MAKING CONNECTIONS

18. Carbon monoxide detectors usually work by one of three technological systems — all of which represent quite new (and not completely reliable) technology. These are: gel-cel technology, semiconductor technology, and electrochemical technology. There are wide variations in reliability, sensitivity, useful life, and battery replacement and/or element replacement periods.

    Student reports will probably balance the increased safety against the extra cost and inconvenience of mandatory detector installation.
19. Opinions will vary. Canadians in general tend not to favour taxing gasoline and transport fuels more than heating fuels.

Reflecting

20. The word "burn" often is used in contexts that have nothing to do with "combustion" — it is often substituted for words like "pain" and "heat."

SECTION 11.3 QUESTIONS

(Page 528)

Understanding Concepts

1. Scientific: Incomplete combustion produces carbon monoxide.
   Technological: Incomplete combustion produces less energy.
   Economic: Incomplete combustion increases heating costs.
   Environmental: Incomplete combustion produces toxic gases.
2. *Note:* There are many possible examples that could be given for the incomplete combustion reaction equations (the second equations).
   (a) $2\ C_4H_{10(g)} + 13\ O_{2(g)} \rightarrow 8\ CO_{2(g)} + 10\ H_2O_{(g)}$
   $C_4H_{10(g)} + 6\ O_{2(g)} \rightarrow 3\ CO_{2(g)} + CO_{(g)} + 5\ H_2O_{(g)}$
   (b) $C_9H_{20(l)} + 14\ O_{2(g)} \rightarrow 9\ CO_{2(g)} + 10\ H_2O_{(g)}$
   $C_9H_{20(l)} + 13\ O_{2(g)} \rightarrow 7\ CO_{2(g)} + 2\ CO_{(g)} + 10\ H_2O_{(g)}$
   (c) $2\ C_{24}H_{50(s)} + 73\ O_{2(g)} \rightarrow 48\ CO_{2(g)} + 50\ H_2O_{(g)}$
   $C_{24}H_{50(s)} + 31\ O_{2(g)} \rightarrow 13\ CO_{2(g)} + 11\ CO_{(g)} + 25\ H_2O_{(g)}$

Applying Inquiry Skills

3. **Analysis**
   (a) One product is water, as shown by the cobalt chloride diagnostic test.
   The other product is carbon dioxide, as shown by the limewater diagnostic test.

   Evaluation
   (b) The evidence is judged adequate for what it does show, but inadequate in that it does not show whether other products may exist. Any other invisible gases, like carbon monoxide or even unreacted hydrocarbons, would not be detected.
   (c) The design could be improved by adding tests for carbon monoxide gas, and for unreacted hydrocarbons, to establish whether the combustion is complete.

11.4 ALKANES AND CYCLOALKANES

PRACTICE

(Page 530)

Understanding Concepts

1. (a) $C_{11}H_{24}$
   (b) $C_{15}H_{32}$

(c) $C_{22}H_{46}$
(d) $C_{77}H_{156}$

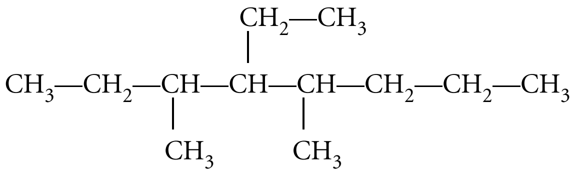
2. Only (b), $C_{12}H_{26}$, could be an alkane.
3. (a) C_3H_7— is a propyl group or: CH_3—CH_2—CH_2—
   (b) C_4H_9— is a butyl group or: CH_3—CH_2—CH_2—CH_2—
4. The molecular formula for this alkane is C_5H_{12}.

PRACTICE

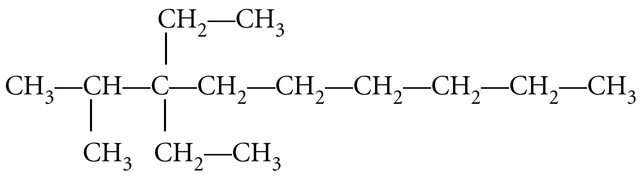
(Page 534)

Understanding Concepts

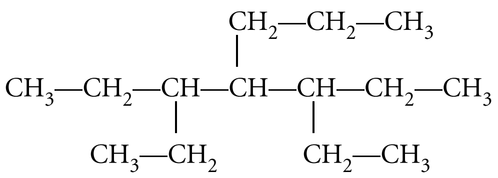
5. (a) 2-methylheptane
   (b) 3,7-dimethylnonane
   (c) 2,4,6-trimethylheptane
   (d) 3-ethyl-6-methyloctane
6. Both octane and 2,2,4-trimethylpentane have 8 carbons and 18 hydrogens, so they must be isomers.
7. (a)



