A NATURAL APPROACH TO CHEMISTRY

The central premise of this program is that chemistry is all around each of us, every day. Chemistry is us. We eat chemistry. We drink chemistry. Chemistry is the complex choreography of atoms and molecules that sustains life. Chemistry also reveals the working details of the non-living world. Chemistry is both how we create the materials of human technology, and also how the natural world builds and renews itself.

Conceptually, this course will take a system-view, wholistic approach to chemistry that is different from the historical reductionist approach. From the very beginning we will use the ideas of atoms, energy, and systems that unify physics, chemistry, earth science, and biology. The goal is to provide students with a useful knowledge of chemistry that can help them succeed in life and in any career, (not only as a scientist.)

The "five-E" model (Engage, Explore, Explain, Elaborate, and Evaluate) provides a well-tested structure for the program's pedagogy. Concepts will progress from hands-on observation in the lab (engage, explore), to conceptual understanding of what happened (explain, elaborate), and finally to rigorous quantitative analysis (evaluate). We strongly believe this approach teaches problem solving skills and critical thinking far better than the opposite "theory-followed by verification" model used by traditional chemistry texts.

In the lab, we will use a hands-on, guided-inquiry approach to build student understanding. The program will have 48 hands-on labs at its core. These labs will allow students to actively investigate and discover the foundational principles of chemistry. Each chapter will begin with an exploratory lab, designed to engage students in the concepts of the chapter. Each chapter will close with a summative lab, asking students to put concepts together to explain a more challenging phenomenon, often with quantitative analysis using their own data.

Special, modern, equipment is being designed to accompany the program. This equipment will make accurate, quantitative measurements accessible to all students. The equipment is designed to work with set per four students. The equipment will include data-collecting probes that can work stand-alone, or with a computer. These probes are simple to use, rugged, and purpose-built for education. A small, temperature-controlled electric heating unit will safely boil 30 ml of water in 3 minutes. No open flames or fume hoods are required to teach this course.

The mathematical level of the course will be limited to basic algebra. While quantitative problem solving will be emphasized in some sections, math will be used to complete the understanding of a concept, rather than as the foundation on which formal understanding is constructed. The course will review and develop appropriate mathematical skills as tools to understand the quantitative relationships in chemistry.

Because the course will emphasize (and build from) the foundational concepts of atoms, systems, and energy, this chemistry program will be an ideal follow-up to a ninth grade physics (or physical science) program. For those students who have not had exposure to (or need review of) the basic ideas, the first chapter will provide an "on-ramp" to these concepts.

All people need to make informed decisions regarding what they eat, and how they interact with Earth's environment. For this reason, we will use the areas of nutrition and environmental chemistry as over-arching themes from which to draw examples. We believe this will greatly help students to connect with the subject of chemistry and to retain what they learn as practical knowledge.

The thematic tie to nutrition and environment makes an ideal transition to biology as a capstone course in high school. For those schools following the P-C-B sequence, Concepts of Chemistry will be a perfect fit. For schools following a more traditional (Bio-Chem-Physics) sequence, the thematic choice will help them connect the new material to what they learned in their previous year.

Each chapter will conclude with an application section that shows how the concepts of the chapter are applied in a real-world context. For example, recent federal legislation requires the labeling of "trans-fats" in foods. Trans-fats are oils that have been partially hydrogenated to enhance their shelf life and make them more solid at room temperature. The application section of the chapter explains what a trans-fat is, and how ordinary oils, such as coconut oil are transformed into trans-fats.

About the authors

Dr. Tom Hsu is nationally known as an innovator in science equipment and curriculum and leader in teacher training. Dr. Hsu has trained more than 15,000 teachers of all levels, leading workshops since 1991. He is the author of five published middle and high school science programs in physics and physical science. A proponent of hands-on science, Dr. Hsu wrote and illustrated his text books, and also designed the experiments and apparatus, and wrote the lab manuals. Dr. Hsu pioneered the concept of bundling hands-on equipment with books and teacher training to provide a coordinated learning system that supports and develops teachers. He has broad teaching experience from grade 4 through graduate school and was nominated for the Goodwin medal for excellence in teaching at MIT. He holds a Ph.D. in applied plasma physics from MIT and a bachelors of science with honors in physics, magna-cum laude from the State University of New York at Stony Brook where he completed 178 credits, including all requirements for a bachelor of engineering degree.

Dr. Manos Chaniotakis has been teaching and doing research at the Massachusetts Institute of Technology for 18 years. For the last 6 years Dr. Chaniotakis has been developing, and teaching an innovative, hands-on electronics course at MIT to non-engineering majors. His innovative approach to lab-based teaching uses portable equipment which allows the student to develop and practice their laboratory and measurement skills in their own environment, outside the lab. He is also the founder and president of MITOS Inc., a technology company which develops measurement and analysis instruments for the analytical chemistry industry. His instruments measure such physical parameters as pH, conductivity, and the concentration of various ions in solution. Dr. Chaniotakis holds a Ph.D. in Plasma Physics and Fusion Engineering from MIT, a Master of Science in Mechanics and a Bachelors in Physics from the University of Minnesota.

Dan Damelin has a masters in chemistry and eleven years teaching experience at all levels of high school. He is a published reseracher in chemistry education, working with the Concord Consortium. Dan is one of the authors of the acclaimed molecular workbench chemistry modeling software and developed the award-winning "chemsite" web site for high school chemistry students.

Questions for thinking about chemistry

Here are some good questions that have answers in chemistry. Can you think of any others?

1. When a tree grows, where does the matter come from? Experiments reveal that the soil mass does NOT diminish significantly so where does the matter in the tree come from?
2. What is fire? Is it a chemical? It is matter? Is it energy?
3. What are vitamins and why are they important to living bodies? Vitamins are chemicals that the body needs but cannot produce from the raw materials in food.
4. Why is England warm but Siberia is frozen although both are at the same latitude? The answer is ocean currents driven by small differences in density caused by gradients in temperature and salinity.
5. Many people are concerned with trans-fats. What is a trans fat and how is it made? Trans-fats are partiallyhydrogenated oils that are derived from natural oils by processing.
6. How does bleach work? How does soap work? Why are these chemicals used to wash clothes, cars, and ourselves?
7. How does a battery work? What is the difference between rechargeable and one-use batteries?
8. How can water be ice, liquid, and steam when it is really the same stuff? How can the properties of ice, water, and steam be so different?
9. What is gasoline? Why is it used for cars and trucks? How are other fuels like alcohol or hydrogen different from gasoline?

10. ______________________________

11. ______________________________

12. ______________________________

13. ______________________________

14. ______________________________

15. ______________________________

16. ______________________________

Monday: Chemistry, Matter, Energy and Atoms

The goal of the first day is to develop the technique of teaching through investigation. A second and interwoven objective is to teach a foundation of basic skills, such as observation and measurement, which students will need for the rest of the course. The content area will be the nature of matter and the meaning of temperature. Matter is made of particles: atoms and molecules. These particles are never at rest, but inconstant motion at the molecular level. That motion is described by temperature. Quantities of matter contain energy due to the thermal motion of atoms and molecules, and that energy is called heat.

Investigations

1. Inquiry and Scientific Evidence (1A)
2. Working with Chemistry (1B)
3. Air is matter and has mass (pressurizing and weighing a 1 liter bottle, air vs. CO_2)
4. Difference between heat and temperature (water mixing experiments with temp probe)
5. The specific heat of steel
6. The heat of fusion of ice
7. Phase changes of water melting > boiling > condensation
8. Distillation as a physical process
9. Using molecular simulation to understand phase changes
10. Using molecular simulation to visualize the importance of hydrogen bonding: i.e. H_2O vs CH_4 melting and boiling comparison

Student outcomes

1. Explain the difference between steam and liquid water in terms of molecular models.
2. Explain why air has such a low density compared to water.
3. Describe the difference between heat and temperature
4. Use the molecular theory of matter to qualitatively explain phase changes
5. Tell the difference between physical change and chemical change.
6. Convert Fahrenheit to Celsius and back
7. Describe the meaning of specific heat in plain English
8. Calculate the energy, temperature, or mass in 1step specific heat problems.
9. Explain qualitatively why the temperature vs time curve has the shape it does when heat is added to ice at a constant rate until it melts and then boils
10. Explain why the distillate from distilled apple juice still smells like apples (apply the concept of separation by boiling point).

