Enthalpy Chapter Test Review
(pg. 366-367)

- Theory: #2 - 4
- Ways of Communicating Enthalpy Change: #5, 6 (need to use the table and extra information from pg. 347 for both questions)
- Exothermic vs. Endothermic: #10
- Calorimetry: #8, 16-22
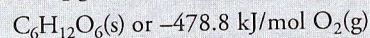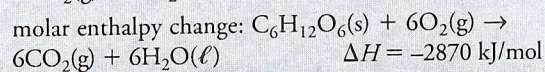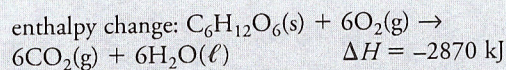- Bond Energy: #15

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

molar enthalpy change: $C_6H_{12}O_6(s) + 6O_2(g) \rightarrow$
$6CO_2(g) + 6H_2O(\ell)$ $\Delta H = -2870$ 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.
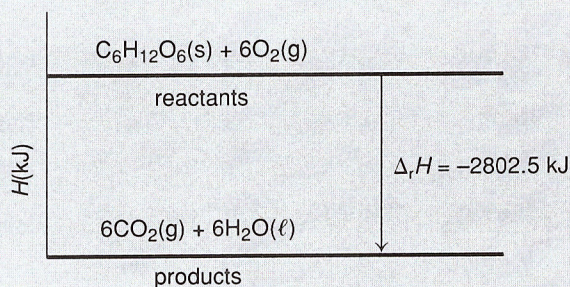
(a) heating water

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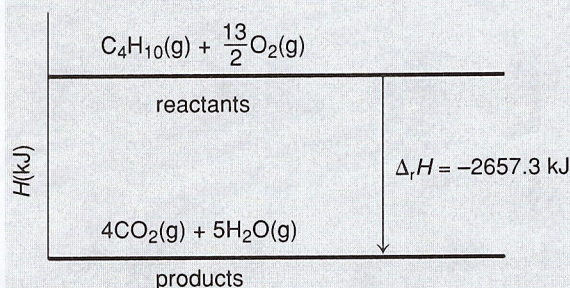
5. (a) $6CO_2(g) + 6H_2O(\ell) \rightarrow C_6H_{12}O_6(s) + 6O_2(g)$
$\Delta H = 2802.5$ kJ
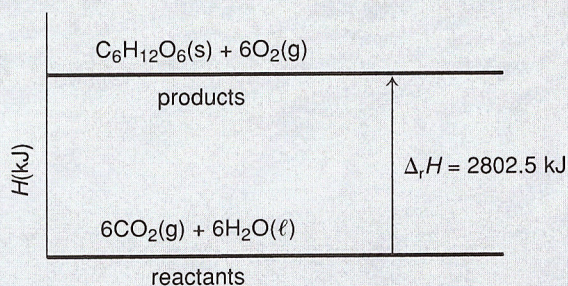
(b) $C_6H_{12}O_6(s) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O(\ell)$
$\Delta H = -2802.5$ kJ

(c) $C_4H_{10}(g) + \dfrac{13}{2}O_2(g) \rightarrow 4CO_2(g) + 5H_2O(g)$
$\Delta H = -2657.3$ 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)
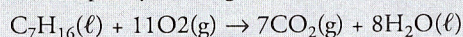
$C_7H_{16}(\ell) + 11O2(g) \rightarrow 7CO_2(g) + 8H_2O(\ell)$
$\Delta_c H = -4816.7$ kJ/mol $C_7H_{16}(\ell)$

(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)
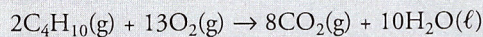
$2C_4H_{10}(g) + 13O_2(g) \rightarrow 8CO_2(g) + 10H_2O(\ell)$
$\Delta_c H = -2877.3$ kJ/mol $C_4H_{10}(g)$

