

produces some hydroelectricity. This involves energy conversions from potential energy of water (above the dam) to kinetic energy (falling water and spinning turbine) to electrical energy. Coal accounts for ~66% of the generated electricity in Alberta, gas for ~23%, and hydro for ~10%.

3. Benefits of Coal

- plentiful
- easy to convert to electrical energy (proven technology)
- inexpensive

Risks of Coal

- causes pollution (produces NO_x and SO_2)
 - contributes to global warming
 - coal mining can result in environmental damage
4. solar energy \rightarrow chemical energy (coal) \rightarrow thermal energy (H_2O) \rightarrow kinetic energy (steam moving the turbine that turns the generator) \rightarrow electrical energy \rightarrow light and heat
5. (a) If the reaction occurs in a particular medium (e.g., water), the change in temperature of that medium can be measured. This change in temperature is a reflection of the quantity of energy absorbed or released by the reaction in the medium, $Q = mc\Delta t$.
- (b) The energy released or absorbed by a chemical reaction is communicated by its enthalpy change, $\Delta_r H$, for a specified chemical equation, or by its molar enthalpy change, $\Delta_r H_m$, for a given substance reacting in a specified reaction.

Chapter 11 REVIEW

Part 1

(Page 519)

1. B
2. 1, 4, 3, 2
3. C
4. 585
5. D
6. 98.9
7. C
8. D
9. 1, 3, 6
10. 2, 4, 5
11. 3, 4, 2, 1
12. 3, 2, 1, 4
13. 1, 2, 4, 3
14. 136.4 [Note error in text: should be labelled +]

Solutions

$$4. \quad Q = mc\Delta t = 1.50 \text{ kg} \times \frac{4.19 \text{ J}}{\text{g} \cdot ^\circ\text{C}} \times (98.6 - 5.5) ^\circ\text{C} = 585 \text{ kJ}$$

$$6. \quad \Delta_c H_m^\circ = \frac{-197.8 \text{ kJ}}{2 \text{ mol}} = -98.9 \text{ kJ/mol}$$

$$\Delta_c H^\circ = \sum n \Delta_f H_m^\circ - \sum n \Delta_r H_m^\circ \quad \text{and} \quad \Delta_c H_m^\circ = \frac{\Delta_r H^\circ}{n}$$

$$12. \quad \Delta_c H_m^\circ : -5074.1 \text{ kJ/mol}; -2043.9 \text{ kJ/mol}; -802.5 \text{ kJ/mol}; -637.9 \text{ kJ/mol}$$

$\text{C}_8\text{H}_{18} \qquad \text{C}_3\text{H}_8 \qquad \text{CH}_4 \qquad \text{CH}_3\text{OH}$

$$\begin{aligned}
 14. \quad & \text{C}_2\text{H}_6(\text{g}) \rightarrow \text{C}_2\text{H}_4(\text{g}) + \text{H}_2(\text{g}) \quad \Delta_r H^\circ = ? \\
 \Delta_r H^\circ &= \left(1 \text{ mol C}_2\text{H}_4 \times \frac{+52.4 \text{ kJ}}{1 \text{ mol C}_2\text{H}_4} + 1 \text{ mol H}_2 \times \frac{0 \text{ kJ}}{1 \text{ mol H}_2} \right) \\
 &\quad - \left(1 \text{ mol C}_2\text{H}_6 \times \frac{-84.0 \text{ kJ}}{1 \text{ mol C}_2\text{H}_6} \right) \\
 &= +136.4 \text{ kJ}
 \end{aligned}$$

Part 2

(Pages 519-521)

15. The sun's energy was initially trapped by photosynthesis in green plants to produce organic compounds. The plant matter (either eaten by animals or left in the plant) eventually was converted by high temperatures and pressures into hydrocarbons.

