

Molar Volume of Hydrogen

Combining the Gas Laws

Introduction

Airbags have been required safety features on new cars since the 1980s and are credited with saving thousands of lives in that time. Airbags contain a compound that decomposes to give nitrogen gas upon impact from a collision. How much nitrogen gas must be generated to fill an airbag? The amount of gas needed to fill any size container can be calculated if we know the molar volume of the gas.

Concepts

- Avogadro's law
- Dalton's law
- Ideal gas law
- Molar volume

Background

Avogadro's law states that equal volumes of gases contain equal numbers of molecules under the same conditions of temperature and pressure. It follows, therefore, that all gas samples containing the same number of molecules will occupy the same volume if the temperature and pressure are kept constant. The volume occupied by one mole of a gas is called the *molar volume*. In this experiment we will measure the molar volume of hydrogen gas at standard temperature and pressure (STP), equal to 273 K and 1 atm.

The reaction of magnesium metal with hydrochloric acid (Equation 1) provides a convenient means of generating small-scale quantities of hydrogen in the lab.



If the reaction is carried out with excess hydrochloric acid, the volume of hydrogen gas obtained will depend on the number of moles of magnesium as well as on the pressure and temperature. The molar volume of hydrogen can be calculated if we measure the volume occupied by a sample containing a known number of moles of hydrogen. Since the volume will be measured under laboratory conditions of temperature and pressure, the measured volume must be corrected to STP conditions before calculating the molar volume.

The relationship among the four gas variables—pressure (P), volume (V), temperature (T) and the number of moles (n)—is expressed in the ideal gas law (Equation 2), where R is a constant called the universal gas constant.

$$PV = nRT \quad \text{Equation 2}$$

The ideal gas law reduces to Equation 3, the combined gas law, if the number of moles of gas is constant. The combined gas law can be used to calculate the volume (V_2) of a gas at STP (T_2 and P_2) from the volume (V_1) measured under any other set of laboratory conditions (T_1 and P_1). In using either the ideal gas law or the combined gas law, remember that temperature must be always be expressed in units of kelvins (K) on the absolute temperature scale.

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \quad \text{Equation 3}$$

Hydrogen gas will be collected by the displacement of water in an inverted graduated cylinder using the apparatus shown in Figure 1. The total pressure of the gas in the cylinder will be equal to the barometric (air) pressure. However, the gas in the cylinder will not be pure hydrogen. The gas will also contain water vapor due to the evaporation of the water molecules over which it is being collected. According to Dalton's law, the total pressure of the gas will be equal to the partial pressure of hydrogen plus the partial pressure of water vapor (Equation 4). The vapor pressure of water depends only on the temperature (see Table 1).

$$P_{\text{total}} = P_{\text{H}_2} + P_{\text{H}_2\text{O}} \quad \text{Equation 4}$$

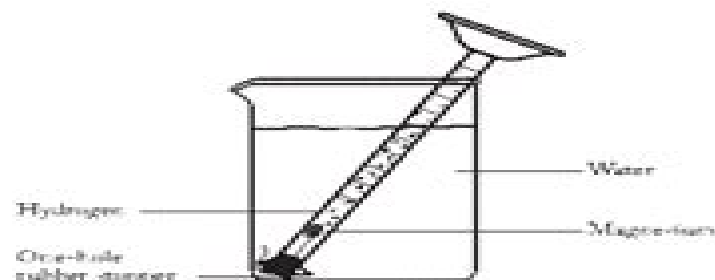


Figure 1.

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Jin-Ying Zhang



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