(b) The simple, inexpensive ways to conserve home heating energy are to reduce water heater temperature, set the thermostat down when away or asleep, and to caulk and/or weatherstrip air-leak locations.

(c) Students normally find that doors, windows, and electrical outlets are areas of air leakage.

22. Diesel fuel is used for some automobiles. Diesel engines are more efficient and very durable, but diesel fuel is more polluting than gasoline.

Propane is also used for some automobiles. Propane is less expensive and very clean-burning, but provides less power than gasoline, must be stored in a tank under high pressure, and creates a severe explosion hazard if it leaks.

Other alternatives under consideration for automobile fuel are methanol and hydrogen and electricity. Methanol can be produced from renewable biomass, but is very toxic and does not provide good power. Hydrogen burns with no pollution at all, producing only water vapour, but is very difficult to produce, liquify, and transport. Electric cars are simple and nonpolluting, but batteries are very heavy and expensive, and don't provide much power.

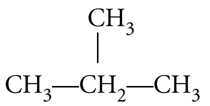
UNIT 5 REVIEW

(Page 600)

Understanding Concepts

1. Organic chemistry deals with all of the many compounds of carbon, except for carbon oxides and ions containing carbon.
2. Baking soda (b), and dry ice (e), are not organic compounds.
3. (a) The major source of hydrocarbons is petroleum.
   (b) The term fossil fuel refers to compounds formed over geologic time by heat and pressure on sediments of living materials deep in the Earth.
4. Crude oil is heated until most of it vaporizes, and is then gradually cooled in a tall tower. As compounds in the vapour stream liquify, they are separated into liquid fractions of the original oil.
5. (a) Cracking, which breaks larger molecules into smaller ones, and reforming, which produces larger molecules from smaller ones, can both be used to produce molecules of the desired sizes for gasoline.
   (b) Catalysts are used in reactions to make them occur much faster, producing more product in less time.
6. (a) cracking $C_{15}H_{32(l)} \rightarrow C_7H_{14(l)} + C_8H_{18(l)}$
   (b) combustion $C_4H_{10(g)} + 13/2\ O_{2(g)} \rightarrow 4\ CO_{2(g)} + 5\ H_2O_{(g)}$
   (c) reforming $C_4H_{10(g)} + C_3H_{6(g)} \rightarrow C_7H_{16(l)}$
   (d) combustion $C_5H_{12(g)} + 8\ O_{2(g)} \rightarrow 5\ CO_{2(g)} + 6\ H_2O_{(g)}$
   (e) cracking $C_{16}H_{34(l)} \rightarrow C_8H_{18(l)} + C_8H_{16(l)}$
7. Breaking bonds requires energy transfer to a chemical system, while forming new bonds transfers energy from the system. A reaction is endothermic or exothermic depending on which process involves the greater amount of energy. A net loss of energy by the system is an exothermic change, and a net gain of energy by the system is an endothermic change.
8. Compounds (c) and (e) could be aliphatic alkanes. Compounds (a) and (d) could be cycloalkanes.
9. (a) The great number of known compounds of carbon is explained by chemists as resulting from the combination of these atomic properties:
   (i) Carbon is a small atom that can form four bonds, more than atoms of most other elements.
   (ii) Carbon atoms have the special property of being able to bond together repeatedly to form chains, rings, spheres, sheets, and tubes.
   (iii) Carbon can form multiple combinations of single, double, and triple covalent bonds with itself and with atoms of other elements.

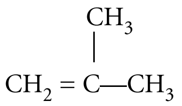
(b) $CH_3—CH_2—CH_2—CH_3$ butane



methylpropane

$CH_2 = CH—CH_2—CH_3$ 1-butene

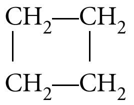
$CH_3—CH = CH—CH_3$ 2-butene



methylpropane

$CH \equiv C—CH_2—CH_3$ 1-butyne

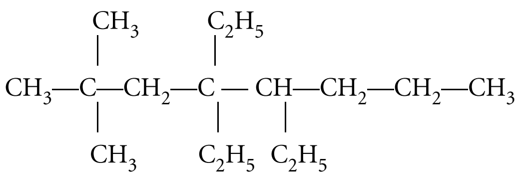
$CH_3—C \equiv C—CH_3$ 2-butyne



cyclobutane

(c) Isomers have the same numbers of C and H atoms.

