 2 liters for 5 classes
- Two rigid plastic bottles (2 liters) with cap (empty soda bottles)
- Triple beam balances (2)
- Stainless steel spatula or plastic spoon
- Funnel

Safety Precautions:

Use eye protection, gloves, and apron.

Disposal: Add to water to dilute the mixture and dispose of in sink with running water. Wash out flasks.

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1. *Focus on Physical Science*, California Edition, Glencoe/McGraw-Hill, Columbus, OH, page 177 (2007).
2. Sarkar, S., *Science Scope*, Volume 31, No. 9, page 52 (2008), NSTA Publications, Arlington, VA.

Procedure - Part A:

1. Pour 150 ml of vinegar into the 2 liter plastic bottle.

2. Mass 5 grams of baking soda in a small paper cup using a triple beam balance.

3. Quickly pour the baking soda into the 2 liter plastic bottle containing the vinegar and immediately cap the bottle tightly.

4. Place the plastic bottle on a triple beam balance, measure the mass of the filled bottle, and record the value. Leave the bottle on the balance.

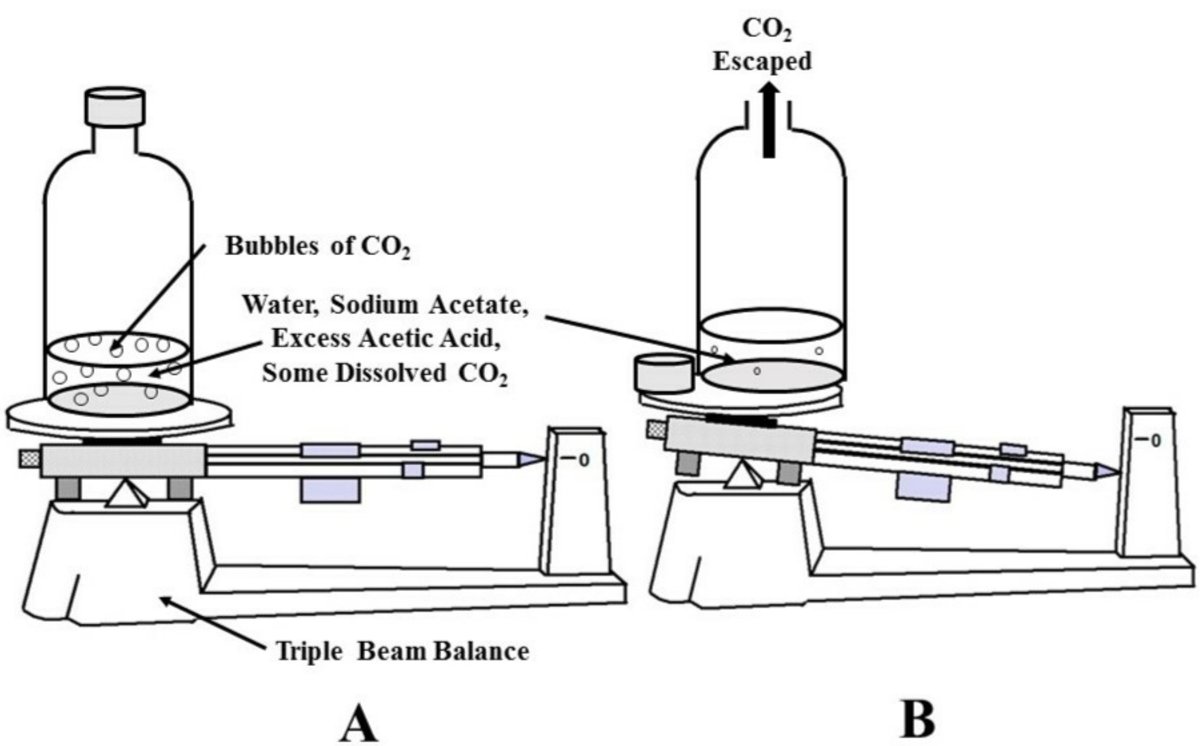
5. After 2 to 3 minutes, check the mass of the bottle again - see **A** in the diagram below. Allow the students to confirm that the balance pointer is unchanged

6. Open the bottle cap and let the students hear the noise of the gas escaping.

7. Keep the open bottle and the cap on the balance pan, wait 2 to 3 minutes and agitate the bottle to allow more of the dissolved carbon dioxide to escape -see **B** in the diagram below and allow the students to confirm that the balance pointer has changed.

8. Measure the mass of the open bottle and cap and record the value.

9. Subtract the final mass value from the original mass value- it should be close to but less than the 2.6 grams calculated from the law of definite proportions because about 10% of the carbon dioxide remains dissolved in the water solution.