1A Inquiry and Scientific Evidence

How can you discover something you cannot see or touch?

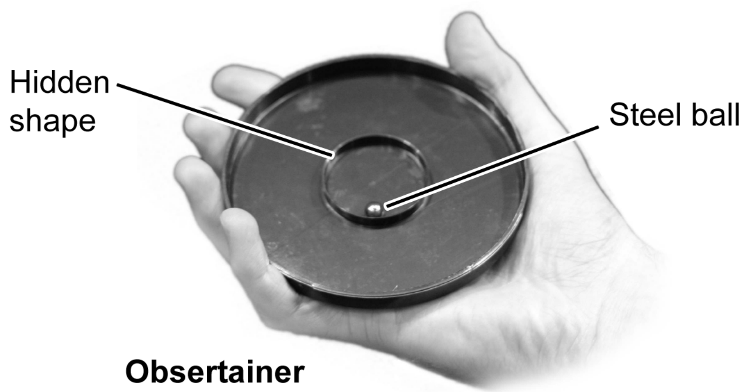
How do scientists know when they have the right explanation? Many of the fundamental ideas in chemistry have to do with atoms, Atoms are so small that you can't see them individually. This activity will show you how scientists "discover" what is unseen and also to compare evidence to check whether your explanation is right or not.

Materials

- Obsertainer kit
- pencils and paper

Part 1: Setting up

This investigation is about how scientists figure things out. Each of you will have several mysteries to solve. The mystery is the shape inside the black Obsertainer. You have to predict what shape is inside without being able to look.

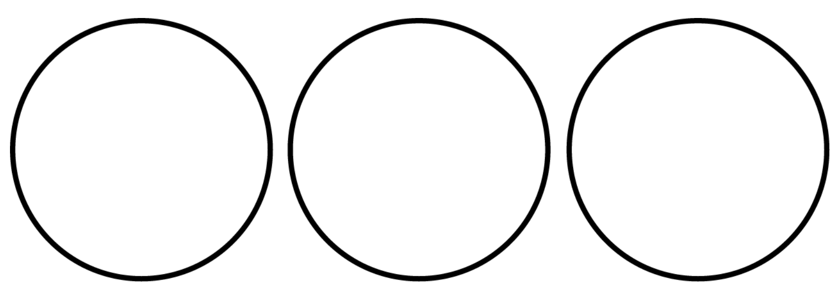


1. Each group should have four Obsertainer containers. Each has a small steel ball inside that can roll around inside a shape.
2. Each Obsertainer has a number on it. Take turns carefully rolling and tilting each one. Make very careful observations of the feel and sound of the ball rolling around the inside. Write your observations down, including any important details.

Part 2: The inquiry

A scientific inquiry is an investigation to find the answer to a question. Your question is "what shape is in the box". The inquiry includes all the things you do, and all the thinking you do to figure it out.

Use the diagrams to record your ideas about what the shape MIGHT be. This diagram is a hypothesis. A hypothesis is a tentative answer to the question that can be tested.



Guess #1 Guess #2 Guess #3

Part 3: Scientific evidence

You need to have evidence to support your hypothesis for what shape is inside the box. Scientific evidence must satisfy two very tough rules before being accepted.

1. #1: Objectivity
   Being *objective* means stating only what actually happened, free from any opinions or suspicions. "The ball made five clicks on one complete revolution" is an objective statement. It says only what happened. "I think the shape is a star" is NOT objective because it is your opinion.
2. #2: Repeatability
   When you or anyone else repeats the experiment the same way, the same thing happens, exactly as reported.

Part 4: Supporting your claims with evidence

a. Write down three observations that support your claim for the shape of at least two of the containers.

b. Include things that you did NOT observe which also cause you to think your hypothesis might be correct.

Part 5: Checking it out

Your groups should come up with a prediction for each of the four containers you have been given. Each prediction should be supported by at least one statement of evidence.

a. Open the four Obsertainers.

b. Sketch the true shapes beside the predicted ones.

c. Was all of your evidence consistent with the actual shapes? Was any of your evidence contradictory?

Predicted shapes

#___ #___ #___ #___

Actual shapes

1B Working with chemistry

How is chemistry done?

Chemistry is about learning what makes up the material world. Chemistry is also about how materials react when they are mixed, heated, or subjected to other changes. Learning chemistry means learning to work with different substances, some dangerous, in safe ways and in precise quantities. This lab will teach you some of the basic chemistry measuring skills.

Materials

- 4 covered vials
- 100 ml graduated cylinder
- 10 ml plastic pipettes
- Balance
- Small scoop
- Powdered laundry detergent
- Tap water
- Canola oil or similar vegetable oil

Part 1: Using the balance

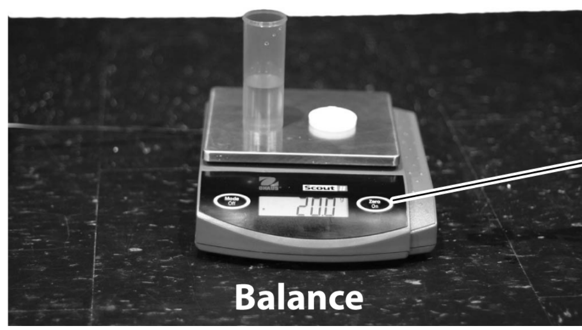
Balance rules:

Use the balance on a flat, level surface.

Be GENTLE, place things carefully on the balance, never drop things.

Always use an appropriate container, NEVER put chemicals directly on the balance

Spills are to be avoided, but cleaned up immediately if they occur.



In some chemistry experiments we want to know what substances are present and precisely how much of each substance there is. In other experiments we mix the right amounts of several substances to get something new. In both cases we need a way to measure things that is accurate and easy to communicate. Chemists use mass to measure and comunicate quantities of matter. A balance lets us measure accurate amounts of mass.

Objective: Get exactly 30 grams of water in the vial

1. Put a vial on the balance, with its cap on the side.
2. Record the mass in grams of the cap and vial
3. Hit the TARE (0) button on the balance
4. Use the pipette to add and subtract water until you have exactly 30 grams in the vial.

Part 2: Why this procedure?

a. Can you describe another way to get 30 grams of water in the vial?

b. What was the purpose of pushing the TARE or (0) button on the balance?

c. Remove the vial with the water from the balance. Does the balance go back to zero? Can you explain why or why not?

Part 3: A mixture

The next step is to add 2 grams of oil to the water in the vial.

1. Write down a 2 or 3 sentence procedure that would allow you to accurately add 2 grams of oil to the water in the vial.
2. Add the oil following your procedure.
3. Describe the resulting mixture. Do the oil and water mix?
4. Cap the vial and shake your mixture gently. Does that make the oil and water mix?
5. Let the vial sit still for a few minutes and evaluate the mixing again.

Part 4: The function of soap

You wash your clothes (and your hands) with soap. Soaps are a useful class of chemicals because of how they affect oil and water mixtures.

1. Use a small weighing paper to measure out 2 grams of powdered detergent (soap)
2. Add the detergent to the vial with the water and oil.
3. Gently shake the vial (GENTLY!).

Part 5: Explaining what you see

a. Describe the behavior of the oil and water mixture with and without the detergent.

b. Propose an explanation for how detergent works.

c. Try the experiment with hot water and cold water. Is there a difference?

