Table of Contents

UNIT 5

Thermochemical Changes

Teaching Unit 5: Thermochemical Changes

Chapter 9 *Energy and Chemical Reactions*

Answers to Questions for Comprehension, notes on Figures and Web Links appear throughout the chapter.

Chapter 10 *Theories of Energy and Chemical Changes*

Answers to Questions for Comprehension, notes on Figures and Web Links appear throughout the chapter.

Chapter 11 *Activation Energy and Catalysts*

Answers to Questions for Comprehension, notes on Figures and Web Links appear throughout the chapter.

Teaching Unit 5: Thermochemical Changes

(20% of the course time; approximately 25 hours)

Student Textbook pages 332–427

General Outcomes

- determine and interpret energy changes in chemical reactions
- explain and communicate energy changes in chemical reactions

Contents

Chapter 9 Energy and Chemical Reactions

Chapter 10 Theories of Energy and Chemical Changes

Chapter 11 Activation Energy and Catalysts

Content Summary

Unit 5 extends students' knowledge of chemical thermodynamics to understanding the energy changes that take place when molecules react, how to calculate the energy involved in a reaction, and the fundamentals of thermochemical experiments. In Alberta, practically all our energy needs are met by fossil fuels, and the energy sector is a major employer and contributor to the economy. Although we're blessed with abundant reserves of fossil fuels, our use of hydrocarbons is economically and environmentally costly. This unit will help students assess the risks and benefits of using hydrocarbon fuels.

Chapter 9 begins by emphasizing that energy is cycled through the environment, with the Sun as the original source of the energy we obtain from fossil fuels. Students are reminded of the law of conservation of energy, but it is stated in a powerful and simple relationship: by determining the energy changes in the surroundings, we can find the energy change in a physical change of state or in a chemical reaction. This leads to the concept of enthalpy and enthalpy change. Enthalpy change is equal to the heat absorbed or released by the system when a change takes place at constant pressure. The experiments performed by students are open to the atmosphere, and therefore essentially take place at constant pressure. Students learn how to write thermochemical equations and how to draw enthalpy diagrams. They will use enthalpy data and stoichiometry to calculate the energy change when the amount of a reactant or product is specified. In Investigation 9.A, students determine the enthalpy of a neutralization reaction. This is followed by Investigation 9.B, where students determine the molar enthalpy of combustion of paraffin wax. Next, students learn how a bomb calorimeter is used to determine more precisely and accurately the energy available from fuels and foods.

Chapter 10 begins by extending the law of conservation of energy to Hess's law. Students learn how to manipulate and combine thermochemical equations to calculate the theoretical amount of energy released or absorbed in a chemical reaction. They will use these skills in Investigation 10.A to determine the enthalpy of combustion of magnesium. Next, students learn how to combine standard molar enthalpies of formation with Hess's law to calculate the theoretical enthalpy change for any reaction. Students are then able to compare various energy sources based on their efficiency and environmental impact, and to evaluate the efficiency of energy use in the home and in thermal energy plants. In Investigation 10.C, students perform a risk-benefit analysis on the use and production of fossil fuels in Alberta. In the investigation that follows, they examine the environmental and economic factors that determine the use of coal or natural gas to fuel plants that generate electrical energy.

In Chapter 11, students learn about the activation energy for a reaction. This concept is used to explain why an input of energy is required to begin many reactions. Students learn how the temperature of a sample is related to the fraction of molecules with energy greater than the activation energy. This qualitatively explains why most reaction rates increase at higher temperatures. Next, students learn that using a catalyst lowers the activation energy for a reaction, and that this is why catalysts increase the rate of a reaction. Students learn about the use of catalysts in some industrial applications, and how a catalytic converter reduces pollution from automobile engines. Students will learn about the essential function of biological catalysts, and finally they will investigate the effect of a catalyst on the decomposition of hydrogen peroxide.

Curriculum Fit

This unit builds on:

- *Science 7,* Unit C: Heat Energy: Transfer and Conservation
- *Science 10,* Unit A: Energy and Matter in Chemical Change
- *Science 10,* Unit B: Energy Flow in Technological Systems
- *Science 10,* Unit D: Energy Flow in Global Systems

This unit prepares students for introductory chemistry courses at the post-secondary level.

Core Concepts

Concept	Outcome	Text Reference
The energy used by plants and animals, and the energy stored in hydrocarbons, originated from the Sun.	30–A1.2k	Unit 5 Opener, p. 332; Chapter 9 opener, p. 338
All chemical reactions are accompanied by changes in energy.	30–A1.2k; 30–A1.4k; 30–A1.10k	Section 9.1, p. 340; Section 9.2, p. 351
The total energy of the universe is constant (the law of conservation of energy): $\Delta E_{\text{universe}} = 0$	30–A1.7k	Section 9.1, p. 340
In thermochemistry, the universe can be reduced to two parts: the system and the surroundings: Universe = System + Surroundings	30–A1.5k	Section 9.1, p. 341
The system refers to the atoms and molecules that undergo a re-arrangement. The surroundings refers to everything else (the beaker, the lab, etc.)	30–A1.5k	Section 9.1, p. 341
$\Delta E_{\text{universe}} = \Delta E_{\text{system}} + \Delta E_{\text{surroundings}} = 0$ (First law of thermodynamics)	30–A1.5k	Section 9.1, p. 341
Energy can be classified into two fundamental types: kinetic energy (E_k), the energy of motion, and potential energy (E_p).	30–A1.5k	Section 9.1, p. 341
Chemical potential energy is the energy stored in chemical bonds.	30–A1.3k	Section 9.1, p. 341
Breaking a bond always requires energy; bond formation always releases energy.	30–A1.5k	Section 9.1, p. 342 Section 10.2, p. 384
When a reaction results in a net absorption of energy, it is called an endothermic reaction. When a reaction results in a net release of energy, it is called an exothermic reaction.	30–A1.10k	Section 9.1, p. 343 Chapter 11 opener, p. 402
Enthalpy, H, is the energy content of a system. Enthalpy change, ΔH, is the difference in enthalpy between the final state and the initial state for some change.	30–A1.3k	Section 9.1, p. 343
$\Delta H = \Delta_{\text{final}}H - \Delta_{\text{initial}}H$ For an exothermic change, ΔH is negative. For an endothermic change, ΔH is positive.	30–A1.10k	Section 9.1, p. 343
Molar enthalpy is ΔH when one mole of the substance undergoes a change.	30–A1.3k	Section 9.1, p. 343
The enthalpy change due to a chemical reaction, $\Delta_r H$, is equal in magnitude to the heat exchanged between the system and the surroundings when the reaction takes place at constant pressure.	30–A1.5k	Section 9.1, p. 344
A thermochemical equation is a chemical equation that includes the change in enthalpy for the reaction.	30–A1.5k	Section 9.1, p. 344
A potential energy diagram is a graphical representation of the change in enthalpy during a chemical or physical change.	30–A1.5k	Section 9.1, p. 345
Photosynthesis is the endothermic process by which green plants absorb energy from the Sun and produce glucose and oxygen.	30–A1.2k	Section 9.1, p. 345
The products of a combustion reaction that takes place in an open system, where the products are allowed to escape, include water vapour.	30–A1.4k 30–A1.9k	Section 9.1, p. 346

Concept	Outcome	Text Reference
The products of a combustion reaction that takes place in an isolated system (e.g. in a bomb calorimeter, or in cellular respiration) where the products are contained, include liquid water.	30–A1.4k 30–A1.9k	Section 9.1, pp. 346-347 Section 9.2, p. 360
The heat capacity of a substance, measured in J/°C or kJ/°C, is the quantity of energy required to raise its temperature by one degree Celsius.	30–A1.8k	Section 9.2, p. 360
The enthalpy change of any process depends only on the initial and final states. The enthalpy change of the overall process is the sum of the enthalpy changes of its individual steps. (Hess's Law)	30–A1.7k	Section 10.1, pp. 370-372
When a thermochemical equation is reversed, the sign of ΔH must be changed; when a thermochemical equation is multiplied by a factor, ΔH must be multiplied by the same factor.	30–A1.7k	Section 10.1, pp. 372-373
The standard molar enthalpy of formation, $\Delta_f H°$, is the change in enthalpy when one mole of a compound is formed directly from its elements in their most stable state at SATP.	30–A1.6k	Section 10.1, pp. 377-378
The standard enthalpy of formation of an element in its most stable state is zero.	30–A1.6k	Section 10.1, p. 377
$\text{Efficiency} = \frac{\text{Energy output}}{\text{Energy input}} \times 100\%$	30–A2.3s	Section 10.2, p. 385
Every energy conversion step in a process reduces its efficiency.	30–A2.3s	Chapter 10 opener, p. 368 Section 10.2, p. 391
Energy sources may be divided into two categories: those that are renewable (e.g., solar and wind energy), or those that are non-renewable (e.g., coal, oil, natural gas, nuclear). Each energy source has an economic and an environmental impact.	30–A2.2sts	Section 10.3, pp. 393-395
The amount of energy available from different fuels, and the emissions produced by each fuel, varies widely.	30–A2.3sts	Section 10.3, p. 397
The rate of a chemical reaction is the change in the amount of reactants consumed or products generated over time.		Chapter 11 opener, p. 402 Section 11.1, p. 404
A reaction takes place when the reactants collide with correct orientation and have sufficient collision energy (activation energy, E_a).	30–A2.2k	Section 11.1, pp. 404-405
The activation energy, E_a, of a reaction is the minimum collision energy required for a successful reaction.	30–A2.1k	Section 11.1, pp. 405-408
As the temperature of a sample increases, the fraction of collisions with energy equal to or greater than the activation energy increases significantly.	30–A2.1k	Section 11.1, p. 405
The activated complex is the highly unstable chemical species that exists with partly broken and partly formed bonds.	30–A2.3k	Section 11.1, p. 407
A catalyst is a substance that increases the rate of a chemical reaction without being consumed by the reaction.	30–A2.4k	Section 11.2, pp. 411-412
A catalyst provides an alternative pathway for a reaction to occur. The alternative pathway has a smaller activation energy than the uncatalyzed reaction.	30–A2.4k	Section 11.2, pp. 411-412
Catalysts are used in many chemical reactions, including industrial processes, the catalytic converter in an automobile, and in nature as enzymes.	30–A2.1sts	Section 11.2, pp. 413-416

Beyond the Core Concepts

Concept	Outcome	Text Reference
The enthalpy of decomposition of a substance is the negative of its heat of formation.		Section 10.1, pp. 379
A substance with a large enthalpy of decomposition is more thermally stable than a substance with a smaller enthalpy of decomposition.		Section 10.1, pp. 379
Students will use tables of $\Delta_f H°$ values to compare the thermal stabilities of substances.		Section 10.1, pp. 379

Related Skills

Skills	Outcome	Text Reference
Students must be able to describe procedures for safe handling, storage and disposal of materials used in the laboratory, with reference to WHMIS and consumer product labelling information.	30–A1.1s 30–A2.1s	Launch Lab, Section 9.1, pp. 339; Investigation 9A, pp. 356; Investigation 9B, pp. 358-359. Launch Lab, Section 10.1, pp. 369; Investigation 10A, pp. 375-376; Investigation 10B, pp. 387-388; Launch Lab, Section 11.3, pp. 403; Investigation 11A, pp. 417-418
Students will design a procedure to investigate the effectiveness of using an ionic compound as a hot or cold pack.	30–A1.1sts	Launch Lab, Section 9.1, pp. 339
Students will write thermochemical equations either showing the enthalpy change in the chemical equation, or by using the ΔH notation.	30–A1.4k	Section 9.1, pp. 344-347
Students will sketch enthalpy diagrams showing the reactant(s), products(s), and the enthalpy change for the reaction.	30–A1.4k 30–A1.3s	Section 9.1, pp. 345-346
Students will perform enthalpy calculations based on the equation $\Delta H = n\Delta_r H$.	30–A1.4k 30–A1.5k	Section 9.1, pp. 348-349 Section 9.2, pp. 354-355 Section 10.2, pp. 386
Students will use the formula $Q = mc\Delta t$ to calculate the quantity of thermal energy absorbed or released by the water or solution in a calorimeter.	30–A1.8k 30–A1.1k 30–A1.4k 30–A1.5k	Section 9.2, pp. 353-355 Section 10.2, pp. 386-387
Students will construct a simple calorimeter and use it to determine the enthalpy change in a chemical reaction.	30–A1.8k	Section 9.2, pp. 351-353; Investigation 9A, section 9.2, pp. 356-357; Investigation 10A, section 10.1, pp. 375-376
Students will construct a flame calorimeter and use it to determine the molar enthalpy of combustion of a fuel.	30–A1.8k; 30–A1.1k 30–A1.4k; 30–A1.5k 30–A1.1s; 30–A1.2s	Investigation 9B, Section 9.2, pp. 358-359
Students will calculate the enthalpy of combustion using data from a bomb calorimeter experiment.	30–A1.8k	Section 9.2, pp. 359-363
Students will design a procedure to investigate the efficiency of an oven.	30–A2.3s	Chapter 10 Launch Lab, pp. 369.

Skills	Outcome	Text Reference
Students will manipulate thermochemical equations and use Hess's law to determine the enthalpy change of a reaction.	30–A1.8k 30–A1.7k 30–A2.2s	Section 10.1, pp. 373-375; Investigation 10A, section 10.1, pp. 375-376.
Students will use Hess's law and tables of $\Delta_f H°$ data to calculate the enthalpy change of a chemical reaction.	30–A1.6k	Section 10.1, pp. 379-383 Section 10.2, pp. 386-387
Students will perform calculations relating to the efficiency of a heating device that produces energy by combustion.	30–A2.3s	Section 10.2, pp. 386-387
Students will design and build a heating device, and evaluate its efficiency.	30–A2.3s 30–A2.4s	Section 10.2, pp. 386-388 Investigation 10.B, section 10.2, pp. 387-388.
Working in small groups, students will analyze the ways energy is used in the home and list some energy-saving tips.	30–A2.2sts	Section 10.2, pp. 389
Students will research and write a report on the technologies and designs that are used to increase the efficiency of home heating.	30–A2.2sts	Section 10.2, pp. 390
Students will research and analyze the risks and benefits of relying on fossil fuels as an energy source.	30–A1.2sts 30–A2.2sts	Investigation 10.C, section 10.3, pp. 396 Section 10.3, pp. 397
Working in small groups, students will use a spreadsheet to assess the thermochemical, environmental, and economic choices for fuels used in thermal power plants.	30–A1.4s 30–A2.3sts 30–A2.2s; 30–A2.3s	Investigation 10.D, section 10.3, pp. 398
Students will sketch potential energy diagrams, and correctly label the axes and each of the following: reactant(s), product(s), $E_{a(fwd)}$, $E_{a(rev)}$, $\Delta_r H$, the region where bonds are being broken and the region where bonds are being formed.		Section 11.1, pp. 408-409
Students will investigate the effect of a catalyst on a chemical reaction.	30–A2.1s	Launch Lab, section 11.1, pp. 403; Investigation 11.A, section 11.2, pp. 417-418

Activities and Target Skills

Activity	Target Skills
Chapter 9: Energy and Chemical Reactions	
Launch Lab: Hot Packs and Cold Packs, p. 339	■ Recall endothermic and exothermic reactions ■ Design a hot or cold pack using soluble ionic compounds
Investigation 9.A: Determining the Enthalpy of a Neutralization Reaction, pp. 356-357	■ Performing calorimetry experiments to determine the molar enthalpy change of chemical reactions ■ Using thermometers or temperature probes when measuring temperature changes
Investigation 9.B: Molar Enthalpy of Combustion, pp. 358-359	■ Performing calorimetry experiments to determine the molar enthalpy change of chemical reactions ■ Designing a method to compare the molar enthalpy change when burning two or more fuels ■ Comparing energy changes associated with a variety of chemical reactions through the analysis of data

Activity	Target Skills
Chapter 10: Theories of Energy and Chemical Changes	
Launch Lab: Bake a Cake, p. 369	■ Building an oven using a light bulb ■ Determining efficiency
Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium, pp. 375-377	■ Performing calorimetry experiments to determine the molar enthalpy change of chemical reactions ■ Using thermometers or temperature probes appropriately when measuring temperature changes ■ Plotting enthalpy diagrams indicating energy changes
Investigation 10.B: Build a Heating Device, pp. 387-388	■ Designing and building a heating device ■ Determining the efficiency of thermal energy conversion systems ■ Evaluating a personally designed and constructed heating device
Thought Lab 10.1: Improving Energy Efficiency at Home, p. 389	■ Identify ways to use energy more efficiently
Investigation 10.C: Fossil Fuels as Energy Sources: A Risk-Benefit Analysis, p. 396	■ Assessing qualitatively the risks and benefits of relying on fossil fuels as energy sources ■ Conducting investigations into relationships and using a broad range of tools and techniques to gather and record data and information ■ Working as a member of a team in addressing problems and applying the skills and conventions of science
Investigation 10.D: Fuelling Thermal Power Plants, p. 398	■ Evaluating the economic and environmental impact of different fuels by relating carbon dioxide emissions and the heat content of fuels ■ Using library and electronic research tools to compile information on the energy content of fuels used in Alberta power plants ■ Assessing whether coal or natural gas should be used to fuel thermal power plants in Alberta
Chapter 11: Activation Energy and Catalysts	
Launch Lab: Does it Gel?, p. 403	■ Testing the characteristics of gelatin ■ Describing enzymes as catalysts
Investigation 11.A: The Effect of a Catalyst on the Decomposition of Hydrogen Peroxide, $H_2O_2(aq)$, pp. 417-418	■ Designing an experimental procedure to illustrate the effect of a catalyst on a chemical reaction ■ Describing safe handling, storage, and disposal procedures

Conceptual Challenges

- Students often neglect the correct use of significant digits when taking readings with a typical thermometer. Typical high school thermometers are graduated in one-degree intervals. Remind students to estimate a decimal place when they read the temperature, for example, 27.4 °C. A value of 25 °C is commonly recorded for a measurement that should properly be written as 25.0 °C.
- Students frequently make an error in the number of significant digits that should be quoted in their final answer when the calculation involves a change in temperature. For example, if the initial temperature is 22.4 °C, and the final temperature is 28.7 °C, students will often give three significant digits in their final answer. Point out that the subtraction of two temperature measurements may reduce the number of significant digits that should be given; in this example, because Δt is 6.3 °C, only two significant digits are allowed in the final answer.

Chapter 9 Energy and Chemical Reactions

Section 9.1

- Students may confuse heat and temperature. Ensure students understand that temperature is a measure of the average thermal energy of the substance in question, while heat is a term used to describe the transfer of thermal energy. A teaspoon of boiling water has a higher temperature than a bathtub of warm water, but the water in the bathtub has more thermal energy in total, and can transfer more heat to a cooler object. Ask students which they would prefer to use to keep warm on a cold night: the teaspoon of boiling water, or the bathtub of warm water.

- Students may have difficulty distinguishing between the system and the surroundings. For example, when an exothermic reaction occurs as two solutions are mixed, students may argue that since the solution became warmer it must have absorbed energy. In fact, the dissolved solutes have reacted and decreased their total potential energy. The water absorbs this energy, increasing the kinetic energy of its particles, which students can observe as an increase in temperature.
- Students may still believe that since a bond is often described as a form of stored energy, bonds should release energy when they are broken. Emphasize that every chemical change requires the breaking of some bonds, and the formation of new ones. Ensure students are clear that forming a bond always releases energy, while breaking a bond always requires energy.
- Many students incorrectly assign an exothermic reaction with a positive change in enthalpy. When an exothermic change takes place, students often think the increase in temperature means that the change must have caused an increase in energy of the system. This difficulty is due to incorrect differentiation between the system and the surroundings. Make sure students know that the system refers essentially to the bonds that will be re-arranged. In a physical change, the enthalpy change results from a re-arrangement of intermolecular forces. In a chemical reaction, the enthalpy change results from a re-arrangement of intramolecular forces. (A brief review of intermolecular forces and intramolecular bonding may be required.) Emphasize that students can never directly measure energy changes in the system. When an exothermic reaction occurs as two solutions are mixed, students may argue that because the solution became warmer it must have absorbed energy. In fact, the dissolved solutes have reacted and decreased their total potential energy. The water absorbs this energy as part of the surroundings. The kinetic energy of the water molecules increases, which students observe as an increase in temperature.
- Students may be confused about the exothermic and endothermic physical changes when they design hot and cold packs, in the Launch Lab for Chapter 9. Similar to chemical reactions, dissolving also involves breaking bonds and making new bonds. Intermolecular forces holding the solute molecules or ions together must be broken, and water molecules must hydrate the dissolved solute molecules. As always, breaking bonds requires energy, and the formation of new bonds releases energy. Consequently, heats of solution may be endothermic or exothermic, depending on the magnitude of the forces involved.
- In Investigation 9.A, students use a simple calorimeter to determine the enthalpy of a neutralization reaction. In their calculations, they must assume that the density and specific heat capacity of a dilute solution is the same as that of pure water. Students may argue that neither assumption is true, and therefore each contributes to the error in their experiments. However, the assumptions introduce much smaller errors than the assumption of no heat loss in their calorimeter. Consequently, the assumptions are valid given the accuracy of the equipment they use.

Section 9.2

- Students will find calorimetry calculations involving solutions the most difficult, often forgetting that the total volume of the solutions is the volume of water used for calorimetry calculations. There may also be a limiting reactant calculation for the quantity of reactant involved in the reaction.
- Students sometimes believe that 100% efficiency in converting energy is possible, if only sources of friction could be eliminated. The first law of thermodynamics holds out the possibility that thermal (kinetic) energy can be converted completely into work, or that an engine could be made 100% efficient. This is not unreasonable from the student's perspective, because the second law of thermodynamics is not part of their curriculum. Teachers can point out that energy losses due to conduction, convection, radiation and friction are unavoidable. Consequently, although energy is indeed conserved, useful energy is not conserved.

Chapter 10 Theories of Energy and Chemical Changes

Section 10.1

- Students should write out the thermochemical equations during the solution to a Hess's law problem to make sure the required equation is achieved when all the species are added and cancelled. Students who take shortcuts at this stage, by manipulating ΔH values without writing out the chemical equations, invariably make mistakes.

Section 10.2

- The first law of thermodynamics holds out the possibility that thermal (kinetic) energy can be converted completely into work, or that an engine could be made 100% efficient. Teachers can point out that energy losses due to conduction, convection and radiation are unavoidable, as is energy loss due to friction. Consequently, although energy is indeed conserved, *useful energy* is not conserved.

Chapter 11 Activation Energy and Catalysts

Section 11.1

- Students will likely want to refer to the "speed of the reaction" instead of "reaction rate." One way to help students appreciate the distinction is to have them compare units used to express speed with units used to express reaction rates. For example, the speed of a runner may be expressed in m/s, whereas the rate of a chemical reaction is usually expressed as a change in concentration divided by time, mol/L•s.

- Water is a common reactant or product in a chemical reaction. Students often choose the wrong value for the heat of formation in a reaction that involves water because they do not pay close attention to its state. Insist that students use subscripts indicating the state of a substance when they solve problems using heats of formation.

Using the Unit 5 Preparation Feature

The unit opener and the Focussing Questions look at uses and measurement of the energy of chemical changes—be it from food for members of a hard-working dog team or gasoline for snowmobiles and cars. The Unit Preparation feature ensures that students are able to describe chemical reactions and are familiar with the laws of thermodynamics and the methods for measuring thermal energy changes. Encourage students to take the Unit Prequiz (found at **www.albertachemistry.ca,** Online Learning Centre, Student Edition) to gauge their recall of these concepts and methods, noting that if they are familiar with the background science, their experience with this unit will be much easier. The Unit 5 Preparation feature includes four practice problems for students to further test their recall. **BLM 9.0.1** is an overhead master, **Describing Chemical Reactions**, which gives students a chance to review how they write equations for chemical reactions. It can be found on the CD-ROM that accompanies this Teacher's Resource or at **www.albertachemistry.ca,** Online Learning Centre, Instructor Edition (password required).

Answers to Practice Problems 1–4

For full solutions to the practice problems, visit **www.albertachemistry.ca,** Online Learning Centre, Instructor Edition, Full Solutions.

Student Textbook page 337

1. 6.1×10^3 J or 6.1 kJ
2. The second beaker absorbs twice as much energy as the first since it has twice the mass.
3. –214 kJ (or 214 kJ are released)
4. 0.7899 J/g•°C. The substance is likely granite.

UNIT 5: COURSE MATERIALS

Chapter, Section	Item Description	Suggested Quantity (assume 40 in class)	Text Activity
Chapters 9, 10, 11	safety goggles	40 pairs	Chapter 9 Launch Lab; Chapter 11 Launch Lab; Investigations: 9.A, 9.B, 10.A, 10.B, 11.A
Chapters 9, 10, 11	nonlatex disposable gloves	40 pairs × 6 investigations	Chapter 9 Launch Lab; Investigations: 9.A, 10.A,
Chapters 9, 10, 11	aprons	40	Chapter 9 Launch Lab; Chapter 11 Launch Lab; Investigations: 9.A, 9.B, 10.A, 10.B, 11.A
Chapter 9, Chapter Opener	a variety of soluble ionic compounds from the following list (choose at least one endothermic and one exothermic): -ammonium nitrate, NH_4NO_3(s) (endothermic) -calcium chloride, $CaCl_2$(s) (exothermic) -sodium chloride, NaCl(s) (endothermic) -sodium acetate, $NaCH_3COO$(s) (exothermic) -ammonium chloride, NH_4Cl(s) (endothermic) water		Chapter 9 Launch Lab: Hot Packs and Cold Packs, p. 339
	common household containers, such as plastic food containers, and resealable bags (include some small and large containers)	1 per group	
	balance	as available	
Chapter 9, Section 9.2	1.00 mol/L HCl(aq) [Note: corrosive and poisonous]	approx 120 mL per group	Investigation 9.A: Determining the Enthalpy of a Neutralization Reaction, pp. 356–357
	1.00 mol/L NaOH(aq) [Note: corrosive and poisonous]	approx 120 mL per group (More of solutions above will be required for repeat trials)	
	polystyrene cups that are the same size	2 per group	
	plastic lid for cup	2 per group	
	100 mL graduated cylinder	1 per group	
	400 mL beaker	1 per group	
	thermometer (alcohol or digital)	1 per group	
	stirring rod	1 per group	
	waste disposal container		
Chapter 9, Section 9.2	candle	1 per group	Investigation 9.B: Molar Enthalpy of Combustion, Part 1: The Molar Enthalpy of Combustion of Paraffin, pp. 358–359
	water		
	matches	2 per group	
	balance	approx. 5	
	calorimeter apparatus: includes retort stand, large (e.g., juice) can with air holes, small (e.g., vegetable) can, ring clamp, wire or stirring rod	1 set of apparatus per group	
	thermometer (alcohol or digital)	1 per group	
	stirring rod	1 per group	
	can lid or cardboard base	1 per group	
Chapter 9, Section 9.2	the same equipment and quantities as in Part 1, except candle		Investigation 9.B: The Molar Enthalpy of Combustion, Part 2: Comparing the Molar Enthalpies of Combustion for Three Fuels, p. 359
	two fuels other than paraffin in similar quantities	as required	
	portable propane burner, alcohol burner, camp stove, or other available heating device whose mass can be measured	1 per group	

Chapter, Section	Item Description	Suggested Quantity (assume 40 in class)	Text Activity
Chapter 10, Chapter Opener	clamp-on light sockets or some other suitable lamps	1 per group	Chapter 10 Launch Lab: Bake a Cake, p. 369
	retort stands	1 per group	
	building materials according to students' experimental design (some material suggestions shown below):	as required	
	-large coffee cans (from calorimetry experiments)		
	-cardboard boxes (approximately the same size as the coffee cans)		
	-aluminium foil		
	-mirror		
	-Styrofoam™		
	-25 to 100 W incandescent light bulbs (up to the maximum wattage recommended for use in the lamp socket)		
	disposable metal pans (tart or muffin size)	1 per group	
	stirring rod (or popsicle sticks if the cake is going to be consumed)	1 per group	
	graduated cylinder and/or measuring spoons	10–15	
	cake mix (any flavour)	30 mL per group	
	oil (to grease the metal pans)	1 tsp per group	
	water	15 mL per group	
	heat resistant gloves	1 pair per group	
Chapter 10, Section 10.1	1.00 mol/L $HCl(aq)$ [Note: corrosive]	200 mL per group	Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium, pp. 375–377
	$MgO(s)$ powder	0.80 g per group	
	Mg ribbon (or Mg turnings) [Note: flammable and poisonous]	0.50 g per group	
	simple calorimeter (2 nested coffee cups supported by a beaker, see student textbook p. 357)	1 per group	
	100 mL graduated cylinder	1 per group	
	scoopula	1 per group	
	electronic balance	1	
	thermometer (alcohol or digital)	1 per group	
	sandpaper or emery paper	1 per group	
	waste disposal container		
Chapter 10, Section 10.2	balance	1	Investigation 10.B: Build a Heating Device, pp. 387–388
	thermometer (alcohol or digital)	1 per group	
	stirring rod	1 per group	
	water		
	other available materials based on students' experimental design, which may include:	as required	
	-graduated cylinder		
	-cardboard box(es)		
	-aluminium foil		
	-Styrofoam™ sheets		
	-mirror		
Chapter 11, Chapter Opener	gelatin (cut into 3 cm × 3 cm squares)	1 square per student for a control, plus 1 square for each fruit to be tested	Chapter 11 Launch Lab: Does It Gel?, p. 403
	variety of fruit (cut into 1 cm squares): apple, banana, kiwi, orange, pineapple, strawberry	3 squares per student of each fruit to be tested	
	balance	1	
	100 mL beaker (or other small beaker) for each fruit to be tested and one for just gelatin	80	

Chapter, Section	Item Description	Suggested Quantity (assume 40 in class)	Text Activity
Chapter 11, Section 11.2	heat resistant gloves	1 pair per group	Investigation 11.A: The Effect of a Catalyst on the Decomposition of Hydrogen Peroxide, $H_2O_2(aq)$, pp. 417–418
	6% (m/v) $H_2O_2(aq)$ [WHMIS: Class C: oxidizing material] [Note: 6% works more effectively than 3% (available from drugstores) and 6% is the recommended concentration; solution can be purchased from a chemical supply company at 30% and diluted]	60 mL per group	
	1.0 mol/L NaI(aq) [WHMIS: Class D2: toxic]	60 mL per group	
	masking tape or grease pencil	5	
	100 mL beaker	1 per group	
	10 mL graduated cylinders	3 per group	
	250 mL Erlenmeyer flask	1 per group	
	clock with a second hand or stopwatch	1 per group	
	Gas collection materials:		
	-water		
	-one-holed stopper, fitted with a piece of glass	1 per group	
	-tubing (must be airtight)		
	-rubber tubing to fit glass tubing (must be airtight)	1 per group	
	-large test tube	1 per group	
	-pneumatic trough or large beaker	1 per group	
	electronic balance accurate to 0.001 g	5	
	petroleum jelly or glycerin (to grease tubing)	1 tube	

CHAPTER 9 ENERGY AND CHEMICAL REACTIONS

Curriculum Correlation

(Note: This correlation includes Chapters 9, 10, 11. Chapter 9 references are in bold.)

General Outcome 1: Students will determine and interpret energy changes in chemical reactions.

	Student Textbook	Assessment Options
Outcomes for Knowledge		
30–A1.1k recall the application of $Q = mc\Delta t$ to the analysis of energy transfer	**Measuring Thermal Energy Changes, Unit 5 Preparation, pp. 336–337** **Chapter 9 Launch Lab: Hot Packs and Cold Packs, p. 339**	**Practice Problems: 1–4, Unit 5 Preparation, p. 337** **Chapter 9 Launch Lab: Hot Packs and Cold Packs, Analysis: 1–3, p. 339** **Questions for Comprehension: 1, 2, Section 9.1, p. 342** **Section 9.1 Review: 1, p. 350** **Chapter 9 Review: 1, p. 366–377** **Chapter 9 Test** Unit 5 Review: 5, 7, pp. 424–427
30–A1.2k explain, in a general way, how stored energy in the chemical bonds of hydrocarbons originated from the Sun	**Enthalpy and Thermochemical Equations, Section 9.1, p. 340** **Enthalpy Changes of Endothermic Reactions, Section 9.1, p. 345**	**Section 9.1 Review: 2, p. 350** **Chapter 9 Review: 3, 15, p. 366–377** **Chapter 9 Test** Unit 5 Review: 1, 7, 20, pp. 424–427
30–A1.3k define enthalpy and molar enthalpy for chemical reactions	**Energy and Enthalpy, Section 9.1, p. 343** **Investigation 9.A: Determining the Enthalpy of a Neutralization Reaction, Section 9.2, pp. 356–357**	**Questions for Comprehension: 3, 4, Section 9.1, p. 346** **Section 9.1 Review: 3–7, p. 350** **Investigation 9.A: Determining the Enthalpy of a Neutralization Reaction, Analysis: 1, 2, 4, Conclusion: 5, Section 9.2, pp. 356–357** **Chapter 9 Review: 2, 14, p. 366–377** **Chapter 9 Test** Chapter 10 Review: 1, p. 401 Unit 5 Review: 4, 10, 24, 29, 30, 31, 36–43, pp. 424–427
30–A1.4k write balanced equations for chemical reactions that include energy changes	**Throughout Chapters 9, 10, and 11** **Energy Changes in Chemical Reactions, Section 9.1, p. 342** **Energy and Enthalpy, Section 9.1, p. 343**	**Questions for Comprehension: 3, 4, Section 9.1, p. 346** **Question for Comprehension: 5, Section 9.1, p. 347** **Section 9.1 Review: 3, 4, 6, 7, p. 350** **Chapter 9 Review: 5, 6, 12, 13, 23, 24, pp. 366–377** **Chapter 9 Test** Chapter 10 Review: 2, 18, p. 400–401 Unit 5 Review: 25, 32, 35, 41, 43, pp. 424–427

	Student Textbook	Assessment Options
30–A1.5k use and interpret ΔH notation to communicate energy changes and to calculate energy changes in chemical reactions	**Throughout Chapters 9, 10, and 11** **Investigation 9.A: Determining the Enthalpy of a Neutralization Reaction, Section 9.2, pp. 356–357** **Investigation 9.B: Molar Enthalpy of Combustion, Section 9.2, pp. 358–359** Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium, Section 10.1, pp. 375–377	**Section 9.1 Review: 3–7, p. 350** **Investigation 9.A: Determining the Enthalpy of a Neutralization Reaction, Analysis: 4, Conclusion: 5, Section 9.2, pp. 356–357** **Investigation 9.B: Molar Enthalpy of Combustion, Part 1: 2, Part 2: 1, 2, Section 9.2, pp. 358–359** **Chapter 9 Review: 2–4, 6, 7, 13, 16–24, pp. 366–367** **Chapter 9 Test** Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium: 1–5, Section 10.1, pp. 375–377 Section 10.1 Review: 1–5, p. 383 Chapter 10 Review: 1, 2, 12, 15–26, pp. 400–401 Chapter 10 Test Unit 5 Review: 19, 25, 29–45, pp. 424–427
30–A1.6k predict the enthalpy change for chemical equations using standard enthalpies of formation	**Calculating Enthalpy Changes, Section 9.1, p. 348** **Sample Problem: Predicting an Enthalpy Change, Section 9.1, p. 348** **Sample Problem: Using Enthalpy Data to Determine the Mass of Products, Section 9.1, p. 349** Hess's Law, Section 10.1, p. 370 Sample Problem: Using Hess's Law to Determine Enthalpy Change for Formation Reactions, Section 10.1, p. 373 Standard Molar Enthalpies of Formation, Section 10.1, p. 377 Sample Problem: Using Enthalpies of Formation, Section 10.1, p. 381 Sample Problem: Using an Enthalpy of Combustion to Determine an Enthalpy of Formation, Section 10.1, p. 382	**Practice Problems: 1–6, Section 9.1, p. 349** **Chapter 9 Test** Practice Problems 1–6, Section 10.1, pp. 374–375 Questions for Comprehension: 1–3, Section 10.1, p. 378 Questions for Comprehension: 4–7, Section 10.1, p. 379 Practice Problems: 7–12, Section 10.1, pp. 382–383 Section 10.1 Review: 2, 3, 5, p. 383 Chapter 10 Review: 2, 3, 10, 15, 16, 18, pp. 400–401 Chapter 10 Test Unit 5 Review: 4, 25, 33, 39–41, 43, pp. 424–427
30–A1.7k explain and use Hess's law to calculate energy changes for a net reaction from a series of reactions	Hess's Law, Section 10.1, pp. 370–383 Sample Problem: Using Hess's Law to Determine Enthalpy Change, Section 10.1, p. 373 Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium, Section 10.1, pp. 375–377 Sample Problem: Using an Enthalpy of Combustion to Determine an Enthalpy of Formation, Section 10.1, p. 382	Practice Problems: 1–6, Section 10.1, pp. 374–375 Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium: 1–6, Section 10.1, pp. 375–377 Questions for Comprehension: 1–3, Section 10.1, p. 378 Practice Problems: 7–12, Section 10.1, pp. 382–383 Chapter 10 Review: 16, 18, 19, pp. 400–401 Chapter 10 Test Unit 5 Review: 25, 29, 37–39, pp. 424–427

	Student Textbook	Assessment Options
30–A1.8k use calorimetry data to determine the enthalpy changes in chemical reactions	**Calorimetry, Section 9.2, pp. 351–353** **Sample Problem: Determining the Enthalpy Change of a Reaction, Section 9.2, p. 354** **Connections: Energy for Living: How Food Fuels You, Section 9.1, pp. 361–362** **Sample Problem: Calculating Thermal Energy in a Bomb Calorimeter, Section 9.2, p. 362** Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium, Section 10.1, pp. 375–377	**Practice Problems: 7–12, Section 9.2, p. 355** **Questions for Comprehension: 7–10, Section 9.2, p. 355** **Practice Problems: 13–17, Section 9.2, p. 363** **Section 9.2 Review: 1–8, p. 364** **Chapter 9 Review: 4, 7–9, 11–13, 16–22, pp. 366–367** **Chapter 9 Test** Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium: 1–5, Section 10.1, pp. 375–377 Chapter 10 Review: 15, 24, 26, pp. 400–401 Chapter 10 Test Unit 5 Review: 11, 30, 32, 36, 44, pp. 424–427
30–A1.9k identify that liquid water and carbon dioxide gas are reactants for photosynthesis and are products for cellular respiration, in an open system, and that gaseous water and carbon dioxide gas are the products of hydrocarbon combustion	**Molar Enthalpy of Combustion, Section 9.1, p. 346** **Connections: Energy for Living: How Food Fuels You, Section 9.2, pp. 361–362**	**Web Link, Section 9.1, p. 347** **Questions for Comprehension: 5, 6, Section 9.1, p. 347** **Practice Problems: 2–4, Section 9.1, p. 349** **Chapter 9 Review: 5, 6, 10, 24, pp. 366-367** **Chapter 9 Test** Chapter 10 Review: 12, 15, 17, 20, 21, 23, 24, 26, 28, pp. 400–401 Unit 5 Review: 7, 8, 22, 24, 30, 32, 35, 42, 48, pp. 424–427
30–A1.10k classify chemical reactions, including those for the processes of photosynthesis, cellular respiration and hydrocarbon combustion as endothermic or exothermic.	**Describing Chemical Reactions, Unit 5 Preparation, p. 334** **Energy Changes in Chemical Reactions, Section 9.1, pp. 342–343** **Enthalpy Changes of Exothermic Reactions, Section 9.1, pp. 344–345** **Enthalpy Changes of Endothermic Reactions, Section 9.1, p. 345** **Molar Enthalpy of Combustion, Section 9.1, p. 346** **Connections: Energy for Living: How Food Fuels You, Section 9.2, pp. 361–362**	**Section 9.1 Review: 2, 5, p. 350** **Chapter 9 Review: 5, 6, 10, 15, 22, pp. 366-367** **Chapter 9 Test** Questions for Comprehension: 2, Section 10.1, p. 378 Unit 5 Review: 1, 3, 36, pp. 424–427

	Student Textbook	Assessment Options
Outcomes for Science, Technology and Society (Emphasis on science and technology)		
30–A1.1sts explain that the goal of technology is to provide solutions to practical problems by ■ *providing examples of personal reliance on the chemical potential energy of matter, e.g., the use of hydrocarbon fossil fuels* ■ *identifying ways to use energy more efficiently*	**Chapter 9 Launch Lab: Hot Packs and Cold Packs, p. 339** **Connections: Energy for Living: How Food Fuels You, Section 9.2, pp. 361–362** Chapter 10 Launch Lab: Bake a Cake, p. 368 Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium, Section 10.1, pp. 375–377 Thought Lab 10.1: Improving Energy Efficiency at Home, Section 10.2, p. 389 Connections: Efficient Home Heating, Section 10.2, p. 390 Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396 Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398 Connections: Car Pollution Solution? Inside a Catalytic Converter, Section 11.2, p. 414	**Chapter 9 Launch Lab: Hot Packs and Cold Packs, Analysis: 3, p. 339** **Connections: Energy for Living: How Food Fuels You: 1, 2, Section 9.2, pp. 361–362** Chapter 10 Launch Lab: Bake a Cake: 1–3, p. 368 Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium: 5, 6, Section 10.1, pp. 375–377 Thought Lab 10.1: Improving Energy Efficiency at Home: 1–4, Section 10.2, p. 389 Connections: Efficient Home Heating: 1, 2, Section 10.2, p. 390 Section 10.2 Review: 1–9, p. 392 Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396 Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398 Section 10.3 Review: 6, p. 398 Chapter 10 Review: 4–9, pp. 400–401 Connections: Car Pollution Solution? Inside a Catalytic Converter: 2, 3, Section 11.2, p. 414 Unit 5 Review: 46–49, pp. 424–427
30–A1.2sts demonstrate an understanding that technological problems often lend themselves to multiple solutions that involve different designs, materials and processes and have intended and unintended consequences by ■ *illustrating the applications of hydrocarbon fossil fuels, with examples from industries in Alberta.*	**Chapter 9 Launch Lab: Hot Packs and Cold Packs, p. 339** Investigation 10.B: Build a Heating Device, Section 10.2, pp. 387–388 Thought Lab 10.1: Improving Energy Efficiency at Home, Section 10.2, p. 389 Connections: Efficient Home Heating, Section 10.2, p. 390 Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396 Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398	**Chapter 9 Launch Lab: Hot Packs and Cold Packs, Analysis: 2, p. 339** Investigation 10.B: Build a Heating Device: 1–3, Section 10.2, pp. 387–388 Thought Lab 10.1: Improving Energy Efficiency at Home: 1–4, Section 10.2, p. 389 Connections: Efficient Home Heating: 1, 2, Section 10.2, p. 390 Section 10.2 Review: 1–9, p. 392 Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396 Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398 Section 10.3 Review: 1–6, p. 398 Chapter 10 Review: 13, 14, pp. 400–401 Unit 5 Review: 46–49, p. 427

	Student Textbook	Assessment Options
Skill Outcomes (Focus on problem solving)		
Initiating and Planning		
30–A1.1s ask questions about observed relationships and plan investigations of questions, ideas, problems and issues by ■ designing a method to compare the molar enthalpy change when burning two or more fuels, identifying and controlling major variables	**Investigation 9.B: Molar Enthalpy of Combustion, Section 9.2, pp. 358–359** Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium, Section 10.1, pp. 375–377	**Investigation 9.B: Molar Enthalpy of Combustion, Part 1: 1–4, Part 2: 1–4, Section 9.2, pp. 358–359** Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium: 1–6, Section 10.1, pp. 375–377 Unit 5 Review: 24, 47, pp. 424–427
■ describing procedures for safe handling, storage and disposal of materials used in the laboratory, with reference to WHMIS and consumer product labelling information.	**Chapter 9 Launch Lab: Hot Packs and Cold Packs, p. 339** **Investigation 9.B: Molar Enthalpy of Combustion, Section 9.2, pp. 358–359** Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium, Section 10.1, pp. 375–377	**Chapter 9 Launch Lab: Hot Packs and Cold Packs, Analysis: 2, p. 339** **Investigation 9.B: Molar Enthalpy of Combustion, Part 1: 3, Part 2: 3, Section 9.2, pp. 358–359** Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium: 6, Section 10.1, pp. 375–377 Unit 5 Review: 24, 47, pp. 424–427
Performing and Recording		
30–A1.2s conduct investigations into relationships among observable variables and use a broad range of tools and techniques to gather and record data and information by ■ performing calorimetry experiments to determine the molar enthalpy change of chemical reactions ■ using thermometers or temperature probes appropriately when measuring temperature changes	**Investigation 9.A: Determining the Enthalpy of a Neutralization Reaction, Section 9.2, pp. 356–357** **Investigation 9.B: Molar Enthalpy of Combustion, Section 9.2, pp. 358–359** Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium, Section 10.1, pp. 375–377	**Investigation 9.A: Determining the Enthalpy of a Neutralization Reaction, Analysis: 1–4, Conclusion: 5, Section 9.2, pp. 356–357** **Investigation 9.B: Molar Enthalpy of Combustion, Part 1: 1–4, Part 2: 1–4, Section 9.2, pp. 358–359** Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium: 1–6, Section 10.1, pp. 375–377 Unit 5 Review: 24, 47, pp. 424–427
■ *using a computer-based laboratory to compile and organize data from an experiment to demonstrate molar enthalpy change*	**Investigation 9.B: Molar Enthalpy of Combustion, Section 9.2, pp. 358–359**	**Investigation 9.B: Molar Enthalpy of Combustion, Part 1: 2, Part 2: 3, Section 9.2, pp. 358–359**
■ *selecting and integrating information from various print and electronic sources to create multiple-linked documents on using alternative fuels.*	**Investigation 9.B: Molar Enthalpy of Combustion, Section 9.2, pp. 358–359** **Connections: Energy for Living: How Food Fuels You, Section 9.2, Section 9.2, pp. 361–362** Investigation 10.B: Build a Heating Device, Section 10.2, pp. 387–388 Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396 Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398	**Investigation 9.B: Molar Enthalpy of Combustion, Part 2: 3, Section 9.2, pp. 358–359** **Connections: Energy for Living: How Food Fuels You: 1–4, Section 9.2, pp. 361–362** Investigation 10.B: Build a Heating Device: 2, Section 10.2, pp. 387–388 Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396 Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398

	Student Textbook	Assessment Options
Analyzing and Interpreting		
30–A1.3s analyze data and apply mathematical and conceptual models to develop and assess possible solutions by ■ comparing energy changes associated with a variety of chemical reactions through the analysis of data and energy diagrams	**Investigation 9.B: Molar Enthalpy of Combustion, Section 9.2, pp. 358–359** Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium, Section 10.1, pp. 375–377 Investigation 10.B: Build a Heating Device, Section 10.2, pp. 387–388	**Investigation 9.B: Molar Enthalpy of Combustion, Part 1: 1, 2, Part 2: 1, 2, Section 9.2, pp. 358–359** Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium: 1–6, Section 10.1, pp. 375–377 Investigation 10.B: Build a Heating Device: 1–3, Section 10.2, pp. 387–388 Unit 5 Review: 11, 28, 35, 36–42, 44, pp. 424–427
■ *manipulating and presenting data through the selection of appropriate tools, e.g., scientific instrumentation, calculators, databases or spreadsheets.*	**Investigation 9.B: Molar Enthalpy of Combustion, Section 9.2, pp. 358–359** Investigation 10.B: Build a Heating Device, pp. 387–388 Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398	**Investigation 9.B: Molar Enthalpy of Combustion, Part 2: 3, Section 9.2, pp. 358–359** Investigation 10.B: Build a Heating Device: 3, pp. 387–388 Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398 Unit 5 Review: 36, pp. 424–427
Communication and Teamwork		
30–A1.4s work collaboratively in addressing problems and apply the skills and conventions of science in communicating information and ideas and in assessing results by ■ using appropriate International System of Units (SI) notation, fundamental and derived units for enthalpy changes and expressing molar enthalpies in kilojoules/mole	**Investigation 9.A: Determining the Enthalpy of a Neutralization Reaction, Section 9.2, pp. 356–357** **Investigation 9.B: Molar Enthalpy of Combustion, Section 9.2, pp. 358–359** Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium, Section 10.1, pp. 375–377 Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398	**Investigation 9.A: Determining the Enthalpy of a Neutralization Reaction, Analysis: 1–3, Conclusion: 5, Section 9.2, pp. 356–357** **Investigation 9.B: Molar Enthalpy of Combustion, Part 1: 1–4, Part 2: 1–4, Section 9.2, pp. 358–359** Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium: 1–5, Section 10.1, pp. 375–377 Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398
■ *using advanced menu features within a word processor to accomplish a task and to insert tables, graphs, text and graphics.*	**Investigation 9.B: Molar Enthalpy of Combustion, Section 9.2, pp. 358–359** Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398	**Investigation 9.B: Molar Enthalpy of Combustion, Part 2: 3, Section 9.2, pp. 358–359** Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398 Chapter 10 Review: 27, p. 401

General Outcome 2: Students will explain and communicate energy changes in chemical reactions.