10. (a)



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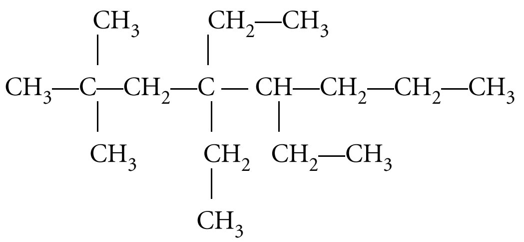

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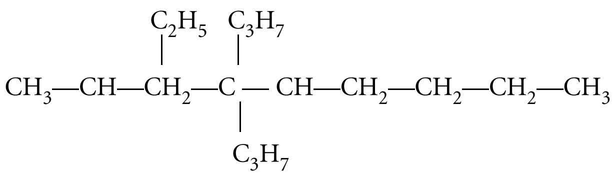

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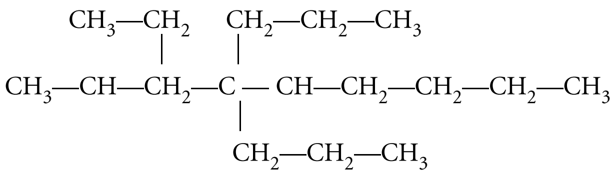

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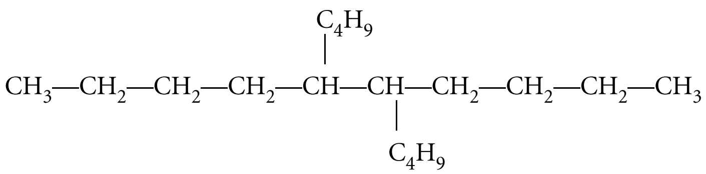

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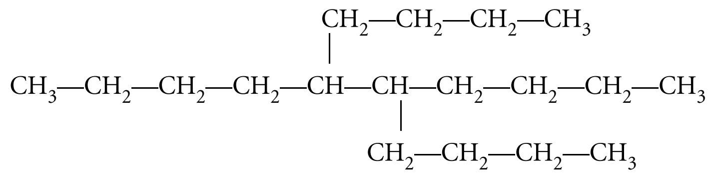

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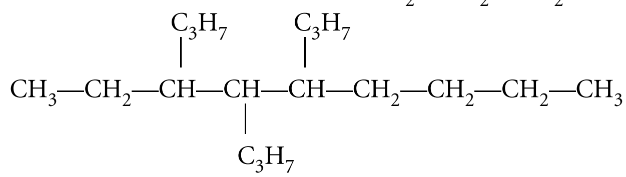

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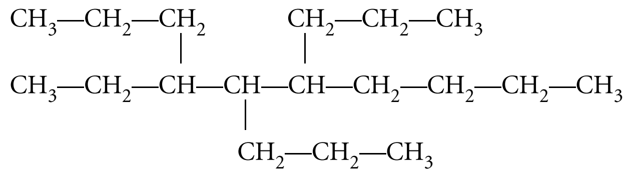
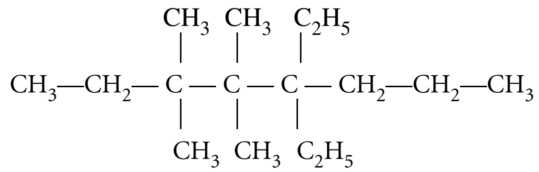


(e)



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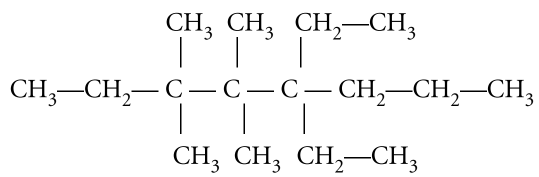
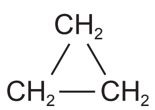


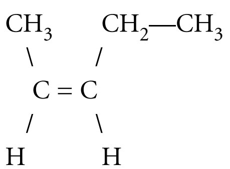
Substances (a) and (e) are isomers — both are $C_{16}H_{34}$.
Substances (c) and (d) are isomers — both are $C_{18}H_{38}$.
Substance (b) has no isomers in this list — it is $C_{17}H_{36}$.