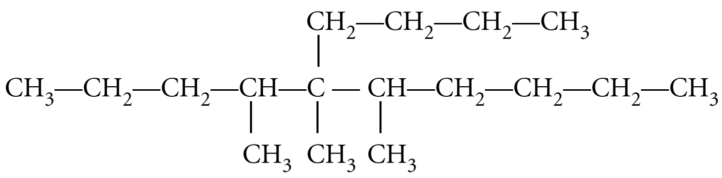
(b)



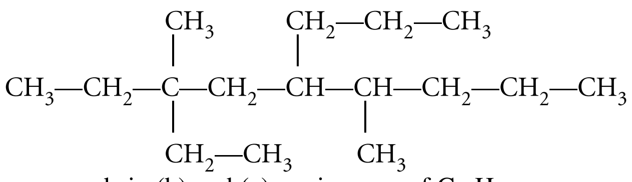
(c)



(d)

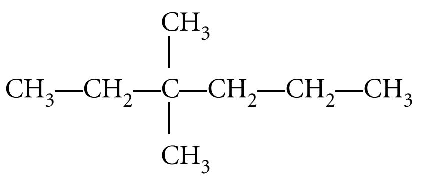


(e)

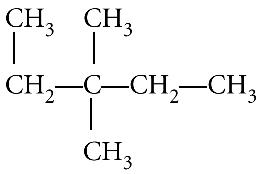


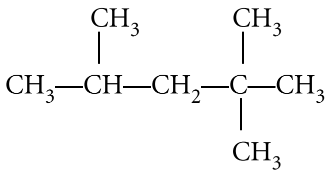
The compounds in (b) and (c) are isomers of $C_{14}H_{30}$.

8. (a)



3,3-dimethylhexane

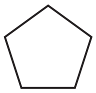
(b)  3,3-dimethylpentane

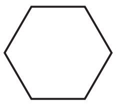
(c)  2,2,4-trimethylpentane

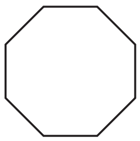
PRACTICE

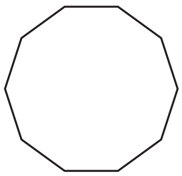
(Page 537)

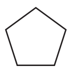
Understanding Concepts


(a) pentagon

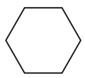

(b) hexagon

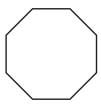

(c) octagon

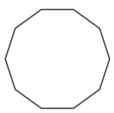

(d) decagon

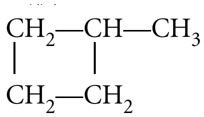
9. (a) $C_5H_{10(l)}$ 

Note: The physical states are like alkanes — all 4 examples are liquid at SATP.

(b) $C_6H_{12(l)}$ 

(c) $C_8H_{16(l)}$ 

(d) $C_{10}H_{20(l)}$ 

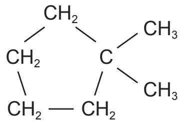
10. (a) 

Note: Please assume from this point to the end of the chapter, that the word *complete* for structural formulas used in questions should generally be omitted.

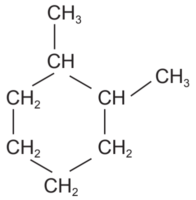
The intention is for students to include the hydrogens, and to show all of the carbon–carbon bonds in hydrocarbons — but *not* to have them show all of the C—H bonds (in other words, to draw what the text defines as *condensed* structural formulas). Bonds within small inorganic molecules like hydrogen, oxygen, halogens, and carbon dioxide should normally be shown.

An exception is question 22 on page 540, where the phrase "complete structural diagrams" means exactly that — *all* bonds should be shown, including C—H bonds in the hydrocarbons.

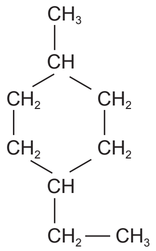
(b)



(c)



(d)



11. For methylcyclobutane, any cyclobutane carbon shown with the methyl group is automatically number one, by definition, so the number need not be mentioned.
12. Cyclopropane is C_5H_{10}, and propane is C_5H_{12}, so they cannot be isomers, having different numbers of hydrogen atoms.

