Section Preview of the Teacher's Edition for

A Natural Approach to Chemistry, 2nd Edition
Chapter 3

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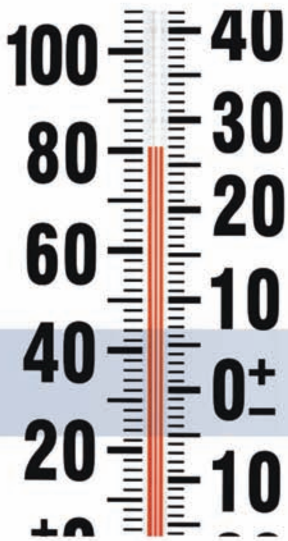
A NATURAL APPROACH TO CHEMISTRY



CHAPTER 3
Temperature, Energy and Heat

	Reading Summary	Learning Level	Key Vocabulary	Assessment
Section 3.1 **Temperature**	Atoms and molecules are in constant motion. Temperature is a measurement of the average kinetic energy of the molecules in contact with the thermometer. Absolute zero (0 K, –273.15°C) is the lowest possible temperature, corresponding to the lowest possible molecular motion. Heat, or thermal energy, is the total energy of motion in a sample of matter.	**Fundamental:** Pages: 70–78 1. Temperature scales 2. What is temperature	Heat, temperature, molecular motion, kinetic energy, random, Fahrenheit, Celsius, Kelvin, thermometer, thermistor, thermocouple, absolute zero	**Practice:** 1–8, 35, 36 58, 61 **Extension:** 9, 10, 34, 37, 38 62, 63
Section 3.2 **Heat and Thermal Energy**	Heat, or thermal energy, is commonly measured in joules, calories and BTUs. As stated in the 2nd law of thermodynamics, heat spontaneously travels from areas of higher temperature to adjoining areas of lower temperature until the temperatures of both areas are equal and thermal equilibrium is reached. Specific heat is the amount of energy required to increase the temperature of 1 g of a material by 1°C. Heat flows more readily through materials that are thermal conductors.	**Fundamental:** Pages: 79–83 3. System surrounding and heat transfer 4. Calculating heat energy **Advanced:** Pages: 84–87	Thermal energy, system, surroundings, thermal energy, joule, calorie, BTU, system, surroundings, 2nd law of thermodynamics, thermal equilibrium, 1st law of thermodynamics (energy conservation), specific heat, conduction, thermal insulator, thermal conductor	**Practice:** 11, 12, 39, 44 64–68 **Extension:** 18–21, 45–47, 69–73
Section 3.3 **Phase Changes**	A phase change occurs when a material changes between solid, liquid, and gas states. Every material has a specific temperature at which phase changes occur, called its melting and boiling points. The heat of fusion (vaporization) is the amount of energy required to convert 1g of a material from solid to liquid (liquid to gas). The surrounding pressure alters the temperatures at which phase changes occur.	**Fundamental:** Pages: 88–93, 96, 97 **Advanced:** Pages: 94, 95 5. Phase changes	Phase change, melting point, boiling point, heat of fusion, heat of vaporization, evaporation, condensation, latent heat, triple point, relative humidity, dew point	**Practice:** 22–30, 48–53 74–77 **Extension:** 31–33, 54–57, 78–84

	Connections to Student Book	Learning Goals	Differentiated Learning Strategies	Materials
Investigation 3A **Heat and Temperature** • How are heat and temperature related to each other? • When substances mix at different temperatures, what happens? • How can the flow of heat be measured?	Sections 3.1, 3.2	Explain how heat flows • Understand that temperature is related to molecular motion • Calculate the mixture temperature and compare it to the experimental mixture temperature	Level 1: Perform investigation Parts 1–Part 5 and then read pages 70–82 Level 2: Perform the complete investigation and then read pages 70–82	• Lab-Master with temperature probe, three 8 oz and one 16 oz foam cups, hot and cold water
Investigation 3B **Specific Heat** • What is specific heat? • Why do some substances change temperature more rapidly than others? • How can two substances, equal in mass and temperature, contain different amounts of heat?	Section 3.2	• Explain the concept of specific heat • Understand that the composition of matter influences a substance's ability to change temperature and hold energy • Calculate the specific heat of steel	Level 1: Perform investigation Part 1–Part 4 and then read pages 83–86 Level 2: Perform the complete investigation and then read pages 83–86	• Lab-Master with temperature probe, two 8 oz foam cups, 10 ½" steel washers, balance, ice, water
Investigation 3C **Heat Flow and Thermal Equilibrium** • What is thermal equilibrium? • How does a substance reach thermal equilibrium? • When does the flow of heat stop?	Section 3.2	• Explain how heat flows • Understand that temperature is related to molecular motion • Graph time vs. temperature data and understand when thermal equilibrium is reached • Understand how the rate of heat flow changes over time	Level 1: Perform the investigation and then read pages 86–87	• Lab-Master with temperature probe and heater, 1-hole rubber stopper, 25 mm test tube, insulation ring, test tube rack, water
Investigation 3D **Heat of Fusion** • What is the heat of fusion? • What happens when ice melts? • Why does the temperature stay constant while ice melts?	Sections 3.3	• Understand what happens to water molecules during a phase change • Graph time vs. temperature data and understand what the plateau represents • Calculate the heat of fusion	Level 1: Read pages 88–93 and then perform the investigation	• Lab-Master with temperature probe, large and small foam cups, balance, hot water, ice

3A: Heat and Temperature

Key Questions: What is heat?
Are heat and temperature the same thing?

In this Investigation, students experiment with heat flow using hot and cold water. Many students understand that temperature is a measure of how hot or cold a substance is. However, most of them have never thought about how temperature changes at the molecular level. Using a simple procedure, students observe and gather data that supports their intuition about heat transfer. By using the same substance in the same amount, students are able to focus specifically on the change in temperature. Based on their observations, students see that the change in temperature takes place as molecules mix.

Reading Summary

This Investigation relates to section 3.1 "Temperature". No prior reading is required of the students

Temperature measures the average kinetic energy of molecules or atoms. At higher temperatures the molecules move more vigorously. In any collection of molecules at a given temperature, some molecules are moving slower, while some are moving faster. However, the majority are moving at a speed that is close to the average energy. Molecules that collide are able to transfer energy. A slow moving particle that is hit by a faster moving particle gains energy. Because energy is always conserved, the faster particle must slow down, due to this loss of energy. The volume of alcohol inside a thermometer expands or contracts based on the speed of the molecules of alcohol. A thermometer reaches thermal equilibrium when it is left in contact with a substance. This means the molecules inside the thermometer are moving at the same speed as molecules outside the thermometer. Heat is another word for thermal energy, and thermal energy is the total energy contained in a collection of molecules.

Questions and Goals

Main Questions

- How are heat and temperature related to each other?
- When substances mix at different temperatures, what happens?
- How can the flow of heat be measured?

Learning Goals

By the end of the Investigation, students will be able to:

- Explain how heat flows
- Understand that temperature is related to molecular motion
- Calculate the mixture temperature and compare it to the experimental mixture temperature

Key Vocabulary

Heat, temperature, kinetic energy, random, Celsius, thermometer, thermistor, thermal energy, system, surroundings, first law of thermodynamics (energy conservation), thermal equilibrium

Materials and Setup

Students work in groups of three or four at lab benches.

Each group should have:

- A Lab-Master (or thermometer), styrofoam cups three 8oz and one 16oz.
- Hot and cold water

Preparation

No preparation required except to have the materials available.

You will need to have access to cold and hot water. Hot water can be obtained from a tap or heated in a beaker on a hot plate. Cold water can be obtained from a tap or a pitcher containing some ice.

Hints:

- Use a cardboard lid with a hole in it for the temperature probe or thermometer. This decreases heat loss.
- Have students repeat part 3 (if there is time) to see if their results are similar.

Suggestions:

- Try the experiment in part 3 with hot and cold water that only differ by 20°C, and then try it with hot and cold water that differ by 40–50°C. See if the larger difference in temperatures affects the average result.

Details

Teaching Time One class period

Assignments Section 3.1 "Temperature" in the Student Book after the Investigation.

Misconceptions Students consider heat and temperature to be the same thing. They think that a thermometer measures the amount of heat.

Outline of the Investigation

Introducing the investigation

1 Measuring temperature
2 What happens?
3 Making heat flow
4 Stop and think
5 Analyzing the data
6 A more complex experiment

Investigation sections	Part	Ideas and Dialog
Introducing the investigation Review what students know about heat and temperature. Have them share ideas from their daily life experiences. Give them a system and have them consider how it would exchange heat with the environment.		*Can you give some examples of how heat is exchanged in the environment, based on your daily life experiences? Can you describe them?* Here we would like some examples such as living near a lake in the summer keeps the air cooler, because the water has a cooling effect on the surrounding air. Why? Because the water is at a lower temperature, and it absorbs some of the heat from the surrounding air. Another good example would be a hot cup of coffee slowly cooling off on a cold day. Even an insulated cup cannot keep it warm indefinitely. A hot or cold pack on a sprain or muscle injury is another good example. For example, students could explain how a cold pack can remove heat and swelling from an new injury. *Our society depends upon thermal energy to provide warmth on a cold day. Where does this energy come from? Give a couple of examples.* Most of the thermal energy, or heat energy, that we use to keep warm comes from the combustion of fossil fuels. The burning of fossil fuels such as oil and coal yields large amounts of heat which warms the air or the water in our homes. *Today you are going to perform an investigation that will help you to better understand the difference between heat and temperature.*
Measuring temperature Students will experience that the rate of energy exchange is different with the hot and cold water systems.	1	*Each group will measure the temperature over a 5 minute time period. This will allow them to observe how heat energy flows from hot to cold. There is also a greater exchange because of the greater temperature difference, compared to the temperature in the room.* Have students explain why the hot water changes temperature faster than the cold water. Have them draw on their daily life experiences here too. Because the temperature difference between the water and the air are greater for hot water, it shows the fastest exchange of heat.
What happens? Help students to think about the flow of energy at the molecular level. Discuss how molecular motion is measured using temperature.	2	*How is temperature measured?* Students will likely say with the temperature probe or a thermometer. Ask them what the temperature probe or thermometer is measuring. *Students should explain which system hot or cold has more thermal energy, and how they think the energy is transferred via a change in temperature.* Students will see that the hot water changes temperature quicker. They might surmise that the molecules in hot water have more energy, because they are at a higher temperature. These higher energy molecules interact more rapidly with the air and therefore lose energy faster.
Making heat flow Allow students to work as independently as possible. Remind them to measure the hot water temperature just prior to mixing.	3	*Prepare your cups with the appropriate amounts of water. Measure the temperature of the hot water last.* Students will see that the mixture temperature is reached quickly. Have them record the highest temperature while gently mixing with the temperature probe. *Was there a flow of heat in your experiment? Briefly explain your thinking.* Student responses here may vary, but should focus around the fact that the cold water warmed up and the hot water cooled down. Both of these processes represent a “flow” of heat. Hopefully, they will note that the flow of heat took place in the direction of hot to cold, until the system reached a balance. We call this balance thermal equilibrium.