11. (a) methylbutane
    (b) pentane
    (c) 2-methylpentane
    (d) dimethylpropane
    (e) 2,3-dimethylbutane
12. (a) $CH_2 = CH—CH_3$ propene (propylene)



cyclopropane

(b) $CH_2 = CH—CH_2—CH_2—CH_3$ 1-pentene



cis-2-pentene

H CH_2—CH_3 trans-2-pentene

\ /

C = C

/ \

CH_3 H

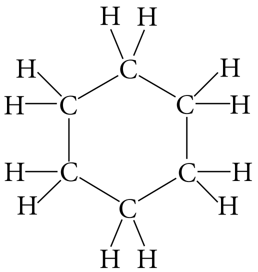
CH_3 cyclopentane

|

CH_3 — CH — CH_2 — CH_3

13. Hydrocarbons are less dense than water, have relatively low melting and boiling points, and are nonpolar substances not soluble in water.
14. Alkanes are very slow to react at SATP, while alkenes and alkynes will react rapidly by addition at SATP with reactive substances like bromine or potassium permanganate. All hydrocarbons will burn rapidly in vapour state at high temperatures.
15. With a simplest formula of CH_2, (molar mass 14.03 g/mol) the compound must be $C_6H_{12(l)}$ to have the required molar mass of 84.18 g/mol (since 84.18/14.03 = 6).

    With the formula being of the general form C_nH_{2n}, the compound must be cyclohexane, because it is saturated. It has no double bond, so it cannot be an alkene (which could also have a C_nH_{2n} general formula).



16 (a) Many alkenes form geometric isomers.
(b) All hydrocarbon families may form structural isomers.
(c) All hydrocarbon families undergo combustion.

17. (a) CH_3—C ≡ C—CH_3 2-butyne

(b) CH_3 3-methyl-1-butene

|

CH_2 = CH—CH—CH_3

(c) H CH_2—CH_3 trans-2-pentene

\ /

C = C

/ \

CH_3 H

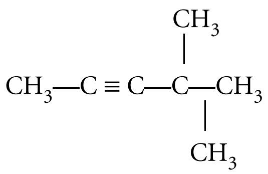
(d) CH_3 2,2-dimethylbutane

|

CH_3—C—CH_2—CH_3

|

CH_3

(e)  4,4-dimethyl-2-pentyne

18. (a) 1-pentyne
(b) 2-pentene
(c) methyl-1-butyne
(d) methyl-2-butene

19. (a) The expression, $q = mc\Delta t$, translates to: "The quantity of heat transferred is equal to the mass (in g) of substance, multiplied by the specific heat capacity (in J/(g ·°C)) of the substance, and by the temperature change (in °C).
(b) Heat transfers to the surroundings when molecules of the system have higher energy than those of the surroundings; and in collisions between the two groups, on average, molecules of the surroundings are speeded up, and those of the system are slowed down.

Heat transfers from the surroundings when molecules of the system have lower energy than those of the surroundings; and in collisions between the two groups, on average, molecules of the surroundings are slowed down, and those of the system are speeded up.
(c) Thermochemical changes are classed as exothermic if heat transfers to the surroundings; and as endothermic if heat transfers from the surroundings.
(d) Breaking bonds requires energy transfer to a chemical system; while forming new bonds transfers energy from the system. A reaction is endothermic or exothermic depending on which process involves the greater amount of energy. A net loss of energy by the system is an exothermic change; and a net gain of energy by the system is an endothermic change.

20. (a) $h_c = 47.51$ kJ/g (ethane, $C_2H_{6(g)}$)

$M = 30.08$ g/mol

$\Delta H_c = ?$

$$\Delta H_c = \frac{47.51\ \text{kJ}}{\cancel{\text{g}}} \times \frac{30.08\ \cancel{\text{g}}}{1\ \text{mol}}$$

$$\Delta H_c = 1429\ \text{kJ/mol} = 1.429\ \text{MJ/mol}$$

The molar heat of combustion of ethane is 1.429 MJ/mol.