	Student Textbook	Assessment Options
Outcomes for Knowledge		
30–A2.1k define activation energy as the energy barrier that must be overcome for a chemical reaction to occur	Activation Energy, Section 11.1, p. 405	Questions for Comprehension: 1–3, Section 11.1, p. 407 Section 11.1 Review: 2, 4, 5, 7, 8, p. 410 Chapter 11 Review: 2, 3, 5, 6, 9, 14, 16, pp. 420–421 Chapter 11 Test Unit 5 Review: 16, 19, 45, pp. 424–427

	Student Textbook	Assessment Options
30–A2.2k explain the energy changes that occur during chemical reactions referring to bonds breaking and forming and changes in potential and kinetic energy	**Types of Energy, Section 9.1, p. 341** **Energy Changes in Chemical Reactions, Section 9.1, p. 342**	Section 11.1 Review: 1–3, p. 410 Chapter 11 Review: 1, 3, 5, 9, pp. 420–421 Unit 5 Review: 1, 6, 9, 20, pp. 424–427
30–A2.3k analyze and label energy diagrams for a chemical reaction, including reactants, products, enthalpy change and activation energy	**Enthalpy Changes of Exothermic Reactions, Section 9.1, pp. 344–345** **Enthalpy Changes of Endothermic Reactions, Section 9.1, p. 345** A Closer Look at a Molecular Collision, Section 11.1, p. 406 Sample Problem: Drawing a Potential Energy Diagram, Section 11.1, pp. 408–409	**Questions for Comprehension: 3, 4, Section 9.1, p. 346** Practice Problems: 1–5, Section 11.1, p. 409 Section 11.1 Review: 6–9, p. 410 Section 11.2 Review: 6, p. 418 Chapter 11 Review: 4, 6, 13–15, 18, 19, pp. 420–421 Chapter 11Test Unit 5 Review: 12, 19, 20, 29, 33, 43, 45, pp. 424–427
30–A2.4k explain that catalysts increase reaction rates by providing alternate pathways for changes without affecting the net amount of energy involved, e.g., *enzymes in living systems.*	Chapter 11 Launch Lab: Does It Gel? p. 403 Catalysts and Reaction Rates, Section 11.2, pp. 411–412 Try This, Section 11.2, p. 416 Investigation 11.A: The Effect of a Catalyst on the Decomposition of Hydrogen Peroxide, H_2O_2(aq), Section 11.2, pp. 417–418	Chapter 11 Launch Lab: Does It Gel? Analysis: 3, p. 403 Questions for Comprehension: 1–3, Section 11.1, p. 407 Questions for Comprehension: 4, 5, Section 11.2, p. 413 Investigation 11.A: The Effect of a Catalyst on the Decomposition of Hydrogen Peroxide, H_2O_2(aq): 1–6, Section 11.2, pp. 417–418 Section 11.2 Review: 1–6, p. 418 Chapter 11 Review: 7, 8, 10, 11, 12, 14, 17–29, p. 420–421 Chapter 11 Test Unit 5 Review: 18, 21, 29, 45, pp. 424–427

	Student Textbook	Assessment Options
Outcomes for Science, Technology and Society (Emphasis on science and technology)		
30–A2.1sts develop an understanding that the goal of technology is to provide solutions to practical problems by ■ *explaining how catalysts reduce air pollution from the burning of hydrocarbons; i.e., catalytic converters on cars*	**Chapter 9 Launch Lab: Hot Packs and Cold Packs, p. 339** Investigation 10.B: Build a Heating Device, Section 10.2, pp. 387–388 Thought Lab 10.1: Improving Energy Efficiency at Home, Section 10.2, p. 389 Connections: Efficient Home Heating, Section 10.2, p. 390 Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396 Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398 Chapter 11 Launch Lab: Does It Gel? p. 403 Connections: Car Pollution Solution? Inside a Catalytic Converter, Section 11.2, p. 414 Career Focus: Building Up and Breaking Down Bitumen, pp. 422–423	**Chapter 9 Launch Lab: Hot Packs and Cold Packs, Analysis: 1, 3, p. 339** Investigation 10.B: Build a Heating Device: 1–3, Section 10.2, pp. 387–388 Thought Lab 10.1: Improving Energy Efficiency at Home: 1–4, Section 10.2, p. 389 Connections: Efficient Home Heating: 1, 2, Section 10.2, p. 390 Section 10.2 Review: 1–9, p. 392 Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396 Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398 Section 10.3 Review: 1–6, p. 398 Chapter 11 Launch Lab: Does It Gel? Analysis: 2, 3, p. 403 Connections: Car Pollution Solution? Inside a Catalytic Converter: 1–3, Section 11.2, p. 414 Chapter 11 Review: 17, 22–29, pp. 420–421 Career Focus: Building Up and Breaking Down Bitumen, Go Further 1–3, pp. 422–423 Unit 5 Review: 46–49, pp. 424–427
30–A2.2sts identify the appropriateness, risks and benefits of technologies and the need to assess each potential application from a variety of perspectives, including sustainability by ■ *assessing qualitatively the risks and benefits of relying on fossil fuels as energy sources*	**Chapter 9 Launch Lab: Hot Packs and Cold Packs, p. 339** **Connections: Energy for Living: How Food Fuels You, Section 9.2, pp. 361–362** Chapter 10 Launch Lab: Bake a Cake, p. 368 Investigation 10.B: Build a Heating Device, Section 10.2, pp. 387–388 Thought Lab 10.1: Improving Energy Efficiency at Home, Section 10.2, p. 389 Connections: Efficient Home Heating, Section 10.2, p. 390 Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396 Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398	**Chapter 9 Launch Lab: Hot Packs and Cold Packs, Analysis: 1–3, p. 339** **Connections: Energy for Living: How Food Fuels You: 1–4, Section 9.2, pp. 361–362** Chapter 10 Launch Lab: Bake a Cake: 1–3, p. 368 Investigation 10.B: Build a Heating Device: 1–3, Section 10.2, pp. 387–388 Thought Lab 10.1: Improving Energy Efficiency at Home: 1–4, Section 10.2, p. 389 Connections: Efficient Home Heating: 1, 2, Section 10.2, p. 390 Section 10.2 Review: 1–9, p. 392 Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396 Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398 Section 10.3 Review: 1–6, p. 398 Chapter 10 Review: 13, 14, p. 400 Chapter 11 Review: 17, 22–29, pp. 420–421 Unit 5 Review: 46–49, pp. 424–427

	Student Textbook	Assessment Options
30–A2.3sts explain that the products of technology are devices, systems and processes that meet given needs but that these products cannot solve all problems by ■ *evaluating the economic and environmental impact of different fuels by relating carbon dioxide emissions and the heat content of a fuel.*	Chapter 10 Launch Lab: Bake a Cake, p. 368 Investigation 10.B: Build a Heating Device, Section 10.2, pp. 387–388 Thought Lab 10.1: Improving Energy Efficiency at Home, Section 10.2, p. 389 Connections: Efficient Home Heating, Section 10.2, p. 390 Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396 Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398	Chapter 10 Launch Lab: Bake a Cake: 3, p. 368 Investigation 10.B: Build a Heating Device: 1–3, Section 10.2, pp. 387–388 Thought Lab 10.1: Improving Energy Efficiency at Home: 1–4, Section 10.2, p. 389 Connections: Efficient Home Heating: 1, 2, Section 10.2, p. 390 Section 10.2 Review: 1–9, p. 392 Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396 Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398 Section 10.3 Review: 1–6, p. 398 Chapter 11 Review: 17, 22–29, pp. 420–421 Unit 5 Review: 46–49, pp. 424–427
Skill Outcomes (Focus on problem solving)		
Initiating and Planning		
30–A2.1s ask questions about observed relationships and plan investigations of questions, ideas, problems and issues by ■ describing procedures for safe handling, storage and disposal of materials used in the laboratory, with reference to WHMIS and consumer product labelling information ■ *designing an experimental procedure to illustrate the effect of a catalyst on a chemical reaction.*	Investigation 11.A: The Effect of a Catalyst on the Decomposition of Hydrogen Peroxide, H_2O_2(aq), Section 11.2, pp. 417–418	Investigation 11.A: The Effect of a Catalyst on the Decomposition of Hydrogen Peroxide, H_2O_2(aq): 1–6, Section 11.2, pp. 417–418 Unit 5 Review: 24, 27, pp. 424–425
Performing and Recording		
30–A2.2s conduct investigations into relationships among observable variables and use a broad range of tools and techniques to gather and record data and information by ■ plotting energy graphs/enthalpy diagrams indicating changes in energy for chemical reactions	**Investigation 9.B: Molar Enthalpy of Combustion, Section 9.2, pp. 358–359** Investigation 11.A: The Effect of a Catalyst on the Decomposition of Hydrogen Peroxide, H_2O_2(aq), Section 11.2, pp. 417–418	**Investigation 9.B: Molar Enthalpy of Combustion, Part 2: 2, Section 9.2, pp. 358–359** Investigation 11.A: The Effect of a Catalyst on the Decomposition of Hydrogen Peroxide, H_2O_2(aq): 2, Section 11.2, pp. 417–418
■ *using library and electronic research tools to compile information on the energy content of fuels used in Alberta power plants*	**Investigation 9.B: Molar Enthalpy of Combustion, Section 9.2, pp. 358–359** Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396 Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398	**Investigation 9.B: Molar Enthalpy of Combustion, Part 2: 3, Section 9.2, pp. 358–359** Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396 Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398
■ *designing and building a heating device.*	**Chapter 9 Launch Lab: Hot Packs and Cold Packs, p. 339** Investigation 10.B: Build a Heating Device, Section 10.2, pp. 387–388	**Chapter 9 Launch Lab: Hot Packs and Cold Packs, Analysis: 1, 3, p. 339** Investigation 10.B: Build a Heating Device: 1–3, Section 10.2, pp. 387–388

	Student Textbook	Assessment Options
Analyzing and Interpreting		
30–A2.3s analyze data and apply mathematical and conceptual models to develop and assess possible solutions by ■ interpreting an enthalpy diagram for a chemical reaction ■ explaining the discrepancy between the theoretical and actual efficiency of a thermal energy conversion system	**Investigation 9.B: Molar Enthalpy of Combustion, Section 9.2, pp. 358–359** Chapter 10 Launch Lab: Bake a Cake, p. 368 Connections: Efficient Home Heating, Section 10.2, p. 390 Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.2, p. 396	**Investigation 9.B: Molar Enthalpy of Combustion, Part 2: 3, Section 9.2, pp. 358–359** Unit 5 Review: 11, 28, 35, 36–42, 44, pp. 424–427 Chapter 10 Launch Lab: Bake a Cake: 2, 3, p. 368 Practice Problems: 13–16, Section 10.2, p. 387 Connections: Efficient Home Heating: 1, Section 10.2, p. 390 Section 10.2 Review: 1–9, p. 392 Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396 Chapter 10 Review: 4–9, pp. 400–401 Chapter 11 Review: 4, 6, 13–15, 18, 19, pp. 420–421
■ *determining the efficiency of thermal energy conversion systems*	Chapter 10 Launch Lab: Bake a Cake, p. 368 Sample Problem: The Efficiency of a Propane Barbecue, Section 10.2, pp. 386–387 Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.2, p. 396	Chapter 10 Launch Lab: Bake a Cake: 3, p. 368 Practice Problems: 13–16, Section 10.2, p. 387 Section 10.2 Review: 1–9, p. 392 Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396 Chapter 10 Review: 4–9, pp. 400–401
■ *assessing whether coal or natural gas should be used to fuel thermal power plants in Alberta*	**Investigation 9.B: Molar Enthalpy of Combustion, Part 1: 1–4, Part 2: 1–4, Section 9.2, pp. 358–359** Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396 Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398	**Investigation 9.B: Molar Enthalpy of Combustion, Part 2: 3, Section 9.2, pp. 358–359** Section 10.2 Review: 1–9, p. 392 Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396 Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398 Section 10.3 Review: 1–6, p. 398 Chapter 10 Review: 13, 14, pp. 400
■ *evaluating a personally designed and constructed heating device, including a calculation of its efficiency.*	Investigation 10.B: Build a Heating Device, Section 10.2, pp. 387–388	Investigation 10.B: Build a Heating Device: 1–3, Section 10.2, pp. 387–388
Communication and Teamwork		
30–A2.4s work collaboratively in addressing problems and apply the skills and conventions of science in communicating information and ideas and in assessing results by ■ using appropriate SI notation, fundamental and derived units for calculating and communicating enthalpy changes	**Investigation 9.A: Determining the Enthalpy of a Neutralization Reaction, Analysis: 1–4, Conclusions: 5, Section 9.2, pp. 356–357** **Investigation 9.B: Molar Enthalpy of Combustion, Section 9.2, pp. 358–359** Investigation 10.B: Build a Heating Device, Section 10.2, pp. 387–388	**Investigation 9.A: Determining the Enthalpy of a Neutralization Reaction, Analysis: 1–4, Conclusion: 5, Section 9.2, pp. 356–357** **Investigation 9.B: Molar Enthalpy of Combustion, Part 1: 1–4, Part 2: 1–4, Section 9.2, pp. 358–359** Investigation 10.B: Build a Heating Device: 1–3, Section 10.2, pp. 387–388
■ *working collaboratively to develop a plan to build an energy conversion device, seeking feedback, testing and reviewing the plan, making revisions and implementing the plan* ■ *using advanced menu features within a word processor to accomplish a task and to insert tables, graphs, text and graphics.*	**Investigation 9.B: Molar Enthalpy of Combustion, Section 9.2, pp. 358–359** Investigation 10.B: Build a Heating Device: Section 10.2, pp. 387–388	**Investigation 9.B: Molar Enthalpy of Combustion, Part 2: 3, Section 9.2, pp. 358–359** Investigation 10.B: Build a Heating Device: 2, 3, Section 10.2, pp. 387–388 Chapter 10 Review: 27, p. 401

Chapter 9

Energy and Chemical Reactions

Student Textbook pages 338–367

Chapter Concepts

Section 9.1 Enthalpy and Thermochemical Equations

- Energy stored in the chemical bonds of hydrocarbons originated from the Sun.
- Enthalpy change (ΔH) refers to the potential energy change of a system during a process.
- Enthalpy changes can be communicated in chemical equations using ΔH notation and potential energy diagrams.
- Chemical reactions can be classified as endothermic or exothermic.

Section 9.2 The Technology of Energy Measurements

- Calorimetry is used to determine enthalpy changes in chemical reactions.
- A calorimeter works on the principle that the heat lost (or gained) by the system is equal to the heat gained (or lost) by the surroundings.

Common Misconceptions

- Students may believe that because a bond is often described as a form of stored energy, bonds should release energy when they are broken. Ensure students are clear that forming a bond releases energy, while breaking a bond requires energy.
- Students will usually describe a metal object they touch as being colder than their wooden desk, though both are at the same temperature. In this case they are confusing the direction of heat conduction with temperature. Because metal is a better thermal conductor than wood, and room temperature is almost always less than the temperature of their skin, heat flows faster from their hand when touching a metal surface compared with touching a wooden object.

Helpful Resources

Books and Journal Articles

- Pétursson, Sigthór. "Three Forms of Energy," *Journal of Chemical Education,* Vol. 80, No. 7, July 2003 p. 776.
- Bartell, Lawrence S. "Stories to Make Thermodynamics and Related Subjects More Palatable," *Journal of Chemical Education,* Vol. 78, No. 3, August 2001 p. 1059.
- Howard, Irmgard, K. "H Is for Enthalpy, Thanks to Heike Kamerlingh Onnes and Alfred W. Porter," *Journal of Chemical Education,* Vol. 79, No. 6, June 2002 p. 697.
- Marsella, Gail. "Hot and Cold Packs," *ChemMatters,* Vol. 5, No. 1, December 1987 p. 6.

Web Sites

Web links related to energy and chemical reactions can be found at **www.albertachemistry.ca**. Go to the Online Learning Centre, and log on to the Instructor Edition. Choose Teacher Web Links.

List of BLMs

Blackline masters (BLMs) have been prepared to support the material in this chapter. The BLMs are either for assessment (AST); use as overheads (OH); use as handouts (HAND), in particular to support activities. Most handouts and all assessment tools are supported by a BLM with the answers (ANS). The BLMs are in digital form, stored on the CD-ROM that accompanies this Teacher's Resource or on the web site at **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, BLMs. They can be modified to suit the needs of your students.

Number (Type) Title

9.0.1 (OH) Describing Chemical Reactions
9.0.2 (HAND) Launch Lab: Hot Packs and Cold Packs
9.0.2A (ANS) Launch Lab: Hot Packs and Cold Packs Answer Key

9.1.1 (AST) Energy and Change PreQuiz
9.1.1A (AST) Energy and Change PreQuiz Answer Key
9.1.2 (OH) Energy Changes in Chemical Reactions
9.1.3 (AST) Endothermic and Exothermic Reactions Quiz
9.1.3A (ANS) Endothermic and Exothermic Reactions Quiz Answer Key
9.1.4 (HAND) Potential Energy Diagrams
9.1.4A (ANS) Potential Energy Diagrams Answer Key
9.1.5 (AST) Specific Heat Capacity Problems
9.1.5A (ANS) Specific Heat Capacity Problems Answer Key
9.1.6 (AST) Thermochemical Equations and Stoichiometry Quiz
9.1.6A (ANS) Thermochemical Equations and Stoichiometry Quiz Answer Key

9.2.1 (HAND) Investigation 9.A: Determining the Enthalpy of a Neutralization Reaction
9.2.1A (ANS) Investigation 9.A: Determining the Enthalpy of a Neutralization Reaction Answer Key
9.2.2 (HAND) Investigation 9.B: Molar Enthalpy of Combustion
9.2.2A (ANS) Investigation 9.B: Molar Enthalpy of Combustion Answer Key

9.3.1 (AST) Chapter 9 Test
9.3.1A (ANS) Chapter 9 Test Answer Key

Using the Chapter 9 Opener

Student Textbook pages 338–339

Teaching Strategies

- If this is the first unit being taught in Chemistry 30, some or all students may benefit from a quick review of writing and balancing equations for chemical reactions and performing stoichiometric calculations.

- Read the Chapter Opener with your students, reviewing the concepts of combustion and what happens during a chemical reaction.

Launch Lab Hot Packs and Cold Packs

Student Textbook page 339

Purpose

The purpose of this launch lab is to review concepts that students have learned in previous science courses and introduce students to the underlying theme of this unit, energy change. Students will make simple hot or cold packs using a selection of soluble salts, water, and a suitable container. They will review their knowledge of endothermic and exothermic reactions as they investigate how to choose the best solute for hot and cold packs. Students will also relate that the quantity of energy produced is associated with the quantity of chemical compound used in a reaction.

Outcomes

- 30-A1.1 k

Advance Preparation

When to Begin	What to Do
2–3 weeks before	■ Ensure the availability of at least four soluble salts from the list below. ■ Purchase or order a selection of suitable containers for the hot and cold packs.
1 day before	■ Photocopy **BLM 9.0.2: Launch Lab.**

Materials
■ balance ■ a variety of soluble ionic compounds from the following list. Choose at least one endothermic and one exothermic reaction. ammonium nitrate, $NH_4NO_3(s)$ (endothermic) calcium chloride, $CaCl_2(s)$ (exothermic) sodium chloride, $NaCl(s)$ (endothermic) sodium acetate, $NaCH_3COO(s)$ (exothermic) ammonium chloride, $NH_4Cl(s)$ (endothermic) ■ water ■ common household containers, such as plastic food containers, and resealable bags. Include some small and large containers.

Time Required

- 30–45 minutes (depending on the amount of time students are given to modify their designs)

Helpful Tips

- Use **BLM 9.0.2 (HAND) Launch Lab: Hot Packs and Cold Packs** to support this activity. Modify as necessary.
- Remind students that they are attempting to design a practical hot/cold pack. Have students come up with a list of desirable features for hot/cold packs.
- Encourage students to come up with a fair experiment by controlling all but one variable (the type of salt used).
- Give students some latitude to fail on their first trial and therefore come up with good ideas for improvements.
- ***Expected Results:*** The results will depend on the enthalpy of solution of the various salts. The molar enthalpies of solution of the suggested salts are listed below:

Salt	$\Delta_{soln}H°$
ammonium nitrate	25.69 kJ/mol
calcium chloride	–81.5 kJ/mol
sodium chloride	3.88 kJ/mol
sodium acetate	–17.32 kJ/mol
ammonium chloride	14.78 kJ/mol

If the students are making comparisons among the salts relative to mass, these values would have to be converted to units of kJ/g.

Safety Precautions

- Ammonium nitrate, ammonium chloride, sodium acetate, and calcium chloride may all cause minor skin irritation and can be harmful if swallowed. If they come in contact with skin, the skin should be rinsed thoroughly. If large quantities of the salts are used, the amount of heat liberated during dissolution may cause minor burns. A few grams of the salt in a small container should be enough to produce the desired results for the lab.
- Ensure that all students have read “Safety in Your Chemistry Laboratory” on pages xii-xv in the student textbook.

Answers to Analysis Questions

1. Students should address the amount of heat absorbed or released. A good hot pack will involve an exothermic reaction that releases neither too much nor too little heat. Similarly, a good cold pack will involve an endothermic

reaction that absorbs neither too much nor too little heat. If too little heat is absorbed/released, then the cold/hot pack is not effective; however, if too much is absorbed/released, then the cold/hot pack could cause skin damage. Students should also address some of the following points: cost, availability of the salt, any disposal concerns (see question 2).

2. Safety concerns that should be considered include possible toxicity concerns. As noted in the safety precautions, many salts are irritants and may be toxic if consumed. Students may discuss the environmental effects of disposal as well.
3. Students may include some of the following points:
   - packages of various sizes
   - ease of mixing the salt and water
   - providing soft packaging

Assessment Options

- Collect and assess students' data tables and answers to Analysis questions.

9.1 Enthalpy and Thermochemical Equations

Student Textbook pages 340–350

Section Outcomes

Students will:

- explain how energy that originates from the Sun is stored in the chemical bonds of hydrocarbons
- classify chemical reactions as endothermic or exothermic
- define enthalpy and enthalpy change
- interpret and use ΔH notation for communicating energy changes in chemical reactions
- write balanced equations for chemical reactions that include energy changes
- draw and interpret potential energy diagrams for chemical reactions
- identify the products and reactants of cellular respiration, photosynthesis, and hydrocarbon combustion
- use appropriate SI units to express enthalpy changes and molar enthalpies

Key Terms

thermodynamics
thermochemistry
system
surroundings
first law of thermodynamics
kinetic energy (E_k)
potential energy (E_p)
endothermic reaction
exothermic reaction
enthalpy, H
enthalpy change, $\Delta_r H$
molar enthalpy
enthalpy of reaction, $\Delta_r H$
standard enthalpy of reaction, $\Delta_r H°$
thermochemical equation
ΔH notation
potential energy diagram
molar enthalpy of combustion, $\Delta_c H$
open system
isolated system

Chemistry Background

- Sunlight is the original source of energy for the formation of fossil fuels. The energy of sunlight is captured in plants through the process of photosynthesis.
- The first law of thermodynamics is easily stated mathematically as $\Delta E_{\text{system}} + \Delta E_{\text{surroundings}} = 0$. This reduces all energy changes to the change being studied (the system) and everything else (the surroundings).
- Heating or cooling a substance changes the average kinetic energy of its particles. The temperature of a substance is a measure of the average kinetic energy of its particles.
- When the temperature of a certain mass (m) of a pure substance (specific heat capacity, c) changes (Δt) with no change of state, the energy change (Q) can be calculated using the formula $Q = mc\Delta t$.
- All changes are final value minus initial value. For example, $\Delta t = t_f - t_i$. This ensures that the sign of a calculated value has meaning. For example, an energy change calculated as a negative quantity means that the substance "lost" energy to its surroundings.
- Enthalpy change, ΔH, is the potential energy change of a system during a process in which intermolecular forces or chemical bonds are broken (at a constant pressure).
- When a certain amount (n, mol) of a pure substance undergoes a change of state, the change in enthalpy can be calculated using $\Delta H = n\Delta_r H$, where $\Delta_r H$ is the appropriate molar enthalpy for the change of state.
- The energy changes associated with chemical reactions involve chemical bonds breaking and forming. Bond breaking always requires energy and bond formation always releases energy. If more energy is required to break the bonds than is released when new bonds are formed, the overall reaction is endothermic. If more energy is released when new bonds are formed than is required when the bonds are broken, the overall reaction is exothermic.

Teaching Strategies

- When introducing thermochemical equations, it is often easiest to explain to students that in an endothermic reaction, the energy term is a reactant because, like all reactants, it is "used up" in the reaction. Similarly, in an exothermic reaction, the energy is a product, because it is produced along with all other products.

- When using ΔH notation, the concept of a bank account will help students use the correct sign. An exothermic reaction “gives away” energy. Giving away money will reduce the quantity of money in your bank account.
- When drawing potential energy diagrams, students will often confuse the shape of a potential energy diagram with what is occurring in a temperature change graph. To help clarify the difference, construct a potential energy diagram for the vapourization of water above a diagram of kinetic energy to illustrate not only the differences, but also that when the potential energy of the system is increasing, the kinetic energy is not, and vice versa.
- Stoichiometric calculations are the most difficult topic in this section. Students must grasp that the enthalpy change term in a thermochemical equation is just another stoichiometric quantity. To help students understand this, teach this concept by extending stoichiometry. Start with a balanced thermochemical equation, such as the one provided for photosynthesis in Figure 9.1 on page 340 of the student textbook. Review gravimetric stoichiometry by calculating the amount of glucose produced when 18.0 g of water is consumed. They will have to use the molar ratio of 1 mol $C_6H_{12}O_6(s)$/6 mol $H_2O(\ell)$ to determine the mass of glucose produced. From there, ask students to calculate the mass of glucose produced when 350 kJ of energy is consumed. Using the same method, students will use the molar ratio 1 mol $C_6H_{12}O_6(s)$/2802.5 kJ. Just as they would find the molar ratio from the balanced equation, they can find an energy ratio from the balanced equation. When the energy value is given in ΔH notation, students will need to be reminded that this value is as if it were written in the equation.
- A quick demonstration can be used to review some of the fundamental terms and concepts in thermodynamics. You will need a small beaker, some ice, water, a hot plate and a thermometer.
  - Heat the ice water slowly while reviewing potential and kinetic energy changes with students. Have students take the temperature of the water while it is being stirred constantly, demonstrating that although heat is being added at a constant rate, the temperature of the water is not increasing proportionately. Students should recognize that although we can measure kinetic energy changes using changes in temperature, we cannot measure the potential energy change in water directly, only through the energy supplied by the hot plate.
- Use a beaker of boiling water to illustrate the difference between system and surroundings. Students should identify the boiling water as the system, and the beaker, stirring rod, hot plate and the classroom as everything else, that is, the surroundings.
- You can reinforce the concept that bond formation releases energy by demonstrating the effect of adding a crystal to a supersaturated solution of sodium acetate. Explain to students that adding a crystal to a supersaturated solution causes solute to precipitate, and in this case the clear colourless solution will become a white solid when a crystal is added. Ask students to predict whether the temperature of the flask will change when precipitation takes place. Many students will predict that the flask will get cooler, likely because they believe solids are cooler than liquids. As the new intermolecular bonds form during precipitation, students will notice that the flask becomes noticeably warmer.
  - To prepare the solution, place about 100 g of sodium acetate trihydrate into an absolutely clean 250 mL Erlenmeyer flask (a new flask works best). Add about 12 mL of distilled water and gently heat the mixture to dissolve the crystals. Add water, drop by drop, to the mixture to completely dissolve the crystals. DO NOT ADD MORE WATER THAN ABSOLUTELY NECESSARY. When all the crystals are dissolved, secure the flask with a clean (new if possible) stopper and allow it to cool. The solution is stable, but solid will precipitate once a small crystal of $NaCH_3COO{\bullet}3H_2O(s)$ is added to the flask. The solution can be easily reformed by gently heating the flask. It may be necessary to add a drop of water to dissolve all of the crystals.
- Revisit the Launch Lab to reinforce the concepts of exothermic and endothermic.
- A number of overhead masters and quizzes have been prepared for this section. You will find them with the Chapter 9 BLMs on the CD-ROM that accompanies this Teacher’s Resource or at **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, BLMs.

Number (Type) Title
9.1.1 (AST) Energy and Change PreQuiz
9.1.1A (AST) Energy and Change PreQuiz Answer Key
9.1.2 (OH) Energy Changes in Chemical Reactions
9.1.3 (AST) Endothermic and Exothermic Reactions Quiz
9.1.3A (ANS) Endothermic and Exothermic Reactions Quiz Answer Key
9.1.4 (HAND) Potential Energy Diagrams
9.1.4A (ANS) Potential Energy Diagrams Answer Key
9.1.5 (HAND) Specific Heat Capacity Problems
9.1.5A (ANS) Specific Heat Capacity Problems Answer Key
9.1.6 (AST) Thermochemical Equations and Stoichiometry Quiz
9.1.6A (ANS) Thermochemical Equations and Stoichiometry Quiz Answer Key

SUPPORTING DIVERSE STUDENT NEEDS

There is a considerable amount of vocabulary in this section. Encourage students to begin a vocabulary list that they can refer to as they answer questions in this chapter. A tutorial on math skills and dimensional analysis methods may prove extremely helpful to students with difficulties in math. Many of the problems in this section are easier if students pay attention to the units involved. The majority of the material in Section 9.1 is a review of Science 10.

Answers to Questions for Comprehension

Student Textbook page 342

Q1. If the door is left open, the kinetic energy of the hot air outside will be transferred more easily to the cool air inside than if the door is closed. Moving air transfers thermal energy more easily than the particles of the door.

Q2. When you touch an object that has a lower temperature than your skin, the thermal energy from your skin is transferred to the colder object. The temperature of the cooler object will increase, and the temperature of your skin will decrease. Eventually, the temperature of both objects will reach the same temperature.

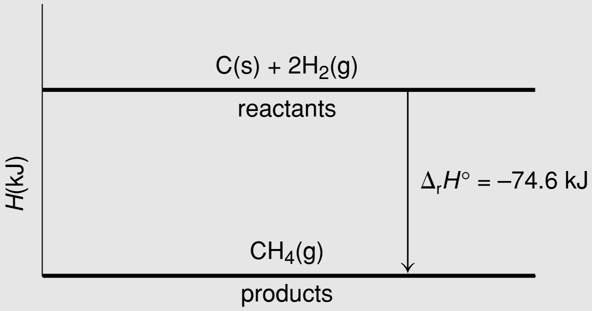
Answers to Questions for Comprehension

Student Textbook page 346

Q3. (a) $C(s) + 2H_2(g) \rightarrow CH_4(g) + 74.6\ kJ$

(b) $C(s) + 2H_2(g) \rightarrow CH_4(g)\ \Delta_rH° = –74.6\ kJ$

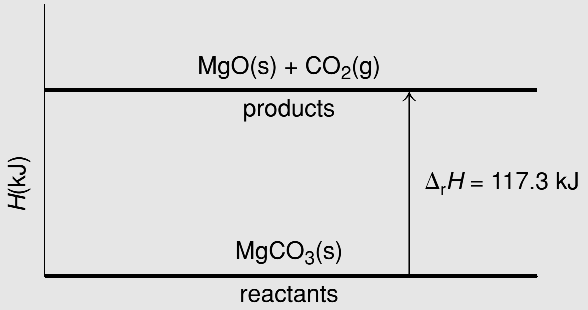
(c)



Q4. (a) $MgCO_3(s) + 117.3\ kJ \rightarrow MgO(s) + CO_2(g)$

(b) $MgCO_3(s) \rightarrow MgO(s) + CO_2(g)\ \Delta_rH = 117.3\ kJ$

(c)



Student Textbook page 347

Q5. (a) $C_5H_{12}(\ell) + 8O_2(g) \rightarrow 5CO_2(g) + 6H_2O(g)$

$\Delta_cH = –3244.8\ kJ/mol$

(b) $C_4H_{10}(g) + \frac{13}{2}O_2(g) \rightarrow 4CO_2(g) + 5H_2O(g)$

$\Delta_cH = –2657.3\ kJ/mol$

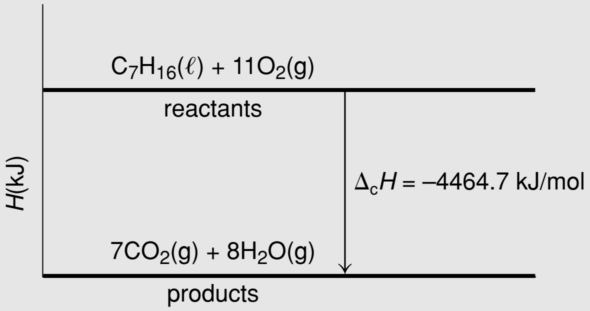
(c) $C_6H_{14}(\ell) + \frac{19}{2}O_2(g) \rightarrow 6CO_2(g) + 7H_2O(g)$

$\Delta_cH = –3854.9\ kJ/mol$

(d) $C_8H_{18}(\ell) + \frac{25}{2}O_2(g) \rightarrow 8CO_2(g) + 9H_2O(g)$

$\Delta_cH = –5074.1\ kJ/mol$

Q6.



Chemistry File: Web Link

Student Textbook page 347

Cellular respiration is a three-stage process that occurs in the cytoplasm and the mitochondria of eukaryotic cells. The first stage, called glycolysis, is actually a 10-step process, catalyzed by 10 different enzymes. The overall reaction that occurs during glycolysis is summarized below:

$C_6H_{12}O_6(aq) + 2NAD^+ + 2ADP + 2P \rightarrow 2C_3H_4O_3(aq)$ (pyruvic acid) $+ 2NADH + 2H + 2ATP + 2H_2O(\ell)$

Once glycolysis has taken place, pyruvic acid combines with Coenzyme A, a complex biological molecule, found in the mitochondria. The reaction, produces Acetyl Coenzyme A:

$C_3H_4O_3(aq) + \text{Coenzyme A} + NAD^+ \rightarrow$
$\text{Acetyl Coenzyme A} + NADH + H^+ + CO(aq)$

Acetyl Coenzyme A, enters the Krebs cycle, an eight step process that produces the final products of cellular respiration.

$\text{Acetyl CoA} + 3NAD + FAD + ADP + P \rightarrow$
$CoA + 3NADH + 3H^+ + FADH_2 + ATP + 2CO_2(aq)$

Since there are two pyruvic acid molecules created during glycolysis, the net products are double what is listed in the two reactions above. At this point, the six molecules of carbon dioxide produced have been released and the glucose is completely oxidized.

Although the Krebs cycle completes the breakdown of glucose, there is an additional process involved in cellular respiration called oxidative phosphorylation, or the electron transport chain. This process converts the energy stored in the bonds of NADH and $FADH_2$ into ATP.

$NADH + 3H^+ + 3ADP + 3P \rightarrow 3NAD^+ + 3ATP$
$FADH^2 + 2ADP + 2P \rightarrow FAD + 2ATP + 2H^+$

The energy stored in NADH and $FADH_2$ is transferred to enzyme complexes that move electrons and protons along and across the mitochondrial membrane. The protons and electrons are eventually accepted by the oxygen required in cellular respiration to form water, the final product.

$2H^+(aq) + O_2(aq) \rightarrow H_2O(\ell)$

The first step in photosynthesis involves the capture of light energy and the splitting of water, called photolysis.

$$H_2O(\ell) + \text{light energy} + ADP + P + NADP+ \rightarrow 2H^+(aq) + \frac{1}{2}O_2(g) + ATP + NADPH$$

In the second stage of photosynthesis, carbon dioxide is converted to an organic form using the energy trapped in the first step. The cycle depends on a variety of enzymes as well as the sugar, ribulose diphosphate (RuDP), which is regenerated at the end of the cycle. It takes six turns of the cycle to produce one glucose molecule.

$$RuDP + 3CO_2(g) + 3ATP + 2NADPH + 2H^+ + 2H2O(\ell) \rightarrow RuDP + C_6H_{12}O_6(s) + 3P + 3ADP + 2NADP^+$$

In both cellular respiration and photosynthesis, numerous enzymes and energy carriers are used to harvest the energy contained in glucose and provided by the Sun. If glucose was "burned" as we do with wood, the uncontrolled release of energy would not only not be containable by the human body, it would be dangerous. The use of enzymes, reaction intermediates and energy carriers allows the cells of plants and animals to safely harness and store energy in organic molecules and from the Sun.

Answers to Practice Problems 1–6

Student Textbook page 349

For full solutions to the practice problems, visit **www.albertachemistry.ca,** Online Learning Centre, Instructor Edition, Full Solutions.

1. –7.17 kJ

2. (a) –405.60 kJ/mol $O_2(g)$

(b) –648.96 kJ/mol $CO_2(g)$

(c) –540.8 kJ/mol $H_2O(\ell)$

3. (a) -2.553×10^3 kJ

(b) -6.04×10^4 kJ

(c) -1.044×10^6 kJ

4. –50.0 kJ

5. 1.03 kg

6. (a) –227 kJ/mol $NH_3(g)$

(b) –181 kJ/mol $O_2(g)$

(c) –227 kJ/mol NO(g)

(d) –151 kJ/mol $H_2O(g)$

Section 9.1 Review Answers

Student Textbook page 350

1. The first law of thermodynamics states that any change in energy of a system is accompanied by an equal and opposite change in energy of the surroundings.

$\Delta E_{\text{system}} = -\Delta E_{\text{surroundings}}$

2. If a reaction is endothermic, more energy is consumed in breaking bonds than is released when bonds are formed.

3. (a) $Ag(s) + \frac{1}{2}Cl_2(g) \rightarrow AgCl(s)\ \Delta_f H^\circ = -127.0$ kJ/mol

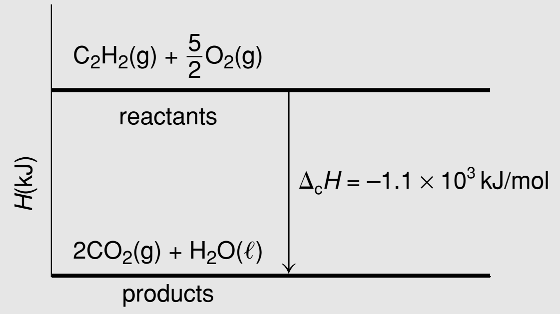
(b) $C_2H_4(g) + 3O_2(g) \rightarrow 2CO_2(g) + 2H_2O(g)$
$\Delta_c H = -1322.9$ kJ/mol

(c) $NaCl(s) \rightarrow Na^+(aq) + Cl^-(aq)\ \Delta H_{\text{sol}} = -44.2$ kJ/mol

4. (a) $C_2H_2(g) + \frac{5}{2}O_2(g) \rightarrow 2CO_2(g) + H_2O(\ell)$

$\Delta_c H = -1.25 \times 10^3$ kJ/mol

(b)



(c) Method 1 Using Formulas

$$n = \frac{m}{M}$$

$$= \frac{2.17 \text{ g } \cancel{C_2H_2(g)}}{\frac{26.04 \text{ g } \cancel{C_2H_2(g)}}{1 \text{ mol } \cancel{C_2H_2(g)}}}$$

$$= 0.0833 \text{ mol } C_2H_2(g)$$

$$\Delta H = n\Delta_c H$$

$$= (0.0833 \cancel{\text{mol } C_2H_2(g)}\left(\frac{-1.25 \times 10^3 \text{ kJ}}{\cancel{\text{mol } C_2H_2(g)}}\right)$$

$$= -104 \text{ kJ}$$

Method 2 Using Dimensional Analysis

$$\text{x kJ} = 2.17 \cancel{\text{g } C_2H_4(g)} \times \frac{1 \cancel{\text{mol } C_2H_2(g)}}{26.04 \cancel{\text{g } C_2H_2(g)}} \times \frac{-1.25 \times 10^3 \text{ kJ}}{\cancel{\text{mol } C_2H_2(g)}}$$

$$= -104 \text{ kJ}$$

5. In exothermic reactions, the potential energy of the products is less than the potential energy of the reactants. If the potential energy of the system decreases, the ΔH is negative and the energy of the surroundings increases. Therefore, the reaction is exothermic.

6. (a) $$11H_2O(\ell) + 12CO_2(g) \rightarrow C_{12}H_{22}O_{11}(s) + 12O_2(g) + 2226.1\text{ kJ}$$

(b) $$11H_2O(\ell) + 12CO_2(g) \rightarrow C_{12}H_{22}O_{11}(s) + 12O_2(g)\ \Delta_fH^\circ = -2226.1\text{ kJ/mol}$$

7. (a) $$H_2S(g) + \frac{3}{2}O_2(g) \rightarrow H_2O(g) + SO_2(g)$$

$\Delta_cH = -519$ kJ/mol

(b) Method 1 Using Formulas

$$\begin{aligned} n &= \frac{m}{M} \\ &= \frac{15.0\ \cancel{\text{g } H_2S(g)}}{\dfrac{34.09\ \cancel{\text{g } H_2S(g)}}{1\text{ mol } H_2S(g)}} \\ &= 0.440\text{ mol } H_2S(g) \end{aligned}$$

$$\begin{aligned} \Delta H &= n\Delta_cH \\ &= (0.440\ \cancel{\text{mol } H_2S(g)})\left(\frac{-519\text{ kJ}}{\cancel{\text{mol } H_2S(g)}}\right) \\ &= -228\text{ kJ} \end{aligned}$$

Method 2 Using Dimensional Analysis

$$\begin{aligned} x\text{ kJ} &= 15.0\ \cancel{\text{g } H_2S(g)} \times \frac{1\ \cancel{\text{mol } H_2S(g)}}{34.09\ \cancel{\text{g } H_2S(g)}} \times \frac{-519\text{ kJ}}{\cancel{\text{mol } H_2S(g)}} \\ &= -228\text{ kJ} \end{aligned}$$

(c) Method 1 Using Formulas

$$\begin{aligned} \Delta H &= n\Delta_cH \\ n &= \frac{\Delta H}{\Delta_cH} \\ &= \frac{-47.2\ \cancel{\text{kJ}}}{-519\ \cancel{\text{kJ}}/\text{mol } SO_2(g)} \\ &= 0.0909\text{ mol } SO_2(g) \end{aligned}$$

Since 1 mol of gas at STP has a volume of 22.4 L, or molar volume is 22.4 L/mol,

$$\begin{aligned} V &= nMV \\ &= 0.0909\ \cancel{\text{mol } SO_2(g)} \times \frac{22.4\text{ L } SO_2(g)}{\cancel{\text{mol } SO_2(g)}} \\ &= 2.04\text{ L } SO_2(g) \end{aligned}$$

Method 2 Using Dimensional Analysis

$$\begin{aligned} x\text{ L } SO_2(g) &= -47.2\text{ kJ} \times \frac{1\ \cancel{\text{mol } SO_2(g)}}{-519\text{ kJ}} \times \frac{22.4\text{ L } SO_2(g)}{\cancel{\text{mol } SO_2(g)}} \\ &= 2.04\text{ L } SO_2(g) \end{aligned}$$

9.2 The Technology of Energy Measurement

Student Textbook pages 351–364

Section Outcomes

Students will:

- determine enthalpy changes using calorimetry data
- design a method to compare molar enthalpies when burning two or more fuels
- compare energy changes associated with a variety of chemical reactions through the analysis of data and energy diagrams
- use appropriate SI units to express enthalpy changes and molar enthalpies.

Key Terms

calorimeter
calorimetry
simple calorimeter
thermal equilibrium
bomb calorimeter
heat capacity, *C*

Chemistry Background

- The enthalpy of a reaction is the heat transfer that occurs as a result of a chemical change at constant pressure. Students can measure changes in kinetic energy using a simple calorimeter.
- Calorimetry calculations are based on the following assumptions: the system is isolated, the quantity of thermal energy exchanged with the thermometer, lids, stirring rods and the calorimeter itself (in the case of a simple calorimeter) is negligible, any solution in the calorimeter retains the specific heat capacity of the solution, and the thermal energy released or absorbed is equivalent to the enthalpy change. These assumptions lead to the equation: thermal energy released by system = –thermal energy absorbed by surroundings.
  The error in these assumptions leads to error in calorimetry measurements.

Teaching Strategies

- The BLMs prepared for this section support the activities. You will find them with the Chapter 9 BLMs on the CD-ROM that accompanies this Teacher's Resource or at **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, BLMs.
- Most students will find this section the most straightforward of the topics in energetics.
- Use the thermochemical equation to reinforce the first law of thermodynamics. The total amount of energy in the

reactants (reactants and a heat term if appropriate) is equal to the total amount of energy in the products (products and a heat term if appropriate). If the reaction is exothermic, then some of the potential energy that was stored in the bonds of the reactants (the system) has been converted to kinetic energy that is released to the surroundings.

SUPPORTING DIVERSE STUDENT NEEDS

Students with weak math skills will need additional practice and coaching in order to become comfortable with stoichiometry.

Answers to Practice Problems 7–12

Student Textbook page 355

For full solutions to the practice problems, visit **www.albertachemistry.ca,** Online Learning Centre, Instructor Edition, Full Solutions.

7. –49.8 kJ/mol $HCl(aq)$

8. **(a)** -4.1×10^2 kJ/mol $Mg(s)$

(b) All the thermal energy released by the reaction is absorbed by the solution; the solution has the same heat capacity as water; the reaction proceeds to completion.

9. -2.9×10^2 kJ/mol $Na(s)$

10. 29.7 °C

11. $HBr(aq) + KOH(aq) \rightarrow KBr(aq) + H_2O(\ell)$

$$\Delta_r H = -57 \text{ kJ}$$

12. -41.9×10^2 kJ/mol $NaOH(aq)$ or
-41.9×10^2 kJ/mol $HCl(aq)$

Answers to Questions for Comprehension

Student Textbook page 355

Q7. Calorimetry is the use of a device called a calorimeter to study the energy changes associated with physical and chemical processes.

Q8. The law of conservation of energy states that the energy of the system plus its surroundings is constant. As energy is released (or absorbed) by a chemical reaction in a calorimeter, it results in a change in the temperature of the calorimeter surrounding it. The enthalpy change of the reaction can be calculated based on the thermal energy transfer in the calorimeter.

Q9. The second law of thermodynamics states that thermal energy is spontaneously transferred from an object at a higher temperature to an object at a lower temperature until the two objects reach the same temperature. Therefore, as energy is released (or absorbed) by a reaction in a calorimeter, heat will be transferred to (or from) the calorimeter and the enthalpy change can be measured.

Q10. A calorimeter will allow you to measure the enthalpy change of a reaction if the system is isolated, the amount of energy exchanged with the calorimeter is either measurable or negligible, any solutions involved in the reaction can be assumed to have the same properties as water, and finally, the reaction occurs at a constant pressure.

Investigation 9.A: Determining the Enthalpy of a Neutralization Reaction

Student Textbook pages 356–357

Purpose

In this investigation, students will be introduced to calorimetry using the reaction between sodium hydroxide and hydrochloric acid.

Outcomes

- 30-A1.2s

Advance Preparation

When to Begin	What to Do
2–3 days before	■ Prepare 1.0 mol/L solutions of NaOH(aq) and HCl(aq). Allow solutions to reach room temperature. ■ Locate MSDS and assemble materials for the lab.
1 day before	■ Punch holes for thermometer and stirring rod in coffee cup lids. ■ Ensure that lids fit the calorimeter snugly. ■ Photocopy **BLM 9.2.1: Investigation 9.A.**

Materials

The following materials are needed for each student group:

- 100 mL graduated cylinder (or two if possible)
- two large polystyrene coffee cups (same size) with lids
- thermometer
- stirring rod
- goggles
- waste disposal container
- 120 mL 1.0 mol/L NaOH(aq)
- 120 mL 1.0 mol/L HCl(aq)
- 400 mL beaker

Time Required

- 50 minutes

SUPPORTING DIVERSE STUDENT NEEDS

Challenge gifted students by having them use the Internet and their problem solving skills to determine theoretical values for temperature change and then calculate percentage error.

Helpful Tips

- Use **BLM 9.2.1 (HAND) Investigation 9.A: Determining the Enthalpy of a Neutralization Reaction** to support this activity. Modify as necessary. **BLM 9.2.1A** shows the answers to questions.
- Depending on the number and precision of balances available, you may want to have students measure the mass of their solutions rather than calculate the mass using volume and density. Or, have some students measure the mass of their solutions, and have other students measure the volume to calculate the mass. Then discuss as a class the accuracy and precision of each method.
- If you cannot find polystyrene lids, any close-fitting lid will reduce heat exchanges.
- The coffee cups must be large enough to accommodate 200 mL of solution. If only small coffee cups are available, half the quantities suggested in the investigation.
- A common mistake in this investigation occurs when students pour their solutions into containers that have not been rinsed with the solution they are pouring. Beakers and graduated cylinders do not have to be dry, but pouring a reagent into a container that was only rinsed with water will dilute the solution.
- Typical high school thermometers are graduated in one-degree intervals. Remind students to estimate a decimal place when they read the temperature, for example, 27.4 °C. A value of 25 °C is commonly recorded for a measurement that should properly be written as 25.0 °C.
- ***Expected Results:*** The temperature change of the solution should, ideally, be about 6.8 °C. However, due to loss of heat from the simple calorimeter, the temperature change will probably be less. Ideally, the enthalpy of neutralization should be –57.3 kJ/mol. Once again, it will probably be lower due to lose of heat from the calorimeter.

