

Unit 3
THERMOCHEMISTRY
Specific Curriculum Outcomes
Suggested Time: 30 Hours

Thermochemistry

Introduction

Energy is the essence of our existence as individuals and as a society. An abundance of fossil fuels has led to a world-wide appetite for energy. There are pros and cons to using fossil fuels. The relationship between energy and chemistry needs to be explored to help us find alternative fuels. Thermochemistry includes energy changes that occur with physical and chemical processes. The study of energy production and the application of chemical change related to practical situations has helped society to progress.

Focus and Context

Thermochemistry focuses on energy in various systems. Skills involving planning, recording, analyzing, and evaluating energy changes will be developed. Fuels for energy provide the context for student research and projects. These fuels could include energy for industry, energy from foods, or any other relevant context. This unit will help students to develop an interest in global energy issues and to appreciate the idea of possible solutions to a problem. Doing lab work and performing calculations allow students to discuss their evidence and problem-solving in order to consolidate their understanding of energy changes.

Science Curriculum Links

Science 1206 included balancing chemical equations. Heat and temperature were discussed in the weather unit. Chemistry 2202 outcomes useful for this unit include measuring amounts of moles as well as the energy transformations associated with bond breaking and forming.

Curriculum Outcomes

STSE	Skills	Knowledge
<p><i>Students will be expected to</i></p> <p>Nature of Science and Technology</p> <p>114-5 describe the importance of peer review in the development of scientific knowledge</p> <p>Relationships Between Science and Technology</p> <p>116-4 analyse and describe examples where technologies were developed based on scientific understanding</p> <p>Social and Environmental Contexts of Science and Technology</p> <p>117-6 analyse why scientific and technological activities take place in a variety of individual and group settings</p> <p>117-7 identify and describe science- and technology-based careers related to the science they are studying</p> <p>117-9 analyse the knowledge and skills acquired in their study of science to identify areas of further study related to science and technology</p> <p>118-2 analyse from a variety of perspectives the risks and benefits to society and the environment of applying scientific knowledge or introducing a particular technology</p> <p>118-8 distinguish between questions that can be answered by science and those that cannot, and between problems that can be solved by technology and those that cannot</p> <p>118-10 propose courses of action on social issues related to science and technology, taking into account an array of perspectives, including that of sustainability</p>	<p><i>Students will be expected to</i></p> <p>Initiating and Planning</p> <p>212-3 design an experiment identifying and controlling major variables</p> <p>212-8 evaluate and select appropriate instruments for collecting evidence and appropriate processes for problem solving, inquiring, and decision making</p> <p>Performing and Recording</p> <p>213-6 use library and electronic research tools to collect information on a given topic</p> <p>213-7 select and integrate information from various print and electronic sources or from several parts of the same source</p> <p>213-8 select and use apparatus and materials safely</p> <p>Analysing and Interpreting</p> <p>214-3 compile and display evidence and information, by hand or computer, in a variety of formats, including diagrams, flow charts, tables, graphs, and scatter plots</p> <p>214-6 apply and assess methods of predicting heats of reaction</p> <p>214-15 propose alternative solutions to a given practical problem, identify the potential strengths and weaknesses of each, and select one as the basis for a plan</p> <p>Communication and Teamwork</p> <p>215-4 identify multiple perspectives that influence a science-related decision or issue</p> <p>215-6 work cooperatively with team members to develop and carry out a plan, and troubleshoot problems as they arise</p>	<p><i>Students will be expected to</i></p> <p>308-2 explain temperature using the concept of kinetic energy and the particle model of matter</p> <p>324-1 write and balance chemical equations for combustion reactions of alkanes</p> <p>324-2 define endothermic reaction, exothermic reaction, specific heat, enthalpy, bond energy, heat of reaction, and molar enthalpy</p> <p>324-3 calculate and compare the energy involved in changes of state and that in chemical reactions</p> <p>324-4 calculate the changes in energy of various chemical reactions using bond energy, heats of formation and Hess's law</p> <p>324-5 illustrate changes in energy of various chemical reactions, using potential energy diagrams</p> <p>324-6 determine experimentally the changes in energy of various chemical reactions</p> <p>324-7 compare the molar enthalpies of several combustion reactions involving organic compounds</p> <p>ACC-8 define, calculate and compare fuel values</p>

Temperature and Kinetic Energy

Outcomes

Students will be expected to

- explain temperature and heat using the concept of kinetic energy and the particle model of matter (308-2)
 - define temperature as a measure of the average kinetic energy of the particles of the system
 - identify and describe the changes to particle movement in systems in which the energy change is accompanied by a change in temperature of the system
 - describe heat as a transfer of kinetic energy from a system of higher temperature (higher average kinetic energy) to a system of lower temperature (lower average kinetic energy) when each is in thermal contact with the other
- calculate and compare the energy involved in changes of temperature (324-3)
 - define the terms: joule, heat capacity and specific heat capacity

Elaborations—Strategies for Learning and Teaching

After defining temperature, the teacher could use temperature differences in the classroom to illustrate differences in particle movement and heat. For example, ask students to place a hand on their desk. The desk will feel cool. What's happening? The temperature of the hand is higher than the temperature of the desk, therefore the kinetic energy (E_k or KE) (particle movement) in the hand is higher than the E_k (particle movement) in the desk. The result is a transfer of E_k from the particles in the hand to particles in the desk as collisions occur in the interface. This is heat transfer from the hand to the desk.

Questioning could be used to lead students to the above explanation.

