Engaging Students in Thermal Expansion and Contraction Phenomena

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Abstract

Much of science involves finding patterns in observations and explaining them in terms of a small number of principles or ideas. For students to appreciate how science works, they need to have a sense of the range of observations (phenomena) that are used to form the patterns and the helpfulness of the principles or ideas in explaining them. Project 2061's evaluations of science textbooks revealed that textbooks rarely engaged students with phenomena relevant to important science ideas, rarely included phenomena that directly address the often incorrect ideas that students may already have, and rarely guided students in reconciling phenomena with scientifically accepted ideas (Kesidou & Roseman, 2002; Stern & Roseman, 2004; American Association for the Advancement of Science [AAAS], 2002, 2005). In response to these deficiencies, Project 2061 and other CCMS researchers are identifying phenomena that could be used to support the teaching and learning of ideas recommended in *Benchmarks for Science Literacy* (AAAS, 1993) and in the *National Science Education Standards* (National Research Council, 1996).

This poster provides three examples of phenomena that are aligned to a middle school key idea about thermal expansion and contraction. For students to be able to fully comprehend these phenomena and relate them to the idea about thermal expansion and contraction, they must also appreciate the importance of careful measurement and/or use of detection instruments or methods more sensitive than the naked eye. Students also need to be shown corresponding representations of the molecular level phenomena in order to link the phenomena to the idea. The poster also illustrates the role that data on students' ideas can play in identifying useful phenomena and strategies for guiding students' interpretation of them.

Key Idea

For any single state of matter, changes in temperature typically change the average distance between atoms or molecules. Most substances or mixtures of substances expand when heated and contract when cooled. (from Benchmarks for Science Literacy 4D/M3b)

What Students are Expected to Know

- As the temperature of a substance increases, the average distance between the atoms/molecules of the substance typically increases, causing the substance to expand.
- As the temperature of a substance decreases, the average distance between the atoms/molecules typically decreases, causing the substance to contract.
- Thermal expansion or contraction can happen to solids, liquids, and gases.
- Expansion or contraction due to changes in temperature can also happen to mixtures of substances.
- Expansion or contraction due to changes in temperature is not permanent (e.g., objects that expand when heated then contract when cooled).
- The number of atoms and the mass of the atoms do not change with changes in temperature.
- Different substances expand and contract differently.

Ideas Students Have

- Some students are unfamiliar with the non-molecular aspects of physical changes in matter, e.g., thermal expansion and contraction, compression and expansion of gases, dissolving, and changes in state, such as melting and condensation (Berkheimer, et. al., 1988).
- Some students believe that solid substances do not expand or contract with changes in temperature (Project 2061 student data, 2006 (unpublished)).

Instructional Implications

- Students should be provided with real-world examples of a variety of solids, liquids, and gases that expand when heated and contract when cooled.
- These examples should occur in one state and should not involve a change of state.
- The set of phenomena should provide students with experiences with different substances and mixtures of substances that expand and contract differently but, nonetheless, expand when heated and contract when cooled.
- It is also important for students to experience the reversibility of the expansion and contraction so that they understand that the expansion and contraction are not permanent.
- Physical models and drawings can be used to represent the increased distance between molecules when the substances are heated and the decreased distance when the substances are cooled.

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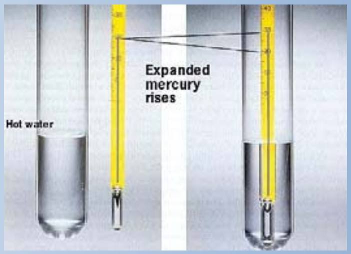
Thermal Expansion and Contraction of a Solid

- A thermal expansion kit consisting of a metal ball and a metal ring, both mounted on wooden handles is used to illustrate the idea that solids expand when heated and contract when cooled.
- Students should observe that the ball fits through the ring when both are at room temperature, but the ball does not fit through the ring when the ball is heated. Students should also observe that after the ball has cooled back down to room temperature, it fits through the ring again.
- Students need to infer that when the ball can no longer pass through the ring, it is because the ball has increased in size and that when the ball cools back to room temperature and can fit through the ring, the ball's size has decreased, even though it may look the same to the students. A second, unheated ball could be used to demonstrate that the ring has not changed in size.

- In a recent study involving about 30 middle school students, 56% of the students knew that atoms and molecules got farther apart when heated, but only 13% of a comparable group could link this knowledge to the actual expansion of the solid object (Herrmann Abell & DeBoer, 2007).
- Students may have difficulty accepting the idea that solids change size with changes in temperature because the changes in size are relatively small and difficult to detect with the naked eye.
- To help students reconcile this phenomenon with their everyday observations that substances don't appear to expand or contract, they need to appreciate that the tight fit of the ring around the ball makes it possible to detect a very small change in size.
- To form the generalization that most solid substances expand when heated and contract when cooled, students will need experiences with several different solids in which they compare what they can detect with the naked eye to what they can detect with a more sensitive detection device (such as a tight-fitting ring around the object being heated and then cooled).

Thermal Expansion of a Liquid in a Thermometer

- To appreciate that liquids expand when heated and contract when cooled, students are shown a mercury thermometer and observe the level of mercury rising as the thermometer is heated and falling as the thermometer is cooled.
- Students need to infer that when the level rises, the liquid in the bulb is expanding, and when the level falls, the liquid in the bulb is contracting.
- Note that the glass of the thermometer is also expanding. However, the mercury expands 10 times more than the glass for a given temperature change.
- Students should not handle mercury thermometers since mercury is highly poisonous. Students may use alcohol thermometers for hands-on activities.



- Students may have difficulty accepting that liquids expand when heated and contract when cooled because the volume changes are relatively small and, hence, are difficult to detect with the naked eye.
- To help students reconcile this phenomenon with their everyday observations that substances don't appear to expand or contract, they need to appreciate that the very thin tube in the thermometer makes it possible to detect a very small change in volume.
- To form the generalization that most liquid substances expand when heated and contract when cooled, students will need experiences with several different liquids in which they compare what they can detect with the naked eye to what they can detect with a more sensitive detection device (such as using a very thin tube).

Gas Contracting in a Mylar Balloon

- A Mylar balloon is filled with helium gas at room temperature and sealed. Mylar balloons work for this phenomenon because they do not stretch like rubber balloons.
- Students should observe that when the balloon is cooled, it looks deflated and when the balloon returns to room temperature, it looks inflated.
- Students must infer that the balloon looks deflated because the gas in it contracted when cooled and the balloon re-inflates when it returns to room temperature is because the gas in it expanded.
- The thermal expansion of gases is much more noticeable than solids and liquids. One liter of gas expands 34 mL for a temperature increase of 10ºC.
- For all phenomena dealing with the expansion and contraction of gases, use a pliable container to allow the gas to expand and contract safely.

Notes:

- The phenomena described on this poster address only the macroscale phenomena of thermal expansion and contraction, not the atomic/molecular phenomenon of the changing distance between atoms, nor do these phenomena address the student misconceptions associated with the atomic/molecular level, such as the idea that students have that the mass of the atoms changes with changes in temperature.
- Because students need to make the link between the macroscale phenomenon and the atomic/molecular phenomenon, a corresponding representation, such as a model or drawing, is needed to illustrate the change in distance between atoms and molecules that accompanies thermal expansion and contraction.

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