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The Repeating "Exploding" Flask: A Demonstration of Heterogeneous Catalysis

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Introduction

The repeating "exploding" flask demonstration is a particularly dramatic one that can be used to illustrate heterogeneous catalysis and thermochemistry. We are not the originators of this demonstration (we don't know who is), but would like to share what we have learned about it. Certain metals such as platinum, palladium, and nickel can catalyze vapor phase reactions. In particular, they can catalyze the oxidation of alcohols. When a wire of these metals is suspended over alcohol vapors in a flask, a regular "bang" accompanies the reaction with a period of 20–90 s, the "explosion" referred to above. The loudness of the bang and the length of the period depend on the type of metal, the alcohol, and also on the size of the flask used in the demonstration. The explosion is due to the exothermic combustion of the alcohol vapor in the flask. Between explosions the metal wire coil is slowly heated due to the exothermic oxidation of the alcohol on the surface.

- **Caution:** This demonstration should not be performed before you have read and **heeded** the cautions at the end of the Demonstration section.

The Reactions

The reactions using methanol are:

- the catalytic oxidation reaction

$$CH_3OH(g) + \tfrac{1}{2}O2(g) \rightarrow CH_2O(g) + H_2O(g)$$
$$\Delta H_m/\mathrm{kJ\cdot mol^{-1}} = -156.3$$

- the combustion reaction

$$CH_3OH(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$$
$$\Delta H_m/\mathrm{kJ\cdot mol^{-1}} = -675.7$$

The comparable reactions using ethanol are:

$$C_2H_5OH(g) + \tfrac{1}{2}O_2(g) \rightarrow CH_3CHO(g) + H_2O(g)$$
$$\Delta H_m/\mathrm{kJ\cdot mol^{-1}} = -172.5$$

and

$$C_2H_5OH(g) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(g)$$
$$\Delta H_m/\mathrm{kJ\cdot mol^{-1}} = -1277.4$$

All data are for 298.15 K.

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Experimental Directions

A number of conditions must be met if the reaction is to produce the rhythmic bangs.

An Erlenmeyer flask must be used to ensure the "whoosh/bang" effect.
The wire must be hot *before* beginning.
The flask must contain adequate quantities of alcohol vapor and air (oxygen).
- 50–75 mL alcohol in the 500-mL flask
- 250 mL alcohol in the 2-L flask

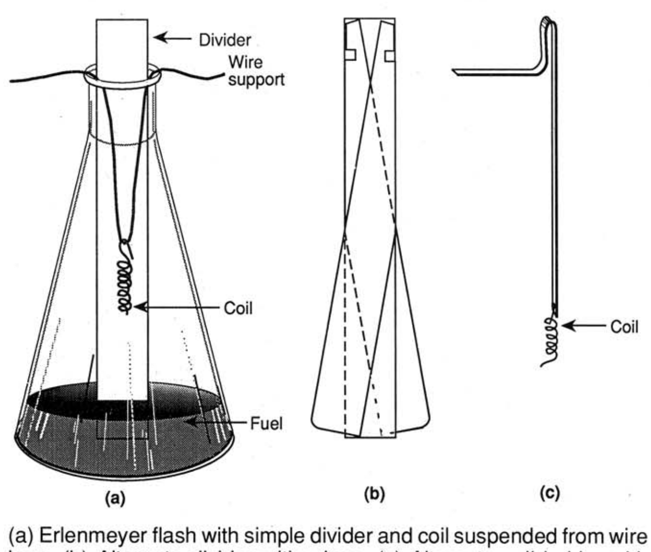
The repeating "exploding" flask is shown in the figure and can be a 500-mL, 1-L, or 2-L Erlenmeyer flask. We have not tried smaller flasks, and our experiments with larger flasks have been unsuccessful. Of course, the loudness of the bang is related to the size of the flask.

The most successful way of ensuring an adequate supply of alcohol vapor is to boil the alcohol and then quickly to pour the alcohol into the reaction flask. With methanol it is usually sufficient simply to boil the alcohol in the flask.

A metal divider made of some inert material (we used a galvanized sheet 0.3–0.5 mm thick) creates the draught necessary to ensure an adequate supply of air after each explosion. The sheet should be longer than the depth of the flask, and the width of the sheet should allow it to just pass through the neck of the Erlenmeyer flask. Part b of the figure shows an expanding style of divider.

The catalytic coil is wound to have a 3–5 mm diameter and is made from a 10–15-cm length of 0.3–1-mm diameter wire. The coil should be about 2–4 cm in length.