Whenever a temperature change occurs, the change in E_k involved can be determined from experimentally obtained data or from data provided, using the First Law of Thermodynamics.

Temperature and Kinetic Energy

Tasks for Instruction and/or Assessment

Paper and Pencil

- Students could distinguish between temperature and heat by relating these to the energy of the atoms and molecules. (324-3)

Journal

- In their science log, students could respond to the following questions:
 - Explain why, on a hot, summer day at the beach, the sand can be unbearably hot on bare feet yet the water is very cold.
 - What happens when direct sunlight is blocked by a cloud? How does this affect the temperature of the sand versus that of the water? (308-2, 117-7, 324-7)
- Students could be told they can use a balance to find the mass of their substance only when it is at room temperature. They should explain this statement. (116-4, 308-2)
- Students could be asked, “Why is it helpful to fill your thermos bottle with hot water before filling it with a hot beverage?” (114-5, 215-4, 308-2)
- A Scottish chemist, Joseph Black (1728–1799), differentiated between temperature and thermal energy. Students could discuss how these are different. They should give an example of an experiment to show when two objects at the same temperature do not necessarily have the same thermal energy. (308-2, 324-2, 212-3)

Resources/Notes

www.gov.nl.ca/edu/science_ref/main.htm

MGH Chemistry, pp. 628-629

MGH Chemistry, pp. 629-632

MGH Chemistry, pp. 628, 632,
pp. 636-637

Calculating Heat

Outcomes

Students will be expected to

- calculate and compare the energy involved in changes of temperature (324-3) (Cont'd)
 - identify that the amount of heat lost or gained by an object is dependent upon; type of material, change in temperature of material, and mass of material
 - perform calculations involving heat capacity, C , and specific heat capacity, c
 - distinguish between a system and surroundings and the relationship of each to the universe
 - define open, closed and isolated systems
 - identify and explain that energy can be exchanged between a system and its surroundings through heat lost or gained by a system
($q_{\text{system}} = -q_{\text{surroundings}}$)
 - state the First Law of Thermodynamics and apply it to determine the amount of heat an object contains

Elaborations—Strategies for Learning and Teaching

Students need to understand that the change in temperature depends on the type of material and the mass which should be illustrated through the concepts of heat capacity (C) and specific heat (c). For example, you wish to boil water for a cup of tea. Why would it be faster to place 250 mL of water in the kettle rather than 2000 mL of water? This reinforces the concept of the importance of mass to energy lost or gained.

For example, it requires more energy to raise the temperature of a 1 kg aluminium frying pan by 200°C than it does to raise the temperature of a 1 kg iron frying pan 200°C. Why? This reinforces the concept of the importance of the type of matter to energy lost or gained. This leads into the explanation of specific heat and related calculations.

For example, a 20.0 g piece of iron has a heat capacity of 8.88 J/°C. Calculate the specific heat of iron. For example: The specific heat of aluminium is 0.890 J/g°C. Calculate the heat capacity of a 500 g aluminium saucepan. Refer to the table of specific heat values for comparison. The previous calculation can quickly lead to calculation of heat lost or gained using the formula $q = mc\Delta T$. Water and its specific heat capacity can be used to introduce the above formula through simple problems.

Some sample problems could include;

- (i) How much energy (q) is required to raise the temperature of 1.00 g of water 1.00 °C? Students will quickly answer 4.18 J because this is the value of the specific heat capacity of water.
- (ii) How much energy (q) is required to raise the temperature of 2.00 g of water by 1.00 °C? Student answer: 8.36 J..... Why?
- (iii) How much energy (q) is required to raise the temperature of 2.00 g of water by 2.00 °C? Student answer: 16.7 J..... Why?
- (iv) How much energy (q) is required to raise the temperature of 511 g of water by 26.3 °C? Now students need a formula to calculate the exact answer. What is the formula?

Energy = (mass) x (specific heat capacity) x (change in temperature)

$$q = mc\Delta T$$

Practise using this formula for calculating one of q , m , c , or ΔT given the other three variables. Teachers should note that math skills in rearranging formulas may be weak for some students. For example, how much energy is lost when of an aluminium mailbox, with a mass of 400.0 g, cools from 26.2 °C to 12.4 °C?

Calculating Heat

Tasks for Instruction and/or Assessment

Performance

- Students could calculate which has more heat: 250.0 mL of water at 90°C or 20 000.0 mL of water at 30°C? They should qualitatively and quantitatively explain their result. (324-3)

Paper and Pencil

- Heat lost equals heat gained. Students could explain this assumption. (324-3)

Presentation

- For a selected reaction, students could make the case that the Law of Conservation of Energy has been “upheld.” (324-5, 214-3)
- Students could investigate industrial applications of heat capacity. For example; refrigerator, household heating systems and cookware design. (324-3)

Resources/Notes

MGH Chemistry, pp. 632-633,
pp. 831-832

MGH Chemistry, pp. 633-637

MGH Chemistry, pp. 627-628

Calculating Heat (*continued*)

Outcomes

Students will be expected to

- calculate and compare the energy involved in changes of temperature (324-3) (Cont'd)
 - define the calorimeter and identify it as the basic instrument for measuring heat transfer
 - calculate the heat gained or lost from a system using the formulas $q = mc\Delta T$ or $q = C\Delta T$ where c is the specific heat capacity, C is the heat capacity and ΔT is the change in temperature

Elaborations – Strategies for Learning and Teaching

Once students understand the concepts of C , c , ΔT , and the calculation of energy (q) lost or gained, the idea that heat lost by a substance(s) is gained by some other substance(s) must also be understood, since energy is always conserved in all processes (First Law of Thermodynamics). This leads to the equation, $q_{\text{system}} = -q_{\text{surroundings}}$ which can be applied to collected experimental data and to problems that determine specific heat (c) or heat capacity (C) of specific substances or objects. The experimental process is referred to as calorimetry and the insulated container used in such experiments is a calorimeter.