Safety Precautions

- Students use 1.00 mol/L HCl(aq) and 1.00 mol/L NaOH(aq) in this investigation, which are concentrated enough to irritate exposed skin and damage eyes. Ensure that students wear safety goggles, and remind students to flush any skin that is exposed to acid or base with copious amounts of cold water.
- Ensure that all students have read "Safety in Your Chemistry Laboratory" on pages xii-xv in the student textbook.

Answers to Analysis Questions

1. Students should calculate the heat absorbed by the solutions using the equation $Q = mc\Delta t$. Students can assume that the density of the solution is about the same as water, 1.00 g/mL. Therefore, the mass (m) of their reaction mixture is 100 g. Students can also assume that the specific heat capacity of the solutions are the same as the specific heat capacity of water, 4.19 J/g•°C. Because the final temperature should be higher than the initial temperature, Q_{solution}, should be a positive value, expressed in joules. The accepted value for the heat of neutralization between a strong acid and a strong base is –55.9 kJ/mol of $H_3O^+(aq)$. Using this value and assuming no heat losses, the expected value for the enthalpy change of the system can be calculated:

$$\begin{aligned}\Delta H &= n\Delta_r H\\ &= (0.05\ \cancel{\text{L HCl(aq)}})\left(\frac{1.00\ \cancel{\text{mol HCl(aq)}}}{\cancel{\text{L HCl(aq)}}}\right)\left(\frac{-55.9\ \text{kJ}}{\cancel{\text{mol HCl(aq)}}}\right)\\ &= -2.80\ \text{kJ}\end{aligned}$$

   The temperature change predicted by the reaction can be calculated from this value. The sign must be changed since the thermal energy released by the system = –(thermal energy absorbed by the surroundings). Since the total volume of the solution is 100 mL, the mass of the water in the calorimeter is 100 g.

$$\begin{aligned}Q &= mc\Delta t\\ \Delta t &= \frac{Q}{mc}\\ &= \frac{2.80 \times 10^3\ \cancel{\text{J}}}{(100\ \cancel{\text{g}})\left(\frac{4.19\ \cancel{\text{J}}}{\cancel{\text{g}} \bullet °\text{C}}\right)}\\ &= 6.68\ °\text{C}\end{aligned}$$

   This is a maximum value, because there will certainly be heat losses. A value for Δt significantly different from 6.68 °C (especially if the value is greater) indicates a mistake, either in experimental procedure or in calculating the temperature difference.

2. The value for energy released by the reaction should be –2.80 kJ. Student values are likely to be 10% lower or more, depending on the calorimeter used. The answer should have three significant digits, based on the initial values used.
3. Amount HCl(aq) = amount of NaOH(aq) = (1.00 mol/L)(0.0500 L) = 0.0500 mol
4. Students should include the following equation: $HCl(aq) + NaOH(aq) \rightarrow H_2O(\ell) + NaCl(aq)$. Students may also include ionic and net ionic equations to emphasize that a neutralization reaction has taken place. Because the temperature of the solution in the calorimeter

increases, students should state that the reaction was exothermic (released energy).

Answer to Conclusion Question

5. Students will calculate the enthalpy of neutralization using the formulas

$Q = mc\Delta t$ and $\Delta H = n\Delta_r H$.

Where n is the number of moles calculated in Analysis question 3, 0.0500 mol; *m* is the mass of water in the calorimeter, which should be approximately 100 g; *c* is the specific heat capacity of water, 4.19 J/g•°C; and Δt is the temperature change of the water, which should be approximately 7 °C. Student answers should be approximately –56 kJ/mol. In general, heat will be lost from the system, resulting in a smaller temperature change and a smaller enthalpy change. Errors of 10 to 15% should be expected.

Answers to Application Questions

6. Neutralizing an acid spill on skin with a base is dangerous, because the base itself can burn the skin. Also, the heat produced by the neutralization reaction can be dangerous. Diluting the acid minimizes the damage caused by the corrosiveness of the acid and does not cause any further damage.

7. **(a)** The enthalpy change would be different because the dissolving of sodium hydroxide has an associated enthalpy change of its own.

(b) Students should indicate that the enthalpy change would have been higher because the dissolving of sodium hydroxide is an exothermic process.

(c) Students should outline a procedure that is similar to the procedure in Investigation 9.A. The difference is that in step 4, the student would accurately obtain 2.0 g sodium hydroxide pellets (which is equivalent to 0.0500 mol of NaOH(s), the same quantity used in this investigation). In step 5, the student would add 100.0 mL of 0.50 mol/L HCl to the calorimeter. The student would record the temperature of the acid, and then quickly add the pellets to the acid. Steps 6 and 7 follow unchanged.

(d) $HCl(aq) + NaOH(\mathbf{s}) \rightarrow H_2O(\ell) + NaCl(aq)$
ΔH will be greater

Assessment Options

- Collect and assess students' data tables, and answers to Analysis and Extension questions.
- Assessment Checklist 1 Designing an Experiment from Appendix A can be used to ensure students understand the requirements for self-designed lab before the investigation
- Use Assessment Checklist 6 Using Math in Science from Appendix A.

Investigation 9.B: Molar Enthalpy of Combustion

Student Textbook pages 358–359

Purpose

In this investigation, students will first be introduced to the equipment involved in measuring the heat of combustion through the experimental determination of the molar enthalpy of paraffin. In the second part of the investigation, students will design an experiment to compare the molar enthalpies of a number of different fuels.

Outcomes

- 30-A1.1s
- 30-A1.2s
- 30-A1.3s

Advance Preparation

When to Begin	What to Do
1–2 months before	■ Ask students to bring large juice cans and small vegetable cans to class.

Advance Preparation

When to Begin	What to Do
1 week before	■ Drill a small hole through both sides of the small can near the open end. ■ Cut the top off the large can if necessary. Use a triangle-opener to cut four or five triangle-shaped air-holes in the large can near the bottom. Cut the bottom off the large can. ■ Cut some clothes hanger wire into suitable lengths (to hold the small can). This step may be omitted if you are using stirring rods to suspend the cans.
2–3 days before	■ Assemble all necessary equipment. ■ Photocopy **BLM 9.2.2: Investigation 9.B.**

Materials

Per Student Group:

Part 1

- balance
- calorimeter apparatus (large can, small can)
- retort stand
- ring clamp
- piece of wire or stirring rod
- thermometer
- stirring rod
- can lid or cardboard base
- matches
- water
- candle

Part 2

- All of the materials from Part 1 (except the candle)
- two additional fuels – could include a portable propane burner, alcohol burner, camp stove, or other available heating device whose mass can be measured.

Time Required

- 45 minutes for Part 1
- 60 minutes for Part 2

Helpful Tips

- Use **BLM 9.2.2 (HAND) Investigation 9.B: Molar Enthalpy of Combustion** to support this activity. Modify as necessary.
- In this experiment, students record data to calculate the molar enthalpy of combustion for paraffin wax. Though the apparatus is simple, and the heat losses are large, the experiment illustrates the principles involved in determining a heat of reaction. The burning of a candle is an example of incomplete combustion. The carbon produced will coat the cooler surface of the small can with a layer of soot. Carbon in the flame becomes incandescent, which causes the flame to have a yellow colour.
- After several uses, the bottom of the small cans will be coated with soot. Wash your hands after handling the cans.
- In this experiment, it is advantageous to have the initial temperature about as far below room temperature as the final temperature will be above room temperature. This is because the heat gained by the cool water at the beginning of the experiment will approximately match the heat lost by the hot water at the end of the experiment.
- Candle wax is primarily paraffin wax, $C_{25}H_{52}(s)$.
- Food and soda cans are most often composed of either aluminium or steel, and may contain some tin. The specific heat capacity of aluminium is 0.900 J/g•°C, the specific heat capacity of steel varies with its composition, but is approximately 0.5 J/g•°C. The most accurate way to determine the specific heat capacity of the small can would be in a calorimetry experiment by measuring the final temperature of hot water when placed in a cold calorimeter.
- Students often forget to include the base when measuring the mass of the candle.
- Small camp stoves, or camp fuel poured into an alcohol-style burner provide an ideal third fuel for students to analyze. If camp stoves are not available, students could test a food instead of a third fuel.
- When attempting to measure enthalpy of combustion of food, ensure that the food is as dry as possible, by drying it in a warm (not hot) oven. Foods such as hamburgers or French fries should be first blended with water, placed in a baking pan and then slowly dried. If the food is dried into cubes, they can be mounted on a pin attached to a cork or cardboard to be combusted.
- If the flow rate of a Bunsen burner is known, or can be determined, then a Bunsen burner (burning natural gas (methane)) can also be used as a third fuel.
- For Part 2, student procedures should model the procedure provided in Part 1 of the lab. In order to appropriately compare fuels, the variables must be controlled not only within each of the trials, but across the trials. The temperature changes, mass of water used, distance from the flame, etc., should all be controlled.
- ***Expected Results:*** The enthalpy of combustion for paraffin is approximately 42 kJ/g. The loss of heat from the calorimeter is expected to be large so the students' calculations will probably be much lower than this.

SUPPORTING DIVERSE STUDENT NEEDS

To enrich the experience of gifted learners, have them calibrate the small can calorimeters before their use. Have students design their own investigation to calibrate their calorimeter.

Safety Precautions

- Students must tie back long hair and secure loose clothing. Ensure that there are no flammable solvents in the laboratory area during this investigation. Flammable solvents should be properly stored in a locked, fireproof cabinet. Ensure students set up their candles so that they are stable. Holes in cans should be punched or drilled out in the school workshop using the appropriate safety equipment. Store constructed apparatus for future use.
- Ensure that all students have read "Safety in Your Chemistry Laboratory" on pages xii-xv in the student textbook.

Answers to Analysis Questions Part 1

Typical student data:

Initial mass of candle and lid = 35.40 g

Final mass of candle and lid = 34.81 g

Initial temperature of water = 13.8 °C

Final temperature of water = 39.9 °C

Initial mass of can = 49.56 g

Final mass of can and water = 189.56 g

1. (a) The mass of water is 189.56 g – 49.56 g = 140.00 g

(b) The mass of the candle burned is 35.40 g – 34.81 g = 0.59 g

2. Assuming that the can is made of aluminium,

heat lost by system = –heat gained by surroundings

$n\Delta H = -(Q_{\text{water}} + Q_{\text{can}})$

$$\Delta H = \frac{-(mc\Delta t + mc\Delta t)}{n}$$

$$= \frac{-\left[(140.00\,\cancel{g})\left(\frac{4.19\text{ J}}{\cancel{g}\bullet\,°\text{C}}\right)(39.9\,\cancel{°\text{C}} - 13.8\,\cancel{°\text{C}}) + (49.56\,\cancel{g})\left(\frac{0.897\text{ J}}{\cancel{g}\bullet\,\cancel{°\text{C}}}\right)(39.9\,\cancel{°\text{C}} - 13.8\,\cancel{°\text{C}})\right]}{(0.59\,\cancel{\text{g C}_{25}\text{H}_{52}\text{(s)}})\left(\frac{1\text{ mol C}_{25}\text{H}_{52}\text{(s)}}{352.77\,\cancel{\text{g C}_{25}\text{H}_{52}\text{(s)}}}\right)}$$

$= -9.9 \times 10^6$ J/mol $C_{25}H_{52}(s)$

$= -9.9 \times 10^3$ kJ/mol $C_{25}H_{52}(s)$

Answers to Conclusion Questions Part 1

3. (a) The two largest sources of experimental error are heat losses and incomplete combustion of the paraffin wax. Measurement errors in reading the thermometer and massing the candle wax and water should also be mentioned. Some students may mention the loss of some water during the experiment due to evaporation, but this is trivial compared with the major sources of error mentioned.

(b) Try to guide students to focus on the large sources of error in the experiment, and how these can be reduced. A common suggestion, to use a thermometer with more precision, is no real improvement if the sources of heat loss are not addressed. The calorimeter used is open, and good suggestions would include ways to close and insulate the calorimeter. The calorimeter has a specific heat capacity that is not precise, as the chemical composition of the can may be in question. The experiment is probably limited to two significant digits because of the amount of candle wax burned. Suggestions to increase the measurement to allow for three significant digits (a more precise balance, or burning more candle wax) may be made. Encourage suggestions to make the burning of the paraffin wax a complete combustion.

4. The appearance of soot confirms that the combustion is incomplete, and therefore the molar enthalpy of combustion is lower than the expected value since not all of the carbon is burned. For every mole of carbon burned, 393 kJ of energy are released (the molar enthalpy of formation of carbon dioxide).

Answer to Analysis Question Part 2

1. Student calculations will vary depending on the fuel that is used, however the skeleton calculation will resemble that of the calculations performed in Part 1.

Answers to Conclusion Questions Part 2

2. (a) Combustion of paraffin: $C_{25}H_{52}(s) + 38O_2(g) \rightarrow 25CO_2(g) + 26H_2O(g)\ \Delta_cH = -9.9 \times 10^3$ kJ/mol

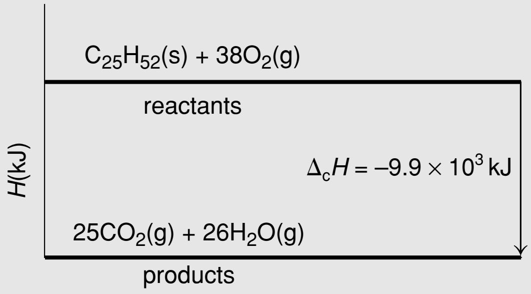
Some other common fuels:

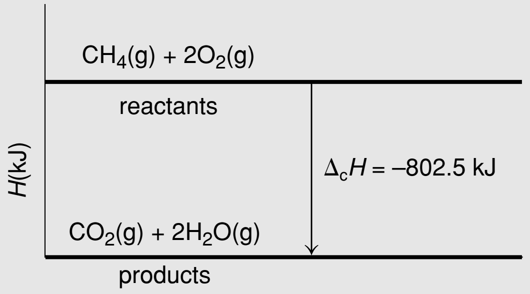
Methane (natural gas): $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)\ \Delta_cH = -802.5$ kJ/mol

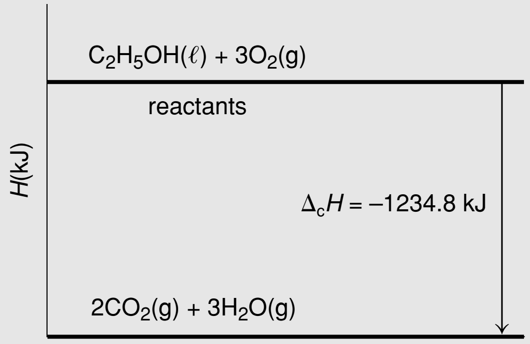
Ethanol (alcohol burners): $C_2H_5OH(\ell) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(g)\ \Delta_cH = -1234.8$ kJ/mol

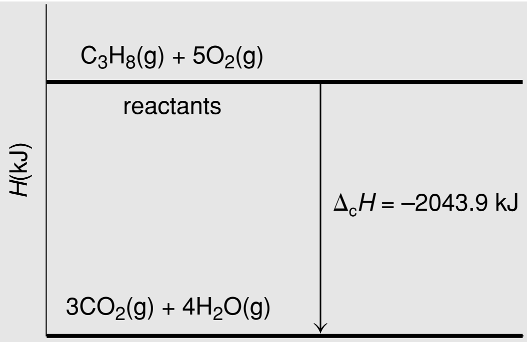
Propane (barbeque): $C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g)\ \Delta_cH = -2043.9$ kJ/mol

(b)









3. For the above fuels:

	Molar enthalpies	Environmental impact	Appropriate use
paraffin	Highest of the four fuels (most carbons)	Since it does not burn completely, there is a residue of carbon, and some carbon monoxide released. This is not a fuel used for heat as much as light	Since it burns incompletely and cooler, it produced light, which is paraffin's principal use.
methane	lowest (fewest carbons)	Considered to be a "clean" fuel. It burns completely, therefore producing little carbon monoxide. It is obtained principally from fossil fuels, so it is limited and requires drilling. When harnessed from waste, methane is considered a renewable resource	Methane, the chief component in natural gas, heats most homes in Alberta and is used for cooking and heating water in many.
ethanol	2 carbons, so higher than methane	Can be obtained from crops, and can therefore be considered renewable. It burns cleanly.	At present, ethanol is primarily used as an additive for gas, increasing the octane level of fuel.
propane	3 carbons, so higher than methane and ethanol	Propane is produced from fossil fuels. It burns more cleanly than heavier fuels (ones with more carbons).	Propane is used mostly as a barbeque fuel. It is portable and burns hotter than methane, making it a more attractive choice for barbeques, especially for portable barbeques.

Answer to Extension Question

4. To be suitable as a survival food, it must not only have a high energy content, but be portable, not need refrigeration, be easily packaged and have a balanced nutrient content. A good survival food should be able to be kept in a knapsack, or car, for long periods of time and keep a hiker alive in adverse conditions.

Assessment Options

- Collect and assess students' data tables and answers to Analysis questions for Part 1.
- Use Assessment Checklist 1 for self evaluation by each student. (This rubric could be given to each student before they design their experiment.)
- Use Assessment Checklist 2 to assess each students' laboratory report.

Connections (Science and Technology): Energy for Living: How Food Fuels You

Student Textbook pages 361–362

Teaching Strategies

- Have students keep track of everything they eat for a day instead of just their favourite foods. This may increase their interest as they will be able to see how many Calories they eat in a day and the overall composition of their diet. The online calculators simplify the process such that it is not significantly more work to keep track of an entire day's intake.
- Students can easily create a spreadsheet that allows them to quickly estimate the Calorie content of any food based on the carbohydrate, protein and fat content.
- Extend the STS connection by having students also keep track of their activity for the same day that they track their caloric intake. Have them predict what would happen to their weight over the course of a year if they ate that way every day.

Answers to Connections Questions

1. Some sample teenage favourites are shown below:

Food	Calorie count (kcal or Cal)
SNICKERS® chocolate bar	273
can of soda pop (cola)	151
hamburger with cheese (WHOPPER® sandwich)	549
pizza slice	235
cold cut sub sandwich	541

Values obtained from: http://www.foodcount.com

2. For the foods above:

Food	Carbohydrate (g)	Protein (g)	Fat (g)	Estimated calorie content (Cal)	Actual Calorie content (Cal)
SNICKERS®	33.7	4.6	14	279	273
soda pop	38.4	0	0	154	151
hamburger with cheese	41.0	34.0	33.7	589	549
pizza slice	27.7	8.9	9.8	235	235
cold cut sub	41.0	30.4	37.4	537	541

The calculated values were all close to the provided values. Some were higher, some were lower.

3. The Canada Food Guide recommends 60% carbohydrate, 30% fat (only 10% saturated), and 10% protein. The average Canadian's diet is higher in fat and protein than recommended. The food guide also has recommendations for the types of fats, proteins and carbohydrates that are consumed.

4. Fat is a "denser" energy form than carbohydrates or proteins, as it releases 9 Calories per gram when burned, while proteins and carbohydrates release only 4 Calories per gram.

Answers to Practice Problems 13–17

Student Textbook page 363

For full solutions to the practice problems, visit **www.albertachemistry.ca,** Online Learning Centre, Instructor Edition, Full Solutions.

13. 616 °C

14. -3.9×10^3 kJ/mol $C_8H_{18}(\ell)$

15. 2.17g $C_3H_8(g)$

16. –20.3 kJ/g

17. –25 kJ/g of fuel

Section 9.2 Review Answers

Student Textbook page 364

1. A calorimeter should isolate the system from the surroundings (not allow heat or matter transfer) and it should either have a known specific heat capacity, or absorb so little energy that it is negligible.

2. Method 1 Using Formulas

$$\begin{aligned} Q &= C\Delta t \\ &= \left(\frac{7.61\ \text{kJ}}{^\circ\text{C}}\right)(5.23\ ^\circ\text{C}) \\ &= 39.8\ \text{kJ} \end{aligned}$$

Method 2 Using Dimensional Analysis

$$\begin{aligned} x\ \text{kJ} &= \frac{7.61\ \text{kJ}}{^\circ\text{C}} \times 5.23\ ^\circ\text{C} \\ &= 39.8\ \text{kJ} \end{aligned}$$

The enthalpy change of the reaction is $\Delta H = -39.8$ kJ.

3.

$$\begin{aligned} Q &= mc\Delta t \\ &= (150\ \text{g})\left(\frac{4.19\ \text{J}}{\text{g}\bullet\ ^\circ\text{C}}\right)(-5.0\ ^\circ\text{C}) \\ &= -3.1\ \text{kJ} \end{aligned}$$

4. A polystyrene cup is suitable for a constant pressure calorimeter because it is an excellent insulator. Polystyrene tends not to react with most chemicals used in the high school laboratory. Polystyrene is hydrophobic, so the cup can usually be dried with vigorous shaking.

5. If you use a concentrated reactant solution in a coffee cup calorimeter, you cannot make the same assumptions as if you used a dilute reactant. A dilute aqueous solution is assumed to have the same density and specific heat capacity as pure water. These assumptions do not hold true for concentrated aqueous solutions, as the densities and specific heat capacities would be significantly different from the density and specific heat capacity of water.

6. **(a)** Equipment and chemicals should include safety equipment, materials to build a coffee cup calorimeter (a cup, lid, thermometer and stirrer), sulfuric acid, and water.

(b) Students' procedures should demonstrate an understanding of calorimetry and concern for safety. Ensure students are adding acid to water, not the other way around. The procedure should involve first finding the temperature of water that has equilibrated to room temperature. Then students should suggest adding a small, measured volume of concentrated sulfuric acid at room temperature to a measured volume of water at room temperature in a calorimeter, and then monitoring the temperature change. Students should point out that concentrated sulfuric acid is extremely corrosive and dangerous.

(c)

	Volume of solution (mL)	Initial temperature (°C)	Final temperature (°C)
sulfuric acid			
water			

(d) Students need to know the density of concentrated sulfuric acid and the concentration of concentrated sulfuric acid. Students may add that they need to know the specific heat capacity of the sulfuric acid solution. If not, then they must include the simplifying assumption that the specific heat capacity of the solution is the same as that of water.

(e) Students assume that energy is conserved and that no heat is absorbed by the calorimeter or the surroundings. They also assume that the specific heat capacity of the solution is the same as the specific heat capacity of water (unless it is in the list of needs above).

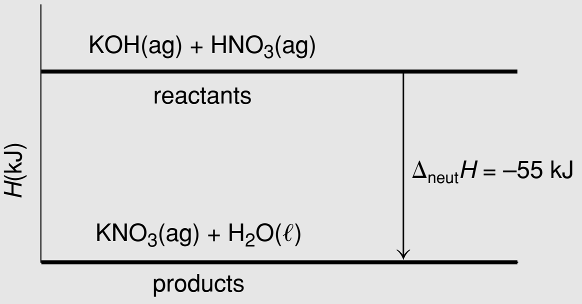
7. (a) The reactants are in stoichiometric quantities, so a calculation for limiting reagent is not required.

$$\begin{aligned} Q &= mc\Delta t \\ &= (200\ \cancel{g})\left(\frac{4.19\ \text{J}}{\cancel{g}\bullet\ \cancel{°\text{C}}}\right)(21.34\ \cancel{°\text{C}} - 21.01\ \cancel{°\text{C}}) \\ &= 276\ \text{J} \end{aligned}$$

The thermal energy of the reaction is therefore –276 J.

$$\begin{aligned} \Delta H &= n\Delta_r H \\ \Delta_r H &= \left(\frac{\Delta H}{n}\right) \\ &= \frac{(-276\ \text{J})}{\left(\frac{0.050\ \text{mol KOH(aq)}}{\cancel{\text{L}}}\right)(0.100\ \cancel{\text{L}})} \\ &= -55\ \text{kJ/mol KOH(aq) or HNO}_3\text{(aq)} \end{aligned}$$

(b) $KOH(aq) + HNO_3(aq) \rightarrow KNO_3(aq) + H_2O(\ell)$
$\Delta_{neut}H = -55$ kJ/mol



(c) The students should indicate that they would repeat the experiment a few times to reduce random error. If the experiment was started just below room temperature, then the final temperature would be slightly above. This should minimize error due to heat loss/gain to and from the surroundings as both conditions should cancel each other out.

8. Students should suggest that the human subject be kept in a room that is insulated from its surroundings. Students may suggest that the room should include exercise equipment, a bed, and adequate food and water. The room would need to be installed with a very sensitive thermometer to measure temperature changes to 1/100 °C. Students will probably suggest that the subject be placed in this room for a period of time and the energy given up by his/her body to the circulating air be monitored over time. Accept all thoughtful proposals that show an understanding of how calorimetry works in general.

Chapter 9 Review Answers

Student Textbook pages 366–367

Answers to Understanding Concepts Questions

1. Any change of energy in the system is accompanied by an equal and opposite energy change in the surroundings.
$\Delta E_{system} = -\Delta E_{surroundings}$

2. (a) Heat capacity, *C*, is the quantity of energy required to raise the temperature of a substance or object by 1 °C, whereas specific heat capacity, *c*, is the quantity of energy to raise 1 g of a pure substance by 1 °C. Heat capacity is generally used for a bomb calorimeter or a calorimeter that has been calibrated, whereas specific heat capacity is usually used for substances that are part of the system, often water.

(b) Enthalpy change, Δ*H*, is the potential energy change of a system during a process, molar enthalpy change is the enthalpy change of the system expressed per mole of one of the substances involved. Enthalpy change is most often for an equation balanced with the smallest whole numbers.

enthalpy change: $C_6H_{12}O_6(s) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O(\ell) \qquad \Delta H = -2870$ kJ

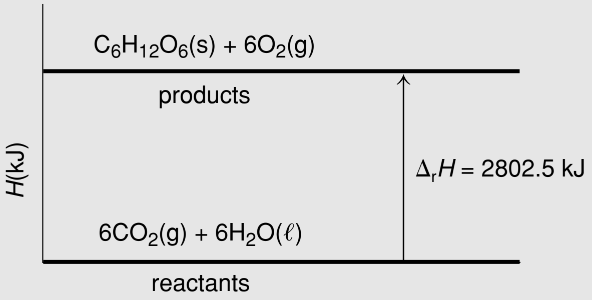
molar enthalpy change: $C_6H_{12}O_6(s) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O(\ell) \qquad \Delta H = -2870$ kJ/mol $C_6H_{12}O_6(s)$ or –478.8 kJ/mol $O_2(g)$

(c) Formation reactions describe the production of one mole of a substance from its elements in standard state, whereas a combustion reaction is the complete combustion of one mole of a substance in the presence of oxygen. For example, in methane's case,

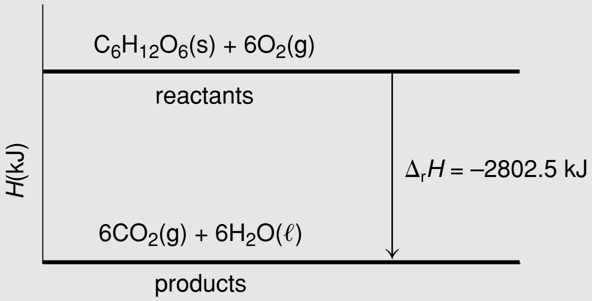
formation: $C(s) + 2H_2(g) \rightarrow CH_4(g)$

combustion: $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$ (the water could be liquid or vapour form, depending on the conditions)

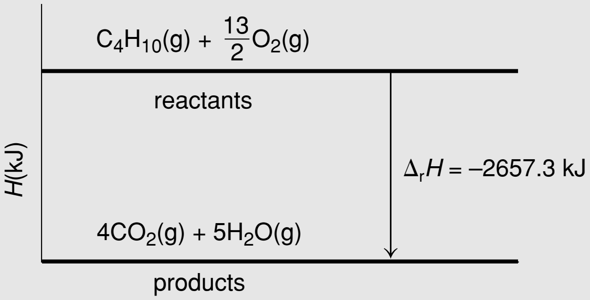
3. Kinetic energy is energy in motion. It is measured as a temperature change. Potential energy is stored in the intermolecular or intramolecular bonds of substances. It is measured as a change in temperature of the surroundings when bonds are broken or formed.
   - **(a)** heating water
   - **(b)** boiling water
   - **(c)** heating water from 25 °C to steam at 100 °C
4. The nickel will show a larger increase in temperature because the specific heat capacity is lower.
5. **(a)** $6CO_2(g) + 6H_2O(\ell) \rightarrow C_6H_{12}O_6(s) + 6O_2(g)$
   $\Delta H = 2802.5$ kJ



   (b) $C_6H_{12}O_6(s) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O(\ell)$
   $\Delta H = -2802.5$ kJ



   (c) $C_4H_{10}(g) + \frac{13}{2}O_2(g) \rightarrow 4CO_2(g) + 5H_2O(g)$
   $\Delta H = -2657.3$ kJ



6. **(a)** $C_7H_{16}(\ell) + 11O_2(g) \rightarrow 7CO_2(g) + 8H_2O(g)$
   $\Delta_c H = -4464.7$ kJ/mol $C_7H_{16}(\ell)$
   (in an open system – gaseous water produced)
   $C_7H_{16}(\ell) + 11O2(g) \rightarrow 7CO_2(g) + 8H_2O(\ell)$
   $\Delta_c H = -4816.7$ kJ/mol $C_7H_{16}(\ell)$
   (in a closed system – liquid water produced)

   (b) $2C_4H_{10}(g) + 13O_2(g) \rightarrow 8CO_2(g) + 10H_2O(g)$
   $\Delta_c H = -2657.3$ kJ/mol $C_4H_{10}(g)$
   (in an open system – gaseous water produced)
   $2C_4H_{10}(g) + 13O_2(g) \rightarrow 8CO_2(g) + 10H_2O(\ell)$
   $\Delta_c H = -2877.3$ kJ/mol $C_4H_{10}(g)$
   (in a closed system – liquid water produced)
7. Polystyrene cups are suitable for a constant pressure calorimeter because polystyrene is an excellent insulator. When nested, the air pocket in-between further insulates the calorimeter from the surroundings. Polystyrene tends not to react with most chemicals used in the high school laboratory. Polystyrene is hydrophobic, so the cup can usually be dried with vigorous shaking.
8. Experiments using a coffee cup calorimeter assume it is a perfectly insulated container, so there are no heat gains or losses. Secondly, it is assumed that the heat capacity of the calorimeter, which includes the thermometer and stirrer, can be neglected. Heat will be transferred to or from water or an aqueous solution in the calorimeter, and it is assumed that the heat capacity of the fluid is the same as that of pure water. If the volume of an aqueous solution is measured, the assumption is made that the density of the solution is identical with that of pure water so that the mass of solution can be calculated.
9. Juice cans do not make very good calorimeters because they do not effectively isolate the system from the surroundings. Polystyrene cups, however, cannot be used for investigations involving combustion, so juice cans are a simple, but not perfect, substitute.

10. (a) exothermic

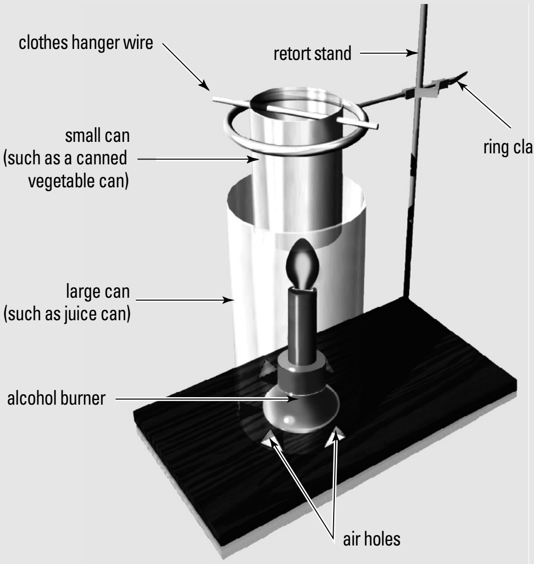
(b) endothermic

(c) exothermic

Answers to Applying Concepts Questions

11. Water is a more suitable solvent in a simple calorimeter because it will dissolve more solutes that are commonly used in high school chemistry labs and it has a high specific heat capacity.

12. (a)



(b), (c) Accept all reasonable procedures. Students will probably design an experiment similar to Investigation 9.B, using a measured mass of ethanol in the lamp to heat water in a calorimeter. They can determine the enthalpy change based on the temperature change of the water.

(d) Students should state that they would assume there are no heat losses to the surroundings, and the heat content of the calorimeter is negligible (if not, they must include the specific heat capacity of the calorimeter in the equation below). They will need to assume that the fuel is pure ethanol. They will also need to assume that complete combustion takes place, although this is probably not the case.

(e) mass of $C_2H_5OH(\ell)$ burned = mass of burner before – mass of burner after

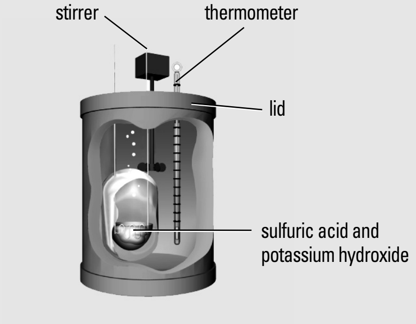
moles (n) of $C_2H_5OH(\ell)$ = mass of $\frac{C_2H_5OH(\ell)(g)}{M}$,

where M = molar mass of $C_2H_5OH(\ell)$ = 46.08 g/mol

$Q = mc\Delta t$ (may also have another $mc\Delta t$ term for the calorimeter), where m = mass of water in the calorimeter, c = 4.19 J/g•°C, Δt = change in temperature of the water (°C)

$\Delta H = n\Delta_r H$ where n = the moles of $C_2H_5OH(\ell)$, ΔH is the thermal energy change of the system which is –(thermal energy change of the surroundings).

13. (a)



(b), (c) Accept all reasonable procedures. Students will probably design an experiment similar to Investigation 9.A, using two solutions. Since sulfuric acid, $H_2SO_4(aq)$, provides two moles of hydrogen ions to the one mole of hydroxide ions of potassium hydroxide, $KOH(aq)$, the volume (or concentration) of the potassium hydroxide should be double that of sulfuric acid to be in stoichiometric quantities. Students can determine the enthalpy change based on the temperature change of the solutions.

(d) Students should state that they would assume there are no heat losses to the surroundings, and the heat content of the calorimeter is negligible. They will need to assume the density and specific heat capacity of the solutions is the same as that of water.

(e) If students do not use twice as much (or double the concentration) of the potassium hydroxide solution, they must do a limiting reagent calculation to determine the number of moles of acid or base that react. They should use the equations:

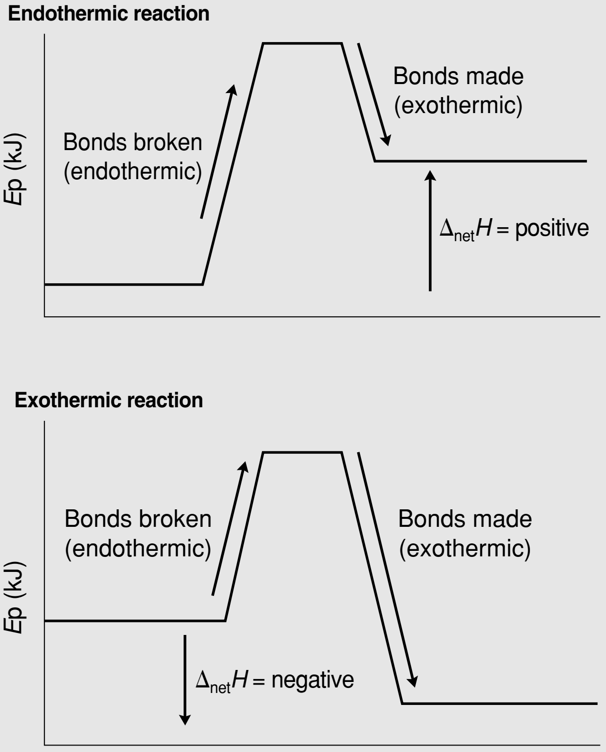
$Q = mc\Delta t$ and $\Delta H = n\Delta_r H$, where

n is the moles of hydrogen or hydroxide ions, m is the total mass of both solutions (the mass of water), c is the specific heat capacity of water, 4.19 J/g•°C, Δt = change in temperature of the two solutions (°C).

14. As the number of carbons in a hydrocarbon increases, the molar enthalpy of combustion increases. In a homologous series, that increase will be proportional to the number of carbons in the hydrocarbon.

15. All chemical reactions involve bonds being broken and other bonds being made. Breaking bonds is endothermic, making bonds is exothermic. The sum of the two energy changes determines whether the overall reaction will be endothermic or exothermic. If more energy is required to break the bonds than is released when making new bonds, then the overall reaction is endothermic. If more energy is released when making bonds than is required to break the bonds, then the overall reaction will be exothermic. These concepts are summarized in the diagram below:

Ep diagrams summarizing endo and exothermic reactions in steps



Answers to Solving Problems Questions

16. $Q = mc\Delta t$

$$= (1.00\ kg)\left(\frac{4.19\ J}{g\bullet °C}\right)(99.0\ °C - 22.0\ °C)\left(\frac{1000\ g}{1\ kg}\right) \times \left(\frac{1\ kJ}{1000\ J}\right)$$

$= 322\ kJ$

17. Method 1 Using Formulas

$$n = \frac{m}{M}$$

$$= \frac{10.0\ g\ CH_3COOH(\ell)}{\dfrac{60.06\ g\ CH_3COOH(\ell)}{mol\ CH_3COOH(\ell)}}$$

$= 0.1665\ mol\ CH_3COOH(\ell)$

$$\Delta H = n\Delta_c H$$

$$\Delta_c H = \frac{\Delta H}{n}$$

$$= \frac{-144.77\ kJ}{0.1665\ mol\ CH_3COOH(\ell)}$$

$= -869\ kJ/mol\ CH_3COOH(\ell)$

Method 2 Using Dimensional Analysis

$$x\ \frac{kJ}{mol\ CH_3COOH(\ell)} = -144.77\ kJ \times \frac{60.06\ \cancel{g\ CH_3COOH(\ell)}}{mol\ CH_3COOH(\ell)} \times \frac{1}{10.0\ \cancel{g\ CH_3COOH(\ell)}}$$

$= -869\ kJ/mol\ CH_3COOH(\ell)$

18. (a) $CH_3OH(\ell) + \frac{3}{2}O_2(g) \rightarrow CO_2(g) + 2H_2O(g)\ \Delta_c H = -727\ kJ/mol$

(b) Method 1 Using Formulas

$$n = \frac{m}{M}$$

$$= \frac{44.3\ \cancel{g\ CH_3OH(\ell)}}{\dfrac{32.05\ \cancel{g\ CH_3OH(\ell)}}{mol\ CH_3OH(\ell)}}$$

$= 1.38\ mol\ CH_3OH(\ell)$

$$\Delta H = n\Delta_c H$$

$$= (1.38\ \cancel{mol\ CH_3OH(\ell)})\left(\frac{-727\ kJ}{\cancel{mol\ CH_3OH(\ell)}}\right)$$

$= -1.00 \times 10^3\ kJ$

Method 2 Using Dimensional Analysis

$$x\ kJ = \frac{-727\ kJ}{\cancel{mol\ CH_3OH(\ell)}} \times 44.3\ \cancel{g\ CH_3OH(\ell)} \times \frac{1\ \cancel{mol\ CH_3OH(\ell)}}{32.05\ \cancel{g\ CH_3OH(\ell)}}$$

$= -1.00 \times 10^3\ kJ$

19. (a) 34.2 g $CaC_2(s)$

(b) 599 kJ

(c) 1.14×10^6 kJ

20. mass of wax burned = 17.36 g – 17.01 g = 0.35 g

$$n = \frac{m}{M}$$

$$= \frac{0.35\ \cancel{g\ C_{25}H_{52}(s)}}{\dfrac{352.77\ \cancel{g\ C_{25}H_{52}(s)}}{mol\ C_{25}H_{52}(s)}}$$

$= 9.9 \times 10^{-4}\ mol\ C_{25}H_{52}(s)$

$$Q = mc\Delta t_{water} + mc\Delta t_{aluminium\ can}$$

$$= (125.03\ \cancel{g})\left(\frac{4.19\ J}{\cancel{g}\bullet\cancel{°C}}\right)(35.7\ \cancel{°C} - 14.3\ \cancel{°C}) + (35.03\ \cancel{g})\left(\frac{0.897\ J}{\cancel{g}\bullet\cancel{°C}}\right)(35.7\ \cancel{°C} - 14.3\ \cancel{°C})$$

$= 11\ 211\ J + 672\ J$

$= 11.9\ kJ$

Therefore, $\Delta H = -11.9\ kJ$.

$$\Delta H = n\Delta_c H$$

$$\Delta_c H = \frac{\Delta H}{n}$$

$$= \frac{-11.9 \text{ kJ}}{9.9 \times 10^{-4} \text{ mol } C_{25}H_{52}(s)}$$

$$= -1.2 \times 10^4 \text{ kJ/mol } C_{25}H_{52}(s)$$

The accepted value for the molar enthalpy of combustion for paraffin is about -1.8×10^4 kJ/mol. The experimental value is lower than expected. This could be due to heat lost to the surroundings (which would decrease the value of the numerator), or incorrectly massing the water, metal can or candle. Perhaps the can was not made of pure aluminium, which would change the value of the specific heat capacity for the can.

$$\text{Percentage Difference} = \frac{\text{Accepted} - \text{Experimental}}{\text{Accepted}} \times 100\%$$

$$= \frac{-1.8 \times 10^4 \cancel{\text{kJ/mol}} - (-1.2 \times 10^4 \cancel{\text{kJ/mol}})}{-1.8 \times 10^4 \cancel{\text{kJ/mol}}} \times 100\%$$

$$= 33\%$$

21. $Q = mc\Delta t$

$$= (500 \text{ g})\left(\frac{4.19 \cancel{\text{J}}}{\text{g}\bullet \cancel{°\text{C}}}\right)(13.5 \text{ °C})\left(\frac{1 \text{ kJ}}{1000 \cancel{\text{J}}}\right)$$

$$= 28.3 \text{ kJ}$$

Therefore, change in enthalpy of reaction is $\Delta H = -28.3$ kJ.

$$\Delta H = n\Delta_c H$$

$$n = \frac{\Delta H}{\Delta_c H}$$

$$= \frac{-28.3 \cancel{\text{kJ}}}{-3508.8 \cancel{\text{kJ}}/\text{mol } C_5H_{12}(\ell)}$$

$$= 8.07 \times 10^{-3} \text{ mol } C_5H_{12}(\ell)$$

$$n = \frac{m}{M}$$

$$m = nM$$

$$= (8.07 \times 10^{-3} \cancel{\text{mol } C_5H_{12}(\ell)})\left(\frac{72.17 \text{ g } C_5H_{12}(\ell)}{\cancel{\text{mol } C_5H_{12}(\ell)}}\right)$$

$$= 0.582 \text{ g } C_5H_{12}(\ell)$$

22. $n = \frac{m}{M}$

$$= \frac{0.930 \cancel{\text{g C(s)}}}{\frac{12.01 \cancel{\text{g C(s)}}}{\text{mol C(s)}}}$$

$$= 0.0774 \text{ mol C(s)}$$

$$\Delta H = n\Delta_c H$$

$$= (0.0774 \text{ mol C(s)})(-394 \text{ kJ/mol C(s)})$$

$$= -30.5 \text{ kJ}$$

The thermal energy change in the calorimeter is 30.5 kJ. Since a bomb calorimeter's heat capacity is not a specific heat capacity, its heat capacity is expressed in kJ/°C, not kJ/g•°C, so the formula should be changed to $Q = c\Delta t$ instead of $Q = mc\Delta t$.

$$Q = c\Delta t$$

$$c = \frac{Q}{\Delta t}$$

$$= \frac{(30.5 \text{ kJ})}{(28.15 \text{ °C} - 25.00 \text{ °C})}$$

$$= 9.68 \text{ kJ/°C}$$

The increase in temperature is evidence that the reaction is exothermic.

Answers to Making Connections Questions

23. a) $\text{x minutes} = 527.18 \text{ kJ} \times \frac{1 \text{ minute}}{20 \text{ kJ}}$

$$= 26 \text{ minutes}$$

b) $\text{x g} = \frac{37.5 \text{ g}}{527.18 \cancel{\text{kJ}}} \times \frac{20 \cancel{\text{kJ}}}{1 \cancel{\text{minute}}} \times \frac{60 \cancel{\text{minutes}}}{1 \text{ h}} \times 4.0 \text{ h}$

$$= 3.4 \times 10^2 \text{ g}$$

c) $\text{x apples} = \frac{1 \text{ apple}}{283 \cancel{\text{kJ}}} \times \frac{20 \cancel{\text{kJ}}}{1 \cancel{\text{minute}}} \times \frac{60 \cancel{\text{minutes}}}{1 \text{ h}} \times 4.0 \text{ h}$

$$= 17 \text{ apples}$$

24. (a) $H_2(g) + O_2(g) \rightarrow H_2O(g)\ \Delta H = -241.8 \text{ kJ}$

(b) 8.3×10^4 L

(c) For hydrogen gas combustion, there are no carbon dioxide or other greenhouse gas emissions; the only by-product is pure water; and it is extremely efficient.

(d) Hydrogen gas requires large storage space and a large engine.

CHAPTER 10 THEORIES OF ENERGY AND CHEMICAL CHANGES

Curriculum Correlation

(Note: This correlation includes Chapters 9, 10, 11. Chapter 10 references are in bold.)

General Outcome 1: Students will determine and interpret energy changes in chemical reactions.