16. The enthalpy change, $\Delta_r H$, refers to the total energy change for a chemical system or substance undergoing change, usually described by a chemical reaction equation. The molar enthalpy, $\Delta_r H_m$, change refers to the energy change per mole of the substance undergoing the change indicated; e.g., combustion and formation.

$$\begin{aligned}
 17. \quad (a) \quad Q &= mc\Delta t \\
 &= 2.0 \text{ kg} \times 4.19 \text{ J/(g }^\circ\text{C)} \times 5.3 \text{ }^\circ\text{C} \\
 &= 44 \text{ kJ}
 \end{aligned}$$

$$(b) \quad Q/m = \frac{44 \text{ kJ}}{1.25 \text{ g}} = 36 \text{ kJ/g}$$

$$\begin{aligned}
 18. \quad (a) \quad Q &= mc\Delta t \\
 &= 2.23 \text{ kg} \times 4.19 \text{ J/(g }^\circ\text{C)} \times 8.04 \text{ }^\circ\text{C} \\
 &= 75.1 \text{ kJ}
 \end{aligned}$$

(b) Because combustion reactions are exothermic and $\Delta_r H = Q$, $\Delta_c H = -75.1 \text{ kJ}$

$$\begin{aligned}
 (c) \quad \Delta_c H_{\text{C}_4\text{H}_{10}} &= \frac{75.1 \text{ kJ}}{1.52 \text{ g} \times \frac{1 \text{ mol}}{58.14 \text{ g}}} \\
 &= 2.87 \text{ MJ/mol}
 \end{aligned}$$

The symbol, value, and sign would be $\Delta_c H_m = -2.87 \text{ MJ/mol}$ for C_4H_{10} .

The ΔH represents the enthalpy change; the subscript "c" specifies a combustion reaction; and the subscript "m" indicates that this is a molar quantity of the substance specified under the symbol. The value is obtained from calorimetry and the negative sign indicates that this is an exothermic reaction, on the basis of the generalization that all combustion reactions are exothermic.

19. Problem

What is the molar enthalpy of neutralization for ethanoic acid?

Analysis

$$Q = mc\Delta t$$

$$= 100 \text{ g} \times \frac{4.19 \text{ J}}{\text{g} \cdot ^\circ\text{C}} \times (27.8 - 22.5)^\circ\text{C}$$

$$= 2.22 \text{ kJ}$$

$$\Delta_{\text{ethanoic acid}} H_{\text{m}}^{\circ} = \frac{2.22 \text{ kJ}}{0.0500 \text{ L} \times \frac{1.00 \text{ mol}}{1 \text{ L}}}$$

$$= 44.4 \text{ kJ/mol}$$

According to the evidence, the molar enthalpy of neutralization for ethanoic acid is -44.4 kJ/mol .

20. (a) $Q = mc\Delta t$
 $= 100 \text{ kg} \times 4.19 \text{ J/(g}^{\circ}\text{C)} \times (58.5 - 6.5)^{\circ}\text{C}$
 $= 21.8 \text{ MJ}$

(b) $\text{CH}_4(\text{g}) + 2 \text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + 2 \text{H}_2\text{O}(\text{g})$

$$\Delta_{\text{res}} H^{\circ} = \left(1 \text{ mol CO}_2 \times \frac{-393.5 \text{ kJ}}{1 \text{ mol CO}_2} + 2 \text{ mol H}_2\text{O} \times \frac{-241.8 \text{ kJ}}{1 \text{ mol H}_2\text{O}} \right)$$

$$- \left(1 \text{ mol CH}_4 \times \frac{-74.6 \text{ kJ}}{1 \text{ mol CH}_4} + 2 \text{ mol O}_2 \times \frac{0 \text{ kJ}}{1 \text{ mol O}_2} \right)$$

$$= -802.5 \text{ kJ}$$

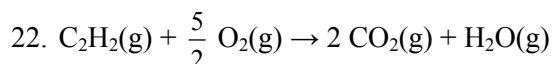
$$m_{\text{CH}_4} = \frac{21.8 \text{ MJ}}{\frac{802.5 \text{ kJ}}{1 \text{ mol}} \times \frac{1 \text{ mol}}{16.05 \text{ g}}}$$

$$= 0.436 \text{ kg}$$

(c) $Q = mc\Delta t$
 $32.5 \text{ MJ} = m \times 4.19 \text{ J/(g}^{\circ}\text{C)} \times (45.5 - 12.3)^{\circ}\text{C}$
 $m = 0.234 \text{ Mg or } 234 \text{ kg}$
 $v = 234 \text{ L}$