For example, 10.0 g of metal X at 280.0 °C is dropped into 200.0 mL of water at 20.0 °C in a coffee cup calorimeter. Metal X and water reach thermal equilibrium (same temperature) at 25.0 °C. Calculate the specific heat capacity of X.

Solution:

$$\text{heat lost} = \text{heat gained} \quad (q_{\text{system}} = -q_{\text{surroundings}})$$

$$(mc\Delta T)_x = -(mc\Delta T)_{\text{water}}$$

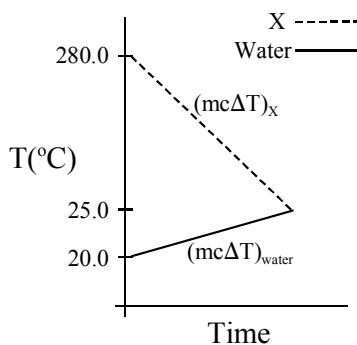
$$\Delta T_x = T_f - T_i = 25.0^\circ\text{C} - 280.0^\circ\text{C} = -255.0^\circ\text{C}$$

$$\Delta T_{\text{water}} = T_f - T_i = 25.0^\circ\text{C} - 20.0^\circ\text{C} = +5.0^\circ\text{C}$$

$$C_x = \frac{-(mc\Delta T)_{\text{water}}}{(m\Delta T)_x} = \frac{-(200.0\text{g})(4.18\text{J/g}^\circ\text{C})(5.0^\circ\text{C})}{(10.0\text{g})(-255.0^\circ\text{C})}$$

$$C_x = 1.6\text{J/g}^\circ\text{C}$$

Simple temperature versus time graphs are often useful in solving such problems.



Students should perform problems involving solutions for any of the 6 variables $m, c, \Delta T$ of X, or $m, c, \Delta T$ of water. Heat capacities can also be incorporated into such problems.

Calculating Heat (*continued*)

Tasks for Instruction and/or Assessment

Journal

- The calorimeter is a basic instrument for measuring heat transfer. Students could explain what a calorimeter is, how it measures heat transfer, and how it works. (324-3)

Paper and Pencil

- Students could explain what is meant by the following terms: specific heat, heat of reaction, and molar enthalpy. (324-2, 324-3)
- As students plan one of their labs for this unit, they should list the skills and knowledge needed to perform the lab properly. (324-3, 117-9)
- Students could calculate the heat gained or lost from the following system:
 - A piece of metal having a mass of 100.0 g, originally at -30.0°C , was dropped in 300.0 g of water at 35°C . The temperature of the water went down to 32.0°C . Students could calculate the specific heat of that metal. (324-2, 324-3)
- $$\text{HCl}_{(aq)} + \text{NaOH}_{(aq)} \rightarrow \text{NaCl}_{(aq)} + \text{H}_2\text{O}_{(l)}$$

When 50.0 mL of 1.00 mol/L $\text{HCl}_{(aq)}$ and 50.0 mL of 1.00 mol/L $\text{NaOH}_{(aq)}$ are mixed in a Styrofoam cup calorimeter, the temperature of the resulting solution increases from 21.0°C to 27.5°C . Students could calculate the heat of this reaction (measured in kilojoules per mole of $\text{HCl}_{(aq)}$). (324-2, 324-3)

Resources/Notes

MGH Chemistry, pp. 661-663

MGH Chemistry, pp. 664-665, p. 832

Enthalpy Change

Outcomes

Students will be expected to

- define enthalpy, endothermic process, exothermic process, and molar enthalpy (324-2)
- calculate and compare the energy involved in changes of state and that in chemical reactions (324-3)
 - use and interpret change in enthalpy (ΔH) notation for communicating energy changes
 - identify and explain that chemical changes and phase changes involve changes in potential energy only
 - explain that energy is required by a system whenever attractive forces between particles are broken and that energy is released from a system whenever new attractive forces form between particles (bond-breaking vs. bond-forming)

Elaborations—Strategies for Learning and Teaching

Enthalpy change (ΔH) is the energy lost or gained during a process (chemical change or phase change) at constant pressure. For comparison purposes ΔH values for specific processes are reported in units of kJ/mol.

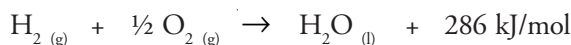
Students should write thermochemical equations to represent enthalpy notation. For example; ΔH_{comb} and ΔH_f .

ΔH values for processes can be indicated by writing the ΔH value immediately after the equation (ΔH notation) or by including it in equations which represent these processes.

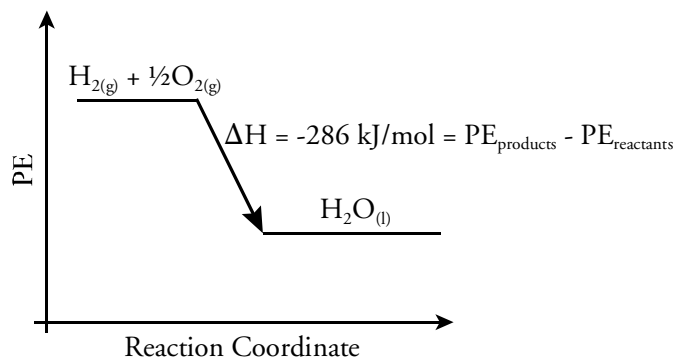
For example:



The sign of ΔH is negative for exothermic processes (energy is a product in the reaction) and positive for endothermic processes (energy is a reactant in the reaction).