Investigation 3A: Heat and Temperature

Part 2: What happens?

a. Consider that temperature describes a type 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 would cause the changes you predicted in question 2b.

d. Measure the temperatures in each cup and see whether the actual temperatures changed as you expected.

Part 3: Making heat flow

1. Prepare a small foam cup with 100 g of hot water.
2. Prepare a second small foam cup with 100 g of cold water.
3. Measure the temperatures in each cup just before you mix them in Step 4.
4. Mix the hot and cold water into the larger (empty) foam cup.
5. Stir the mixture with the temperature probe and quickly record the temperature of the mixture.

Measure the temperature of the hot and cold water just before mixing

Mix the hot and the cold water and measure the final mixture temperature

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 of water had more energy: the one with hot water or the one with cold water? Why?

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

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

Example Answers

Investigation sections	Part	Ideas and Dialog
Stop and think What happened to the energy contained in each cup of hot and cold water?	4	*Now let's take some time to think about what happened when you mixed the hot and cold water. It is helpful to think about all of the small water molecules contained in each cup and what happened when they were mixed.* Most students will guess that the hot water has more energy, because it is at a higher temperature. Ask them to think about whether or not energy is only affected by temperature. Could there be other things besides temperature that effect the energy of the water? Some of the students might say the amount of water also effects the energy. *What did you think the temperature of the mixture would be?* Here students will say they expected the temperature to be in the middle (average) between the two starting temperatures, because the mixture contained equal masses of the same substance. *Compare the energy of the system (cups of water) before mixing and after mixing.* Here we want students to say something that addresses the face that before mixing the cold water had less energy than the hot water. After mixing the hot water and the cold water mix and their energies reach thermal equilibrium (balance out), effectively redistributing the energy over the whole mixture.
Analyzing the data Ask students to evaluate their data before and after mixing.	5	*Fill in your table and calculate the gram-degrees for the hot and cold water.* Students will find that the gram-degrees for the hot water is higher than the gram degrees for the cold water. *Now fill in your total mass and total gram degrees. What does the unknown box represent?* Have students add up the total mass and gram degrees as shown on the flow chart. The unknown box represents the mixture temperature. *Based on your data calculate the unknown temperature from your data.* Students will divide the total gram degrees by the total mass. *How does your measured value for the mixture's temperature compare with your calculated value?* Have students compare their values and make a list on the board. If they are different, students should consider why. What measurement(s) would have limited their accuracy and precision?
A more complex experiment Students will see that the same thinking applies even when the results are not as easy to predict. Follow-up with a discussion to compare before mixing with after mixing temperatures.	6	*Follow the procedure for part 6. This time there will be three cups that contain different amounts of water. Collect your data and use it to calculate your final mixture temperature as you did before.* Here students will not be able to simply predict the mixture temperature because of the different amounts of water. They will have to add them all up to get an average, which will reinforce the concept of temperature being the average, while energy is the total. *Did the results of your experiment agree with your calculated result for the mixture temperature?* The results should be within one degree (+/− 1°C). This is likely due to the temperature measurement, which is the least precise. The mass is recorded to one place past the decimal, so it is more precise. Students need to be careful during transfer that they do not lose any mass. Another source of error could be not mixing or waiting for the water to reach thermal equilibrium. Of course, heat loss is also an issue. Have the students discuss sources of error in this experiment. *What does it mean when your results "agree?"* Results agree if the answer and the measured value are within the allowed error based on the precision of the balance and the temperature probe used to measure.

Investigation 3A: Heat and Temperature

Part 5: Analyzing the data

	Mass (g)		Temperature (°C)		gram degrees (g · °C)
Before mixing					
Cold Water	100.0	×	4	=	400
	+				+
Hot Water	100.0	×	68	=	6,800
After mixing	=				=
Mixture	200.0	×	36 (unknown)	=	7,200

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

b. For the mixture, fill in the total mass and total gram-degrees. *Do not fill in the mixture temperatures!*

c. What does the "unknown" box represent?

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

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

Part 6: A more complex experiment

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

What happens when you add three cups together at different temperatures?

Table 3. Data for mixing unequal masses of water

Sample	Mass (g)	Temperature (°C)
Cup #1	99.6	31
Cup #2	70.0	51
Cup #3	60.0	12
Mixture	230.6	33

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Example Answers

Teaching tips

Presenting thermal energy this way allows students to focus on conservation of energy without having to understand specific heat, or do complicated math. Because the same substance is being mixed, students are generally successful in deducing what happens. The fact that it is intuitive helps them to remember and makes it easier for them to understand the concept of energy conservation when it is applied.

Students can easily observe how the temperature changes when the hot and cold water is mixed. Since there are no other variables students can see that a change in temperature accompanies a change in the total energy of the collection of molecules.

Students should be very close with their estimates when comparing their data to their calculated values. Usually this is a good thing, but some students may dismiss this as being "too easy" and not fully take the time to contemplate the idea that temperature is different than thermal energy. Have them write about how they are different if they move through the lab quickly.

It is helpful to have students try part 6, so that they really have to think about what is going on at the molecular level. It may seem very simplistic to them initially, and that is good, but we want them to fully consider the idea of how temperature affects molecular motion and the flow of thermal energy.

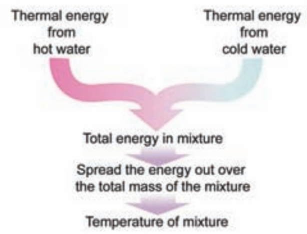
Investigation sections	Part	Ideas and Dialog
Doing the math Students will use the idea of energy conservation to calculate the mixture temperature.	7	*Fill out the flow chart with your data from Part 6. Calculate the final mixture temperature based on your results.* Students will once again calculate the gram degrees for each cup (1-3). By adding all of the energy contained in cups 1, 2 and 3 they will obtain the total energy in gram degrees. Students then add the masses of each of the three cups to obtain the total mass of the mixture. Finally, the total energy divided by the total mass gives the estimated mixture temperature. Here students will realize they cannot simply find the midpoint as there are three cups with different masses. Students make the assumption that energy is conserved to calculate the mixture temperature. Their results agree with the actual temperature that they measured, which supports the fact that the total energy is evenly distributed among all of the molecules in the mixture. It is very important that the mixture was formed from the same substance, in this case water, because this allows us to ignore the specific heat.
Why did the calculation work? Have students consider the logic behind their calculation.	8	*How closely do your calculated results agree with your experimental results?* The results "agree" meaning they are within the reasonable range of accuracy given the precision of the measuring instruments. Most of the time students will obtain a measurement that is the same as the measured temperature, or within +/- one degree. The temperature probes are accurate to within +/- one degree. If the group's results are NOT within a degree chances are they were sloppy with their technique and lost mass (spilled some water) or they were not careful in taking their temperature measurements.

Investigation 3A: Heat and Temperature

Part 7: Doing the math

The thermal energy associated with a certain amount of mass is related to its 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 store different amounts of thermal energy, even at the same temperature.

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



	Mass (g)		Temperature (°C)		gram degrees (g · °C)
Before mixing					
Cup 1	99.6	×	31	=	3,088
	+				+
Cup 2	70.0	×	51	=	3,570
	+				+
Cup 3	60.0	×	12	=	720
After mixing	=				=
Mixture	230.6	×	32 (unknown)	=	7,378

a. Fill in the light blue boxes in the "Before mixing" section. Calculate the gram-degrees for both 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 10 cups of water with different masses and temperatures. 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.

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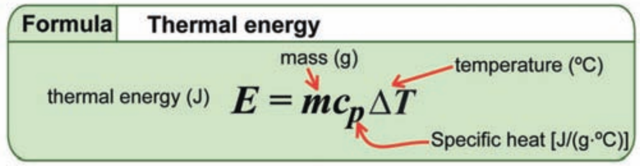
Example Answers

3B: Specific Heat

Key Question: If you know the temperature of something, how much energy is there?

In this Investigation, students experiment with different substances and observe how they transfer energy. By using the same amount of two different substances students discover that different types of matter store and release energy differently. The composition of matter affects how much energy it can hold, and how much its temperature changes. Students are able to use their prior experiences and knowledge to extend their thinking. The molecular and atomic composition of matter is central to students' understanding of specific heat.



Example: How much energy is needed to raise the temperature of 10 g of water by 1°C?

$E = (10\ g) \times (4.18\ J/g°C) \times (1°C)$
$= 41.8\ J$

Reading Summary

This Investigation relates to section 3.2 "Heat and Thermal Energy."

Heat is another word for thermal energy, and thermal energy is the total energy contained in a collection of molecules. On the macroscopic level thermal energy is proportional to the temperature of a collection of molecules. The joule (J) is the SI unit of energy and heat. The Second Law of thermodynamics states that heat flows in the direction of hot to cold. The flow of heat energy is important in technology and in nature.

To understand how heat flows we need to define our system under study, which can be anything we want it to be. Things outside our system are called the surroundings.

The First Law of Thermodynamics states that energy is always conserved between the system and the surroundings. The amount of energy in a particular substance is proportional to its mass and temperature.

Mixtures reach thermal equilibrium over time due to the exchange of heat. Specific heat is the amount of heat energy required to raise 1.0 gram of a substance by 1 degree Celsius.

Questions and Goals

Main Questions

- What is specific heat?
- Why do some substances change temperature more rapidly than others?
- How can two substances, equal in mass and temperature, contain different amounts of heat?

Learning Goals

By the end of the Investigation, students will be able to:

- Explain the concept of specific heat.
- Understand that the composition of matter influences a substance's ability to change temperature and hold energy.
- Calculate the specific heat of steel.

Key Vocabulary

Heat, temperature, kinetic energy, random, Celsius, thermal energy, system,surroundings, first law of thermodynamics (energy conservation), thermal equilibrium, second law of thermodynamics, specific heat, conduction.

Materials and Setup

Students work in groups of three or four at lab benches.

Each group should have:

- A Lab-Master (or thermometer), temperature probe, two 8 oz. styrofoam cups, ten 1/2-inch steel washers, balance
- Ice and water

Preparation

No preparation required except to have the materials available.