	Student Textbook	Assessment Options
Outcomes for Knowledge		
30–A1.1k recall the application of $Q = mc\Delta t$ to the analysis of energy transfer	Measuring Thermal Energy Changes, Unit 5 Preparation, pp. 336–337 Chapter 9 Launch Lab: Hot Packs and Cold Packs, p. 339	Practice Problems: 1–4, Unit 5 Preparation, p. 337 Chapter 9 Launch Lab: Hot Packs and Cold Packs, Analysis: 1–3, p. 339 Questions for Comprehension: 1, 2, Section 9.1, p. 342 Section 9.1 Review: 1, p. 350 Chapter 9 Review: 1, p. 366–377 Chapter 9 Test Unit 5 Review: 5, 7, pp. 424–427
30–A1.2k explain, in a general way, how stored energy in the chemical bonds of hydrocarbons originated from the Sun	Enthalpy and Thermochemical Equations, Section 9.1, p. 340 Enthalpy Changes of Endothermic Reactions, Section 9.1, p. 345	Section 9.1 Review: 2, p. 350 Chapter 9 Review: 3, 15, p. 366–377 Chapter 9 Test Unit 5 Review: 1, 7, 20, pp. 424–427
30–A1.3k define enthalpy and molar enthalpy for chemical reactions	Energy and Enthalpy, Section 9.1, p. 343 Investigation 9.A: Determining the Enthalpy of a Neutralization Reaction, Section 9.2, pp. 356–357	Questions for Comprehension: 3, 4, Section 9.1, p. 346 Section 9.1 Review: 3–7, p. 350 Investigation 9.A: Determining the Enthalpy of a Neutralization Reaction, Analysis: 1, 2, 4, Conclusion: 5, Section 9.2, pp. 356–357 Chapter 9 Review: 2, 14, p. 366–377 Chapter 9 Test **Chapter 10 Review: 1, p. 401** Unit 5 Review: 4, 10, 24, 29, 30, 31, 36–43, pp. 424–427
30–A1.4k write balanced equations for chemical reactions that include energy changes	**Throughout Chapters 9, 10, and 11** Energy Changes in Chemical Reactions, Section 9.1, p. 342 Energy and Enthalpy, Section 9.1, p. 343	Questions for Comprehension: 3, 4, Section 9.1, p. 346 Question for Comprehension: 5, Section 9.1, p. 347 Section 9.1 Review: 3, 4, 6, 7, p. 350 Chapter 9 Review: 5, 6, 12, 13, 23, 24, pp. 366–377 Chapter 9 Test **Chapter 10 Review: 2, 18, p. 400–401** Unit 5 Review: 25, 32, 35, 41, 43, pp. 424–427

	Student Textbook	Assessment Options
30–A1.5k use and interpret ΔH notation to communicate energy changes and to calculate energy changes in chemical reactions	Throughout Chapters 9, 10, and 11 Investigation 9.A: Determining the Enthalpy of a Neutralization Reaction, Section 9.2, pp. 356–357 Investigation 9.B: Molar Enthalpy of Combustion, Section 9.2, pp. 358–359 **Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium, Section 10.1, pp. 375–377**	Section 9.1 Review: 3–7, p. 350 Investigation 9.A: Determining the Enthalpy of a Neutralization Reaction, Analysis: 4, Conclusion: 5, Section 9.2, pp. 356–357 Investigation 9.B: Molar Enthalpy of Combustion, Part 1: 2, Part 2: 1, 2, Section 9.2, pp. 358–359 Chapter 9 Review: 2–4, 6, 7, 13, 16–24, pp. 366–367 Chapter 9 Test **Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium: 1–5, Section 10.1, pp. 375–377** **Section 10.1 Review: 1–5, p. 383** **Chapter 10 Review: 1, 2, 12, 15–26, pp. 400–401** **Chapter 10 Test** Unit 5 Review: 19, 25, 29–45, pp. 424–427
30–A1.6k predict the enthalpy change for chemical equations using standard enthalpies of formation	Calculating Enthalpy Changes, Section 9.1, p. 348 Sample Problem: Predicting an Enthalpy Change, Section 9.1, p. 348 Sample Problem: Using Enthalpy Data to Determine the Mass of Products, Section 9.1, p. 349 **Hess's Law, Section 10.1, p. 370** **Sample Problem: Using Hess's Law to Determine Enthalpy Change for Formation Reactions, Section 10.1, p. 373** **Standard Molar Enthalpies of Formation, Section 10.1, p. 377** **Sample Problem: Using Enthalpies of Formation, Section 10.1, p. 381** **Sample Problem: Using an Enthalpy of Combustion to Determine an Enthalpy of Formation, Section 10.1, p. 382**	Practice Problems: 1–6, Section 9.1, p. 349 Chapter 9 Test **Practice Problems 1–6, Section 10.1, pp. 374–375** **Questions for Comprehension: 1–3, Section 10.1, p. 378** **Questions for Comprehension: 4–7, Section 10.1, p. 379** **Practice Problems: 7–12, Section 10.1, pp. 382–383** **Section 10.1 Review: 2, 3, 5, p. 383** **Chapter 10 Review: 2, 3, 10, 15, 16, 18, pp. 400–401** **Chapter 10 Test** Unit 5 Review: 4, 25, 33, 39–41, 43, pp. 424–427
30–A1.7k explain and use Hess's law to calculate energy changes for a net reaction from a series of reactions	**Hess's Law, Section 10.1, pp. 370–383** **Sample Problem: Using Hess's Law to Determine Enthalpy Change, Section 10.1, p. 373** **Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium, Section 10.1, pp. 375–377** **Sample Problem: Using an Enthalpy of Combustion to Determine an Enthalpy of Formation, Section 10.1, p. 382**	**Practice Problems: 1–6, Section 10.1, pp. 374–375** **Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium: 1–6, Section 10.1, pp. 375–377** **Questions for Comprehension: 1–3, Section 10.1, p. 378** **Practice Problems: 7–12, Section 10.1, pp. 382–383** **Chapter 10 Review: 16, 18, 19, pp. 400–401** **Chapter 10 Test** Unit 5 Review: 25, 29, 37–39, pp. 424–427

	Student Textbook	Assessment Options
30–A1.8k use calorimetry data to determine the enthalpy changes in chemical reactions	Calorimetry, Section 9.2, pp. 351–353 Sample Problem: Determining the Enthalpy Change of a Reaction, Section 9.2, p. 354 Connections: Energy for Living: How Food Fuels You, Section 9.1, pp. 361–362 Sample Problem: Calculating Thermal Energy in a Bomb Calorimeter, Section 9.2, p. 362 **Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium, Section 10.1, pp. 375–377**	Practice Problems: 7–12, Section 9.2, p. 355 Questions for Comprehension: 7–10, Section 9.2, p. 355 Practice Problems: 13–17, Section 9.2, p. 363 Section 9.2 Review: 1–8, p. 364 Chapter 9 Review: 4, 7–9, 11–13, 16–22, pp. 366–367 Chapter 9 Test **Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium: 1–5, Section 10.1, pp. 375–377** **Chapter 10 Review: 15, 24, 26, pp. 400–401** **Chapter 10 Test** Unit 5 Review: 11, 30, 32, 36, 44, pp. 424–427
30–A1.9k identify that liquid water and carbon dioxide gas are reactants for photosynthesis and are products for cellular respiration, in an open system, and that gaseous water and carbon dioxide gas are the products of hydrocarbon combustion	Molar Enthalpy of Combustion, Section 9.1, p. 346 Connections: Energy for Living: How Food Fuels You, Section 9.2, pp. 361–362	Web Link, Section 9.1, p. 347 Questions for Comprehension: 5, 6, Section 9.1, p. 347 Practice Problems: 2–4, Section 9.1, p. 349 Chapter 9 Review: 5, 6, 10, 24, pp. 366-367 Chapter 9 Test **Chapter 10 Review: 12, 15, 17, 20, 21, 23, 24, 26, 28, pp. 400–401** Unit 5 Review: 7, 8, 22, 24, 30, 32, 35, 42, 48, pp. 424–427
30–A1.10k classify chemical reactions, including those for the processes of photosynthesis, cellular respiration and hydrocarbon combustion as endothermic or exothermic.	Describing Chemical Reactions, Unit 5 Preparation, p. 334 Energy Changes in Chemical Reactions, Section 9.1, pp. 342–343 Enthalpy Changes of Exothermic Reactions, Section 9.1, pp. 344–345 Enthalpy Changes of Endothermic Reactions, Section 9.1, p. 345 Molar Enthalpy of Combustion, Section 9.1, p. 346 Connections: Energy for Living: How Food Fuels You, Section 9.2, pp. 361–362	Section 9.1 Review: 2, 5, p. 350 Chapter 9 Review: 5, 6, 10, 15, 22, pp. 366-367 Chapter 9 Test **Questions for Comprehension: 2, Section 10.1, p. 378** Unit 5 Review: 1, 3, 36, pp. 424–427

	Student Textbook	Assessment Options
Outcomes for Science, Technology and Society (Emphasis on science and technology)		
30–A1.1sts explain that the goal of technology is to provide solutions to practical problems by ■ *providing examples of personal reliance on the chemical potential energy of matter, e.g., the use of hydrocarbon fossil fuels* ■ *identifying ways to use energy more efficiently*	Chapter 9 Launch Lab: Hot Packs and Cold Packs, p. 339 Connections: Energy for Living: How Food Fuels You, Section 9.2, pp. 361–362 **Chapter 10 Launch Lab: Bake a Cake, p. 368** **Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium, Section 10.1, pp. 375–377** **Thought Lab 10.1: Improving Energy Efficiency at Home, Section 10.2, p. 389** **Connections: Efficient Home Heating, Section 10.2, p. 390** **Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396** **Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398** Connections: Car Pollution Solution? Inside a Catalytic Converter, Section 11.2, p. 414	Chapter 9 Launch Lab: Hot Packs and Cold Packs, Analysis: 3, p. 339 Connections: Energy for Living: How Food Fuels You: 1, 2, Section 9.2, pp. 361–362 **Chapter 10 Launch Lab: Bake a Cake: 1–3, p. 368** **Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium: 5, 6, Section 10.1, pp. 375–377** **Thought Lab 10.1: Improving Energy Efficiency at Home: 1–4, Section 10.2, p. 389** **Connections: Efficient Home Heating: 1, 2, Section 10.2, p. 390** **Section 10.2 Review: 1–9, p. 392** **Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396** **Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398** **Section 10.3 Review: 6, p. 398** **Chapter 10 Review: 4–9, pp. 400–401** Connections: Car Pollution Solution? Inside a Catalytic Converter: 2, 3, Section 11.2, p. 414 Unit 5 Review: 46–49, pp. 424–427
30–A1.2sts demonstrate an understanding that technological problems often lend themselves to multiple solutions that involve different designs, materials and processes and have intended and unintended consequences by ■ *illustrating the applications of hydrocarbon fossil fuels, with examples from industries in Alberta.*	Chapter 9 Launch Lab: Hot Packs and Cold Packs, p. 339 **Investigation 10.B: Build a Heating Device, Section 10.2, pp. 387–388** **Thought Lab 10.1: Improving Energy Efficiency at Home, Section 10.2, p. 389** **Connections: Efficient Home Heating, Section 10.2, p. 390** **Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396** **Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398**	Chapter 9 Launch Lab: Hot Packs and Cold Packs, Analysis: 2, p. 339 **Investigation 10.B: Build a Heating Device: 1–3, Section 10.2, pp. 387–388** **Thought Lab 10.1: Improving Energy Efficiency at Home: 1–4, Section 10.2, p. 389** **Connections: Efficient Home Heating: 1, 2, Section 10.2, p. 390** **Section 10.2 Review: 1–9, p. 392** **Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396** **Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398** **Section 10.3 Review: 1–6, p. 398** **Chapter 10 Review: 13, 14, pp. 400–401** Unit 5 Review: 46–49, p. 427

	Student Textbook	Assessment Options
Skill Outcomes (Focus on problem solving)		
Initiating and Planning		
30–A1.1s ask questions about observed relationships and plan investigations of questions, ideas, problems and issues by ■ designing a method to compare the molar enthalpy change when burning two or more fuels, identifying and controlling major variables	Investigation 9.B: Molar Enthalpy of Combustion, Section 9.2, pp. 358–359 **Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium, Section 10.1, pp. 375–377**	Investigation 9.B: Molar Enthalpy of Combustion, Part 1: 1–4, Part 2: 1–4, Section 9.2, pp. 358–359 **Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium: 1–6, Section 10.1, pp. 375–377** Unit 5 Review: 24, 47, pp. 424–427
■ describing procedures for safe handling, storage and disposal of materials used in the laboratory, with reference to WHMIS and consumer product labelling information.	Chapter 9 Launch Lab: Hot Packs and Cold Packs, p. 339 Investigation 9.B: Molar Enthalpy of Combustion, Section 9.2, pp. 358–359 **Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium, Section 10.1, pp. 375–377**	Chapter 9 Launch Lab: Hot Packs and Cold Packs, Analysis: 2, p. 339 Investigation 9.B: Molar Enthalpy of Combustion, Part 1: 3, Part 2: 3, Section 9.2, pp. 358–359 **Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium: 6, Section 10.1, pp. 375–377** Unit 5 Review: 24, 47, pp. 424–427
Performing and Recording		
30–A1.2s conduct investigations into relationships among observable variables and use a broad range of tools and techniques to gather and record data and information by ■ performing calorimetry experiments to determine the molar enthalpy change of chemical reactions ■ using thermometers or temperature probes appropriately when measuring temperature changes	Investigation 9.A: Determining the Enthalpy of a Neutralization Reaction, Section 9.2, pp. 356–357 Investigation 9.B: Molar Enthalpy of Combustion, Section 9.2, pp. 358–359 **Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium, Section 10.1, pp. 375–377**	Investigation 9.A: Determining the Enthalpy of a Neutralization Reaction, Analysis: 1–4, Conclusion: 5, Section 9.2, pp. 356–357 Investigation 9.B: Molar Enthalpy of Combustion, Part 1: 1–4, Part 2: 1–4, Section 9.2, pp. 358–359 **Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium: 1–6, Section 10.1, pp. 375–377** Unit 5 Review: 24, 47, pp. 424–427
■ *using a computer-based laboratory to compile and organize data from an experiment to demonstrate molar enthalpy change*	Investigation 9.B: Molar Enthalpy of Combustion, Section 9.2, pp. 358–359	Investigation 9.B: Molar Enthalpy of Combustion, Part 1: 2, Part 2: 3, Section 9.2, pp. 358–359
■ *selecting and integrating information from various print and electronic sources to create multiple-linked documents on using alternative fuels.*	Investigation 9.B: Molar Enthalpy of Combustion, Section 9.2, pp. 358–359 Connections: Energy for Living: How Food Fuels You, Section 9.2, Section 9.2, pp. 361–362 **Investigation 10.B: Build a Heating Device, Section 10.2, pp. 387–388** **Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396** **Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398**	Investigation 9.B: Molar Enthalpy of Combustion, Part 2: 3, Section 9.2, pp. 358–359 Connections: Energy for Living: How Food Fuels You: 1–4, Section 9.2, pp. 361–362 **Investigation 10.B: Build a Heating Device: 2, Section 10.2, pp. 387–388** **Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396** **Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398**

	Student Textbook	Assessment Options
Analyzing and Interpreting		
30–A1.3s analyze data and apply mathematical and conceptual models to develop and assess possible solutions by ■ comparing energy changes associated with a variety of chemical reactions through the analysis of data and energy diagrams	Investigation 9.B: Molar Enthalpy of Combustion, Section 9.2, pp. 358–359 **Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium, Section 10.1, pp. 375–377** **Investigation 10.B: Build a Heating Device, Section 10.2, pp. 387–388**	Investigation 9.B: Molar Enthalpy of Combustion, Part 1: 1, 2, Part 2: 1, 2, Section 9.2, pp. 358–359 **Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium: 1–6, Section 10.1, pp. 375–377** **Investigation 10.B: Build a Heating Device: 1–3, Section 10.2, pp. 387–388** Unit 5 Review: 11, 28, 35, 36–42, 44, pp. 424–427
■ *manipulating and presenting data through the selection of appropriate tools, e.g., scientific instrumentation, calculators, databases or spreadsheets.*	Investigation 9.B: Molar Enthalpy of Combustion, Section 9.2, pp. 358–359 **Investigation 10.B: Build a Heating Device, pp. 387–388** **Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398**	Investigation 9.B: Molar Enthalpy of Combustion, Part 2: 3, Section 9.2, pp. 358–359 **Investigation 10.B: Build a Heating Device: 3, pp. 387–388** **Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398** Unit 5 Review: 36, pp. 424–427
Communication and Teamwork		
30–A1.4s work collaboratively in addressing problems and apply the skills and conventions of science in communicating information and ideas and in assessing results by ■ using appropriate International System of Units (SI) notation, fundamental and derived units for enthalpy changes and expressing molar enthalpies in kilojoules/mole	Investigation 9.A: Determining the Enthalpy of a Neutralization Reaction, Section 9.2, pp. 356–357 Investigation 9.B: Molar Enthalpy of Combustion, Section 9.2, pp. 358–359 **Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium, Section 10.1, pp. 375–377** **Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398**	Investigation 9.A: Determining the Enthalpy of a Neutralization Reaction, Analysis: 1–3, Conclusion: 5, Section 9.2, pp. 356–357 Investigation 9.B: Molar Enthalpy of Combustion, Part 1: 1–4, Part 2: 1–4, Section 9.2, pp. 358–359 **Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium: 1–5, Section 10.1, pp. 375–377** **Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398**
■ *using advanced menu features within a word processor to accomplish a task and to insert tables, graphs, text and graphics.*	Investigation 9.B: Molar Enthalpy of Combustion, Section 9.2, pp. 358–359 **Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398**	Investigation 9.B: Molar Enthalpy of Combustion, Part 2: 3, Section 9.2, pp. 358–359 **Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398** Chapter 10 Review: 27, p. 401

General Outcome 2: Students will explain and communicate energy changes in chemical reactions.

	Student Textbook	Assessment Options
Outcomes for Knowledge		
30–A2.1k define activation energy as the energy barrier that must be overcome for a chemical reaction to occur	Activation Energy, Section 11.1, p. 405	Questions for Comprehension: 1–3, Section 11.1, p. 407 Section 11.1 Review: 2, 4, 5, 7, 8, p. 410 Chapter 11 Review: 2, 3, 5, 6, 9, 14, 16, pp. 420–421 Chapter 11 Test Unit 5 Review: 16, 19, 45, pp. 424–427

	Student Textbook	Assessment Options
30–A2.2k explain the energy changes that occur during chemical reactions referring to bonds breaking and forming and changes in potential and kinetic energy	Types of Energy, Section 9.1, p. 341 Energy Changes in Chemical Reactions, Section 9.1, p. 342	Section 11.1 Review: 1–3, p. 410 Chapter 11 Review: 1, 3, 5, 9, pp. 420–421 Unit 5 Review: 1, 6, 9, 20, pp. 424–427
30–A2.3k analyze and label energy diagrams for a chemical reaction, including reactants, products, enthalpy change and activation energy	Enthalpy Changes of Exothermic Reactions, Section 9.1, pp. 344–345 Enthalpy Changes of Endothermic Reactions, Section 9.1, p. 345 A Closer Look at a Molecular Collision, Section 11.1, p. 406 Sample Problem: Drawing a Potential Energy Diagram, Section 11.1, pp. 408–409	Questions for Comprehension: 3, 4, Section 9.1, p. 346 Practice Problems: 1–5, Section 11.1, p. 409 Section 11.1 Review: 6–9, p. 410 Section 11.2 Review: 6, p. 418 Chapter 11 Review: 4, 6, 13–15, 18, 19, pp. 420–421 Chapter 11Test Unit 5 Review: 12, 19, 20, 29, 33, 43, 45, pp. 424–427
30–A2.4k explain that catalysts increase reaction rates by providing alternate pathways for changes without affecting the net amount of energy involved, e.g., *enzymes in living systems.*	Chapter 11 Launch Lab: Does It Gel? p. 403 Catalysts and Reaction Rates, Section 11.2, pp. 411–412 Try This, Section 11.2, p. 416 Investigation 11.A: The Effect of a Catalyst on the Decomposition of Hydrogen Peroxide, H_2O_2(aq), Section 11.2, pp. 417–418	Chapter 11 Launch Lab: Does It Gel? Analysis: 3, p. 403 Questions for Comprehension: 1–3, Section 11.1, p. 407 Questions for Comprehension: 4, 5, Section 11.2, p. 413 Investigation 11.A: The Effect of a Catalyst on the Decomposition of Hydrogen Peroxide, H_2O_2(aq): 1–6, Section 11.2, pp. 417–418 Section 11.2 Review: 1–6, p. 418 Chapter 11 Review: 7, 8, 10, 11, 12, 14, 17–29, p. 420–421 Chapter 11 Test Unit 5 Review: 18, 21, 29, 45, pp. 424–427

	Student Textbook	Assessment Options
Outcomes for Science, Technology and Society (Emphasis on science and technology)		
30–A2.1sts develop an understanding that the goal of technology is to provide solutions to practical problems by ■ *explaining how catalysts reduce air pollution from the burning of hydrocarbons; i.e., catalytic converters on cars*	Chapter 9 Launch Lab: Hot Packs and Cold Packs, p. 339 **Investigation 10.B: Build a Heating Device, Section 10.2, pp. 387–388** **Thought Lab 10.1: Improving Energy Efficiency at Home, Section 10.2, p. 389** **Connections: Efficient Home Heating, Section 10.2, p. 390** **Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396** **Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398** Chapter 11 Launch Lab: Does It Gel? p. 403 Connections: Car Pollution Solution? Inside a Catalytic Converter, Section 11.2, p. 414 Career Focus: Building Up and Breaking Down Bitumen, pp. 422–423	Chapter 9 Launch Lab: Hot Packs and Cold Packs, Analysis: 1, 3, p. 339 **Investigation 10.B: Build a Heating Device: 1–3, Section 10.2, pp. 387–388** **Thought Lab 10.1: Improving Energy Efficiency at Home: 1–4, Section 10.2, p. 389** **Connections: Efficient Home Heating: 1, 2, Section 10.2, p. 390** **Section 10.2 Review: 1–9, p. 392** **Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396** **Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398** **Section 10.3 Review: 1–6, p. 398** Chapter 11 Launch Lab: Does It Gel? Analysis: 2, 3, p. 403 Connections: Car Pollution Solution? Inside a Catalytic Converter: 1–3, Section 11.2, p. 414 Chapter 11 Review: 17, 22–29, pp. 420–421 Career Focus: Building Up and Breaking Down Bitumen, Go Further 1–3, pp. 422–423 Unit 5 Review: 46–49, pp. 424–427
30–A2.2sts identify the appropriateness, risks and benefits of technologies and the need to assess each potential application from a variety of perspectives, including sustainability by ■ *assessing qualitatively the risks and benefits of relying on fossil fuels as energy sources*	Chapter 9 Launch Lab: Hot Packs and Cold Packs, p. 339 Connections: Energy for Living: How Food Fuels You, Section 9.2, pp. 361–362 **Chapter 10 Launch Lab: Bake a Cake, p. 368** **Investigation 10.B: Build a Heating Device, Section 10.2, pp. 387–388** **Thought Lab 10.1: Improving Energy Efficiency at Home, Section 10.2, p. 389** **Connections: Efficient Home Heating, Section 10.2, p. 390** **Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396** **Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398**	Chapter 9 Launch Lab: Hot Packs and Cold Packs, Analysis: 1–3, p. 339 Connections: Energy for Living: How Food Fuels You: 1–4, Section 9.2, pp. 361–362 **Chapter 10 Launch Lab: Bake a Cake: 1–3, p. 368** **Investigation 10.B: Build a Heating Device: 1–3, Section 10.2, pp. 387–388** **Thought Lab 10.1: Improving Energy Efficiency at Home: 1–4, Section 10.2, p. 389** **Connections: Efficient Home Heating: 1, 2, Section 10.2, p. 390** **Section 10.2 Review: 1–9, p. 392** **Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396** **Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398** **Section 10.3 Review: 1–6, p. 398** **Chapter 10 Review: 13, 14, p. 400** Chapter 11 Review: 17, 22–29, pp. 420–421 Unit 5 Review: 46–49, pp. 424–427

	Student Textbook	Assessment Options
30–A2.3sts explain that the products of technology are devices, systems and processes that meet given needs but that these products cannot solve all problems by ■ *evaluating the economic and environmental impact of different fuels by relating carbon dioxide emissions and the heat content of a fuel.*	**Chapter 10 Launch Lab: Bake a Cake, p. 368** **Investigation 10.B: Build a Heating Device, Section 10.2, pp. 387–388** **Thought Lab 10.1: Improving Energy Efficiency at Home, Section 10.2, p. 389** **Connections: Efficient Home Heating, Section 10.2, p. 390** **Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396** **Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398**	**Chapter 10 Launch Lab: Bake a Cake: 3, p. 368** **Investigation 10.B: Build a Heating Device: 1–3, Section 10.2, pp. 387–388** **Thought Lab 10.1: Improving Energy Efficiency at Home: 1–4, Section 10.2, p. 389** **Connections: Efficient Home Heating: 1, 2, Section 10.2, p. 390** **Section 10.2 Review: 1–9, p. 392** **Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396** **Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398** **Section 10.3 Review: 1–6, p. 398** Chapter 11 Review: 17, 22–29, pp. 420–421 Unit 5 Review: 46–49, pp. 424–427
Skill Outcomes (Focus on problem solving)		
Initiating and Planning		
30–A2.1s ask questions about observed relationships and plan investigations of questions, ideas, problems and issues by ■ describing procedures for safe handling, storage and disposal of materials used in the laboratory, with reference to WHMIS and consumer product labelling information ■ *designing an experimental procedure to illustrate the effect of a catalyst on a chemical reaction.*	Investigation 11.A: The Effect of a Catalyst on the Decomposition of Hydrogen Peroxide, H_2O_2(aq), Section 11.2, pp. 417–418	Investigation 11.A: The Effect of a Catalyst on the Decomposition of Hydrogen Peroxide, H_2O_2(aq): 1–6, Section 11.2, pp. 417–418 Unit 5 Review: 24, 27, pp. 424–425
Performing and Recording		
30–A2.2s conduct investigations into relationships among observable variables and use a broad range of tools and techniques to gather and record data and information by ■ plotting energy graphs/enthalpy diagrams indicating changes in energy for chemical reactions	Investigation 9.B: Molar Enthalpy of Combustion, Section 9.2, pp. 358–359 Investigation 11.A: The Effect of a Catalyst on the Decomposition of Hydrogen Peroxide, H_2O_2(aq), Section 11.2, pp. 417–418	Investigation 9.B: Molar Enthalpy of Combustion, Part 2: 2, Section 9.2, pp. 358–359 Investigation 11.A: The Effect of a Catalyst on the Decomposition of Hydrogen Peroxide, H_2O_2(aq): 2, Section 11.2, pp. 417–418
■ *using library and electronic research tools to compile information on the energy content of fuels used in Alberta power plants*	Investigation 9.B: Molar Enthalpy of Combustion, Section 9.2, pp. 358–359 **Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396** **Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398**	Investigation 9.B: Molar Enthalpy of Combustion, Part 2: 3, Section 9.2, pp. 358–359 **Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396** **Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398**
■ *designing and building a heating device.*	Chapter 9 Launch Lab: Hot Packs and Cold Packs, p. 339 **Investigation 10.B: Build a Heating Device, Section 10.2, pp. 387–388**	Chapter 9 Launch Lab: Hot Packs and Cold Packs, Analysis: 1, 3, p. 339 **Investigation 10.B: Build a Heating Device: 1–3, Section 10.2, pp. 387–388**

	Student Textbook	Assessment Options
Analyzing and Interpreting		
30–A2.3s analyze data and apply mathematical and conceptual models to develop and assess possible solutions by ■ interpreting an enthalpy diagram for a chemical reaction ■ explaining the discrepancy between the theoretical and actual efficiency of a thermal energy conversion system	Investigation 9.B: Molar Enthalpy of Combustion, Section 9.2, pp. 358–359 **Chapter 10 Launch Lab: Bake a Cake, p. 368** **Connections: Efficient Home Heating, Section 10.2, p. 390** **Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.2, p. 396**	Investigation 9.B: Molar Enthalpy of Combustion, Part 2: 3, Section 9.2, pp. 358–359 Unit 5 Review: 11, 28, 35, 36–42, 44, pp. 424–427 **Chapter 10 Launch Lab: Bake a Cake: 2, 3, p. 368** **Practice Problems: 13–16, Section 10.2, p. 387** **Connections: Efficient Home Heating: 1, Section 10.2, p. 390** **Section 10.2 Review: 1–9, p. 392** **Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396** **Chapter 10 Review: 4–9, pp. 400–401** Chapter 11 Review: 4, 6, 13–15, 18, 19, pp. 420–421
■ *determining the efficiency of thermal energy conversion systems*	**Chapter 10 Launch Lab: Bake a Cake, p. 368** **Sample Problem: The Efficiency of a Propane Barbecue, Section 10.2, pp. 386–387** **Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.2, p. 396**	**Chapter 10 Launch Lab: Bake a Cake: 3, p. 368** **Practice Problems: 13–16, Section 10.2, p. 387** **Section 10.2 Review: 1–9, p. 392** **Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396** **Chapter 10 Review: 4–9, pp. 400–401**
■ *assessing whether coal or natural gas should be used to fuel thermal power plants in Alberta*	Investigation 9.B: Molar Enthalpy of Combustion, Part 1: 1–4, Part 2: 1–4, Section 9.2, pp. 358–359 **Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396** **Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398**	Investigation 9.B: Molar Enthalpy of Combustion, Part 2: 3, Section 9.2, pp. 358–359 Section 10.2 Review: 1–9, p. 392 **Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396** **Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398** **Section 10.3 Review: 1–6, p. 398** **Chapter 10 Review: 13, 14, pp. 400**
■ *evaluating a personally designed and constructed heating device, including a calculation of its efficiency.*	**Investigation 10.B: Build a Heating Device, Section 10.2, pp. 387–388**	**Investigation 10.B: Build a Heating Device: 1–3, Section 10.2, pp. 387–388**
Communication and Teamwork		
30–A2.4s work collaboratively in addressing problems and apply the skills and conventions of science in communicating information and ideas and in assessing results by ■ using appropriate SI notation, fundamental and derived units for calculating and communicating enthalpy changes	Investigation 9.A: Determining the Enthalpy of a Neutralization Reaction, Analysis: 1–4, Conclusions: 5, Section 9.2, pp. 356–357 Investigation 9.B: Molar Enthalpy of Combustion, Section 9.2, pp. 358–359 **Investigation 10.B: Build a Heating Device, Section 10.2, pp. 387–388**	Investigation 9.A: Determining the Enthalpy of a Neutralization Reaction, Analysis: 1–4, Conclusion: 5, Section 9.2, pp. 356–357 Investigation 9.B: Molar Enthalpy of Combustion, Part 1: 1–4, Part 2: 1–4, Section 9.2, pp. 358–359 **Investigation 10.B: Build a Heating Device: 1–3, Section 10.2, pp. 387–388**
■ *working collaboratively to develop a plan to build an energy conversion device, seeking feedback, testing and reviewing the plan, making revisions and implementing the plan* ■ *using advanced menu features within a word processor to accomplish a task and to insert tables, graphs, text and graphics.*	Investigation 9.B: Molar Enthalpy of Combustion, Section 9.2, pp. 358–359 **Investigation 10.B: Build a Heating Device: Section 10.2, pp. 387–388**	Investigation 9.B: Molar Enthalpy of Combustion, Part 2: 3, Section 9.2, pp. 358–359 **Investigation 10.B: Build a Heating Device: 2, 3, Section 10.2, pp. 387–388** **Chapter 10 Review: 27, p. 401**

Chapter 10

Theories of Energy and Chemical Changes

Student Textbook pages 368–392

Chapter Concepts

Section 10.1 Hess's Law

- Hess's law can be used to determine the net enthalpy change for a chemical reaction from a series of reactions.
- Enthalpy change (ΔH) can be predicted from standard enthalpies of formation.
- Calorimetry can be used along with Hess's law to determine enthalpy changes.

Section 10.2 Energy and Efficiency

- The efficiency of a thermal energy conversion system is given by:
  $$\text{Efficiency} = \frac{\text{Energy output}}{\text{Energy input}} \times 100\%$$
- Hess's law and calorimetry data can be combined to determine the efficiency of a thermal energy conversion device.
- Consumer products differ in efficiency, and consumers can choose more energy-efficient products.

Section 10.3 Fuelling Society

- Canadians rely on the potential energy stored in fossil fuels for everyday life.
- Although fossil fuels have many benefits, using them comes at a cost to the environment.
- Fuels can be evaluated based on their efficiency, heat content, and harmful emissions.

Common Misconceptions

- Students often think that "efficiency" is only about accomplishing a task in a minimal amount of time. Although this is one definition of efficiency, there are others that should also be considered. Definitions should not be limited to either minimal time or minimal energy.
- Students often do not distinguish between different fossil fuels regarding their heat content, the impact on the environment made to bring the fuel to the customer, or how cleanly they burn. All fossil fuels are not equal.

Helpful Resources

Books and Journal Articles

- Rohrig, B. "Chemistry of the Lightbulb," *ChemMatters*, Vol. 21, No. 2, April 2003, p. 11
- Jones, D. "Hydrogen Fuel Cells for Future Cars," *ChemMatters*, Vol. 18, No. 4, December 2000, p. 4.
- Jansen, M.P. "The Cost of Converting a Gasoline-Powered Vehicle to Propane. A Practical Review Problem for Senior High School or Introductory Chemistry," *Journal of Chemical Education,* Vol. 77, No. 12, December 2000, p. 1578.
- Jensen, W.B. "The Thermodynamics and Kinetics of 'HeaterMeals'," *Journal of Chemical Education*, Vol. 77, No. 6, June 2000, p. 713.

Web Sites

Web links related to energy and chemical change can be found at **www.albertachemistry.ca.** Go to the Online Learning Centre, and log on to the Instructor Edition. Choose Teacher Web Links.

List of BLMs

Blackline masters (BLMs) have been prepared to support the material in this chapter. The BLMs are either for assessment (AST); use as overheads (OH); use as handouts (HAND), in particular to support activities. Most handouts and all assessment tools are supported by a BLM with the answers (ANS). The BLMs are in digital form, stored on the CD-ROM that accompanies this Teacher's Resource or on the web site at **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, BLMs. They can be modified to suit the needs of your students.

Number (Type) Title

10.0.1 (HAND) Launch Lab: Bake a Cake
10.0.1A (ANS) Launch Lab: Bake a Cake Answer Key

10.1.1 (OH) Hess's Law: Two Pathways, One Change
10.1.2 (OH) Using Hess's Law to Determine Enthalpy Change
10.1.3 (OH) Using Hess's Law to Determine Enthalpy Change for Formation Reactions
10.1.4 (HAND) Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium
10.1.4A (ANS) Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium Answer Key

10.2.1 (HAND) Investigation 10.B: Build a Heating Device
10.2.1A (ANS) Investigation 10.B: Build a Heating Device Answer Key
10.2.2 (HAND) Thought Lab 10.1: Improving Energy Efficiency at Home
10.2.2A (ANS) Thought Lab 10.1: Improving Energy Efficiency at Home Answer Key

10.3.1 (HAND) Investigation 10.C: Fossil Fuels as Energy Sources: A Risk-Benefit Analysis
10.3.1A (ANS) Investigation 10.C: Fossil Fuels as Energy Sources: A Risk-Benefit Analysis Answer Key
10.3.2 (HAND) Investigation 10.D: Fuelling Thermal Power Plants
10.3.2A (ANS) Investigation 10.D: Fuelling Thermal Power Plants Answer Key

10.4.1 (AST) Chapter 10 Test
10.4.1A (ANS) Chapter 10 Test Answer Key

Using the Chapter 10 Opener

Student Textbook pages 368–369

Teaching Strategies

- Have students read the chapter opener. Discuss how the bats are conserving "wasted" energy. Ask students if they do anything in their daily lives that conserves energy that would otherwise be wasted? Students will likely identify how the bats are conserving energy by huddling together, thereby decreasing the surface area for heat loss to the surroundings. Students may have more difficulty identifying ways in which they conserve energy. Have them list some of the ways they use energy, such as cooking on a stove or oven and lighting their rooms. Then, have them list the types of energy produced, for example, in lighting their rooms, the light bulbs also produce heat. If they are heating their homes, then the wasted heat from the light bulb helps to heat their homes. Similarly, the wasted heat from an oven also helps to heat their homes.
- Using a car as an example, have students describe the useful energy conversions in a car, and what happens to the "wasted" energy. If the purpose of the car is to move from one place to another, then all other energy is wasted. Yet, car manufacturers have found ways to harness much of that potentially "wasted" energy into functions that we find useful, like heat, music, and even charging the battery.

Launch Lab Bake a Cake

Student Textbook page 369

Purpose

Students will develop an understanding of efficiency by constructing a working oven from an incandescent light bulb and other household materials. By using a light bulb as a heat source instead of a light source, students will see that useful energy output and wasted energy output depends on their frame of reference.

Outcomes

- 30-A1.1sts
- 30-A2.3s

Advance Preparation

When to Begin	What to Do
1 month before	■ Order clamp-on light sockets or some other appropriate light source that can accommodate up to 100 W light bulbs if necessary.
2 weeks before	■ Ensure that light bulbs of varying wattage are available (up to the wattage accommodated by the light sockets available). ■ Ensure that a variety of building materials are available.
1 week before	■ Purchase the remaining baking supplies. ■ Photocopy **BLM 10.0.1: Launch Lab.**

Materials

Per student group:

- clamp-on light sockets or some other suitable lamps (one per group)
- retort stands (one per group)
- building materials (some material suggestions shown below)
  - large coffee cans (from calorimetry experiments)
  - cardboard boxes (approximately the same size as the coffee cans)
  - aluminium foil
  - mirror
  - Styrofoam™
  - 25 to 100 W incandescent light bulbs (up to the maximum wattage recommended for use in the lamp socket)
- disposable metal pans (tart or muffin size)
- stirring rod (or popsicle sticks if the cake is going to be consumed)
- graduated cylinder and/or measuring spoons
- cake mix (any flavour) (30 mL per group)
- oil (to grease the metal pans)
- water (15 mL per group)

Time Required

- 30 minutes (if done as a demo)
- 45–60 minutes if done as a lab

Helpful Tips

- Use **BLM 10.0.1 (HAND) Launch Lab: Bake a Cake** to support this activity. Modify as necessary.
- You may remember Easy-Bake® oven from your childhood. This Launch Lab plays off the idea that you really can cook with a light bulb. This leads into the discussion of how a light bulb is not a good energy converter; it is almost as good a heat source as it is a light source; therefore, a significant percentage of energy is wasted. In

fact, an incandescent light bulb is only about 2% efficient at creating light. The majority of the energy wasted is converted to heat.
- Cookie dough can be used instead of a cake mix and baked on a piece of foil. This is much faster and less messy.
- If students are going to consume their baked goods, ensure that they have used new materials for the mixing and baking.
- Clamp-on light sockets are ideal for this lab because they can be easily clamped on to a retort stand, and the light bulbs easily changed. If these are not available, trouble lights, or any other light socket, flashlight or lamp can be used.
- Student data tables should have some way to compare how long it took to bake the cake or cookie. They should control how large the cake or cookie is but allow for all other variables to be changed to improve efficiency.
- If you have access to an Easy-Bake® oven, have students compare the efficiency of the homemade oven with that of the commercially available one. Ask students to identify the improvements that were made on the commercially available oven and whether they improved the efficiency of the oven.
- ***Expected Results:*** Students will probably measure the temperature of the oven and the baking time to test the efficiency of their oven. The ovens that are best insulated will, of course, be the most efficient. An incandescent light bulb is relatively efficient for baking because roughly 95% of the energy it releases is in the form of heat. It would be interesting if some students used a compact fluorescent bulb for comparison because they produce much less heat.

Safety Precautions

Ensure students understand "Safety in Your Chemistry Laboratory and Classroom" on pages xii-xv in the student textbook. Although they are dealing with food, students should be reminded that they are using glassware that will get as hot as anything they would cook at home in the oven. Students must be careful not to have any flammable materials close to the heat source.

Answers to Analysis Questions

1. The most likely criterion used to judge the efficiency of their oven is how long it took to bake the cake or cookie. Another possibility is how much energy was used to bake the cake or cookie. If the oven is fairly large, they may also include a term for the number of cakes or cookies that could be baked.
2. All designs would have a heat source. If students have applied the knowledge they learned in Chapter 9, they will include some method to help isolate the oven from the surroundings. This could include a box or a large juice can. They may want to line their box or can with aluminium foil or Styrofoam™ in an attempt to reduce heat transfer to the surroundings.
3. A light bulb is designed to produce light, not heat, so students are not likely to consider it a very efficient heat source to bake a cake. They may mention how much time it took to bake a cake or cookie in their oven compared to a conventional oven or microwave.

Assessment Options

- Collect and assess students' designs, data tables and answers to Analysis questions.
- Use Assessment Checklist 3: Performance Task Self-Assessement from Appendix A.

10.1 Hess's Law

Student Textbook pages 370–383

Section Outcomes

Students will:
- explain and use Hess's law to calculate energy changes for a net reaction from a series of reactions
- predict the enthalpy change for chemical reactions by using standard heats of formation
- compare molar enthalpy data from calorimetry experiments with theoretical values obtained by using Hess's law

Key Terms

Hess's law
thermal stability
Standard molar enthalpy of formation, $\Delta_f H$

Chemistry Background

- Hess's law of heat summation is a result of the law of conservation of energy.
- The enthalpy change of a chemical reaction can be calculated using thermochemical equations, or by using values for the molar enthalpies of formation of the reactants and products.
- The enthalpy of formation of an element in its standard state is zero. In other than standard state, the enthalpy of formation of an element is not zero and therefore must be included in Hess's law calculations.

Teaching Strategies

- Three overhead masters have been prepared for this section. You will find them with the Chapter 10 BLMs on the CD-ROM that accompanies this Teacher's Resource or at **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, BLMs.
  Number (Type) Title
  10.1.1 (OH) Hess's Law: Two Pathways, One Change

10.1.2 (OH) Using Hess's Law to Determine Enthalpy Change
10.1.3 (OH) Using Hess's Law to Determine Enthalpy Change for Formation Reactions

- Figure 10.3 on page 371 of the student textbook provides a good analogy for Hess's law. You could challenge students to elaborate on the analogy. For example, a person who hikes down the mountain from the starting point to the finishing point will experience the same net change in gravitational potential energy as the cyclists. A person who hang glides from the starting point, then travels a great distance, rising and falling on air currents, but who winds up at the same finishing point, will also experience the same net change in gravitational potential energy. The analogy assumes that each of the people traveling from the starting point to the finishing point has the same mass. If students have difficulty relating to the analogy because they do not understand gravitational potential energy, simplify the analogy by saying that the cyclists, hiker, and hang glider experience the same net change in vertical position from the starting point to the finishing point.
- Insist that students include subscripts to indicate the state of reactants and products when manipulating thermochemical equations. Only species that are identical in composition and state can be cancelled or added when solving a Hess's law problem.
- Students should write out the thermochemical equations when solving a Hess's law problem to make sure the target equation is achieved when all the species are added and cancelled. Students who take shortcuts at this stage, by manipulating ΔH values without writing out the chemical equations, invariably make mistakes. Achieving the target equation is a check that the problem may have been correctly solved, with an addition or an error in sign the only other mistakes that may be present.
- To make it easier to cancel correctly the reactants and products when adding thermochemical equations, students should line up all of the reaction arrows.
- Remind students that molar enthalpy of reaction (usually for reactions such as combustion, formation, etc.) must be expressed as kJ/mol of the substance. Students may need to divide the coefficients and the enthalpy change by a constant to obtain one mole of the desired substance.

SUPPORTING DIVERSE STUDENT NEEDS

Hess's law problems are straightforward once students understand the concept. Encourage students to take their time and write all thermochemical equations to ensure that unneeded reactants and products cancel, leaving only the target equation.

Answers to Practice Problems 1–6

Student Textbook pages 374–375

For full solutions to the practice problems, visit **www.albertachemistry.ca,** Online Learning Centre, Instructor Edition, Full Solutions.

1. –44.2 kJ
2. –507 kJ
3. –121.0 kJ
4. 30 kJ
5. 52.6 kJ/mol
6. –128.8 kJ/mol

Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium

Student Textbook pages 375–377

Purpose

In this investigation, students use Hess's law to determine the enthalpy of combustion for magnesium without actually carrying out the reaction. They will perform two calorimetry experiments and use this data along with the known enthalpy value for the formation of water from its elements to determine the enthalpy change for the target reaction.

Outcomes

- 30-A1.7k
- 30-A1.1sts
- 30-A1.1s
- 30-A1.2s
- 30-A1.4s
- 30-A1.3s
- ICT C6-4.2

Advance Preparation

When to Begin	What to Do
2–3 days before	■ Prepare 1.0 mol/L HCl(aq). ■ Obtain graph paper. ■ Assemble materials for the lab.
1 day before	■ Have students read the lab and make predictions. ■ Photocopy **BLM 10.1.4: Investigation 10.A.**

Materials

- safety goggles
- simple calorimeter
- thermometer
- scoopula
- 100 mL graduated cylinder
- balance
- $MgO(s)$ powder
- $Mg(s)$ ribbon (or turnings)
- sandpaper or emery paper
- 210 mL 1.0 mol/L $HCl(aq)$
- waste container

Time Required

- 60 minutes

Helpful Tips

- Use **BLM 10.1.4 (HAND) Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium** to support this activity. Modify as necessary.
- Before beginning this investigation, students should feel very comfortable adding equations to obtain a target equation. Several days before the investigation, work through the Sample Problems on page 373 and 374 of the student textbook. Have students complete at least some, and preferably all, of Practice Problems 1–6 on pages 374–375 in the student textbook.
- Ensure that the magnesium you use is not coated with its oxide. It is therefore preferable to use magnesium ribbon rather than turnings—turnings are almost impossible to clean. If you are using magnesium ribbon, stress to students that they should sand the magnesium to obtain a shiny surface before finding its mass. Note the safety precaution regarding sanding these strips.
- To carry out Investigation 10.A on the microscale, use two small (30 mL) plastic disposable cups (e.g. medicine dispensers). Place a small elastic band about a third of the way down on one cup and place it in the other cup. The air space acts as insulation. Use 20 mL of solution instead of 100 mL and stir with a thermometer. Use no more than 0.16 g of magnesium oxide in part 1, and no more than 0.10 g of magnesium in part 2. You do not need to use a lid or stirring rod.
- ***Expected Results:*** The enthalpy of combustion of magnesium is 2.50×10^4 J/g. The experimental value obtained by the students will probably be lower due to heat loss in the calorimeters.

SUPPORTING DIVERSE STUDENT NEEDS

Analysis question 1 of this investigation assumes that students are comfortable with calorimetry calculations and offers no guidance in determining the enthalpy change of the reactions using calorimetry data. In Analysis question 2, students are expected to write thermochemical equations for the two reactions studied. Students may need additional guidance in writing the reactions and supplying the appropriate enthalpy change for the reaction as written.

Safety Precautions

Ensure that students have read "Safety in Your Chemistry Laboratory" on pages xii-xv in the student textbook. Ensure students follow all safety precautions outlined for this investigation in the student textbook. Caution students to be careful not to inhale the $MgO(s)$ powder. If you sand magnesium ribbon, this operation needs to be done with care. The edges of the ribbon are sometimes sharp and minor cuts are possible. Students must not be permitted to ignite the magnesium strips. The light produced by the reaction is bright enough to seriously harm students' eyes.

Answers to Prediction Questions

1. The molar enthalpy of formation of magnesium oxide (which is also the molar enthalpy of combustion of magnesium) as listed in the data booklet is –601.6 kJ/mol.
2. In predicting the enthalpies of reactions (2) and (3), having the "right" answer is not important. Accept all reasonable answers with a logical explanation. Students may predict that since equation (1) is highly exothermic, equation (3) will probably be exothermic as well. Students may predict that equation (2) is exothermic because it is spontaneous (which is not necessarily the case, but a reasonable statement in terms of the students' knowledge). Other students may predict that since equation (1) is highly exothermic, equation (2) will probably be endothermic (the equation is reversed when equations (2), (3), and (4) are added to give equation (1), thus when reversed an endothermic reaction would be exothermic, increasing the ΔH for equation (1). In the investigation, students will find that the reactions are both exothermic.

Answers to Analysis Questions

1. Students will use their temperature data to determine Δt. Remember, $\Delta t = t_f - t_i$. Since both reactions are exothermic, the value of Δt for both will be positive. Students should use 4.19 J/g•°C for c. If students did not measure the mass of the solutions, they should use $m = d \bullet V$ to determine mass, where $d = 1.00$ g/mL (making the assumption that the density of the solution is close to the density of water) and $V = 100.0$ mL. Students will then determine the enthalpy change using the equations $\Delta H = n\Delta_x H$ and $Q = mc\Delta t$. Students should use the equation $n = m/M$ to determine the amounts (in mol) of $MgO(s)$ and $Mg(s)$ used, if they do their calculation in two steps. For example, if a student used 0.80 g of $MgO(s)$ in Part 1, the calculation is as follows:

$$n = \frac{m}{M}$$

$$= \frac{0.80\ \cancel{\text{g MgO(s)}}}{\frac{40.31\ \cancel{\text{g MgO(s)}}}{\text{mol MgO(s)}}}$$

$$= 0.020\ \text{mol MgO(s)}$$

Similarly, if a student used 0.50 g of Mg(s) in Part 2, the calculation is:

$$n = \frac{m}{M}$$

$$= \frac{0.50\ \cancel{\text{g Mg(s)}}}{\frac{24.31\ \cancel{\text{g Mg(s)}}}{\text{mol Mg(s)}}}$$

$$= 0.021\ \text{mol Mg(s)}$$

Using $\Delta H = n\Delta H_x$ and $Q = mc\Delta t$ and their answers for mole calculations, students can determine the enthalpy change for 1 mol of MgO(s) (equation (2)) or Mg(s) (equation (3)). For equation (2), the literature value for $\Delta H°$ is –146 kJ/mol MgO(s).

For equation (3), the literature value for $\Delta H°$ is –462 kJ/mol Mg(s).

2. **(2)** $MgO(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2O(\ell)\ \Delta H = -146\ kJ$

(3) $Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)\ \Delta H = -462\ kJ$

3. **(a)** Students should show that the reverse of equation (2), plus equations (3) and (4), add to give equation (1). Students should use their ΔH values for equations (2) and (3), and ΔH for equation (4) provided in the introduction to the experiment. Check that students multiply ΔH for equation (2) by –1 when they reverse the equation.

$$\cancel{MgCl_2}(aq) + \cancel{H_2O}(\ell) \rightarrow MgO(s) + 2\cancel{HCl}(aq)$$
$$\Delta H = -(-146\ kJ) = +146\ kJ$$

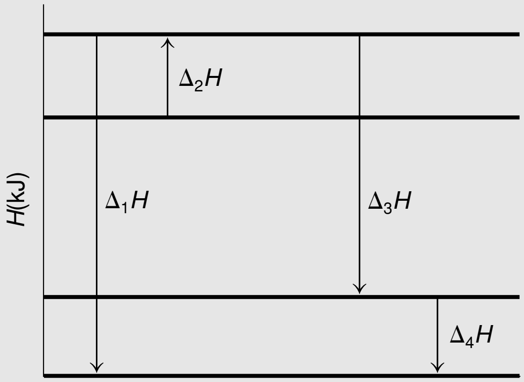
$$Mg(s) + 2\cancel{HCl}(aq) \rightarrow \cancel{MgCl_2}(aq) + \cancel{H_2}(g)$$
$$\Delta H = -462\ kJ$$

$$\cancel{H_2}(g) + \frac{1}{2}O_2(g) \rightarrow \cancel{H_2O}(\ell)\ \Delta H = -285.8\ kJ$$

$$Mg(s) + \frac{1}{2}O_2(g) \rightarrow MgO(s)$$
$$\Delta H = (146 - 462 - 285.8) = -602\ kJ$$

Student results should only have two significant digits, since the mass of magnesium has only two significant digits.

(b)



4. **(a)** The accepted value of $\Delta H°$ for the combustion of magnesium (also the formation of magnesium oxide) is –601.6 kJ/mol.

percent difference =

$$\left| \frac{\text{experimental value} - (-601.6\ \text{kJ/mol})}{-601.6\ \text{kJ/mol}} \right| \times 100\%$$

Student results should only have two significant digits, since the mass of magnesium has only two significant digits.

