PREPARING TO INVESTIGATE

In this investigation, you will make observations of an everyday item, a rubber band. Based on what you already know about rubber bands and how they behave, consider the following:

1. Picture holding a rubber band by looping your thumbs through the band so the band sits on your thumbs, but is unstretched. If you wait, will the band ever spontaneously stretch and fall off your thumbs?
2. Picture holding a rubber band between your thumbs as before, but this time stretched to nearly its limit. If you quickly pull a thumb out of the band, will the band spontaneously remain stretched out?

The two situations above may sound ridiculous. They describe the opposite of your past experiences with rubber bands. Anyone who has ever let fly a rubber band from her fingers or had a rubber band suddenly break knows that she can reasonably expect a stretched rubber band to contract when released. This change is spontaneous, and at everyday temperatures and pressures happens quite quickly. The reverse change, for a rubber band to go from a contracted position to a stretched position without an outside force acting on it, such as the pull of your thumbs, is not spontaneous.

Is there a way to determine if a change will be spontaneous or not? There is a quantity called Gibbs free energy (G) that can help. For a change in a system, if the amount of free energy decreases, that is, if $\Delta G < 0$, the change is spontaneous.

Different variables contribute to ΔG. Expressed as an equation, $\Delta G = \Delta H - T\Delta S$, where ΔH is change in enthalpy, T is temperature in Kelvin, and ΔS is change in entropy. All quantities are from the viewpoint of the system. Enthalpy is a measure of the internal energy of the system. We cannot measure the enthalpy of a system directly, but can measure changes in enthalpy as the thermal energy released or absorbed when changes in the system occur at constant pressure. From the viewpoint of the system, if thermal energy is released by the system, it has been transferred out of the system, and ΔH would have a negative sign. Entropy is a way of expressing how many different ways the particles and energy of a system can be arranged. For changes, nature favors increases in entropy ($\Delta S > 0$) that will maximize the number of different possible arrangements of particles and energy in the system.

In this investigation, you will observe whether thermal energy is absorbed or released from a rubber band as it is stretched and allowed to contract. Then, you will design a way to measure any stretching or contraction of a rubber band when it is heated. Using your observations, you will consider the changes in enthalpy and entropy that occur in the system of the rubber band, and how they contribute to the system's free energy changes.

GATHERING EVIDENCE

1. Obtain a wide rubber band. Hook both your thumbs into the rubber band, so you can use your thumbs to stretch out the band.

2. Hold the rubber band hooked on your thumbs so that the band is just snug enough to remain on your thumbs, but is not stretched out. Hold the wide, flat part of the band to your forehead. Does it feel warmer, cooler, or the same as your forehead? Repeat this step a few times to be sure of your initial observation.
3. Hold the rubber band hooked on your thumbs. Hold it near your forehead but not touching it. Quickly stretch the band out to the sides and immediately touch the wide, flat part of the band to your forehead. In the "Observations" column of the data table below, record your observations of whether it feels warmer, cooler, or the same as your forehead. Repeat this step a few times to be sure of your initial observation. In between the different tries, allow the band to contract to its original size and hold it unstretched for about 20 seconds to be sure it is at its original temperature.
4. Hold the rubber band hooked on your thumbs. Stretch the band out to the sides. Keep the band stretched out for about 20 seconds to be sure it is at its original temperature. While still looping your thumbs into the band, quickly allow the band to contract to its original position and immediately touch the wide, flat part of the band to your forehead. In the "Observations" column of the data table below, record your observations of whether it feels warmer, cooler, or the same as your forehead. Repeat this step a few times to be sure of your initial observation.
5. Based on your observations in steps 3 and 4, predict what will happen if you heat a stretched rubber band.
6. Design and set up a method, using materials your instructor has made available, to qualitatively measure any change, stretching, contracting, or staying the same, in the length in a stretched rubber band as it is heated with a hair dryer or heat gun. You may cut the rubber band into a single long strip if you wish. Keep the hair dryer or heat gun moving slowly to avoid overheating and melting the rubber band.
7. Use your method to observe any change in the length of the stretched rubber band as it is heated with a hair dryer or heat gun. In the "Observations" column of the data table below, record your observations.

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

ANALYZING EVIDENCE

1. Based on the temperature changes you observed when you held the stretched rubber band and the contracted rubber band to your forehead in steps 3 and 4, determine whether the system (the rubber band) absorbs or gives off thermal energy in these cases. Use this information to fill in the column "System absorbs or gives off thermal energy?" for "stretching band (step 3)" and "contracting band (step 4)."
2. Did the system (the rubber band) absorb or give off thermal energy when you used the hair dryer/heat gun in step 7? Use this information to fill in the column "System absorbs or gives off thermal energy?" for "heating band (step 7)."
3. Is the change in enthalpy (ΔH) for a system positive or negative if the system absorbs thermal energy? If the system gives off thermal energy? Remember, the sign is from the perspective of the system. Has the thermal energy in the system increased or decreased? Use this information to fill in the column "ΔH +/–" with the appropriate signs.
4. Fill in the column "Process spontaneous? yes/no," depending on whether the change that occurred was spontaneous.
5. Is the change in free energy (ΔG) for a system positive or negative when the system undergoes a spontaneous reaction? Use this information to fill in the column "ΔG +/–" with the appropriate signs.

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.
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.
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.

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

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

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.
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?
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.