You will need to have access to water and ice. Hot water can be obtained from a tap or heated in a beaker on a hot plate.

Hints:

- Use a cardboard lid with a hole in it for the temperature probe or thermometer. This decreases heat loss.
- Steel washers should all be made of the same type of steel so that students can compare results.
- Transferring the washers from ice to water needs to be done quickly.
- Be careful to avoid having the temperature probe touch the washers while measuring the temperature.

Suggestions:

- Determine the specific heat of your steel washers ahead of time so that you know. Some galvanized washers have a higher specific heat, while other washers have a lower specific heat due to a higher carbon content.

Details

Teaching Time One class period

Assignments Section 3.2 "Heat and Thermal Energy" in the **Student Book** after the Investigation.

Misconceptions Students often think that they did something wrong when the temperature does not change very much after adding the cold washers to the water.

Outline of the Investigation

Introducing the investigation

1 The experiment
2 Analyzing the data
3 Thinking about what you observed
4 The specific heat of steel
5 Problems to think about
6 Were we sloppy in our math?

Investigation sections	Part	Ideas and Dialog
Introducing the investigation Discuss the idea of energy conservation with your students. Have them share examples of heat transfer with their classmates.		*Sometimes energy appears to be "lost" when really it is conserved. Can you give an example of this?* Students will most likely think of burning wood or fossil fuels as examples of heat or energy "lost" as it dissipates into the air. It is able to spread out over such a large space, therefore it has a small overall effect. The idea of energy conservation is easy to understand if the system under study is well defined. Energy can be converted to some other useful function as well. For example, food energy is used by the body and converted to heat and used for movement. *How does one object transfer heat to another object?* Here most students will give examples of heat transfer through direct contact, or think of heat transfer by conduction. When an object at a higher temperature is in contact with an object at a lower temperature, heat flows from the warm object to the cold object. Molecules that are in contact (touching) have collisions with each other and transfer kinetic energy. *This investigation will show you how different forms of matter can hold different amounts of heat energy.*
The experiment Students will observe the heat transfer between cold washers and hot water.	1	*Each group should follow the directions for the investigation. Try to avoid heat loss when possible.* Remind students to cover the washers with plenty of ice and add a little water. It is important that the washers get close to zero, so that the students "believe in" the math of the simplified calculation. Have students leave the washers in for 3-5 minutes! This is very important otherwise their data will not be as accurate. Quick transfer of washers also helps them to get a closer result for their specific heat.
Analyzing the data Help students to fill in their flow chart, and calculate the specific heat of steel.	2	*Record your data in the flow chart in your lab manual. Find your total energy in Joules before mixing. Use this value to determine how much energy was initially in the washers. This will allow you to determine the specific heat of your washers.* Help students to calculate the total energy before mixing. If their steel did not get to zero they will need to use zero for now, but in part 6 they will go back and approximate. Using zero for now simplifies the math of the calculation and leaves less room for small math errors. It also sends the message that water is responsible for most of the energy, which is essentially true. You do not have to measure exactly 100 g of hot water. Any value close to 100 g will do. In the sample data we use 98.4 g which was also the mass of the washers. You should reemphasize the results from investigation 3A by observing that the temperature when water and steel mix is closer to the initial water temperature than the steel temperature.
Thinking about what you observed Allow students time to compare and discuss their results for the specific heat.	3	*Why did the steel and water mixture temperature not come out half way in between the initial temperatures of the steel and water?* Since the students mixed equal amounts of the steel and water they may have thought the temperature would be in between, similar to their earlier experience. However, at the very least they will be surprised at how little the water temperature changes! In their explanation students should discuss the fact that water and steel are different substances and it must be the make-up or composition that accounts for this phenomenon. They may speculate that the molecules/atoms hold heat differently. *Do you think that the steel actually had zero energy? Briefly explain your thinking.* Student responses here may vary, but they should focus around the fact that at zero degrees Celsius the molecules in the steel are moving slowly. They may think that the molecules/atoms have NO energy. Be sure to explain that even in cold temperatures molecules/atoms are still moving and contain kinetic energy. In part 6 they will check their approximation and see that the energy contributed by the steel is essentially negligible, because the specific heat is so low relative to that of water.

Investigation 3B: Specific Heat

Part 2: Analyzing the data

Before mixing

specific heat	×	mass	×	initial temperature	=	joules	
? (specific heat of steel (?))	×	98.4 (mass of steel)	×	0 °C (initial temperature of steel)	=	0 (joules)	A
						+	
4.18 J/g °C (specific heat of water)	×	98.4 (mass of water)	×	66 °C (initial temperature of water)	=	27146.6 (joules)	B
						=	
				total energy		27146.6	A+B

After mixing

specific heat	×	mass	×	mixture temperature	=	result	
4.18 J/g °C (specific heat of water)	×	98.4 (mass of water)	×	57 °C (mixture temperature)	=	23444.6 (subtract the energy left in the water from the total energy (A+B-C))	C
0.66 (specific heat of steel)	×	98.4 (mass of steel)	×	57 °C (mixture temperature)	=	3701.2 (energy in steel washers)	A+B-C

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. (This means that we are measuring the energy relative to 0°C, not that the actual energy is zero). 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?

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Example Answers

Teaching tips

The traditional approach uses the "heat lost = heat gained" method and (mass) × (specific heat) × (ΔT), but students make sign and algebra mistakes using this method. This takes away from their understanding the "big idea" of specific heat as a property of matter.

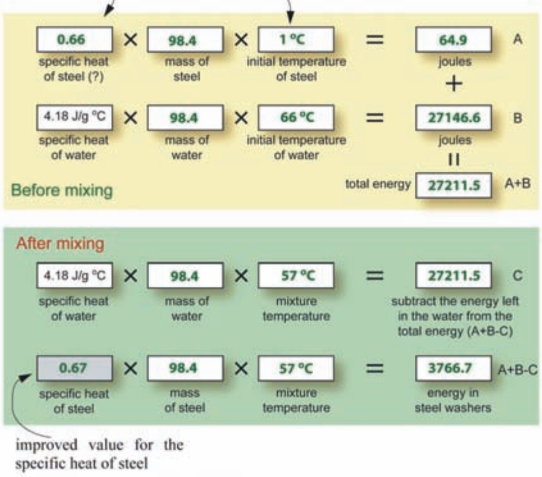
Investigation sections	Part	Ideas and Dialog
The specific heat of steel Ask students to discuss the property of specific heat in their groups. Ask for student volunteers to explain the meaning of specific heat.	4	*In your group discuss how the concept of specific heat relates to the chemical composition of matter.* Most students will give a few examples based on the background reading in their textbook. With heavier atoms or molecules fewer are contained in a given mass of a compound, so heat energy has a greater effect because there are fewer atoms or molecule to transfer energy to. Lighter molecules have a greater number in a given mass, so they do not change temperature as easily. How atoms and molecules are packed influences the specific heat of the substance. *Why is specific heat important to consider when calculating the energy contained in a certain mass of a substance at a given temperature?* Specific heat relates to how a substance can absorb or release heat, therefore it is necessary to consider.
Problems to think about Ask students to practice these questions to help them to better understand the meaning of specific heat.	5	*Suppose you add 100 J of heat energy to 50 g of water. What is the temperature increase?* $100\ J / (50\ g \times 4.18\ J / g°C) = 0.48°C$ The water will change by 0.48°C. *Describe a situation where two objects have the same mass and the same temperature, but different amounts of thermal energy.* This would happen when the substances are made of different molecules / atoms. The specific heats would be different changing the amount of thermal energy contained in the substances. *Describe a situation where two objects have the same mass and the same amount of thermal energy but different temperatures.* This situation would be similar to the previous one and the specific heat of the objects would need to be different. *Suppose you add 100 g of gold (0.13 J / g°C) at 100°C to 100 g of water at 0°C. What is the mixture temperature likely to be?* Closer to 0°C than to 50°C. The gold will change temperature the most and the water very little due to its high specific heat.
Were we sloppy in our math? It is important that students understand that the calculations actually give accurate results. This helps them to understand the assumptions we made.	6	*Students should enter their data into the flow chart, to facilitate the calculations.* When students calculate the actual energy contributed by the steel it will be a very low value in comparison to the water. Some will also have a temperature of zero for their steel, in which case they will use the value as a reference. *Is the value of the energy of the steel small or large compared to the energy of the water?* Here students make the connection that indeed the energy contributed by the steel was negligible, because its specific heat is quite low relative to water. The low temperature and the low specific heat cause the overall energy to be low for the steel. *Recalculate the specific heat of steel with the actual temperature and the experimentally determined specific heat. Is your new value close to your original value?* These calculations reinforce the concept of specific heat. Having students go back and substitute the values is a very useful exercise. They have to think about the amount of energy contributed by the steel and how that affects the overall result for the specific heat of steel.

Investigation 3B: Specific Heat

Part 6: Were we sloppy in our math?

We ignored the energy contained in the steel when it was cold. We assumed that the temperature was 0°C therefore, it did not matter what the specific heat was, the contribution would still be zero. Of course, this is not exactly true! You likely found that the temperature of the steel was not zero, but was a few degrees.

a. The diagram below is similar to the one used on page 28.
Here we will enter the value of specific heat you calculated in Part 2.
We will also enter the actual temperature of the steel.



b. Calculate the energy contribution from the steel.

c. Is the energy from the steel large or small compared to the energy in the water?

d. Complete the calculation using your value for the specific heat of steel. By the time you get to the bottom of the chart, your new answer is a better estimate for the specific heat of steel!

e. Is the new estimate close to the first one? Why do you think that is?

The technique you just learned is called successive approximation. At first we made an assumption that allowed us to get to an answer. We then used our answer to check our assumption and arrived at an even better answer!

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Example Answers

Teaching tips

This lab is intended to provide students with an investigative approach to specific heat. By performing the experiments students will have the information necessary to ask appropriate questions that will lead them to understand the concept of specific heat.

Students expect the temperature of the water to change much more than it does when the steel washers are added. The fact that it does not might interest them and they may want to find out why. Thinking at the molecular / atomic level causes students to think about how molecules and atoms are "packed" together.

Students should be very close with their estimates when comparing their data to actual values. Steel varies depending upon the content of carbon, and whether or not it is galvanized. Students should pool data to see how well the class results for steel agree.

It is important to emphasize that our assumption of 0°C for steel does not mean that its atoms have no energy, but that we are using this as a point of reference. This reference allows us to gather accurate data with uncomplicated math. Using reference points is very common in science and in our daily lives. For example "sea level" is an arbitrary reference point from which we can measure the heights of mountains and the depths of oceans. Here using zero as our reference for the temperature of steel allows us to calculate the specific heat and not get lost in the math.