Part 6: Doing the math

If you were designing a laundry detergent, you would want to tell people how much detergent to add to how much water. The percent concentration is a good way to give this information. The percent concentration tells you exactly what fraction of a mixture is soap, or oil, or water. The formula for percent concentration is

$$\text{percent concentration} = \left(\frac{\text{mass of substance}}{\text{total mass}}\right) \times 100\%$$

You should have 34 grams of solution, including water, oil, and soap. Calculate the percent concentration of each of the three components. The total should add up to 100%

Table 1: Percent concentration

Substance	Total mass (g)	Substance mass (g)	% concentration
water			
oil			
detergent			

a. Is the concentration of detergent enough to disperse the oil in water? Why do you think so?

b. Should the detergent concentration be higher or lower compared to the concentration of oil?

2C Density of Air

Is air matter?

Air might seem like “nothing” but air is matter, just like water is matter. Air can have considerable mass. In this Investigation you will measure the density of a solid, a liquid, and a gas and compare the number of atoms per cubic meter.

Materials

- Digital thermometer 0-100°C
- Mass balance
- 1-liter plastic soda bottle Prepared bottle cap with inserted tire valve
- Tire pressure gaugeIce water
- Bicycle pump
- Large graduated cylinder

Part 1: The gas phase

Safety Note: Be careful with the bottle, and DO NOT exceed 70 pounds per square inch (psi) of pressure.

1. Get the prepared cap with the tire valve inside and a 1-liter carbonated soda bottle.
2. Fill the bottle to the very top with water. Empty the water into a graduated cylinder to measure the volume of the bottle.
3. Put the cap on the empty bottle (full of air) and measure the mass.
4. Use the bicycle pump to raise the pressure in the bottle to 10 psi. Check the pressure with your gauge.
5. Use the balance to measure and record the mass of the bottle (and air) at 10 psi pressure.
6. Repeat the pumping and mass measurement for pressures between 10 psi and 70 psi. DO NOT exceed 70 psi!

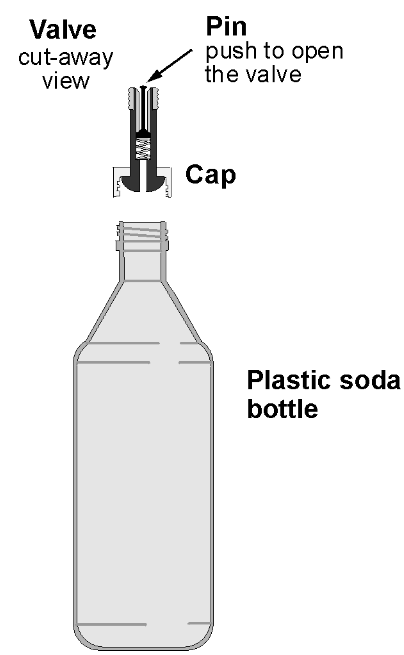


Table 1: Pressure and mass data

Gauge pressure (psi)	Mass (g)	Volume (ml)

Part 2: Thinking about what you observed

a. What happens to the mass as you increase the pressure in the bottle?

b. Explain why the mass increases.

Part 3: Graphing the data

a. Use Table 2 to calculate the mass of air added to the bottle at different pressures.

Table 2: Calculating the mass of air

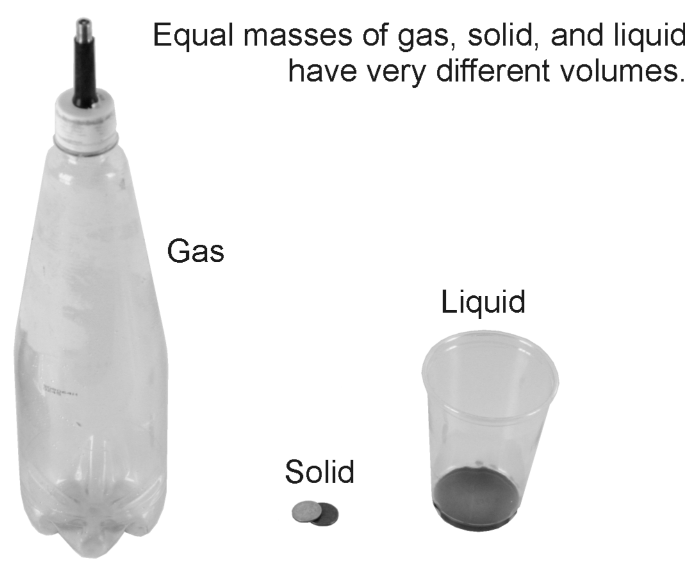
Pressure (psi)	Mass of bottle and air (g)		Mass of bottle at zero gauge pressure		Mass of air added to bottle (g)
		-		=	
		-		=	
		-		=	
		-		=	
		-		=	
		-		=	

b. Make a graph showing the mass of air plotted against the pressure.

c. When the pressure is zero on the gauge, is there any air in the bottle? Use the graph (or your data) to estimate the mass of air in the bottle at atmospheric pressure (zero on the gauge).

Part 4: Liquid and solid phases

1. Use your balance to measure out a quantity of water of equal mass to the air at zero gauge pressure.
2. Use your balance to measure out a quantity of solid material (coins, salt or sugar work well) of equal mass to the air at zero gauge pressure.



Part 5: Thinking about what you observed

a. Compare the total amount of matter in the gas, liquid, and solid samples. Does one have more matter? Does one have less matter? Or, do all have about the same amount of matter?

b. How does the number of atoms compare in each of the three samples (solid, liquid, gas)? How can the number of atoms be different if the total mass is the same?

c. Calculate the density of each of the three samples (solid, liquid, gas). Do your calculation in units of grams per mL (or grams per cm^3). For the air, use the highest pressure you measured.

d. The density of one of the matter samples changed a great deal during the experiment. Calculate the highest and lowest density you observed for the sample which changed.

e. Propose an explanation for why the density changed so much in the gas sample.

3A Heat and Temperature

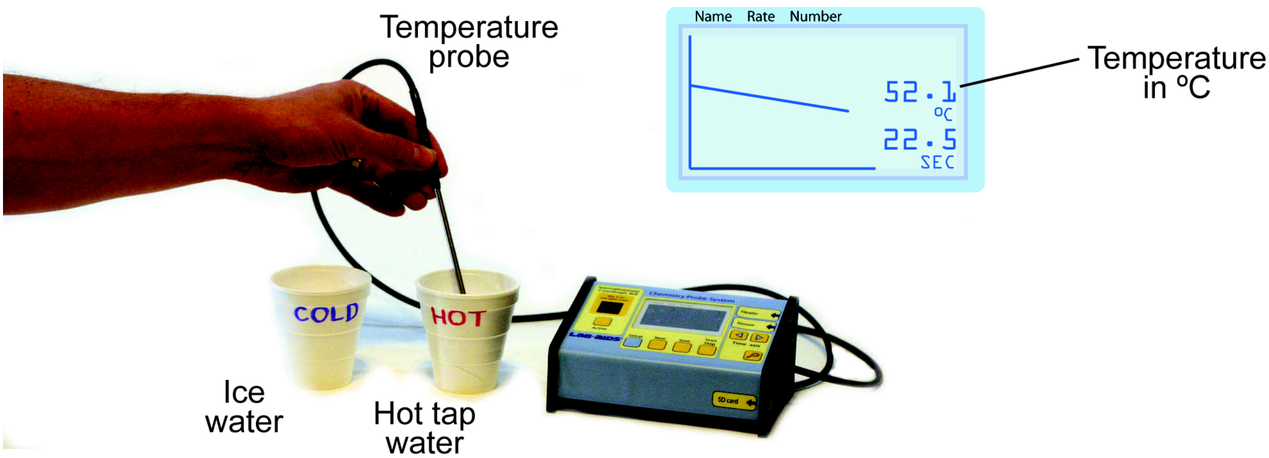
What is heat? Are heat and temperature the same thing?

