Entropy Bomb

Demo Grand Prix
19th BCCE
Purdue University

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Chemical Concepts

This demonstration illustrates numerous concepts and can be used to illustrate any of them individually or to tie them together. The chemical concepts illustrated are: entropy, conversion of heat to work, P-V work, endothermicity, and spontaneity. This demonstration could also be used to illustrate geysers in a geology class.

How the Demonstration Illustrates these Concepts

Liquid nitrogen in a closed container evaporates and builds up pressure until the container bursts. This provides a dramatic example of work, specifically, P-V work. However, many of the concepts listed above are abstract, and the presenter must point them out to the students. What the presenter says depends upon the level of the audience, and sample commentaries are given below.

Preparation

Prior to the start of the demonstration, a 30-gallon plastic garbage container is placed on a flat surface outdoors (placing it on cement gives a more dramatic result) and filled with water. (This demonstration should not be done indoors!) Also, a 20- or 24-oz plastic soda bottle is securely attached to a weight (at least 3 kg) using string. Taping the bottle to the weight is not recommended. Place the weight and bottle on the ground next to the garbage container.

Presenting the Demonstration

Safety

Liquid nitrogen is extremely cold and can cause frostbite. The presenter might want to wear winter gloves for screwing the lid on and handling the bottle. Once sealed, the bottle is essentially a time bomb and highly dangerous. The explosive force of the bottle could break bones or cause loss of fingers. Do not fill the bottle over one-half full of liquid nitrogen! If the bottle gets free from the weight (string breaks, knot comes untied, etc.) during the presentation, do not attempt to retrieve it! The bottle will float on the surface of the water if it is not attached to the weight; just let it explode and try again.

Presentation

Using a funnel, fill the soda bottle about one-third to one-half full of liquid nitrogen. Screw the cap on the bottle tightly and quickly drop the bottle and weight in the water. Move back at least ten feet. After 15-30 seconds, the bottle will rupture, and the released gas will cause the water in the garbage container to shoot up into the air.

Sample Commentaries

As noted earlier, the concepts that the presenter discusses depend on the audience. I typically present this demonstration for general chemistry students or for physical chemistry students. Here I provide examples of what I say to each class as I perform this demonstration. Actions are listed in brackets []. I ask the class questions to make sure that they are thinking about the chemistry behind what they are about to see. (Expected answers follow the questions in parentheses.)

General Chemistry

[Stand next to the garbage container, bottle and weight at my feet.] What is work? (Transfer of energy because of imbalanced forces) What type of work have we studied? (P-V work, expansion/compression of gases) [Pour a little liquid nitrogen onto the ground.] What did the nitrogen just do? (Evaporate) What is the thermicity (exo/endo) of evaporation? (Endothermic) Where is energy flowing, from where to where? (From surroundings to system) Here in this demonstration, what is the system and what is the surroundings? (Liquid nitrogen is system, water is surroundings)

OK, if a process is endothermic, can it be spontaneous? (Yes) What must be true? ($\Delta S>0$) Is that the case for evaporation? (Yes) Why? (Increase in the number of moles of gas) [Pout liquid nitrogen into the bottle] OK, once I seal this, it is basically a time bomb (students typically take several steps back upon hearing this). [Screw on cap, quickly place bottle and weight in water] As the nitrogen evaporates, pressure builds up until…

Physical Chemistry

[Stand next to the garbage container, bottle and weight at my feet.] What will happen when I pour liquid nitrogen into the bottle? (Evaporate) What is the thermicity (exo/endo) of evaporation? (Endothermic) Endothermic means energy flows from where to where? (From surroundings to system) Here in this demonstration, what is the system and what is the surroundings? (Liquid nitrogen is system, water is surroundings) OK, the liquid nitrogen will evaporate; what will happen to the pressure in the bottle? (Increase) Eventually, what will happen? (The bottle will burst) What type of energy transfer will happen then? (Work, specifically P-V work)

OK, if a process is endothermic, can it be spontaneous? (Yes) What must be true? ($\Delta S>0$) Is that the case for evaporation? (Yes) Why? (Increase in the number of moles of gas) [Pout liquid nitrogen into the bottle] OK, once I seal this, it is basically a time bomb (students typically take several steps back upon hearing this). [Screw on cap, quickly place bottle and weight in water] As the nitrogen evaporates, pressure builds up until…

Fostering Learning

Before starting the demonstration, I hand out a "quiz" that I tell the students they must fill out and hand in at the beginning of the next class meeting. Here are some common questions that I ask

General Chemistry

1. I added about 100 mL of liquid nitrogen (N_2) to the 20 oz. soda bottle and dropped it in the container of water. This is a scientific experiment ☺ so describe your observations.

2. How many moles of N_2 are in 100 mL of liquid nitrogen? You will need the density of liquid nitrogen for this calculation. You can find it on the Internet, but be careful! You can't believe everything you read on the Internet. Hint: liquid N_2 is less dense than water.

3. The volume of the bottle was(!) 591 mL. Assuming all of the liquid N_2 evaporated and that the temperature of the gas in the bottle was about 0ºC, calculate the pressure of the N_2 gas in the bottle.

4. When the bottle exploded, the N_2 gas expanded into the atmosphere until its pressure equaled the atmospheric pressure. The atmospheric pressure is about 1.0 atm, so calculate the volume the N_2 would occupy at that pressure.

5. Does the surroundings do work on the system, or vice versa?

6. The amount of work done can be calculated using the formula $w = -P_{ext}\Delta V$. P_{ext} is the pressure against which the gas expanded, 1.0 atm. Calculate the amount of work done in the experiment. You will get strange units, atm·L. This can be converted to more familiar energy units using 1 atm·L = 101.325 J.

7. Does the sign of your answer for #6 agree with your answer for #5? Why or why not?

8. Write a summary paragraph that describes the process that occurred. Include the identity of the system and surroundings, the direction of heat flow, the reason that the process was spontaneous, the direction of work done, and the amount of work that you calculated was done.

Physical Chemistry

1. Summarize the energy flow in this process, starting with the evaporation of the liquid nitrogen and ending with the explosive escape of the gas.

2. What does your answer to #1 tell you about heat and work?

3. Was the process reversible or irreversible? Justify your answer.

4. Assuming that the nitrogen expanded against a constant pressure of approximately 1.0 atm, calculate the work done by the nitrogen. About 100 mL of liquid nitrogen was added to the bottle; assume it all evaporated and that the temperature of the gas in the bottle was about 0°C.

5. Would this process be the way to get the maximum amount of work out of the expanding gas? Why or why not?