3C: Heat Flow and Thermal Equilibrium

Key Question: Why does heat flow?

In this Investigation, students experiment with heat flow and the concept of thermal equilibrium. Students record time and temperature readings while using the Lab-Master system to set and maintain a fixed temperature. As water is heated the temperature probe measures the change in temperature, while students gently stir the mixture. Students use the knowledge they have gained about heat flow and energy conservation from their previous investigations to think about thermal equilibrium. Students are challenged to consider what happens as energy is added to the collection of water molecules.

Reading Summary

Students read section 3.2 "Heat and Thermal Energy" before the Investigation.

Heat is another word for the flow of thermal energy,and thermal energy is the total energy contained in a collection of molecules. Heat flows in the direction of hot to cold, according to the Second Law of Thermodynamics. The transfer of heat takes place when two objects of different temperatures are in contact with each other. Temperature measures the average kinetic energy of molecules or atoms. At higher temperatures the molecules move more vigorously. In any collection of molecules at a given temperature, some molecules are moving fast, while others are moving more slowly. Molecules that collide are able to transfer energy. A slow moving particle that is hit by a faster moving particle gains energy. The faster particle must slow down because energy is always conserved, due to this loss of energy. Two substances reach the same temperature and thermal equilibrium when left in contact. Heat flow is faster when the two objects are very different in temperature,and it slows down as the objects become closer in temperature.

Questions and Goals

Main Questions

- What is thermal equilibrium?
- How does a substance reach thermal equilibrium?
- When does the flow of heat stop?

Learning Goals

By the end of the Investigation, students will be able to:

- Explain how heat flows.
- Understand that temperature is related to molecular motion.
- Graph time vs. temperature data and understand when thermal equilibrium is reached.
- Understand how the rate of heat flow changes over time.

Key Vocabulary

Heat, temperature, kinetic energy, random, Celsius, thermometer, thermistor, thermal energy, system, surroundings, first law of thermodynamics (energy conservation), thermal equilibrium, second law of thermodynamics.

Materials and Setup

Students work in groups of three or four at lab benches.

Each group should have:

- A Lab-Master (or thermometer), temperature probe, heater, 1 hole rubber stopper, 25 mm test tube, insulation ring, test tube rack
- Room temperature water

Preparation

No preparation is required except to have the materials available.

You will need to have access to water.

Hints:

- Use insulated gloves to remove the hot test tubes from the Lab-Master.
- Be sure the students secure the heater and close it around the test tube. This affects the heating process (rate and time) of the Lab-Master.

Suggestions:

- Remind students to stir gently with their temperature probe and not to let it sit in the test tube for very long. The water needs to be mixed often to evenly distribute the heat.

Details

Teaching Time One class period

Assignments Section 3.2 "Heat and Thermal Energy" in the **Student Book** before the Investigation.

Misconceptions Students may think that thermal equilibrium is a static situation.

Outline of the Investigation

Introducing the investigation
1 Temperature and heat
2 Think about it
3 Heat flow
4 Think about what you observed

Investigation sections	Part	Ideas and Dialog
Introducing the investigation Review what students know about heat and temperature. Help them relate this information to thermal equilibrium. Molecular motion and equilibrium principles are important aspects of this discussion.		*What causes heat to flow? Explain your thinking at the molecular level.* Students will use their life experiences as well as previous investigations to answer this question. Heat will flow from a warmer object to a cooler object due to molecular collisions. The temperature of an object or system dictates the speed of the molecules. The random molecular collisions between two objects at different temperatures cause energy to be transferred. Over time the energy difference between the molecules becomes less and less which causes the "flow" and transfer of heat to slow down. Heat flow stops when thermal equilibrium is reached. *Are molecules still exchanging energy after thermal equilibrium is achieved?* Molecules are constantly moving and colliding with each other, but the overall average kinetic energy of the collection of molecules remains the same once the temperature has stabilized. *Today you are going to perform an investigation that will help you better understand thermal equilibrium.*
Temperature and heat Students will observe how the temperature changes over time as the heater raises the temperature of the water.	1	*Each group will measure and record the temperature of 15–20 mL of water over a 5 minute time period.* The Lab-Master will record the data for the students, but they should also record it in their lab note-books. Students must stir the water gently and continuously. The heater adds a large amount of heat initially which will heat the water molecules touching the outside of the test tube quickly. To maintain a uniform temperature and proper heating the water must be stirred. The heater sends less power and shuts off once it reaches 50°C. *How does the heat affect the water molecules?* It makes them move faster and have more energetic collisions. *Does the temperature change continuously during the 5 minutes you are heating it?* No, the temperature goes up quickly, but then levels off once the target temperature of 50°C is reached. *Make a graph of your data.*
Think about it These questions help students to think about what is happening during the heating process.	2	*Why do you need to stir the water?* The heater heats the water near the outside of the test tube first and it can get hot quickly. It is necessary to mix continuously to establish an even distribution of heat. *What was the highest reading recorded on the temperature probe?* The temperature probe reaches 50°C (+/− 1°C). Students need to read the temperature and not simply rely on setting the heater temperature. *Describe your temperature vs. time graph for the 50˚C and the 100˚C degree temperatures.* The graph shows that the temperature rises quickly to 50°C and then stays at approximately 50°C over the 5 minute time period. *Did heat transfer stop at some point, or continue the whole time?* Heat transfer seemed to stop once the water reached the target temperature. It will turn back on as the water cools down or if the temperature probe is removed. In the 5 minute period, the heater will likely not have to turn back on for such a small volume of water (unless the probe is lifted above the surface of the water).

Example Answers

Time (min)	Heater set to 50 °C	Heater set to 100 °C
0.0		
0.5		
1.0		
1.5		
2.0		
2.5		
3.0		
3.5		
4.0		
4.5		
5.0		

SAMPLE DATA AND GRAPH REMOVED

Part 2: Think about it

- **a.** Why is it important not to have too much water in the test tube?
- **b.** Why do you have to stir the water while heating it?
- **c.** What was the highest reading you saw on the temperature probe?
- **d.** Describe the temperature vs. time graph. What is the difference between the two plots.

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Investigation sections	Part	Ideas and Dialog
Heat flow Students now use foam insulation and a one hole stopper to simulate a closed and insulated system.		*Now let's try heating the water again with a one-hole stopper and some foam insulation around the test tube above the heater. What effect do you think this will have on the water?* Have the students consider what effect these changes will have on the temperature of the water. Previously, heat flow into the system was accompanied by heat flow out of the system, when water molecules were allowed to escape and air cooled the top of the test tube. Now water cannot simply vaporize and leave the test tube because of the foam insulation, so the test tube loses less heat to the air. *Observe the water temperature for a few minutes. Does the final temperature get higher or stay about the same?* Students will observe that the temperature reading on the probe is now higher and closer to the temperature of 50°C, which is where the heater is set.
Thinking about what you observed Give the students time to discuss what effect these changes had on the system. Ask students to explain what they think happened to other groups to see if the results are similar.	1	*What was the purpose of insulating the test tube?* Students will have no trouble suggesting that the insulation keeps some heat from escaping. They may wonder about the bottom and other areas of the test tube that are uninsulated. However, with the data they collect they will see that this makes a difference. *A pot with a lid on it boils faster than one without a lid. Why is that, and how does this concept relate to your laboratory?* Students understand that the lid keeps the heat from escaping, but they may not realize that water molecules escaping in the vapor phase are taking heat with them as well. A closed system does not allow matter to escape. The stopper in this experiment allows the water to reach the target temperature faster. *Explain why the temperature of the water increased, even though the heater was set at the same temperature.* Student responses will relate to the fact that less heat was lost so the water temperature was able to get closer to the heater temperature. *Is your test tube at thermal equilibrium? Explain your reasoning.* As long as the water is well mixed and the heater is not inputting energy, then there is no heat transfer occurring, at that moment. Heat flow requires a temperature difference. However, as soon as the water cools the heater will once again turn on to keep the system at the desired setting. For a moment in time the insulation and the high specific heat of the water will create a thermal equilibrium.

Investigation 3C: Heat Flow and Thermal Equilibrium

e. Was heat transferred from the heater to the water at the same rate the entire time? Was the energy transfer reduced or even stopped at some point? What evidence do you have to support your claim? (Hint: Look at the power display on the lower right of the Lab-Master screen.)

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

Part 3: Heat flow

1. Add a foam insulation ring to the test tube.
2. Put the temperature probe through a one-hole stopper so it sits below the surface of the water
3. Observe the temperature for a few minutes while the heater is set to 50°C. Does the final temperature get higher than before, or does it stay about the same?

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 covered pot boils much faster than an open pot. Discuss why that is and how it relates to why putting the cap on the test tube changed the maximum temperature of the water.

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 shortly after.

e. *Thermal equilibrium* is the situation when all temperatures have become equal. No heat flows in thermal equilibrium. Is your test tube in thermal equilibrium 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.

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Example Answers

Teaching tips

Help the students understand how the Lab-Master works, so that they can concentrate on their system and what is happening. Students have not covered phase changes at this point, so they may need help in thinking about the water at 100°C. Have them think about what happens to a boiling pot of water left on the stove for a period of time. This should help them to realize that water molecules are being lost as water boils. These molecules take heat with them as they escape from the solution.

Students understand the importance of an insulated system from their previous labs where they used foam cups. Here the insulation added in part 3 allows the water to come closer to the target temperature because not as much heat is lost.

Point out that even though the graphs both show a plateau at the target temperature, they do so for very different reasons. Students will likely think they both level off because the target temperature has been reached.

You can use the set point on the Lab-Master to make the temperature probe regulate the heater. That will make the water temperature will be closer to the heater temperature.

3D: Heat of Fusion

Key Question: Why doesn't the temperature change as ice melts?

In this Investigation, students experiment with the heat of fusion. Students learn about phase changes and how heat energy is involved in the physical change from solid ice to liquid water. The Lab-Master system facilitates their learning by recording time and temperature data, and graphing it on the display. Students use their knowledge about heat and temperature to understand what happens to the added energy as the ice melts. Students use their data to calculate the heat of fusion of ice. Their estimate is compared to the actual value for the heat of fusion.

Reading Summary

This Investigation relates to section 3.3 "Phase Changes".

