Rubber Band Equilibria

Overview

This lesson uses the elasticity of a rubber band to explore the concepts of equilibrium and reversible changes.

Key Concepts

- equilibrium
- LeChatelier's principle
- polymers
- reversible processes

National Science Education Standards

Science as Inquiry

Abilities Necessary to Do Scientific Inquiry

- *Students use logic and evidence to formulate explanations about the change in energy when a rubber band stretches or contracts. (5–8, 9–12)*

Physical Science

Transfer of Energy

- *Students observe that when a rubber band is stretched, heat is released and flows from the rubber band to the environment, causing an increase in temperature. They also observe a decrease in temperature as the stretched rubber band is allowed to contract. They learn that this is a type of energy transfer. (5–8)*

Structure and Properties of Matter

- *Students learn that rubber bands are composed of numerous polymer chains. The molecules in a relaxed rubber band have significant freedom of movement. When stretched, the molecules have less freedom of movement. (9–12)*

Chemical Reactions

- *Students use the stretching and relaxing of a rubber band as a physical analogy for the reversible process in chemical reactions. LeChatelier's principle can be applied to predict how adding or removing heat will affect a rubber band. (9–12)*

Conservation of Energy and the Increase in Disorder

- *Students observe that stretching a rubber band causes it to transfer energy to its surroundings due to a decrease in the movement of atoms. Relaxing the rubber band causes it to become cooler due to an increase in the movement of atoms. The heat released when the rubber band stretches is regained when it contracts. (9–12)*

Part A: Student Exploration

Is there a change in energy when a rubber band stretches or contracts? Try the following activity and find out.

Materials

- wide rubber band
- plastic six-pack ring cut into 6 smaller pieces

Procedure

1. Examine the rubber band. When you pull on opposite sides it stretches; when you release one end it contracts. *Is the stretching and relaxing of the rubber band a reversible process or an irreversible process?*
2. Hold the rubber band against your upper lip or forehead for several seconds and notice how it feels. Move it away from your lip, then stretch it and quickly touch it to your lip or forehead again. *What change, if any, do you feel?* Hold the stretched rubber band against your upper lip. Move it away, allow it to contract, and touch it to your upper lip or forehead again. *What change, if any, do you feel? Make a claim regarding the behavior of a rubber band. Be prepared to provide evidence to substantiate your claim in a class discussion.*
3. Rubber bands are made of long polymer chains. Six-pack rings are made from polymers too. Predict what would happen if you quickly stretched the six-pack ring. Test to see if your prediction is right. Hold one of the six-pack rings against your upper lip or forehead. Move it away, then quickly stretch it and touch it to your lip again.

Part B: Teacher Demonstration

How does temperature affect the length of a rubber band?

Materials

- meterstick with hole at one end
- 2 rubber bands, 90 mm (3.5 inches) long × 3 mm (⅛-inch) wide
- ring stand
- 2 clamps that have a cylindrical surface on which the meterstick can pivot like a lever (See Figure 2 in Preparation.)
- paper clip
- electric hair dryer or heat gun

Procedure

1. Gently move the free end of the meterstick up and down to illustrate how it will move if the rubber band stretches or contracts.
2. Ask students to predict what will happen to the free end of the meterstick when the rubber band is heated.
3. Heat the entire rubber band by moving a hair dryer or heat gun up and down the length of the rubber band, as shown in Figure 1.