(b) The major source of error is heat lost from the calorimeter to the surroundings. The heat absorbed by the calorimeter should also be mentioned, and measurement errors in reading the thermometer, the graduated cylinder, and measuring the mass of solids. Relatively small errors include assuming the density of the solution is 1.00 g/mL, and the specific heat capacity of the solution is 4.19 J/g•°C. The fact that conditions are not at SATP is a trivial source of error. To improve the experiment, more trials should be undertaken. As well, now that students know that the reactions are exothermic and the approximate temperature change, they can minimize heat loss or gain to and from the surroundings by starting the investigation as far below room temperature as possible since the temperature will increase above room temperature.

Answer to Conclusion Question

5. Students should briefly explain that they carried out two reactions and used a calorimeter to determine enthalpy values for thermochemical equations. Using the equation of a reaction with a known ΔH, they were able to manipulate and add those three equations to obtain the target equation and find its ΔH. This was possible because of Hess's Law which states that the enthalpy change of a chemical process depends only on the beginning and end conditions; ΔH is independent of the pathway. Students may reproduce here the solution shown for Analysis question 3.

The thermochemical equation should be written using the student's results for ΔH:

$Mg(s) + \frac{1}{2}O_2(g) \rightarrow MgO(s)\ \Delta H = -601.6$ kJ

Answer to Application Question

6. Students should design an investigation that is similar to Investigation 10.A. Using a simple calorimeter, students would be able to determine ΔH for equations (1), (2), and (3), and check whether the calculated ΔH from equations (1) and (3) add up to the empirically determined ΔH for equation (2), verifying Hess's law. For equation (1), students would find the mass of some NaOH(s) pellets, then determine the enthalpy of dissolving of the pellets in an accurately measured volume of water. For equation (2), students would add an accurately measured sample of NaOH(s) pellets to neutralize 0.500 mol/L HCl(aq). The mass of NaOH(s) used should be the stoichiometric quantity to just neutralise the HCl(aq). For equation (3), students would use an accurately measured sample of NaOH(aq) solution to neutralize the HCl(aq). Ensure that students include appropriate safety precautions and detailed procedure steps.

Assessment Options

- Collect and assess students' Predictions, Data Tables, and answers to Analysis questions.
- Use Assessment Checklist 6: Using Math in Science from Appendix A.

Answers to Questions for Comprehension

Student Textbook page 378

Q1. (a) $\frac{1}{2}H_2(g) + \frac{1}{2}I_2(g) \rightarrow HI(g)\ \Delta_f H° = 26.5$ kJ/mol

(b) $2Fe(s) + \frac{3}{2}O_2(g) \rightarrow Fe_2O_3(s)$

$\Delta_f H° = -824.2$ kJ/mol

(c) $Ba(s) + \frac{1}{2}O_2(g) \rightarrow BaO(s)\ \Delta_f H° = -548.0$ kJ/mol

(d) $\frac{1}{2}H_2(g) + \frac{1}{2}Cl_2(g) + 2O_2(g) \rightarrow HClO_4(\ell)$

$\Delta_f H° = -40.6$ kJ/mol

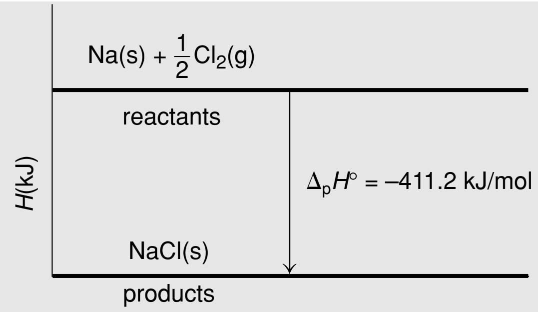
Q2. (a) endothermic

(b) exothermic

(c) exothermic

(d) exothermic

Q3.



Answers to Questions for Comprehension

Student Textbook page 379

Q4. (a) $C(s) + 2H_2(g) \rightarrow CH_4(g)\ \Delta_f H° = -74.6$ kJ/mol

(b) $6C(s) + 3H_2(g) \rightarrow C_6H_6(\ell)\ \Delta_f H° = 49.1$ kJ/mol

(c) $Na(s) + \frac{1}{2}Cl_2(g) \rightarrow NaCl(s)\ \Delta_f H° = -411.2$ kJ/mol

(d) $Mg(s) + \frac{1}{2}O_2(g) \rightarrow MgO(s)\ \Delta_f H° = -601.6$ kJ/mol

(e) $Ca(s) + C(s) + \frac{3}{2}O_2(g) \rightarrow CaCO_3(s)$

$\Delta_f H° = -1207.6$ kJ/mol

Q5. most thermally stable $CaCO_3(s)$, $MgO(s)$, $NaCl(s)$, $CH_4(g)$, $C_6H_6(\ell)$ least stable

Q6. $H_2(g) + \frac{1}{8}S_8(s) + 2O_2(g) \rightarrow H_2SO_4(\ell)$

$\Delta_f H° = -814.0$ kJ/mol

Q7. formation: $6C(s) + 6H_2(g) + 3O_2(g) \rightarrow C_6H_{12}O_6(s)$

$\Delta_f H° = -1273.3$ kJ/mol

photosynthesis: $6CO_2(g) + 6H_2O(\ell) \rightarrow C_6H_{12}O_6(s) + 6O_2(g)\ \Delta H = 2802.5$ kJ/mol

Although both result in the formation of glucose, the heat of formation is exothermic, whereas the photosynthesis reaction is endothermic. The formation reaction forms glucose from its elements, and photosynthesis forms glucose from water and carbon dioxide. In a formation reaction, there are no by-products. Photosynthesis produces oxygen as a by-product.

Answers to Practice Problems 7–12

Student Textbook pages 382–383

For full solutions to the practice problems, visit **www.albertachemistry.ca,** Online Learning Centre, Instructor Edition, Full Solutions.

7. –136.4 kJ

8. –882.6 kJ

9. –77.6 kJ

10. (a) –637.9 kJ/mol

(b) 2.49×10^3 kJ

11. –102.7 kJ/mol

12. –224.2 kJ/mol

Section 10.1 Review Answers

Student Textbook page 383

1. When a reaction occurs in the opposite direction, the sign of the ΔH must be reversed due to the law of conservation of energy. For example, when glucose is formed in photosynthesis,

$$6CO_2(g) + 6H_2O(\ell) \rightarrow C_6H_{12}O_6(s) + 6O_2(g) \quad \Delta H = 2802.5 \text{ kJ/mol}$$

2802.5 kJ/mol of glucose is stored as energy in the chemical bonds. When cellular respiration occurs, the reverse of photosynthesis, the same amount of energy that was stored, 2802.5 kJ/mol, will be released into the surroundings. Since this reaction is exothermic, the sign will be the negative of that of photosynthesis.

2. Most stable: $NaCl(s)$, $H_2S(g)$, $O_2(g)$, $C_2H_4(g)$, $C_2H_2(g)$ least stable

3. (a) $6C(s) + 3H_2(g) \rightarrow C_6H_6(\ell)\ \Delta_fH^\circ = 49.1$ kJ/mol

(b) Method 1 Using Formulas

$$\begin{aligned} n &= \frac{m}{M} \\ &= 0.4173 \text{ mol } C_6H_6(\ell) \end{aligned}$$

$$\begin{aligned} \Delta H &= n\Delta_fH \\ &= (0.4173\ \cancel{\text{mol } C_6H_6(\ell)})\left(\frac{49.1 \text{ kJ}}{\cancel{\text{mol } C_6H_6(\ell)}}\right) \\ &= 20.5 \text{ kJ} \end{aligned}$$

Method 2 Using Dimensional Analysis

$$\begin{aligned} x \text{ kJ} &= \frac{49.1 \text{ kJ}}{\cancel{\text{mol } C_6H_6(\ell)}} \times \frac{1\ \cancel{\text{mol } C_6H_6(\ell)}}{78.12\ \cancel{\text{g } C_6H_6(\ell)}} \times 32.6\ \cancel{\text{g } C_6H_6(\ell)} \\ &= 20.5 \text{ kJ} \end{aligned}$$

4. $2 \times$ **(1)** $2H_3BO_3(aq) \rightarrow 2HBO_2(aq) + 2H_2O(\ell)$

$$\Delta H^\circ = 2(-0.02 \text{ kJ})$$

$-\frac{1}{2} \times$ **(2)** $\cancel{2HBO_2}(aq) \rightarrow \frac{1}{2}H_2B_4O_7(s) + \frac{1}{2}H_2O(\ell)$

$$\Delta H^\circ = -\frac{1}{2}(-11.3 \text{ kJ})$$

$\frac{1}{2} \times$ **(3)** $\cancel{\frac{1}{2}H_2B_4O_7}(s) \rightarrow B_2O_3(s) + \frac{1}{2}H_2O(\ell)$

$$\Delta H^\circ = \frac{1}{2}(17.5 \text{ kJ})$$

$2H_3BO_3(aq) \rightarrow B_2O_3(s) + 3H_2O(\ell)\ \Delta H^\circ = 14.4$ kJ

5. Although mathematically, due to the law of conservation of energy, using enthalpies of formation is a shortcut for manipulating and adding equations, students should understand that in most reactions, the reactants do not actually break down into their elements and then react to form products.

10.2 Energy and Efficiency

Student Textbook pages 384–392

Section Outcomes

Students will:

- determine the efficiency of thermal energy conversion systems
- design, build, and evaluate a heating device
- explain the discrepancy between the theoretical and the actual efficiency of energy conversion systems
- identify ways to use energy more efficiently
- use appropriate SI units to express enthalpy changes and molar enthalpies

Key Terms

efficiency
energy output
energy input

Chemistry Background

- Chemical reactions are generally one or two orders of magnitude more energetic than physical changes.
- Although energy is conserved, "useful" energy is not. Efficiency is defined as useful energy output (the desired form) divided by the energy input, expressed as a percentage.
- Hess's law calculations provide a value for energy input, while calorimetry or other experimental data provides a value for energy output.
- EnerGuide labels provide energy consumption data for new appliances and vehicles sold in Canada. EnerGuide labels for cars also include an estimated annual fuel cost.
- An appliance or vehicle with an ENERGY STAR® label is one of the most energy efficient in its category.
- The Kyoto Protocol was signed by Canada in 1997, and commits Canada to reducing its greenhouse gas emissions to 6% below 1990 levels by 2012.
- Calculations for energy efficiency may encompass only the final conversion, that of energy input vs. useful energy output (such as heating water on a stove); or it may look at the efficiency of the energy conversions from the source (heating water using hydroelectric power, which provides the electricity for the stove). The fewer number of conversions, the more efficient the process.

Teaching Strategies

- This section addresses the concepts of energy efficiency in more detail than is strictly called for in the curriculum. Students will, in extending this portion of the curriculum, see a connection to their lives that they otherwise may not.
- When discussing the definition of efficiency, return to the Launch Lab and ask students how, if at all, their definition of efficiency has changed as they study Section 10.2.

- Efficiency can be a difficult concept because it has different meanings in different contexts. The equation for efficiency on page 385 of the student textbook is a good definition to use when discussing energy sources.
- Brainstorm with students to list factors that contribute to the "energy used" term. For example, coal needs to be mined and transported, both of which require energy. Then the coal is burned, and the energy produced needs to be converted to electrical energy. Energy used to maintain the power plant where this occurs may be included in the "energy used" term. Stress to students that the "energy used" term may include all, some, or none of these and other factors, depending on the definition being used. The simplest definition of "energy used" is the total energy ideally contained in the coal, based on the enthalpy of reaction for the combustion of carbon.
- Several weeks before teaching the section, challenge students to scan newspapers or the internet for energy-related articles. If the term *efficiency* is used, discuss what the author of the article means by the term, and whether an adequate definition was provided. Discuss any environmental issues that arise.
- At this age, students are now thinking about driving and getting their own car. Use the EnerGuide labels to have students not only calculate the efficiency of a vehicle of their choice, but also the estimated annual operating costs. Students will then begin to tie energy efficiency with monetary savings.
- The information provided in this section should be supplemented with the most current energy efficiency information.
- The BLMs prepared for this section support the activities. You will find them with the Chapter 10 BLMs on the CD-ROM that accompanies this Teacher's Resource or at **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, BLMs.

SUPPORTING DIVERSE STUDENT NEEDS

Gifted students should be encouraged to explore the topic of energy efficiency in more detail. Unlike most topics in high school chemistry, this topic is constantly evolving as new technologies are developed.

Answers to Practice Problems 13–16

Student Textbook page 387

For full solutions to the practice problems, visit **www.albertachemistry.ca,** Online Learning Centre, Instructor Edition, Full Solutions.

13. 18%

14. 69%

15. 0.88 g

16. 38.7%

Investigation 10.B: Build a Heating Device

Student Textbook page 387–388

Purpose

In this investigation, students will be required to determine the efficiency of a heating device that they have designed and constructed. They will then account for the discrepancy between the theoretical and actual efficiency of their heating device.

Outcomes

- 30-A2.2s
- 30-A2.3s

Advance Preparation

When to Begin	What to Do
1 month before	■ Ensure you have the required supplies on hand for a heat source.
2 weeks before	■ As you are introducing students to the Launch Lab at the beginning of the chapter, provide them with the background for this investigation. Have them begin work in groups to develop an initial design and list of any materials required.
1 week before	■ Ask students for their initial materials list. If approved, acquire needed materials. If not approved, ask students to re-evaluate their design.
2 days before	■ Gather all materials. ■ Photocopy **BLM 10.2.1: Investigation 10.B.**

Materials
Per student group: ■ balance ■ thermometer ■ stirring rod ■ water ■ heat source

Materials

Possible list of materials from students:

- graduated cylinder
- cardboard box(es)
- aluminium foil
- Styrofoam™ sheets
- mirror

Time Required

- 30 minutes for initial planning
- 60 minutes to carry out investigation and improve design

Helpful Tips

- Use **BLM 10.2.1 (HAND) Investigation 10.B: Build a Heating Device** to support this activity. Modify as necessary.
- Students must be able to calculate an energy input in order to calculate efficiency; therefore, unless the flow rate of a Bunsen burner is known, they must use a fuel source that they can mass before and after the experiment. All fuel sources mentioned for Investigation 9.B would be appropriate. Students could also use an electrical source and use calculations introduced in Unit 6 to determine the electrical energy input.
- If this investigation is introduced at the same time as the Launch Lab, students will be able to apply what they learned in evaluating an oven to developing a heating device.
- Encourage students to think carefully about the data they are collecting to ensure they will have enough appropriate data to do their calculations. Have them start their calculations by developing an equation and then listing all of the unknowns they require.
- ***Expected Results:*** Although designs and efficiency will vary significantly, the key to the most efficient heating device will probably be the thermal insulation.

Safety Precautions

The safety precautions will depend on the design. Most student designs will involve an open flame; students should roll up sleeves and tie back long hair. They must also plan to have all flammable materials in their design kept away from the open flame.

Answers to Plan and Construct Questions

7. (a) The energy output to the water would be calculated using the formula $Q = mc\Delta t$. Students would have recorded the following data:

Mass (or volume) of water (m)

Initial temperature of water (t_i)

Final temperature of water (t_f)

From this data, they would calculate the change in temperature, Δt, by subtracting t_i from t_f. They would then calculate Q.

Using the following sample data:

Mass of water = 175.35 g

Initial temperature of water (t_i) = 19.3 °C

Final temperature of water (t_f) = 22.5 °C

$$\begin{aligned} Q &= mc\Delta t \\ &= (175.35\ \cancel{\text{g}})\left(\frac{4.19\ \text{J}}{\cancel{\text{g}\bullet{}^\circ\text{C}}}\right)(22.5\ \cancel{{}^\circ\text{C}} - 19.3\ \cancel{{}^\circ\text{C}}) \\ &= 2.4\ \text{kJ} \end{aligned}$$

(b) The theoretical energy input would be calculated by writing an equation for the combustion of the fuel, using Hess's Law and the formula and $\Delta H = n\Delta_x H$, or by looking up the theoretical enthalpy of combustion and then using the formula $\Delta H = n\Delta_x H$. The mass of the fuel before and after combustion must be collected.

Using an ethanol burner, the theoretical value for the molar enthalpy of combustion of ethanol in an open system can be calculated:

$$C_2H_5OH(\ell) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(g)$$

$$\begin{aligned} \Delta_c H^\circ &= \Sigma(n\Delta_f H^\circ \text{ products}) - \Sigma(n\Delta_f H^\circ \text{ reactants}) \\ &= [(2\ \text{mol})(\Delta_f H^\circ\ CO_2(g)) + (3\ \text{mol})(\Delta_f H^\circ\ H_2O(g))] \\ &\quad - [(1\ \text{mol})(\Delta_f H^\circ\ C_2H_5OH(\ell)) + (3\ \text{mol})(\Delta_f H^\circ\ O_2(g))] \\ &= [(2\ \text{mol})(-393.5\ \text{kJ/mol}) + (3\ \text{mol})(-241.8\ \text{kJ/mol})] \\ &\quad - [(1\ \text{mol})(-277.6\ \text{kJ/mol}) + (3\ \text{mol})(0\ \text{kJ/mol})] \\ &= -1512.4\ \text{kJ} - (-277.6\ \text{kJ}) \\ &= -1234.8\ \text{kJ/mol}\ C_2H_5OH(\ell) \end{aligned}$$

Given the following sample data from the lab:

Mass of ethanol burner before = 127.32 g

Mass of ethanol burner after = 125.46 g

The mass of ethanol burned = 127.32 g − 125.46 g
= 1.86 g

Method 1 Using Formulas

$$\begin{aligned} n &= \frac{m}{M} \\ &= \frac{1.86\ \cancel{\text{g}\ C_2H_5OH(\ell)}}{\dfrac{46.08\ \cancel{\text{g}\ C_2H_5OH(\ell)}}{\text{mol}\ C_2H_5OH(\ell)}} \\ &= 0.04036\ \text{mol}\ C_2H_5OH(\ell) \end{aligned}$$

$$\begin{aligned} \Delta H &= n\Delta_c H \\ &= (0.04036\ \cancel{\text{mol}\ C_2H_5OH(\ell)})\left(\frac{-1234.8\ \text{kJ}}{\cancel{\text{mol}\ C_2H_5OH(\ell)}}\right) \\ &= -49.8\ \text{kJ} \end{aligned}$$

Method 2 Using Dimensional Analysis

$$\text{x kJ} = \frac{-1234.8\text{ kJ}}{\cancel{\text{mol C}_2\text{H}_5\text{OH}(\ell)}} \times \frac{1\ \cancel{\text{mol C}_2\text{H}_5\text{OH}(\ell)}}{46.08\ \cancel{\text{g C}_2\text{H}_5\text{OH}(\ell)}} \times 1.86\ \cancel{\text{g C}_2\text{H}_5\text{OH}(\ell)}$$

$$= -49.8\text{ kJ}$$

(c) $$\text{Efficiency} = \left|\frac{\text{Energy output}}{\text{Energy input}}\right| \times 100\%$$

$$= \left|\frac{2.35\text{ kJ}}{-49.8\text{ kJ}}\right| \times 100\%$$

$$= 4.7\%$$

8. Some sources of energy loss include losses to the air, beaker (or other container holding water), the thermometer, stirring rod, and box (or other container).

Answers to Evaluate and Communicate Questions

1. Design modifications should include ways to further isolate the system from the surroundings, such as using Styrofoam™ or other insulator inside their container, reflecting more heat back into the container, and perhaps trying to burn the fuel more efficiently.

2. The most common way to improve the efficiency of a storage tank water heater is to add an insulating blanket around the heater and the surrounding pipes. Experts also recommend cleaning the water heater on a regular basis to remove sediments. The first recommendation could be applied to the classroom water heaters, by providing better insulation around the beaker holding the water, and by isolating the heating system from the surrounding air.

3. Most student designs will be quite similar and will have comparable efficiency ratings (less than 10%). The best designs will likely be smaller, which would better isolate the system (the beaker of water and the burner) from the rest of the surroundings.

Assessment Options

- Collect and assess students' materials lists, initial designs, modifications, calculations and answers to Evaluate and Communicate questions.
- Use Assessment Checklists 1: Designing an Experiment; 3: Performance Task Self-Assessment; and 4: Performance Task Group Assessment from Appendix A.

Chemistry File: Web Link

Student Textbook page 388

In the ever-changing political climate, Canada's level of commitment to meeting the Kyoto Protocol continues to change. You may want to set up a class debate about Canada's progress in meeting its Kyoto goals. You could also ask students to bring in clippings of recent news stories about Canada and the Kyoto Protocol.

Thought Lab 10.1: Improving Energy Efficiency at Home

Student Textbook page 389

Purpose

In this Thought Lab, students will look at their energy consumption during regular activities and research ways in which they could reduce energy consumption and realize monetary savings.

Outcomes

- C1-4.1
- C1-4.2
- C1-4.4
- C2-4.1
- C7-4.3
- F2-4.7
- F3-4.1
- P3-4.1
- P3-4.2
- P3-4.3
- P5-4.1
- P5-4.2
- 30–A1.1sts

Advance Preparation

When to Begin	What to Do
1 month before (if necessary)	■ Book the class into the computer lab.
1 day before	■ Photocopy **BLM 10.2.2: Thought Lab 10.1.**

Materials
■ Computers with Internet access

Time Required

- 20 minutes to generate a list of activities
- 60 minutes to complete necessary Internet research

Helpful Tips

- Use **BLM 10.2.2 (HAND) Thought Lab 10.1: Improving Energy Efficiency at Home** to support this activity. Modify as necessary.
- Organize students into categories based on those listed in the pie chart shown on page 390 of the student textbook. Some groups may need help in starting their lists.
- Up to date and focussed web sites will drastically reduce the amount of time students will have to spend gathering background information. Have students begin their web search at **www.albertachemistry.ca,** Online Learning Centre, Student Edition.

Answers to Analysis Questions

1. Some of the possible energy-saving tips that students may list are shown below:

Category	Behaviour changes	Technology
space heating	■ Turn down the heat and wear warmer clothes. ■ Turn down the heat at night and when not at home.	■ Install a programmable thermostat to lower the heat at night and when you are not at home. ■ Install an energy-efficient furnace. ■ Install a furnace that burns natural gas instead of heating using electricity
water heating	■ Turn down the water heater to the recommended temperature. ■ Take short showers instead of longer ones or baths. ■ Wash clothes in warm or cold water instead of hot. ■ Only run the dishwasher or washing machine with full loads.	■ Replace your inefficient water heater with a more efficient one, or an in-line water heater. ■ Install an insulating blanket around your water heater and pipes.
appliances	■ Use the most efficient appliance for the job (don't use a conventional oven if you can use a microwave). ■ Turn off the television and other appliances when not in the room. ■ Turn off the computer and printer, don't just let it go into "sleep" mode which still requires energy. ■ Limit appliance use to when necessary. ■ Use the oven to cook numerous items at one time.	■ Buy ENERGY STAR® rated appliances.
air conditioning	■ Turn up the temperature on the air conditioner to 25 °C. ■ Sleep in the basement instead of using an air conditioner.	■ Buy ENERGY STAR® rated air conditioners.
lighting	■ Turn off the lights when not in the room. ■ Light with natural light whenever possible.	■ Use lower wattage bulbs. ■ Buy more energy-efficient lightbulbs (compact fluorescents instead of incandescents).

The behaviour-based tips have no inherent costs associated with them; however, students may mention a decrease in comfort level or having to wait longer to get the desired effect. To perform a cost-benefit analysis for the technology-based tips, students should consider the cost of implementing the tip versus the energy savings. See **www.albertachemistry.ca,** Online Learning Centre, Instructor Edition, Teacher Web Links for a list of some specific web sites that provide information on energy savings. All energy-efficient models of appliances and light bulbs will lead to a net savings over the course of the appliance's lifetime, however, the initial outlay for the appliance is generally higher. For example, by replacing 12 incandescent bulbs with compact fluorescent bulbs, you would save approximately \$90 in a year. The initial cost of the 12 light bulbs, depending on where they are purchased is approximately \$60, whereas purchasing the same number of incandescent bulbs is approximately \$12. In one year, the net savings would be \$90 – \$60 + \$12 = \$42.

2. Depending on the size of your school and the programs offered, students should mention turning off lights when the room is not in use, purchasing more energy-efficient appliances, and perhaps finding more energy-efficient ways to heat and cool the school.
3. Students will likely not support tips that would require a significant shift in behaviour, such as taking shorter showers and making less use of appliances such as the computer.

Answer to Extension Question

4. Water can be conserved using a variety of technological and behaviour modifications. Changing shower heads to low-flow, replacing top loading washing machines with front loading and buying low-flush toilets are all

technological ways to conserve water. By taking showers instead of baths, turning off the taps while brushing your teeth, and by using the garbage can to dispose of tissues instead of flushing them are all behavioural ways to conserve water.

Assessment Options

- Collect and assess students' web pages, pamphlets, posters and answers to Analysis questions.
- Use Assessment Checklists 3: Performance Task Self-Assessment, 4: Performance Task Group Assessment from Appendix A.

Connections (Science and Technology): Efficient Home Heating

Student Textbook page 390

Teaching Strategies

- The questions following this feature make good topics for class discussions.
- Ask students to consider how the heating of their own homes could be made more efficient and create a list or report.

Answers to Questions

1. Older homes are generally not as well insulated as newer homes, so more heat escapes. Use this question to stimulate a class discussion. Have students prepare for the discussion by independently researching home heating efficiency and older homes.
2. Divide students into groups of three or four and have them present their findings to the class.

Section 10.2 Review Answers

Student Textbook page 392

1. The energy associated with physical changes are smallest, and those associated with nuclear processes are largest. The energy required to boil 1 mol of water is 40.65 kJ, the molar enthalpy of combustion of coal is about 3900 kJ, while the fusion of 1 mol of uranium-235 releases about 2.1×10^{10} kJ.
2. Students should ask the following questions: What definition of efficiency are you using? What is your definition of "useful energy"? What factors are included in your definition of "energy used"?
3. A simple experiment involves heating water in a beaker. Students will need to determine the flow rate of the gas and the time the gas burns, to find the quantity of gas burned. They should compare ideal enthalpy change for the burning to the amount of heat actually absorbed to increase the temperature of the water, say, by 30 °C. An experiment like this would give the efficiency of a laboratory burner in performing the specific task of heating water in a beaker. The efficiency definition is based on the ratio between the actual energy used to heat the water as compared with the ideal quantity of heat released by burning the gas.
4. Under operating conditions in a furnace where the water formed is gaseous, the enthalpy of combustion of methane is $\Delta_c H° = –802.5$ kJ/mol.

   $$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g) \quad \Delta_c H° = –802.5 \text{ kJ/mol}$$

   However, if the gaseous water produced is condensed, further heat is released. The molar enthalpy of condensation for water is –40.65 kJ/mol, so if the two moles of water are condensed, an extra 81 kJ of energy is released. This increases the efficiency of the furnace by 10%.
5. **(a)** The manufacturer is probably using a definition that compares electrical energy used by the device to thermal energy gained by the water in the kettle.

   (b) $$\text{Efficiency} = \left| \frac{\text{Energy output}}{\text{Energy input}} \right| \times 100\%$$

   $$= \left| \frac{\text{heat absorbed by water}}{\text{electrical energy used}} \right| \times 100\%$$

   $$= 95\%$$

   (c) Students should outline an experiment that monitors the electrical energy used to raise a measured volume of water in the kettle to 100 °C, comparing it to the calculated energy change based on the specific heat capacity of water. Safety precautions should include care using electricity and water.
6. From a purely environmental perspective, the "best" barbecue would be the natural gas barbecue. From a purely economical perspective, the choice would be a hibachi. The propane barbecue may be considered a compromise, however its lower cost may not compensate for the environmental cost of propane over natural gas. Students may also consider the availability of propane (if they don't have a natural gas connection available) or the convenience of natural gas if they do have a connection available.
7. **(a)** Part 1 Energy input

   Since the methane burner is heating a beaker of water, we can assume it is an open system. From Table 9.3, the molar enthalpy of combustion of methane, $CH_4(g)$, is –802.5 kJ/mol.

   Method 1 Using Formulas

   $$n = \frac{m}{M}$$

   $$= \frac{0.37 \cancel{\text{ g } CH_4(g)}}{\frac{16.05 \cancel{\text{ g } CH_4(g)}}{\text{mol } CH_4(g)}}$$

   $$= 0.0231 \text{ mol } CH_4(g)$$

$$\begin{aligned}\Delta H &= n\Delta H_c\\ &= (0.0231\ \cancel{\text{mol CH}_4\text{(g)}})\left(\frac{-802.5\ \text{kJ}}{\cancel{\text{mol CH}_4\text{(g)}}}\right)\\ &= -18.5\ \text{kJ}\end{aligned}$$

Method 2 Using Dimensional Analysis

$$\begin{aligned}x\ \text{kJ} &= 0.37\ \cancel{\text{g CH}_4\text{(g)}} \times \frac{1\ \cancel{\text{mol CH}_4\text{(g)}}}{16.05\ \cancel{\text{g CH}_4\text{(g)}}} \times \frac{-802.5\ \text{kJ}}{\cancel{\text{mol CH}_4\text{(g)}}}\\ &= -18.5\ \text{kJ}\end{aligned}$$

Part 2 Energy output

Mass of water = 427.96 g – 275.38 g = 152.58 g

Temperature change = 37.9 °C – 25.3 °C = 12.6 °C

$$\begin{aligned}Q &= (mc\Delta t)_{\text{water}} + (mc\Delta t)_{\text{glass}}\\ &= (152.58\ \cancel{\text{g}})\left(\frac{4.19\ \text{J}}{\cancel{\text{g}}\bullet\cancel{^\circ\text{C}}}\right)(12.6\ \cancel{^\circ\text{C}}) + (275.38\ \cancel{\text{g}})\left(\frac{0.84\ \text{J}}{\cancel{\text{g}}\bullet\cancel{^\circ\text{C}}}\right)(12.6\ \cancel{^\circ\text{C}})\\ &= 11.0\ \text{kJ}\end{aligned}$$

$$\begin{aligned}\text{Efficiency} &= \left|\frac{\text{Energy output}}{\text{Energy input}}\right| \times 100\%\\ &= \left|\frac{11.0\ \text{kJ}}{-18.5\ \text{kJ}}\right| \times 100\%\\ &= 60\%\end{aligned}$$

(b) The majority of the wasted energy would have been used to heat up the surroundings, which includes the air surrounding the burner, the burner itself, the thermometer and stirring rod.

(c) To decrease heat lost and reduce wasted energy, the system must be insulated as best as possible from the surroundings. By shielding the beaker from the outside air with an insulating substance such as Styrofoam™, and by putting a lid on the beaker, this would minimize heat loss and therefore increase efficiency.

8. (a) This is worse than the posted fuel economy, since the gas consumption is higher than the posted consumptions.

(b) Some reasons may include: driving at higher speeds in the city, idling the engine, driving with under-inflated tires, accelerating quickly from a stop, not coasting to a stop (all would increase fuel consumption). As well, a new car with an engine that is not yet broken in will have higher fuel consumption.

(c) Fuel economy can be improved by changing your driving habits. Driving slower, not idling the car, accelerating slowly from a stop and allowing a car to slow down by taking your foot off the gas rather than applying the brakes will all improve fuel economy.

9. To use the waste heat produced by any cooling system, which could include an air-conditioner as well as a refrigerator, you could build something similar to a solar-heating system. The warm air exiting the air conditioner or refrigerator would have to be contained and circulated around piping containing water. The preheated water would then already be partially warmed before entering the hot water tank, reducing energy costs. Heated water could also be used as radiant floor heating.

10.3 Fuelling Society

Student Textbook pages 393–398

Section Outcomes

Students will:
- analyze personal reliance on hydrocarbon fossil fuels
- illustrate the applications of hydrocarbon fossil fuels
- evaluate the economic and environmental impact of different fuels based on emissions and heat content
- evaluate whether coal or natural gas should be used to fuel thermal power plants

Key Terms

greenhouse gas
global warming
non-renewable energy source
renewable
heat content

Chemistry Background

- Greenhouse gases trap heat in the Earth's atmosphere. Scientists believe that increased greenhouse gas levels are leading to global warming.
- Renewable resources are not depleted by their use, whereas non-renewable resources are. Some resources, like wood, may be renewable or non-renewable, depending on how they are used.
- Canadians rely on fossil fuels for approximately 80% of their energy requirements; Albertans rely on considerably more, as almost all of Alberta's electricity is produced from either coal or natural gas.
- "Clean" fuels produce fewer emissions than others. Coal and oil both produce more carbon monoxide, nitrogen oxides, sulfur dioxide and particulates than does natural gas.
- The heat content is the quantity of energy produced per kilogram of the fuel.

Teaching Strategies

- Introduce students to this section by discussing the section, "Thinking About the Environment." Students have studied greenhouse gases, global warming, and renewable and non-renewable resources in the past. Get students thinking about these topics in an Alberta context. Many students will have driven by or visited towns where wind power is harnessed, or a sour gas plant has been built.
- Because Alberta uses coal and natural gas as its principal methods of producing electricity, our greenhouse gas emissions per kilowatt hour of electricity is the highest in the country. Have students discuss this fact and look at

how other provinces are using cleaner fuels to produce their electricity.

- Ask students to stand if someone in their immediate family works in the energy sector. Discuss Alberta's economic dependence on the revenue from fossil fuels.
- During this section, have students collect news articles on the environmental impact of the use and transport of fossil fuels to discuss in class.
- The BLMs prepared for this section support the activities. You will find them with the Chapter 10 BLMs on the CD-ROM that accompanies this Teacher's Resource or at **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, BLMs.

Investigation 10.C: Fossil Fuels as Energy Sources: A Risk-Benefit Analysis

Student Textbook pages 396

Purpose

In this investigation, students will work in teams to research the use and production of fossil fuels in Alberta and propose a plan to reduce our dependency on fossil fuels and their impact on the environment.

Outcomes

- 30-A2.2sts
- 30-A2.2s
- 30-A2.4s

Advance Preparation

When to Begin	What to Do
Up to 1 month before	■ Book the computer lab. ■ Photocopy **BLM 10.3.1: Investigation 10.C.**

Time Required

- 70 minutes for research and doing a risk-benefit analysis
- 60 minutes to present findings

Helpful Tips

- Use **BLM 10.3.1 (HAND) Investigation 10.3: Fossil Fuels as Energy Sources** to support this activity. Modify as necessary.
- Ideal group size is around three students. To save time, make the groups larger.
- The principal fossil fuels produced and used in Alberta include: coal, natural gas, sour gas, crude oil and its fractions. Students should be encouraged to look at only one fraction of crude oil, such as ethene (ethylene), gasoline, kerosene, naphthas, diesel, fuel oil.
- Review the form of a risk-benefit analysis.

Answers to Opinions and Recommendations

1. (a) Generally, students will find that provincial and federal governments attempt to regulate and educate the public and industry about safety, environmental and health concerns. However, if any students are avid news readers or watchers, they will be familiar with on-going conflicts between communities, industry and the government over sour gas plants and environmental hazards caused by fossil fuel production and use. These students may voice the opinion that it is only when industry is caught that the government forces the issue with industry, as is commonly seen in the cleanup of environmental spills.

(b) Students may point out the economic benefits of these industries to conclude that the benefits outweigh the risk. If students have performed some calculations to attach a cost to environmental cleanups and address potential wide scale safety breaches, they may suggest that the risks do not outweigh the benefits.

(c) Students should explain their proposal in detail and assess the potential for its implementation.

Assessment Options

- Collect and assess students' posters or presentations and answers to Analysis questions.
- Use Assessment Checklists 3: Performance Task Self Assessment and Assessment Checklist 4: Performance Task Group Assessment from Appendix A.

Chemistry File: Web Link

Student Textbook page 397

As shown in Table 10.4 on page 397 of the student textbook, there is a considerable difference in the amount of harmful emissions produced by various fuels when burned. The fewer harmful emissions, including carbon dioxide, the cleaner a fuel is. Table 10.4 provides average emission levels for each of natural gas, oil and coal, however the actual level of emissions varies greatly depending on the location of the fuel's recovery and the quantity of processing that takes place before combustion. For example, coal is sub-classified by its moisture content, degree of transformation (anthracite is the hardest form of coal), and sulfur content. Alberta coal tends to be less than 0.5% sulfur, therefore producing less sulfur dioxide than coal mined in other parts of the country.

Investigation 10.D: Fuelling Thermal Power Plants

Student Textbook page 398

Purpose

In this investigation, students will work in small teams to compile data on the heat content of fuels used in Alberta's thermal power plants along with environmental data to assess the fuels' suitability.

Outcomes

- 30-A2.3sts
- 30-A2.2s
- 30-A2.3s

Advance Preparation

When to Begin	What to Do
Up to 1 month before	■ Book the computer lab. ■ Photocopy **BLM 10.3.2: Investigation 10.D.**

Time Required

- 60 minutes for research and developing a spreadsheet and graph

Helpful Tips

- Use **BLM 10.3.2 (HAND) Investigation 10.D: Fuelling Thermal Power Plants** to support this activity. Modify as necessary.
- Groups of two are ideal for this investigation as each student can research one fuel.
- Encourage students to look at more than just the environmental impact of combustion. They should also be looking at hazards involved in the recovery and transport of the fuel.

Answers to Opinions and Recommendations

1. **(a)** Most students will come to the conclusion that natural gas is a better fuel to use in a power plant, since it is both cleaner and causes less environmental damage when recovered. Students who look deeper into the issue will note that a significant economic investment has been made in coal, and if that were not continued, jobs would be lost and retrofitting of existing power plants would have to be undertaken.

   (b) Although it is unlikely that Alberta would commit to one fuel or the other given that there are power plants in operation using both fuels, some students may suggest that all of the power plants should switch to natural gas, regardless of the economic impact. It is, however, unlikely that a power plant fitted to burn coal would be refit for natural gas unless the economic benefits outweighed the costs.

   (c) Students should look at other groups' plans and remark on ideas that other groups looked at that they did not.

Assessment Options

- Collect and assess students' presentations/posters and answers to Analysis questions.
- Use Assessment Checklist 3: Performance Task Self Assessment from Appendix A.

Section 10.3 Review Answers

Student Textbook page 398

1. Some activities that use fossil fuels include: showering and cooking breakfast in a warm home (natural gas to heat the water, space and cook food), watching television (coal burned to create electricity), and driving to and from school (gasoline for the car).
2. A clean fuel is one that does not produce emissions. There are "clean" fuels, in that when they are used to produce heat or electricity, there are no emissions generated directly (such as wind or hydro); however in harnessing these forms of energy, other forms of energy are used (such as the gasoline used in the transportation of workers) that do not use clean fuels. Therefore, no energy source is ultimately "clean."
3. **(a)** global warming – $CO_2(g)$ (primarily)

   (b) acid rain or snow – $CO_2(g)$, $NO_2(g)$, $SO_2(g)$

   (c) smog – $NO_2(g)$
4. Heat content is measured in kJ/kg of fuel, whereas enthalpy of combustion is measured in kJ/mol of fuel. Heat content is more useful in evaluating fuels as consumers purchase and transport fuels using units of litres or kilograms, not moles.
5.

Risks of relying on fossil fuels	Benefits of relying on fossil fuels
■ their combustion contributes to global warming	■ fossil fuels are plentiful in Alberta, and we can sell them to others
■ they are a non-renewable resource	■ we have an economic base in fossil fuels that can be exploited

Risks of relying on fossil fuels	Benefits of relying on fossil fuels
■ their recovery is harmful to the environment	■ the technology to use them is inexpensive and plentiful

6. Natural gas is a better choice for use in thermal power plants because it is a cleaner burning fuel, producing lower levels of carbon monoxide, nitrogen oxides, sulfur dioxide and particulates than coal or oil. These emissions contribute to global warming, acid rain and smog.

Chapter 10 Review Answers

Student Textbook pages 400–401

Answers to Understanding Concepts Questions

1. If the enthalpy change for the original equation is ΔH, then the enthalpy change for the manipulated equation will be $3 \times -\Delta H$. The molar enthalpy change of the reaction is not changed.
2. **(a)** (a) $Ag(s) + \frac{1}{2}Cl_2(g) \rightarrow AgCl(s)$

   $\Delta_f H° = -127.0$ kJ/mol

   (b) $2C(s) + 3H_2(g) + \frac{1}{2}O_2(g) \rightarrow C_2H_5OH(\ell)$

   $\Delta_f H° = -277.6$ kJ/mol

   (c) $N_2(g) + 2H_2(g) + \frac{3}{2}O_2(g) \rightarrow NH_4NO_3(s)$

   $\Delta_f H° = -365.6$ kJ/mol

   (b) Least stable to most stable: $AgCl(s)$, $C_2H_5OH(\ell)$, $NH_4NO_3(s)$
3. The standard state of an element is its most stable form at SATP (25 °C and 100 kPa). At these conditions, iodine is a solid. For 1 mol of $I_2(s)$ to sublimate and form $I_2(g)$, 21 kJ of energy must be absorbed.
4. Efficiency is usually defined as useful energy output divided by the energy input, expressed as a percentage. In this case, efficiency would be best described as moving the most people using the least amount of energy. In this case, the bus would be more efficient than a car.
5. The lawn could be mowed using a more efficient electric mower, or an even more efficient push mower.
6. The useful energy output by a hair dryer would be the moving hot air (using energy to heat the air and move the air). The rest of the energy would be waste. This would include the noise made by the hair dryer and the heating of the hair dryer itself.
7. A smart shopper should look for an EnerGuide and an ENERGY STAR® sticker on their appliances. The EnerGuide label allows a consumer to quickly judge the energy efficiency of the appliance compared to others in its class using a sliding scale. If present, the ENERGY STAR® label is an easy way to tell that this appliance is one of the most energy efficient in its category.
8. A car will operate at its maximum fuel efficiency if it is well maintained and has its tires inflated to the proper pressure. By driving at or below the speed limit and by not accelerating or decelerating quickly, a driver can further improve their fuel efficiency.
9. Using hydro or wind to produce electricity is more efficient than using coal or natural gas because there are fewer energy conversions. Wind turns the turbines directly to produce electricity, whereas coal must be burned to heat water and create steam to turn turbines. There are more steps, so more energy is lost along the way.

Answers to Applying Concepts Questions

10. Step 1: Determine the heat of combustion of carbon in excess oxygen to form carbon dioxide:

    (1) $C(s) + O_2(g) \rightarrow CO_2(g)\ \Delta H_1$

    Step 2: Determine the enthalpy change for the combustion of CO(g) in excess oxygen to form $CO_2(g)$:

    (2) $CO(g) + \frac{1}{2}O_2(g) \rightarrow CO_2(g)\ \Delta H_2$

    The heat of formation of CO(g) can be determined using these two equations and Hess's law:

$$\begin{array}{ll} CO_2(g) \rightarrow CO(g) + \frac{1}{2}O_2(g) & -\Delta H_2 \\ C(s) + O_2(g) \rightarrow CO_2(g) & \Delta H_1 \\ \hline C(s) + \frac{1}{2}O_2(g) \rightarrow CO(g) & \Delta_f H° = \Delta H_1 - \Delta H_2 \end{array}$$

11. There are many ways to reduce greenhouse gas emissions and still keep driving a car. Making some simple changes in driving habits and performing regular maintenance will make any car more fuel-efficient. As well, energy can be saved at home by having shorter showers and by using a low-flow showerhead. Students could direct their friend to one of the websites they have used during this chapter to investigate ways to conserve energy and reduce greenhouse gas emissions.
12. **(a)** Since the overall enthalpy change for the reaction is negative and the enthalpy of formation of hydrogen, $H_2(g)$, is zero, then the potential energy stored in acetylene, $C_2H_2(g)$ must be higher (have a higher enthalpy of formation) than ethylene, $C_2H_4(g)$.

    (b) Acetylene would release more energy when burned since it has a higher enthalpy of formation; it has more stored energy in its three bonds, which would be released when burned.
13. Students should disagree with this statement. Although harnessing electricity does not directly produce any emissions, building and running the plant does. In constructing a hydroelectric power plant, ecosystems are permanently destroyed, therefore, there is considerable harm to the environment.
14. A primary reason why nuclear energy is not a viable alternative for Alberta is that these plants require a significant

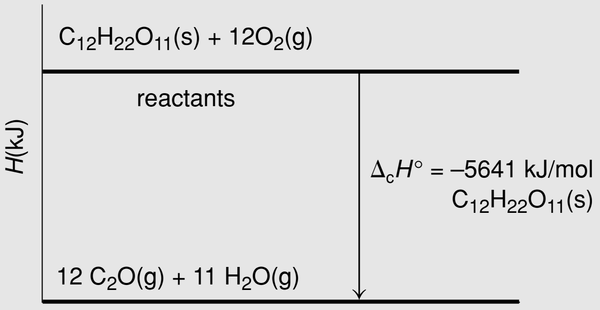
amount of water for cooling. Although uranium is mined in Saskatchewan, it is processed in Ontario, which would add shipping costs to the cost of producing energy. Since Alberta is rich in coal and other fossil fuels, it is economically better to produce energy using closely available resources. To decide whether it would be feasible to produced energy using nuclear power, students should perform a risk-benefit analysis. Students could include the following topics: available technology, economic issues, availability of fossil fuels and uranium, potential hazards to the environment, effects on the Alberta economy, and potential health problems resulting from the use of these fuels.

Answers to Solving Problems Questions

15. (a) $-5641\text{ kJ} = [(12\text{ mol})(-393.5\text{ kJ/mol}) + (11\text{ mol})(-285.8\text{ kJ/mol})] - [(12\text{ mol})(0\text{ kJ/mol}) + (1\text{ mol})(\Delta_f H^\circ\ C_{12}H_{22}O_{11}(g))]$

$\Delta_f H^\circ\ C_{12}H_{22}O_{11}(g) = -2225\text{ kJ/mol}$

(b)



E_p Diagram for the Combustion of Sucrose

16. $-1 \times \mathbf{(3)}\ CHCl_3(\ell) \rightarrow \cancel{C(s)} + \frac{1}{2}\cancel{H_2(g)} + \frac{3}{2}Cl_2(g)$

$\Delta H^\circ = -1(-134.5\text{ kJ})$

$-3 \times \mathbf{(1)}\ 3HCl(g) \rightarrow \frac{3}{2}\cancel{H_2(g)} + \frac{3}{2}Cl_2(g)$

$\Delta H^\circ = -3(-92.3\text{ kJ})$

$\mathbf{(2)}\ \cancel{C(s)} + 2\cancel{H_2(g)} \rightarrow CH_4(g) \quad \Delta H^\circ = -74.6\text{ kJ}$

$CHCl_3(\ell) + 3HCl(g) \rightarrow CH_4(g) + 3Cl_2(g)$

$\Delta H^\circ = (134.5\text{ kJ} + 276.9\text{ kJ} -74.6\text{ kJ})$

$= 336.8\text{ kJ}$

17. $\Delta H^\circ = \Sigma(n\Delta_f H^\circ\text{ products}) - \Sigma(n\Delta_f H^\circ\text{ reactants})$

$-1178\text{ kJ} = [(2\text{ mol} \times \Delta_f H^\circ\ CO_2(g)) + (3\text{ mol} \times \Delta_f H^\circ\ H_2O(\ell))] - [(1\text{ mol} \times \Delta_f H^\circ\ (CH_2OH)_2(\ell)) + 0]$

$-1178\text{ kJ} = [(2\text{ mol} \times -393.5\text{ kJ/mol}) + (3\text{ mol} \times -285.8\text{ kJ/mol})] - [1\text{ mol} \times \Delta_f H^\circ (CH_2OH)_2(\ell)]$

$-1178\text{ kJ} = -787.0\text{ kJ} - 857.4\text{ kJ} - (1\text{ mol}) \times (\Delta_f H^\circ\ (CH_2OH)_2(\ell))$

$\Delta_f H^\circ\ (CH_2OH)_2(\ell) = -466\text{ kJ/mol}$

18. (a) $H_2(g) + O_2(g) \rightarrow H_2O_2(\ell)$

(b) $-\frac{1}{2} \times \mathbf{(1)}\ \cancel{H_2O}(\ell) + \frac{1}{2}O_2(g) \rightarrow H_2O_2(\ell)$

$\Delta H^\circ = -\frac{1}{2}(-196\text{ kJ})$

$\mathbf{(1)}\ H_2(g) + \frac{1}{2}O_2(g) \rightarrow \cancel{H_2O}(\ell)$

$\Delta H^\circ = -286\text{ kJ}$

$H_2(g) + O_2(g) \rightarrow H_2O_2(\ell)$

$\Delta H^\circ = (+98\text{ kJ} - 286\text{ kJ})$

$\Delta H^\circ = -188\text{ kJ}$

19. $\frac{1}{2} \times \mathbf{(1)}\ \frac{1}{2}H_2(g) + C(s) + \frac{1}{2}N_2(g) \rightarrow HCN(g)$

$\Delta H^\circ = \frac{1}{2}(270\text{ kJ})$

$-1 \times \mathbf{(3)}\ CH_4(g) \rightarrow C(s) + 2H_2(g)$

$\Delta H^\circ = -1(-75\text{ kJ})$

$-\frac{1}{2} \times \mathbf{(2)}\ NH_3(g) \rightarrow \frac{1}{2}N_2(g) + \frac{3}{2}H_2(g)$

$\Delta H^\circ = -\frac{1}{2}(-92\text{ kJ})$

$CH_4(g) + NH_3(g) \rightarrow HCN(g) + 3H_2(g)$

$\Delta H^\circ = (+135\text{ kJ} + 75\text{ kJ} + 46\text{ kJ})$

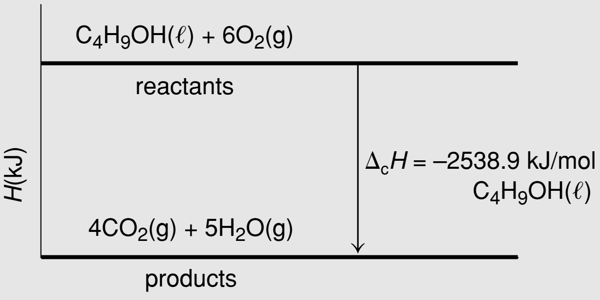
$\Delta H^\circ = +256\text{ kJ}$

20. (a) $\Delta_c H = [4(\Delta_f H^\circ\ CO_2(g)) + 5(\Delta_f H^\circ\ H_2O(g))] - [6(\Delta_f H^\circ\ O_2(g)) + 1(\Delta_f H^\circ\ C_4H_9OH(\ell))]$

$\Delta_c H = [(4\text{ mol})(-393.5\text{ kJ/mol}) + (5\text{ mol})(-241.8\text{ kJ/mol})] - [(6\text{ mol})(0\text{ kJ/mol}) + (1\text{ mol})(-244.4\text{ kJ/mol})]$

$\Delta_c H = -2538.6\text{ kJ/mol}$

(b)



(c) Method 1 Using Formulas

$$n = \frac{m}{M}$$

$$= \frac{10.0\ \cancel{g\ C_4H_9OH(\ell)}}{\frac{74.14\ \cancel{g\ C_4H_9OH(\ell)}}{\text{mol } C_4H_9OH(\ell)}}$$

$$= 0.1349\text{ mol } C_4H_9OH(\ell)$$

$$\Delta H = n\Delta_c H$$

$$= (0.1349\ \cancel{\text{mol } C_4H_9OH(\ell)})\left(\frac{-2538.6\text{ kJ}}{\cancel{\text{mol } C_4H_9OH(\ell)}}\right)$$

$$= -342\text{ kJ}$$

Method 2 Using Dimensional Analysis

$$x\text{ kJ} = 10.0\ \cancel{\text{g C}_4\text{H}_9\text{OH}(\ell)} \times \frac{1\ \cancel{\text{mol C}_4\text{H}_9\text{OH}(\ell)}}{74.14\ \cancel{\text{g C}_4\text{H}_9\text{OH}(\ell)}} \times \frac{-2538.6\text{ kJ}}{\cancel{\text{mol C}_4\text{H}_9\text{OH}(\ell)}}$$

$$= -342\text{ kJ}$$

21. First, the molar enthalpy of combustion of ethanol must be calculated:

$$\text{C}_2\text{H}_5\text{OH}(\ell) + 3\text{O}_2(\text{g}) \rightarrow 2\text{CO}_2(\text{g}) + 3\text{H}_2\text{O}(\text{g})$$

$$\begin{aligned}\Delta H^\circ &= \Sigma(n\Delta_f H^\circ \text{ products}) - \Sigma(n\Delta_f H^\circ \text{ reactants})\\ &= [(2\text{ mol})(\Delta_f H^\circ\ \text{CO}_2(\text{g})) + (3\text{ mol})(\Delta_f H^\circ\ \text{H}_2\text{O}(\text{g}))]\\ &\quad - [(1\text{ mol})(\Delta_f H^\circ\ \text{C}_2\text{H}_5\text{OH}(\ell)) + (3\text{ mol})(\Delta_f H^\circ\ \text{O}_2(\text{g}))]\\ &= [(2\text{ mol})(-393.5\text{ kJ/mol}) + (3\text{ mol})(-241.8\text{ kJ/mol})]\\ &\quad - [(1\text{ mol})(-277.6\text{ kJ/mol}) + (3\text{ mol})(0\text{ kJ/mol})]\\ &= -1512.4\text{ kJ} - (-277.6\text{ kJ})\\ &= -1234.8\text{ kJ/mol C}_2\text{H}_5\text{OH}(\ell)\end{aligned}$$

The molar enthalpy of combustion from question 20 is –2538.6 kJ/mol.

