CIPIMA CLASSROOM LESSON/ACTIVITY: THE LONG AND SHORT OF ELASTOMERS
(Simplification of Anael Verdugo's Elastomer Project for Use in Class)

by

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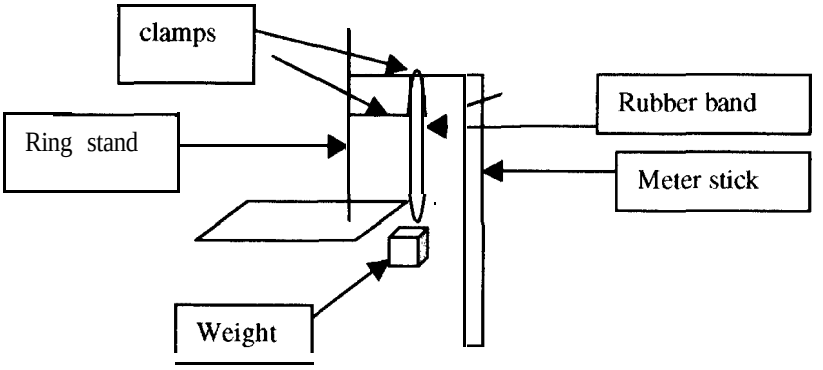
CONTEXT: scientific investigation methods, problem solving, entropy, polymers, elastomers

PURPOSE: To establish how the effect of temperature on elastomers differs from that of most other materials (including other polymers) and to be able to explain why these differences occur in terms of polymer behavior.

MATERIALS: 4-6 large rubber bands per group, 2 loops of polyethylene (or other plastic) cut from a narrow plastic bag, -1 kg weight with hook, ring stand and two clamps, hair dryer.

SET-UP:



Set up the ring stand with two clamps: one clamp will support the dangling rubber band and the other clamp will hold up the meter stick. Adjust the meter stick so that zero is at the top of the dangling rubber band. Either the ring stand should be pretty tall or it should be set up near the edge of a table so the rubber band, weight and meter stick can hang below the tabletop. You may need to counter weight the ring stand with some massive object(s) (books?). Whether you use one rubber band or two together will be determined by the amount of weight you actually use. I found that two standard large rubber bands (-0.6 cm wide and -9.5 cm long) worked well with 1 kg mass.

PRELIMINARY (INTRODUCTION): Have students stretch a rubber band and allow it to contract while it is contact with their forehead or their upper lip. Ask them to determine if there is any temperature change as they stretch it and allow it to contract. (They should notice that it becomes warmer as it is stretched and relatively cooler as it is allowed to contract). Based on their observations (and, perhaps, their understanding of entropy), ask them to predict and write down the effect of temperature on the length of a rubber band under tension.

PROCEDURE:

1. Use the set-up described above to measure the length of the rubber band(s) under tension at room temperature.
2. Heat the rubber band with a heat gun or hair-dryer, observe, and record the length of greatest difference from room temperature. (I recorded 3 cm less length for the two large rubber bands I used to support a 1.2 kg mass. I found that the rubber bands will eventually break-probably due to overstress of the elastomer-but I found all the rubber bands to shrink first).
3. Allow the rubber band to cool back to room temperature and observe (and record) the length to which is returns.
4. Repeat the procedure for another rubber band (or two).
5. Repeat the procedure for band-like loops of plastic (like polyethylene) cut out of narrow plastic bags. (These loops may break before reaching a stable length, but have the students record the length noted which has the greatest difference from room temperature before the loop broke).

A data table similar to this one could be used:

Material	Unstressed Length	Stressed Length @ Room Temperature	Stressed Length Heated	**A** Length
rubber band				
polyethylene				

DISCUSSION ON PROCEDURE: A variety of polymer materials can be used, but for simplicity and consistency they should be looped and of similar length to the rubber bands used. You can also try cooling the rubber band, which should cause it to lengthen. I found adequate cooling to be a more challenging problem than heating. Blowing air into a dewar flask of liquid nitrogen and exposing the rubber band to the cold vapor coming out did cause a small (0.5 cm) increase in length, but the result did not seem to be worth the effort. I also tried heating and cooling the rubber bands by placing them in boiling water and ice water, respectively. I initially assumed that the rubber bands wouldn't absorb much water, but I found significant increases in length in both boiled and chilled rubber bands. In fact, they both seemed to come back to room temperature very quickly after being removed from the baths, but increased in length, anyway. In fact, the dry vs. wet variable might be another source of investigative activity for your students. I let my rubber bands soak for 5 minutes. Bob Zafran (IBM Almaden) told me that he has tried pouring hot water over a rubber band while it was suspended under tension with a weight. He, also, found that the rubber band increased in length in this case.

POSSIBLE CONCLUSION QUESTIONS/FOLLOW-UP:

1. How does the elastomer (the rubber band) differ in its behavior from other polymers and most materials?

2. How are the results you obtained in this experiment consistent with the observations you made of the temperatures of the stretched and relaxed rubber band'?

3. Explain the results of your investigation of the rubber band behavior in terms of entropy (when do you think it increases, when do you think it decreases).

4. Try to give a physical description of what the polymers are like when they are stretched and what they are like when they are relaxed.

DISCUSSION ON ELASTOMER THEORY AND THERMODYNAMICS:

In my opinion this is not a topic for the faint-hearted or regular high school students to go into too deeply. It is quite difficult to explain and, frankly, I know I do not have a very deep understanding of this topic. Here is a short version of the explanation for some of the phenomena we see in this activity.

Most of the work which goes into stretching an elastomer is used to stretch the coiled, cross-lined polymers of the elastomer. Stretching the polymers reduces the entropy of the polymers. In the stretched state the cross-linked polymers of the rubber have fewer conformations that they can assume. In the situation where an elastomer is held to a constant length, increasing the temperature increases the amount of force required to hold it to that length (stress increases). Conversely, if the force is kept constant (constant tension--the hanging weight) and the temperature is raised, the stress increases and the length decreases. In the case of the rubber band stretched across the forehead or upper lip, the rise in temperature of the rubber band is mostly the result of the work acting on the rubber material to stretch being converted into heat.

REFERENCES

Young and Lovell, *Introduction to Polymers*, 2nd Ed., Chapman and Hall, 1994

Sperling, *Introduction to Physical Polymer Science*, 2nd Ed., John Wilely and Sons, 1992