$h_c = 47.15$ kJ/g (ethene, $C_2H_{4(g)}$)

$M = 28.06$ g/mol

$\Delta H_c = ?$

$$\Delta H_c = \frac{47.15\ \text{kJ}}{\cancel{\text{g}}} \times \frac{28.06\ \cancel{\text{g}}}{1\ \text{mol}}$$

$$\Delta H_c = 1323\ \text{kJ/mol} = 1.323\ \text{MJ/mol}$$

The molar heat of combustion of ethene is 1.323 MJ/mol.

$h_c = 48.31$ kJ/g (ethyne, $C_2H_{2(g)}$)

$M = 26.04$ g/mol

$\Delta H_c = ?$

$$\Delta H_c = \frac{48.31\ \text{kJ}}{\cancel{\text{g}}} \times \frac{26.04\ \cancel{\text{g}}}{1\ \text{mol}}$$

$$\Delta H_c = 1258\ \text{kJ/mol} = 1.258\ \text{MJ/mol}$$

The molar heat of combustion of ethyne is 1.258 MJ/mol.

(b) $C_2H_{6(g)} + 7/2\ O_{2(g)} \rightarrow 2\ CO_{2(g)} + 3\ H_2O_{(g)}$

$C_2H_{4(g)} + 3\ O_{2(g)} \rightarrow 2\ CO_{2(g)} + 2\ H_2O_{(g)}$

$C_2H_{2(g)} + 5/2\ O_{2(g)} \rightarrow 2\ CO_{2(g)} + H_2O_{(g)}$

(c) All of these substances are used to make many petrochemical products. The uses of ethene alone are too numerous to list.

21\. (a) $\Delta H_r = \dfrac{400\text{ kJ}}{1\text{ mol}}$ (1 is an exact value...)

$\Delta H_r = 400\text{ kJ/mol}$ (hydrazine)

The exothermic molar heat of reaction of hydrazine is 400 kJ/mol.

(b) $\Delta H_r = \dfrac{400\text{ kJ}}{3\text{ mol}}$ (3 is an exact value...)

$\Delta H_r = 133\text{ kJ/mol}$ (oxygen)

The exothermic molar heat of reaction of oxygen is 133 kJ/mol.

(c) $m = 8.00\text{ g}$ (oxygen, $O_{2(g)}$)

$M = 32.00\text{ g/mol}$

$\Delta H_r = 133\text{ kJ/mol}$

$q = ?$

$$n_{O_2} = 8.00\ \cancel{\text{g}} \times \frac{1\text{ mol}}{32.00\ \cancel{\text{g}}}$$

$$n_{O_2} = 0.250\text{ mol}$$

$$q = 0.250\ \cancel{\text{mol}} \times \frac{133\text{ kJ}}{1\ \cancel{\text{mol}}}$$

$$q = 33.3\text{ kJ}$$

The heat released to the surroundings by the reaction of 8.00 g of oxygen is 33.3 kJ.

22\. $\Delta H_r = \dfrac{129\text{ kJ}}{2\text{ mol}}$ (2 is an exact value...)

$\Delta H_r = 64.5\text{ kJ/mol}$ (baking soda)

The endothermic molar heat of reaction of baking soda is 64.5 kJ/mol.

23\. (a) $h_c = 50.0\text{ kJ/g}$ (methane, $CH_{4(g)}$)

$M = 16.05\text{ g/mol}$

$\Delta H_c = ?$ (complete combustion)

$$\Delta H_c = \frac{50.0\text{ kJ}}{\cancel{\text{g}}} \times \frac{16.05\ \cancel{\text{g}}}{1\text{ mol}}$$

$$\Delta H_c = 803\text{ kJ/mol}$$

The molar heat of complete combustion of methane is 803 kJ/mol.