Procedure - Part B:

1. Mass 5 grams of baking soda in a small cup on a triple beam balance and pour it all into a balloon using a funnel.

2. Measure 150 ml of vinegar with a 250 ml Erlenmeyer flask and pour it into a 2 liter plastic bottle.

3. Fit the balloon over the mouth of the bottle, **BEING CAREFUL NOT TO TIP THE BOTTLE OR INVERT THE BALLOON.**

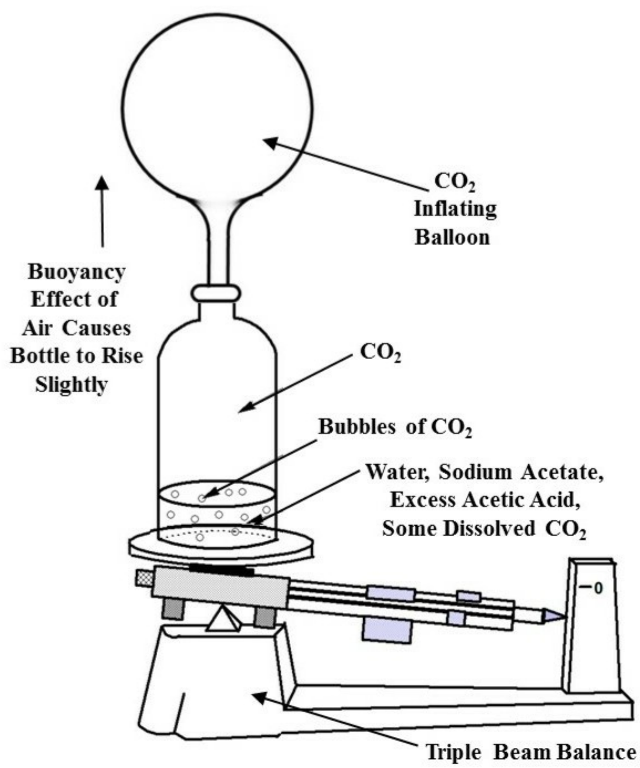
4. Place the bottle with the balloon attached on a triple beam balance, measure its mass and record the value. Leave the flask on the balance.

5. Invert the balloon so the baking soda falls into the bottle.

6. Watch the reaction that takes place immediately and ask the class how they know that a chemical reaction is occurring.

7. As the balloon inflates, ask the class to observe the balance to see if the mass increases or decreases.

8. After the reaction subsides (about 3 minutes), the balance should show that the mass has decreased slightly. Ask the class if they know why. Explain the effect of the buoyant force.



9. As an extra demonstration, measure the circumference of the filled balloon using a cloth tape measure placed around the center of the balloon and ask a student to record the result.

Circumference Measurement

Compare Part A and Part B:

Check the mass of the bottle prepared in Part B with that in Part A, which should be unchanged. There is no buoyant force effect, so the mass of the products equals the mass of the reactants.

Calculations: (Optional)

Show the reaction sequence on the board and have the students write this on their worksheet:

$$\mathbf{NaHCO_3 + CH_3CO_2H \text{ -------> } CH_3CO_2Na + H_2O + CO_2}$$

Compute the mass of each molecule by adding the masses of each atom:

Na	**23**		**2C**	**24**		**2C**	**24**		**2H**	**2**		**C**	**12**
H	**1**		**4H**	**4**		**3H**	**3**		**O**	**<u>16</u>**		**2O**	**<u>32</u>**
C	**12**		**2O**	**<u>32</u>**		**2O**	**32**						
3O	**<u>48</u>**					**Na**	**<u>23</u>**						
					Molecule Masses								
	84	**+**		**60**	**=**		**82**	**+**		**18**	**+**		**44**
		144								**144**			

The conservation of mass says that if we start with 84 grams of sodium bicarbonate, we should produce 44 grams of carbon dioxide. Since we used only 5 grams of sodium bicarbonate, then by proportion we should get 2.6 grams of carbon dioxide:

$\frac{5g}{84} = \frac{m}{44}$ (m = grams of carbon dioxide); $m = \frac{5g \times 44}{84} = \frac{220g}{84} = 2.6$ grams

For Part A:

The solubility of CO_2 in water is 90 cm^3/100 cm^3 of water at 20ºC. This means that 135 cm^3 of CO_2 would remain in solution. The mass of 135 cm^3 of CO_2 is:

$$M = V \times d, \text{ where the density of } CO_2 \text{ is } 0.001975\ g/cm^3,$$

$$135\ cm^3 \times 0.001975\ g/cm^3 = 0.27\ g$$

Thus, about 10% of the CO_2 remains in solution, so the mass of CO_2 measured should be no more than 2.3 g.

Fort Part B:

The volume of 2.6 grams of CO_2 is: $V = m/d$, where the density of CO_2 is 0.001975 g/cm^3,

$$V = \frac{2.6\ g}{0.001975 g/cm^3} = 1{,}316\ cm^3$$

If we account for the amount of dissolved CO_2, then the volume would be reduced to 1,181 cm^3.

What should be the circumference, C, of the filled balloon be if we know the volume?

$$V = \frac{C^3}{6\pi^2} \qquad 1{,}181\ cm^3 = \frac{C^3}{(6 \text{ x } 3.1415 \text{ x } 3.1415)}$$

$$1{,}181 \text{ x } 59.16\ cm^3 = C^3$$

$$69{,}868\ cm^3 = C^3 \qquad 41.2\ cm = C$$

Compare this with the measured circumference. The measured circumference will be about 1-2 cm less than this value because of measurement error.