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Laboratories and Demonstrations

Demonstrating Catalysis with a Bang!

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A simple yet highly effective means of demonstrating the use of a standard Pd/C hydrogenation catalyst to initiate the explosive reaction of hydrogen and oxygen gases is reported. Addition of approximately 30 mg of 5% Pd/C to a one-liter plastic soda bottle containing a 1:1 hydrogen and oxygen mixture results in, after a brief induction period, a dramatic explosion that is louder than that of a similar mixture initiated by a flame.

The addition of 5% Pd/C provides a novel means of initiating the dramatic reaction between hydrogen and oxygen gases.

Introduction

Catalysis is pervasive in modern chemistry [1], but only a few demonstrations are available to illustrate this important concept. Most involve reactions of hydrogen peroxide or metal-catalyzed oxidation reactions of NH_3 or alcohols [2]. It has been said that hydrogen and oxygen can be used to illustrate all the principles of chemistry [3]. The well-known explosive reaction of hydrogen and oxygen gases initiated by a flame is an effective and often used demonstration in introductory

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chemistry courses [4]. In this report we describe how to initiate this reaction using a standard palladium on carbon hydrogenation catalyst as a dramatic means of demonstrating how a catalyst can provide a new pathway for transforming reactants to products [5]. This demonstration is appropriate for introductory courses in general, organic, or physical chemistry.

Procedure

Caution: Hydrogen gas is highly flammable and forms explosive mixtures with oxygen. Ear protection should be worn by the demonstrator and the audience cautioned to shield their ears.

One-liter plastic soft drink bottles are filled by water displacement with an approximately 1:1 mixture of H_2 and O_2 gases. A 20-by-10-mm hole is cut in the bulb of a plastic Beral pipet and a 30-mg sample of 5% Pd/C catalyst is placed in the bulb. The bottle is clamped on a ring stand and the pipet containing the catalyst is dropped into the bottle immediately after the cap is removed. The demonstrator should step back from the bottle. After a short (approximately 5-second) delay a violent explosion ensues. The bottle is slightly warm to the touch.

At a distance of 3 meters (front row of a 350-seat lecture hall), a Tenma 72-860 Digital Sound Survey Meter recorded a peak reading of 126 dB. For comparison, a second bottle ignites from a flame source near the mouth of the bottle instantaneously when the cap is removed using a string. This gave a peak reading of 115 dB. Similar results can be obtained using 591-mL (20-oz) plastic soda bottles (catalyzed, 125 dB; flame, 115 dB). Most of the catalyst remains in the pipet for easy reuse (which may be demonstrated) or disposal. Somewhat longer delay times are noted when the catalyst is reused. Because trace amounts of catalyst may remain inside the bottles, we do NOT recommend that the bottles be refilled with hydrogen.

Results and Discussion

Noble metal catalysis of the H_2/O_2 reaction was noted as early as 1819 by Erman, who reported that Pt wire heated to 50 °C caused the gaseous mixture to ignite [6]. The addition of 5% Pd/C provides a novel means of initiating the dramatic reaction between hydrogen and oxygen gases. A 1:1 mixture of gases gives reliable ignition without an

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unduly long delay after the catalyst is placed in the bottle. A modified Beral pipet provides a safe and convenient means of delivering the catalyst into the bottle and of reusing the catalyst. Compared to the instantaneous ignition with a flame, the short induction period prior to the explosion in the case of the catalyzed reaction can be ascribed to activation of the catalyst with hydrogen. Qualitatively, a larger quantity of catalyst leads to shorter induction periods. The length of the induction period is also a function of the size of the hole in the pipet bulb and the history of the catalyst. Because of the induction period, this method is not a useful means of probing the stoichiometry of the reaction. We have not attempted, nor do we recommend attempting, this demonstration on a larger scale, but containers smaller than 250 mL exhibited more erratic initiation behavior, possibly because of escape of hydrogen gas from the container. Quantitative sound-level measurements confirmed our qualitative impression that the intensity of the catalyzed explosion was greater than that of the flame-initiated reaction. This may be a consequence of increased rate of initiation (production of hydrogen radicals) on the catalyst surface [7].

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