6. Heat Transfer in Fluids

Mixing Temperatures

Objectives

Students investigate what happens to the temperature of a solution when two substances of different temperatures are mixed.

Students investigate the mixing of substances at different temperatures while they:

- Develop the understanding that energy is a property of many substances and is associated with heat, light, electricity, mechanical motion, and the nature of a chemical
- Recognize that heat can be transferred through a fluid
- Learn that heat moves in predictable ways, flowing from warmer objects to cooler objects, until both reach the same temperature
- Gain skills and confidence in using scientific measurement tools, the temperature and pressure sensors, as well as the graphing capability of a computer to represent and analyze data

Procedural Overview

Students gain experience conducting the following procedures:

- Setting up the equipment and work area to measure the temperature of three samples of water
- Measuring the temperature of a sample of cold water
- Measuring the temperature of a sample of hot water
- Measuring the temperature of a mixture of equal volumes of cold and hot water after mixing them
- Using math skills to average temperatures

Time Requirement

Introductory discussion and lab activity, Part 1 – Making predictions	25 minutes
Lab activity, Part 2 – Measuring temperatures of solutions, Part 3 – Observing the temperature changes of the water mixture	40 minutes
Analysis	25 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Temperature sensor, fast response
- Graduated cylinder, 250-mL
- Beakers or cups (2), 150-mL
- Insulated container
- Hot water, 125 mL
- Cold water, 125 mL
- Red and blue food dyes (optional)
- Stirring rod

Concepts Students Should Already Know

Students should be familiar with the following concepts or skills:

- Use of a graduated cylinder to measure liquid volume, as well as the meaning of the term *volume*
- The arithmetic necessary to set up and compute averages
- How to read and interpret a coordinate graph, as well as be familiar with the SI unit of measure for temperature (degrees Celsius)
- Basics of using the data collection system

Related Labs in This Guide

Labs conceptually related to this one include:

- Transfer of Energy in Chemical Reactions
- Exploring Environmental Temperatures

Using Your Data Collection System

Students use the following technical procedures in this activity. The instructions for them are in the appendix that corresponds to your PASCO data collection system (identified by the number following the symbol: "�"). Please make copies of these instructions available for your students.

- Starting a new experiment on the data collection system �(1.2)
- Connecting a sensor to the data collections system �(2.1)
- Monitoring live data �(6.1)
- Displaying data in a digits display �(7.3.1)
- Saving your experiment �(11.1)

Background

When cold and warm items come into contact, the cooler item gets warmer while the warmer item gets cooler, until eventually both are the same temperature. With unequal starting amounts, the final temperature of a mixture is closer to the temperature of the largest quantity. For example, if you begin with more hot water than cold water, the temperature of the mixture of the hot and cold water will be warmer than the average of the two temperatures. In general, the final temperature is the mass-weighted average of the starting temperatures. Expressed as an equation, this is:

$$T_{\text{final}} = \frac{(m_{\text{hot}} \times T_{\text{hot}}) + (m_{\text{cold}} \times T_{\text{cold}})}{m_{\text{hot}} + m_{\text{cold}}}$$

In the above equation, m stands for the mass, and T stands for the temperature.

Standard temperature scales, such as the Fahrenheit and Celsius scales, are based on a substance's average thermal kinetic energy per atom or molecule. The more kinetic energy each molecule of water for example, has on average, the more frenetic its motion, and the more thermal energy it can transfer to surrounding water molecules it bumps into. It is this "bumping into" or pushing on surrounding molecules that transfers the heat energy, because at the molecular level, the water molecules are doing work.

Pre-Lab Discussion and Activity

Students in grades 5 to 8 can have difficulty understanding the phenomenon known as heat energy and heat transfer. They are not yet able to grasp the abstract molecular or particulate model of matter, nor understand that temperature is a measure of the average kinetic energy of those particles. The goal is to build up students' set of experiences with energy transfer. The big idea is that when cooler things and warmer things come into contact, the cooler things get warmer while the warmer things get cooler until eventually both are the same temperature (have the same amount of heat energy).

Temperatures of Different Objects

Ask the students to look around the room and select areas they think might have different temperatures. Make a list on the board of the areas selected by the students. Many students will be surprised that most things in the room are the same temperature, even surfaces or objects that "feel" cool to the touch. Many students will not list or select the air in the room, because air to them doesn't seem to have any temperature at all.