After the alcohol has been poured into the reaction flask, the coil, suitably suspended from an inert V-shaped metal wire (we used copper wire) is heated in a Bunsen flame (or an alcohol burner flame) and quickly suspended in the reaction flask. The position of the coil with respect to the alcohol surface is important, and we found it best to suspend the coil about halfway down the flask. Within minutes the "bangs" should begin. It takes longer for the explosions to start with ethanol contrasted to methanol. There is frequently an initial explosion. An alternate method for intro-



(a) Erlenmeyer flash with simple divider and coil suspended from wire loop. (b) Alternate divider with wings. (c) Alternate coil holder with long handle. Coil is held in place with a set screw.

ducing the coil is shown in part c of the figure using a support with a handle.

Not all of the metal and alcohol combinations we tried worked. Our results showed that platinum or palladium in methanol to be the best combinations. A summary of some of our results is given in the table.

Experiments with 2-propanol proved to be unsuccessful as did experiments with copper, steel, and nickel–chromium alloy. Silver did work for a short while with methanol but then the metal melted! The "sometimes successful" metals appeared to develop an oxide coating that, after a few explosions, effectively poisoned the catalyst.

Catalyst/Fuel Combinations

metal catalyst	methanol	ethanol	1-propanol
platinum	A	A	S
palladium	A	A	S
nickel	A	S	N
nickel–copper	A	S	N
silver	S	S	N

A, always successful; S, sometimes successful; and N, not successful.

The variability of these reactions is one of the charms of the demonstration. The periodicity and even the loudness of the explosion (from little "poofs" to loud bangs) depend very much on local conditions such as the vapor pressure of the alcohol, and the amount of oxygen in the flask (which depends on the length and the efficiency of the "chimney" divider). Turning out the lights makes the effect more dramatic.The explosions will continue while the alcohol vapor remains, and we have run them for several hours. The explosions are stopped by removing the coil.

Cautions

- Sometimes, the alcohol vapor ignites as the coil is lowered into the flask, and burns at the mouth of the flask. This is due to the alcohol being too hot. The flame can be quickly and simply extinguished by placing a damp cloth over the top of the flask and smothering the flame.
- Care must be taken in handling the wire coil holder (part a of figure), which gets very hot. It, too, should be handled with a wet cloth. The handle/coil-holder (part c of figure) is safer in this regard.
- The flask gets very hot in a short time and should be handled carefully. We have never experienced any breakage, but as a precaution you should **always have a fire extinguisher handy.**
- If you experience a build-up of formaldehyde fumes (especially in a small room), you should conduct the demonstration in a hood.

Occasionally the explosions do not start (rarely with the platinum, palladium and methanol combinations). This may be due to

the solvent not being hot enough
the coil not being initially hot enough
there being insufficient oxygen in the flask.

The first two problems may be remedied by reheating. The last problem can be overcome by carefully blowing air into the back half of the flask, using a piece of tubing.

Depending on the audience, this demonstration can be solely used for fun or for illustrating chemical principles such as combustion and catalysis. The advent of exhaust catalytic converters for automobiles makes this a topical experiment and highlights the importance of the foremost industrial catalysts—platinum and palladium.

This is one of the most popular demonstrations we do.

Delayed Explosions

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Delayed explosions are one of the sure-fire demonstrations we have been doing for some time. In these demonstrations, a container is filled with a fuel through a hole in the bottom, and a flame is lit at a small orifice at the top. After the flame burns quietly for a period of time there is a sudden, loud explosion. This paper describes some systematic studies of these explosions and gives some results and parameters that should prove useful in doing these demonstrations safely.

Our studies began with the most commonly used combination: Pringles potato chip cans and hydrogen gas (*1*). The potato chip cans have the advantages of being inexpensive and easily available. Further, they are made of light-weight cardboard and have a metal seal at one end and a replaceable plastic lid at the other. In our investigations, we tested a variety of other containers and also tried natural gas (primary constituent is methane) as another fuel. The types of containers and their relevant dimensions are given in Table 1.

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Pringles Cans

We will first discuss what happens in a Pringles can and then extend the discussion to the other containers tested. The orifices drilled in the center of the metal end ranged from 2 to 7 mm in 1-mm increments. The bottom openings (in the plastic lid) were 25.4, 38.0, 50.2, and 72.5 mm. The largest opening was obtained by using the tube without the plastic lid.

The procedure for filling a container with the gaseous fuel was the same in all cases. A 25-cm tube at the end of a sufficiently long piece of rubber tubing connected to the gas supply was inserted as far into the container as it could go. The gas was turned on and some was allowed to escape through the orifice. *This is important for complete and reproducible filling of the containers.* When using just one container, the orifice was sealed with a finger tip. The gas-filling tube was slowly removed, with care being taken to move it around the inside of the container while doing so. Once the tube was removed, the gas was turned off.

The container must be held in the vertical position because both hydrogen and natural gas are less dense than air. The container is then seated in a suitable safety holder, such as that shown in Figure 1, which permits air to flow

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