Temperature tells you when it is hot or cold. You know adding heat raises the temperature. In this investigation we will learn precisely how heat and temperature are related. Heat and temperature are NOT the same thing, but, they ARE closely related.

Materials

- Probe System with temperature probe and heater
- Three 8 oz foam cups
- One 16 oz foam cup

Part 1: Measuring temperature



1. Connect the Probe System with a temperature probe.
2. Fill a foam cup about half full of ice water
3. Fill a second foam cup half full of hot water
4. Measure the temperature of each and record it in Table 1 along with the time of day to the minute.
5. Let the cups stand while you answer the questions in Part 2. Measure the temperatures again after about 5 minutes has passed.

Table 1: Water temperatures

Clock time	Cold water temperature (°C)	Hot water temperature (°C)

Part 2: What happens?

a. Consider that temperature describes a kind of energy. Do you think hot or cold water has more of this kind of energy? Explain in one sentence why you think so.

b. How do you expect the temperature of the water in each of the two cups to change over time?

c. Describe the flow of energy that causes the changes you predicted in question 2b.

d. Measure and see if the actual temperatures change as you expected.

Part 3: Making heat flow

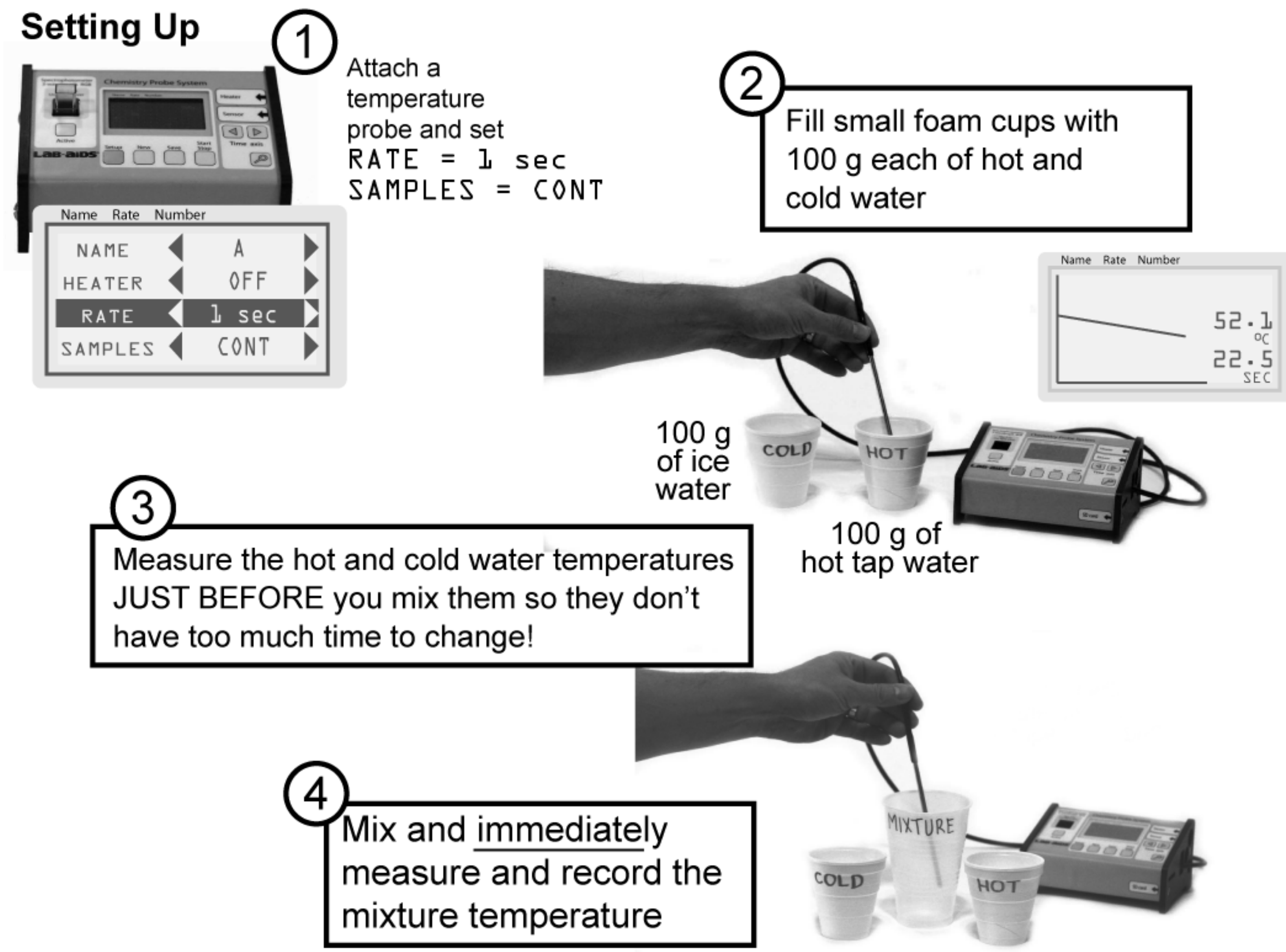


Table 2: Temperature data for mixing equal masses of water

Cold water temperature before mixing (°C)	Hot water temperature before mixing (°C)	Mixture temperature (°C)

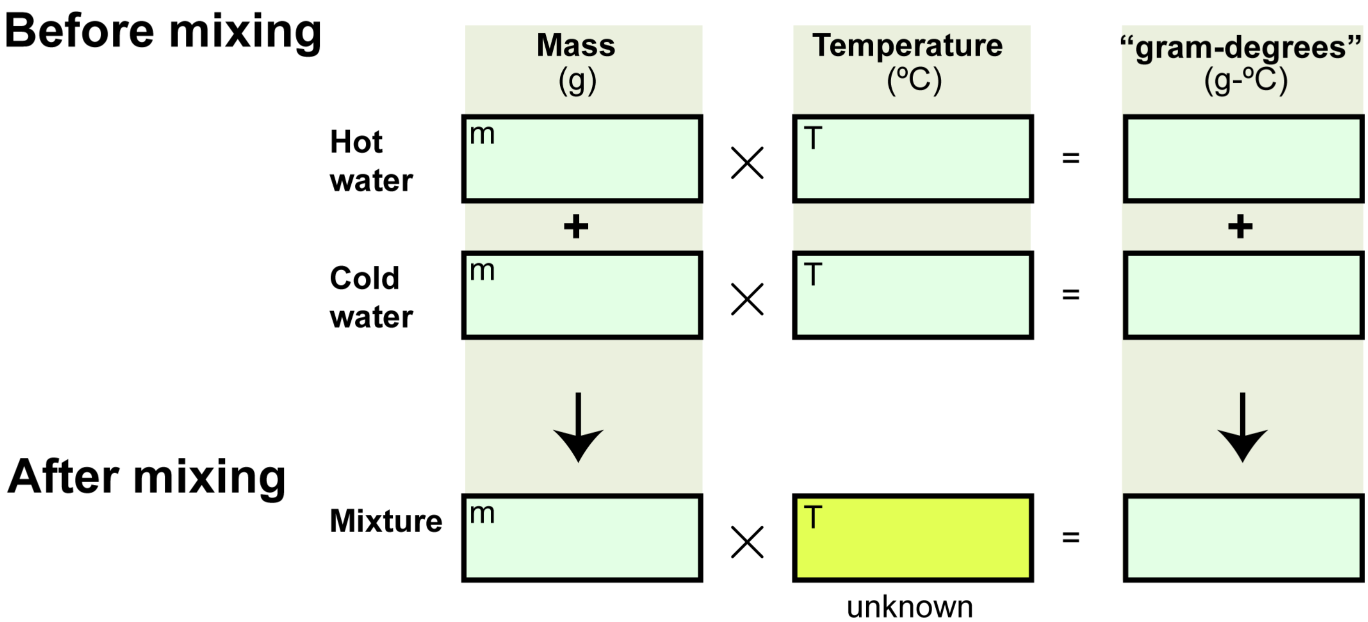
Part 4: Stop and think

a. Which cup has more energy, the hot one or the cold one? Why do you think so?

b. What did you think the temperature of the mixture would be? Why?

c. If the system includes both the cold and hot water, compare the energy of the system before mixing to the energy after mixing. You may ignore any energy going to air or friction.

