A permanent demonstration of vapor pressures of solids, liquids and mixtures

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A final approach is to mix Solutions A and B together and dip heavy-weight filter paper into the reaction mixture while in a darkened area. The treated paper is then dried in the dark and becomes a type of blueprint paper. When the surface of the paper is covered with an object and subsequently exposed to intense light such as sunlight, an overhead projector, or a photo flash, the outline of the object is clearly shown. This also can be preserved by rinsing the paper free of excess reactants.

Cautions

Both the oxalic acid and potassium ferricyanide are skin irritants and are toxic. Appropriate care should be taken in handling them and their solutions.

Solution B should not be stored longer than one week due to the gradual hydrolysis of the ferricyanide ion which liberated hydrogen cyanide in the presence of oxalic acid.

Simple Demonstrations of the Liquefaction of Gases

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The states of matter and changes in state are important topics in both introductory and advanced chemistry courses. Students learn that a gas can be liquified by lowering its temperature or, if it is below its critical temperature, by applying pressure. These topics are especially relevant to processes such as refrigeration[1] and the liquifaction of natural and propane gases.[2] Natural gas is mostly methane, which has a critical temperature of −82.3°C.[3] It must be cooled below that temperature in order to be liquified, while propane, with a critical temperature of 96.8°C,[3] can easily be liquified at ambient temperatures simply by applying pressure. These phenomena can be readily demonstrated to students by means of the gases butane and Freon 114 ($C_2Cl_2F_4$). Butane is readily available in the form of canisters used to fill cigarette lighters. However, these canisters do contain a mixture of isomers, and one might prefer to obtain a lecture bottle of pure butane from a chemical company. Freon 114 is relatively inexpensive and can be purchased from many of the chemical supply companies in the form of lecture bottles.

Freon 114 has physical properties that make it particularly well suited to these demonstrations. Its normal boiling point is 3.77°C,[3] and it has a heat of vaporization of 23.2 kJ/mol.[3] By applying the Clausius-Clapeyron equation to this system, it can be shown that the vapor pressure of liquid Freon 114 is 1.75 atm at 20°C and 2.05 atm at 25°C. Therefore, if one applies such pressure to a sample of Freon 114 contained in a syringe, liquifaction of the gas will be observed.

The critical temperature of Freon 114 is 145.7°C,[3] and the critical pressure is 32.2 atm.[3] It is interesting to compare Freon 114 to nitrogen, the main constituent of air. The boiling point of nitrogen is −196°C, and its critical temperature and pressure are −147°C and 33.6 atm, respectively.[3] It is informative for students to compare the compressibility of Freon 114 to that of air. The students are amazed that the Freon can readily be compressed about a hundred-fold and liquified, while air can only be compressed about five-fold and can not be liquified at room temperatures.

In addition to being able to liquify Freon 114 by applying pressure to it at room temperature, one can also liquify it by immersing it in an ice bath that would be almost four degrees below its boiling point. The enormous change in volume is quite striking to the students.

The properties of butane are comparable to those of Freon 114. It boils at −0.50°C and has a heat of vaporization of 24.3 kJ/mol.[3] Its critical pressure and critical temperature are 152.3 atm and 37°C, respectively.[3] A comparison of these values suggests that butane would be more difficult to liquify than Freon 114. Application of the Clausius-Clapeyron equation indicates that a pressure of 2.1 atm at 20°C and 2.5 atm at 25°C must be applied in order to liquify this gas. It is found that the butane sample has to be cooled somewhat in order to be easily liquified if a 50-ml syringe is used. A syringe with a smaller plunger diameter is preferable to use with the butane sample. The major reason why the butane sample is so much more difficult to liquify is that it contains a mixture of isomers of butane.

Procedure

The force needed to be applied to a syringe in order to achieve a given pressure will depend inversely on the area of the plunger. It has been found that B-D syringes of 50-ml capacity work well for Freon, but syringes of smaller capacity and plunger diameter are easier to use for butane.

In order to fill the syringe, it is necessary to have a means of closing the delivery end. A Pharmaseal three-way stopcock available at many medical supply companies is particulary well suited for this purpose. Luer-Lok syringe tips will also work, but some air will probably be left in the syringe after filling. If the three-way stopcock is available, connect one end to the syringe, another to the gas tank, using suitable tubing, and leave the third open to the atmosphere. Open the valve between the syringe and the atmosphere, and completely empty the syringe. Next open the valve between the syringe and the gas tank, and allow the gas to push the plunger slowly back to the desired position. Repeat the procedure several times in order to flush out all of the air. Once the syringe is filled to the desired capacity and the valve is securely closed, the demonstration can be used for several days before refilling is required.

It is instructive to compare the compressibility of Freon or butane with that of air. The former are easily liquified while the latter cannot be liquified at room temperature. In order to see the liquid in the syringe, the students should be within a few feet of the demonstration. In a small class, this can be accomplished by either walking the demonstration around the room or allowing the students to do the demonstration themselves. In a mass lecture, the syringe can be projected onto a screen by means of an overhead projector. The droplets of liquid are readily observed after the syringe is compressed. Upon releasing the pressure, the liquid appears to boil and quickly disappears.

In order to demonstrate the liquification of the gas by lowering the temperature, a balloon filled with the gas can be used. It is essential that the balloon be filled and emptied several times so that all air is flushed out. When the balloon is immersed in an ice-water bath or better yet a ice-salt-water bath, it readily shrinks in size as the gas turns to a liquid. Upon placing the cold liquid in a container of warm water, a rapid expansion of the balloon occurs as the liquid vaporizes.

Safety Precautions

Preparations should be done under a hood or in a well-ventilated area. Butane is flammable and so care must be taken to avoid fires.

Acknowledgment

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[1] Sears, F. W.; Zemansky, M. W.; Young, H. H. "University Physics", 5th ed.; Addison-Wesley: Reading, MA, 1976; pp 338, 339.

[2] Chang, R. "Chemistry", 2nd ed.; Random House: New York, 1984; pp 280–285.

[3] "Handbook of Chemistry and Physics", 63rd ed.; The Chemical Rubber Co.: Cleveland, OH, 1982–3; (Sections on Physical Properties of Fluorocarbon Refrigerants and Critical Temperatures and Critical Pressures of Organic and Inorganic Compounds).