

The Odd Behavior of Rubber Bands

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Abstract:

Rubber bands behave in a manner opposite to that of most solids: They contract when heated, expand when cooled. Further, the length of a stretched rubber band does not return immediately to its original non-stretched length. These behaviors are due to the structure of rubber, being long, loose, twisted chain molecules. Experiments that can demonstrate these effects are included in this module.

Objectives: The student will be able to

Describe the structure of a rubber band

Observe the behavior of rubber bands when stretched and when contracted

Observe and effects of temperature and stretching on the rubber band's structure

Explain the effects of heat on the structure of a rubber band

MatEd core competencies addressed (most important in bold)

0B Prepare tests and analyze data

4A Demonstrate effective work with teams

6B Apply basic concepts of heat

10B Compare properties and applications of thermoset plastics

16A Distinguish the effects of processing and manufacturing variations on material properties

Key Words: Rubber, properties, heat, applications

Type: Classroom demonstration/lab

Time Required

Simple exploration: 10 minutes including discussion

Effects of heat and hysteresis needs another 20 minutes

Grade level:

College level; High school level only if the class is sufficiently controlled not to use the rubber bands as weapons.

Equipment and supplies needed

A supply of various sizes of rubber bands

A means of suspending the rubber bands while stretching them
Weights and a means of hanging them on the rubber bands
Hair dryer for heating
Ice or dry ice for cooling

Instructor background and notes

The molecules in rubber can be envisaged as disordered, entangled and coiled upon one another (much more intertwined and twisted than spaghetti being boiled in a pot). In natural rubber, there is generally only a very weak linkage between molecules, which are held together by this entanglement. If rubber bands were made from natural rubber, they would gradually pull apart and fail as the molecules uncoil and slide past one another. In synthetic rubbers, additives are used to form “cross links” between molecules. Such rubber has an elastic limit, which occurs when the molecules’ motion past one another is stopped by these cross-links.

The disorder in the rubber band is described in scientific terms by its “entropy.” By definition, the entropy of the band is high when disorder is present. Upon stretching, the molecules straighten out and align along the axis of the stretch. This stretching causes the coils of molecules to uncoil and thus the structure becomes more ordered; this means that the entropy of the band decreases when stretched. When the entropy of a system goes down, the system gives out heat. Thus, when the rubber band is stretched, it should give out heat, and conversely, when contracted, it should absorb heat. This can be felt by holding a rubber band on a sensitive place on the body (try lips or forehead) and then alternately stretching and allowing the rubber band to contract. Using the same effect, a stretched rubber band will contract on its own when heated. By heating the rubber band, we increase the entropy. The molecules become more disordered and tangled, and thus the rubber band shrinks. This is just the opposite of what happens when we stretch the band.

When the stretching force is removed from a stretched rubber band, the molecules also have trouble returning to their original length. This is because the structure of the band has been altered. Stretching uncoils the kinks and tangles in the molecules, which do not return to their original positions when unstretched. This is called “hysteresis.” Further, if the band is stretched past its elastic limit, the cross links can also be stretched, causing a permanent lengthening of the rubber band.

The important point here is that these properties of the rubber band are related directly to the molecular structure of the rubber band. Without the unique distribution of the molecules in the rubber band, these properties would not exist.

Experimental process: Part 1 (simple exploration)

1. Distribute a set of relatively heavy (strong) rubber bands to the students. Have them experiment with the maximum stretch for the band. Discuss the structure of rubber, the presence of cross-links and ask them to demonstrate when the cross-links come into play.
2. Ask the students to stretch the rubber band then touch it to a heat-sensitive place on

- their face (usually a lip or the forehead provides the best result).
3. Then ask the student to allow the rubber band to contract and hold it to the same spot on their face. Ask what the difference in temperature is.
 4. Have them repeat the experiment several times to make sure that they feel the difference in temperature. Discuss in terms of the structure of the rubber band.

Experimental process: Part 2 (applying heat and observing hysteresis)

5. Students should work in groups for this experiment, or choose a small team of students to demonstrate this to the rest of the class. Have the students hang a rubber band from a hook or a doorknob and suspend a small bucket from it. Add weights to the bucket, weights that are heavy enough to stretch the rubber band (use whatever is available). Mark the maximum stretch length of the rubber band.
6. Warm up a hair dryer, and then aim it at the rubber band. Have the student observe the change in length. Mark the new length and calculate the percentage change in length. Have them explain, in light of the earlier experiments, why they observe this change in length.
7. To observe hysteresis, use another rubber band, hang it from a hook or door knob, add the bucket and use a scale so the length of the band can be determined exactly. Add weights to the bucket and note the length after each weight is added. Now remove each weight in the reverse order to which it was added. Note the length. How much change is seen between stretching and contraction. Have the students discuss in terms of the structure of the rubber band.

Further study

- Repeat experiments 6 and 7 by cooling instead of heating the rubber band. Use ice water or CO₂ vapors for cooling.
- Investigate further properties of rubber using texts or the internet
- Predict the outcome of these experiments if natural rubber were used in place of the synthetic rubber in the rubber band.

References:

Rubber band basics on Wikipedia

http://en.wikipedia.org/wiki/Rubber_band

Basic thermodynamics of the rubber band

"Thermodynamics of a Rubber Band", *American Journal of Physics* **31** (5): 397–397, May 1963

Hysteresis experiment with rubber bands

http://www.madphysics.com/exp/hysteresis_and_rubber_bands.htm

Evaluation

Student evaluation questions (discussion or quiz):

1. Explain what happens when a rubber band is stretched; when it is contracted.
2. Demonstrate the heating effect on a rubber band

3. Define "hysteresis" and explain the effect in rubber
4. Would hysteresis effects be seen in rubber tires when high speed driving causes them to heat up? Why or why not?

Instructor evaluation questions:

1. At what grade level was this module used?
2. Was the level and rigor of the module what you expected? If not, how can it be improved?
3. Did the activity work as presented? Did they add to student learning? Please note any problems or suggestions.
4. Was the background material sufficient for your background? Sufficient for your discussion with the students? Comments?
5. Did the activity generate interest among the students? Explain.
6. Please provide your input on how this module can be improved, including comments or suggestions concerning the approach, focus and effectiveness of this activity in your context.

Course evaluation questions (for the students)

1. Was the activity clear and understandable?
2. Was the instructor's explanation comprehensive and thorough?
3. Was the instructor interested in your questions?
4. Was the instructor able to answer your questions?
5. Was the importance of materials testing made clear?
6. What was the most interesting thing that you learned?