Part 5: Analyzing the data



a. Fill in the measurements for the hot and cold water and calculate the gram-degrees.

b. For the mixture, fill in the total mass and total gram-degrees. <u>Do not fill in the mixture temperature!</u>

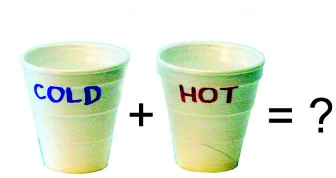
c. What does the "unknown" box represent?

d. Calculate the unknown temperature from the mass and total gram-degrees.

e. How close did this come to your actual measured temperature?

Part 6: A more complex experiment

1. Prepare 2 foam cups containing different amounts of hot and cold water. This time measure the mass of water in each cup. Use at least 100 grams of water of either temperature.
2. Measure and record the temperatures before mixing.
3. Mix the water, stir well, and measure the final temperature.



What happens when the masses are not equal?

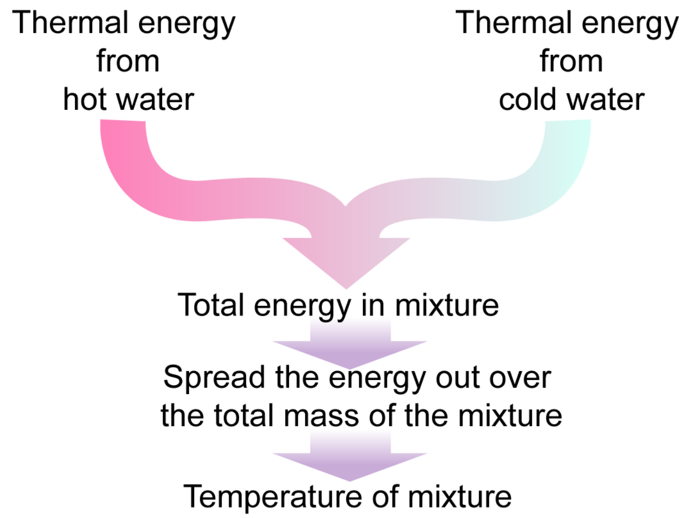
Table 3: Data for mixing unequal masses of water

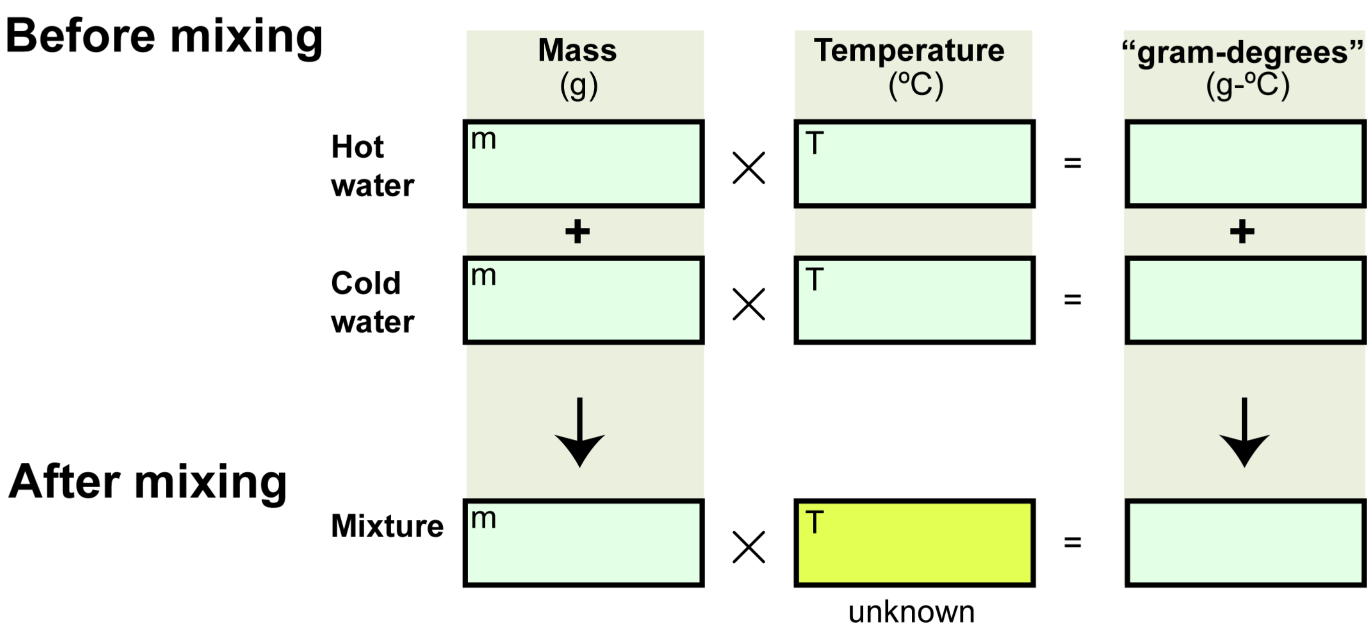
	Mass (g)	Temperature (°C)
Hot water		
Cold water		
Mixture		

Part 7: Doing the math

Thermal energy is energy due to temperature. The thermal energy in the water is proportional to the mass of water multiplied by the temperature. The energy is only "proportional" because different materials sture different amounts of thermal energy, even at the same temperature.

For now, assume the "energy" is in units of gram-degrees, or g-°C. Heres how to think about the experiment in terms of energy.





a. Fill in the light green boxes in the "Before mixing" section. Calculate the gram-degrees for the hot and cold water.

b. Add up the masses and the gram-degrees to get the total mass and gram degrees for the mixture.

c. Solve the "After mixing" section to get the mixture temperature.

Part 8: Why did the calculation work?

a. Did the result of the experiment agree with your prediction? Discuss the meaning of "agree" in terms of the accuracy and precision of your experiment.

b. Assume you have 3 cups of water with different masses and temperature. Describe a way to predict the temperature of the mixture if you know the masses and temperatures of the water in the cups.

c. Describe a situation where two objects have the same temperature but different amounts of energy.

d. Describe a situation where two objects have the same energy but different temperatures.

3B Heat Flow and Thermal Equilibrium

Why does heat flow?

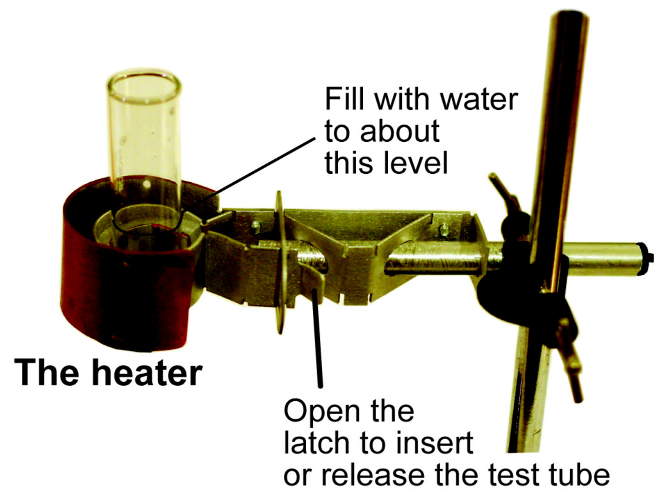
Everybody knows that an icy cold drink warms up if you leave it in a warm room. The drink gets warmer, so heat energy must be flowing into it. But, when the drink gets to the same temperature as the room, it stops warming up! What slows down and eventually stops the flow of heat energy from the room to the drink?