The common phases of matter are solid, liquid, and gas. Each of these phases has physical characteristics that are unique. When a substance changes phase it rearranges its particles. An increase in temperature creates an increase in thermal energy. When this energy is absorbed the substance's particles become less organized. When a substance melts it changes phase from a solid to a liquid. The temperature at which it melts is called the melting point. The heat of fusion is the energy required to cause a substance to change phase from a solid to a liquid or a liquid to a solid. For example when ice melts it absorbs energy to loosen the molecules. When ice freezes it releases energy to its surroundings as the water molecules form stronger attractions. During any exchange of energy the First Law always applies. Energy that is absorbed during a phase change is not available to also increase the temperature of the substance. More energy is required for a phase change when a substance has strong attractive forces between its atoms or molecules.

Questions and Goals

Main Questions

- What is the heat of fusion?
- What happens when ice melts?
- Why does the temperature stay constant while ice melts?

Learning Goals

By the end of the Investigation, students will be able to:

- Understand what happens to water molecules during a phase change.
- Graph time vs. temperature data and understand what the plateau represents.
- Calculate the heat of fusion.

Key Vocabulary

Phase change, melting point, heat of fusion, heat, temperature, kinetic energy, random, thermal energy, system, surroundings, First Law of Thermodynamics (energy conservation).

Materials and Setup

Students work in groups of three or four at lab benches.

Each group should have:

- A Lab-Master (or thermometer), temperature probe, large and small foam cups, balance
- Warm / hot water, ice

Preparation

No preparation required except to have the materials available.

You will need to have access to water.

Hints:

- The melting of 100 g of ice can take a while, especially if the water is not hot.
- Use a paper towel to pick up cubes and transfer them to the cup. Try to avoid any melting.
- Depending upon the amount of time you have it might be worthwhile to use less ice (20 g) and 100 g of water that is closer to 50°C. This will make the ice melt faster.
- It is helpful to have students weigh the water first, so that once the ice is weighed it can be added directly to it.

Suggestions:

- If time allows have students do more than one trial. Their results are often better the second time.
- Have students reweigh their water once the ice has melted, and have them check to see that this corresponds to the mass of the water and ice alone.
- Use a lid with a single hole in it for the temperature probe to avoid heat loss.

Details

Teaching Time One class period

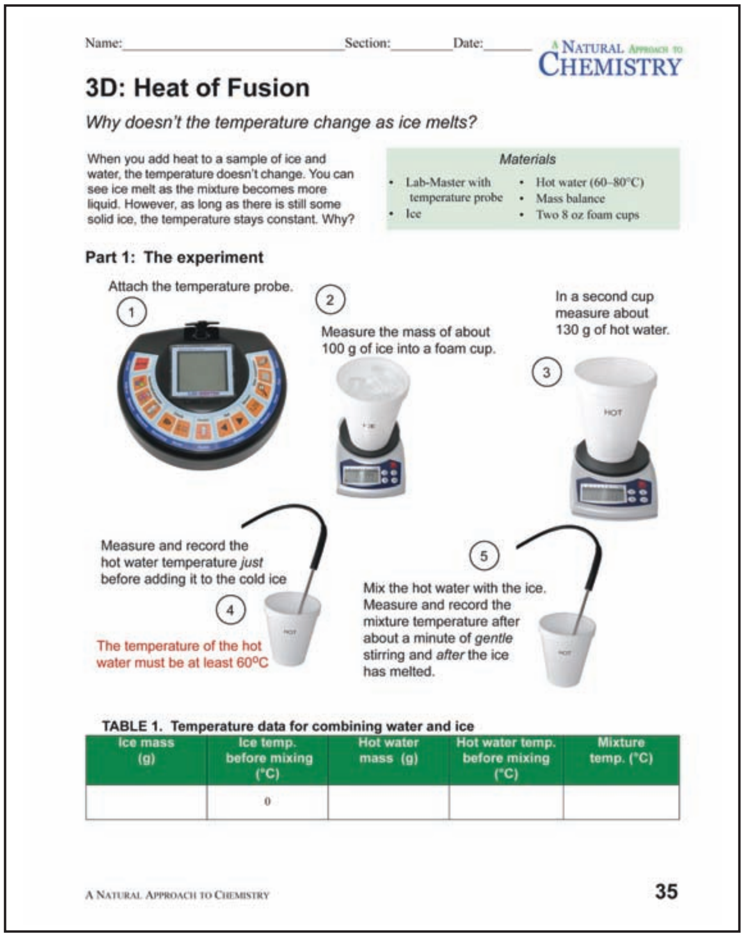
Assignments Section 3.3 "Phase Changes" in the **Student Book** before the Investigation.

Misconceptions Students expect the temperature of their water to reach zero by adding ice.

Outline of the Investigation

Introducing the investigation
1 The experiment
2 Analyzing the data
3 Thinking about what you observed

Investigation sections	Part	Ideas and Dialog
Introducing the investigation Review what students know about the melting process. Ask students to explain some examples they are familiar with.		*What happens when you hold an ice cube in your hand? Explain. Think about what happens to the molecules of water.* The ice uses heat from your hand to change phase from a solid to a liquid. Students will mention the fact that the solid ice turns into liquid water. However, many of them are not sure whether the same molecular structure is present in water. Some think that the molecules change when a solid becomes a liquid. The thing to focus on here is that heat is transferred from the hand to the ice and it absorbs the energy causing it to melt. *Most metals are solid at room temperature, but mercury (Hg, atomic number 80) is a liquid at room temperature. What does this tell you about the attractive forces between mercury atoms?* The attractive forces between mercury atoms are relatively weak at room temperature in comparison to other metals. This is because in the liquid phase atoms can slide past each other, which indicates they are looser than in a solid. In the solid phase atoms are held more tightly together and unable to slide past one another.
The experiment Students will observe that the temperature remains constant while the ice is melting.	1	*Prepare the set-up as instructed by part 1 in the investigation.* Remind students to take the temperature of the hot water just before adding the ice. You may wish to demonstrate or explain how to transfer the ice with minimal melting. Don't tell them why this is important, because they can think about this at the end of their experiment. *What happens when you add the ice to the water? Watch for a few minutes and describe what you observe.* The students will say that the temperature of the water goes down. However, most of them will be surprised by how little it drops. There is no large initial drop. Hopefully, they will mention that the ice starts to melt rapidly—well above 0ºC. They may wonder about this, and they may wait expecting their temperature to reach 0°C. *Why is it important to stir the mixture gently?* It allows for the even distribution of hot and cold temperatures.
Analyzing the data Help students understand how to fill in their flow charts. Allow them to work independently on their calculations.	2	*How much energy is provided by the ice at the start of the experiment?* Because the initial temperature is assumed to be zero, the ice contributes no energy. Of course this is a big assumption and unrealistic. The ice is likely closer to the temperature of the freezer, but this method allows for an approximation. *What was the total energy present in the mixture BEFORE?* This value will be based on their water. For example $100\text{ g} \times 4.18\text{ J / g°C} \times 80\text{°C} = 33{,}440\text{ J}$ *AFTER mixing how much energy did you determine was required to melt the ice?* Students subtract the energy of the water after mixing from the total energy present before mixing to obtain this answer. It is then entered in their flow chart, so that they can then estimate the heat of fusion. *Do you feel that the melting of the ice required much energy? Explain your reasoning.* The melting of the ice required most of the energy—about 75% of it! Loosening the molecules required most of the energy initially supplied by the hot water.



Name:______________________Section:________Date:________

A NATURAL APPROACH TO CHEMISTRY

3D: Heat of Fusion

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 can see ice melt as the mixture becomes more liquid. However, as long as there is still some solid ice, the temperature stays constant. Why?

Materials

- Lab-Master with temperature probe
- Ice
- Hot water (60–80°C)
- Mass balance
- Two 8 oz foam cups

Part 1: The experiment

1. Attach the temperature probe.
2. Measure the mass of about 100 g of ice into a foam cup.
3. In a second cup measure about 130 g of hot water.
4. Measure and record the hot water temperature *just* before adding it to the cold ice. The temperature of the hot water must be at least 60°C
5. Mix the hot water with the ice. Measure and record the mixture temperature after about a minute of *gentle* stirring and *after* the ice has 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 temp. (°C)
	0			

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Teaching tips

Explain to the students that the Lab-Master will collect the data and graph it; however, you want them to record the data in their lab notebooks as well. It is important for them to know that the Lab-Master keeps track of all the data and they can scroll back to record any missed data points. Students have not covered intermolecular forces of attraction yet and do not know about hydrogen bonding, so here we just want to focus on the "attractive forces" or the "glue" holding the water molecules together.

Focus on the First Law and conservation of energy. The fact that the warm water lost heat means that it had to go somewhere. Where did it go? In an insulated system, like the coffee cup calorimeter, most of it was NOT allowed to escape into the surroundings, so it must have gone into melting the ice. Using our energy formula we can calculate the amount of heat lost by the water and then deduce how much must have gone into melting the ice and raising its temperature.

It is key to realize that we are making some big assumptions here. The first one is that the temperature of the ice is zero at the start. You could place a thermometer in the freezer with the ice and see what the temperature is. The ice will likely be at the temperature of the freezer, and then some students could figure out how much heat was required to warm the ice to its melting point. The second assumption is that no heat was lost. Have the students speculate how both of these assumptions would affect their value for the heat of fusion (i.e. raise or lower their experimental value).

Point out that even though we are estimating, we obtain a reasonable result that teaches our students about the heat of fusion and the concept of phase changes.

Finally, you can obtain accurate results with one or two ice cubes and 50 mL of warm tap water. This saves time and the need to have hot water. Less ice melts faster, allowing students to repeat the experiment.

Investigation sections	Part	Ideas and Dialog
Thinking about what you observed Give the students time to discuss their results with the group. Ask for a few volunteers to share their results.	3	*Why was the final temperature of the water not halfway between the water and the ice?* Even though students used equal masses, the substances (both water) were not in the same phase, and solids and liquids have different specific heats and physical properties. Energy has to be conserved, and as the hot water cooled that energy was used to melt the ice. The energy was then unavailable to warm the water to a higher temperature. *How many joules of energy did the ice contribute to the mixture?* Using zero degrees Celsius as the reference point gives a result of zero Joules. Ice does freeze and melt at zero degrees Celsius, so this is a good reference point to use for an estimation. *How many joules did the water provide to the mixture?* Students can look at their flow charts and see what the results are. For example, 100 g × 4.18 J / g°C × 70°C = 29,260 J *How does your value for the heat of fusion compare to the accepted value of 334 J / g?* Using sample data students will obtain values in the low 300's. This is primarily due to heat loss and the fact that the ice is likely lower than 0°C to start. Raising the temperature of the ice to its melting point also requires energy that we did not account for.

