Energy & Entropy of a Stretched Rubber Band
A Lab Investigation

Summary

In this investigation, students work with a real-world item, a rubber band, to explore the concepts of Gibbs free energy, enthalpy, and entropy and their relation to the spontaneity of a physical process. They make observations of any thermal energy absorbed or given off by the rubber band as it is stretched and as it is allowed to contract by touching the band to their forehead. Then, they heat a stretched rubber band and observe whether its length stretches further, contracts, or stays the same.

Objective

Students learn about Gibbs free energy, enthalpy, and entropy, and the idea of assigning positive or negative values to each. They are then related to the spontaneity of stretching or contracting a rubber band.

Safety

- It is recommended that students wear goggles for this investigation, as rubber bands can break and could do so in a student's face.
- When heating the rubber bands, students should be careful not to hold the hair dryer or heat gun on one part of the rubber band for an extended period of time, as the rubber could melt and/or burn.
- If you elect to use the optional high-intensity light bulbs, be aware they get very hot. Also, without some sort of shade, they can be bright for the eyes.

Materials

- Wide rubber band for each student
- Several hair dryers or heat guns for class to share
- Materials for students to design set-up in step 6 (see Lab Tips below)

Time Required

One class period, approximately 45–50 minutes.

Lab Tips

Various lab equipment items could be placed in the laboratory area to inspire students as they design their method in step 6 to test the stretch/contraction of the rubber band as it is heated. These could include: ring stands, clamps, digital balances, weights, rulers, paper clips, safety pins, binder clips, and scissors. Different lab set-ups to measure a change in the rubber band could be:

1. Attach one end of a cut rubber band to a clamp that is attached to a ring stand. Attach a weight to the other end of the band. Adjust so the weight is partially resting on a digital balance, so only part of its weight registers. Any change in the length of the band will result in an increase or decrease in the balance reading.
2. Attach one end of a cut rubber band to a clamp that is attached to a ring stand. Attach a weight to the other end of the band. Use a ruler or other measurement scale next to the weight to observe any change in length. A wooden splint could be attached to the weight, with the end sticking out from the side of the weight, to more easily view any changes.
3. An uncut band could be looped around a doorknob or drawer pull, with a weight or heavy object looped through the bottom of the band. Use a ruler or other measurement scale next to the weight to observe any change in length. A wooden splint could be attached to the weight or object, with the end sticking out from the side of the weight, to more easily view any changes.

The best results are obtained if the band is stretched close to its maximum length. Instead of a hair dryer or heat gun, high-intensity light bulbs could be used.

Pre-Lab Discussion

This investigation introduces the concepts of Gibbs free energy (G), enthalpy (H), entropy (S), and spontaneity. These terms, their symbols, and their connection to each other in the equation $\Delta G = \Delta H - T\Delta S$ could be discussed before the lab; however, the investigation can be done without this discussion.

It can be pointed out that whether a process is spontaneous or not is not related to how quickly the process occurs. Other examples of spontaneous physical changes could be discussed. One common example is the melting of ice, which at ordinary pressures is spontaneous at temperatures above 0 °C.

Integrating into the Curriculum

This investigation would fit into units on thermodynamics and polymers.

TEACHER'S KEY

In this investigation, students work with a real-world item, a rubber band, to explore the concepts of Gibbs free energy, enthalpy, and entropy, and their relation to the spontaneity of a physical process.

Analyzing Evidence

Process	Observations	System absorbs or gives off thermal energy?	ΔH +/–	Process spontaneous? yes/no	ΔG +/–
stretching band (step 3)	*feels warm*	*gives off thermal energy*	–	*no*	+
contracting band (step 4)	*feels cool*	*absorbs thermal energy*	+	*yes*	–
heating band (step 7)	*band contracts*	*absorbs thermal energy*	+	*yes*	–

Interpreting Evidence

1. If the process of a stretched rubber band returning to its original size by contracting was written as the equation: stretched band $\longrightarrow$ contracted band, would "thermal energy" be shown in the equation as a reactant or product? Explain.

   Thermal energy would be shown as a reactant. Thermal energy is added to the system, the rubber band, as it contracts. This is why the band feels cool on the forehead, since energy flows from the forehead to the band.

2. Is allowing a stretched band to contract an exothermic or endothermic reaction? Describe the direction of the flow of thermal energy between the system of the rubber band and its surroundings, which include your forehead.