Materials

- Probe System with temperature probe and heater
- cold tap water
- 25 mm test tube

Part 1: Temperature and heat

1. Setup the probe system with the heater and a temperature probe.
2. You need about 10 mL of water. Clamp the test tube so that the water level is just above the metal ring holding the test tube. The temperature probe should be just below the surface of the water.
3. Set the heater to 50 degrees.
4. Record the temperature every 30 seconds for 5 minutes
5. After 5 minutes, save the temperature vs. time graph and set the heater to 100 degrees.



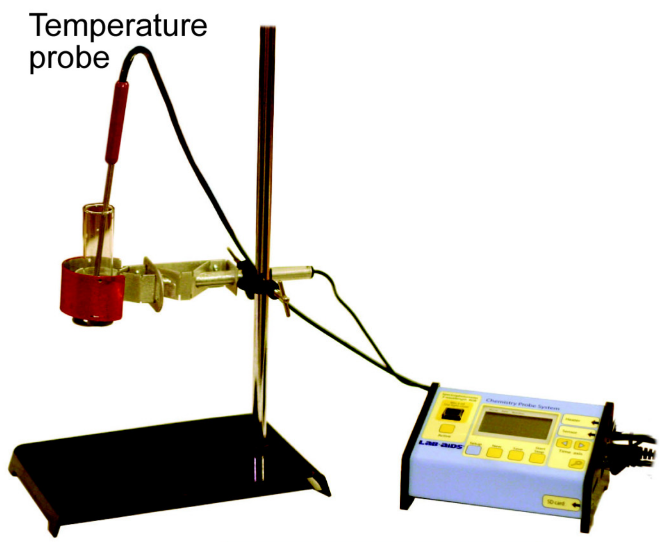
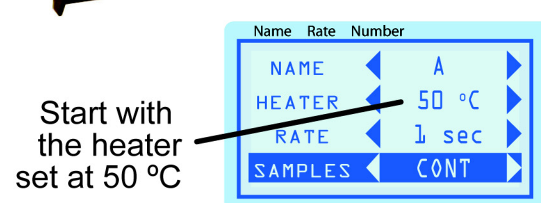


Table 1: Temperature of water

Time (min)	Temperature (°C)
0.0	
0.5	
1.0	
1.5	
2.0	
2.5	



Part 2: Think about it

a. Why is it important not to have too much water in the test tube?

b. What was the highest reading you saw on the temperature probe?

c. Describe the temperature vs. time graph.

d. Was heat being transferred from the heater to the water the whole time? Or did energy transfer stop at some point? What evidence do you have to support your claim? (hint: look at the Probe display)

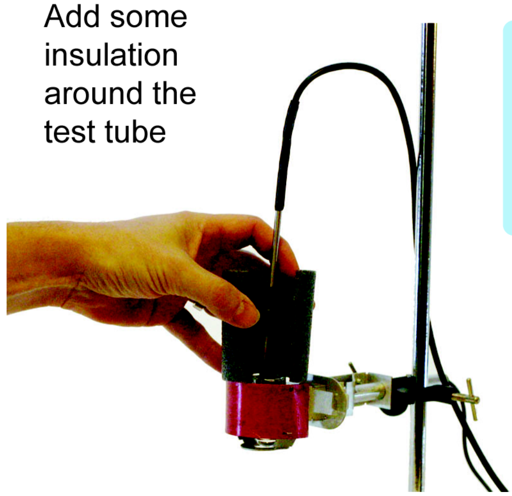
e. Why didn't the water get to the same temperature as the heater?

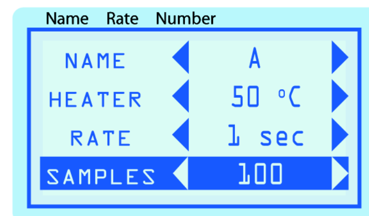
Part 3: Heat flow

Cap the test tube with a 1-hole stopped.

The probe tip must be about 1 cm into the water

Add some insulation around the test tube





The heater should still be set to 50 °C

Does the water get to a higher temperature? Why?

1. Add some insulation to the test tube.
2. Put the temperature probe in a stopper so it sits below the surface of the water
3. Observe the temperature for a few minutes while the heater is still set to 50°C

Part 4: Thinking about what you observed

a. What was the purpose of insulating the test tube? Think about heat as energy and where the energy goes.

b. A pot with a lid on it boils a lot faster than an open pot. Discuss why that is, and how it relates to why putting the cap on the test tube changes the temperature the water reaches.

c. Explain why the water became warmer even though the temperature of the heater stayed the same.

d. Explain why the POWER of the heater starts high but drops to a very low value after a while.

e. THERMAL EQUILIBRIUM is the situation when all temperature have become equal.No heat flows in thermal equilibrium. Is your test tube in thermal equilbrium or not? Why do you think so? This is a hard question! Discuss it with your class and your lab group then write up a short answer with a paragraph.

3C Specific Heat

Suppose you know the temperature, how much energy is there?

Two objects of the same mass and the same temperature can have different amounts of energy! This may see odd, but it is true. Do the experiment and see for yourself.

