tested demonstrations

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An Experiment To Demonstrate the Application of the Scientific Method

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The introductory course in chemistry at West Los Angeles College is taught on the basis of the scientific method. We emphasize the observation and the interpretation of facts to form hypotheses as to the nature of matter, in keeping with the approach taken by the CHEM Study course[1].

We have developed a deceptively simple experiment to encourage our students to follow the principles of the scientific method. The experiment is merely the heating of a beaker of water until it boils vigorously. Yet, there are several scientific principles that are illustrated that may be utilized as vehicles for further discussion. In that it emphasizes the importance and value of careful observations, it is similar to the CHEM Study burning candle experiment[2].

This experiment is performed late in the semester, after the topics involved have been covered in class. It is performed as a demonstration, with the instructor guiding the students in making the observations. The students are told to observe the facts at each part of the experiment and to write them down in their notebooks. The report that each student is asked to prepare is composed of the observed facts and proposed hypotheses to explain them.

The Experiment

The experiment that we do is as follows:

1. Partially fill a beaker with cold tap water, dry the outside of the beaker, and place it on a ring stand on a plain wire gauze. Place a burner under the beaker.
2. Turn on, but do not light the gas.
3. After approximately 20 s, light the gas.
4. Heat the beaker to boiling.

The Observations

The observations that the students are encouraged to make are

1. The water from the tap may be cloudy (this depends upon your water supply).
2. The cloudiness, if present, will disappear quickly. The beaker and its contents will be dry on the outside and the contents clear.
3. Turning on the gas produces no change in the appearance of the beaker and its contents.
4. Immediately after the burner has been lit, the outside of the beaker becomes covered with moisture and assumes a frosty appearance.
5. As the water is heated, the condensation on the outside of the beaker starts to clear up, and small bubbles start to appear throughout the body of the liquid, some sticking to the walls of the beaker.
6. As the heating continues, the moisture on the outside of the beaker vanishes completely, and the rate of evolution of the small bubbles decreases. Eventually no bubbles can be seen.
7. Continued heating produces bubbles that start at or near the bottom of the beaker. These bubbles eventually break loose and rise to the top of the water. As the heating continues, the rate of bubble formation at the bottom of the beaker increases, and the bubbles get larger and break the surface with great vigor.

After the observations have been made, the students are asked to hypothesize as to the causes of their observations. This is assigned as homework.

The Deductions

The explanation of these observations should include:

1. The cloudiness in the tap water is due to the presence of air in the water to form a heterogeneous mixture.
2. Clearing of the heterogeneous mixture is due to the escape of the air mixed with the water.
3. The gas itself from the burner produces no change in the appearance of the beaker, so that the moisture that appears in the next step does not come from the gas.
4. The water that condenses on the beaker comes from the heavily moisture-laden gas produced by the flame, as the gas (usually methane) burns to produce water and carbon dioxide. The temperature of the water in the beaker is now lower than the dew point of the moisture-rich gases produced by the burning methane.
5. As the water in the beaker warms up, the temperature of the beaker exceeds the dew point of the gases flowing past it, and the water on the beaker starts to evaporate. The bubbles that start to form are due to dissolved oxygen (a homogeneous mixture). The solubility of gases in liquids generally decreases with increasing temperature, so that as the solubility is exceeded, the oxygen is evolved.
6. As the amount of oxygen dissolved in the water gets reduced, the rate of evolution decreases, until no more oxygen is evolved.
7. The boiling point is reached and boiling starts.

Summary

This simple experiment illustrates the principles of the scientific method in that an experiment is designed, observations are made, and hypotheses are proposed to explain the observations. During the discussion of this experiment many topics may be addressed, including absolute and relative humidity, solubility of gases in liquids as a function of temperature, heterogeneous and homogeneous mixtures, products of chemical reactions, phase changes, definition of temperature, changes in refractive index, etc. The distance of the audience from the demonstration is critical. Certainly if students are very close (or closed-circuit TV with monitors is used), more detail may be observed. Without TV projection, the demonstration should be limited to a class of 50.

[1] Malm, L. E., Ed. *Laboratory Manual for Chemistry;* Prepared by Chemical Education Material Study; Freeman: San Francisco, 1960.