21. Comparing Photosynthesis, Cellular Respiration, and Hydrocarbon Combustion

Reaction	Reactants	Products	Endothermic/ Exothermic	Enthalpy change +/-
photosynthesis	$\text{CO}_2 + \text{H}_2\text{O}$	$\text{C}_6\text{H}_{12}\text{O}_6 + \text{O}_2$	endothermic	+
cellular respiration	$\text{C}_6\text{H}_{12}\text{O}_6 + \text{O}_2$	$\text{CO}_2 + \text{H}_2\text{O}$	exothermic	-
combustion	hydrocarbon + O_2	$\text{CO}_2 + \text{H}_2\text{O}$	exothermic	-



$$\Delta_{\text{c}} H^{\circ} = \left(2 \text{ mol CO}_2 \times \frac{-393.5 \text{ kJ}}{1 \text{ mol CO}_2} + 1 \text{ mol H}_2\text{O} \times \frac{-241.8 \text{ kJ}}{1 \text{ mol H}_2\text{O}} \right)$$

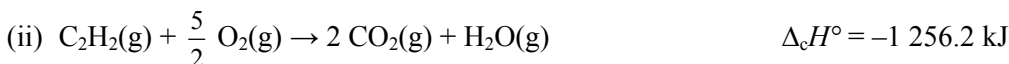
$$- \left(1 \text{ mol C}_2\text{H}_2 \times \frac{+227.4 \text{ kJ}}{1 \text{ mol C}_2\text{H}_2} + \frac{5}{2} \text{ mol O}_2 \times \frac{0 \text{ kJ}}{1 \text{ mol O}_2} \right)$$

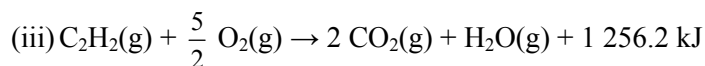
$$= (-1028.8 \text{ kJ}) - (+227.4 \text{ kJ}) \quad [\text{For use in the graph below.}]$$

$$= -1256.2 \text{ kJ}$$

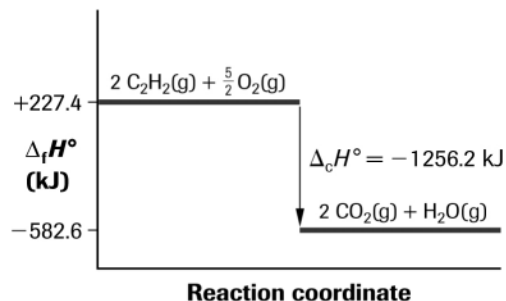
$$\Delta_{\text{c}} H_{\text{m}}^{\circ} = \frac{-1256.2 \text{ kJ}}{1 \text{ mol}} = -1256.2 \text{ kJ/mol}$$

(i) $\Delta_{\text{c}} H_{\text{m}}^{\circ} = -1256.2 \text{ kJ/mol}$
 C_2H_2





(iv) **Combustion of Ethyne**



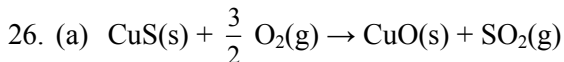
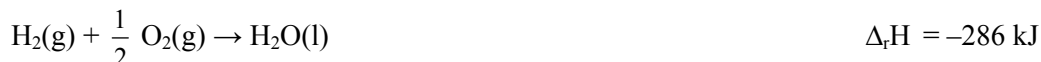
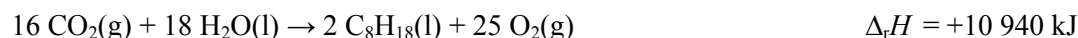
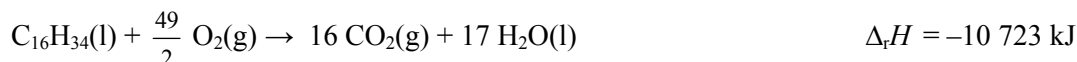
23. The molar enthalpies of formation method can be used to determine the enthalpy change for a particular reaction. The standard molar enthalpies of formation for each of the entities in the desired reaction can be obtained from a table of standard molar enthalpies of formation. These values can then be used in the equation:

$$\Delta_r H^\circ = \sum n \Delta_f H_m^\circ - \sum n \Delta_r H_m^\circ$$

to find the enthalpy change for the reaction.