The amount of energy released by the mixture can be calculated by determining the amount of energy released by each of the components and then adding them together. In a 1.0 g sample, there would be 0.70 g of ethanol and 0.30 g of butan-1-ol. By determining how much energy is released by these quantities of each fuel, a total amount of energy per gram of the fuel in the burner can be determined.

Method 1 Using Formulas

For butan-1-ol

$$\begin{aligned}n &= \frac{m}{M}\\ &= \frac{0.30\ \cancel{\text{g C}_4\text{H}_9\text{OH}(\ell)}}{\dfrac{74.14\ \cancel{\text{g C}_4\text{H}_9\text{OH}(\ell)}}{\text{mol C}_4\text{H}_9\text{OH}(\ell)}}\\ &= 0.00405\text{ mol C}_4\text{H}_9\text{OH}(\ell)\end{aligned}$$

$$\begin{aligned}\Delta H &= n\Delta_c H\\ &= (0.00405\ \cancel{\text{mol C}_4\text{H}_9\text{OH}(\ell)})\left(\frac{-2538.6\text{ kJ}}{\cancel{\text{mol C}_4\text{H}_9\text{OH}(\ell)}}\right)\\ &= -10\text{ kJ}\end{aligned}$$

For ethanol

$$\begin{aligned}n &= \frac{m}{M}\\ &= \frac{0.70\ \cancel{\text{g C}_2\text{H}_5\text{OH}(\ell)}}{\dfrac{46.08\ \cancel{\text{g C}_2\text{H}_5\text{OH}(\ell)}}{\text{mol C}_2\text{H}_5\text{OH}(\ell)}}\\ &= 0.0152\text{ mol C}_2\text{H}_5\text{OH}(\ell)\end{aligned}$$

$$\begin{aligned}\Delta H &= n\Delta_c H\\ &= (0.0152\ \cancel{\text{mol C}_2\text{H}_5\text{OH}(\ell)})\left(\frac{-1234.8\text{ kJ}}{\cancel{\text{mol C}_2\text{H}_5\text{OH}(\ell)}}\right)\\ &= -19\text{ kJ}\end{aligned}$$

Therefore, the total amount of energy released per gram of fuel can be determined:

$$\begin{aligned}\Delta H &= -10\text{ kJ} + (-19\text{ kJ})\\ &= -29\text{ kJ/g of burner fuel}\end{aligned}$$

Method 2 Using Dimensional Analysis

$$\begin{aligned}x\text{ kJ} &= 0.30\ \cancel{\text{g C}_4\text{H}_9\text{OH}(\ell)} \times \frac{1\ \cancel{\text{mol C}_4\text{H}_9\text{OH}(\ell)}}{74.14\ \cancel{\text{g C}_4\text{H}_9\text{OH}(\ell)}} \times \frac{-2538.6\text{ kJ}}{\cancel{\text{mol C}_4\text{H}_9\text{OH}(\ell)}} + 0.70\ \cancel{\text{g C}_2\text{H}_5\text{OH}(\ell)} \times\\ &\quad \frac{1\ \cancel{\text{mol C}_2\text{H}_5\text{OH}(\ell)}}{46.08\ \cancel{\text{g C}_2\text{H}_5\text{OH}(\ell)}} \times \frac{-1234.8\text{ kJ}}{\cancel{\text{mol C}_2\text{H}_5\text{OH}(\ell)}}\\ &= -29\text{ kJ/g of burner fuel}\end{aligned}$$

22. First, the enthalpy change for the reaction must be calculated:

$$3\text{H}_2(\text{g}) + \text{CO}(\text{g}) \rightarrow \text{CH}_4(\text{g}) + \text{H}_2\text{O}(\text{g})$$

$$\begin{aligned}\Delta H^\circ &= \Sigma(n\Delta_f H^\circ \text{ products}) - \Sigma(n\Delta_f H^\circ \text{ reactants})\\ &= [(1\text{ mol})(\Delta_f H^\circ\ \text{CH}_4(\text{g})) + (1\text{ mol})(\Delta_f H^\circ\ \text{H}_2\text{O}(\text{g}))]\\ &\quad - [(3\text{ mol})(\Delta_f H^\circ\ \text{H}_2(\text{g})) + (1\text{ mol})(\Delta_f H^\circ\ \text{CO}(\text{g}))]\\ &= [(1\text{ mol})(-74.6\text{ kJ/mol}) + (1\text{ mol})(-241.8\text{ kJ/mol})]\\ &\quad - [(3\text{ mol})(0) + (1\text{ mol})(-110.5\text{ kJ/mol})]\\ &= -205.9\text{ kJ}\end{aligned}$$

Now, you can find the quantity of energy released or absorbed:

Method 1 Using Formulas

$$\begin{aligned}n &= \frac{m}{M}\\ &= \frac{7.9\ \cancel{\text{g CH}_4(\text{g})}}{\dfrac{16.05\ \cancel{\text{g CH}_4(\text{g})}}{\text{mol CH}_4(\text{g})}}\\ &= 0.492\text{ mol CH}_4(\text{g})\end{aligned}$$

$$\begin{aligned}\Delta H &= n\Delta_r H\\ &= (0.492\ \cancel{\text{mol CH}_4(\text{g})})\left(\frac{-205.9\text{ kJ}}{\cancel{\text{mol CH}_4(\text{g})}}\right)\\ &= -1.0 \times 10^2\text{ kJ}\end{aligned}$$

Method 2 Using Dimensional Analysis

$$\begin{aligned}x\text{ kJ} &= 7.9\ \cancel{\text{g CH}_4(\text{g})} \times \frac{1\ \cancel{\text{mol CH}_4(\text{g})}}{16.05\ \cancel{\text{g CH}_4(\text{g})}} \times \frac{-205.9\text{ kJ}}{\cancel{\text{mol CH}_4(\text{g})}}\\ &= -1.0 \times 10^2\text{ kJ}\end{aligned}$$

23. **(a)**, **(b)**, **(c)** Accept all reasonable procedures. Students will probably design an experiment similar to Investigation 9.B on page 358-359, using a measured mass of camping fuel in an alcohol burner (or other similar burner) to heat water in a calorimeter. They can determine the enthalpy change based on the temperature change of the water.

(d) The experimental value is likely lower, as the accepted value for the molar enthalpy of combustion assumes there are no heat losses to the surroundings, and the heat content of the calorimeter is negligible. The accepted value is also based on an assumption that complete combustion takes place, although this is probably not the case.

24. Energy input = mass of fuel × enthalpy of combustion

$$= (3.25\ \text{g})(-44.6\ \text{kJ/g})$$
$$= -145\ \text{kJ}$$

Energy Ouput

$$Q = mc\Delta t_{\text{water}} + mc\Delta t_{\text{aluminium}}$$
$$= (250\ \text{g})\left(\frac{4.19\ \text{J}}{\cancel{\text{g}}\bullet\cancel{°\text{C}}}\right)(85.0\ \cancel{°\text{C}} - 2.5\ \cancel{°\text{C}}) + (150\ \text{g})\left(\frac{0.897\ \text{J}}{\cancel{\text{g}\bullet°\text{C}}}\right)(85.0\ \cancel{°\text{C}} - 2.5\ \cancel{°\text{C}})$$
$$= 97.5\ \text{kJ}$$

$$\text{Efficiency} = \left|\frac{\text{Energy output}}{\text{Energy input}}\right| \times 100\%$$
$$= \left|\frac{97.5}{-145}\right| \times 100\%$$
$$= 67\%$$

25. Energy input is equal to the amount of energy provided by 4.75 g of methane. The molar enthalpy of combination of methane in an open system can be found in Table 9.1 on page 347.

Energy input

Method 1 Using Formulas

$$n = \frac{m}{M}$$
$$= \frac{4.75\ \cancel{\text{g CH}_4\text{(g)}}}{\dfrac{16.05\ \cancel{\text{g CH}_4\text{(g)}}}{\text{mol CH}_4\text{(g)}}}$$
$$= 0.2960\ \text{mol CH}_4\text{(g)}$$

$$\Delta H = n\Delta_{\text{c}}H$$
$$= (0.2960\ \cancel{\text{mol CH}_4\text{(g)}})\left(\frac{-802.5\ \text{kJ}}{\cancel{\text{mol CH}_4\text{(g)}}}\right)$$
$$= -238\ \text{kJ}$$

Method 2 Using Dimensional Analysis

$$x\ \text{kJ} = 4.75\ \cancel{\text{g CH}_4\text{(g)}} \times \frac{1\ \cancel{\text{mol CH}_4\text{(g)}}}{16.05\ \cancel{\text{g CH}_4\text{(g)}}} \times \frac{-802.5\ \text{kJ}}{\cancel{\text{mol CH}_4\text{(g)}}}$$
$$= -238\ \text{kJ}$$

$$\text{Efficiency} = \left|\frac{\text{Energy output}}{\text{Energy input}}\right| \times 100\%$$
$$47\ \% = \left|\frac{\text{Energy output}}{-238\ \text{kJ}}\right| \times 100\%$$

Energy output = 112 kJ

Use the energy output to determine the mass of water that could be heated.

$$Q = mc\Delta t$$
$$m = \frac{Q}{c\Delta t}$$
$$= \frac{1.12 \times 10^5\ \cancel{\text{J}}}{\left(\dfrac{4.19\ \cancel{\text{J}}}{\text{g}\bullet\cancel{°\text{C}}}\right)(100\ \cancel{°\text{C}} - 10\ \cancel{°\text{C}})}$$
$$= 3.0 \times 10^2\ \text{g}$$

26. First, calculate the amount of energy required to preheat the barbeque (energy output)

$$Q = mc\Delta t$$
$$= (5000\ \cancel{\text{g}})\left(\frac{0.46\ \text{J}}{\cancel{\text{g}}\bullet\cancel{°\text{C}}}\right)(175\ \cancel{°\text{C}} - 25\ \cancel{°\text{C}})$$
$$= 345\ \text{kJ}$$

$$\text{Efficiency} = \left|\frac{\text{Energy output}}{\text{Energy input}}\right| \times 100\%$$
$$50\% = \left|\frac{345\ \text{kJ}}{\text{Energy input}}\right| \times 100\%$$

Energy input = 690 kJ

Use the required energy input and the molar enthalpy of combustion of propane (found in Table 9.1 on page 347) to determine the mass of propane required.

Method 1 Using Formulas

$$\Delta H = n\Delta_{\text{c}}H$$
$$n = \frac{\Delta H}{\Delta_{\text{c}}H}$$
$$= \frac{-690\ \cancel{\text{kJ}}}{\dfrac{-2043.9\ \cancel{\text{kJ}}}{\text{mol C}_3\text{H}_8\text{(g)}}}$$
$$= 0.338\ \text{mol C}_3\text{H}_8\text{(g)}$$

$$n = \frac{m}{M}$$
$$m = nM$$
$$= (0.338\ \cancel{\text{mol C}_3\text{H}_8\text{(g)}})\left(\frac{44.11\ \text{g C}_3\text{H}_8\text{(g)}}{\cancel{\text{mol C}_3\text{H}_8\text{(g)}}}\right)$$
$$= 15\ \text{g C}_3\text{H}_8\text{(g)}$$

Method 2 Using Dimensional Analysis

$$x\ \text{g C}_3\text{H}_8\text{(g)} = -690\ \cancel{\text{kJ}} \times \frac{\cancel{\text{mol C}_3\text{H}_8\text{(g)}}}{-2043.9\ \text{kJ}} \times \frac{44.11\ \text{g C}_3\text{H}_8\text{(g)}}{\cancel{\text{mol C}_3\text{H}_8\text{(g)}}}$$
$$= 15\ \text{g C}_3\text{H}_8\text{(g)}$$

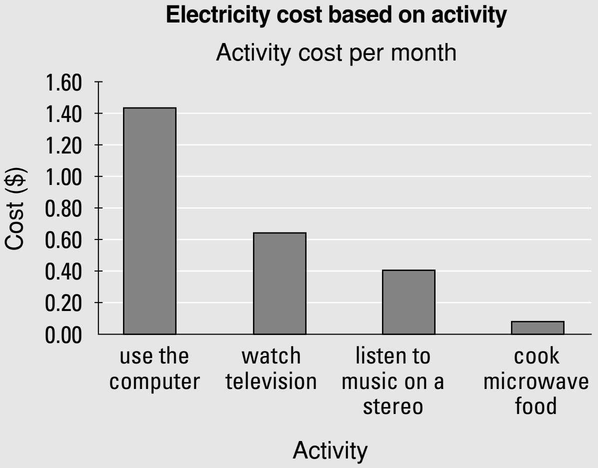
Answers to Making Connections Questions

27. (a) and **(b)** Sample calculations are shown below:

Based on an electrical cost of $ 0.06/kWh

Activity	Typical Wattage (W)	Hours/ month used (h)	Cost per month ($)
use the computer	200	120	1.44
watch television	180	60	0.72
listen to music on a stereo	115	60	0.41
cook microwave food	600	2.5	0.09

(c)



(d) The activities that use the most energy, and therefore cost the most, are likely ones that students will not think of, and include heating their homes, the water they shower in and the laundry they wash. Of the activities that students will likely list, the computer is probably the most energy-consuming.

(e) Student spreadsheets should include a table such as the one above, where the electrical cost would be entered into a cell and then referenced in the calculation for "Cost per month".

28. (a) $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$

$$\begin{aligned}\Delta_c H^\circ &= \Sigma(n\Delta_f H^\circ \text{ products}) - \Sigma(n\Delta_f H^\circ \text{ reactants})\\ &= [(1\text{ mol})(\Delta_f H^\circ\ CO_2(g)) + (2\text{ mol})(\Delta_f H^\circ\ H_2O(g))] - [(1\text{ mol})(\Delta_f H^\circ\ CH_4(g)) + (2\text{ mol})(\Delta_f H^\circ\ O_2(g))]\\ &= [(1\text{ mol})(-393.5\text{ kJ/mol}) + (2\text{ mol})(-241.8\text{ kJ/mol})] - [(1\text{ mol})(-74.6\text{ kJ/mol}) + (2\text{ mol})(0\text{ kJ/mol})]\\ &= -802.5\text{ kJ/mol } CH_4(g)\end{aligned}$$

$$x\,\frac{\text{kJ}}{\text{g } CH_4(g)} = \frac{-802.5\text{ kJ}}{\cancel{\text{mol } CH_4(g)}} \times \frac{\cancel{\text{mol } CH_4(g)}}{16.05\text{ g } CH_4(g)}$$

$$= -50.0\,\frac{\text{kJ}}{\text{g } CH_4(g)}$$

$$H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(g)$$

$$\Delta_c H^\circ = \Delta_f H^\circ\ H_2O(g) = -241.8\text{ kJ/mol } H_2(g)$$

$$\times\,\frac{\text{kJ}}{\text{g } H_2(g)} = \frac{-241.8\text{ kJ}}{\cancel{\text{mol } H_2(g)}} \times \frac{\cancel{\text{mol } H_2(g)}}{2.02\text{ g } H_2(g)}$$

$$= -120\,\frac{\text{kJ}}{\text{g } H_2(g)}$$

(b) Hydrogen, $H_2(g)$, has a higher heat content.

(c) If both fuels burned completely, then hydrogen would allow you to drive farther since it has a higher heat content.

(d) Methane (natural gas), a fossil fuel, can be drilled for and found along with crude oil, or by itself, in pockets located in sedimentary rock. It can also be collected from decomposing material in landfills and sewage treatment plants. Hydrogen is most commonly obtained from the electrolysis of water. Currently, producing methane is much less expensive than producing hydrogen as the technology is in place and in use on a large scale.

(e) Students will likely consider hydrogen the more environmentally-friendly fuel, since the combustion of hydrogen produces only water and energy. The production of hydrogen, however, consumes electricity, which has its own environmental costs. There is an environmental cost to the production of methane and its combustion (primarily greenhouse gases), however, unlike hydrogen, the energy is already stored in the methane, so there is no environmental cost in its "production."

CHAPTER 11 ACTIVATION ENERGY AND CATALYSTS

Curriculum Correlation

(Note: This correlation includes Chapters 9, 10, 11. Chapter 11 references are in bold.)

General Outcome 1: Students will determine and interpret energy changes in chemical reactions.

	Student Textbook	Assessment Options
Outcomes for Knowledge		
30–A1.1k recall the application of $Q = mc\Delta t$ to the analysis of energy transfer	Measuring Thermal Energy Changes, Unit 5 Preparation, pp. 336–337 Chapter 9 Launch Lab: Hot Packs and Cold Packs, p. 339	Practice Problems: 1–4, Unit 5 Preparation, p. 337 Chapter 9 Launch Lab: Hot Packs and Cold Packs, Analysis: 1–3, p. 339 Questions for Comprehension: 1, 2, Section 9.1, p. 342 Section 9.1 Review: 1, p. 350 Chapter 9 Review: 1, p. 366–377 Chapter 9 Test Unit 5 Review: 5, 7, pp. 424–427
30–A1.2k explain, in a general way, how stored energy in the chemical bonds of hydrocarbons originated from the Sun	Enthalpy and Thermochemical Equations, Section 9.1, p. 340 Enthalpy Changes of Endothermic Reactions, Section 9.1, p. 345	Section 9.1 Review: 2, p. 350 Chapter 9 Review: 3, 15, p. 366–377 Chapter 9 Test Unit 5 Review: 1, 7, 20, pp. 424–427
30–A1.3k define enthalpy and molar enthalpy for chemical reactions	Energy and Enthalpy, Section 9.1, p. 343 Investigation 9.A: Determining the Enthalpy of a Neutralization Reaction, Section 9.2, pp. 356–357	Questions for Comprehension: 3, 4, Section 9.1, p. 346 Section 9.1 Review: 3–7, p. 350 Investigation 9.A: Determining the Enthalpy of a Neutralization Reaction, Analysis: 1, 2, 4, Conclusion: 5, Section 9.2, pp. 356–357 Chapter 9 Review: 2, 14, p. 366–377 Chapter 9 Test Chapter 10 Review: 1, p. 401 Unit 5 Review: 4, 10, 24, 29, 30, 31, 36–43, pp. 424–427
30–A1.4k write balanced equations for chemical reactions that include energy changes	**Throughout Chapters 9, 10, and 11** Energy Changes in Chemical Reactions, Section 9.1, p. 342 Energy and Enthalpy, Section 9.1, p. 343	Questions for Comprehension: 3, 4, Section 9.1, p. 346 Question for Comprehension: 5, Section 9.1, p. 347 Section 9.1 Review: 3, 4, 6, 7, p. 350 Chapter 9 Review: 5, 6, 12, 13, 23, 24, pp. 366–377 Chapter 9 Test Chapter 10 Review: 2, 18, p. 400–401 Unit 5 Review: 25, 32, 35, 41, 43, pp. 424–427

	Student Textbook	Assessment Options
30–A1.5k use and interpret ΔH notation to communicate energy changes and to calculate energy changes in chemical reactions	**Throughout Chapters 9, 10, and 11** Investigation 9.A: Determining the Enthalpy of a Neutralization Reaction, Section 9.2, pp. 356–357 Investigation 9.B: Molar Enthalpy of Combustion, Section 9.2, pp. 358–359 Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium, Section 10.1, pp. 375–377	Section 9.1 Review: 3–7, p. 350 Investigation 9.A: Determining the Enthalpy of a Neutralization Reaction, Analysis: 4, Conclusion: 5, Section 9.2, pp. 356–357 Investigation 9.B: Molar Enthalpy of Combustion, Part 1: 2, Part 2: 1, 2, Section 9.2, pp. 358–359 Chapter 9 Review: 2–4, 6, 7, 13, 16–24, pp. 366–367 Chapter 9 Test Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium: 1–5, Section 10.1, pp. 375–377 Section 10.1 Review: 1–5, p. 383 Chapter 10 Review: 1, 2, 12, 15–26, pp. 400–401 Chapter 10 Test Unit 5 Review: 19, 25, 29–45, pp. 424–427
30–A1.6k predict the enthalpy change for chemical equations using standard enthalpies of formation	Calculating Enthalpy Changes, Section 9.1, p. 348 Sample Problem: Predicting an Enthalpy Change, Section 9.1, p. 348 Sample Problem: Using Enthalpy Data to Determine the Mass of Products, Section 9.1, p. 349 Hess's Law, Section 10.1, p. 370 Sample Problem: Using Hess's Law to Determine Enthalpy Change for Formation Reactions, Section 10.1, p. 373 Standard Molar Enthalpies of Formation, Section 10.1, p. 377 Sample Problem: Using Enthalpies of Formation, Section 10.1, p. 381 Sample Problem: Using an Enthalpy of Combustion to Determine an Enthalpy of Formation, Section 10.1, p. 382	Practice Problems: 1–6, Section 9.1, p. 349 Chapter 9 Test Practice Problems 1–6, Section 10.1, pp. 374–375 Questions for Comprehension: 1–3, Section 10.1, p. 378 Questions for Comprehension: 4–7, Section 10.1, p. 379 Practice Problems: 7–12, Section 10.1, pp. 382–383 Section 10.1 Review: 2, 3, 5, p. 383 Chapter 10 Review: 2, 3, 10, 15, 16, 18, pp. 400–401 Chapter 10 Test Unit 5 Review: 4, 25, 33, 39–41, 43, pp. 424–427
30–A1.7k explain and use Hess's law to calculate energy changes for a net reaction from a series of reactions	Hess's Law, Section 10.1, pp. 370–383 Sample Problem: Using Hess's Law to Determine Enthalpy Change, Section 10.1, p. 373 Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium, Section 10.1, pp. 375–377 Sample Problem: Using an Enthalpy of Combustion to Determine an Enthalpy of Formation, Section 10.1, p. 382	Practice Problems: 1–6, Section 10.1, pp. 374–375 Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium: 1–6, Section 10.1, pp. 375–377 Questions for Comprehension: 1–3, Section 10.1, p. 378 Practice Problems: 7–12, Section 10.1, pp. 382–383 Chapter 10 Review: 16, 18, 19, pp. 400–401 Chapter 10 Test Unit 5 Review: 25, 29, 37–39, pp. 424–427

	Student Textbook	Assessment Options
30–A1.8k use calorimetry data to determine the enthalpy changes in chemical reactions	Calorimetry, Section 9.2, pp. 351–353 Sample Problem: Determining the Enthalpy Change of a Reaction, Section 9.2, p. 354 Connections: Energy for Living: How Food Fuels You, Section 9.1, pp. 361–362 Sample Problem: Calculating Thermal Energy in a Bomb Calorimeter, Section 9.2, p. 362 Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium, Section 10.1, pp. 375–377	Practice Problems: 7–12, Section 9.2, p. 355 Questions for Comprehension: 7–10, Section 9.2, p. 355 Practice Problems: 13–17, Section 9.2, p. 363 Section 9.2 Review: 1–8, p. 364 Chapter 9 Review: 4, 7–9, 11–13, 16–22, pp. 366–367 Chapter 9 Test Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium: 1–5, Section 10.1, pp. 375–377 Chapter 10 Review: 15, 24, 26, pp. 400–401 Chapter 10 Test Unit 5 Review: 11, 30, 32, 36, 44, pp. 424–427
30–A1.9k identify that liquid water and carbon dioxide gas are reactants for photosynthesis and are products for cellular respiration, in an open system, and that gaseous water and carbon dioxide gas are the products of hydrocarbon combustion	Molar Enthalpy of Combustion, Section 9.1, p. 346 Connections: Energy for Living: How Food Fuels You, Section 9.2, pp. 361–362	Web Link, Section 9.1, p. 347 Questions for Comprehension: 5, 6, Section 9.1, p. 347 Practice Problems: 2–4, Section 9.1, p. 349 Chapter 9 Review: 5, 6, 10, 24, pp. 366-367 Chapter 9 Test Chapter 10 Review: 12, 15, 17, 20, 21, 23, 24, 26, 28, pp. 400–401 Unit 5 Review: 7, 8, 22, 24, 30, 32, 35, 42, 48, pp. 424–427
30–A1.10k classify chemical reactions, including those for the processes of photosynthesis, cellular respiration and hydrocarbon combustion as endothermic or exothermic.	Describing Chemical Reactions, Unit 5 Preparation, p. 334 Energy Changes in Chemical Reactions, Section 9.1, pp. 342–343 Enthalpy Changes of Exothermic Reactions, Section 9.1, pp. 344–345 Enthalpy Changes of Endothermic Reactions, Section 9.1, p. 345 Molar Enthalpy of Combustion, Section 9.1, p. 346 Connections: Energy for Living: How Food Fuels You, Section 9.2, pp. 361–362	Section 9.1 Review: 2, 5, p. 350 Chapter 9 Review: 5, 6, 10, 15, 22, pp. 366-367 Chapter 9 Test Questions for Comprehension: 2, Section 10.1, p. 378 Unit 5 Review: 1, 3, 36, pp. 424–427

	Student Textbook	Assessment Options
Outcomes for Science, Technology and Society (Emphasis on science and technology)		
30–A1.1sts explain that the goal of technology is to provide solutions to practical problems by ■ *providing examples of personal reliance on the chemical potential energy of matter, e.g., the use of hydrocarbon fossil fuels* ■ *identifying ways to use energy more efficiently*	Chapter 9 Launch Lab: Hot Packs and Cold Packs, p. 339 Connections: Energy for Living: How Food Fuels You, Section 9.2, pp. 361–362 Chapter 10 Launch Lab: Bake a Cake, p. 368 Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium, Section 10.1, pp. 375–377 Thought Lab 10.1: Improving Energy Efficiency at Home, Section 10.2, p. 389 Connections: Efficient Home Heating, Section 10.2, p. 390 Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396 Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398 **Connections: Car Pollution Solution? Inside a Catalytic Converter, Section 11.2, p. 414**	Chapter 9 Launch Lab: Hot Packs and Cold Packs, Analysis: 3, p. 339 Connections: Energy for Living: How Food Fuels You: 1, 2, Section 9.2, pp. 361–362 Chapter 10 Launch Lab: Bake a Cake: 1–3, p. 368 Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium: 5, 6, Section 10.1, pp. 375–377 Thought Lab 10.1: Improving Energy Efficiency at Home: 1–4, Section 10.2, p. 389 Connections: Efficient Home Heating: 1, 2, Section 10.2, p. 390 Section 10.2 Review: 1–9, p. 392 Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396 Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398 Section 10.3 Review: 6, p. 398 Chapter 10 Review: 4–9, pp. 400–401 **Connections: Car Pollution Solution? Inside a Catalytic Converter: 2, 3, Section 11.2, p. 414** Unit 5 Review: 46–49, pp. 424–427
30–A1.2sts demonstrate an understanding that technological problems often lend themselves to multiple solutions that involve different designs, materials and processes and have intended and unintended consequences by ■ *illustrating the applications of hydrocarbon fossil fuels, with examples from industries in Alberta.*	Chapter 9 Launch Lab: Hot Packs and Cold Packs, p. 339 Investigation 10.B: Build a Heating Device, Section 10.2, pp. 387–388 Thought Lab 10.1: Improving Energy Efficiency at Home, Section 10.2, p. 389 Connections: Efficient Home Heating, Section 10.2, p. 390 Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396 Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398	Chapter 9 Launch Lab: Hot Packs and Cold Packs, Analysis: 2, p. 339 Investigation 10.B: Build a Heating Device: 1–3, Section 10.2, pp. 387–388 Thought Lab 10.1: Improving Energy Efficiency at Home: 1–4, Section 10.2, p. 389 Connections: Efficient Home Heating: 1, 2, Section 10.2, p. 390 Section 10.2 Review: 1–9, p. 392 Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396 Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398 Section 10.3 Review: 1–6, p. 398 Chapter 10 Review: 13, 14, pp. 400–401 Unit 5 Review: 46–49, p. 427

	Student Textbook	Assessment Options
Skill Outcomes (Focus on problem solving)		
Initiating and Planning		
30–A1.1s ask questions about observed relationships and plan investigations of questions, ideas, problems and issues by ■ designing a method to compare the molar enthalpy change when burning two or more fuels, identifying and controlling major variables	Investigation 9.B: Molar Enthalpy of Combustion, Section 9.2, pp. 358–359 Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium, Section 10.1, pp. 375–377	Investigation 9.B: Molar Enthalpy of Combustion, Part 1: 1–4, Part 2: 1–4, Section 9.2, pp. 358–359 Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium: 1–6, Section 10.1, pp. 375–377 Unit 5 Review: 24, 47, pp. 424–427
■ describing procedures for safe handling, storage and disposal of materials used in the laboratory, with reference to WHMIS and consumer product labelling information.	Chapter 9 Launch Lab: Hot Packs and Cold Packs, p. 339 Investigation 9.B: Molar Enthalpy of Combustion, Section 9.2, pp. 358–359 Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium, Section 10.1, pp. 375–377	Chapter 9 Launch Lab: Hot Packs and Cold Packs, Analysis: 2, p. 339 Investigation 9.B: Molar Enthalpy of Combustion, Part 1: 3, Part 2: 3, Section 9.2, pp. 358–359 Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium: 6, Section 10.1, pp. 375–377 Unit 5 Review: 24, 47, pp. 424–427
Performing and Recording		
30–A1.2s conduct investigations into relationships among observable variables and use a broad range of tools and techniques to gather and record data and information by ■ performing calorimetry experiments to determine the molar enthalpy change of chemical reactions ■ using thermometers or temperature probes appropriately when measuring temperature changes	Investigation 9.A: Determining the Enthalpy of a Neutralization Reaction, Section 9.2, pp. 356–357 Investigation 9.B: Molar Enthalpy of Combustion, Section 9.2, pp. 358–359 Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium, Section 10.1, pp. 375–377	Investigation 9.A: Determining the Enthalpy of a Neutralization Reaction, Analysis: 1–4, Conclusion: 5, Section 9.2, pp. 356–357 Investigation 9.B: Molar Enthalpy of Combustion, Part 1: 1–4, Part 2: 1–4, Section 9.2, pp. 358–359 Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium: 1–6, Section 10.1, pp. 375–377 Unit 5 Review: 24, 47, pp. 424–427
■ *using a computer-based laboratory to compile and organize data from an experiment to demonstrate molar enthalpy change*	Investigation 9.B: Molar Enthalpy of Combustion, Section 9.2, pp. 358–359	Investigation 9.B: Molar Enthalpy of Combustion, Part 1: 2, Part 2: 3, Section 9.2, pp. 358–359
■ *selecting and integrating information from various print and electronic sources to create multiple-linked documents on using alternative fuels.*	Investigation 9.B: Molar Enthalpy of Combustion, Section 9.2, pp. 358–359 Connections: Energy for Living: How Food Fuels You, Section 9.2, Section 9.2, pp. 361–362 Investigation 10.B: Build a Heating Device, Section 10.2, pp. 387–388 Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396 Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398	Investigation 9.B: Molar Enthalpy of Combustion, Part 2: 3, Section 9.2, pp. 358–359 Connections: Energy for Living: How Food Fuels You: 1–4, Section 9.2, pp. 361–362 Investigation 10.B: Build a Heating Device: 2, Section 10.2, pp. 387–388 Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396 Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398

	Student Textbook	Assessment Options
Analyzing and Interpreting		
30–A1.3s analyze data and apply mathematical and conceptual models to develop and assess possible solutions by ■ comparing energy changes associated with a variety of chemical reactions through the analysis of data and energy diagrams	Investigation 9.B: Molar Enthalpy of Combustion, Section 9.2, pp. 358–359 Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium, Section 10.1, pp. 375–377 Investigation 10.B: Build a Heating Device, Section 10.2, pp. 387–388	Investigation 9.B: Molar Enthalpy of Combustion, Part 1: 1, 2, Part 2: 1, 2, Section 9.2, pp. 358–359 Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium: 1–6, Section 10.1, pp. 375–377 Investigation 10.B: Build a Heating Device: 1–3, Section 10.2, pp. 387–388 Unit 5 Review: 11, 28, 35, 36–42, 44, pp. 424–427
■ *manipulating and presenting data through the selection of appropriate tools, e.g., scientific instrumentation, calculators, databases or spreadsheets.*	Investigation 9.B: Molar Enthalpy of Combustion, Section 9.2, pp. 358–359 Investigation 10.B: Build a Heating Device, pp. 387–388 Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398	Investigation 9.B: Molar Enthalpy of Combustion, Part 2: 3, Section 9.2, pp. 358–359 Investigation 10.B: Build a Heating Device: 3, pp. 387–388 Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398 Unit 5 Review: 36, pp. 424–427
Communication and Teamwork		
30–A1.4s work collaboratively in addressing problems and apply the skills and conventions of science in communicating information and ideas and in assessing results by ■ using appropriate International System of Units (SI) notation, fundamental and derived units for enthalpy changes and expressing molar enthalpies in kilojoules/mole	Investigation 9.A: Determining the Enthalpy of a Neutralization Reaction, Section 9.2, pp. 356–357 Investigation 9.B: Molar Enthalpy of Combustion, Section 9.2, pp. 358–359 Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium, Section 10.1, pp. 375–377 Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398	Investigation 9.A: Determining the Enthalpy of a Neutralization Reaction, Analysis: 1–3, Conclusion: 5, Section 9.2, pp. 356–357 Investigation 9.B: Molar Enthalpy of Combustion, Part 1: 1–4, Part 2: 1–4, Section 9.2, pp. 358–359 Investigation 10.A: Hess's Law and the Enthalpy of Combustion of Magnesium: 1–5, Section 10.1, pp. 375–377 Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398
■ *using advanced menu features within a word processor to accomplish a task and to insert tables, graphs, text and graphics.*	Investigation 9.B: Molar Enthalpy of Combustion, Section 9.2, pp. 358–359 Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398	Investigation 9.B: Molar Enthalpy of Combustion, Part 2: 3, Section 9.2, pp. 358–359 Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398 Chapter 10 Review: 27, p. 401

General Outcome 2: Students will explain and communicate energy changes in chemical reactions.

	Student Textbook	Assessment Options
Outcomes for Knowledge		
30–A2.1k define activation energy as the energy barrier that must be overcome for a chemical reaction to occur	**Activation Energy, Section 11.1, p. 405**	**Questions for Comprehension: 1–3, Section 11.1, p. 407** **Section 11.1 Review: 2, 4, 5, 7, 8, p. 410** **Chapter 11 Review: 2, 3, 5, 6, 9, 14, 16, pp. 420–421** **Chapter 11 Test** Unit 5 Review: 16, 19, 45, pp. 424–427

	Student Textbook	Assessment Options
30–A2.2k explain the energy changes that occur during chemical reactions referring to bonds breaking and forming and changes in potential and kinetic energy	Types of Energy, Section 9.1, p. 341 Energy Changes in Chemical Reactions, Section 9.1, p. 342	**Section 11.1 Review: 1–3, p. 410** **Chapter 11 Review: 1, 3, 5, 9, pp. 420–421** Unit 5 Review: 1, 6, 9, 20, pp. 424–427
30–A2.3k analyze and label energy diagrams for a chemical reaction, including reactants, products, enthalpy change and activation energy	Enthalpy Changes of Exothermic Reactions, Section 9.1, pp. 344–345 Enthalpy Changes of Endothermic Reactions, Section 9.1, p. 345 **A Closer Look at a Molecular Collision, Section 11.1, p. 406** **Sample Problem: Drawing a Potential Energy Diagram, Section 11.1, pp. 408–409**	Questions for Comprehension: 3, 4, Section 9.1, p. 346 **Practice Problems: 1–5, Section 11.1, p. 409** **Section 11.1 Review: 6–9, p. 410** **Section 11.2 Review: 6, p. 418** **Chapter 11 Review: 4, 6, 13–15, 18, 19, pp. 420–421** **Chapter 11Test** Unit 5 Review: 12, 19, 20, 29, 33, 43, 45, pp. 424–427
30–A2.4k explain that catalysts increase reaction rates by providing alternate pathways for changes without affecting the net amount of energy involved, e.g., *enzymes in living systems.*	**Chapter 11 Launch Lab: Does It Gel? p. 403** **Catalysts and Reaction Rates, Section 11.2, pp. 411–412** **Try This, Section 11.2, p. 416** **Investigation 11.A: The Effect of a Catalyst on the Decomposition of Hydrogen Peroxide, H_2O_2(aq), Section 11.2, pp. 417–418**	**Chapter 11 Launch Lab: Does It Gel? Analysis: 3, p. 403** **Questions for Comprehension: 1–3, Section 11.1, p. 407** **Questions for Comprehension: 4, 5, Section 11.2, p. 413** **Investigation 11.A: The Effect of a Catalyst on the Decomposition of Hydrogen Peroxide, H_2O_2(aq): 1–6, Section 11.2, pp. 417–418** **Section 11.2 Review: 1–6, p. 418** **Chapter 11 Review: 7, 8, 10, 11, 12, 14, 17–29, p. 420–421** **Chapter 11 Test** Unit 5 Review: 18, 21, 29, 45, pp. 424–427

	Student Textbook	Assessment Options
Outcomes for Science, Technology and Society (Emphasis on science and technology)		
30–A2.1sts develop an understanding that the goal of technology is to provide solutions to practical problems by ■ *explaining how catalysts reduce air pollution from the burning of hydrocarbons; i.e., catalytic converters on cars*	Chapter 9 Launch Lab: Hot Packs and Cold Packs, p. 339 Investigation 10.B: Build a Heating Device, Section 10.2, pp. 387–388 Thought Lab 10.1: Improving Energy Efficiency at Home, Section 10.2, p. 389 Connections: Efficient Home Heating, Section 10.2, p. 390 Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396 Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398 **Chapter 11 Launch Lab: Does It Gel? p. 403** **Connections: Car Pollution Solution? Inside a Catalytic Converter, Section 11.2, p. 414** Career Focus: Building Up and Breaking Down Bitumen, pp. 422–423	Chapter 9 Launch Lab: Hot Packs and Cold Packs, Analysis: 1, 3, p. 339 Investigation 10.B: Build a Heating Device: 1–3, Section 10.2, pp. 387–388 Thought Lab 10.1: Improving Energy Efficiency at Home: 1–4, Section 10.2, p. 389 Connections: Efficient Home Heating: 1, 2, Section 10.2, p. 390 Section 10.2 Review: 1–9, p. 392 Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396 Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398 Section 10.3 Review: 1–6, p. 398 **Chapter 11 Launch Lab: Does It Gel? Analysis: 2, 3, p. 403** **Connections: Car Pollution Solution? Inside a Catalytic Converter: 1–3, Section 11.2, p. 414** **Chapter 11 Review: 17, 22–29, pp. 420–421** Career Focus: Building Up and Breaking Down Bitumen, Go Further 1–3, pp. 422–423 Unit 5 Review: 46–49, pp. 424–427
30–A2.2sts identify the appropriateness, risks and benefits of technologies and the need to assess each potential application from a variety of perspectives, including sustainability by ■ *assessing qualitatively the risks and benefits of relying on fossil fuels as energy sources*	Chapter 9 Launch Lab: Hot Packs and Cold Packs, p. 339 Connections: Energy for Living: How Food Fuels You, Section 9.2, pp. 361–362 Chapter 10 Launch Lab: Bake a Cake, p. 368 Investigation 10.B: Build a Heating Device, Section 10.2, pp. 387–388 Thought Lab 10.1: Improving Energy Efficiency at Home, Section 10.2, p. 389 Connections: Efficient Home Heating, Section 10.2, p. 390 Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396 Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398	Chapter 9 Launch Lab: Hot Packs and Cold Packs, Analysis: 1–3, p. 339 Connections: Energy for Living: How Food Fuels You: 1–4, Section 9.2, pp. 361–362 Chapter 10 Launch Lab: Bake a Cake: 1–3, p. 368 Investigation 10.B: Build a Heating Device: 1–3, Section 10.2, pp. 387–388 Thought Lab 10.1: Improving Energy Efficiency at Home: 1–4, Section 10.2, p. 389 Connections: Efficient Home Heating: 1, 2, Section 10.2, p. 390 Section 10.2 Review: 1–9, p. 392 Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396 Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398 Section 10.3 Review: 1–6, p. 398 Chapter 10 Review: 13, 14, p. 400 **Chapter 11 Review: 17, 22–29, pp. 420–421** Unit 5 Review: 46–49, pp. 424–427

	Student Textbook	Assessment Options
30–A2.3sts explain that the products of technology are devices, systems and processes that meet given needs but that these products cannot solve all problems by ■ *evaluating the economic and environmental impact of different fuels by relating carbon dioxide emissions and the heat content of a fuel.*	Chapter 10 Launch Lab: Bake a Cake, p. 368 Investigation 10.B: Build a Heating Device, Section 10.2, pp. 387–388 Thought Lab 10.1: Improving Energy Efficiency at Home, Section 10.2, p. 389 Connections: Efficient Home Heating, Section 10.2, p. 390 Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396 Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398	Chapter 10 Launch Lab: Bake a Cake: 3, p. 368 Investigation 10.B: Build a Heating Device: 1–3, Section 10.2, pp. 387–388 Thought Lab 10.1: Improving Energy Efficiency at Home: 1–4, Section 10.2, p. 389 Connections: Efficient Home Heating: 1, 2, Section 10.2, p. 390 Section 10.2 Review: 1–9, p. 392 Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396 Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398 Section 10.3 Review: 1–6, p. 398 **Chapter 11 Review: 17, 22–29, pp. 420–421** Unit 5 Review: 46–49, pp. 424–427
Skill Outcomes (Focus on problem solving)		
Initiating and Planning		
30–A2.1s ask questions about observed relationships and plan investigations of questions, ideas, problems and issues by ■ describing procedures for safe handling, storage and disposal of materials used in the laboratory, with reference to WHMIS and consumer product labelling information ■ *designing an experimental procedure to illustrate the effect of a catalyst on a chemical reaction.*	**Investigation 11.A: The Effect of a Catalyst on the Decomposition of Hydrogen Peroxide, H_2O_2(aq), Section 11.2, pp. 417–418**	**Investigation 11.A: The Effect of a Catalyst on the Decomposition of Hydrogen Peroxide, H_2O_2(aq): 1–6, Section 11.2, pp. 417–418** Unit 5 Review: 24, 27, pp. 424–425
Performing and Recording		
30–A2.2s conduct investigations into relationships among observable variables and use a broad range of tools and techniques to gather and record data and information by ■ plotting energy graphs/enthalpy diagrams indicating changes in energy for chemical reactions	Investigation 9.B: Molar Enthalpy of Combustion, Section 9.2, pp. 358–359 **Investigation 11.A: The Effect of a Catalyst on the Decomposition of Hydrogen Peroxide, H_2O_2(aq), Section 11.2, pp. 417–418**	Investigation 9.B: Molar Enthalpy of Combustion, Part 2: 2, Section 9.2, pp. 358–359 **Investigation 11.A: The Effect of a Catalyst on the Decomposition of Hydrogen Peroxide, H_2O_2(aq): 2, Section 11.2, pp. 417–418**
■ *using library and electronic research tools to compile information on the energy content of fuels used in Alberta power plants*	Investigation 9.B: Molar Enthalpy of Combustion, Section 9.2, pp. 358–359 Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396 Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398	Investigation 9.B: Molar Enthalpy of Combustion, Part 2: 3, Section 9.2, pp. 358–359 Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396 Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398
■ *designing and building a heating device.*	Chapter 9 Launch Lab: Hot Packs and Cold Packs, p. 339 Investigation 10.B: Build a Heating Device, Section 10.2, pp. 387–388	Chapter 9 Launch Lab: Hot Packs and Cold Packs, Analysis: 1, 3, p. 339 Investigation 10.B: Build a Heating Device: 1–3, Section 10.2, pp. 387–388

	Student Textbook	Assessment Options
Analyzing and Interpreting		
30–A2.3s analyze data and apply mathematical and conceptual models to develop and assess possible solutions by ■ interpreting an enthalpy diagram for a chemical reaction	Investigation 9.B: Molar Enthalpy of Combustion, Section 9.2, pp. 358–359	Investigation 9.B: Molar Enthalpy of Combustion, Part 2: 3, Section 9.2, pp. 358–359 Unit 5 Review: 11, 28, 35, 36–42, 44, pp. 424–427
■ explaining the discrepancy between the theoretical and actual efficiency of a thermal energy conversion system	Chapter 10 Launch Lab: Bake a Cake, p. 368 Connections: Efficient Home Heating, Section 10.2, p. 390 Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.2, p. 396	Chapter 10 Launch Lab: Bake a Cake: 2, 3, p. 368 Practice Problems: 13–16, Section 10.2, p. 387 Connections: Efficient Home Heating: 1, Section 10.2, p. 390 Section 10.2 Review: 1–9, p. 392 Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396 Chapter 10 Review: 4–9, pp. 400–401 **Chapter 11 Review: 4, 6, 13–15, 18, 19, pp. 420–421**
■ *determining the efficiency of thermal energy conversion systems*	Chapter 10 Launch Lab: Bake a Cake, p. 368 Sample Problem: The Efficiency of a Propane Barbecue, Section 10.2, pp. 386–387 Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.2, p. 396	Chapter 10 Launch Lab: Bake a Cake: 3, p. 368 Practice Problems: 13–16, Section 10.2, p. 387 Section 10.2 Review: 1–9, p. 392 Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396 Chapter 10 Review: 4–9, pp. 400–401
■ *assessing whether coal or natural gas should be used to fuel thermal power plants in Alberta*	Investigation 9.B: Molar Enthalpy of Combustion, Part 1: 1–4, Part 2: 1–4, Section 9.2, pp. 358–359 Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396 Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398	Investigation 9.B: Molar Enthalpy of Combustion, Part 2: 3, Section 9.2, pp. 358–359 Section 10.2 Review: 1–9, p. 392 Investigation 10.C: Fossil Fuels as Energy Sources: A Risk–Benefit Analysis, Section 10.3, p. 396 Investigation 10.D: Fuelling Thermal Power Plants, Section 10.3, p. 398 Section 10.3 Review: 1–6, p. 398 Chapter 10 Review: 13, 14, pp. 400
■ *evaluating a personally designed and constructed heating device, including a calculation of its efficiency.*	Investigation 10.B: Build a Heating Device, Section 10.2, pp. 387–388	Investigation 10.B: Build a Heating Device: 1–3, Section 10.2, pp. 387–388
Communication and Teamwork		
30–A2.4s work collaboratively in addressing problems and apply the skills and conventions of science in communicating information and ideas and in assessing results by ■ using appropriate SI notation, fundamental and derived units for calculating and communicating enthalpy changes	Investigation 9.A: Determining the Enthalpy of a Neutralization Reaction, Analysis: 1–4, Conclusions: 5, Section 9.2, pp. 356–357 Investigation 9.B: Molar Enthalpy of Combustion, Section 9.2, pp. 358–359 Investigation 10.B: Build a Heating Device, Section 10.2, pp. 387–388	Investigation 9.A: Determining the Enthalpy of a Neutralization Reaction, Analysis: 1–4, Conclusion: 5, Section 9.2, pp. 356–357 Investigation 9.B: Molar Enthalpy of Combustion, Part 1: 1–4, Part 2: 1–4, Section 9.2, pp. 358–359 Investigation 10.B: Build a Heating Device: 1–3, Section 10.2, pp. 387–388
■ *working collaboratively to develop a plan to build an energy conversion device, seeking feedback, testing and reviewing the plan, making revisions and implementing the plan* ■ *using advanced menu features within a word processor to accomplish a task and to insert tables, graphs, text and graphics.*	Investigation 9.B: Molar Enthalpy of Combustion, Section 9.2, pp. 358–359 Investigation 10.B: Build a Heating Device: Section 10.2, pp. 387–388	Investigation 9.B: Molar Enthalpy of Combustion, Part 2: 3, Section 9.2, pp. 358–359 Investigation 10.B: Build a Heating Device: 2, 3, Section 10.2, pp. 387–388 Chapter 10 Review: 27, p. 401

Chapter 11

Activation Energy and Catalysts

Student Textbook pages 402–421

Chapter Concepts

Section 11.1 Reaction Pathways

- Activation energy is the energy barrier that must be overcome for reactions to occur.
- You can use energy diagrams that include both enthalpy change and activation energy data for a chemical reaction.