⚠ *If the rubber band is heated too much in one spot, it may melt or break.*

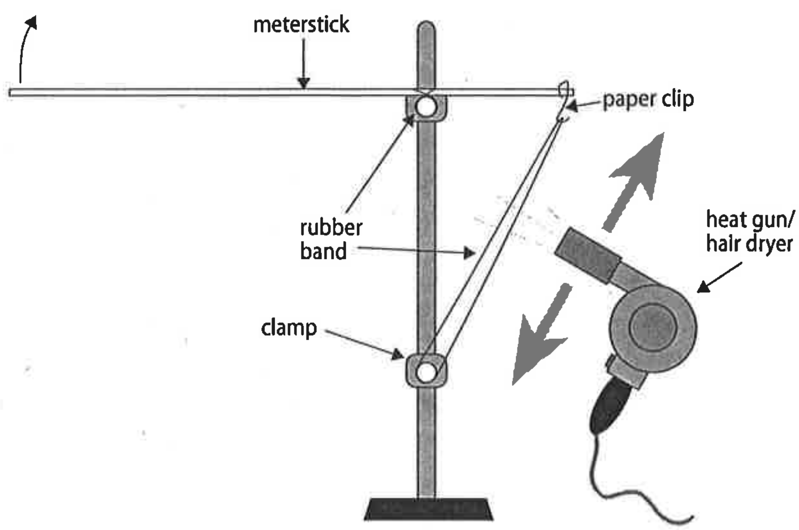


Figure 1: Heating the rubber band with a heat gun or hair dryer

Instructor Notes

Preparation

- For Part B, you will need to use a ring stand with two clamps that have cylindrical surfaces projecting outward. The type of ends the clamps have is not important. (See Figure 2.)

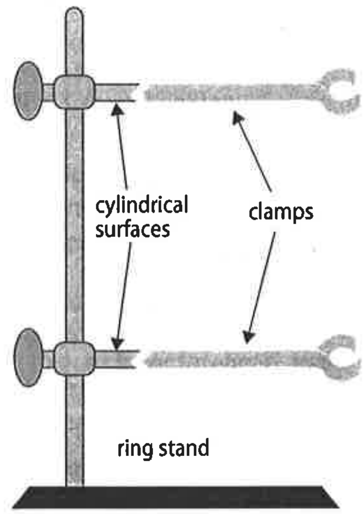


Figure 2: Side view of apparatus setup

- Using a ring stand, clamps, meterstick, paper clip, and rubber bands, assemble the lever apparatus shown in Figure 1. Unbend the paper clip so that one end hooks securely into the hole in the meterstick and the other end hooks into an end of the rubber band. The meterstick should freely pivot on a cylindrical part of the upper clamp. You should have about 15 cm (6 inches) of the meterstick on the rubber band side. The pull of the rubber band can be adjusted by moving the lower clamp until the meterstick is approximately horizontal. Use the other rubber band to lightly secure the meterstick to the upper clamp, but be sure that the meterstick can freely pivot as a lever.
- Put a piece of poster board behind the free end of the meterstick, or put the apparatus close to a wall so that the motion of the free end can easily be detected.

Tips and Instructional Strategies

- Challenge students to relate the stretching and relaxing of a rubber band to equilibrium concepts. LeChatelier's principle states that when a stress is applied to a system at equilibrium, the equilibrium position shifts to relieve the stress. Help students write an equation for what they saw in the demonstration:

  stretched rubber band + heat $\rightleftarrows$ *unstretched rubber band*

- You may want to have students warm a 2-L, polyethylene terephthalate (PET) soft-drink bottle with a hair dryer. Ask them how the behavior of the bottle compares to the stretched rubber band.
- For more advanced classes, you may want to compare the behavior of the rubber band when heated to that of metals when heated. (Heated metals expand.) Replace the rubber band in Part B with a copper wire. Heat the copper wire with a heat gun and have students note the direction of movement of the free end of the meterstick. With the rubber band, the free end of the meterstick will move up, since the rubber band contracts when heated. With the copper wire, the meterstick will move down, since the wire expands. This movement will be very small, so great care must be taken in observing the free end of the meterstick. You may wish to make pencil marks on the poster board noting the position of the free end when the wire is cold and when hot. A heat gun works best because it can heat the copper wire better than a hair dryer.
- As an alternative setup for Part B, you can use a 100-g weight or equivalent and a rubber band cut into a strip. (A strip about 150 mm long × 5 mm wide works well with a 100-g weight. Use a larger weight with a thicker band.) Follow the procedure below. (See Figure 3.)
    - Tie the rubber band strip to a ring clamp attached to a ring stand. Hang a 100-g weight from the rubber band so that the weight just barely touches the base of the ring stand or the top of the table. Challenge students to predict what will happen when the rubber band is heated.
    - Heat the entire rubber band by moving a hair dryer or heat gun up and down the length of the rubber band.
    - Be sure that students observe the position of the weight as the rubber band is heated.