Alternatively, a version of Hess' law, which combines known equations for which enthalpy changes have been established, can be used. In this case, the equations are manipulated and added to produce the desired net equation. The sum of the enthalpy changes for the individual equations, which result in the desired equation, will yield the enthalpy change for the desired process.

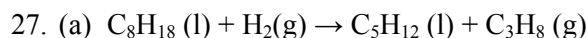
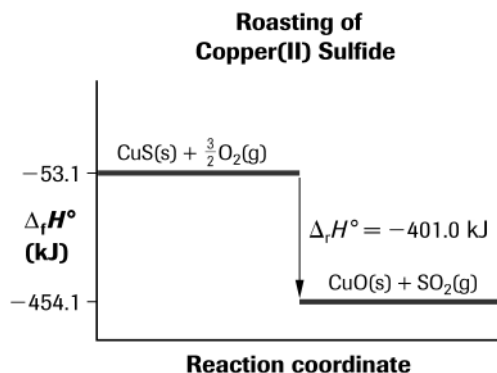
$$\Delta_{\text{net}} H = \sum \Delta_r H$$



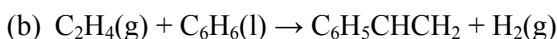
$$\begin{aligned} \Delta_c H^\circ &= \left(1 \text{ mol CuO} \times \frac{-157.3 \text{ kJ}}{1 \text{ mol CuO}} + 1 \text{ mol SO}_2 \times \frac{-296.8 \text{ kJ}}{1 \text{ mol SO}_2} \right) \\ &\quad - \left(1 \text{ mol CuS} \times \frac{-53.1 \text{ kJ}}{1 \text{ mol CuS}} + \frac{3}{2} \text{ mol O}_2 \times \frac{0 \text{ kJ}}{1 \text{ mol O}_2} \right) \\ &= (-454.1 \text{ kJ}) - (-53.1 \text{ kJ}) \quad [\text{For use in the graph below.}] \\ &= -401.0 \text{ kJ} \end{aligned}$$

$$\Delta_f H_m^\circ = \frac{-401.0 \text{ kJ}}{1 \text{ mol}} = -401.0 \text{ kJ/mol}$$

(b)



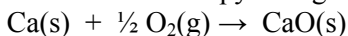
$$\begin{aligned}\Delta_r H^\circ &= \left(1 \text{ mol C}_5\text{H}_{12} \times \frac{-173.5 \text{ kJ}}{1 \text{ mol C}_5\text{H}_{12}} + 1 \text{ mol C}_3\text{H}_8 \times \frac{-103.8 \text{ kJ}}{1 \text{ mol C}_3\text{H}_8} \right) \\ &\quad - \left(1 \text{ mol C}_8\text{H}_{18} \times \frac{-250.1 \text{ kJ}}{1 \text{ mol C}_8\text{H}_{18}} + 1 \text{ mol H}_2 \times \frac{0 \text{ kJ}}{1 \text{ mol H}_2} \right) \\ &= -27.2 \text{ kJ}\end{aligned}$$



$$\begin{aligned}\Delta_r H^\circ &= \left(1 \text{ mol C}_6\text{H}_5\text{CHCH}_2 \times \frac{+103.8 \text{ kJ}}{1 \text{ mol C}_6\text{H}_5\text{CHCH}_2} + 1 \text{ mol H}_2 \times \frac{0 \text{ kJ}}{1 \text{ mol H}_2} \right) \\ &\quad - \left(1 \text{ mol C}_2\text{H}_4 \times \frac{+52.4 \text{ kJ}}{1 \text{ mol C}_2\text{H}_4} + 1 \text{ mol C}_6\text{H}_6 \times \frac{+49.1 \text{ kJ}}{1 \text{ mol C}_6\text{H}_6} \right) \\ &= +2.3 \text{ kJ}\end{aligned}$$

28. Problem

What is the enthalpy change for the reaction?