Section 11.2 Catalysts and Reaction Rates

- Catalysts increase reaction rates by providing alternative pathways for change.
- Technologies using catalysts are used to reduce air pollution caused by the burning of hydrocarbons.
- Catalysts in the human body are called enzymes and are essential for life-sustaining processes.

Common Misconceptions

- Students may have difficulty interpreting Maxwell-Boltzmann distribution curves, such as the one shown in Figure 11.3 on page 405 of the student textbook. They may think that the curve with the higher peak should refer to the reaction that occurs at the higher temperature. Ensure students realize that the vertical axis refers to the fraction of the total number of collisions that have a given energy. Note that for the lower temperature (T_1) the curve peaks at lower energy than the higher temperature (T_2) curve. For T_2, a greater number of collisions have $E = E_A$, or $E > E_A$ than for T_1. This makes sense, because at a higher temperature, the particles have a higher average energy. The key information students should get from the curve is that, at higher temperatures more particles have enough energy to react when they collide.

Helpful Resources

Books and Journal Articles

- Copper, C.L. and Koubek, E. "An Experiment to Demonstrate How a Catalyst Affects the Rate of a Reaction," *J. Chem. Ed.*, Vol. 76, No. 12, December 1999, p. 1714.
- Olbris, D.J. and Herzfeld, J. "Depletion: A Game with Natural Rules for Teaching Reaction Rate Theory," *J. Chem. Ed.*, Vol. 79, No. 10, October 2002, p. 1232-1234.
- Sanger, M.J. et al. "Rate Law Determination of Everyday Processes," *J. Chem. Ed.*, Vol. 79, No. 8, August 2002, p. 989-991.
- Scott, D. "Designer Catalysts," *ChemMatters*, April 1994, p. 13-15.

Web Sites

Web links to related to energy and catalysts can be found at **www.albertachemistry.ca**. Go to the Online Learning Centre, and log on to the Instructor Edition. Choose Teacher Web Links.

List of BLMs

Blackline masters (BLMs) have been prepared to support the material in this chapter. The BLMs are either for assessment (AST); use as overheads (OH); use as handouts (HAND), in particular to support activities. Most handouts and all assessment tools are supported by a BLM with the answers (ANS). The BLMs are in digital form, stored on the CD-ROM that accompanies this Teacher's Resource or on the web site at **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, BLMs. They can be modified to suit the needs of your students.

Number (Type) Title

11.0.1 (HAND) Launch Lab: Does It Gel?
11.0.1A (ANS) Launch Lab: Does It Gel Answer Key

11.1.1 (OH) Temperature and Activation Energy
11.1.2 (OH) Tracing a Reaction with a Potential Energy Diagram
11.1.3 (OH) Drawing a Potential Energy Diagram

11.2.1 (OH) How a Catalyst Works
11.2.2 (HAND) Investigation 11.A: The Effect of a Catalyst on the Decomposition of Hydrogen Peroxide, $H_2O_2(aq)$
11.2.2A (ANS) Investigation 11.A: The Effect of a Catalyst on the Decomposition of Hydrogen Peroxide, $H_2O_2(aq)$ Answer Key

11.3.1 (AST) Chapter 11 Test
11.3.1A (ANS) Chapter 11 Test Answer Key

Using the Chapter 11 Opener

Student Textbook pages 402–403

Teaching Strategies

- Review how to draw and label potential energy diagrams for endothermic and exothermic reactions.

Launch Lab Does it Gel?

Student Textbook page 403

Purpose

Students will gain first hand visual experience with the effect of enzymes on the digestion of gelatin. The effect of some fruits on gelatin can be used throughout the remainder of this chapter to illustrate the concepts of activation energy and the effect of a catalyst.

Outcomes

- 30-A2.4k
- 30-A2.1sts

Advance Preparation

When to Begin	What to Do
2 days before	■ Purchase gelatin of any flavour, fresh fruit (and canned fruit).
1 day before	■ Make gelatin in a small square cake pan. ■ Cut fruit into 1 cm squares. ■ Photocopy **BLM 11.0.1: Launch Lab.**

Materials
Per student group: ■ balance ■ one 100 mL beaker (or other small beaker) for each fruit tested and one for gelatin alone ■ one 3 cm × 3 cm square of gelatin for each fruit tested ■ three 1 cm square cubes of each fruit tested

Time Required

- 20 minutes for initial setup on day 1
- 20 minutes for data collection and clean-up on day 2

Helpful Tips

- Use **BLM 11.0.1 (HAND) Launch Lab: Does It Gel?** to support this activity. Modify as necessary.
- Pineapple, kiwi, and papaya contain enzymes that digest protein. Pineapple and kiwi contain bromelain; papaya contains papain. The protein bonds in gelatin will be broken by the presence of these enzymes, liquefying the gelatin and reducing the gelatin cube's mass overnight.
- Enzymes are destroyed (coagulated) at the extremely high temperatures reached during the canning process of fruit. Only fresh fruit will affect the gelatin.
- Ask students to predict which fruit (if any) will have an effect on the stability of the gelatin. They may have had previous experience with gelatin, or have read the warning in the instructions on use on the side of the box.
- Ensure that the gelatin squares are dried before students measure their mass on day 2.
- This lab may be extended to include canned fruit.
- ***Expected Results:*** Many tropical fruits such as kiwi, pineapples, and papayas contain papain, a protease. Proteases are enzymes that digest proteins. Cooking (including canning) the fruits usually destroys the enzymes so fresh fruit must be used in this activity. Thus, fresh kiwi, pineapples, and papayas will break down the protein in the gelatin and thus reduce the mass of the solid gelatin. It is interesting to note which fruits you normally see in gelatin desserts.

Answers to Analysis Questions

1. The three fruit that should have an effect on the mass of gelatin are pineapple, papaya, and kiwi (if all three fruit were used).
2. The answer to this question may depend on what happened to the beaker containing only gelatin. If this square lost mass, students may conclude that the gelatin will deteriorate over time, although it is actually only losing water through evaporation. Most students will conclude that the gelatin may dehydrate over time but will not deteriorate as they have likely observed gelatin over time in their own refrigerators.
3. Gelatin, which is mostly protein, will deteriorate over time because it is losing water through evaporation. Enzymes can act as catalysts in the process and break up the protein. These catalysts speed up the rate at which the gelatin deteriorates. The combustion of cellulose is similar because moisture is also being lost over time. However, the catalyst required for the combustion of cellulose is a spark, lightning strike, or even a tossed cigarette.

11.1 Reaction Pathways

Student Textbook pages 404–410

Section Outcomes

Students will:

- define activation energy and activated complex
- explain, using collision theory, the requirements for a chemical reaction
- analyze and sketch potential energy diagrams for chemical reactions
- explain the energy changes that occur during chemical reactions in terms of bonds breaking and forming and of changes in potential and kinetic energy

Key Terms

reaction rate
collision theory
activation energy, E_a
activated complex
transition state

Chemistry Background

- It is important that once students have been introduced to the concept of "reaction rate" that this term be used instead of speed. Although using the term speed is an appropriate analogy for students, speed refers specifically to distance travelled divided by elapsed time, while reaction rate is a change in the concentration of a reactant or product divided by elapsed time.

- Matter is made up of particles in motion. When two reactants are mixed or otherwise come into contact, the particles of the different substances collide with one another. According to collision theory, a collision is necessary for a reaction to take place.
- Not every molecular collision results in a reaction. Reactants must have the correct orientation and sufficient collision energy (activation energy) for a reaction to occur. When temperature increases, the average kinetic energy of the particles increases; therefore, more collisions occur with sufficient energy for a reaction to occur.

Teaching Strategies

- Although reaction rate is mentioned only briefly at the beginning of Chapter 11, students need to understand and be able to apply this concept for Section 11.2.
- The success that students will have with this section hinges on their ability to draw simple potential energy diagrams. Ensure that students have a solid grasp of this material before adding the concept of activation energy.
- Combine molecular models and potential energy diagrams to illustrate the idea of orientation of reactants. Create models of $NO(g)$ and $NO_3(g)$, and demonstrate the collisions shown in Figure 11.2 on page 405. Have students trace potential energy diagrams for this reaction as you demonstrate it.
- Use the analogy of a roller coaster to illustrate the concept of activation energy for students. If a roller coaster is at the bottom of a hill (do not show students where the roller coaster started), will it make it up the hill (representing activation energy)? Students will say that it depends on how fast the roller coaster is going when it reaches the bottom of the hill; if it is going fast enough (has enough kinetic energy), it will make it up the hill; if it is not (does not have enough kinetic energy), then it will not. This is comparable to what happens during a chemical reaction. Discuss with students the energy transfer from kinetic to potential and back to kinetic again.
- Ensure that students understand the effect of increased temperature on the rate of a reaction by using Figure 11.4 on page 405. The number of successful collisions is represented by the area under the curve above the activation energy barrier.
- Three overhead masters have been prepared for this section. You will find them with the Chapter 11 BLMs on the CD-ROM that accompanies this Teacher's Resource or at **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, BLMs.

  Number (Type) Title
  11.1.1 (OH) Temperature and Activation Energy
  11.1.2 (OH) Tracing a Reaction with a Potential Energy Diagram
  11.1.3 (OH) Drawing a Potential Energy Diagram

SUPPORTING DIVERSE STUDENT NEEDS

Students for whom English is a second language should establish a vocabulary list with new terms before attempting to understand the concepts behind them.

Answers to Questions for Comprehension

Student Textbook page 407

Q1. Activation energy is the minimum energy that is required for a successful reaction between colliding molecules.

Q2. Activation energy is NOT related to, nor can it be predicted from, the enthalpy change for a reaction.

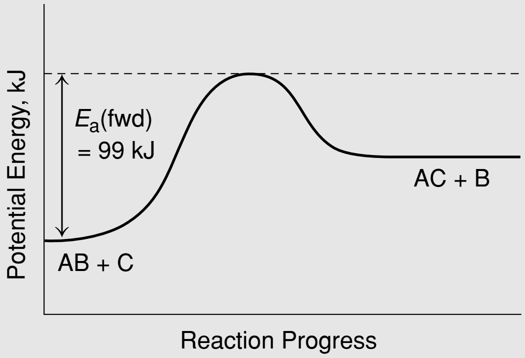
Q3. The spark provides the activation energy for the combustion reaction.

Answers to Practice Problems 1–5

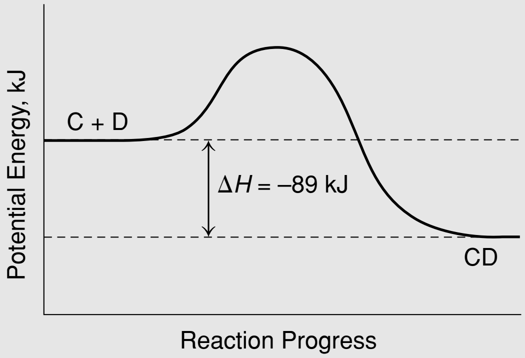
Student Textbook page 409

For full solutions to the practice problems, visit **www.albertachemistry.ca,** Online Learning Centre, Instructor Edition, Full Solutions.

1. The reaction is endothermic
2. $E_{a(fwd)}$ = 99 kJ

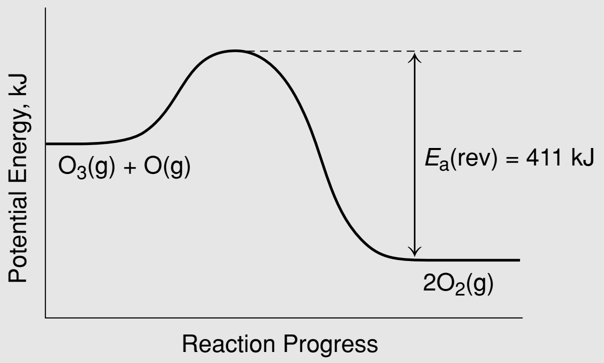


3. ΔH = –89 kJ



4. $E_{a(fwd)}$ = 42 kJ; $E_{a(rev)}$ = 67 kJ; ΔH = –25 kJ; exothermic reaction

5. $E_{a(rev)}$ = 411 kJ

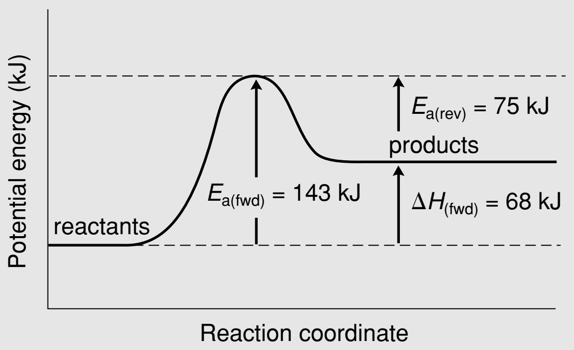


Section 11.1 Review Answers

Student Textbook page 410

1. In order for a reaction to occur, molecules must collide with sufficient energy (activation energy) and correct collision geometry.
2. An increase in temperature increases the rate of a chemical reaction. If temperature is increased, the molecules will have a higher average kinetic energy so more collisions will have the activation energy to result in a reaction.
3. When molecules collide with sufficient energy, the kinetic energy of the collision is converted to potential energy as chemical bonds are broken and energy is stored in the partial bonds of the activated complex. As the partial bonds in the unstable activated complex form chemical bonds of the products, the potential energy is transformed into potential energy stored in the chemical bonds of the products. Remaining energy will be converted back into kinetic energy.
4. An activated complex is a highly unstable transition species that has partial bonds. It is neither product nor reactant, but something in-between.
5. A boulder sitting on the top of the mountain is unstable. It has gravitational potential energy and could roll off the mountain in either direction. An activated complex is similar in that it is unstable, in a high energy state, and could easily decompose to reform reactants, or form products.
6. **(a)** The reaction is endothermic in the forward direction.

(b)



The enthalpy change for the reaction can be calculated:

$$E_{a(rev)} = E_{a(fwd)} + |\Delta H^{o}|$$

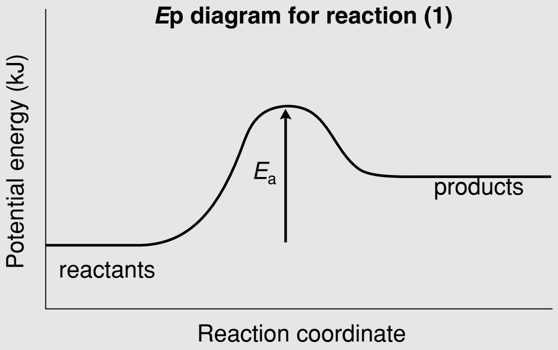
$$|\Delta H^{o}| = E_{a(rev)} - E_{a(fwd)}$$

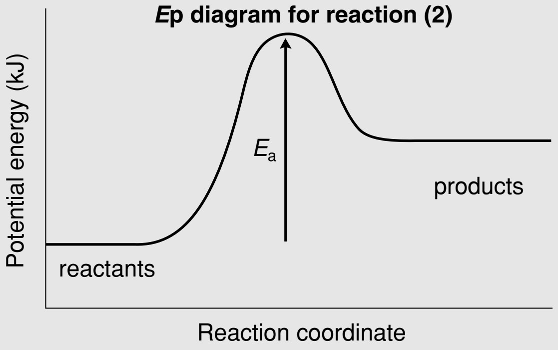
$$= 75\ \text{kJ} - 143\ \text{kJ}$$

$$= \pm\ 68\ \text{kJ}$$

The forward reaction is endothermic since its activation energy is larger than that of the reverse reaction, so the enthalpy change of the reaction in the forward direction is +68 kJ.

7. (a)


***E*p diagram for reaction (1)**


***E*p diagram for reaction (2)**

(b) Since reaction (1) has the smaller activation energy, it is likely to occur more quickly than reaction (2), assuming other factors such as temperature are similar in both reactions.

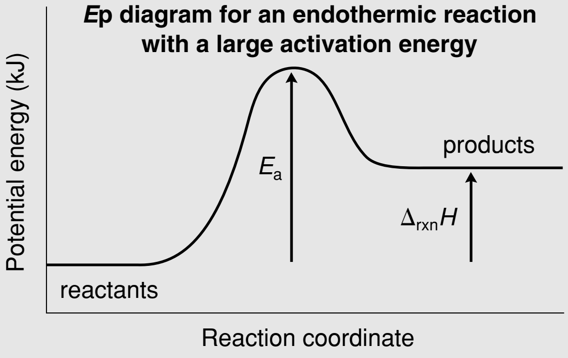
8. (a) I

(b) IV

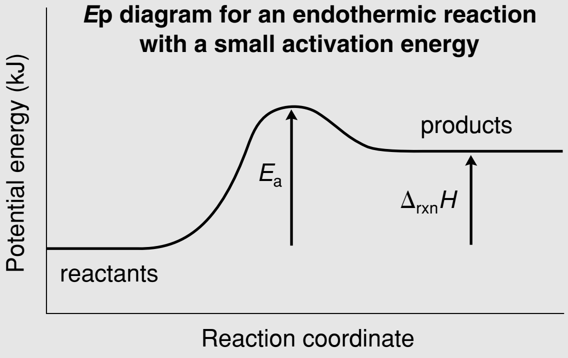
(c) III

(d) II

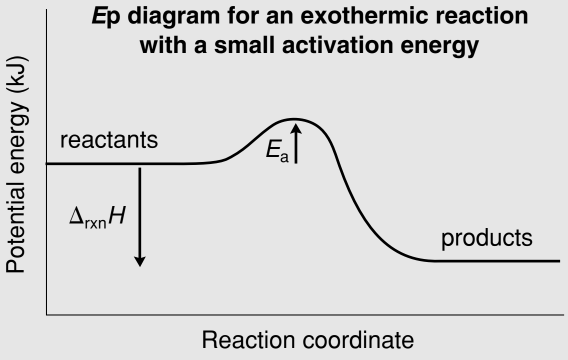
9. Activation energy is defined as the minimum energy that is required for a successful reaction between colliding molecules. It describes how much energy must be put in to get the reaction going, whereas enthalpy change is the amount of energy released or consumed when the reaction occurs. Activation energy and enthalpy change are completely independent of each other; that is, you cannot predict the activation energy of a reaction based on the enthalpy change. An exothermic reaction may have a very small or very large activation energy, as can an endothermic reaction. Regardless of whether a reaction is endothermic or exothermic, the larger the activation energy, the slower the reaction (assuming other factors such as reaction orientation are similar). Some examples of enthalpy change and activation energy are shown below:



***E*p diagram for an endothermic reaction with a large activation energy**



***E*p diagram for an endothermic reaction with a small activation energy**



***E*p diagram for an exothermic reaction with a small activation energy**

11.2 Catalysts and Reaction Rates

Student Textbook pages 411–418

Section Outcomes

Students will:

- explain that catalysts increase reaction rates by providing alternative pathways
- design and carry out an investigation to illustrate the effect of a catalyst on a chemical reaction
- explain how enzymes function as biological catalysts
- explain how catalysts reduce air pollution caused by the burning of hydrocarbons

Key Terms

catalyst
enzyme
active site
substrate

Chemistry Background

- In order to simplify this concept for students, chemical equations have been portrayed in one step, although most reactions occur via mechanisms made up of more than one step called elementary reactions. Each elementary reaction consists of one event, such as a biomolecular collision, or the breakdown of a molecule in response to an input of energy (such as ultraviolet radiation).
- Catalysts change the rate of a reaction by providing alternative mechanisms. If a catalyst increases the rate of a chemical reaction, the activation energies of the steps of the alternative mechanism are smaller than the activation energy or energies of the original mechanisms.
- The key to the function of an enzyme is its ability to stabilize the reacting molecules so they will have the correct collision geometry. Unlike reacting molecules in industrial applications, the molecules that must collide in a living system will not collide with the correct geometry sufficiently often for any measurable reaction to occur.

Teaching Strategies

- Students who are taking or have taken biology will already have a solid understanding of enzymes and how they work. Use their knowledge to guide the discussion on catalysts.
- This section contains a number of marginal items describing different catalysts and enzymes. Break the class into groups and have each group research one catalyst in detail and present their findings to the class.
- One overhead **BLM 11.2.1 (OH) How a Catalyst Works,** has been prepared for this section. You will find it with the Chapter 11 BLMs on the CD-ROM that accompanies this Teacher's Resource or at **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, BLMs.

Figure 11.10

Student Textbook page 412

A catalyst has no effect on the enthalpy change of a reaction. Just as with Hess's Law calculations, enthalpy change is dependent only on the potential energy stored in the reactants and products, not on the pathway taken.

Chemistry File: Web Link

Student Textbook page 412

Chlorofluorocarbons, CFCs, will release a chlorine atom ($Cl(g)$, not $Cl^{-}(g)$) when struck by ultraviolet light. This chlorine atom is extremely unstable and reacts readily with ozone, $O_3(g)$.

$$Cl(g) + O_3(g) \rightarrow ClO(g) + O_2(g)$$

The chlorine oxide molecule will then react with an oxygen atom to produce oxygen gas and a chlorine atom which can then catalyze the split of another ozone molecule.

$$ClO(g) + O(g) \rightarrow Cl(g) + O_2(g)$$

Overall, the reaction that occurs is (add the two equations using Hess's Law):

$$O_3(g) + O(g) \rightarrow 2O_2(g)$$

Since the chlorine atom is regenerated, it can then react with other ozone molecules.

Answers to Questions for Comprehension

Student Textbook page 413

Q4. (a) $E_{a(fwd)}$ is lower with the addition of a catalyst.

(b) $E_{a(rev)}$ is lower with the addition of a catalyst.

(c) There is no change in ΔH with the addition of a catalyst.

(d) The speed of the forward reaction is increased.

(e) The speed of the reverse reaction is increased.

Q5. After the reaction is complete, the catalyst is restored to its pre-reaction state.

Figure 11.12

Student Textbook page 413

In order to have any effect, the catalyst must be involved in the collision between the reactant molecules. By laying out the catalyst in a mesh, it maximizes the surface area and therefore the number of collisions that can occur.

Connections (Science and Technology): Car Pollution Solution? Inside a Catalytic Converter

Student Textbook page 414

Teaching Strategies

- Students in Alberta are accustomed to smog-free days, although most will have seen smog in Calgary, or heard weather reports from Toronto about the ill-effects of smog, especially on the young, elderly, and those with respiratory illness. Discuss with students what life in Alberta would be like today if catalytic converters had not been put in place over 30 years ago.
- Discuss student answers to Question 2.

Answers to Connections Questions

1. $2CO(g) + O_2(g) \rightarrow 2CO_2(g)$

2. If students support the movement to alternatively fuelled vehicles, their support will include the elimination or drastic reduction in carbon dioxide, volatile organic compounds, and nitrous oxides. They will also mention the positive move from the use of a non-renewable resource (gasoline) to a renewable one, as long as the electricity used is generated from a renewable source.

If students support the continued use of gasoline-powered vehicles, they will discuss the advances made in reducing their environmental impact, including improved catalytic converters and more fuel-efficient vehicles. Although hybrids and electric cars are likely to become more popular in the future, right now, the majority of cars are gasoline-powered, so developers should continue to work to improve existing technology.

3. (a) You can reduce your fuel consumption by ensuring your vehicle is well-maintained and your tires properly inflated. By driving at or below the speed limit and accelerating/decelerating gradually, you can further improve your fuel economy.

(b) There are a variety of vehicles available at varying fuel economies. In general, the larger the vehicle, the higher the fuel consumption. Some examples in a variety of classes are shown below.

Vehicle	City consumption (L/100 km)	Highway consumption (L/100 km)	Estimated annual cost ($)	Overall rank (based on fuel efficiency 2005 results)
Chevrolet Blazer 4x4	15.6	10.9	1807	782
Chevrolet Corvette	13.2	7.6	1623	469
Chevrolet Optra	10.9	7.4	1250	208
Chrysler Sebring Convertible	11.1	7.7	1282	251
Dodge Dakota	15.9	10.8	1823	798
Ford Escape	10.9	8.6	1322	322

Vehicle	City consumption (L/100 km)	Highway consumption (L/100 km)	Estimated annual cost ($)	Overall rank (based on fuel efficiency 2005 results)
Ford Escape Hybrid	6.6	7.0	909	20
Ford Explorer 4x4	16.9	11.8	1957	871
Honda Civic	8.0	5.7	933	23
Honda Civic Hybrid	4.9	4.6	639	4
Jeep Liberty 4x4	11.6	9.1	1404	424
Mazda 3	9.3	6.8	1095	76
Mazda Tribute 4x4	12.7	9.9	1533	599
Pontiac Vibe	8.2	6.3	984	34
Saturn Ion	9.5	6.1	1068	62
Subaru Impreza 2.5rs Sdn Awd	10.3	7.2	1193	142
Toyota Camry Solara	11.5	7.3	1288	257
Volkswagen New Beetle Tdi	6.5	5.2	757	10

Data obtained from: http://oee.nrcan.gc.ca.

Chemistry File: Try This

Student Textbook page 416

Students will likely predict that cooking the pineapple will deactivate the enzyme. They should design an experiment similar to the Launch Lab that would involve setting up three (or more) beakers containing cubes of gelatin. A controlled lab would compare the effect of cooked pineapple and raw pineapple against a square of gelatin the same size that was not subjected to any pineapple. Students should measure the mass of the three gelatin samples after one day.

Investigation 11.A: The Effect of a Catalyst on the Decomposition of Hydrogen Peroxide, $H_2O_2(aq)$

Student Textbook pages 417–418

Purpose

In this investigation, students will design a procedure to illustrate the effect of a catalyst, $I^-(aq)$, on the decomposition of hydrogen peroxide, $H_2O_2(aq)$.

Outcomes

- 30-A2.1s

Advance Preparation

When to Begin	What to Do
1 week before	■ Introduce the investigation and have students write their own procedures.
1 day before	■ Assemble materials and equipment for the lab. ■ Allow solutions of hydrogen peroxide and distilled water to reach room temperature. ■ Photocopy **BLM 11.2.2: Investigation 11.A.**

Materials

Per student group:
Gas collection materials:
- pneumatic trough or large beaker
- large test tube
- rubber tubing to fit glass tubing (must be airtight)
- one-holed stopper, fitted with a piece of glass tubing (must be airtight)
- water

Measuring a loss in mass:
- electronic balance accurate to 0.001 g

Both procedures:
- 100 mL beaker
- 250 mL Erlenmeyer flask
- 3 × 10 mL graduated cylinders
- 2 medicine droppers or plastic pipettes
- grease pencil or masking tape
- stopwatch or clock with a second hand
- 60 mL 6% (or 3% if 6% is not available) $H_2O_2(aq)$
- 60 mL 1.0 mol/L NaI(aq)

Time Required

- 60 minutes

Helpful Tips

- Use **BLM 11.2.2 (HAND) Investigation 11.A: The Effect of a Catalyst** to support this activity. Modify as necessary.
- Have students prepare their procedures several days before the investigation is to take place so that you have time to check them for safety and feasibility.
- If you have a pressure sensor, challenge your more advanced students to design their procedures using this device.
- Students may either design a procedure that tests only the presence or absence of a catalyst, or they may test the effect of a varying amount of a catalyst. Regardless of which procedure they design, they should perform at least three trials.
- To insert a piece of glass tubing into a stopper, use a small amount of petroleum jelly or glycerin on the glass.
- The delivery tube must be airtight.
- To record the volume of gas collected in the test tube, mark the level of gas on the test tube with a grease pencil or piece of masking tape. Fill the gas collection test tube to the line with water and then pour it into a graduated cylinder.
- Measuring the change in mass may not work well if your electronic balance has only two decimal places.
- Some students will need help with the procedure. Have them first list all of the variables before attempting to draw a data table. Their manipulated variable should be the presence or absence of a catalyst (or a varying quantity of the catalyst), the responding variable, the volume of gas collected (or mass of the system) after the reaction. Remind them that they must control everything other than the presence or absence of a catalyst. This includes the total volume of the system and the time allowed for the reaction.
- A sample procedure and data table are shown below:
    1. Measure 10.0 mL of 6% H_2O_2(aq) in a graduated cylinder.
    2. Measure 10.0 mL of 1.0 mol/L NaI(aq) in another graduated cylinder.
    3. Assemble the gas collecting apparatus as shown on page 417 of Student Textbook. If the test tube is not completely filled with water, students should mark the initial water level on the test tube with a grease pencil.
    4. Pour the H_2O_2(aq) into the Erlenmeyer flask.
    5. While your partner holds the rubber tubing in the gas collecting tube, quickly pour the NaI(aq) into the H_2O_2(aq) and seal the tube with the rubber stopper. Start the stopwatch.
    6. After 60 seconds have elapsed, record the volume of water remaining in the test tube with a grease pencil.
    7. Invert the collecting tube. Fill the collecting tube with water to the grease pencil line.
    8. Use a graduated cylinder to record the volume of gas collected.
    9. Dispose of any waste as directed by your teacher.
    10. Repeat the experiment five additional times with the volumes listed in the data table. With each trial, add the specified quantity of distilled water to the NaI(aq) solution before adding this mixture to the H_2O_2(aq).

Table 1: The Effect of Changing Volumes of NaI(aq) on the Decomposition of 10.0 mL H_2O_2(aq)

Trial	Volume of NaI(aq)	Volume of $H_2O(\ell)$	Volume of gas collected (mL)
1	10.0	0.0	
2	8.0	2.0	
3	6.0	4.0	
4	4.0	6.0	
5	2.0	8.0	
6	0.0	10.0	

- Students MUST include at least one trial with catalyst and one trial with no catalyst in order to test their prediction.
- In order to test for a potential change in rate, remind students that they must conduct the experiment for a given amount of time, since rate is measured in units (such as mL of gas) per time.
- ***Expected Results:*** Iodine acts as a catalyst that increases the rate of the decomposition of hydrogen peroxide. The reaction rate should be increased sufficiently so that oxygen bubbles will be clearly seen visibly.

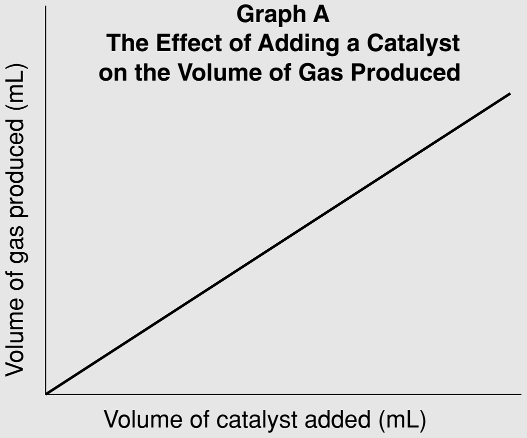
Safety Precautions

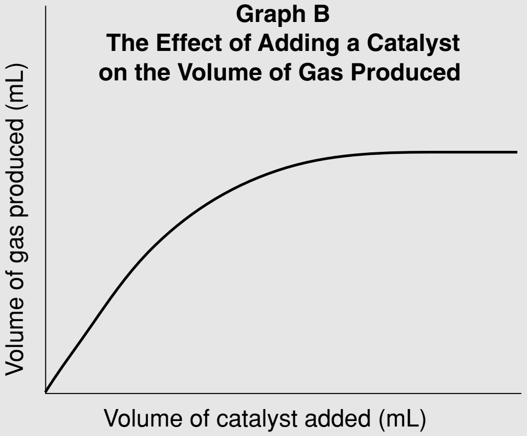
Ensure that students have read "Safety in Your Chemistry Laboratory" on pages xii-xv in the student textbook. Emphasize to students that 6% hydrogen peroxide is an irritant and is also reactive. It is easy to forget this, since hydrogen peroxide solution looks exactly like water. Remind students to treat hydrogen peroxide with care.

Answers to Analysis Questions

1. The addition of a catalyst increased the volume of gas produced (or increased the drop in mass). With increasing amount of catalyst added, the amount of gas produced in the time allotted increased; that is, the rate of reaction increased with increasing amount of catalyst. Since the gas produced (or mass change) was measured after a specific amount of time, this translates into an increase in reaction rate.

2. Student graphs will vary, however they should all have volume of catalyst on the x-axis and volume of gas (or change in mass) on the y-axis. They should see that adding a catalyst will increase the amount of gas produced in a specific amount of time. If they perform trials with varying amounts of catalyst, they should see that the more catalyst that is added, the more gas will be produced (graph A). If they continue to add more catalyst, eventually they will likely obtain a graph similar to graph B. At some point, enough catalyst will be added that the reaction likely will be complete within the time allowed and subsequent trials with even more catalyst will not have an effect on the volume of gas produced.





3. Students should try this experiment using a wider variety of volume of catalyst. They could also repeat the experiment using a different catalyst.

Answer to Conclusion Question

4. Iodide increases the rate of decomposition of hydrogen peroxide. This is measured as an increase in the volume of gas produced (or a greater decrease in the mass) in a specific period of time.

Answer to Application Question

5. The ΔH should not be affected by the use of other catalysts because ΔH is not affected by the presence of any catalyst.

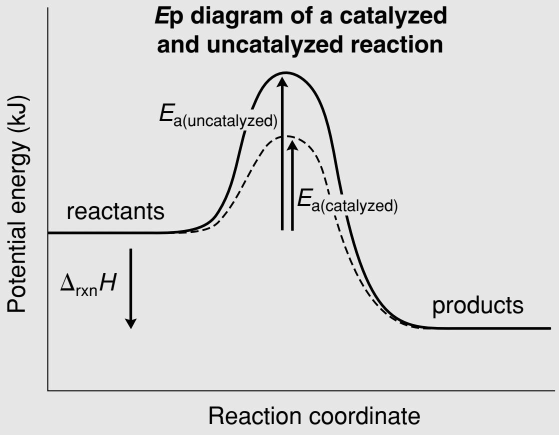
Assessment Options

- Collect and assess students' variables, procedures, data tables and answers to Analysis questions.
- Use Assessment Checklist 1: Designing an Experiment or Checklist 2: Laboratory Report from Appendix A.

Section 11.2 Review Answers

Student Textbook page 418

1. A catalyst has no effect on the total energy change from reactants to products because ΔH is only dependent on the potential energy difference between the reactants and products, not the pathway taken. As shown in the diagram below, the initial and final potential energy positions have not changed, so the enthalpy change for the reaction does not change.



2. Only a small amount of catalyst is necessary because a catalyst is regenerated when the reaction is complete and can be reused.
3. Enzymes and catalysts both speed up reactions and are regenerated at the completion of the reaction. Enzymes are extremely large molecules that only operate well at temperatures found in living systems, while catalysts are small molecules, often ions, that are not adversely affected by temperature.
4. **(a)** Pt(s), Pd(s), and Rh(s)
   (b) hydrocarbons, CO(g), and NOx(g) are removed; CO_2(g), H_2O(g), and N_2(g) are the eventual products
5. The difference between a reactant in a reaction and a catalyst is that a reactant is consumed, whereas a catalyst is regenerated when the reaction is complete. If chlorine atoms were reactants, once they were consumed, they would no longer affect the ozone layer. Since they are

catalysts, however, the chlorine atoms present can promote the destruction of the ozone layer forever (unless they can be removed in another way).

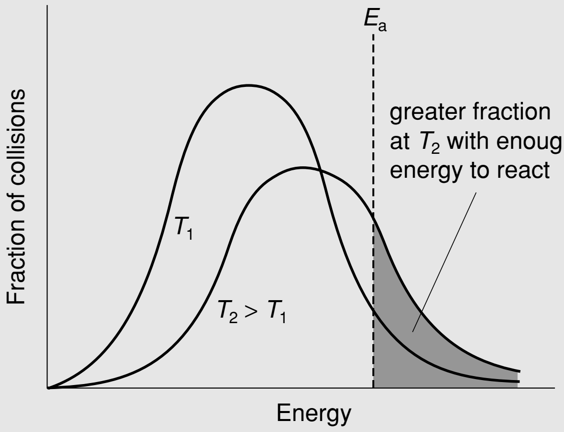
6. Students' answers will depend on the values they interpolate from the graph.
   - **(a)** 575 kJ
   - **(b)** 350 kJ
   - **(c)** The catalyzed reaction is faster because the activation energy is lower.
   - **(d)** 750 kJ
   - **(e)** 525 kJ
   - **(f)** –175 kJ
   - **(g)** 175 kJ
   - **(h)** According to Hess's Law, if you reverse a reaction, you change the sign of the ΔH. In this case, the reaction is reversed, so the ΔH changes from –175 kJ to 175 kJ.

Chapter 11 Review Answers

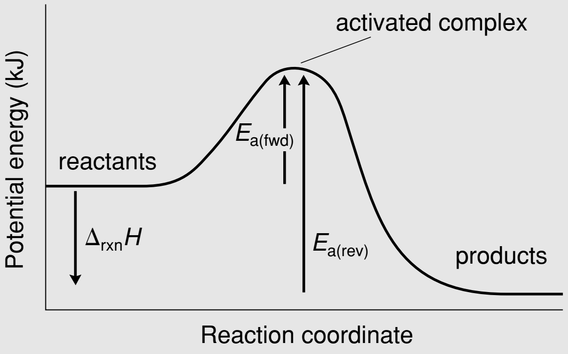
Student Textbook pages 420–421

Answers to Understanding Concepts Questions

1. For a reaction to take place, molecules must collide with the correct orientation geometry and with sufficient (activation) energy.
2. A match will not light spontaneously. With the input of the kinetic energy of the strike, the chemicals reach the activation energy and the match will burn completely.
3. The activated complex is a highly unstable species that is neither product nor reactant. It is so unstable because it contains only partial bonds and has the most potential energy of all of the substances found in the reaction since it is at the highest peak of the reaction mechanism.
4. When temperature is increased, the fraction of collisions with sufficient energy to cause a reaction, represented by the area under the curve, increases. If there are more successful collisions, the rate of reaction increases.



5. The energy required to reach activation energy comes from the kinetic energy of the colliding molecules. As they collide, the kinetic energy is converted to potential energy.
6. The reaction is exothermic.



7. Catalysts are substances that increase the rate of a reaction by providing an alternate, lower activation energy pathway. If the energy barrier is lowered, a larger proportion of molecules will have sufficient energy when they collide to result in a reaction.
8. There is no effect on ΔH when a catalyst is added, therefore the enthalpy change of reaction remains the same. The catalyst changes the pathway of the reaction but as per Hess's law this has no effect on the enthalpy change of the reaction.
9. As molecules collide, their kinetic energy is converted to potential energy as bonds are broken. The species formed during this process is the activated complex, a highly unstable arrangement containing partial bonds. As the bonds reform to make more stable products, the potential energy is converted back into kinetic energy.
10. A catalyst, although part of a reaction, is not consumed or produced during the reaction and cannot be considered a reactant or product. Therefore, above the arrow, indicating that it is part of the reaction but not reactant or product is most appropriate.
11. **(a)** One example of an industrial catalyst is vanadium (V) oxide, $V_2O_5(s)$, used to speed up the second reaction of the contact process to produce sulfuric acid, $H_2SO_4(aq)$, commercially. Other industrial catalysts include Mo(VI) complexes which are used to make polyesters, nickel or platinum to hydrogenate vegetable oil and platinum, palladium and rhodium catalysts used in catalytic converters.
    (b) One example of an enzyme is pepsin. It is produced by cells of the stomach and is used to digest protein in the stomach. Enzymes are used throughout the body to catalyze important reactions. Other enzymes include amylase, which digests starch, and carbonic anhydrase which catalyzes the conversion of carbon dioxide gas into carbonic acid.

(c) Both enzymes and catalysts increase the rate of reactions by providing an alternate lower-energy pathway. Catalysts are often small molecules or atoms that catalyze reactions between other relatively small molecules. These reactions may occur at very high temperatures. Enzymes must be able to facilitate effective collisions between very large molecules at relatively low temperatures. To do this, enzymes are complex, very large molecules that are folded in a specific way to create an active site on which the substrate molecules bind. Because the enzyme's activity is dependent on its shape, which in turn is dependent on conditions, its activity can be regulated through changes in pH, such as what happens with pepsin's activation in the stomach (low pH) and deactivation in the intestine (high pH).

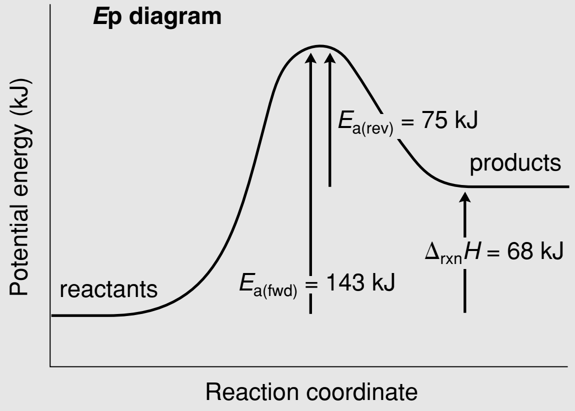
12. At high temperatures, the shape of an enzyme is altered which changes the shape of the active site. This change in shape will decrease or eliminate the enzyme activity, reducing the rate of the reaction.

Answers to Applying Concepts Questions

13. (a) The reaction is endothermic since the $E_{a(fwd)}$ is larger than the $E_{a(rev)}$.

$\Delta H = E_{a(fwd)} - E_{a(rev)} = 143\text{ kJ} - 75\text{ kJ} = 68\text{ kJ}$; since this is positive we know the reaction is endothermic.

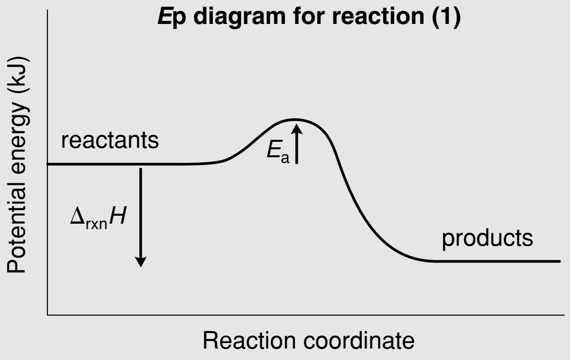
(b)



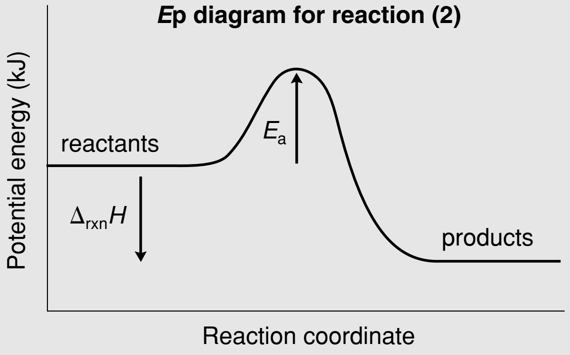
14. (a) $\Delta H = 50\text{ kJ}$, $E_{a(fwd)} = 70\text{ kJ}$, $E_{a(rev)} = 20\text{ kJ}$

(b) $\Delta H = 50\text{ kJ}$, $E_{a(fwd\text{-}cat)} = 58\text{ kJ}$, $E_{a(rev\text{-}cat)} = 8\text{ kJ}$

15. (a)



Reaction coordinate



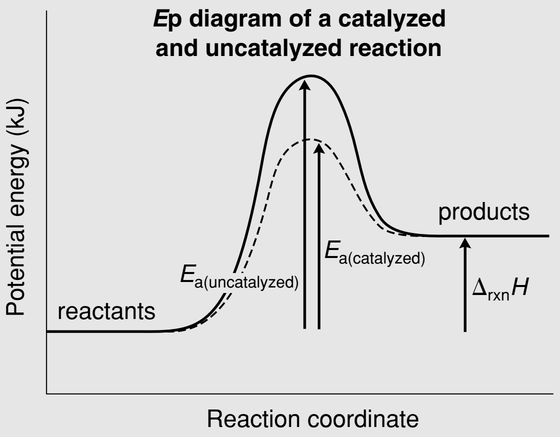
(b) Reaction (1) would have a faster rate given the same conditions, as its activation energy is lower, so more collisions will be effective.

16. The activated complex cannot be isolated because it is highly unstable, due to its partial bonds, and it is short-lived.

17. The activation energy required for the combustion of gasoline must be quite high, so the reaction will not occur spontaneously. The spark required for ignition provides the necessary activation energy.

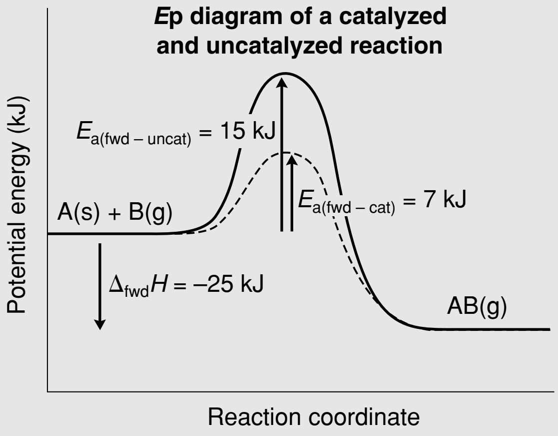
18. (a) A catalyst has no effect on the total energy change because it only affects the path taken from reactants to products. As the potential energy diagram in (b) illustrates, the initial and final potential energy positions of the reactants and products do not change with the addition of a catalyst.

(b)



19. (a) 7 kJ

(b)



20. **(a)** Measure the volume of gas ($H_2(g)$) produced over time.

(b) Record the time until the violet colour disappears.

(c) Measure the change in gas pressure over time.

(d) Measure the decrease in gas pressure over time, or the change in mass of the precipitate after a specific amount of time.

21. Since inhibitors decrease the rate of reaction, they may act to increase the activation energy.

22. **(a)** The spark is providing activation energy; it is not a catalyst as it is not a substance.

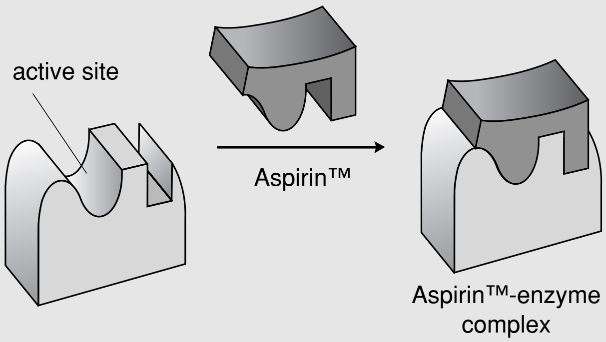
(b) The metal is likely acting as a catalyst since it is required for the reaction to occur. Although it is not mentioned, it appears that the metal is not consumed in the reaction, which is also true for catalysts.