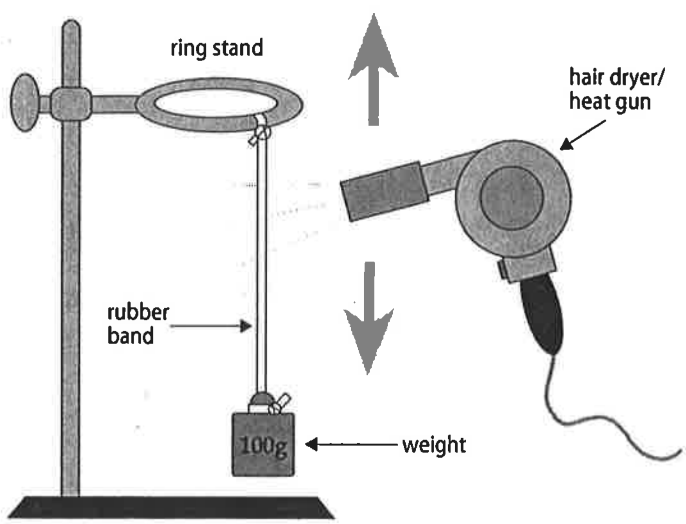


Figure 3: Heating the rubber band with a heat gun

Explanation

Rubber consists of intertwined polymer chains. When a relaxed rubber band is stretched, it transfers heat to the surroundings (including the students' skin in this lesson). Since the heat transferred is a relatively small amount, it is easiest to detect on especially sensitive skin, such as the upper lip. After observing this phenomenon, the reverse can be tried; a stretched rubber band is allowed to contract to the relaxed state. This time, the rubber band feels cooler, which is consistent with the rubber band absorbing energy from the skin.

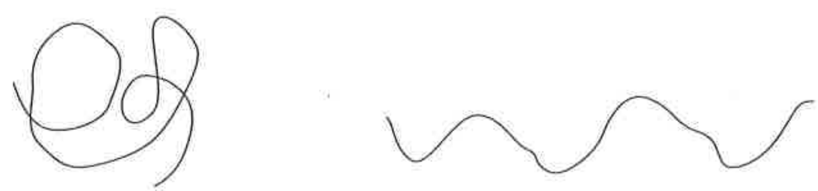
The plastic six-pack ring is also composed of long intertwined polymer chains and produces heat when stretched. In fact, the stretched six-pack ring typically gives off even more heat than the rubber band.

It is counterintuitive that a rubber band contracts when heated since most materials expand when heated. Nevertheless, contraction is exactly what happens with the rubber band. This phenomenon is consistent with LeChatelier's principle, which states that when a stress is applied to a system at equilibrium, the equilibrium position shifts to relieve the stress.

$$\textit{stretched rubber band + heat} \rightleftharpoons \textit{unstretched rubber band}$$

If heat is added, according to LeChatelier's principle, the rubber band should absorb heat and move from the stretched configuration to the unstretched configuration (because that direction counteracts the stress). Likewise, going from unstretched to stretched should liberate heat as observed.

These observations are consistent with the disordered, folded polymer chain of unstretched rubber (see Figure 4a) becoming more ordered, aligned, and straightened as the rubber band is stretched (see Figure 4b). Applying heat to the stretched, aligned, and straightened rubber band causes greater movement of atoms and greater disorder—in other words, a return to a state similar to the initial disordered, folded state, which occurs in the contracted, unstretched rubber band.



(a) (b)

Figure 4: Polymer chain of rubber when (a) unstretched and (b) stretch

Answers to Student Questions

Part A

Step 1

Stretching a rubber band is usually a reversible process. (Breaking the rubber band is an irreversible process.)

Step 2

a. The rubber band feels warmer after it is stretched.

b. The rubber band feels cooler after it contracts.