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DETERMINATION OF THE MOLAR VOLUME OF HYDROGEN FROM THE METAL-ACID REACTION: AN EXPERIMENTAL ALTERNATIVE

Introduction

This article describes an alternative technique for determining the molar volume of hydrogen from the metal-acid reaction in which the metal sample is encased in a specially prepared cage and a pipette filler is used to fill an inverted burette with water. The reaction between a metal and an acid has been used to determine the molar volume of hydrogen at room temperature and pressure using different techniques to that described here (Dietz, Tellefsen, Parry, & Steiner, 1977; Reed, 1987; Sorsby, 1975; Teen & Ellis, 1978); to observe the effect of using different acids on the volume of hydrogen produced (Sorsby, 1975); to reinforce the 'activity series' for metals and hydrogen (Sorsby, 1975); to determine the rate law, activation energy, and stoichiometry for the reaction (Birk & Walters, 1993); and to determine the chemical equivalent of a metal (Bonatti, Zurita, & Solimo, 1995). One of the procedures commonly employed, especially for magnesium, is to wrap the metal ribbon through a copper coil or around a small glass rod to prevent it from rising to the liquid surface inside an inverted gas measuring tube. The acid concentration is higher at the bottom of the inverted tube than at the top so that if metal rises to the liquid surface the reaction slows down significantly. This difference in acid concentration occurs when the gas measuring tube, containing the metal, has been filled with water, inverted over water, and acid finally added to the system to commence the

reaction, or, a gas measuring tube is partially filled with acid, water is added to fill the tube, and then the metal inserted and the system inverted over water. However, even when the metal is supported at the bottom of the liquid column where acid concentration is higher, metal is eventually eaten away from the support as the reaction proceeds and the dislodged pieces of metal rise to the surface where it may take some time for the reaction to reach completion. The technique outlined in this article minimises the chance of dislodged pieces of metal rising to the liquid surface before the reaction is completed and can be used for metals which cannot be supported like magnesium.

Other techniques such as that outlined by Reed (1987) involve adding the metal to the acid before closing off the system. In this case, some gas may escape before the system has been closed off and the volume calculation is rather cumbersome. In the technique outlined in this article, the volume measurement is direct and is accomplished with the same apparatus as used to collect the gas.

Construction of the apparatus

Firstly, a small carrying vessel for the metal sample, shown in Figure 1, was constructed from a plastic test tube with a lid. The dimensions of the test tube and the carrying vessel constructed from it are shown in Figure 1. The test tube was cut 1.5 cm from the bottom and small holes drilled in the wall of the bottom cut-off section and also in the top of the lid. These holes allow acid to get access to the metal and the fact that the metal is now encased minimises the chance of dislodged metal pieces rising to the liquid surface as the reaction proceeds.

The metal, accurately weighed and transferred to its carrying vessel, was now placed in the bottom of a 500 mL measuring cylinder and a glass filter funnel with a PVC or rubber spacing was inverted over the metal in the bottom of the measuring cylinder. The spacer allows free access of liquid throughout the system. A 50 mL burette was inverted over the funnel and arranged as shown in Figure 2.

Experimental details

The measuring cylinder was half-filled with water. Using a pipette filler attached to the spout of the burette and with the burette tap open, water was now sucked up into the burette past the tap at which point the tap was closed. Using a pipette, 25 mL of acid was now added to the measuring cylinder near the metal sample to commence the metal-acid reaction. Hydrogen was collected in the burette by the downward displacement of water. About 2 millimoles of metal was used in the reaction. Acid concentration (HCI) was 5 M for the magnesium reaction but a higher concentration can be used for less active metals. A burette volume reading is taken at atmospheric pressure by adjusting the apparatus so that the liquid level height in the burette is the same as in the measuring cylinder. The dead space volume in the burette was determined by transferring water from the dead space to a measuring cylinder.

Experimental results

A set of student results for the magnesium-hydrochloric acid reaction are given in Table 1. These results can be used in two ways. The stoichiometry of the reaction can be determined by comparing the number of moles of magnesium reacted with the number of moles of hydrogen calculated from the ideal gas law using the experimental values of pressure, volume and temperature, or, given the stoichiometry of the reaction, the molar volume of hydrogen can be determined on the basis of the number of moles of metal consumed. The results of both calculations are shown in Table 1.

Conclusion

The technique described here has been used by the authors during a Science Summer Camp for Years 10 and 11 students and has proved most satisfactory for determining the molar volume of hydrogen gas. The apparatus is simple to handle and avoids some of the difficulties experienced when using other techniques. The major difficulties overcome are the dislodging of metal from its support and consequent rising to the liquid surface, the manipulative difficulties in preparing the metal on its support and the inversion of the gas measuring tube in a tank whilst full of liquid, and in one case at least (Reed, 1987), a cumbersome volume calculation.

Table 1.

Molar volume of hydrogen gas determined from the reaction of different masses of magnesium ribbon and excess 5 moi L^{-1} hydrochloric acid. Note: The data were collected at 24.5 degrees C, 765 mm Hg with a water vapour pressure of 23.3 mm Hg.

Legend for Chart:

A - Mass of Mg (g)
B - Moles of Mg
C - Volume of H_2 (mL)
D - Moles of H_2 (n= PV/RT)
E - Molar Volume of H_2 (L)

A	B	C	D	E
0.0476	1.96×10^{-3}	49.50	1.98×10^{-3}	24.5
0.0467	1.92×10^{-3}	46.28	1.85×10^{-3}	23.4
0.0490	2.02×10^{-3}	49.12	1.97×10^{-3}	23.6
0.0472	1.94×10^{-3}	48.75	1.95×10^{-3}	24.4

DIAGRAM: Figure 1. Dimensions of material used to prepare the apparatus for the metal-acid reaction. A = plastic test tube for preparing the carrying vessel. B = carrying vessel for the metal sample. C = filter funnel. D = spacer.

DIAGRAM: Figure 2. The apparatus for preparing hydrogen from the metal-acid reaction.

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