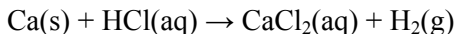


Prediction

According to the table of molar enthalpies of formation, the enthalpy change is -634.9 kJ because the chemical equation represents the formation of one mole of calcium oxide.

Analysis

Reaction #1



$$\underset{\text{(calorimeter)}}{Q} = mc\Delta t$$

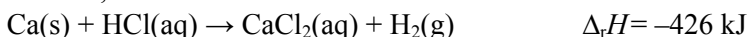
$$= 100 \text{ g} \times \frac{4.19 \text{ J}}{\text{g} \cdot ^\circ\text{C}} \times (34.5 - 21.3) ^\circ\text{C}$$

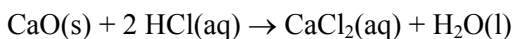
$$= 5.53 \text{ kJ}$$

$$\Delta_r H_{\text{Ca}} = \frac{5.53 \text{ kJ}}{0.52 \text{ g} \times \frac{1 \text{ mol}}{40.08 \text{ g}}}$$

$$= 426 \text{ kJ/mol}$$

According to the evidence, the enthalpy change for the reaction, based on one mole of calcium, is:



Reaction #2

$$Q_{\text{(calorimeter)}} = mc\Delta t$$

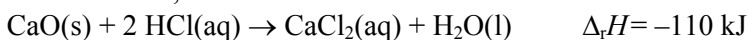
$$= 100 \text{ g} \times \frac{4.19 \text{ J}}{\text{g} \cdot ^\circ\text{C}} \times (28.0 - 21.1) ^\circ\text{C}$$

$$= 2.89 \text{ kJ}$$

$$\Delta_r H_{\text{m, CaO}} = \frac{2.89 \text{ kJ}}{1.47 \text{ g} \times \frac{1 \text{ mol}}{56.08 \text{ g}}}$$

$$= 110 \text{ kJ/mol}$$

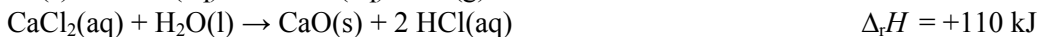
According to the evidence, the enthalpy change for the reaction, based on one mole of calcium oxide, is

**Reaction #3**

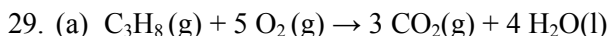
According to the table of molar enthalpies of formation,



Applying Hess' law,

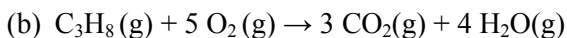


According to the evidence collected and Hess' law, the enthalpy change for the given reaction is -602 kJ.



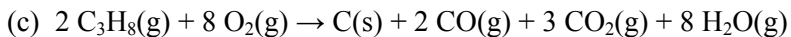
$$\begin{aligned} \Delta_c H^\circ &= \left(3 \text{ mol CO}_2 \times \frac{-393.5 \text{ kJ}}{1 \text{ mol CO}_2} + 4 \text{ mol H}_2\text{O} \times \frac{-285.8 \text{ kJ}}{1 \text{ mol H}_2\text{O}} \right) \\ &\quad - \left(1 \text{ mol C}_3\text{H}_8 \times \frac{-103.8 \text{ kJ}}{1 \text{ mol C}_3\text{H}_8} + 5 \text{ mol O}_2 \times \frac{0 \text{ kJ}}{1 \text{ mol O}_2} \right) \\ &= -2219.9 \text{ kJ} \end{aligned}$$

$$\Delta_c H_{\text{m, C}_3\text{H}_8}^\circ = \frac{-2219.9 \text{ kJ}}{1 \text{ mol}} = -2219.9 \text{ kJ/mol}$$