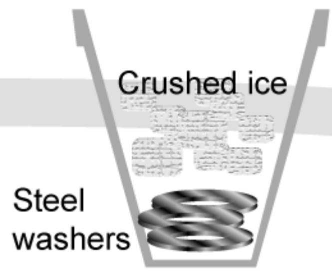
Materials

- 10 1/2" steel washers
- ice
- water
- balance
- temperature probe

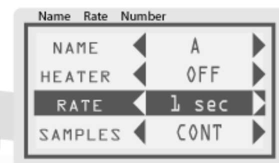
Part 1: The experiment

1. Measure the mass of at least 100 g of steel washers into a foam cup. Record the mass in Table 1

2. Cover the washers with crushed ice and a little water

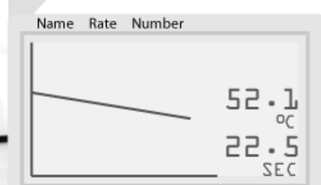


3. Attach a temperature probe and set RATE = 1 sec SAMPLES = CONT



4. Fill a second cup with a mass of hot water equal to the steel

5. Measure and record the water temperature JUST before adding the cold steel washers



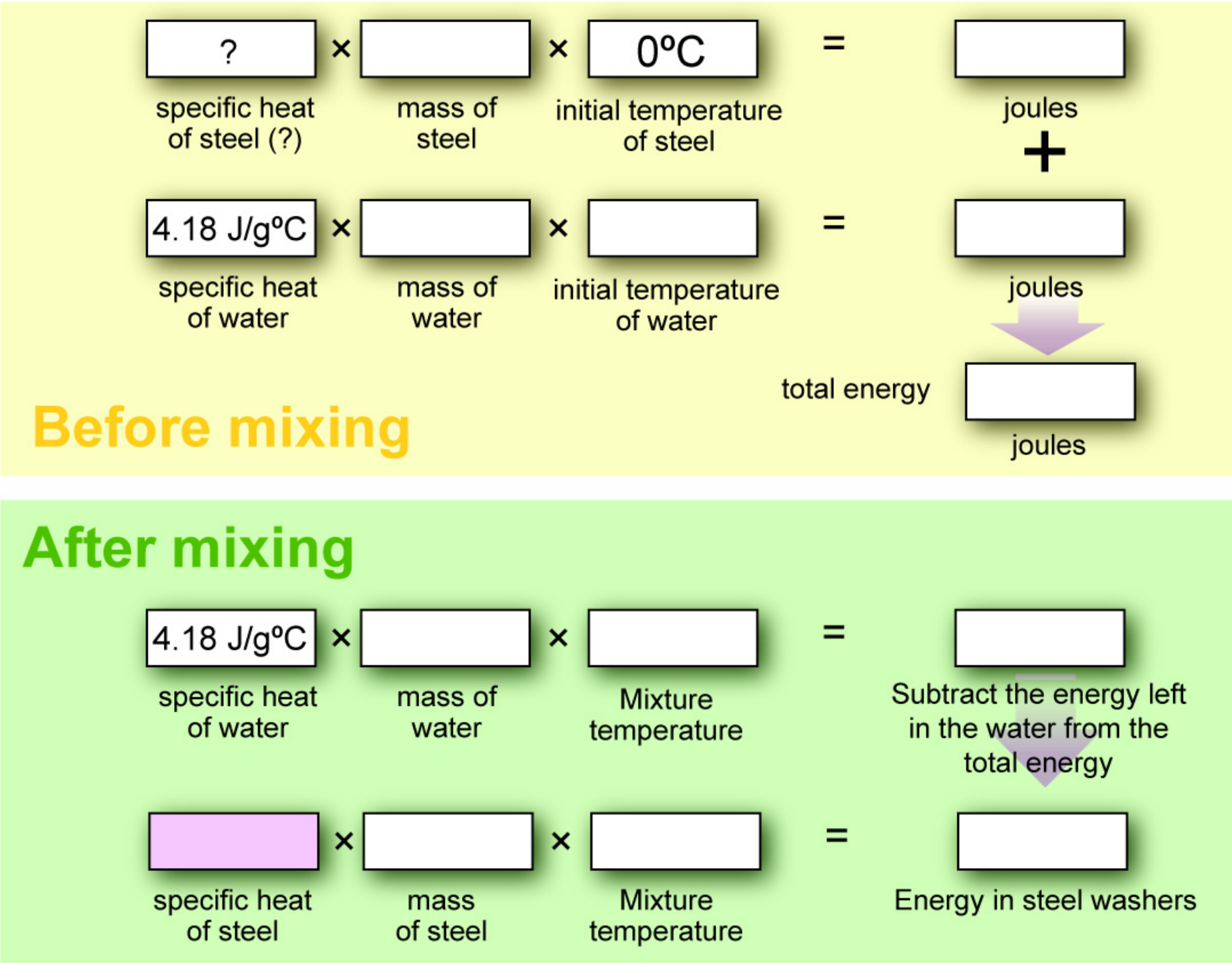
6. Carefully pick the steel washers out of the ice and drop them into the hot water. Be sure NOT to put and ice in with the steeo washers.

7. Measure and record the mixture temperature after about a minute of gentle stirring

Table 1: Temperature data for combining water and steel washers

Washer Mass (kg)	Washer temp. bef. mixing (°C)	Hot water mass (kg)	Hot water temp. bef. mixing (°C)	Mixture temp. (°C)

Part 2: Analyzing the data



Part 3: Thinking about what you observed

a. Propose an explanation for why the temperature of the steel and water mixture did NOT come out halfway between cold and hot, even though you mixed equal masses?

b. Now that you have a measurement of the specific heat, assume 0°C represents zero relative energy. How many joules of energy did the steel contribute to the mixture?

c. How many joules of energy did the water contribute to the mixture?

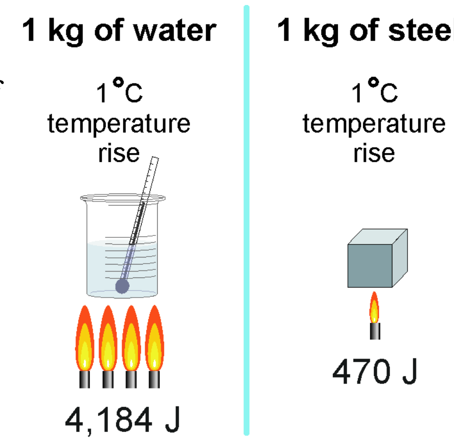
d. How good was the approximation we started with, that the steel contributed NO energy to the mixture?

e. Go back and recalculate the total energy using the actual energy for the steel. Use the actual temperature you measured for the steel just before mixing.

f. Now calculate a new (more accurate) value for the specific heat of steel. How different is this new value from the one you had?

Part 4: The specific heat of steel

Specific heat is a property of a material that describes how temperature and thermal energy are related for that material. For example, the specific heat of water is 4.18 J/g°C. That means it takes 4.18 joules of energy to raise the temperature of 1 gram of water by 1°C.



The total amount of thermal energy stored in a material depends on three things.

- the specific heat
- the mass
- the temperature

The relationship is given below

Formula | **Thermal energy**

Thermal energy (J), Mass (g), Specific heat (J/g °C), Temperature (°C)

$$E = mc_pT$$

Example: How much energy will raise 10g of water by 1°C?

$$E = (10g) \times (4.18\ J/g^oC) \times (1^oC)$$
$$= 41.8\ J$$

Part 5: Problems to think about

a. Suppose you add 100 joules of heat energy to 50 grams of water. How much will the temperature of the water increase?

b. Describe a situation where two objects have the same mass and the same temperature, but different amounts of thermal energy.

c. Describe a situation where two objects have the same mass and the same amount of thermal energy but different temperatures.

d. The specific heat of gold is 0.13 J/g°C. Suppose you add 100g of gold at 100°C to 100 grams of water at 0°C. Is the mixture temperature likely to be
a) closer to 0°C than to 50°C
b) closer to 100°C than to 50°C
c) around 50°C
Explain why you think so.

3D Phase changes of water

How do you change ice to water or water to steam?

The chemical "water" (H_20) can be a solid (ice), a liquid (water), or a gas (steam). Solid, liquid, and gas are the three phases of matter. Water, oxygen, iron, and every other chemical can exist in any of these three phases. In this investigation you will find out exactly how to change water from one phase to another. You will also discover why you don't often find solid oxygen and gaseous iron on Earth.

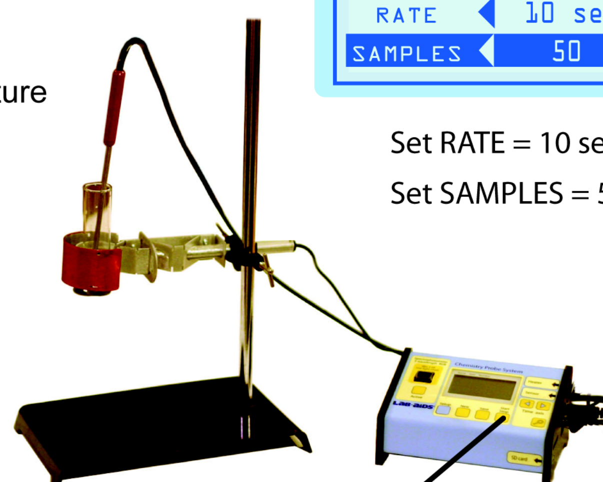
Materials

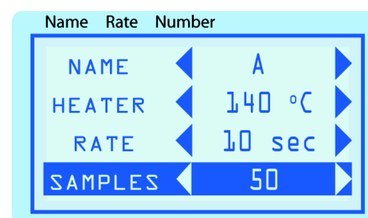
- Probe System with temperature probe and heater
- crushed ice
- 25 mm test tube

Part 1: Setting up.

Fill the test tube about half full with crushed ice and a little water

Set the heater to 140 °C and stir constantly (gently) with the temperature probe





Set RATE = 10 sec

Set SAMPLES = 50

Press Start/Stop to begin the experiment

1. Place a few boiling chips in the test tube then fill it about half full of crushed ice and a little water.
2. Record the temperature of the ice water in the table below. This is the temperature at "0 minutes."
3. Set the heater to 140 °C.
4. Set the Sample Rate to 10 seconds and the SAMPLES to 50. This will take a temperature measurement every 10 seconds for 500 seconds, which is 8.3 minutes.
5. Stir the test tube CONSTANTLY but GENTLY.
6. Watch carefully and note the time when all the ice has melted.
7. Watch and record the time when the water starts to boil.