$CH_{4(g)} + 2\ O_{2(g)} \rightarrow CO_{2(g)} + 2\ H_2O_{(g)} + 803\text{ kJ}$

(b) $h_c = 32.4\text{ kJ/g}$ (methane, $CH_{4(g)}$)

$M = 16.05\text{ g/mol}$

$\Delta H_c = ?$ (an incomplete combustion to $CO_{(g)}$ and $H_2O_{(g)}$)

$$\Delta H_c = \frac{32.4\text{ kJ}}{\cancel{\text{g}}} \times \frac{16.05\ \cancel{\text{g}}}{1\text{ mol}}$$

$$\Delta H_c = 520\text{ kJ/mol}$$

A molar heat of incomplete combustion of methane is 520 kJ/mol.

$CH_{4(g)} + 3/2\ O_{2(g)} \rightarrow CO_{(g)} + 2\ H_2O_{(g)} + 520\ \text{kJ}$

Note: Many other incomplete combustion reactions are possible.

(c) $m = 80.0\ \text{g}$ (methane, $CH_{4(g)}$)

$h_c = 50.0\ \text{kJ/g}$ (complete combustion)

$q = ?$

$$q = \frac{80.0\ \cancel{\text{g}} \times 50.0\ \text{kJ}}{\cancel{\text{g}}}$$

$$q = 4.00 \times 10^3\ \text{kJ} = 4.00\ \text{MJ}$$

The heat released to the surroundings by the complete combustion of 80.0 g of methane is 4.00 MJ.

$m = 80.0\ \text{g}$ (methane, $CH_{4(g)}$)

$h_c = 32.4\ \text{kJ/g}$ (incomplete combustion)

$q = ?$

$$q = \frac{80.0\ \cancel{\text{g}} \times 32.4\ \text{kJ}}{\cancel{\text{g}}}$$

$$q = 2.59 \times 10^3\ \text{kJ} = 2.59\ \text{MJ}$$

The heat released to the surroundings by the incomplete combustion of 80.0 g of methane is 2.59 MJ.

The difference in energy produced for 80.0 g of methane burned in the two combustion systems is (4.00 – 2.59) MJ = 1.41 MJ.

24. $m_r = ?$ (reactant – candle wax)

$h = 47\ \text{kJ/g}$

$m = 2.50\ \text{kg}$ (water heated)

$c = 4.18\ \text{J/(g} \cdot {}^\circ\text{C)}$

$\Delta t = |98.5^\circ\text{C} - 2.0^\circ\text{C}| = 96.5^\circ\text{C}$

$$\Delta E = q$$

$$m_r h = mc\Delta t$$

$$m_r = \frac{mc\Delta t}{h}$$

$$m_r = \frac{2.50\ \cancel{\text{k}}\cancel{\text{g}} \times \dfrac{4.18\ \cancel{\text{J}}}{\cancel{\text{g}} \cdot {}^\circ\cancel{\text{C}}} \times 96.5^\circ\cancel{\text{C}}}{\dfrac{47\ \cancel{\text{kJ}}}{\text{g}}}$$

$$m_r = 21\ \text{g}$$

The mass of candle wax required is 21 g.

25. $m = 1.00\ \text{g}$ (hydrogen, $H_{2(g)}$)

$h_c = ?$

$C = 20.0\ \text{kJ/}^\circ\text{C}$

$\Delta t = 7.08^\circ\text{C}$

$$\Delta E = q$$

$$mh_c = C\Delta t$$

$$h_c = \frac{C\Delta t}{m}$$

$$= \frac{\frac{20.0\ \text{kJ}}{\cancel{°\text{C}}} \times 7.08\cancel{°\text{C}}}{1.00\ \text{g}}$$

$$h_c = 142\ \text{kJ/g}$$

M_{H_2} = 2.02 g/mol

ΔH_c = ?

$$\Delta H_c = \frac{142\ \text{kJ}}{\cancel{\text{g}}} \times \frac{2.02\ \cancel{\text{g}}}{1\ \text{mol}}$$

$$\Delta H_c = 286\ \text{kJ/mol}$$

The exothermic molar heat of combustion of hydrogen is 286 kJ/mol.

