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Demonstration of Atomic Emission from Exploding Hydrogen Balloons for (Almost) Everybody

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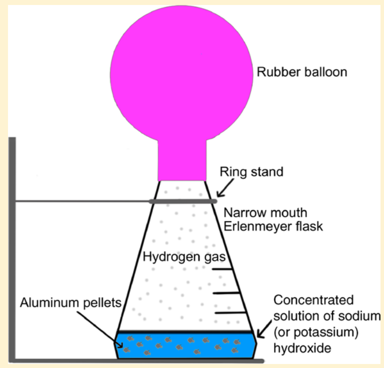
ABSTRACT: A variation on the preparation of the exploding hydrogen balloons demonstration is presented. A simple method for filling a balloon with hydrogen gas is described. Such a method can be used in most laboratories, making the demonstration easily accessible to almost every school.



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In this *Journal*, some papers have been published about the lecture hall demonstration of colored hydrogen balloons.[1−4] The experiment involves the ignition of balloons filled with hydrogen and a solid metal chloride, which is volatile at the temperature of hydrogen ignition, able to give a colorful emission spectrum. The demonstration can be employed for introducing and illustrating combustion reactions, gas laws, emission spectra of elements, and their electronic energy levels.[1,2] However, the above cited papers refer to the use of either hydrogen bottles or generators for filling the balloons. None of them presents an alternative production of the gas, thus neglecting the practical issues (especially relevant for high schools) connected to the storage and purchase of explosive gas bottles.

To our knowledge, only Lisk[5] presents an alternative apparatus for the production of hydrogen to be used for filling balloons. However, such an apparatus seems to be rather tricky to build. In addition, Lisk does not give any suggestion about the chemicals to be used for producing hydrogen.

■ NEW METHOD

We have found that a good method is to use little pellets ripped out of a household aluminum foil. Their reaction with a concentrated sodium (or potassium) hydroxide aqueous solution in a narrow mouth Erlenmeyer flask can effectively serve the scope. Aluminum reacts exothermically with the hydroxide ion to produce hydrogen gas:[6]

$$2Al(s) + 2OH^{-}(aq) + 6H_2O(l) \rightarrow 2[Al(OH)_4]^{-}(aq) + 3H_2(g) \quad (1)$$

After the pellets have been poured into the solution, a piece of gauze can be tightened to the mouth of the flask with a rubber band. Then, a rubber balloon can be tightened around the mouth of the flask, previously clamped onto a ring stand. As the reaction proceeds (eq 1), the balloon gets inflated with hydrogen. The gauze ensures the hydrogen in the balloon to be mostly free of droplets of base. A small quantity of aluminum pellets, 1.0−1.1 g, and 120 mL of a 1.3 M solution of sodium hydroxide in a 250 mL Erlenmeyer flask are the optimized and tested conditions for hydrogen balloons with a diameter of around 12 cm. The apparatus is shown in Figure 1. If the flask becomes too hot and the reaction is too vigorous, the submersion of the flask in an ice or cold-water bath would be advisable.

To obtain a colored explosion, 2 g of a 25% (w/w) suspension of either lithium chloride (LiCl for a red flare), copper(II) chloride ($CuCl_2$, anhydrous or hydrated, for a green-blue flare), sodium chloride (NaCl for a yellow flare), or cesium chloride (CsCl for a faint violet flare) in isopropyl alcohol can be spread with a plastic pipet inside the rubber balloon. Then, the balloon filled with the suspension should be swirled for some seconds and its contents emptied. For optimal results, this procedure should be repeated two to three times. Afterward, the excess isopropyl alcohol in the balloon might be dried under a fume hood before the balloon is filled with hydrogen gas. The above-mentioned salts provide the vivid bright colors of the flame. Other metal chlorides such as strontium chloride ($SrCl_2$ for a crimson flare), potassium chloride (KCl for a lavender flare), or calcium chloride ($CaCl_2$ for a brick red flare) may also be used. The use of isopropyl