Enthalpy diagrams can also be used to represent ΔH of reactions. Here the difference between potential energy (E_p or PE) of reactants and products is related to ΔH .



Enthalpy Change

Tasks for Instruction and/or Assessment

Journal

- Students could answer, “What sources of potential energy have I used during this day?” They could make a chart. (214-3, 324-3)

Paper and Pencil

- Students could define a practical problem with an energy change, then propose a solution. (214-15, 324-3)
- Students could practise writing the different representations for thermochemical equations for both endothermic and exothermic reactions. (324-2)

Presentation

- Students could explain the difference in the energies of reactants and products with reference to a given thermochemical equation. (324-2)

Resources/Notes

MGH Chemistry, pp. 639-643

MGH Chemistry, pp. 641, 645, 648

Enthalpy Change (*continued*)

Outcomes

Students will be expected to

- calculate and compare the energy involved in changes of state and that in chemical reactions (324-3) (Cont'd)
 - define molar enthalpy change, ΔH , as the difference between the potential energy of products and the potential energy of reactants for phase changes and chemical changes
 - define exothermic and endothermic with respect to heat exchange between the system and its surroundings
 - identify and explain that energy changes are observed during phase changes and chemical changes where forces of attractions between particles are formed or broken yet no change in the temperature of the system occurs

Elaborations—Strategies for Learning and Teaching

It is very important for students to understand that during chemical and phase changes there is no change in temperature although temperature changes may be observed in the surroundings.

For example, a candle burns and releases energy equal to the change in potential energy between the reactants (candle wax and oxygen) and the products (CO_2 and H_2O). This energy is observed as it warms up the surrounding air and unburned candle wax (melted wax). This concept is more easily understood in phase changes because, for example, everyone is familiar with pure water freezing at 0°C , and at 0°C only (at 1 atm).

One way to introduce phase changes and this concept is to have students do a cooling curve of the pure substance, paradichlorobenzene, which freezes at 53°C . Place approximately 10 g of paradichlorobenzene and a thermometer in a small test tube and heat it in a water bath to 100°C . Ask students to remove the test tube and record temperature every 20 seconds, while stirring continuously until the temperature reaches 40.0°C . The temperature drops quickly to 53°C but then remains constant for about 15 minutes before dropping quickly to 40.0°C .

Teachers might begin by having students pose questions about energy changes in a system. Students should discuss heating, cooling and phase changes in terms of forces between particles, particle movement, heat content and changes in potential energy. Teachers could identify these areas if they are not mentioned by students. Changes to particle movement in systems in terms of change in temperature could be introduced. Changes in potential energy in matter could be discussed.

Enthalpy Change (*continued*)

Tasks for Instruction and/or Assessment

Journal

- Students could analyze the following: “As a living person, my energy exchange position is exothermic.” Discuss this statement. (324-3, 324-5, 214-3)
- Fire in a fireplace is started by lighting crumpled paper under logs with a match. Students could explain the energy transfers using the terms potential energy, kinetic energy, kindling temperature, system surroundings, endothermic, and exothermic. (324-3, 213-6, 213-7)

Paper and Pencil

- Liquid water turns to ice. Students could be asked if this endothermic or exothermic. They should explain their answer. (324-3)

Presentation

- Students could explain the energy changes in situations such as:
 - (i) when a frozen pond melts, the surrounding air temperature drops
 - (ii) a layer of ice may form on a propane cylinder while it is being used
 - (iii) why vineyards in Ontario spray their crops with water if a frost warning is issued. (324-3)

Resources/Notes

MGH Chemistry, pp. 639-641

Thermochemistry and Potential Energy

Outcomes

Students will be expected to

- illustrate changes in energy of various chemical reactions, using potential energy diagrams (324-5)
 - draw and interpret potential energy diagrams based on experimental data for chemical changes
 - label enthalpy diagrams given either the ΔH for a process, or a thermochemical equation
 - identify exothermic and endothermic processes from the sign of ΔH , from thermochemical equations or from labelled enthalpy diagrams
 - write thermochemical equations including the quantity of energy exchanged given either the value of ΔH or a labelled enthalpy diagram
 - explain that catalysts alter the reaction mechanism without affecting ΔH

Elaborations—Strategies for Learning and Teaching

Teachers could ask students for everyday examples involving endothermic and exothermic changes. Examples might include heating and freezing of ice, hot and cold packs, evaporation and condensation of water, and production and decomposition of ammonia.

Students should use a properly labelled enthalpy diagram to describe energy changes in a multi-step process. This should help students understand that an overall enthalpy change (of a multi-step process) is independent of how many steps, or the magnitude of individual steps. This is the fundamental basis of Hess's Law.

