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Simplicity and Elegance of the Wash Bottle in Water Displacement Schemes

Frazier Nyasulu*, Rebecca Barlag, Lauren McMills, Whalmany Ounkham, Phyllis Arthasery

Department of Chemistry and Biochemistry, Ohio University, Athens, OH, United States

Abstract Wash bottles greatly simplify the determination of the volume of a gas produced by a chemical reaction using a water displacement scheme. A versatile and elegant system consisting of two wash bottles is described.

Keywords Water Displacement, Gas Producing Reactions, General Chemistry

1. Introduction

Water displacement schemes are widely used in entry-level chemistry labs to determine the volume of gases produced by chemical reactions [1-10]. The popularity is due in part to the simplicity of the setup with items ordinarily available in teaching laboratories. The classic water displacement setups are shown in Figure 1, with examples of gas collector systems on the right and gas generator reaction systems on the left.

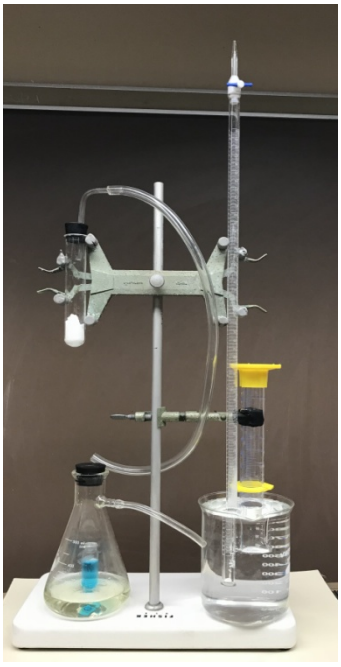

Figure 1. Classic water displacement schemes

* Corresponding author:
fwmnyasulu@gmail.com (Frazier Nyasulu)
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Water Displacement Schemes Based on Wash Bottles: Teggins and Mahaffy introduced the use of a unitary wash bottle to determine the kinetics of the decomposition of H_2O_2 (*aq*) catalyzed by KI (*aq*) in 1997 [6]. The H_2O_2 (*aq*) and KI (*aq*) were mixed in a beaker then transferred to a unitary wash bottle. After 3-4 minutes, the rate of the reaction was determined by measuring the volume of solution displaced over a period of 60 seconds. Many instructors are not aware of the simplicity and elegance of using a wash bottle for the collection of gases in water displacement. We share some of our experiences and insights herein.

Considering the kinetics of the water displacement exercise described above, we have reported a modified arrangement [10]. Unlike the Teggins and Mahaffy procedure [6], the H_2O_2 (*aq*) and KI (*aq*) mixture is placed in a test tube, which is then placed in a unitary wash bottle. In this setup, water is expelled from the wash bottle instead of the reaction solution, allowing for small volumes of reagents to be used. This is a cost effective and environmentally friendly option especially if post-reaction mixtures cannot be discarded down the drain. Since some gas is lost, this setup is most useful for qualitative work.

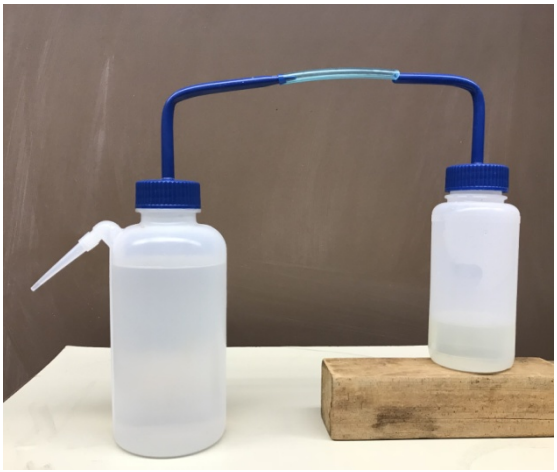

Figure 2. Water displacement scheme consisting of two wash bottles

For most quantitative work, it is important to secure the wash bottle lid before the reaction begins. When one of the reagents can be added as a solid, the solid can be held in a gelatin capsule. It takes 3-4 minutes for the capsule to dissolve, allowing ample time to secure the lid.