Investigation 3D: Heat of Fusion

Part 2: Analyzing the data

Before mixing

specific heat		mass		temperature		result	
? (specific heat of ice?)	×	99.5 (mass of ice)	×	0°C (initial temperature of ice)	=	0 joules	A
+							
4.18 J/(g·°C) (specific heat of water)	×	150.3 (mass of water)	×	69 (initial temperature of water)	=	43,350 joules	B
				total energy	=	43,350	A+B

After mixing

4.18 J/(g·°C) (specific heat of water)	×	249.8 (total mass of water)	×	12 (mixture temperature)	=	12,530	C

Subtract the thermal energy in the water from the total energy (A+B−C)

310 (heat of fusion of ice)	×	99.5 (mass of ice)	=	30,820 (energy needed to melt ice)	A+B−C

Part 3: Thinking about what you observed

a. Suggest an explanation for why the temperature of the water did *not* end up halfway between cold and hot, even though you mixed equal masses.

b. We have assumed that a temperature of 0°C represents zero thermal energy by measuring 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?

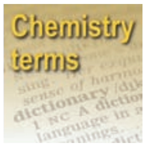
e. All substances that undergo phase changes have a heat of fusion. How do other substances compare to water? Research the heat of fusion for at least four other substances.

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

Example Answers

A NATURAL APPROACH TO CHEMISTRY

CHAPTER 3
Temperature, Energy and Heat



Brownian motion, kinetic energy, temperature, random, Fahrenheit scale, Celsius scale, thermometer, thermistor, thermocouple, absolute zero, Kelvin scale, heat, joule, calorie, British thermal unit (BTU), second law of thermodynamics, system, open system, closed system, isolated system, first law of thermodynamics, thermal equilibrium, specific heat, conduction, thermal conductor, thermal insulator, phase change, melting point, heat of vaporization, boiling point, heat of fusion, evaporation, condensation, latent heat, triple point, relative humidity, dew point

Teaching the Chapter

This is the first chapter to be treated in depth. Heat and temperature are core concepts in figuring out how chemistry works. All four investigations prompt the students to track the flow of energy, giving them a chance to truly assimilate the concept of energy conservation. Students also begin to work on quantitative problems involving matter and energy.

Main Ideas

Matter is made of atoms and molecules that are in constant motion. Temperature is the average kinetic energy of this constant motion and can be expressed in degrees Celsius (°C) or in kelvins (K). Temperature should not be confused with heat, which is expressed in joules (J), calories, or BTUs. Adding more heat does not always result in a higher temperature. Different types of matter have different specific heats, heats of fusion, and heats of vaporization.

Section Summaries

3.1: Temperature

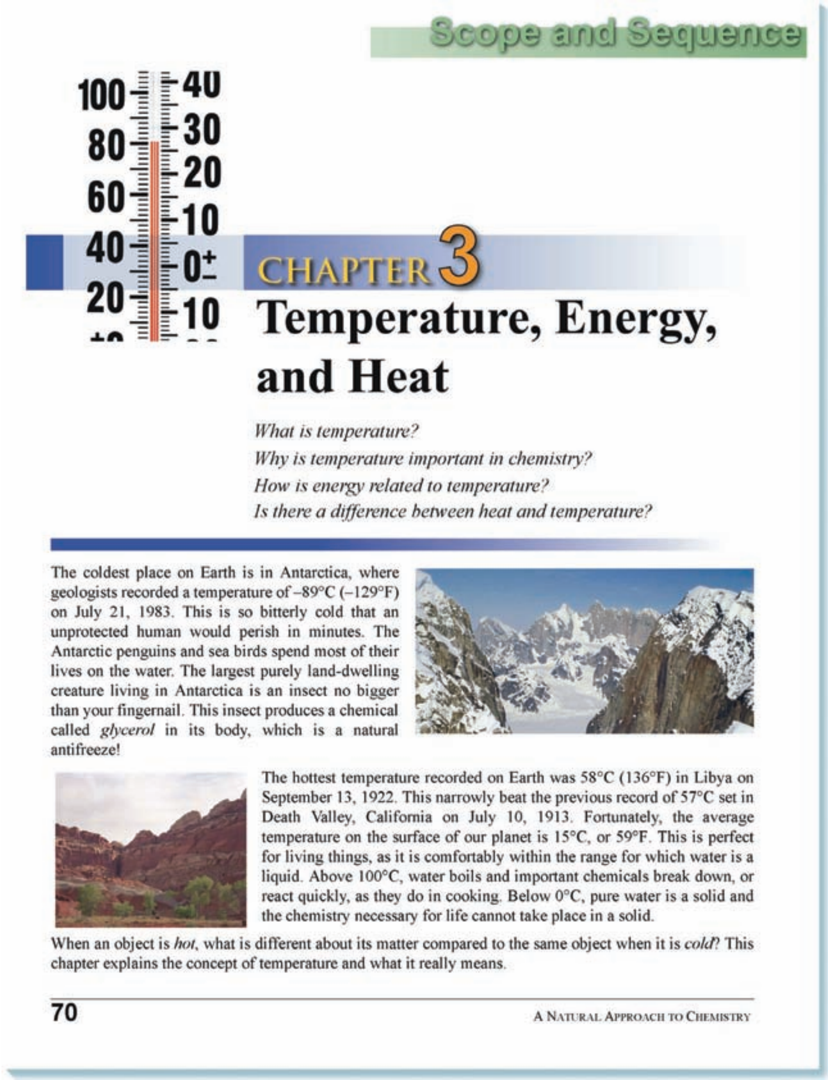
Atoms and molecules are in constant motion. Temperature is a measurement of the average kinetic energy of the molecules in contact with the thermometer. Absolute zero (0°K, or –273.15°C) is the lowest possible temperature, where molecules have essentially zero thermal energy. Heat, or thermal energy, is the total energy of motion in a sample of matter.

3.2: Heat and Thermal Energy

Heat, or thermal energy, is commonly measured in joules, calories, and BTUs. As stated in the second law of thermodynamics, heat spontaneously travels from an area of higher temperature to an adjoining area of lower temperature, until both areas reach thermal equilibrium. Specific heat is the amount of energy required to increase 1 g of a material by 1°C. Heat flows more readily through materials that are thermal conductors.

3.3: Phase Changes

Phase changes occur when a material changes among solid, liquid, and gas states. Every material has a specific temperature at which phase changes occur, called its melting and boiling points. The heat of fusion (vaporization) is the amount of energy required to convert 1 g of a material from solid to liquid (liquid to gas). The surrounding pressure affects the temperatures at which phase changes occur.



Scope and Sequence

CHAPTER 3

Temperature, Energy, and Heat

What is temperature?
Why is temperature important in chemistry?
How is energy related to temperature?
Is there a difference between heat and temperature?

The coldest place on Earth is in Antarctica, where geologists recorded a temperature of –89°C (–129°F) on July 21, 1983. This is so bitterly cold that an unprotected human would perish in minutes. The Antarctic penguins and sea birds spend most of their lives on the water. The largest purely land-dwelling creature living in Antarctica is an insect no bigger than your fingernail. This insect produces a chemical called *glycerol* in its body, which is a natural antifreeze!

The hottest temperature recorded on Earth was 58°C (136°F) in Libya on September 13, 1922. This narrowly beat the previous record of 57°C set in Death Valley, California on July 10, 1913. Fortunately, the average temperature on the surface of our planet is 15°C, or 59°F. This is perfect for living things, as it is comfortably within the range for which water is a liquid. Above 100°C, water boils and important chemicals break down, or react quickly, as they do in cooking. Below 0°C, pure water is a solid and the chemistry necessary for life cannot take place in a solid.

When an object is *hot*, what is different about its matter compared to the same object when it is *cold*? This chapter explains the concept of temperature and what it really means.

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Pacing Suggestions

This chapter might require 8–10 class periods to cover. This includes four class periods set aside for investigations. Extra time to go over calculations might be necessary.

Investigations

3A: Heat and Temperature

Students experiment with heat flow using hot and cold water and gather data that supports their intuition about heat transfer. By using the same amount of the same substance, students are able to focus specifically on the change in temperature.

3B: Specific Heat

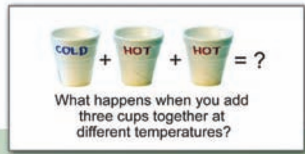
Students observe how different substances transfer energy. By using the same amount of two different substances students discover that different types of matter store and release energy differently. Students use their data to deduce the specific heat of steel.

3C: Heat Flow and Thermal Equilibrium

Students experiment with heat flow and the concept of thermal equilibrium. Students record time and temperature readings and use their previous knowledge of heat flow and energy conservation to think about thermal equilibrium.

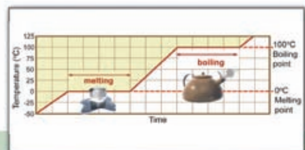
3D: Heat of Fusion

Students experiment with the heat of fusion of water and learn how energy is involved in the physical change from ice to liquid water. The Lab-Master system facilitates their learning by recording time and temperature data and graphing it on the display.



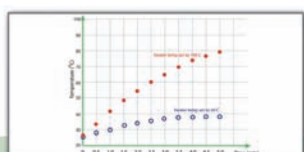
Engage

- Chapter 3 engages students by opening with the intriguing question, “Is there a difference between heat and temperature?”
- Investigations 3A and 3B engage students by having them track the energy flow when different amounts of matter at different temperatures are mixed together.
- Investigation 3C engages students with the question, “Why does a cold drink warm up when left in a warm room, but then stops warming up?”
- Investigation 3D engages students by asking why the temperature of a heated ice-water mixture stays constant until all the ice has melted.
- The dry ice experiment on page 71 engages students with a fun way to observe and study phase changes.



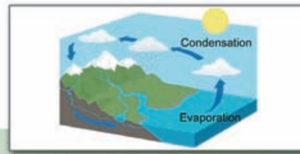
Explore

- Investigations 3A through 3D prompt students to explore the law of energy conservation and how it can be used to determine the heat of phase changes and specific heats.
- In Investigation 3A students use their intuition of mixing hot and cold water to explore the concepts of heat and temperature.
- In Investigation 3C students explore heat flow and the second law of thermodynamics.
- In Chapter 3 (page 74) students explore the idea of temperature as an average using a graph of thermal energy distribution.
- In Chapter 3 (page 90) students explore the idea that adding more heat does not always cause an increase in temperature.