[2] McClellan, A. L.; MacNab, W. K.; et al. *Teacher's Laboratory Guide for Chemistry: Experiments and Principles;* Heath: Lexington, MA, 1968.

The Liquid Phase of Carbon Dioxide: A Simple Lecture Demonstration

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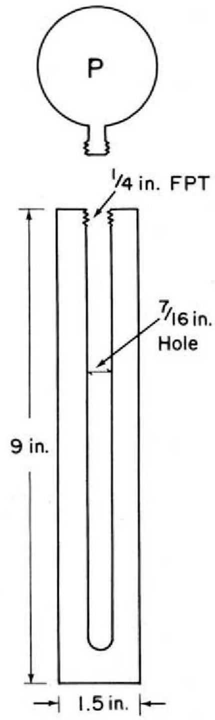
In teaching first-year university chemistry over 20 years, I have noticed that students are intrigued by dry ice in general and by the *lack* of a liquid phase at normal pressures in particular. In order to demonstrate that the liquid phase may be observed at higher pressures, I have developed a



The apparatus.

simple lecture demonstration to reinforce textbook discussions of phase equilibria.[1,2] (This demonstration is not designed to show the critical region, which is the subject of other resports,[3,4] owing to the potential danger to students from the high pressures required.) The figure shows a simple "test tube" made of transparent Plexiglas 1.5-in.-o.d. rod stock. A 7/16-in. hole was drilled to within 1/2 in. of the bottom of the rod and the top entrance was threaded with nominal 1/4-in. female pipe threads to take a standard pressure gauge of range 0–160 psig.

For the lecture demonstration, the tube at room temperature is half filled with crushed dry ice, and the pressure gauge is screwed into place. In about 1 min the pressure increases from atmospheric as the temperature increases from the normal sublimation temperature (−78.1 °C) until the triple-point temperature (−56.6 °C) and pressure (5.1 atm absolute or 61 psig) are reached. The pressure remains constant while the dry ice melts into a liquid that can be clearly observed in the bottom of the Plexiglas tube. Further increase in temperature causes bubble formation in the liquid and the pressure increases along the liquid–vapor-phase isotherm boundary line. At approximately 120 psig it is prudent to unscrew the gauge partially to release CO_2 pressure and return the CO_2 system to the triple point, where some of the liquid refreezes. This can be observed by the students. Further release to pressures less than 61 psig gives only solid dry ice without liquid. This liquefaction cycle can be repeated until the sample is exhausted. As the inside of the Plexiglas tube cools, a longer time is required to build up sufficient pressure to liquefy CO_2.

Two modifications to the simple tube shown in the figure would be useful for many demonstrators. Another 7/16-in. hole could be drilled in the side of the tube 2 in. from the top, and a small "pop-off" pressure–release valve set to release at 120 psig could be permanently installed. This automatic pressure release would remove the urgency of unscrewing the gauge as pressure increases. The more elaborate addition of a 1/4-in. female pipe cross and nipple to the top of the Plexiglas tube provides ports for a hand-operated valve, a pressure–release "pop-off" valve, and the pressure gauge. The valve allows pressure releasing and recycling the process without unscrewing the gauge. A pressure-release pop-off valve set to release at 120 psig would minimize the possibility of an accident and is strongly recommended.

After several cooling cycles the *inside* surface of the Plexiglas tube developed cracks of less than 1/32 in. in depth that reduced the transparency of the tube. These cracks are probably due to thermal shocking of the Plexiglas and should not affect the structural integrity of the tube. It is prudent to wear safety goggles and gloves when performing this demonstration and to *release pressure at some safe limit* (120 psig has proved safe for this tube).

[1] Mahan, B. H. *University Chemistry*, 3rd ed.; Addison–Wesley: Reading, MA, 1975.

[2] Segal, B. G. *Chemistry;* Wiley: New York, 1985.

[3] Smith, S. R.; Boyington, R. J. *J. Chem. Educ.* **1974,** *51*, 86.

[4] Banna, M. S.; Mathews, R. D. *J. Chem. Educ.* **1979,** *56*, 838.