Thermochemistry and Potential Energy

Tasks for Instruction and/or Assessment

Paper and Pencil

- Teachers could ask students which would cause a more severe burn: 100 g of water at 100°C or 100 g of steam at 100°C? They should give reasons to support their decision. (118-8)
- Students could draw and label a potential energy (enthalpy) diagram for each of the following:
 - exothermic
 - endothermic
 - catalyst added to the exothermic/endothermic reaction (324-5, 214-3)
- Students could begin by looking at various potential energy diagrams showing heat content of products and of reactants. Students should draw and interpret the potential energy graphs and be able to determine whether the reaction is exothermic or endothermic. They should identify the reactants and products, and determine the amount of energy involved. They should also draw and correctly label the axis and write an interpretation. (324-5, 214-3)

Resources/Notes

MGH Chemistry, pp. 640-641

MGH Chemistry, p. 642

Thermochemical Equations

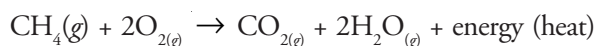
Outcomes

Students will be expected to

- compare the molar enthalpies of several combustion reactions involving organic compounds (324-7)
- write and balance thermochemical equations including the combustion reaction of alkanes (324-1)
 - write thermochemical equations to represent the process given enthalpy notation for ΔH_{comb} , ΔH_f , ΔH_{fus} , ΔH_{vap} , ΔH_{soln}
 - calculate the heat gained or lost from a system using the formula $q = n\Delta H$ when ΔH is the molar heat of a phase change or chemical reaction
 - calculate the ΔH for a system, given the mass of a reactant (or vice versa)

Elaborations—Strategies for Learning and Teaching

Students should balance complete hydrocarbon combustion reactions using up to ten carbon atoms. Equations, including molar enthalpies of possible combustion reactions, could be identified. As students become familiar with energy and thermochemistry throughout this unit, students could add to their project information. The complete combustion of hydrocarbons produces carbon dioxide, CO_2 , and water, H_2O . Showing students the molar enthalpies will help them realize the importance of energy.



Since chemical changes and phase changes involve no change in temperature for the system, the formula $q = mc\Delta T$ cannot be used to calculate energy lost or gained because $\Delta T = 0$. Because values of ΔH are in units of kJ/mol, the formula used to calculate energy lost or gained is $q = n\Delta H$. (n = number of moles of substance undergoing the chemical or phase change). It is important that students practise using this formula here. e.g., Calculate the energy required to melt 54.06 g of ice.

$$\Delta H_{fus} = \text{H}_2\text{O}(s) = 6.03\text{kJ/mol}$$

Solution:

$$q = n\Delta H = \left(\frac{\text{mass}}{M}\right) \times \Delta H = \left(\frac{54.06\text{g}}{18.02\text{g/mol}}\right) \times 6.03\text{kJ/mol} = 18.09\text{kJ}$$

ΔH values can be determined experimentally using calorimetry similar to the method and calculations used previously to determine specific heat. The energy lost or gained by the chemical reaction or phase change (q_{system}) is now calculated using the formula $q_{\text{system}} = n\Delta H$. This energy normally warms or cools some substance in the calorimeter, usually water or the calorimeter and its contents. See CORE LAB #6.

Thermochemical Equations

Tasks for Instruction and/or Assessment

Paper and Pencil

- Students could write a balanced chemical equation for the combustion reaction of each of these alkanes: methane, ethane, propane, butane, and octane. (324-1)
- Students could look up the molar enthalpies of the combustion of butane and octane. They should determine what they have in common. (324-7)
- Students could determine the amount of energy given off from the combustion of 26.0 g of methane. (324-1)

Resources/Notes

MGH Chemistry, p. 643

MGH Chemistry, pp. 642-647

MGH Chemistry, pp. 644, 648

MGH Chemistry, pp. 644-645

Thermochemical Equations (*continued*)

Outcomes

Students will be expected to

- write and balance thermochemical equations including the combustion reaction of alkanes (324-1) (Cont'd)
 - perform calculations which apply the First Law of Thermodynamics in determining the heat of a reaction (or phase change) given experimental data for changes to the surroundings

$$q_{\text{system}} = -q_{\text{surroundings}}$$
 - perform calculations based on data gathered from calorimetry experiments (bomb calorimetry and/or simple/insulated cup calorimetry) demonstrating energy changes in chemical and phase changes
- perform an experiment identifying and controlling major variables (212-3)
- evaluate instruments for collecting data (212-8)
- apply and assess methods of predicting heats of reaction (214-6)

Elaborations—Strategies for Learning and Teaching

Students should practise with problem-solving using $q = mc\Delta T$, $q = n\Delta H$, and $q_{\text{system}} = -q_{\text{surroundings}}$. These calculations may be problematic for some students. Teachers could provide many examples to help overcome this.

For example, 20.0g of NaOH (s) is dropped into 200 mL of H₂O at 22.1 °C. The final temperature of the solution is 43.9 °C. Calculate ΔH for the dissolving of NaOH. **Note:** It is important for students to understand that both the NaOH (s) and the 200.0 mL of H₂O are initially at 22.1 °C. Also, the solution (NaOH and H₂O) is the substance warmed by the energy released in the reaction. Therefore, for $q = mc\Delta T$, $m = 220.0$ g not 200.0 g. Since water makes up the vast majority of the final solution, the specific heat capacity of liquid water (4.184 J/g °C) can be used in the calculation.

Another possible example, 0.852 g of glucose, C₆H₁₂O₆, ($\Delta H_{\text{comb}} = -2808$ kJ/mol) is burned in a bomb calorimeter. The temperature of the calorimeter rises from 22.06 °C to 24.29 °C. Calculate the heat capacity (C), of the calorimeter.

Students should recognize that calculation of $q_{\text{surroundings}}$ may involve more than one process. For example; a liquid heats up and evaporates, or a liquid and a container undergo a heat change (see question 6a of Core Lab #5).

The Laboratory outcomes 212-3, 212-8, 214-6 and, in part, 324-1 are addressed by completing *The Heat of Combustion of a Candle*, CORE LAB #5.

