Thermo Demos

A teaching experiment produced by

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Concepts to explore in this lab:

- Laws of thermodynamics
- Expansion and compression of gases
- Expansion of solids
- Entropy

Course learning goals to accomplish:

- State and formulate the first law of thermodynamics.
- Interpret the signs use for work, heat, change of energy of the universe and surroundings.
- Compare the different types of gas expansions.
- State and formulate the second law of thermodynamics.
- Apply the second law of thermodynamics.

THERMO DEMOS

Thermodynamics

Thermodynamics is the science that studies the transformation of heat into other types of energy and vice versa; it is also a macroscopic science concerning such properties as pressure, temperature, and volume. Classical thermodynamics is based on the following four laws:

Zeroth law

If two bodies are each in thermal equilibrium with a third body, then they are also in thermal equilibrium with each other.

First law

The change in the internal energy of a system (ΔU), during a thermodynamic process, equals the heat (q) added to the system, minus the work (w) the system performs on its environment. $\Delta U = q + (-w)$. The internal energy U of an isolated system is constant.

Second law

For any process that proceeds in an isolated system, there is a unique direction of spontaneous change and the change of entropy $\Delta S > 0$.

Third law

The entropy of a perfect crystal at a temperature of zero Kelvin (absolute zero) is equal to zero.

Enthalpy and Entropy as Driving Forces

The heat release or absorbed during a chemical reaction at constant pressure (q_P) defines the enthalpy change of the reaction ($\Delta_r H$). When heat is released by an exothermic chemical reaction to the environment, the entropy of the surroundings increases by a magnitude of $-\frac{\Delta_r H}{T}$.

Enthalpy and entropy are the two factors that indicate whether a change can occur spontaneously. These two factors sometimes work in unison and sometimes oppose each other. When they oppose each other, the spontaneity determinant is the factor that is larger. That larger factor is called the driving force in determining spontaneity.

The thermodynamic property that relates the entropy and enthalpy changes along with the temperature is called the Gibbs free energy (G) change. When the free Gibbs energy change (ΔG) of a process is negative, the process is said to occur spontaneously; if the ΔG is positive, the process is non-spontaneous. The equation for the free Gibbs energy change of a system under conditions of constant pressure and temperature is:

$$\Delta G = \Delta H - T\Delta S$$

Therefore, the sign of ΔG depends on the magnitudes and signs of ΔH and ΔS; as well as the value of the temperature. A reaction could be spontaneous at a low temperature but if the reaction is carried out at a higher temperature it may become non-spontaneous.

PART ONE

Pre-experiment Questions (write answers on your notebook)

1. Read appendix A and write three bullet points of what you learnt.
2. If you have a gas trapped in a syringe (see picture on the right) and you decrease the volume considerably, **do you think** the temperature of the gas increases or decreases or does not change? Explain.
3. If you have water vapor inside an open soda can at 212 ^{o}F and suddenly you change the temperature to 32 ^{o}F, what **do you think** if will happen? Explain.
4. If you have a ball and ring set (see picture on the right), the ball can go through the ring completely if they are well made. **Do you think** the latter will change if you cool down the ring to -320 ^{o}F ? Explain

General Protocol (Read entire protocol before starting the experiment)

In this laboratory, you will complete several small experiments, your professor will assign to you the first experiment for you to carry out; after you finish that experiment, you will move to the next one until you finish all the experiments. Make sure you leave everything clean for the next group. This laboratory is only one part so you should complete the whole lab in one lab section. Feel free to take pictures or record videos of the experiments.

Experiment

Note: clean and organize all the materials after you finish each experiment.

Fire Syringe:

5. Make sure the inside of the tube is dry and clean, if not use a Q-tip or paper towel to clean it.
6. Take a small piece of cotton with a set of tweezers and place it at the bottom of the tube.
7. Insert the plunger tube into the syringe tube.
8. Place the fire syringe on top of the foam.
9. Raise the plunger to its highest point.
10. Hold the syringe tube firmly and quickly push down on the plunger and write your observations.
11. Repeat numerals 2-7 one time and make sure you push the plunger down strongly.

Imploding Can:

12. Fill a 2000 mL beaker with approximately 1500 mL of water.
13. Completely fill with ice a 150 mL beaker, then add the ice to the water.
14. Take an empty soda can and put about 45 mL of water.
15. Heat it up over a Bunsen burner until the water starts boiling and boil it for 15 seconds.
16. Turn off the flame, bring the can above the beaker with water, turn the can upside down, and submerge it by immersing the can's hole into the cold water. Write your observations.

Ball and Ring:

17. Take a set of a ball and a ring with wooden handles, check if the ball passes through the ring. Write your observations.
18. Using a Bunsen burner heat up the ball for 20 seconds and try to make the ball pass through the ring. Write your observations.
19. Repeat 3 times numeral 15 and write your observation for every repetition.