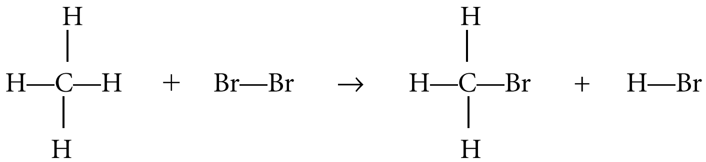
PRACTICE

(Page 540)

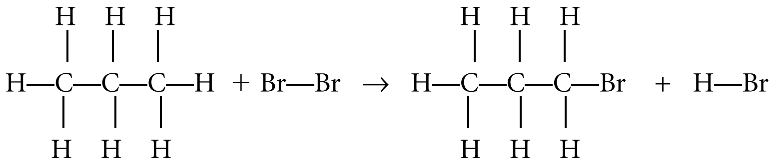
Understanding Concepts

13. Alkanes can be obtained directly from crude oil, from refining processes that create them chemically, and from living things.
14. Alkanes generally
    (a) are less dense than water, with density of straight-chain alkanes increasing as molecular size increases.
    (b) are negligibly soluble in water.
    (c) at SATP (room conditions) are gases if they have 4 carbons or fewer, and liquids if they have 5 carbons or more.
    Note: Students at this point have no way to predict which alkanes will be solid at SATP — the concepts are much too complex to include here, involving molecular size, shape, and packing. The largest simple straight-chain alkane that is liquid at SATP is heptadecane, $C_{17}H_{36(l)}$, m.p.t. 22°C, (which is right on the borderline and will solidify in a cool room). Octadecane, $C_{18}H_{38(l)}$, melts at 28°C (which means it will melt in your hand, held in a plastic bag).
    (d) will float, being both immiscible with, and less dense than, water.
15. (a) Alkanes are negligibly soluble in water because their molecules have only London intermolecular forces (they are nonpolar), whereas water molecules have van der Waals forces (they are polar) and hydrogen bonding. (Hydrogen bonding forces are much, much stronger, and this keeps the water molecules together — not allowing alkane molecules to move between them.)
    (b) Alkanes have very low melting and boiling points because their molecules have only (relatively weak) London intermolecular forces to hold them together.
16. Alkanes undergo cracking, reforming, and combustion reactions.
17. Alkane reactions are generally difficult, or slow (at room temperatures) because the covalent bonding holding alkane molecules together is very strong, requiring a lot of energy to break these bonds to begin a reaction.

18. Saturated molecules have the maximum number of single bonds possible for their component atoms. Empirically, this means that reaction at room temperature will be slow, even with a very reactive halogen, like bromine — so watching for very slow colour loss of bromine added to a sample is a diagnostic test for saturation of a hydrocarbon.
19. These two compounds are isomers — both are $C_8H_{18(l)}$ — so the molecules have exactly the same number and kinds of atoms. The easiest prediction is that the boiling point of 2,2,4-trimethylpentane will be the same as that of its isomer, octane. However, research shows the boiling point of octane to be 126°C (Table 3) and that of 2,2,4-trimethylpentane to be 113°C (see any good reference, such as *The CRC Handbook of Chemistry and Physics*, or Hawley's *Chemical Dictionary*), which conflicts with this prediction.
20. Propane should dissolve in hexane, because they both have nonpolar molecules — by the "like dissolves like" generalization. (Conceptually, this means their London force intermolecular attractions should attract each other's molecules about as well as their own molecules.)
21. These gases have different boiling points, so they can be separated by cooling a vapour mixture slowly, and removing them as they liquefy.
22. (a)



(b)



23. (a) $CH_{4(g)} + 2\ O_{2(g)} \rightarrow CO_{2(g)} + 2\ H_2O_{(g)}$

(b) $2\ C_8H_{18(l)} + 25\ O_{2(g)} \rightarrow 16\ CO_{2(g)} + 18\ H_2O_{(g)}$

Making Connections

24. (a) Butane cooled to near its boiling point will not have enough vapour pressure to come out of a lighter.

(b) At room conditions the vapour pressure of liquid butane is quite low, and a plastic container is considered safe enough to hold it — if the quantity is small. Propane has a much higher vapour pressure at the same conditions, so a metal tank is mandatory for liquid propane, for safety reasons. Rupture of the pressurized container in either case means that the fuel in it would come out quite rapidly, vaporizing and creating an explosion hazard. Both these fuels are denser than air, so their vapours tend to "pool" near ground level, increasing the hazard.

(c) Methane has a very low boiling point, so at normal outside temperatures liquid methane in a tank will have a very, very high vapour pressure — so the tank must be very strong. If the tank ruptured, all the fuel in it would come out immediately, vaporizing and creating a great explosion hazard.