Heat Flow

Suggest to the students that if some part of the room is hotter than another area, heat will flow from the hotter area to the cooler area until both areas are the same temperature. If it's a cold day outside and the classroom windows or doors are opened, heat will flow towards the colder area (outside) until both areas have reached the same temperature. If the thermostat is turned on, the furnace will continue to furnish heat to the room, and that heat will continue to flow to the colder outdoors. If the thermostat is turned off, the room will quickly become just as cold as the outdoors.

Challenge the students to think of other substances besides air that have different temperatures, and can be observed mixing every day. If students have difficulty coming up with ideas, suggest filling a bathtub with water. Ask them if they ever filled their bathtub and discovered just as they were about to get in, that the water was too hot or cold. Ask students to share their ideas.

Direct students to "Thinking About the Question." Have the students discuss the material in this section within their lab groups and then share their answers with the class. If necessary, prompt students to suggest that when equal amounts of hot and cold water are used, the resulting temperature of the mixture is exactly halfway between the two starting temperatures. In other words, the final temperature is the average of the two starting temperatures. As an equation, this is:

$$T_{\text{final}} = \frac{T_{\text{hot}} + T_{\text{cold}}}{2}$$

In this equation, T stands for temperature. Standard temperature scales, such as the Fahrenheit and Celsius scales, are based on a substance's average thermal kinetic energy per atom or molecule. The more kinetic energy each molecule of water for example, has on average, the more frenetic its motion, and the more thermal energy it can transfer to surrounding water molecules it bumps into. It is this "bumping into" or pushing on surrounding molecules that transfers the heat energy, because at the molecular level, the water molecules are doing work.

Direct students to Investigating the Question.

Preparation and Tips

These are the material and equipment to set up prior to the lab:

- An excellent source of insulated containers can be provided by students themselves, if they have access at home to hot beverage "travel mugs" with spill-proof lids. A day or so ahead of the activity, ask students to bring in their travel mugs to share with the class. Make provisions – such as tape and a marker – for students to label their mugs to take them back home.

- If possible, provide students with red and blue food dye for their water samples. The visual reinforcement for hot and cold water can be very helpful for many learners. In addition, as students pour their mixed water solution out of the insulated container, they will observe that the colors have "mixed" as well as the temperatures, resulting in a new color somewhere between the original two, again serving as visual reinforcement.

- Be sure to remind students to measure the temperatures of the hot and cold water samples and then *quickly* pour those samples into the insulated container. Waiting too long will result in heat loss to the surrounding atmosphere that will throw off the students' results.

Safety

Add these important safety precautions to your normal laboratory procedures:

- Wear safety goggles for the duration of this activity.

- Do not use water above 40 °C. Painful burns may result.

Driving Question

What is the resulting temperature when you mix equal parts hot and cold water?

Thinking about the Question

Have you ever heated a drink only to discover that it became too hot to drink? You could let the drink sit for a time until it cooled enough to drink, or you could add a cooler substance to the cup to cool it faster.

If you've ever taken a bath, you're probably familiar with bath-water that's too hot to get into comfortably, or water that's not warm enough for your preference. Either way, you know that you can change the temperature of the bath-water by adding more water of the temperature you want. You simply add more cold water to your bath if it's too hot, or you add more hot water if it's not warm enough.

When two liquids of different temperatures are mixed together, the warmer one loses heat energy and the cooler one gains heat energy. The final temperature of the mixture is always somewhere between the two starting temperatures. Discuss with your lab group how the amount of the cooler substance added determines the final temperature.

Answers will vary. Students should suggest that the more cool substance is added to a warm substance, the cooler the final temperature will be.

Sequencing Challenge

Note: This is an optional ancillary activity.

The steps below are part of the Procedure for this lab activity. They are not in the right order. Determine the proper order and write numbers in the circles that put the steps in the correct sequence.

1	4	2	5	3
Make certain that each member of your lab group is aware of the safety rules and procedures for this activity.	In an insulated container, carefully combine equal volumes of hot and cold water samples of known temperatures.	Obtain equal volumes of hot and cold water.	Determine the final temperature of the mixture of the hot and cold water samples.	Measure the temperature of the hot and the cold water samples.