20. Prepare a cooling bath with a temperature of –40 °C, this can be achieved with a 1:0.8 mass ratio of calcium chloride hexahydrate to ice.

21. Immerse the ring into the cooling bath and leave it there for about 10 minutes, take it out and check if the ball passes through the ring. Write your observations.

Balloon Inversion:

22. Take a 125 mL Erlenmeyer and tightly attach a balloon to the mouth of the flask.
23. Place the Erlenmeyer on a hot plate. Turn on the hot plate and select a medium-low heat setting. Let the Erlenmeyer on the hot plate for 10-15 minutes. Write your observations.
24. Take another 125 mL Erlenmeyer and add about 30 mL of DI water.
25. Place the Erlenmeyer on a hot plate and heat it up until the water starts boiling, let it boil for 30 seconds and remove it from the flask using the hot hands. Immediately attach a balloon to the mouth of the flask and let it cool down on the hot pad. Write your observations.

IF YOU ARE ALLERGIC TO LATEX, PLEASE DO NOT MANIPULATE THE RUBBER BANDS!

Rubber band:

26. Each student in the group will take a rubber band, unless latex allergy. Take the rubber band with your thumbs but do not stretch it! Put it un-stretched near your forehead and touch your forehead with it for a second. Then stretch the rubber band as much as you can and quickly touch your forehead. Did the rubber band feel cooler or hotter? Write your observations.
27. Do the contrary, first stretch the band and touch your forehead with it; then let it shrink and touch your forehead again. Did the rubber band feel cooler or hotter? Write your observations.

28. Hang the rubber band on a clamp attached to one of the supports on your bench and suspend a metal weight on the band. Lower the clamp until the mass in the balance registers 45-55 grams.
29. Cover the balance with the gray foam (see picture on the right) to avoid air currents. Wait until the weight becomes stable to the first decimal (the other two decimals will more likely be changing)
30. One student will start recording a video of the experiment, focusing on the mass display. The other student will start heating up the rubber band using the hair dryer. Place the hair dryer about 1.5 inches from the rubber band and move it up and down to heat up the rubber band. Do this for about minute and repeat this procedure with a new rubber band. Write your observations.

Thinking About the Data

Note: think on the molecular level and then in the macroscopic effect.

Fire Syringe:

31. Think about what you did in the fire syringe experiment, explain the experiment in terms of the molecules of air inside the syringe.
32. will you say the process is a reversible isothermal compression or a reversible adiabatic compression or an irreversible adiabatic compression? Explain your choice.

33. In your experience, did the temperature of the gas changed upon compression? What observation take you to that conclusion?
34. Compare your predictions in numeral 2 with your results in numeral 10 – 11. Why do you think your predictions differ or are the same from your observations (think of key factors)?
35. Compare your results from numerals 31 – 34 with other two groups.

Imploding Can and Balloon inversion:

36. Think about what you did in the imploding can and balloon inversion experiment, explain the experiment in terms of the molecules of water inside the can or flask.
37. What kind of process is this? Explain.
38. Explain why the can imploded and the balloon went inside the flask.
39. Compare your predictions in numeral 3 with your observations in numeral 16. Why do you think your predictions differ or are the same from your observations (think of key factors)?
40. Compare your results from numerals 36 – 39 with other two groups.

Ball and Ring: (solid thermal expansion and compression)

41. Think about what you did in the ball and ring experiment, explain the experiment in terms of the atoms forming the metallic ball and ring.
42. What kind of process is this? Explain.
43. Explain why the ball does not fit in the ring after either heating up the ball or cooling down the ring.
44. Compare your predictions in numeral 4 with your results in numeral 21. Why do you think your predictions differ or are the same from your observations (think of key factors)?
45. Compare your results from numerals 41 – 44 with other two groups.

Rubber band:

46. Based on your observations from numeral 26, decide the sign of ΔH, report the sign (student#1 or #2) in the table below under *from un-stretched to stretched*. Then, compare with your partner and come to a consensus for the sign (group).
47. Based on your observations from numeral 27, decide the sign of ΔH, report the sign (student#1 or #2) in the table below under *from stretched to un-stretched*. Then, compare with your partner and come to a consensus for the sign (group).
48. Based on your observations from numerals 26 – 27, decide with your partner the sign of ΔG for both *un-stretched to stretched and stretched to un-stretched*. Explain your answer.
49. Based on your observations from numeral 30, when you heated up the rubber band, did the band stretched or un-stretched? Explain your answer.
50. Based on your answer from numeral 49, as you heated up the band, did the polymer chains become freer or less free to move?
51. Based on your observations from numerals 30 and answers from numerals 49 – 50, decide with your partner the sign of ΔS. Explain your answer.
52. Discuss your answers for numerals 46 – 51 with the whole class and come to a consensus for the signs of ΔH, ΔG and ΔS in each case.