$$\begin{aligned} \Delta_c H^\circ &= \left(3 \text{ mol CO}_2 \times \frac{-393.5 \text{ kJ}}{1 \text{ mol CO}_2} + 4 \text{ mol H}_2\text{O} \times \frac{-241.8 \text{ kJ}}{1 \text{ mol H}_2\text{O}} \right) \\ &\quad - \left(1 \text{ mol C}_3\text{H}_8 \times \frac{-103.8 \text{ kJ}}{1 \text{ mol C}_3\text{H}_8} + 5 \text{ mol O}_2 \times \frac{0 \text{ kJ}}{1 \text{ mol O}_2} \right) \\ &= -2043.9 \text{ kJ} \end{aligned}$$

$$\Delta_c H_{\text{m, C}_3\text{H}_8}^\circ = \frac{-2043.9 \text{ kJ}}{1 \text{ mol}} = -2043.9 \text{ kJ/mol}$$



$$\begin{aligned}\Delta_r H^\circ &= \left(1 \text{ mol C} \times \frac{0 \text{ kJ}}{1 \text{ mol C}} + 2 \text{ mol CO} \times \frac{-110.5 \text{ kJ}}{1 \text{ mol CO}} + 3 \text{ mol CO}_2 \times \frac{-393.5 \text{ kJ}}{1 \text{ mol CO}_2} \right) \\ &\quad + \left(8 \text{ mol H}_2\text{O} \times \frac{-241.8 \text{ kJ}}{1 \text{ mol H}_2\text{O}} \right) - \left(2 \text{ mol C}_3\text{H}_8 \times \frac{-103.8 \text{ kJ}}{1 \text{ mol C}_3\text{H}_8} + 8 \text{ mol O}_2 \times \frac{0 \text{ kJ}}{1 \text{ mol O}_2} \right) \\ &= -3128.3 \text{ kJ} \\ \Delta_r H_{\text{m}}^\circ &= \frac{-3128.3 \text{ kJ}}{2 \text{ mol}} = -1564.2 \text{ kJ/mol}\end{aligned}$$

(d) incomplete combustion, combustion to produce water vapour, combustion to produce liquid water

(e) The most efficient type of furnace is a condensing high-efficiency furnace. One way in which these devices differ from conventional furnaces is that they contain additional heat exchange surfaces that remove much of the remaining heat contained in the combustion gases before these gases are exhausted to the exterior of the building. On one of these surfaces, combustion gases are allowed to cool until water vapour condenses, which releases energy stored in the vapour. The increased efficiency is explained by the combustion of propane to produce liquid water, releasing more energy than a similar process involving the production of water vapour (see above). A furnace that operates inefficiently exhausts combustion gases that still contain a considerable amount of energy.

Note that the incomplete combustion of propane in part (c) released the least amount of energy. Complete combustion is increased in high-efficiency furnaces by directly providing combustion air from the outside. This (fresh combustion air) feature reduces the quantity of warm air being taken from a home for combustion. (It also reduces the possibility of a back-draft of carbon monoxide and carbon dioxide into the home from the furnace chimney when a fireplace is burning and drawing significant quantities of air from the home).

30. Prior to the advent of refrigerators, the Inuit stored and shared their meat in a communal fashion—the meat had to be eaten before it spoiled. The advent of the individually owned refrigerator has destroyed this sense of community sharing and dependence. Thus, while technological progress may bring independence, it exacts a social cost.

Extension

31. *[Student responses will vary, depending on the alternative fuel chosen, the sources used, the perspectives examined, and the target audience. Possible choices of alternative sources of energy include tidal, solar/photovoltaic, biomass, and geothermal. Possible perspectives include environmental, economic, and social.]*

32. (a) The efficiency of converting available chemical energy into electrical energy in thermal electric power stations ranges from 27.11% to 40.01%.

Most fuels have a similarly low efficiency for converting chemical energy into electrical energy—around one-third (33%). Lignite is consistently the least efficient coal used in thermal electric power stations.

Light fuel oil (LFO) has a slightly lower percent efficiency than heavy fuel oil (HFO). The efficiency of wood used in thermal electric power stations has steadily decreased over time.

(b) Non-combustible energy sources include:

- solar energy—photovoltaic/solar panels, thermal electric (using giant arrays of mirrors) and hydroelectric (using the water cycle)
- geothermal energy
- tidal energy
- wind energy, and
- nuclear energy