Investigating the Question

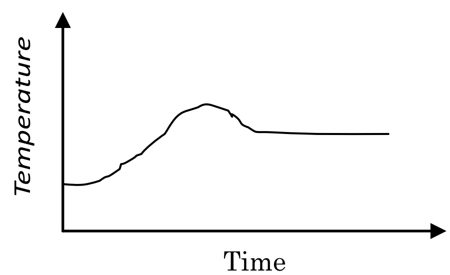
Note: When students see the symbol "�" with a superscripted number following a step, they should refer to the numbered Tech Tips listed in the Tech Tips appendix that corresponds to your PASCO data collection system. There they will find detailed technical instructions for performing that step. Please make copies of these instructions available for your students.

Part 1 – Making predictions

1. ☐ What will happen when equal amounts of hot and cold water are mixed.

   Answers will vary. One student group predicted as follows: We think that when we mix equal amounts of hot and cold water, the mixed water will not be as hot as the original hot water, and also it won't be as cold as the original cold water. It will be about in between.

2. ☐ In the space below, sketch a temperature versus time graph that reflects your prediction.



Part 2 – Measuring temperatures of solutions

3. ☐ Start a new experiment on the data collection system. �(1.2)

4. ☐ Connect a temperature sensor to the data collection system. �(2.1)

5. ☐ Display Temperature in a graph display. �(7.1.1)

6. ☐ If you are using food dye, color the hot water red and the cold water blue.

7. ☐ Measure 125 mL of hot water into a 150-mL beaker.

8. ☐ Insert the temperature sensor into the beaker and begin data recording. �(6.2)

9. ☐ When the temperature stabilizes, record it in Table 1. You may need to adjust the scale of the graph to see all of your data. �(7.1.2)

10. ☐ Stop data recording. �(6.2)

11. ☐ Measure 125 mL of cold water into a 150-mL beaker

12. ☐ Insert the temperature sensor into the beaker and begin data recording. �(6.2)

13. ☐ When the temperature stabilizes, record it in Table 1. You may need to adjust the scale of the graph to see all of your data. �(7.1.2)

14. ☐ Stop data recording. �(6.2)

Table 1: Water sample volumes and temperatures

Volume of Water Samples	125 mL
Temperature of Hot Water	39.9 °C
Temperature of Cold Water	25.1 °C

Part 3 – Observing the temperature changes of the water mixture

15. ☐ Mix the equal amounts of hot and cold water in the insulated container.

16. ☐ Place the temperature sensor into the mixture in the insulated container and close the lid as much as possible.

17. ☐ Begin data recording. �(6.2) After the temperature of the mixture stabilizes, record the temperature.

Temperature of mixture: 31.7 °C

18. ☐ a. Why is it important to use the same volume of water for each sample in this part of the activity?

Answers will vary. One student group answered as follows. We think we have to use equal amounts or volumes of water so that the volume is not accidentally a non-controlled variable. If the amounts were different, we would not be comparing the same thing. Also, our equation probably would not work.