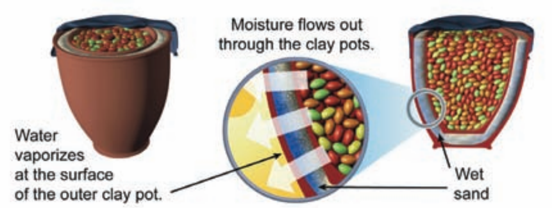
Explain

- In Investigation 3B, students explain that the “missing” energy is due to the specific heat of steel.
- In Investigation 3C (Part 4) students explain why insulating a test tube during heating helps the solution reach the designed temperature faster.
- In Investigation 3D (Part 3) students explain why adding equal amounts of hot water and ice does not yield a temperature that is half-way in between the two initial temperatures.
- In Problem 34 students explain why Brownian motion provides evidence that molecules are in constant random motion.
- In Problem 47 students explain why the temperature on tropical islands remains relatively constant.

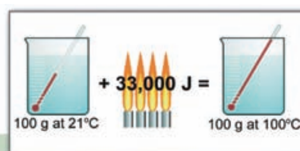


Elaborate

- In Chapter 3 (Section 1) students elaborate upon their understanding of motion and thermal energy by considering the notion of absolute zero and the Kelvin temperature scale.
- Chapter 3 (Section 3) elaborates upon the students’ knowledge of phase changes by introducing the water cycle and its environmental significance.
- The Chemistry Connections section on pages 96–97 elaborates upon the concepts of energy and phase changes by describing a real life example of how chemistry helps people in Nigeria refrigerate their food.

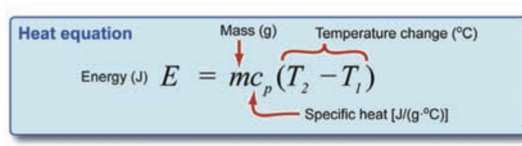


- In Investigation 3A (Part 6) students elaborate upon their knowledge of heat and temperature by predicting the final temperature of a mixture of three different amounts of water at different initial temperatures.
- Investigation 3D (Part 2) elaborates upon the students’ knowledge of energy flow by having them determine the heat of fusion for water.



Evaluate

- Problem 56 evaluates student understanding of the importance of water by having them describe how water’s high heat of fusion and heat of vaporization helped to make life possible on Earth.
- Problem 77 evaluates whether students can use the heat equation to calculate the amount of energy necessary to raise a sample of ethanol by a specified temperature.



- In Investigation 3A (Part 8) students evaluate the accuracy of their calculations by comparing their predictions with their experimental data.
- Investigation 3B (Part 6) evaluates students’ reasoning skills by having them determine the specific heat of steel using successive approximation.
- Investigation 3D (Part 3) evaluates students’ concept of scale by having them compare the heat of fusion of water with that of other materials.

Students should know that . . .

- molecules at a given temperature have a range of energies,
- temperature can be recorded in degrees Fahrenheit (°F), in degrees Celsius (°C), or in kelvins (K),
- the Kelvin scale is an absolute temperature scale,
- the lowest possible temperature is called absolute zero.

Key Questions

- What is the difference between heat and temperature?
- Does “15 degrees” mean the same thing in the United States and in France?
- What happens at absolute zero?

Investigations

3A: Heat and Temperature

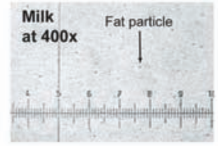
Students experiment with heat flow using hot and cold water and gather data that supports their intuition about heat transfer. By using the same amount of the same substance, students are able to focus specifically on the change in temperature.

Section 3.1 Temperature

3.1 Temperature

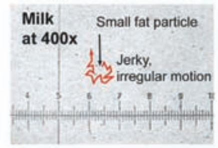
Particles of matter are in constant motion

Milk looks like a uniform liquid, but it really isn't. Under the microscope, you can see tiny globules of fat suspended in water. These fat particles are in constant motion! The particles jitter around in a very agitated way and *never slow down or stop*. This is strange when you think about it. Motion requires energy. What possible source of energy keeps the fat particles dancing around?



Brownian motion

If you look more carefully at the very smallest particles, you see they don't move smoothly as they would if they were floating. Instead, they move in a jerky, irregular way. The jerky movement of a very small particle in water is called **Brownian motion** and is a direct consequence of atoms and temperature. In 1905, Albert Einstein proved that matter was made of atoms by explaining Brownian motion.



Why Brownian motion occurs

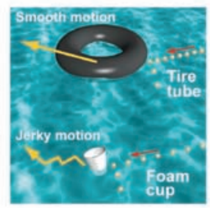
Brownian motion occurs for two important reasons:

1. Matter (including water) is made of atoms.
2. Atoms and molecules are in constant, agitated motion.

If the fat particle is *very* small, collisions with single molecules of water are visible because the mass of a water molecule is not that much smaller. The constant motion of individual water molecules causes Brownian motion.

A human-sized example

Imagine throwing marbles at both a tire tube and a foam cup floating in a pool. The motion of the tube is smooth because each marble has a lot less mass than the tube. The foam cup jerks under the impact of each marble, like the fat particle in Brownian motion. This is because the mass of the cup is not much greater than the mass of a single marble. Brownian motion proves that matter exists in discrete atoms and molecules. It also proves that, *at room temperature*, atoms and molecules are in constant, agitated motion.



Chemistry terms

Brownian motion: the erratic, jerky movement of tiny particles suspended in a fluid caused by the random impacts of individual molecules in thermal motion.

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Differentiated Instruction Resources

Concept	Text	AV Slides	Skill Sheets	Hands-On	Assess and Practice
Temperature and energy	72–74	1–9	No. 1	Inv3A	1–2, 4, 8, 34, 37–38
Temperature scales	75	10–12	No. 2		3, 7, 10, 35–36
Celsius and Fahrenheit	75–76	10–17	No. 2		58–61
Temperature measurement	77	18–20		Inv3A	5, 9
Absolute zero	78	21–29			6, 62–63

Audio-Visual Slide Presentations

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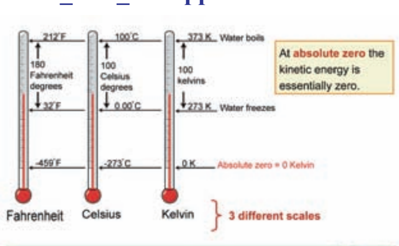

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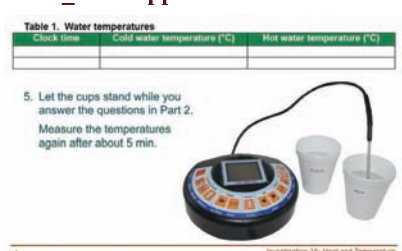

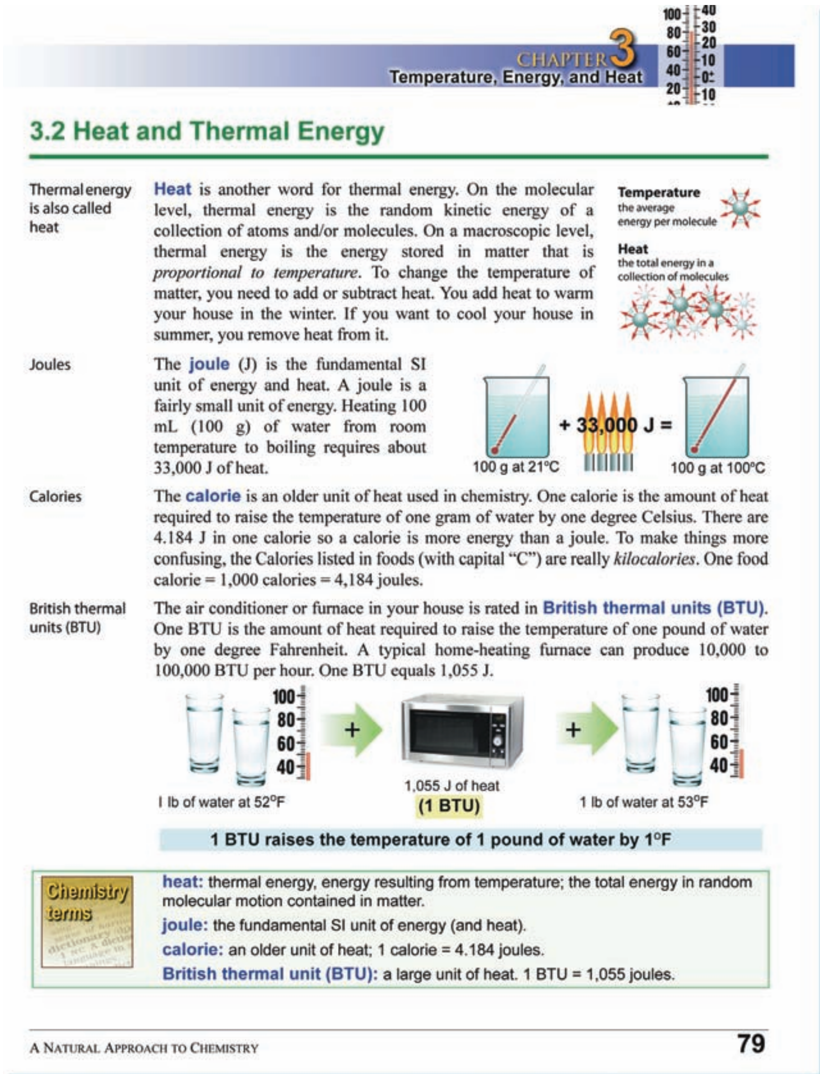

CHAPTER 3 Temperature, Energy, and Heat

3.2 Heat and Thermal Energy

Thermal energy is also called heat

Heat is another word for thermal energy. On the molecular level, thermal energy is the random kinetic energy of a collection of atoms and/or molecules. On a macroscopic level, thermal energy is the energy stored in matter that is *proportional to temperature*. To change the temperature of matter, you need to add or subtract heat. You add heat to warm your house in the winter. If you want to cool your house in summer, you remove heat from it.

Joules

The **joule** (J) is the fundamental SI unit of energy and heat. A joule is a fairly small unit of energy. Heating 100 mL (100 g) of water from room temperature to boiling requires about 33,000 J of heat.

Calories

The **calorie** is an older unit of heat used in chemistry. One calorie is the amount of heat required to raise the temperature of one gram of water by one degree Celsius. There are 4.184 J in one calorie so a calorie is more energy than a joule. To make things more confusing, the Calories listed in foods (with capital "C") are really *kilocalories*. One food calorie = 1,000 calories = 4,184 joules.

British thermal units (BTU)

The air conditioner or furnace in your house is rated in **British thermal units (BTU)**. One BTU is the amount of heat required to raise the temperature of one pound of water by one degree Fahrenheit. A typical home-heating furnace can produce 10,000 to 100,000 BTU per hour. One BTU equals 1,055 J.