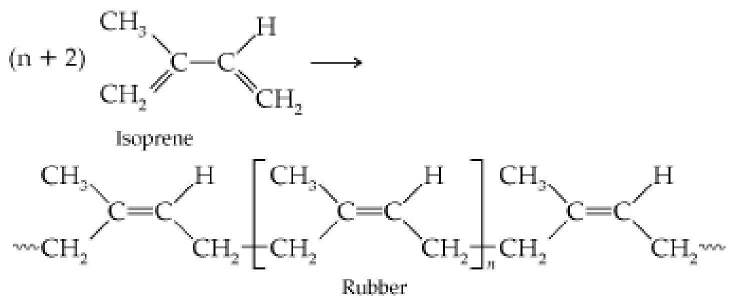
		ΔH	**ΔG**	**ΔS**
From un-stretched to stretched	**Student#1**			
	Student#2			

	Group			
	Class			
From stretched to un-stretched	**Student#1**			
	Student#2			
	Group			
	Class			

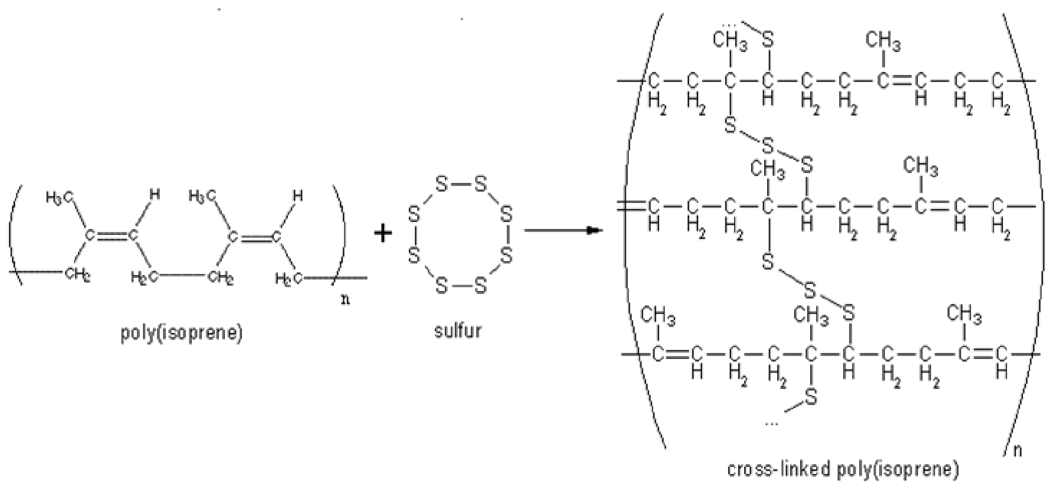
53. Based on your results in numeral 30, how does the temperature affect these thermodynamic properties in analyzed in numeral 52? What process is spontaneous *un-stretched to stretched* or vice versa? Think on the signs of ΔG, ΔH and ΔS for the process. Explain the signs you choose. What is happening at the molecular level to the rubber band when you heat it up? Think if the polymer chains are more or less restricted when they are stretched.
54. Write a few conclusions of what you learnt in this laboratory.

Appendix A: Rubber Bands

Natural rubber is an elastomer (an elastic hydrocarbon polymer) that was originally derived from latex, a milky colloid produced by some plants. The plants would be 'tapped', that is, an incision made into the bark of the tree and the sticky, milk colored latex sap collected and refined into a usable rubber. The purified form of natural rubber is the chemical polyisoprene, which can also be produced synthetically. Natural rubber is used extensively in many applications and products, as is synthetic rubber. It is normally very stretchy and flexible and extremely waterproof.



Latex is a natural polymer of isoprene (most often cis-1,4-polyisoprene) – with a molecular weight of 100,000 to 1,000,000. Typically, a small percentage (up to 5% of dry mass) of other materials, such as proteins, fatty acids, resins and inorganic materials (salts) are found in natural rubber. Polyisoprene is also created synthetically, producing what is sometimes referred to as "synthetic natural rubber".



Natural rubber is often vulcanized, a process by which the rubber is heated and sulfur, peroxide or bisphenol are added to improve resistance and elasticity, and to prevent it from perishing. The development of vulcanization is most closely associated with Charles Goodyear in 1839.

Rubber is a curious material because, unlike metals, strain energy is stored thermally. In its relaxed state, rubber consists of long, coiled-up polymer chains that are interlinked at a few points. Between a pair of links, each monomer can rotate freely about its neighbor, thus giving each section of chain leeway to assume a large number of geometries, like a very loose rope attached to a pair of fixed points. (Retrieved from http://www.madehow.com/knowledge/Natural_rubber.html on April 3rd 2018)