FLASHBACK AND LAMINAR FLAMES
A Classroom Demonstration

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This demonstration is ideal for a presentation topic related to flashback and laminar flames. Fires require four components (the fire tetrahedron):[1] fuel, an oxidant, an ignition source, and a chain reaction. A good reference source on flammability is Crowl and Louvar's[2] Chapter 6.

Flammability of liquids is characterized by their flash point and their upper and lower flammability limits. The flash point is the minimum fluid temperature at which the vapor over the liquid, in air, can be ignited. The flash point is easily measured and easily understood; it is used by the NFPA and by fire departments across the USA for hazard ratings of flammables. Any fuel with a flash point below 37.7°C (100°F) is termed a "Class 1" flammable. Both gasoline and ethyl alcohol are Class 1 flammables with flash points of -43°C and 13°C, respectively. Note that the vapor over gasoline is flammable at temperatures far lower than alcohol. At ordinary ambient temperatures, however, the equilibrium vapor over alcohol can be far more hazardous than the equilibrium vapor over gasoline. This can be demonstrated in the manner described below.

VAPOR FLAMMABILITY DEMONSTRATION

Required equipment:

- *Two, one gallon "F"-style metal cans, with closures. (One gallon plastic containers may be used; see details below.)*
- *A small supply (100 ml) of reasonably fresh gasoline. (Coleman fluid works well.)*
- *A similar supply of denatured alcohol. The denatured alcohol sold in hardware stores is suitable.*

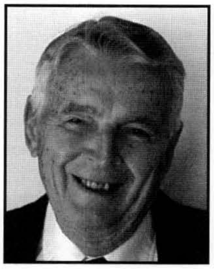
To carry out the experiment, add about 10 ml of gasoline to one of the cans and a similar amount of alcohol to the other. Close the cans, shake well, and wait about 60 minutes at ambient temperature to permit vapor equilibration. Remove the cap from the gasoline-containing can and pass a small ignition source (match flame, lighter flame, etc.) over the opening. A small, stable laminar flame will appear and will continue to burn quietly for many minutes.

The experimentalist should wear a face shield, a long-sleeve shirt, and leather gloves when igniting the cans. Also, a portable visible shield can be placed in front of the cans for further protection.

Next, remove the cap from the alcohol-containing can and present a similar flame at the opening, taking care to keep fingers, etc., well away from the opening. A flashback will occur, accompanied by an angry noise (a "whoosh").

CAUTION: *Make sure that the can opening (the spout) is unobstructed. Ignition of alcohol vapor in an unvented can or through a small opening may cause the can to burst with considerable violence. Cans with openings less than 2 cm in diameter can deform, and cans with openings less than 1.3 cm in diameter can burst.*[3]

The demonstration can also be carried out in a plastic 1-gallon juice or milk high density polyethylene (HDPE) container (spout opening of about 3 cm) for an even more visual effect. In our testing, the HDPE didn't ignite during the demonstration (recall the fire tetrahedron requirements). In fact,



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it took a direct flame from a propane torch to get the HDPE to ignite, and then only a mild flame ensued.

Differences in the ignition behavior of equilibrium alcohol vapor and gasoline vapor follow from differences in flammability limits. Vapor mixtures containing just the right proportion of fuel to combine with the available oxygen, so-called oxygen-balanced mixtures, are obviously most energetic. Mixtures on either side of the oxygen balance may also be flammable. The range of compositions on either side of the oxygen balance that will support combustion is characterized by a lower flammability limit (LFL) and an upper flammability limit (UFL). It is conventional to define these limits in terms of volume percent of "fuel" in the vapor. For example, handbook data indicate that gasoline has an LFL of about 1.3 volume % and a UFL of about 7.6 volume %. Ethyl alcohol has a LFL of about 3.3 volume % and a UFL of about 19 volume %.[2]

We are now in a position to understand the difference in flammability of gasoline and alcohol vapor as demonstrated in the experiment. The equilibrium vapor pressure over gasoline at common ambient temperatures is quite high. For example, at 21°C the vapor pressure is about 0.46 bar. Accordingly, gasoline vapor concentration above the liquid is about 46 volume % at this temperature, far above the 7.6 % UFL of gasoline. (Those who have tried to start a "flooded" gasoline engine have experienced the UFL phenomenon). If a gasoline container is open to the atmosphere at its spout, there will be a diffusion region containing a flammable air/gasoline mixture. Ignition will lead to a fire front in the form of a calm laminar flame, as observed in the demonstration. In contrast, the equilibrium vapor over ethyl alcohol at 21°C contains about 5.9 volume % alcohol (vapor pressure of 0.059 bar), well within the flammable limits and very near the stoichiometric ratio for complete combustion to CO_2 and H_2O (5.7% alcohol in air). In a closed container, or one with a restricted opening, the mixture inside the container is flammable, as observed.

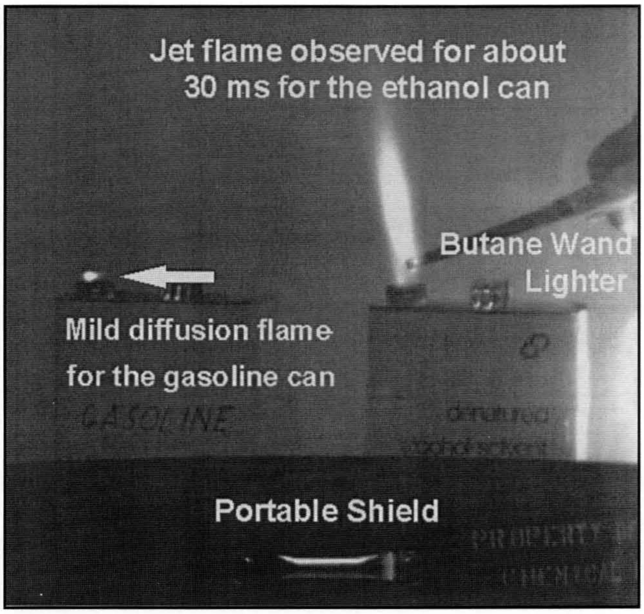

Figure 1. *Photograph of demonstration. Peak jet flame appeared about 400 ms after the butane lighter flame was brought near the spout.*
(Oxford Lasers, Inc., Littleton, MA, is gratefully acknowledged for assistance in obtaining this photograph.)

One may ask under what conditions will gasoline-can flashback occur? This can happen if the can is equilibrated at temperatures well below 0°C, something not easily done in the classroom. Another possibility, confirmed by our testing, is to reduce the quantity of gasoline to match the oxygen balance inside the can. This quantity is around 1 ml, well below the 10 ml recommended. Thus, shaking the can in the classroom beforehand and listening to the gasoline swirl around inside ensures that enough gasoline is present to prevent flashback.

Professors can designate as homework an assignment that consists of looking up the flammable properties of gasoline and ethanol (denatured alcohol). Later, the students can write a short essay as to why the results are what they observed. Other assignments could include the determination of the vapor composition in a confined container via the Antoine equation and comparing it to the flammability limits of the materials. Or alternatively, using the published LFL, stoichiometric (oxygen balance) amounts and UFL, students can calculate (via the Antoine equation) the temperatures that match the vapor pressure/composition given by these three quantities for each material.

ACKNOWLEDGEMENT

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REFERENCES

1. See, for example, http://www.firesafety.umaryland.edu/chemistryfire_of.htm
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3. Shanley, E.S., "The Safety of Small Containers for Flammable Fluids," *J. Chem. Edu.*, **65**, A6 (1988) ❐