Thermochemical Equations (*continued*)

Tasks for Instruction and/or Assessment

Performance

- With a partner, students could design a lab to calculate the molar heat of solution of NH_4Cl and of NaOH . They should include safety issues that should be addressed. After their plan is approved, they should carry out their procedure and collect evidence (data) and report their findings. (212-3, 215-6, 212-8, 324-2, 324-3)
- Students could select and use appropriate equipment to make an inexpensive hand warmer. (Hint: Use these substances: powdered iron; H_2O ; NaCl ; and vermiculite.) They should design their experiment and consider safety precautions. If approval is obtained, they could do this experiment. A teacher or student could test the results. (212-3, 215-6, 212-8, 324-2)

Paper and Pencil

- Students could calculate the mass of iron at $210.2\text{ }^\circ\text{C}$ that is placed in an insulated cup containing 155 mL of water at $25.8\text{ }^\circ\text{C}$. After a short period of time it is observed that no water remains just as the iron has cooled to $100.0\text{ }^\circ\text{C}$. (specific heat capacity of iron is $0.444\text{ J/g}\cdot^\circ\text{C}$). (324-1)

Resources/Notes

MGH Chemistry, pp. 671-672,
p. 832

Core Lab #5: *“The Heat of Combustion of a Candle”*,
pp. 671-672

Heating and Cooling Curves

Outcomes

Students will be expected to

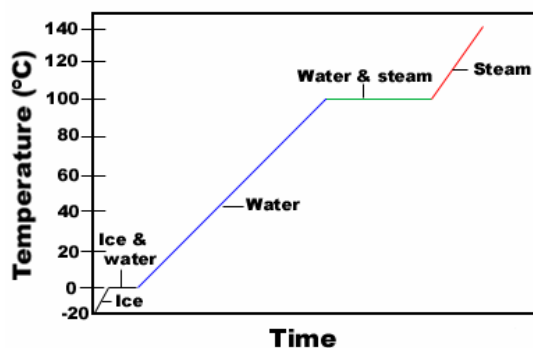
- compile, display and interpret evidence and information in a graphical format (214-3)
 - draw and interpret heating/cooling curves for phase changes

- use heating and cooling curves to represent and explain changes in potential energy and kinetic energy of a system

- calculate the total heat for a multi-step process that includes a temperature and phase change

Elaborations—Strategies for Learning and Teaching

Students should be able to construct a heating or cooling curve for a particular substance given the appropriate data (melting point and boiling point). In addition, they must be able to calculate the total energy involved in the process. For example; How much energy is needed to raise the temperature of 50.0 g of H₂O from -20.0 °C to 140.0 °C?



Re-emphasize here that changes of temperature always involve a change in E_K whereas changes of state always involve a change in E_p . Changes in E_p are often more difficult for students to understand than changes in E_K . One way to demonstrate this change in E_p is to make a saturated solution of sodium thiosulfate (10 mL); let it cool to room temperature to form a supersaturated solution; then add a crystal of sodium thiosulfate. The resulting rapid crystallization of the excess sodium thiosulfate releases a large amount of energy (an obvious conversion of potential energy to kinetic energy). Ask students to feel the test tube before and after. Another way to emphasize this concept is to generate discussion around issues such as the following:

1. Why does steam at 100°C give you a much more severe burn than water at 100°C ?
2. If you are lost in the woods in winter and you are thirsty, why should you drink water from a stream rather than eating snow or ice to help prevent hypothermia ?

In solving these problems, the energy units involving temperature change ($mc\Delta T$) are generally in joules whereas the units for phase change ($n\Delta H$) are generally in kilojoules. Students often forget to convert to one common unit before adding to get the total energy.

Heating and Cooling Curves

Tasks for Instruction and/or Assessment

Paper and Pencil

- Linda wants to know how much heat energy is released when 25 kg of steam at 100 °C is cooled to 25 kg of ice at -15 °C. Students could calculate the total heat energy released. (214-3)
- Students could describe, in terms of kinetic and potential energy, a piece of aluminum cooling from 900 °C to room temperature. Students could then identify the values required to calculate the heat released when this occurs. (214-3)

Resources/Notes

MGH Chemistry, pp. 651-652

MGH Chemistry, pp. 653-655

Science Decisions Involving Thermochemistry

Outcomes

Students will be expected to

- analyze the knowledge and skills acquired in their study of thermochemistry to identify areas of further study (117-9)
 - identify and describe sources of energy including present sources and possible new ones
 - compare physical, chemical, and nuclear changes in terms of the species and the magnitude of energy involved

Elaborations—Strategies for Learning and Teaching

Students should explore practical situations involving heat and energy transfer, such as a fire in a fireplace, solar collectors, eating food to fuel your body, or photosynthesis.

One point to emphasize is the difference between the specific heats of different phases of the same substance. Also, explain in terms of forces of attraction as to why ΔH_{vap} is always larger than ΔH_{fus} .

Students should compare physical, chemical, and nuclear changes in terms of the species and the magnitude of energy changes involved. This works well with estimation.

It is enough to indicate that phase change usually involves 10's of kJ/mol, chemical changes involve 100's or 1000's of kJ/mol, and nuclear changes involve millions and billions of kJ/mol.