26. m_{CH_4} = 3.21 g

M_{CH_4} = 16.05 g/mol

ΔH_c = 802.7 kJ/mol

h_c = ?

$$h_c = \frac{802.7\ \text{kJ}}{1\ \cancel{\text{mol}}} \times \frac{1\ \cancel{\text{mol}}}{16.05\ \text{g}}$$

$$h_c = 50.0\ \text{kJ/g}$$

$$\Delta E_c = q = \frac{3.21\ \cancel{\text{g}} \times 50.0\ \text{kJ}}{\cancel{\text{g}}}$$

$$q = 161\ \text{kJ}$$

m = 1.50 ~~L~~ × 1 kg/~~L~~ = 1.50 kg

c = 4.18 J/(g · °C)

Δt = ?

$$q = mc\Delta t$$

$$\Delta t = \frac{q}{mc}$$

$$\Delta t = \frac{161\ \cancel{\text{kJ}}}{1.50\ \cancel{\text{kg}} \times \frac{4.18\ \cancel{\text{J}}}{\cancel{\text{g}} \cdot °\text{C}}}$$

$$\Delta t = 25.6°\text{C}$$

The temperature increase of the water is 25.6°C.

27. The primary uses of hydrocarbons are burning as fuels (about 95%) and production of petrochemical products (about 5%).

Applying Inquiry Skills

28. **Analysis**

(a) If the formula were CH_2, the molar mass would be 14.03 g/mol. The actual molar mass is 56.12/14.03 = 4 times as much, so the molecular formula must be C_4H_8.

(b) The compound has a double bond, because it reacts rapidly with bromine solution – and because it has cis-trans isomers. This means the carbons on either end of the double bond cannot be symmetric — so the double bond cannot be on the first carbon. The structure(s) must be:

```
 H        CH3              CH3     CH3
   \      /                  \     /
    C = C         and         C = C
   /      \                  /     \
 CH3       H                H       H
```

(c) The compound is 2-butene.

29. **Analysis**

(a) m = 1.05 g

C = 10.4 kJ/°C

h_c = ? (combustion of methanol, $CH_3OH_{(l)}$)

$\Delta t = |24.36°C - 22.35°C| = 2.01°C$

$$\Delta E_c = q$$

$$mh_c = C\Delta t$$

$$h_c = \frac{C\Delta t}{m}$$

$$h_c = \frac{\frac{10.4\ \text{kJ}}{°\cancel{C}} \times 2.01°\cancel{C}}{1.05\ \text{g}}$$

$$h_c = 19.9\ \text{kJ/g}$$

The exothermic specific heat of combustion of methanol is 19.9 kJ/g.

m = 1.12 g

C = 10.4 kJ/°C

h_c = ? (combustion of ethanol, $C_2H_5OH_{(l)}$)

$\Delta t = |26.12°C - 23.14°C| = 2.98°C$

$$\Delta E_c = q$$

$$mh_c = C\Delta t$$

$$h_c = \frac{C\Delta t}{m}$$

$$h_c = \frac{\frac{10.4\ \text{kJ}}{°\cancel{C}} \times 2.98\ °\cancel{C}}{1.12\ \text{g}}$$

$$h_c = 27.7\ \text{kJ/g}$$

The exothermic specific heat of combustion of ethanol is 27.7 kJ/g.

(b) $M_{CH_3OH_{(l)}} = 32.05$ g/mol

$$\Delta H_c = ?$$

$$\Delta H_c = \frac{19.9\ \text{kJ}}{\cancel{\text{g}}} \times \frac{32.05\ \cancel{\text{g}}}{1\ \text{mol}}$$

$$\Delta H_c = 638\ \text{kJ/mol}$$

The exothermic molar heat of combustion of methanol is 638 kJ/mol.

$M_{C_2H_5OH_{(l)}} = 46.08$ g/mol

$\Delta H_c = ?$

$$\Delta H_c = \frac{27.7 \text{ kJ}}{\cancel{\text{g}}} \times \frac{46.08 \cancel{\text{g}}}{1 \text{ mol}}$$

$\Delta H_c = 1.28 \times 10^3$ kJ/mol = 1.28 MJ/mol

The exothermic molar heat of combustion of ethanol is 1.28 MJ/mol.