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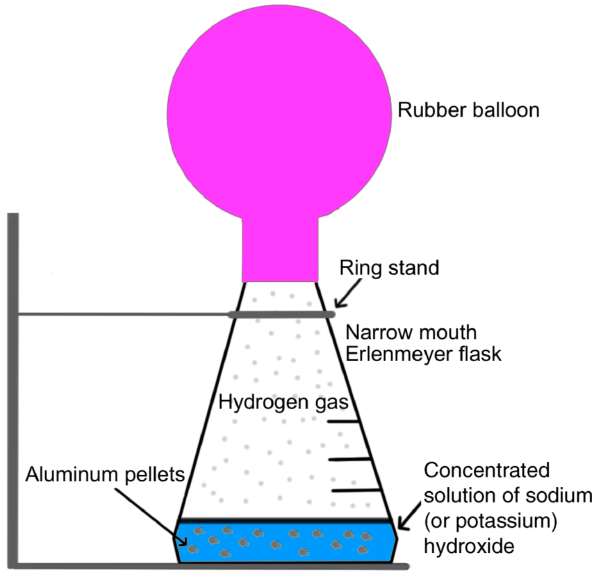

Figure 1. A sketch of the experimental apparatus for filling a rubber balloon with hydrogen. The piece of gauze tightened to the mouth of the flask is not visible.

alcohol reduces the hazards related to methanol. In addition, by letting the isopropyl alcohol evaporate first, the relatively bright yellow flame associated with its combustion is reduced.[7] To further minimize such a yellow light, ethyl alcohol could be used in place of isopropyl alcohol.

In our experience, balloons with a diameter larger than 10–15 cm (with the associated increased auditory risks[8−10]) are unnecessary for a lecture hall of up to 200 seats. With a diameter of 10–15 cm, the balloons do not float but they can be attached with adhesive tape to the top of long metallic rods and exploded with ignited fireplace matches attached with adhesive tape to the top of another long metallic rod (preferred length: 1.0–1.2 m).

The in situ preparation would also prevent possible problems related to the transportation of the balloons.[11]

IN-CLASS USE

The demonstration was successfully implemented for introducing the chemistry module of a civil engineering bachelor's degree course. The preparation of the experiment could be employed for illustrating the corrosion resistance of aluminum and its alloys in aqueous media. This resistance is due to the formation of a thin coherent, passivating layer of aluminum oxide, Al_2O_3, formed by the reaction of the metal with air:[12]

$$4Al(s) + 3O_2(g) \rightarrow 2Al_2O_3(s) \quad (2)$$

In water, this passivating oxide layer can transform to a gelatinous trihydroxide, $Al(OH)_3$.[12] If going to completion, the reaction can be written as

$$Al_2O_3(s) + 3H_2O(l) \rightarrow 2Al(OH)_3(s) \quad (3)$$

The solubility of the aluminum trihydroxide is pH-dependent (stability range: 4.0–8.5).[12] Therefore, aluminum trihydroxide dissolves readily in strongly acidic and alkaline solutions, as in the conditions of the above-described procedure. Once the aluminum oxide layer has been reacted away, the underlying metallic aluminum can be acted upon by the base, as described in the reaction given in eq 1.

Finally, the experiment could also be useful for illustrating the reaction of the metal with water (a conversion of interest for the production of hydrogen[13]).

HAZARDS

Sodium (or potassium) hydroxide and its solutions are highly caustic. The hot vapors from the reaction with aluminum may carry tiny droplets of base solution, especially if quantities different from those described above are used. Such droplets can be severely irritating in the case of skin or eye contact and very hazardous by inhalation or ingestion. Isopropyl alcohol is flammable and toxic by ingestion or inhalation of large quantities, but the small amount required reduces this concern. Potassium and sodium chlorides are slightly irritant in the case of skin or eye contact and slightly hazardous in the case of ingestion or inhalation. Their oral LD_{50} for rats is 2600 and 3000 mg/kg, respectively. Lithium, cesium, calcium, and strontium chlorides are irritant in the case of skin or eye contact and hazardous in the case of ingestion or inhalation. Their oral LD_{50} for rats is 526, 2600, 1000, and 2250 mg/kg, respectively. Copper(II) chloride is very irritant in the case of skin or eye contact and very hazardous in the case of ingestion or inhalation. It is corrosive to eyes and skin, too.[14]

A laboratory coat, goggles, and safety gloves should be worn for the preparation and execution of the experiment. The use of matches and isopropyl alcohol and the production of hydrogen necessitate the presence of a fire extinguisher close at hand, as well as possibly a fire blanket. Close electric sparks could unintentionally ignite the balloon. The bang caused by the explosive reaction of hydrogen is not very loud if the above-mentioned quantities are followed. However, the use of protective earplugs is advisable.

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Notes

The authors declare no competing financial interest.

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