Some reactions have a tendency to produce bubbles or froth extensively, causing the solution to overflow the test tube. An example is the reaction between Mg powder and HCl (*aq*). The use of a large wash bottle (1000 mL) and a wide/long test tube (10 inch) solves this problem. Unfortunately, frothing displaces some of the metal powder to the top sides of the test tube resulting in incomplete reaction. An alternative setup (Figure 2) can overcome this issue.

2. New Water Displacement Scheme

The smaller wash bottle is a standard wash bottle (reactor) and the larger one is a unitary wash bottle (collector). The cover on the unitary wash bottle is that from a standard wash bottle. In both wash bottle covers, the internal outflow tube is removed. Gelatin capsules can be used when one of the reagents is a solid.

One classic experiment using water displacement schemes is the identification of an unknown metal [7, 8]. The metal is reacted with excess HCl (*aq*) and the volume of the H_2 (*g*) is determined. The H_2 (*g*) pressure is equal to the atmospheric pressure and the temperature of the H_2 (*g*) is equal to the room temperature. The amount of gas is calculated according to the ideal gas law and the moles of metal are calculated assuming a +2 metal ion charge. From the mass of the metal and the moles of metal, the molar mass of the metal is calculated. Using the setup in Figure 3, students determined the molar mass of an unknown metal to be 24.3 ± 0.2 g/ mol (N = 9) and thereby unambiguously identified the metal as magnesium.

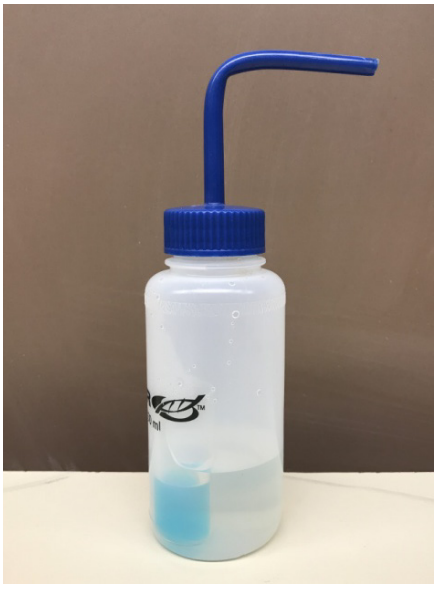

Figure 3. Procedure to mix two solutions

When the reaction is between two solutions, a test tube can hold reagent 1. The test tube must be 1-2 cm longer than the diameter of the reactor to avoid unintentional mixing before the reactor lid is secured. Figure 3 shows the blue reagent 1 in the test tube and the clear reagent 2 in the reactor. To start the reaction, the reactor is tilted to allow the sample vial content to flow out. This setup also allows for the determination of the mass of gas produced by weighing the reactor before and after the reaction.

3. Conclusions

Wash bottles allow students to accurately determine the volume of gas produced by chemical reactions. The mass of the gas produced can be determined by subtracting the mass of the product system from the mass of the reaction system. The density of the gas can then be calculated, which in turn can be used to calculate the molar mass of the gas. When reagents are not known, students can identify the gas produced. If the pressure (typically equal to the atmospheric pressure) and temperature (typically equal to the room temperature) of the gas are also measured, the moles of gas can be calculated, which can then open up a number of follow-up exercises. For example, the ideal gas law constant can be determined within 5% of the literature value [9]. There are many possible applications of wash bottle water displacement schemes. Some examples appear in the manuscript *A Simple, Safe, and Easy Water Displacement Exercise for the Identification of Two Metals and the Composition of a Mixture* in this journal.

The simplicity of these setups allows for repetition of runs and therefore enables meaningful statistical analyses to be performed. Additionally, this method is cost effective due to the use of plastic wash bottles, smaller reagent(s) volumes, and a reduction in chemical waste. Plastic wash bottles remove the need for glassware, improving safety in the laboratory. Overall, these setups are simple, cost effective, and environmentally friendly.

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