(c) The molar heat of combustion of ethanol is much greater than that of methanol.

Making Connections

30. Winter gasoline blends contain more substances of lower molar mass, so that the fuel mixture will vaporize more easily in cold conditions. The hydrocarbons in gasoline cannot burn until mixed with air in a vapour state.

31. (a) $q = ?$

$m = 70 \cancel{\text{kL}} \times 1 \text{ Mg}/\cancel{\text{kL}} = 70$ Mg

$c = 4.18$ J/(g · ºC)

$\Delta t = |30.0ºC - 10.5ºC| = 19.5ºC$

$$q = mc\Delta t$$

$$= \frac{70 \text{ M}\cancel{\text{g}} \times 4.18 \text{ J}}{\cancel{\text{g}} \cdot \cancel{ºC}} \times 19.5\cancel{ºC}$$

$$q = 5.7 \times 10^3 \text{ MJ} = 5.7 \text{ GJ}$$

The quantity of heat transferred to the pool water is 5.7 GJ.

(b) $5.7 \cancel{\text{GJ}} \times \frac{8.77 \text{ \$}}{\cancel{\text{GJ}}} = 50 \text{ \$}$

Solar heating is a saving of $50 over natural gas heating.

(c) Solar energy is renewable and nonpolluting.

32. (a) The efficiency of a gas furnace is calculated as the percentage of heat produced from combustion that remains in the house and does not escape up the chimney.

(b) Gas furnace efficiencies correspond to the type of burner. Standard open burners use a standing pilot light, and draft naturally through the heat exchanger into a hood and chimney, and are usually less than 80% efficient. Other open burners use electronic ignition and a vent motor to meter the exhaust gases through the heat exchanger and into a chimney, and are from 80–90% efficient. Condensing gas furnaces use a sealed chamber, a condensing coil to extract as much heat from the exhaust gases as possible, and a vent motor to meter the flow through the exchanger, then vent into a small-diameter PVC pipe. Such furnaces have efficiency ratings greater than 90%.

(c) Furnaces are made more efficient by changing from pilot lights to electronic ignition, thereby saving the gas that would be burned by the pilot light. The most effective efficiency technology, however, is a change in firebox design to recirculate the heated air until more of the heat is transferred to air within the house, or to recover heat by condensing the water vapour formed during combustion, which would also provide a hot-water supply for the house.

(d) Replacing a less efficient furnace with a more efficient one will initially cost a significant amount. This cost is then offset over time with savings on fuel bills. The greater the fuel use, the more costly the fuel, and the longer the furnace is used, the greater the savings will be. It is possible to predict confidently that natural gas prices are unlikely to decline in future, because natural gas is a nonrenewable resource.

33. Fuel cells convert a continuous fuel input flow into electric current. Students will find that the only current fuel cell type practical for home and automotive use is the PMEFC (positive membrane exchange fuel cell) which uses hydrogen as fuel. Because hydrogen is so difficult to transport and store, all common current research designs use methane or propane (hydrocarbons) or methanol, which is reacted in a reformer to produce hydrogen — which is then used in the fuel cell. At this time methanol, which has the advantages of being liquid (easy to use and store) and easy to produce renewably from biomass, seems to be the most probable choice for fuel for an automotive fuel cell.

Exploring

34. "Canada-Wide Tune-Up" has many practical suggestions for reducing home heating costs — from caulking and weather stripping, to reglazing and upgrading insulation, to the improved mechanical technology of programmable thermostats, fluorescent lighting, and high-efficiency furnaces.
35. Sulfur content of fossil fuels is a matter of considerable health concern as sulfur oxides are toxic and irritants. The permissible level of sulfur in gasoline in Canada, for example, must by law be dramatically reduced in the next few years. Students will find that typically, sulfur atoms in hydrocarbons can be converted to $H_2S_{(g)}$ by hydrotreating (i.e., reacting with hydrogen under high pressure and temperature). The $H_2S_{(g)}$ can then be extracted by selective solution in an aqueous amine scrubber, using diethanolamine or an equivalent substance. The polar $H_2S_{(g)}$ is soluble in this solution, while nonpolar hydrocarbons are not.