(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.
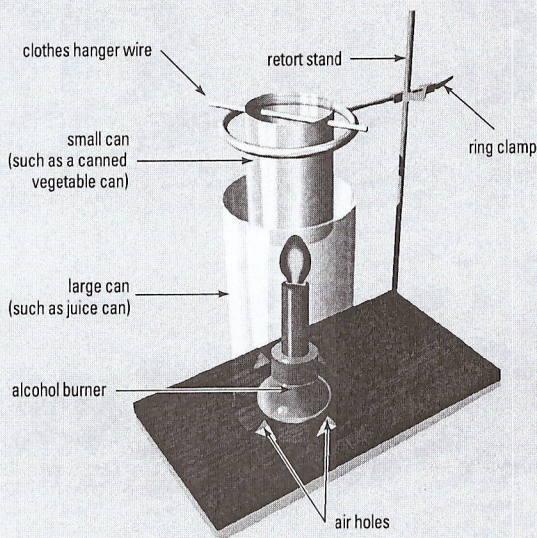
9. Juice cans do not make very good calorimeters because they do not effectively isolate the system from the surroundings. Polystyrene cups, however, cannot be used for investigations involving combustion, so juice cans are a simple, but not perfect, substitute.

＊ 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)

clothes hanger wire

retort stand

small can (such as a canned vegetable can)

ring clamp

large can (such as juice can)

alcohol burner

air holes

(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.
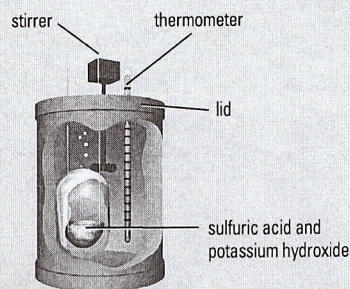
(d) Students should state that they would assume there are no heat losses to the surroundings, and the heat content of the calorimeter is negligible (if not, they must include the specific heat capacity of the calorimeter in the equation below). They will need to assume that the fuel is pure ethanol. 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 $\dfrac{C_2H_5OH(\ell)(g)}{M}$,

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)

stirrer

thermometer

lid

sulfuric acid and potassium hydroxide

(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
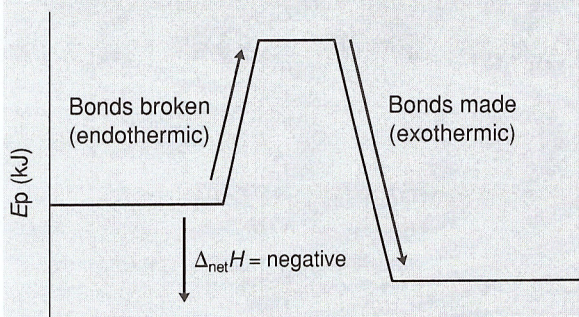
bonds, then the overall reaction will be exothermic. These concepts are summarized in the diagram below:

Ep diagrams summarizing endo and exothermic reactions in steps

Endothermic reaction
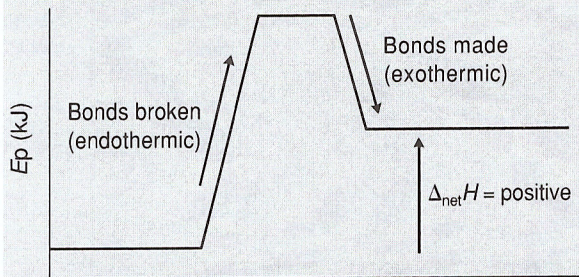
Exothermic reaction

Answers to Solving Problems Questions

16. $Q = mc\Delta t$

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

$$= 322 \text{ kJ}$$

17. Method 1 Using Formulas

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

$$= \frac{10.0 \text{ g CH}_3\text{COOH}(\ell)}{\dfrac{60.06 \text{ g CH}_3\text{COOH}(\ell)}{\text{mol CH}_3\text{COOH}(\ell)}}$$

$$= 0.1665 \text{ mol CH}_3\text{COOH}(\ell)$$

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

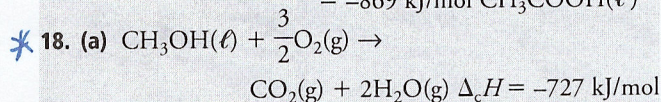$$\Delta_c H = \frac{\Delta H}{n}$$

$$= \frac{-144.77 \text{ kJ}}{0.1665 \text{ mol CH}_3\text{COOH}(\ell)}$$

$$= -869 \text{ kJ/mol CH}_3\text{COOH}(\ell)$$

Method 2 Using Dimensional Analysis

$$x \frac{\text{kJ}}{\text{mol CH}_3\text{COOH}(\ell)} = -144.77 \text{ kJ} \times$$