Answers to Making Connections Questions

23. Lead in gasoline and in paint can cause lead poisoning. Lead interferes with the enzyme delta-aminolevulinic acid dehydratase that is important in the synthesis of the heme complex, part of hemoglobin, which is responsible for carrying oxygen in the blood. Although leaded gasoline has been banned in North America for more than 20 years, it is still being sold in third world countries, Eastern Europe and elsewhere in the world. North America and its citizens were quick to spend money on new technology to bring in unleaded gasoline and vehicles equipped with catalytic converters; however, in areas of the world where money and technology are more difficult to come by, leaded gasoline will not be phased out as quickly.

24. The reaction catalyzed in the catalytic converter is only effective at temperatures above 288 °C. To solve this problem, the catalytic converter could be preheated before the car is started using a block heater.

25. Student answers should note that Aspirin™ inhibits the enzyme that produces prostaglandins, the messengers that trigger inflammation in the body. Researchers have shown that Aspirin™ forms a strong bond to the enzyme, changing its shape and permanently blocking that molecule. The diagram below illustrates how Aspirin™ binds to the active site of the enzyme. Unlike the substrate, the Aspirin™ forms a strong bond with the enzyme, preventing the enzyme from bonding with a substrate molecule.



26. Student answers should note that detergents are products that contain enzymes and are designed to remove dirt.

27. **(a)** Ethanol is toxic. During binge drinking, ethanol will accumulate in the body faster than it can be broken down by alcohol dehydrogenase. The accumulation of ethanol impairs heart function and breathing and can lead to death.

(b) Ethanol will compete with methanol for the active site on alcohol dehydrogenase enzymes, acting as a competitive inhibitor. If the methanol metabolism is slowed enough that the formaldehyde levels do not accumulate in the body, blindness and death can be avoided.

28. **(a)** If lead forms strong bonds with an enzyme's active site, the enzyme cannot bind to the substrate and catalyze the reaction necessary for life, leading to sickness.

(b) The lead must also bind to a site on either egg white or milk. The stomach must be pumped to remove the lead/egg white or lead/milk compound from the digestive system before the milk and egg white are digested and the lead is absorbed into the bloodstream.

29. Since temperature affects the rate of all chemical reactions, when cold-blooded animals are not able to increase their body temperatures, all of their bodily processes, including cellular respiration, which produces the energy required to move, would be slowed.

Career Focus: Building Up and Breaking Down Bitumen

Student Textbook pages 422-423

Teaching Strategies

- If possible, invite a petroleum engineer, technologist, or geophysicist to talk to the class about bitumen and related chemical processes in the petroleum industry.
- Remind students of the environmental topics that have been discussed in this unit and how they relate to the petroleum industry and its products.
- If you wish, you could inform students that in Unit 7 the tar sands of Alberta and bitumen will be discussed in more detail.
- General information about bitumen and the tar sands in Alberta can be found at http://www.energy.gov.ab.ca/100.asp and http://www.ags.gov.ab.ca/activities/CBM/alberta_oil_sands.html
- The following web sites may be of interest to students interested in pursuing occupations mentioned in this Career Focus.
  - http://www.engineering.ualberta.ca/petroleum/
  - http://www.alis.gov.ab.ca/occinfo/Content/RequestAction.asp?aspAction=GetHTMLProfile&format=html&occPro_ID=71002691
  - The Society of Petroleum Engineers at http://www.spe.org
  - The Association of Science and Engineering Technology Professionals of Alberta (ASET) at http://www.aset.ab.ca

Answers to Go Further Questions

1. Students should cite properties relating to bitumen's viscosity; its behaviour at various temperatures, including the ease with which it can be shaped and worked at various temperatures and its stability at other temperatures; its lack of permeability; and its suitability for combination with other substances.
2. Corrosion is the chemical degradation of metals, usually when they come into contact with water. Bitumen has been used since Roman times to waterproof materials, and its lack of permeability and stability made it a logical early choice as an anti-corrosive. While its stability and impermeability make it useful as an anti-corrosive, research has continued to find more environmentally friendly substances (such as polymers) to use to fight corrosion in the future.
3. The key environmental benefit of putting waste plastic, including plastic bags, into the bitumen mix to make longer-lasting road surfaces is putting post-consumer plastic waste to further use and keeping it out of landfill sites. This use is being tested primarily on roads in India and New Zealand. Some concerns have been raised about the plastics leaching into the soil after a rain (particularly if hard plastics are used) and the suitability of plastic bags for the process.

Unit 5 Review Answers

Student Textbook pages 424–427

Answers to Understanding Concepts Questions

1. An endothermic reaction is one where more energy is required to break the bonds of the reactants than is released in the formation of the bonds of the products.
2. Since there is twice as much liquid in beaker B, the temperature change (Δt) will be one-half that of beaker A.
3. **(a)** endothermic
   (b) exothermic
   (c) endothermic
   (d) exothermic
   (e) exothermic
4. The standard molar enthalpy of formation for all elements in their standard state is zero. Absolute enthalpy cannot be measured. Since enthalpy is always measured as a change, the reference point can be set wherever it is convenient, as long as it is consistent. Therefore, chemists decided to reference all potential energy relative to elements that are given a molar enthalpy of zero.
5. System is referring to the objects that are being studied, and whose enthalpy change will be measured and/or calculated. The surroundings, on the other hand, include all objects other than the system. The system usually includes the calorimeter; and the reactions taking place inside the calorimeter, the surroundings would be the air, the thermometer (unless its enthalpy change is included in the calculations), and the stirring rod.
6. If the reactants have more potential energy than the products, then the reaction is exothermic, since the additional energy that was in the reactants was released to the surroundings in the formation of the lower energy products.
7. Photosynthesis and cellular respiration are the reverse of each other. Photosynthesis stores the energy originating from the Sun in the chemical bonds of glucose. Cellular respiration harnesses that energy through the combustion of glucose in the cells of living things. Photosynthesis takes place only in plants, some bacteria and some protists, whereas cellular respiration takes place in all living things.
8. In an open system, the water produced through hydrocarbon combustion will be gaseous ($H_2O(g)$), whereas in a closed system, the water produced will be in liquid form ($H_2O(\ell)$).
9. The energy stored in chemical bonds originates almost entirely from the Sun. The Sun's energy is trapped in glucose through photosynthesis. The energy stored in the

chemical bonds in glucose is released through photosynthesis to be used by living things. The sun's energy is also the driving force in generating electricity through hydroelectricity, wind power and in burning fossil fuels.

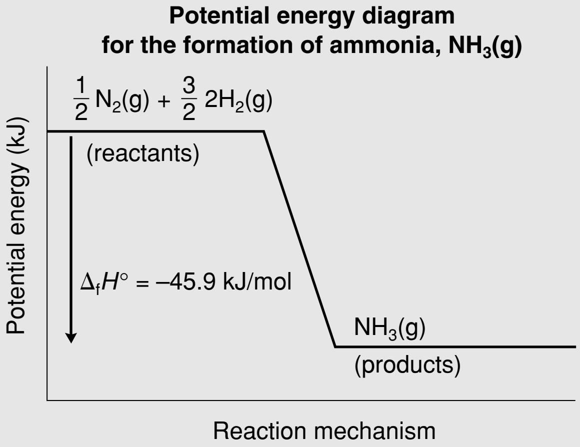
10. Enthalpy is the total internal energy of a substance at constant pressure. Molar enthalpy is the quantity of thermal energy absorbed or released when one mole of the substance undergoes a potential energy change.

11. The higher the specific heat capacity of a substance, the more energy is required to increase the temperature of that substance. Therefore, given a constant rate of energy input, platinum, which has the lowest specific heat capacity, will reach 30 °C with the least amount of energy input and therefore the least amount of time. Similarly, titanium has the highest specific heat capacity so it will require the largest amount of energy input and therefore the longest amount of time to reach 30 °C.

12. **(a)** $\frac{1}{2}N_2(g) + \frac{3}{2}H_2(g) \rightarrow NH_3(g)\ \Delta_fH^\circ = -45.9$ kJ/mol

$\frac{1}{2}N_2(g) + \frac{3}{2}H_2(g) \rightarrow NH_3(g) + 45.9$ kJ

(b)



13. Calorimetry is the technological process of measuring the heat released or absorbed during a chemical or physical process. The most commonly used calorimeter is a simple calorimeter which consists of two nested polystyrene cups with a lid. This calorimeter can be used for reactions taking place in solution. To measure enthalpies of combustion, a calorimeter can be constructed from an aluminium can. The can is filled with water and suspended above the fuel. When the fuel is burned, it will heat up the metal and the water.

14. If the calorimeter absorbs a significant amount of heat, then it must be included in the calculations. To include the heat absorbed by the calorimeter, its heat capacity must be known.

15. Specific heat capacity is defined as the quantity of energy required to raise the temperature of 1 g of the substance by 1 °C. Heat capacity is defined as the quantity of energy required to raise the temperature of that object by 1 °C.

(a) The units for specific heat capacity are J/g•°C, for heat capacity, J/°C.

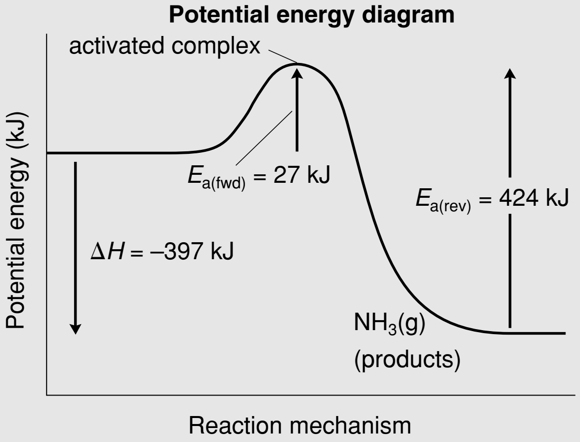
(b) Specific heat capacity is used for pure substances, whereas heat capacity is usually used to calculate heat for calorimeters, which may be made of a variety of substances. Its heat capacity will be calibrated using materials of known specific heat capacity.

16. Activation energy, E_a, is the minimum energy that a collision must have for a reaction to take place.

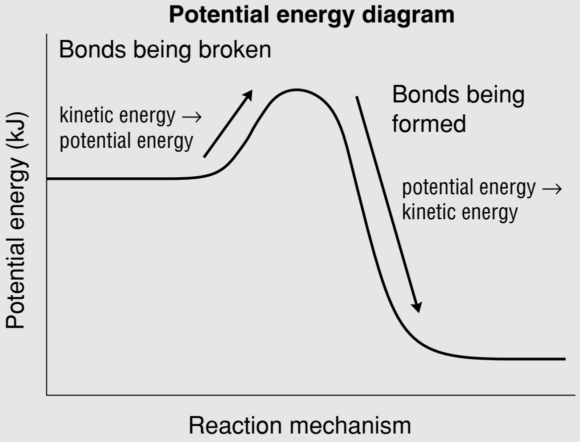
17. For a reaction to occur, molecules must collide with the correct collision geometry and with sufficient energy (activation energy).

18. Catalysts provide a lower energy pathway for the reaction, thereby lowering the activation energy. If the activation energy is lowered, more collisions will have sufficient energy for a reaction to occur and therefore the reaction should proceed more quickly.

19.



20.



21. Enzymes and catalysts both speed up reactions and are regenerated at the completion of the reaction. Enzymes are extremely large molecules that only operate well at temperatures found in living systems, while catalysts are small molecules, often ions, that are not adversely affected by temperature.

22. Both heat content and heat of combustion describe the quantity of energy released when a substance is burned. Heat content is measured in kJ/kg and is useful in the discussion of energy content in practical applications since fuels would be commonly purchased by mass (or perhaps volume). Heat of combustion is measured in kJ/mol. This value is more applicable in situations where moles are used, that is, in a chemistry lab.

Answers to Applying Concepts Questions

23. When NaOH(s) and HCl(aq) are mixed, the acid will be neutralized by the base. The increase in temperature represents the enthalpy of neutralization.

24. Students should design an experiment similar to Investigation 9.B on pages 358–359 of the student textbook.

25. (a) $2C(s) + 2H_2(g) + O_2(g) \rightarrow CH_3COOH(\ell)\ \Delta_f H^\circ = -484.3\ \text{kJ/mol}$

(b) $Ba(s) + \frac{1}{8}S_8(s) + 2O_2(g) \rightarrow BaSO_4(s)\ \Delta_f H^\circ = -1473.2\ \text{kJ/mol}$

(c) $2C(s) + H_2(g) \rightarrow C_2H_2(g)\ \Delta_f H^\circ = 227.4\ \text{kJ/mol}$

(d) $\frac{1}{2}N_2(g) + O_2(g) \rightarrow NO_2(g)\ \Delta_f H^\circ = 33.2\ \text{kJ/mol}$

26. The more thermally stable a compound, the more energy is required to decompose the substance. Therefore, the least thermally stable has the highest molar enthalpy of formation; the most thermally stable has the lowest molar enthalpy of formation. Ranked from the least thermally stable to the most thermally stable: $C_2H_2(g)$, $NO_2(g)$, $CH_3COOH(\ell)$, $BaSO_4(s)$.

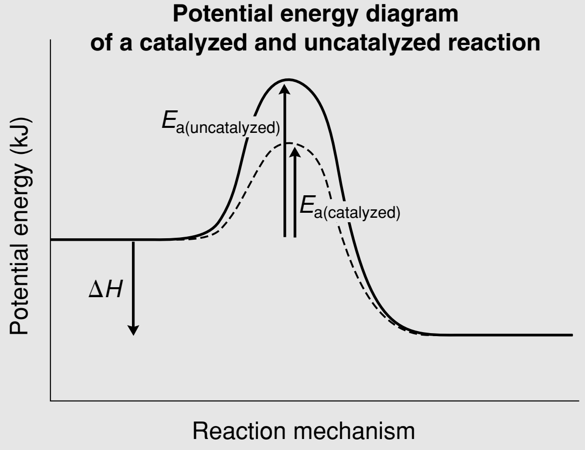
27. It is more efficient to produce electricity from flowing water than from burning fossil fuels because there are fewer energy conversions. Although energy is conserved, with each energy conversion, some energy is "lost" to a form of energy that is not useful. The energy in falling water is converted to electricity in only one conversion, whereas the production of electricity from fossil fuels involves at least two energy conversions, not to mention the mining and transportation of the fossil fuels to the power plant.

28. (a) The expected yearly consumption is 648 kWh.

(b) This model is better than average. The most energy efficient model uses approximately 56 kWh annually, and the least energy efficient model uses 972 kWh annually.

(c) The most energy efficient models will have an ENERGY STAR™ logo.

29. (a) A catalyst has no effect on the enthalpy change of a reaction since it affects only activation energy, and therefore reaction rate. As you can see from the figure below, a catalyst does not change the enthalpy of the reactants and the products which are the only conditions that will affect ΔH.


Potential energy diagram of a catalyzed and uncatalyzed reaction

(b) Student procedures should be similar to Investigation 11.A on page 417 of the student textbook. In order to measure the enthalpy change as well as the effect of a catalyst, students should include a step where they measure the initial and final temperatures of the system.

(c) $H_2O_2(aq) \rightarrow H_2O(\ell) + \frac{1}{2}O_2(g)$

$$\begin{aligned}\Delta_r H &= [1(\Delta_f H^\circ\ H_2O(\ell)) + \tfrac{1}{2}(\Delta_f H^\circ O_2(g))] - [1(\Delta_f H^\circ\ H_2O_2(aq))]\\ &= [(1\ \text{mol})(-285.8\ \text{kJ/mol}) + \left(\tfrac{1}{2}\ \text{mol}\right)(0\ \text{kJ/mol})] - [(1\ \text{mol})(-187.8\ \text{kJ/mol})]\\ &= -98.0\ \text{kJ/mol}\end{aligned}$$

Answers to Solving Problems Questions

30. (a)
$$\begin{aligned}\Delta t &= 18.3\ ^\circ\text{C} - 15.7\ ^\circ\text{C}\\ &= 2.6\ ^\circ\text{C}\end{aligned}$$

$$\begin{aligned}\text{mass of ethanol} &= 47.39\ \text{g} - 47.19\ \text{g}\\ &= 0.20\ \text{g}\ C_2H_5OH(\ell)\end{aligned}$$

$$\begin{aligned}\text{mass of water} &= 239.36\ \text{g} - 84.37\ \text{g}\\ &= 154.99\ \text{g}\end{aligned}$$

$$E_{\text{system}} = E_{\text{surroundings}}$$

$$n\Delta_c H = -(mc\Delta t_{\text{water}} + mc\Delta t_{\text{aluminium}})$$

$$\Delta_c H = -\frac{(mc\Delta t_{\text{water}} + mc\Delta t_{\text{aluminium}})}{n}$$

$$= -\frac{(154.99\ \cancel{\text{g}})\left(\frac{4.19\ \text{J}}{\cancel{\text{g}}\bullet\cancel{^\circ\text{C}}}\right)(2.6\ \cancel{^\circ\text{C}}) + (84.37\ \cancel{\text{g}})\left(\frac{0.897\ \text{J}}{\cancel{\text{g}}\bullet\cancel{^\circ\text{C}}}\right)(2.6\ \cancel{^\circ\text{C}})}{(0.20\ \cancel{\text{g}\ C_2H_5OH(\ell)})\left(\frac{1\ \text{mol}\ C_2H_5OH(\ell)}{46.08\ \cancel{\text{g}\ C_2H_5OH(\ell)}}\right)}$$

$$= -\frac{1.885\text{ kJ}}{0.0043\text{ mol }C_2H_5OH(\ell)}$$

$$= -4.4 \times 10^2\text{ kJ/mol }C_2H_5OH(\ell)$$

(b) $$\%\text{ difference} = \left|\frac{\text{accepted} - \text{experimental}}{\text{accepted}}\right| \times 100\%$$

$$= \left|\frac{-507\ \cancel{\text{kJ/mol}} - (-440\ \cancel{\text{kJ/mol}})}{-507\ \cancel{\text{kJ/mol}}}\right| \times 100\%$$

$$= 13\%$$

(c) The “lost” energy was converted into forms other than heat such as light, or it was lost to the surroundings, heating up the air and the burner.

31. Method 1 Using Formulas

Find the number of moles of CaO(s) reacted

$$n = \frac{m}{M}$$

$$= \frac{1.0 \times 10^2\ \cancel{\text{g CaO(s)}}}{\frac{56.08\ \cancel{\text{g CaO(s)}}}{\text{mol CaO(s)}}}$$

$$= 1.78\text{ mol CaO(s)}$$

Determine the amount of energy released when that amount of CaO(s) reacts

$$\Delta H = n\Delta H^\circ$$

$$= (1.78\ \cancel{\text{mol CaO(s)}})\left(\frac{-65\text{ kJ}}{\cancel{\text{mol CaO(s)}}}\right)$$

$$= -1.16 \times 10^2\text{ kJ}$$

Determine the number of moles of methane that would produce that amount of energy

$$\Delta H = n\Delta H^\circ$$

$$n = \frac{\Delta H}{\Delta H^\circ}$$

$$= \frac{-1.16 \times 10^2\ \cancel{\text{kJ}}}{\frac{-8.0 \times 10^2\ \cancel{\text{kJ}}}{\text{mol }CH_4(g)}}$$

$$= 0.145\text{ mol }CH_4(g)$$

Use the conversion factor, 1 mol of any gas at STP occupies 22.4 L to find volume

$$x\text{ L }CH_4(g) = 0.145\ \cancel{\text{mol }CH_4(g)} \times \frac{22.4\text{ L }CH_4(g)}{\cancel{\text{mol }CH_4(g)}}$$

$$= 3.2\text{ L }CH_4(g)$$

Method 2 Using Dimensional Analysis

$$x\text{ L }CH_4(g) = 1.0 \times 10^2\text{ g CaO(s)} \times \frac{\text{mol CaO(s)}}{56.08\text{ g CaO(s)}}$$

$$\times \frac{-65\ \cancel{\text{kJ}}}{\cancel{\text{mol CaO(s)}}} \times \frac{\cancel{\text{mol }CH_4(g)}}{-8.0 \times 10^2\ \cancel{\text{kJ}}} \times \frac{22.4\text{ L }CH_4(g)}{\cancel{\text{mol }CH_4(g)}}$$

$$= 3.2\text{ L }CH_4(g)$$

32. **(a)** $C_{12}H_{22}O_{11}(s) + 12O_2(g) \rightarrow$

$$12CO_2(g) + 11H_2O(g)\ \Delta_c H = -5.65 \times 10^3\text{ kJ}$$

(b) Method 1 Using Formulas

$$n = \frac{m}{M}$$

$$= \frac{5.00\ \cancel{\text{g }C_{12}H_{22}O_{11}(s)}}{\frac{342.34\ \cancel{\text{g }C_{12}H_{22}O_{11}(s)}}{\text{mol }C_{12}H_{22}O_{11}(s)}}$$

$$= 0.0146\text{ mol }C_{12}H_{22}O_{11}(s)$$

$$\Delta H = n\Delta_c H$$

$$= (0.0146\ \cancel{\text{mol }C_{12}H_{22}O_{11}(s)})\left(\frac{-5.65 \times 10^3\text{ kJ}}{\cancel{\text{mol }C_{12}H_{22}O_{11}(s)}}\right)$$

$$= -82.5\text{ kJ}$$

Method 2 Using Dimensional Analysis

$$x\text{ kJ} = 5.00\ \cancel{\text{g }C_{12}H_{22}O_{11}(s)} \times$$

$$\frac{1\ \cancel{\text{mol }C_{12}H_{22}O_{11}(s)}}{342.34\ \cancel{\text{g }C_{12}H_{22}O_{11}(s)}} \times \left(\frac{-5.65 \times 10^3\text{ kJ}}{\cancel{\text{mol }C_{12}H_{22}O_{11}(s)}}\right)$$

$$= -82.5\text{ kJ}$$

(c) $$Q = mc\Delta t$$

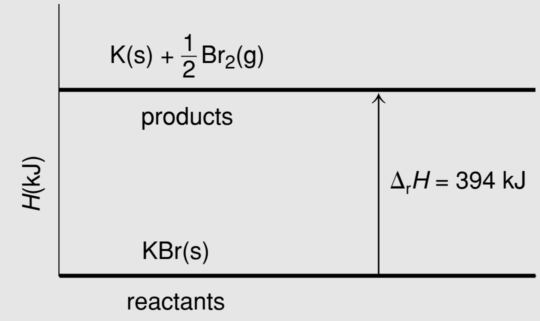
$$m = \frac{Q}{c\Delta t}$$

$$= \frac{82.5\ \cancel{\text{kJ}}}{\left(\frac{4.19\text{ J}}{\cancel{\text{g}}\bullet\cancel{^\circ\text{C}}}\right)\left(\frac{1\ \cancel{\text{kJ}}}{1000\ \cancel{\text{J}}}\right)(5.0\ \cancel{^\circ\text{C}})\left(\frac{1000\ \cancel{\text{g}}}{1\text{ kg}}\right)}$$

$$= 3.9\text{ kg}$$

33. **(a)** $KBr(s) \rightarrow K(s) + \frac{1}{2}Br_2(g)\ \Delta H = 394\text{ kJ}$

(b)



(c) If the molar enthalpy of decomposition is 394 kJ/mol, the molar enthalpy of formation is –394 kJ/mol.

Method 1 Using Formulas

$$\begin{aligned} n &= \frac{m}{M} \\ &= \frac{1.37\ \text{g KBr(s)}}{\dfrac{119.00\ \text{g KBr(s)}}{\text{mol KBr(s)}}} \\ &= 0.0115\ \text{mol KBr(s)} \end{aligned}$$

$$\begin{aligned} \Delta H &= n\Delta_c H \\ &= (0.0115\ \text{mol KBr(s)})\left(\frac{-394\ \text{kJ}}{\text{mol KBr(s)}}\right) \\ &= -4.54\ \text{kJ} \end{aligned}$$

Method 2 Using Dimensional Analysis

$$\begin{aligned} x\ \text{kJ} &= 1.37\ \text{g KBr(s)} \times \frac{1\ \text{mol KBr(s)}}{119.00\ \text{g KBr(s)}} \times \frac{-394\ \text{kJ}}{\text{mol KBr(s)}} \\ &= -4.54\ \text{kJ} \end{aligned}$$

34. (a) Method 1 Using Formulas

$$\begin{aligned} n &= \frac{m}{M} \\ &= \frac{1.37 \times 10^3\ \text{g}\ \cancel{\text{Fe(s)}}}{\dfrac{55.85\ \text{g}\ \cancel{\text{Fe(s)}}}{\text{mol Fe(s)}}} \\ &= 24.5\ \text{mol Fe(s)} \end{aligned}$$

$$\begin{aligned} \Delta H &= n\Delta_c H^\circ \\ &= (24.5\ \cancel{\text{mol Fe(s)}})\left(\frac{-1.65 \times 10^3\ \text{kJ}}{4\ \cancel{\text{mol Fe(s)}}}\right) \\ &= -10.1 \times 10^3\ \text{kJ} \\ &= -10.1\ \text{MJ} \end{aligned}$$

Method 2 Using Dimensional Analysis

$$\begin{aligned} x\ \text{kJ} &= 1.37 \times 10^3\ \cancel{\text{g Fe(s)}} \times \frac{1\ \cancel{\text{mol Fe(s)}}}{55.85\ \cancel{\text{g Fe(s)}}} \times \left(\frac{-1.65 \times 10^3\ \text{kJ}}{4\ \cancel{\text{mol Fe(s)}}}\right) \\ &= -10.1 \times 10^3\ \text{kJ} \\ &= -10.1\ \text{MJ} \end{aligned}$$

(b) Method 1 Using Formulas

$$\begin{aligned} \Delta H &= n\Delta H^\circ \\ n &= \frac{\Delta H}{\Delta H^\circ} \\ &= \frac{-3.75 \times 10^3\ \cancel{\text{kJ}}}{\dfrac{-1.65 \times 10^3\ \cancel{\text{kJ}}}{2\ \text{mol Fe}_2\text{O}_3\text{(s)}}} \\ &= 4.545\ \text{mol Fe}_2\text{O}_3\text{(s)} \end{aligned}$$

$$\begin{aligned} n &= \frac{m}{M} \\ m &= nM \\ &= (4.545\ \cancel{\text{mol Fe}_2\text{O}_3\text{(s)}})\left(\frac{159.70\ \text{g Fe}_2\text{O}_3\text{(s)}}{\cancel{\text{mol Fe}_2\text{O}_3\text{(s)}}}\right) \\ &= 726\ \text{g Fe}_2\text{O}_3\text{(s)} \end{aligned}$$

Method 2 Using Dimensional Analysis

$$\begin{aligned} x\ \text{g Fe}_2\text{O}_3\text{(s)} &= -3.75 \times 10^3\ \cancel{\text{kJ}} \times \frac{2\ \cancel{\text{mol Fe}_2\text{O}_3\text{(s)}}}{-1.65\ \times 10^3\ \cancel{\text{kJ}}} \times \frac{159.7\ \text{g Fe}_2\text{O}_3\text{(s)}}{\cancel{\text{mol Fe}_2\text{O}_3\text{(s)}}} \\ &= 726\ \text{g Fe}_2\text{O}_3\text{(s)} \end{aligned}$$

35. (a) greatest energy $C_8H_{18}(\ell)$, $C_2H_5OH(\ell)$, $CH_4(g)$, $H_2(g)$ least energy

(b) $C_8H_{18}(\ell) + \frac{25}{2}O_2(g) \rightarrow 8CO_2(g) + 9H_2O(\ell)$ $\quad \Delta_c H = -5\ 513\ \text{kJ/mol}$

$C_2H_5OH(\ell) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(\ell)$ $\quad \Delta_c H = -1367\ \text{kJ/mol}$

$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(\ell)$ $\quad \Delta_c H = -890\ \text{kJ/mol}$

$H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(\ell)$ $\quad \Delta_c H = -285\ \text{kJ/mol}$

(c) To determine the heat content, divide each by the molar mass (in g/mol)

$$\begin{aligned} x\ \frac{\text{kJ}}{\text{g } C_8H_{18}(\ell)} &= \frac{-5513\ \text{kJ}}{\cancel{\text{mol } C_8H_{18}(\ell)}} \times \frac{\cancel{\text{mol } C_8H_{18}(\ell)}}{114.26\ \text{g } C_8H_{18}(\ell)} \\ &= -48.25\ \text{kJ/g } C_8H_{18}(\ell) \end{aligned}$$

$$\begin{aligned} x\ \frac{\text{kJ}}{\text{g } C_2H_5OH(\ell)} &= \frac{-1367\ \text{kJ}}{\cancel{\text{mol } C_2H_5OH(\ell)}} \times \frac{\cancel{\text{mol } C_2H_5OH(\ell)}}{46.08\ \text{g } C_2H_5OH(\ell)} \\ &= -29.66\ \text{kJ/g } C_2H_5OH(\ell) \end{aligned}$$

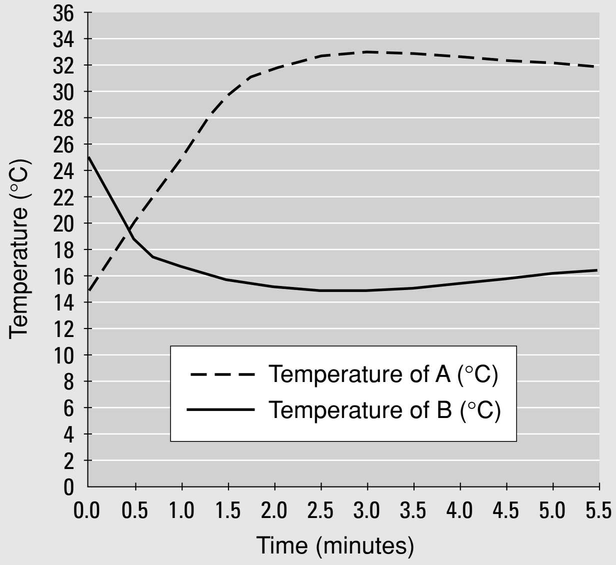
$$\begin{aligned} x\ \frac{\text{kJ}}{CH_4(g)} &= \frac{-890\ \text{kJ}}{\cancel{\text{mol } CH_4(g)}} \times \frac{\cancel{\text{mol } CH_4(g)}}{16.05\ \text{g } CH_4(g)} \\ &= -55.4\ \text{kJ/g } CH_4(g) \end{aligned}$$

$$\begin{aligned} x\ \frac{\text{kJ}}{\text{g } H_2(g)} &= \frac{-285\ \text{kJ}}{\cancel{\text{mol } H_2(g)}} \times \frac{\cancel{\text{mol } H_2(g)}}{2.02\ \text{g } H_2(g)} \\ &= -141\ \text{kJ/g } H_2(g) \end{aligned}$$

greatest energy $H_2(g)$, $CH_4(g)$, $C_8H_{18}(\ell)$, $C_2H_5OH(\ell)$ least energy

(d) For most applications, heat content is likely more appropriate. Most people will buy fuel by mass or volume, so knowing how much energy a litre or kilogram will provide is more useful than the measurement in moles. Another useful measurement would be based on fuel costs (kJ/$) or on emissions produced (kJ/kg $CO_2(g)$).

36. (a) Change in temperature as solids A & B are dissolved



(b) When solid A dissolves, the temperature increases. Therefore, the enthalpy of solution of solid A is exothermic. When solid B dissolves, the temperature decreases. Therefore, the enthalpy of solution of solid B is endothermic.

(c) For A, the maximum temperature is 33.0 °C.

$$\Delta t = 33.0\ ^\circ\text{C} - 15.0\ ^\circ\text{C}$$
$$= 18.0\ ^\circ\text{C}$$

$$n\Delta H = mc\Delta t$$

$$\Delta H = -\frac{(110\ \cancel{\text{g}})\left(\dfrac{4.19\ \text{J}}{\cancel{\text{g}}\bullet\cancel{^\circ\text{C}}}\right)(18.0\ \cancel{^\circ\text{C}})}{10.0\ \text{g A(s)}}$$

$$= -830\ \text{J/g A(s)}$$

For B, the minimum temperature is 15.0 °C.

$$\Delta t = 15.0\ ^\circ\text{C} - 25.0\ ^\circ\text{C}$$
$$= -10.0\ ^\circ\text{C}$$

$$n\Delta H = mc\Delta t$$

$$\Delta H = -\frac{(110\ \cancel{\text{g}})\left(\dfrac{4.19\ \text{J}}{\cancel{\text{g}}\bullet\cancel{^\circ\text{C}}}\right)(-10.0\ \cancel{^\circ\text{C}})}{10.0\ \text{g B(s)}}$$

$$= 461\ \text{J/g B(s)}$$

(d) Both plots indicate that the calorimeter is not a perfect insulator. The graph for solid A evidently rises above room temperature and then begins to fall. The graph for solid B falls below room temperature and then begins to rise.

37. $3\times\ \ 3C(s) + 6H_2(g) \rightarrow 3CH_4(g)$

$$\Delta H^\circ = -74.8\ \text{kJ} \times 3$$

$2\times\ \ 2H_2(g) + O_2(g) \rightarrow \cancel{2H_2O}(g) \quad \Delta H^\circ = -241.8\ \text{kJ} \times 2$

$-2\times\ \ \cancel{2H_2O}(g) \rightarrow 2H_2O(\ell) \quad \Delta H^\circ = 44.0\ \text{kJ} \times -2$

$CO(g) + \frac{1}{2}O_2(g) \rightarrow CO_2(g) \quad \Delta H^\circ = -283.1\ \text{kJ}$

$-3\times\ \ 3CO(g) \rightarrow 3C(s) + \frac{3}{2}\cancel{O}_2(g)$

$$\Delta H^\circ = -110.5\ \text{kJ} \times -3$$

$4CO(g) + 8H_2(g) \rightarrow 3CH_4(g) + CO_2(g) + 2H_2O(\ell)$

$$\Delta H^\circ = -747.6\ \text{kJ}$$

38. $-1 \times$ **(4)** $H_2S(g) \rightarrow \cancel{H_2(g)} + \cancel{\frac{1}{8}S_8(s)}$

$$\Delta H^\circ = -21\ \text{kJ} \times -1$$

$2 \times$ **(2)** $H_2(g) + F_2(g) \rightarrow 2HF(g) \quad \Delta H^\circ = -273\ \text{kJ} \times 2$

(3) $\cancel{\frac{1}{8}S_8(s)} + 3F_2(g) \rightarrow SF_6(g) \quad \Delta H^\circ = -1220\ \text{kJ}$

$H_2S(g) + 4F_2(g) \rightarrow 2HF(g) + SF_6(g)$

$$\Delta H^\circ = -1745\ \text{kJ}$$

39. (a)
$$\begin{aligned}\Delta_r H^\circ &= \Sigma(n\Delta_f H^\circ \text{ products}) - \Sigma(n\Delta_f H^\circ \text{ reactants})\\ &= [(1\ \text{mol})(\Delta_f H^\circ\ CaCO_3(s))] - \\ &\quad [(1\ \text{mol})(\Delta_f H^\circ\ CaO(s)) + (1\ \text{mol})(\Delta_f H^\circ\ CO_2(g))]\\ &= [(1\ \text{mol})(-1207.6\ \text{kJ/mol})] - \\ &\quad [(1\ \text{mol})(-634.9\ \text{kJ/mol}) + (1\ \text{mol})(-393.5\ \text{kJ/mol})]\\ &= -179.2\ \text{kJ}\end{aligned}$$

(b)
$$\begin{aligned}\Delta_r H^\circ &= \Sigma(n\Delta_f H^\circ \text{ products}) - \Sigma(n\Delta_f H^\circ \text{ reactants})\\ &= [(1\ \text{mol})(\Delta_f H^\circ\ C_2H_6(g))] - \\ &\quad [(1\ \text{mol})(\Delta_f H^\circ\ C_2H_2(g)) + (2\ \text{mol})(\Delta_f H^\circ\ H_2(g))]\\ &= [(1\ \text{mol})(-84.0\ \text{kJ/mol})] - \\ &\quad [(1\ \text{mol})(227.4\ \text{kJ/mol}) + (2\ \text{mol})(0\ \text{kJ/mol})]\\ &= -311.4\ \text{kJ}\end{aligned}$$

(c)
$$\begin{aligned}\Delta_r H^\circ &= \Sigma(n\Delta_f H^\circ \text{ products}) - \Sigma(n\Delta_f H^\circ \text{ reactants})\\ &= [(4\ \text{mol})(\Delta_f H^\circ\ NO(g)) + \\ &\quad (6\ \text{mol})(\Delta_f H^\circ\ H_2O(g))] - \\ &\quad [(4\ \text{mol})(\Delta_f H^\circ\ NH_3(g)) + (5\ \text{mol})(\Delta_f H^\circ O_2(g))]\\ &= [(4\ \text{mol})(91.3\ \text{kJ/mol}) + \\ &\quad (6\ \text{mol})(-241.8\ \text{kJ/mol})] - \\ &\quad [(4\ \text{mol})(-45.9\ \text{kJ/mol}) + (5\ \text{mol})(0\ \text{kJ/mol})]\\ &= -902.0\ \text{kJ}\end{aligned}$$

40. $\Delta_r H^\circ = \Sigma(n\Delta_f H^\circ \text{ products}) - \Sigma(n\Delta_f H^\circ \text{ reactants})$

$$-182.6\text{ kJ} = [(1\text{ mol})(\Delta_f H^\circ\ SiF_4(g)) + (2\text{ mol})(\Delta_f H^\circ\ H_2O(\ell))] - [(1\text{ mol})(\Delta_f H^\circ SiO_2\ (g)) + (4\text{ mol})(\Delta_f H^\circ HF(g))]$$

$$-182.6\text{ kJ} = [(1\text{ mol})(\Delta_f H^\circ SiF_4(g)) + (2\text{ mol})(-285.8\text{ kJ/mol})] - [(1\text{ mol})(-910.7\text{ kJ/mol}) + (4\text{ mol})(-273.3\text{ kJ/mol})]$$

$$-182.6\text{ kJ} = (1\text{ mol})(\Delta_f H^\circ\ SiF_4(g)) + 1432.3\text{ kJ}$$

$$\Delta_f H^\circ\ SiF_4(g) = -1614.9\text{ kJ/mol } SiF_4(g)$$

41. (a) $C_3H_5(NO_3)_3(\ell) \rightarrow \frac{3}{2}N_2(g) + \frac{5}{2}H_2O(g) + 3CO_2(g) + \frac{1}{4}O_2(g)\ \Delta H = -1.15 \times 10^4\text{ kJ/mol } C_3H_5(NO_3)_3(\ell)$

(b) $\Delta H^\circ = \Sigma(n\Delta_f H^\circ \text{ products}) - \Sigma(n\Delta_f H^\circ \text{ reactants})$

$$-1.15 \times 10^4\text{ kJ} = \left[\left(\frac{3}{2}\text{ mol}\right)(\Delta_f H^\circ\ N_2(g)) + \left(\frac{5}{2}\text{ mol}\right)\left(\Delta_f H^\circ\ H_2O(g)\right) + (3\text{ mol})(\Delta_f H^\circ\ CO_2(g)) + \left(\frac{1}{4}\text{ mol}\right)(\Delta_f H^\circ\ O_2(g))\right] - [(1\text{ mol})(\Delta_f H^\circ\ C_3H_5(NO_3)_3(\ell))]$$

$$-1.15 \times 10^4\text{ kJ} = \left[\left(\frac{3}{2}\text{ mol}\right)(0\text{ kJ/mol}) + \left(\frac{5}{2}\text{ mol}\right)(-241.8\text{ kJ/mol}) + (3\text{ mol})(-393.5\text{ kJ/mol}) + \left(\frac{1}{4}\text{ mol}\right)(0\text{ kJ/mol}\right] - [(1\text{ mol})(\Delta_f H^\circ\ C_3H_5(NO_3)_3(\ell))]$$

$$-1.15 \times 10^4\text{ kJ} = -1785.0\text{ kJ} - (1\text{ mol})(\Delta_f H^\circ\ C_3H_5(NO_3)_3(\ell))$$

$$\Delta_f H^\circ C_3H_5(NO_3)_3(\ell) = 9.72 \times 10^3\text{ kJ/mol } C_3H_5(NO_3)_3(\ell)$$

42. (a) –22 kJ

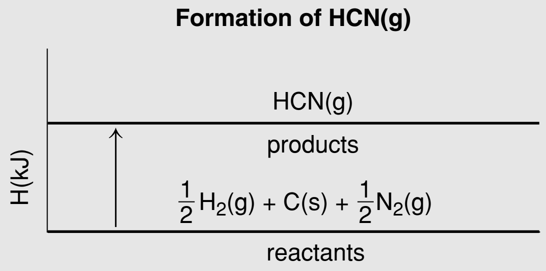
(b) 5.76 g $O_2(g)$

(c) $C_2H_5OH(\ell) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(g)$ $\quad \Delta_c H = -1234.8\text{ kJ/mol}$

(d) 20.5 g $C_2H_5OH(\ell)$

43. (a) $\frac{1}{2}H_2(g) + C(s) + \frac{1}{2}N_2(g) \rightarrow HCN(g)$ $\quad \Delta H = 135\text{ kJ/mol}$

(b)



(c) 301 kJ

44. The theoretical value for the molar enthalpy of combustion of propane, $C_3H_8(g)$, in an open system can be calculated:

$$C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g)$$

$$\begin{aligned}\Delta_c H^\circ &= \Sigma(n\Delta_f H^\circ \text{ products}) - \Sigma(n\Delta_f H^\circ \text{reactants})\\ &= [(3\text{ mol})(\Delta_f H^\circ CO_2(g)) + (4\text{ mol})(\Delta_f H^\circ\ H_2O(g))] - [(1\text{ mol})(\ \Delta_f H^\circ C_3H_8(g)) + (5\text{ mol})(\Delta_f H^\circ O_2(g))]\\ &= [(3\text{ mol})(-393.5\text{ kJ/mol}) + (4\text{ mol})(-241.8\text{ kJ/mol})] - [(1\text{ mol})(\ -103.8\text{ kJ/mol}) + (5\text{ mol})(0\text{ kJ/mol})]\\ &= -2043.9\text{ kJ/mol } C_3H_8(g)\end{aligned}$$

Energy Input Calculation:

Method 1 Using Formulas

$$n = \frac{m}{M}$$

$$= \frac{4.48\text{ g } C_3H_8(g)}{\dfrac{44.11\text{ g } C_3H_8(g)}{\text{mol } C_3H_8(g)}}$$

$$= 0.1016\text{ mol } C_3H_8(g)$$

$$\begin{aligned}\Delta H &= n\Delta_c H\\ &= (0.1016\ \cancel{\text{mol } C_3H_8(g)})\left(\frac{-2043.9\text{ kJ}}{\cancel{\text{mol } C_3H_8(g)}}\right)\\ &= -208\text{ kJ}\end{aligned}$$

Method 2 Using Dimensional Analysis

$$\text{x kJ} = \frac{-2043.9\text{ kJ}}{\cancel{\text{mol } C_3H_8(g)}} \times \frac{1\ \cancel{\text{mol } C_3H_8(g)}}{44.11\ \cancel{\text{g } C_3H_8(g)}} \times 4.48\ \cancel{\text{g } C_3H_8(g)}$$

$$= -207\text{ kJ}$$

Energy Output Calculation:

$$Q = mc\Delta t_{\text{soup}} + mc\Delta t_{\text{steel}}$$

$$= (275.37\ \cancel{g})\left(\frac{3.57\text{ J}}{\cancel{g}\bullet\cancel{{}^\circ C}}\right)(75.4\ \cancel{{}^\circ C} - 4.5\ \cancel{{}^\circ C}) + (575.00\ \cancel{g})\left(\frac{0.503\text{ J}}{\cancel{g}\bullet\cancel{{}^\circ C}}\right)(75.4\ \cancel{{}^\circ C} - 4.5\ \cancel{{}^\circ C})$$

$$= 90.2\text{ kJ}$$

Efficiency Calculation:

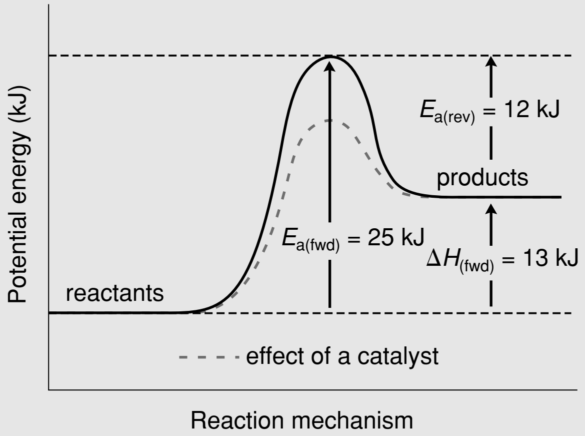
$$\text{Efficiency} = \left|\frac{\text{Energy output}}{\text{Energy input}}\right| \times 100\%$$

$$= \left|\frac{90.2\ \cancel{\text{kJ}}}{-208\ \cancel{\text{kJ}}}\right| \times 100\%$$

$$= 43.4\%$$

In order to improve the camp stove's efficiency, the heat lost to the surroundings must be decreased. Adding a lid to the pot would prevent heat loss from the soup to the air. The pot should be placed very close to the flame, and if possible, sides could be added to the stove to better direct the hot air towards the pot.

45. (a)



(b) The activation energy for the reverse reaction is 25 kJ – 13 kJ = 12 kJ.

(c) See figure above.

Answers to Making Connections Questions

46. (a) Some examples are shown in the table below. Students should take note of the engine size and number of cylinders as well as the type of transmission.

Year	Make/ model	Engine size/ cylinders	Transmission	City consumption (L/100 km)	Highway consumption (L/100 km)
2006	Chrysler PT Turbo Convertible	2.4 / 4	automatic	11.40	8.10
2006	Chrysler PT Turbo Convertible	2.4 / 4	manual	10.40	7.90
2006	Chrysler PT Turbo Convertible	2.4 / 4	auto with manual	11.40	8.10
2006	Chrysler Sebring Convertible	2.7 / 6	automatic	11.20	7.80
2006	Chrysler Sebring Convertible	2.7 / 6	auto with manual	11.10	7.70
2006	Ford Focus	2.0 / 4	manual	9.00	6.40
2006	Ford Focus	2.3 / 4	manual	10.60	6.90
2006	Honda Civic	1.8 / 4	automatic	8.20	5.70
2006	Honda Civic	1.8 / 4	manual	7.80	5.70
2006	Honda Civic Hybrid	1.3 / 4	variable	4.70	4.30
2006	Honda Civic Si	2.0 / 4	manual	10.20	6.80
2006	Mazda 3	2.0 / 4	manual	8.40	6.10
2006	Mazda 3	2.0 / 4	auto with manual	9.10	6.40
2006	Mazda 3	2.3 / 4	manual	9.20	6.70
2006	Mazda 3	2.3 / 4	auto with manual	9.40	6.90

(b) The following options should be considered, although students are asked what concessions they are willing to make to improve fuel efficiency.

- smaller/lighter car
- smaller engine
- fewer cylinders
- hybrid instead of gasoline

(c) A car will operate at its maximum fuel efficiency if it is well-maintained and has its tires inflated to the proper pressure. By driving at or below the speed limit and by not accelerating or decelerating quickly, a driver can further improve fuel efficiency.

47. You would need to consider:

- the relative safety of the fuels
- the ratio of the dollar cost of the fuel per kJ of useful fuel delivered
- the cost of maintaining the furnace
- the environmental impact of the fuel: How is the fuel obtained? How much energy is expended in order to deliver the fuel? What kinds and what quantities of by-products are produced?

You would assume the delivery and availability of each fuel would be the same.

48. First, find the volume of the gas in litres:

$$\begin{aligned}\text{Volume } CH_4(g) &= (0.95 \times 10^3\ \cancel{ft^3})(12\ \cancel{in}/\cancel{ft})^3 \\ &\qquad (1\ L/\ 1000\ \cancel{cm}^3)(2.54\ \cancel{cm}/\cancel{in})^3 \\ &= 2.7 \times 10^4\ L\end{aligned}$$

$$\begin{aligned}\text{The amount of methane} &= 2.7 \times 10^4\ L \times \frac{mol}{24\ L} \\ &= 1.1 \times 10^3\ mol\end{aligned}$$

$\Delta_c H$ for $CH_4(g) = –803$ kJ/mol

The amount of energy released by burning 1.1×10^3 mol of $CH_4(g)$ can be determined:

$$\begin{aligned}\Delta H &= n\Delta_c H \\ &= 1.1 \times 10^3\ mol\ CH_4(g) \times –803\ kJ\backslash mol\ CH_4(g) \\ &= 8.8 \times 10^5\ kJ\end{aligned}$$

This is approximately 10×10^5 kJ, which is 1 GJ. The claim is probably valid.

49. Student answers should include (or all) of the following information. Pepsin is a protein digesting enzyme that is produced by the cells of the stomach. It functions most effectively at a pH between 1 and 3. Pepsin breaks large proteins into smaller ones called peptides. Lipase is a fat digesting enzyme. It is produced by the pancreas and other cells in the body. Its role is to break down lipids into its component parts, glycerol and triglycerides. Pancreatic lipase functions optimally at a pH of 8.0. Other lipases, including stomach lipase, are most effective at a lower pH.