1 BTU raises the temperature of 1 pound of water by 1°F

Chemistry terms

heat: thermal energy, energy resulting from temperature; the total energy in random molecular motion contained in matter.

joule: the fundamental SI unit of energy (and heat).

calorie: an older unit of heat; 1 calorie = 4.184 joules.

British thermal unit (BTU): a large unit of heat. 1 BTU = 1,055 joules.

A NATURAL APPROACH TO CHEMISTRY 79

Students should know that . . .

- thermal energy is also called heat, in
- an isolated system neither matter nor energy can be exchanged with the surroundings,
- energy lost from one system is gained by the surroundings or another system,
- heat flows from higher temperature to lower temperature.

Key Questions

- Can we predict the temperature of a mixture of hot and cold water?
- Why does freshly brewed coffee become cold over time?
- Does it take more energy to heat up 1 g of water or 1 g of steel?

Investigations

3B: Specific Heat

Students observe how different substances transfer energy. By using the same amount of two different substances students discover that different types of matter store and release energy differently. Students use their data to deduce the specific heat of steel.

3C: Heat Flow and Thermal Equilibrium

Students experiment with heat flow and the concept of thermal equilibrium. Students record time and temperature readings and use their previous knowledge of heat flow and energy conservation to think about thermal equilibrium.

Differentiated Instruction Resources

Concept	Text	AV Slides	Skill Sheets	Hands-On	Assess and Practice
Heat and energy	79	1–8		Inv3A, 3B, 3C	11, 15, 43
Systems	80	9–10	No. 3	Inv3C	12
Conservation of energy	81	11–15		Inv3A, 3C	14
Thermal equilibrium	82	16–17		Inv3C	17, 40
Specific heat	83–84	18–20	No. 4	Inv3B	19, 39, 41–42, 44
Calculating temperature and heat	85–86	21–27	No. 4	Inv3A	64–73
Heat transfer	87	28–31	No. 3	Inv3A, 3C	13, 18, 21

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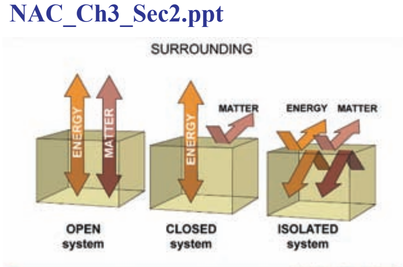

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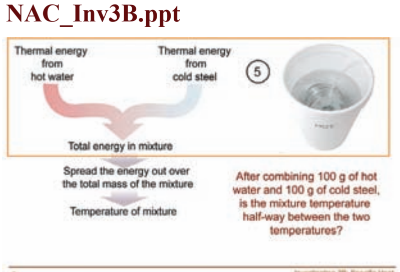

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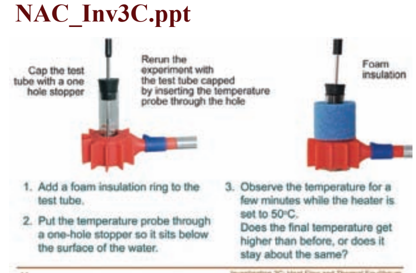


Students should know that . . .

- a phase change is a type of physical change,
- the heat of fusion and heat of vaporization refer to the energy required for substances to change phase,
- during evaporation a substance goes from the liquid phase to the gas phase without reaching its boiling point,
- there is a relationship among pressure, temperature, and the physical phase of a substance,
- relative humidity describes how much water vapor is in the air compared to how much water vapor the air can hold.

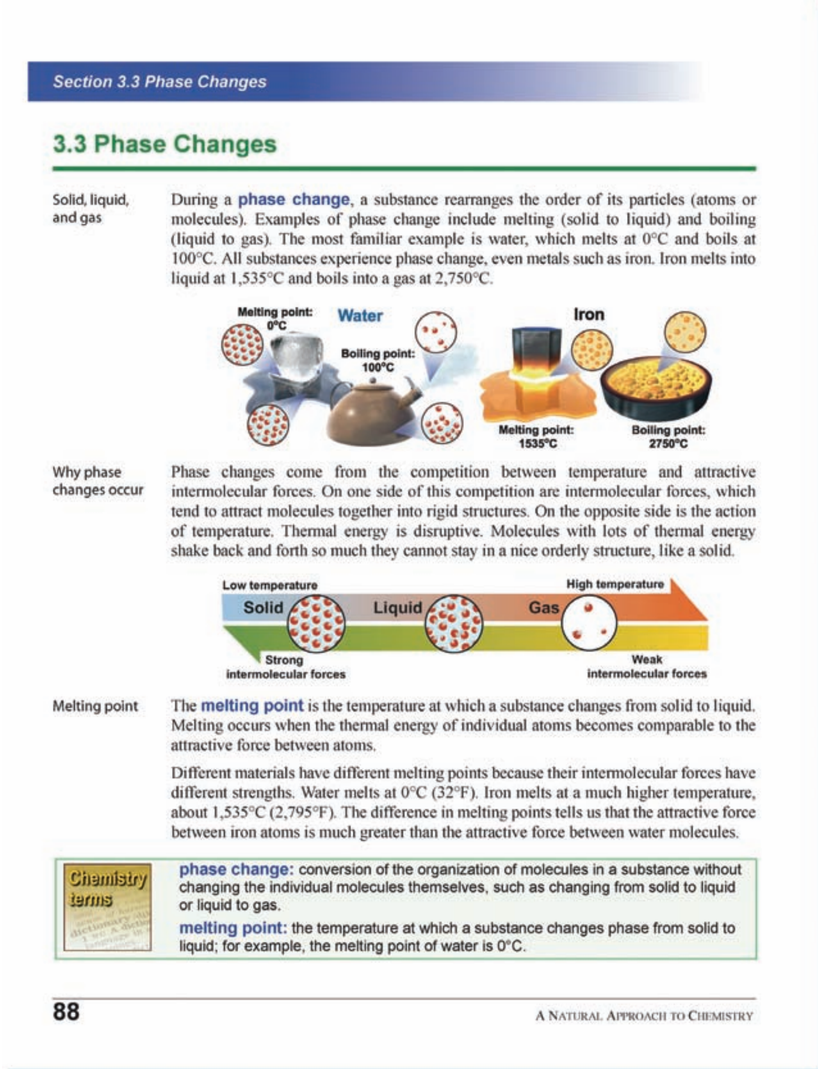
Key Questions

- Are chemical bonds broken during phase changes?
- Why doesn't temperature always rise when heat is added?
- Why does rubbing alcohol feel cool when it dries off?

Investigations

3D: Heat of Fusion

Students experiment with the heat of fusion of water and learn how energy is involved in the physical change from ice to liquid water. The Lab-Master system facilitates their learning by recording time and temperature data and graphing it on the display.



Section 3.3 Phase Changes

3.3 Phase Changes

Solid, liquid, and gas

During a **phase change**, a substance rearranges the order of its particles (atoms or molecules). Examples of phase change include melting (solid to liquid) and boiling (liquid to gas). The most familiar example is water, which melts at 0°C and boils at 100°C. All substances experience phase change, even metals such as iron. Iron melts into liquid at 1,535°C and boils into a gas at 2,750°C.

Why phase changes occur

Phase changes come from the competition between temperature and attractive intermolecular forces. On one side of this competition are intermolecular forces, which tend to attract molecules together into rigid structures. On the opposite side is the action of temperature. Thermal energy is disruptive. Molecules with lots of thermal energy shake back and forth so much they cannot stay in a nice orderly structure, like a solid.

Melting point

The **melting point** is the temperature at which a substance changes from solid to liquid. Melting occurs when the thermal energy of individual atoms becomes comparable to the attractive force between atoms.

Different materials have different melting points because their intermolecular forces have different strengths. Water melts at 0°C (32°F). Iron melts at a much higher temperature, about 1,535°C (2,795°F). The difference in melting points tells us that the attractive force between iron atoms is much greater than the attractive force between water molecules.

Chemistry terms

phase change: conversion of the organization of molecules in a substance without changing the individual molecules themselves, such as changing from solid to liquid or liquid to gas.

melting point: the temperature at which a substance changes phase from solid to liquid; for example, the melting point of water is 0°C.

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Differentiated Instruction Resources

Concept	Text	AV Slides	Skill Sheets	Hands-On	Assess and Practice
Phase changes	88	1–5	No. 5	Inv3D	22–24, 27, 31, 33, 48–49
Heat of vaporization	89	6–13	No. 5		25, 30, 50
Heat of fusion	90	6–13	No. 5	Inv3D	28, 50
Solving phase-change problems	91	14–17	No. 5	Inv3D	74–77
Evaporation	92	18–19		*17A, 19A	26, 51, 53
Condensation	93	20–23		*17A, 19A	57
Effect of pressure	94	24–27			57, 80–84
Relative humidity	95	28–31			32, 57, 80–84

* Investigation from another chapter related to spiraling nature of curriculum

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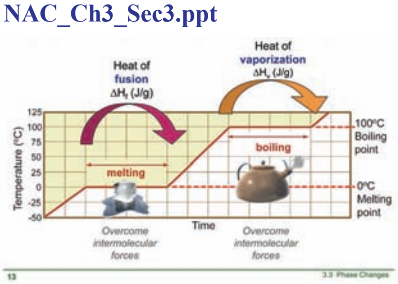

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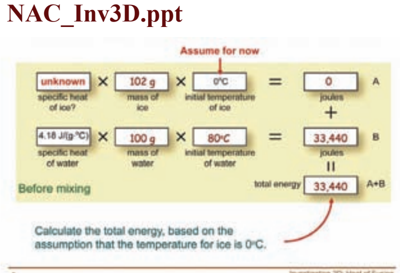

Vocabulary

Match each word to the sentence where it best fits.

Section 3.1

kinetic energy	thermometer
Brownian motion	thermistor
Fahrenheit	absolute zero
random	Kelvin
temperature	Celsius

Section 3.2

specific heat	heat
joule	first law
calorie	conductor
thermal equilibrium	insulator
second law	
system	

QUESTIONS AND ANSWERS HAVE BEEN REMOVED FROM THE NEXT SEVERAL PAGES

Section 3.3

gas	heat of fusion
solid	melting point
liquid	boiling point
triple point	phase change
vaporization	dew point
evaporation	

Conceptual Questions

Section 3.1

Section 3.2

Section 3.3

Quantitative Problems

Section 3.1

Section 3.2

Section 3.3