$$\frac{60.06 \text{ g CH}_3\text{COOH}(\ell)}{\text{mol CH}_3\text{COOH}(\ell)} \times \frac{1}{10.0 \text{ g CH}_3\text{COOH}(\ell)}$$

$$= -869 \text{ kJ/mol CH}_3\text{COOH}(\ell)$$

18. (a) $CH_3OH(\ell) + \dfrac{3}{2}O_2(g) \rightarrow$

$$CO_2(g) + 2H_2O(g) \, \Delta_c H = -727 \text{ kJ/mol}$$

(b) Method 1 Using Formulas

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

$$= \frac{44.3 \text{ g CH}_3\text{OH}(\ell)}{\dfrac{32.05 \text{ g CH}_3\text{OH}(\ell)}{\text{mol CH}_3\text{OH}(\ell)}}$$

$$= 1.38 \text{ mol CH}_3\text{OH}(\ell)$$

$$\Delta H = n\Delta_c H$$
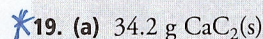
$$= (1.38 \text{ mol CH}_3\text{OH}(\ell))\left(\frac{-727 \text{ kJ}}{\text{mol CH}_3\text{OH}(\ell)}\right)$$

$$= -1.00 \times 10^3 \text{ kJ}$$

Method 2 Using Dimensional Analysis

$$x \text{ kJ} = \frac{-727 \text{ kJ}}{\text{mol CH}_3\text{OH}(\ell)} \times 44.3 \text{ g CH}_3\text{OH}(\ell) \times$$

$$\frac{1 \text{ mol CH}_3\text{OH}(\ell)}{32.05 \text{ g CH}_3\text{OH}(\ell)}$$

$$= -1.00 \times 10^3 \text{ kJ}$$

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

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

$$= \frac{0.35 \text{ g C}_{25}\text{H}_{52}(s)}{\dfrac{352.77 \text{ g C}_{25}\text{H}_{52}(s)}{\text{mol C}_{25}\text{H}_{52}(s)}}$$

$$= 9.9 \times 10^{-4} \text{ mol C}_{25}\text{H}_{52}(s)$$

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

$$= (125.03 \text{ g})\left(\frac{4.19 \text{ J}}{\text{g} \cdot °C}\right)(35.7 \text{ °C} - 14.3 \text{ °C}) +$$

$$(35.03 \text{ g})\left(\frac{0.897 \text{ J}}{\text{g} \cdot °C}\right)(35.7 \text{ °C} - 14.3 \text{ °C})$$

$$= 11\,211 \text{ J} + 672 \text{ J}$$

$$= 11.9 \text{ kJ}$$

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

$\Delta H = n\Delta_c H$

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

$ = \dfrac{-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.

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

$\phantom{\text{Percentage Difference}} = \dfrac{-1.8 \times 10^4 \text{ kJ/mol} - (-1.2 \times 10^4 \text{ kJ/mol})}{-1.8 \times 10^4 \text{ kJ/mol}} \times 100\%$

$\phantom{\text{Percentage Difference}} = 33\%$

✻21. $Q = mc\Delta t$

$ = (500 \text{ g})\left(\dfrac{4.19 \text{ J}}{\text{g} \cdot {}^\circ\text{C}}\right)(13.5\ {}^\circ\text{C})\left(\dfrac{1 \text{ kJ}}{1000 \text{ J}}\right)$

$ = 28.3 \text{ kJ}$

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

$\Delta H = n\Delta_c H$

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

$ = \dfrac{-28.3 \text{ kJ}}{-3\overset{1}{\cancel{5}}44.8 \text{ kJ/mol } C_5H_{12}(\ell)}$

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

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

$m = nM$

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

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

✻22. $n = \dfrac{m}{M}$

$ = \dfrac{0.930 \text{ g } C(s)}{\dfrac{12.01 \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 $Q = mc\Delta t$.

$Q = c\Delta t$

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

$ = \dfrac{(30.5 \text{ kJ})}{(28.15\ {}^\circ\text{C} - 25.00\ {}^\circ\text{C})}$

$ = 9.68 \text{ kJ/}{}^\circ\text{C}$

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

Answers to Making Connections Questions

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

$\phantom{x \text{ minutes}} = 26 \text{ minutes}$

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

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

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

$\phantom{x \text{ apples}} \times 4.0 \text{ h}$

$\phantom{x \text{ apples}} = 17 \text{ apples}$

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