   It is an endothermic reaction. Thermal energy flows from the surroundings (forehead) to the system (rubber band). This makes the band feel cool on the forehead.

3. As discussed in Preparing to Investigate, a rubber band contracting is a spontaneous process, meaning ΔG for that process is negative. Using the equation below and based on your observations during the investigation, label the variables ΔG, ΔH, and T with the appropriate sign, + or –, for the contraction process.

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

$$(-) = (+) - (+)(\Delta S)$$

4. What should the sign for ΔS be in the equation above for the contraction process to be spontaneous?

   The sign for ΔS must be positive in order for the right-hand side of the equation to be negative to agree with the sign of the left-hand side.

5. How did your observations in steps 3 and 4 when you touched the rubber band to your forehead relate to the result you saw in step 7 when you heated the rubber band?

   When the band stretched, it gave off thermal energy, which made the forehead feel warm. When the band contracted, it absorbed thermal energy, which made the forehead feel cool. When the band was heated with a hair dryer, the system was absorbing thermal energy. The system absorbing thermal energy is connected with the process of contracting.

Reflecting on the Investigation

1. Based on the sign for ΔS, positive or negative, that you answered for question 4 in Interpreting Evidence, explain how the arrangement of the cross-linked polymer chains in the rubber band can result in an increase or decrease in entropy when it is contracted compared to when it is stretched. Explain or draw what happens on the molecular level.

   When the band is stretched, the cross-linked polymer chains straighten out and are more aligned with each other, like a bundle of uncooked spaghetti noodles. There are fewer potential arrangements of particles in this situation. When the band is allowed to contract, the chains are not as straight and become more tangled, like a mass of cooked spaghetti noodles. There are more potential arrangements of particles in this situation.

2. How does the action of the heated rubber band in step 7 compare with what happens when other everyday materials, such as metal, are heated?

   Typically, materials such as metal expand when they are heated, rather than contracting as the rubber band did.

3. Picture using the method and set-up you designed in step 6 of Gathering Evidence, but instead of heating the stretched band, you cool it. Predict what would happen. Explain.

   Since thermal energy is being given off by the system, or removed from it, the rubber band should stretch.

Post-Lab Discussion

A review of the equation ΔG = ΔH – TΔS, its variables, and what a positive or negative sign for each variable means could be useful. Depending on their answers to Reflecting on the Investigation question 1, students might need a further discussion of what happens on the molecular level as a rubber band stretches/contracts.

Extensions

Students could also investigate the effect of heating the rubber band to different temperatures, such as using low/high settings on a hair dryer or various settings on a heat gun. Does the temperature change the amount of contraction?

An additional polymer to explore is a toy called Shrinky Dinks. Pieces of this plastic can be decorated with colored pencils or markers, then baked. When heated, the plastic contracts dramatically, resulting in a piece approximately one-third its original length and width, but much thicker. The change of this material is not easily reversible and could be contrasted with that of rubber bands, which can be stretched and contracted over and over. Instead of buying commercially available kits, transparent deli containers with the recycle code #6 can also be used.

As an advanced, challenging extension, students could construct a rubber band heat engine using directions available online. The spokes on a bicycle wheel rim are replaced with rubber bands. Each spoke is cut, and the ends remaining on the wheel are bent into hooks so the rubber band can be looped around them. The wheel is then mounted so it can rotate freely. A heat lamp is placed near one area of the rubber bands. As the lamp heats the rubber bands, they contract, which moves the wheel. The heated rubber bands rotate away and cool down, with different rubber bands coming close to the lamp to heat up and continue the process. Directions are available online:

http://bit.ly/highschoolnrg17

Videos of constructed rubber band heat engines can also be found online. The engine was described by physicist Richard Feynman (Feynman, R. P.; Leighton, R. B.; Sands, M. *The Feynman Lectures on Physics*, Vol. I: The New Millennium Edition: Mainly Mechanics, Radiation, and Heat. New York: Basic Books, 2010, p 44-2):

http://bit.ly/highschoolnrg18

Additional Resources

- Summerlin, L. R.; Ealy, J. L., Jr. *Chemical Demonstrations: A Sourcebook for Teachers*, Volume 1, second ed. Washington, DC: American Chemical Society, 1988, p 73.
- Hirsch, W. “Rubber Bands, Free Energy, and Le Châtelier’s Principle.” *J. Chem. Educ.*, 2002, 79 (2), pp 200A–B.