Science Decisions Involving Thermochemistry

Tasks for Instruction and/or Assessment

Presentation

- Students could present their project using multimedia, audiovisual, or other suitable format. They should present their scenario to the class. The following questions might be helpful with their thinking:
 - What are the characteristics of a good chemical fuel?
 - What makes your fuel a good choice?
 - What is the most common method of producing your fuel?
 - What are some advantages of your fuel? Some disadvantages?
 - Outline the process of your fuel's development.
 - What energy efficiency does your fuel have according to industry?
 - What impact will the fuel have on the local environment?(117-6, 118-2, 118-8, 118-10, 324-7, 117-9)

Paper and Pencil

- Students could select one of the following and collect and organize information about it. They should describe the science needed to commercially develop the energy source. Possible topics: coal, petroleum, natural gas, sun biomass, synthetic fuels, nuclear hydrogen, seed oil, methanol, geothermal (heat pumps), oil shale. (213-6, 213-7, 117-9)

Resources/Notes

MGH Chemistry, pp. 692, 694, 695, 699, 701

MGH Chemistry, pp. 692-693

Science Decisions Involving Thermochemistry (*continued*)

Outcomes

Students will be expected to

- define, calculate and compare fuel values (ACC-8)
- propose and analyze solutions to solving energy problems using the concepts of fuel value (214-15)
- analyze examples where technologies were developed based on thermochemistry, using the idea of the choice of fuel in a device (116-4)
- identify perspectives that influence a decision involving fuels used in devices, and, the choices made in the Calorie content and serving size of the foods we eat (215-4)
- analyze why scientific and technological activities take place when making choices for maintaining a healthy lifestyle (117-6)
- analyze the risks and benefits to society and the environment in relation to fossil fuel use and healthy lifestyle choices (118-2)
- analyze the knowledge acquired in their study of thermochemistry to identify areas of further study, specifically chemical engineering and nutrition (117-9)

Elaborations—Strategies for Learning and Teaching

The CORE STSE component of this unit incorporates a broad range of Chemistry 3202 outcomes. More specifically, it targets (in whole or in part) ACC-8, 214-15, 116-4, 215-4, 117-6, 118-2, and 117-9. The STSE component, *What Fuels You?*, can be found in Appendix A.

Science Decisions Involving Thermochemistry (*continued*)

Tasks for Instruction and/or Assessment

Paper and Pencil

- Students could prepare a newspaper article about an energy source and its potential for energy production. They should include information in their article about their energy source, such as its useable lifetime as a commercial source, impact on the environment, appeal to an individual consumer, and/or appeal to a community of consumers. (114-5, 213-6, 213-7, 215-4)
- Students could consider climatic, economic, and supply factors in their search for an energy source for the future. They should include these in the research project that they began at the beginning of this unit. (114-5, 213-6, 213-7, 215-4)

Resources/Notes

Core STSE #3: “*What Fuels You?*”,
Appendix A

Hess's Law

Outcomes

Students will be expected to

- calculate the changes in energy of various chemical reactions using Hess's Law (324-4)
 - identify, with reference to Hess's law, that the internal energy and enthalpy of a system are state functions and that changes in each are independent of the reaction path chosen
 - use the method of addition of chemical equations and corresponding enthalpy changes to compute the enthalpy change of the overall process
- calculate the changes in energy of various chemical reactions using heats of formation (324-4)
 - use a standard molar enthalpies of formation table to calculate heat of reaction for a chemical change
- interpret information on heats of formation from diagrams, flow charts, tables, and graphs (214-3)
 - recognize a relationship between the ΔH_f° of a compound and its stability

Elaborations—Strategies for Learning and Teaching

Teachers should point out that Hess's law is a method of determining ΔH for reactions that are too difficult, too expensive, too slow, or too dangerous to measure ΔH experimentally (e.g., using calorimetry).

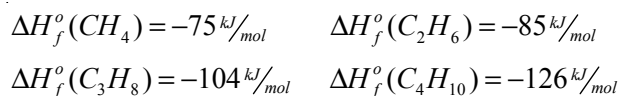
An analogy is useful here to illustrate that Hess's Law is based on the concept that the energy involved in a chemical reaction is independent of the path taken to change reactants into products. An example might be to suggest the whole class meet at a particular spot later in the day. Each person may take a different route but the outcome is the same.

Student practice is required here to master the use of Hess' Law. Problems used should not include more than 3 equations to combine. The CORE LAB could be done at this point to confirm the validity of Hess's Law.

Teachers should emphasize that the use of ΔH_f° values to find ΔH_{rxn}° of reaction is yet another method of determining enthalpies values. The process of summation of ΔH_f° values is an extension of Hess's Law without having to combine the equations. Students must practice using the equation: $\Delta H_{rxn}^\circ = \sum n\Delta H_f^\circ(\text{products}) - \sum n\Delta H_f^\circ(\text{reactants})$ and tables of ΔH_f° values.

There is a relationship between the size of ΔH_f° of a compound and its stability. The more negative the value of ΔH_f° (more exothermic) the more stable the compound formed. Trends also exist in homologous series of organic compounds which may be represented in tables or graphs.

For example; alkanes



Sample question: Given values of ΔH_f° for CH_4 , C_3H_8 , C_4H_{10} , predict a possible value for C_2H_6 .

Hess's Law

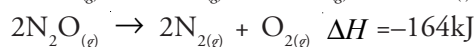
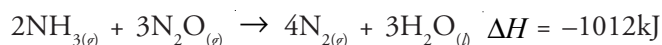
Tasks for Instruction and/or Assessment

Performance

- Students could demonstrate correct use of chemical disposal while doing a Hess's Law lab. (324-4, 214-6, 116-4)

Paper and Pencil

- Given the following reactions and ΔH values:



Students could calculate ΔH , using Hess's Law for



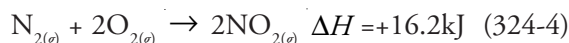
- From their knowledge of standard states and from an enthalpy of formation chart, students could list the standard enthalpy of formation of each of the following substances: (324-4)



- Students could calculate ΔH for the following reaction:



- Students could calculate the heat of formation, ΔH_f , of NO_2 .