Part 2: Analyzing the data

a. When the experiment is done, transfer time and temperature data every 30 seconds to Table 1. Use the arrow keys to scroll back through the graph to look at the data points.

b. Plot your own graph of temperature versus time using the data from Table 1. The graph should look a lot like the graph of the Probe System screen.

Table 1: Temperature of water

Time (seconds)	Temperature (degrees Celcius)
0	
30	
60	
90	
120	
150	

Part 3: Thinking about what you observed

a. Describe the temperature vs. time graph. Are some parts sloped differently than others?

b. Was heat energy being transferred from the heater to the water the whole time? Or did the energy transfer stop at some point? What evidence do you have to support your claim?

c. Why didn't the temperature rise while there was ice in the test tube? This is a hard question! Discuss it with your group and your class before writing up your answer.

d. What was the highest reading you saw on the temperature probe? What was the water doing at that time?

e. Why did the temperature stop rising when the water started boiling? This is a hard question! Discuss it with your group and your class before writing up your answer.

Part 4: Making connections

a. A chemistry book writes "H_20 (s)", "H_20 (l)", and "H_20 (g)". What do the letters in the parentheses ( ) mean?

b. At ordinary atmospheric pressure, what is the highest temperature that liquid water can reach before it boils? Your data from Table 1 should show you this. Compare your results with the rest of the class and figure out the average value.

c. What is the highest temperature that ice can reach before it melts? Your data from Table 1 should show you this. Compare your results with the rest of the class and figure out the average value.

d. These two temperatures are known as the boiling point and the melting point of water. Every chemical has its own melting point and boiling point. Why don't you see solid oxygen and gaseous iron as often as you see ice and steam?

3E Energy and Phase Changes

Why doesn't the temperature change as ice melts?

When you add heat to a sample of ice and water, the temperature doesn't change. You see ice melting, and the mixture becoming more liquid. But, as long as there is still some solid ice, the temperature stays constant. Why?

Materials

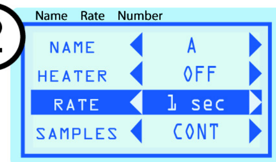
- Probe system with temperature probe
- ice
- water
- balance

Part 1: The experiment

1. Measure the mass of at about 100 g of ice into a foam cup

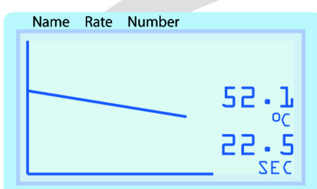
Record the mass in Table 1
TRY NOT TO GET ANY LIQUID WATER

2. Attach a temperature probe and set RATE = 1 sec SAMPLES = CONT



3. Fill a second cup with a mass of hot water equal to the mass of your ice

4. Measure and record the hot water temperature JUST before adding it to the cold ice

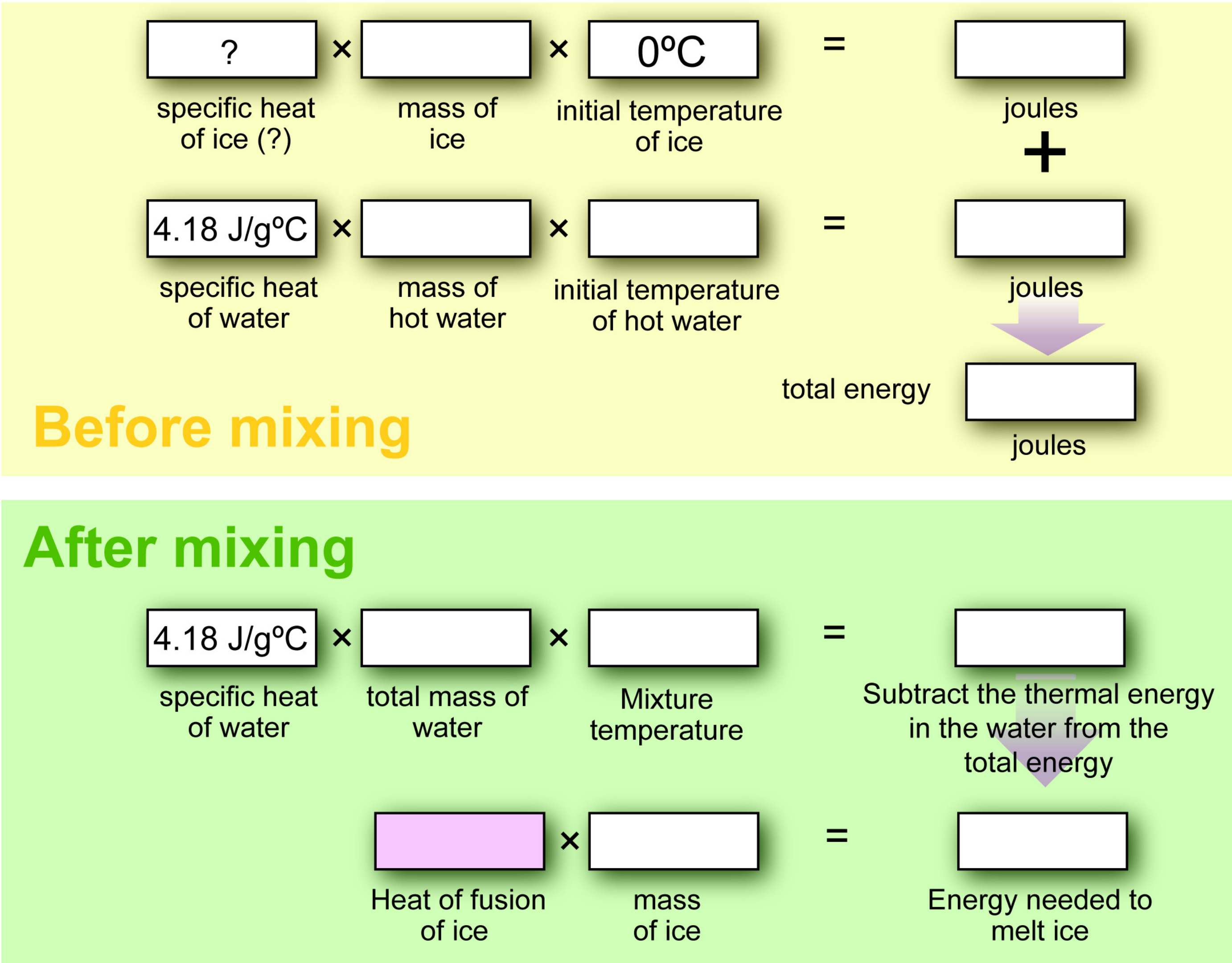


5. Measure and record the mixture temperature after about a minute of gentle stirring and AFTER the ice is melted

Table 1: Temperature data for combining water and ice

Ice Mass (g)	Ice temp. before mixing (°C)	Hot water mass (g)	Hot water temp. before mixing (°C)	Mixture temperature (°C)

Part 2: Analyzing the data



Part 3: Thinking about what you observed

a. Propose an explanation for why the temperature of the water did NOT come out halfway between cold and hot, even though you mixed equal masses?

b. We have assumed that 0°C represents zero thermal energy relative to the reference point of 0°C. How many joules of thermal energy did the solid ice contribute to the mixture?

c. How many joules of thermal energy did the water contribute to the mixture?

d. How does your value for the heat of fusion of ice compare to the accepted value?

e. All substances that undergo phase changes have a heat of fusion. How do other substances compare to water? Research the heat of fusion of at least four other substances and see for yourself.

f. Propose an explanation for why the heat of fusion of ice is similar or different from the other substances you chose.