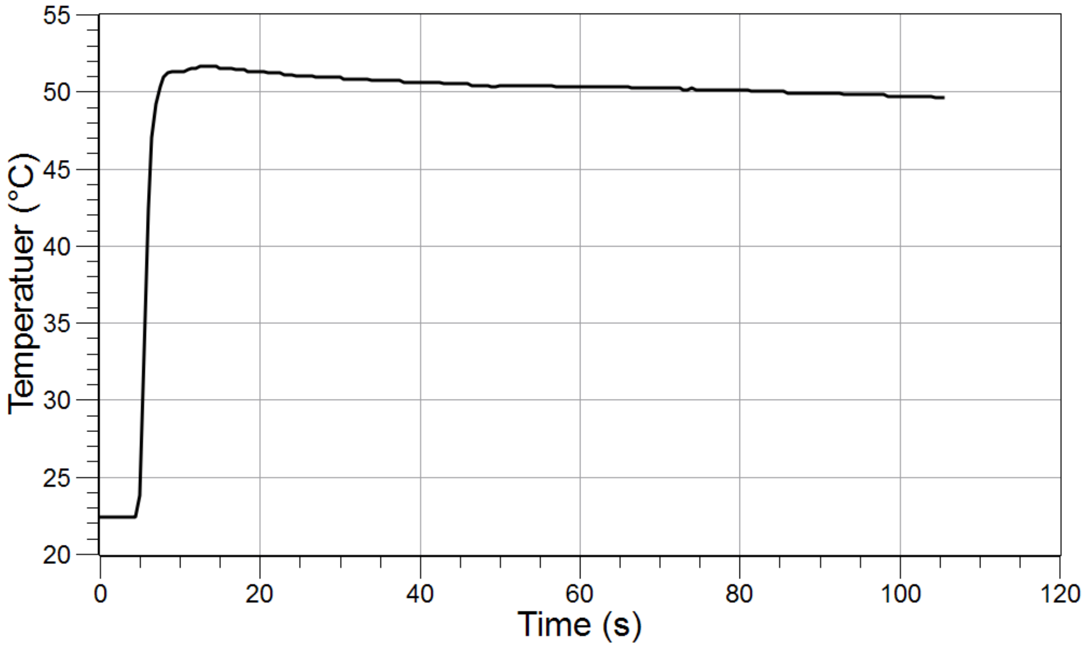
b. If you pour equal volumes of hot and cold water together into one container, what fraction of the mixture is represented by the hot water? Once you have tested your prediction for equal volumes of hot and cold water, what other fractional amounts could you measure and test?

Answers will vary. One student group answered as follows. When we used equal volumes, each was considered a half of the mixture. We could also test 1/4 and 3/4 or maybe tenths. For tenths we could do 100 mL of total water so it would be easier.

19. ☐ Use the equation your class came up with to calculate the final temperature. Is this what your lab group predicted or expected? In the space below, record your calculations and your results.

Answers will vary. One group answered as follows: Our class figured out how to average the temperatures. We would add the two temperatures and divide by 2. If this actually worked perfectly, we should have made the water mixture come out to be 32.5 degrees C, because we did 39.9 + 25.1 = 65. Then we divided 65 ÷2 = 32.5. But our results were a lower temperature, 31.7 degrees C.

Sample Data



Answering the Question

Analysis

1. After reviewing your data, describe the relationship that you see from the beginning and final temperatures of your water mixture.

    The mixture of the hot and cold water had a temperature almost right in between the two original temperatures.

2. How did your predictions from Part 1 compare to the results from Part 3? How closely does your predicted graph match what you actually recorded? How can you explain any difference you saw between the prediction you made and the experimental results?

    Answers will vary. One group answered as follows: Our prediction was that the mixed water would be in between the temperatures of the hot and cold water, which they were. But, our prediction graph did not really match the graph we got. We think that the difference came from maybe losing some heat from the hot water when we poured it, because maybe we let it sit in the glass too long before we poured it into the insulated cup.

3. Where does the heat energy go when two liquids of different temperatures are mixed together?

    Answers will vary. One group answered as follows: The heat energy seems to go toward the colder side of things. The hot liquid's heat goes toward warming up the cold liquid. It is like the hot one is sharing with the cold one so they each have the same amount.

Key Term Challenge

Fill in the blanks from the randomly ordered words below. Note that words may be used more than once:

heat	warm	degrees Celsius	temperature
average	flow	cold	energy

1. By measuring the ______temperature______of a substance you can get an idea of how much thermal energy its particles contain.

2. ______Heat______ is a form of______energy______ that is associated with the motion of the molecules of that substance.

3. Thermal or heat ______energy______ tends to ______flow______ from ______warm______ objects or substances to ______cold______ objects or substances.

4. In the SI system ______degrees Celsius______ is the unit of measure for ______temperature______.

5. When equal amounts of a ______warm______ and a ______cold______ substance are mixed, the resulting ______temperature______ is the ______average______ of the two initial temperatures.

6. When ______cool______things and ______warm______things come into contact with each other eventually both reach the same______temperature______, or in other words both have the same amount of ______heat______ ______energy______.

Further Investigations

Investigate what happens if the cold water is a mixture of ice and water.

How could you use the results of this activity to determine the amount of cold water that should be added to a hot bath to bring it to a comfortable temperature?

Rubric

For scoring students' accomplishments and performance in the different sections of this laboratory activity, refer to the Activity Rubric in the Introduction.