- Hydrazine, $\text{N}_2\text{H}_{4(g)}$, is used as a fuel in liquid-fuelled rockets. It can react with $\text{O}_{2(g)}$ or $\text{N}_2\text{O}_{4(g)}$ both producing $\text{N}_{2(g)}$ and $\text{H}_2\text{O}_{(g)}$. Students could write balanced chemical equations for the two reactions. They should calculate ΔH for each reaction, using information from an enthalpy table and compare the values. Students could then determine which is the more efficient rocket fuel. (324-4)

Resources/Notes

MGH Chemistry, pp. 677-678

MGH Chemistry, pp. 678-681,
p. 832

MGH Chemistry, pp. 648-687,
p. 832

MGH Chemistry, p. 686

Determining Enthalpy Change

Outcomes

Students will be expected to

- determine experimentally the changes in energy of various chemical reactions (324-6)
- apply Hess's Law and/or Heats of Formation methods of predicting heats of reactions to your experimentally determined lab values (214-6)
- select and use apparatus and materials safely (213-8)
- propose alternative solutions to a given practical problem, identify the potential strengths and weaknesses of each, and select one as the basis for a plan (214-15)
- evaluate and select appropriate instruments for collecting evidence and appropriate processes for problem solving, inquiring, and decision making (212-8)

Elaborations—Strategies for Learning and Teaching

The Laboratory outcomes 324-6, 214-6, 213-8, 214-15, 212-8, 324-4 and, in part, 324-6 are addressed by completing *Hess's Law and the Enthalpy of Combustion of Magnesium*, CORE LAB #6.

Determining Enthalpy Change

Tasks for Instruction and/or Assessment

Resources/Notes

Core Lab #6: *"Hess's Law and the Enthalpy of Combustion of Magnesium"*, pp. 682-683

Bond Energy

Outcomes

Students will be expected to

- calculate the changes in energy of various chemical reactions using bond energies (324-4)
 - define bond energy
 - use average bond energies to estimate the ΔH for a desired reaction

Elaborations – Strategies for Learning and Teaching

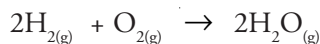
The use of bond energies is another method of finding ΔH for reactions. However, ΔH values calculated using bond energies will be slightly different from values calculated using heats of formation or determined experimentally. The reason for this is that the bond energies in tables are average bond energies for each particular bond type. For example, an exact value for the bond energy of the H-H bond can be determined because the molecule H_2 contains a single H-H bond only. However, the exact bond energy for the C-H bond cannot be determined exactly because there is no such molecule C-H. The carbon in the C-H bond always has other atoms bonded to it which affects the C-H bond energy. Teachers should note the average bond energy values on the mini-table on page 688 of the textbook do not always match the average bond energy values on the more detailed table given in the appendix of the textbook.

Take for example, CH_4 or CH_2Cl_2 , or CH_3F . The bond energy for C-H is therefore an average of the C-H bond energies in several different environments. Therefore, ΔH values calculated using these average bond energies will be slightly different.

The formula used to calculate ΔH from bond energies is different from the ones used for calculating ΔH using ΔH_f° values, although they look similar. In this case, it is: Reactants - Products.

$$\Delta H = \sum (\text{Bond energies of all reactant bonds broken}) - \sum (\text{Bond energies of all product bonds formed})$$

For example; Calculate ΔH for the formation of water from its elements using bond energies and the equation below:



$$\Delta H_{rxn} = \sum H(\text{bond breakage}) - \sum H(\text{bond formation})$$

$$\Delta H_{reaction} = \sum BE(\text{reactants}) - \sum BE(\text{products})$$

$$\Delta H_{reaction} = [2(BE_{H-H}) + 1(BE_{O=O})] - [4(BE_{H-O})]$$

$$\Delta H_{reaction} = [2(435 \text{ kJ/mol}) + 1(498 \text{ kJ/mol})] - [4(464 \text{ kJ/mol})]$$

$$\Delta H_{reaction} = -498 \text{ kJ}$$

At this point students could calculate ΔH for the same reaction using ΔH_f° values for comparison.

$$\Delta H_{rxn} = \sum n\Delta H_f^\circ(\text{products}) - \sum n\Delta H_f^\circ(\text{reactants})$$

$$\Delta H_{rxn} = [2\Delta H_f^\circ(H_2O_{(g)})] - [2\Delta H_f^\circ(H_{2(g)}) + 1\Delta H_f^\circ(O_{2(g)})]$$

$$\Delta H_{rxn} = [2(-241.8 \text{ kJ/mol})] - [2(0) + 1(0)]$$

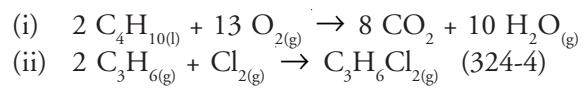
$$\Delta H_{rxn} = -483.6 \text{ kJ}$$

Bond Energy

Tasks for Instruction and/or Assessment

Paper and Pencil

- Students could, using bond energies, calculate the enthalpy of reaction for:



Resources/Notes

MGH Chemistry, pp. 688-690