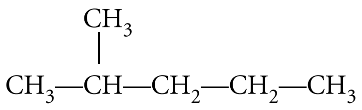
SECTION 11.4 QUESTIONS

(Page 541)

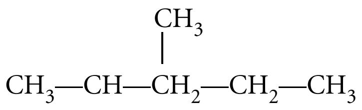
Understanding Concepts

1. Hexane, $C_6H_{14(l)}$, has five isomers:

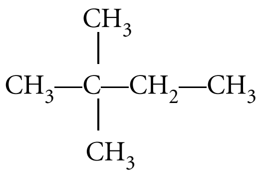
$CH_3—CH_2—CH_2—CH_2—CH_2—CH_3$ hexane



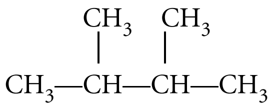
2-methylpentane



3-methylpentane

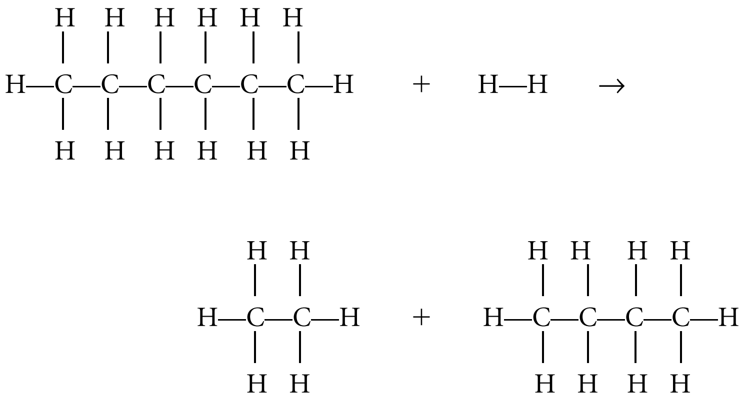


2,2-dimethylbutane

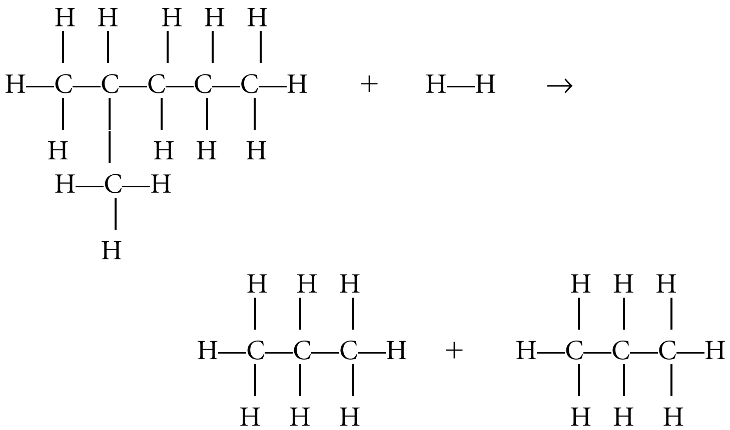


2,3-dimethylbutane

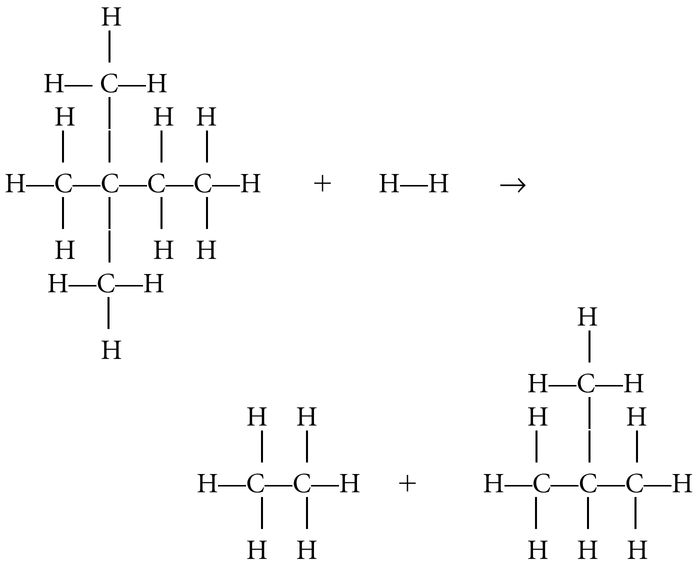
2. (a)



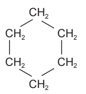
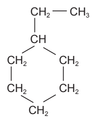
(b)



(c)



3. (a) Propane reacts with pentane to form octane plus hydrogen.

(b)  $+ \quad CH_3—CH_3 \quad \rightarrow$  $+ \quad H—H$

(c) Hexane reacts to form 2,2-dimethylbutane.

(d) Answers are any two of the following isomers:

$CH_3—CH_2—CH_2—CH_2—CH_2—CH_3$ hexane

$$\begin{array}{ccccccccc} & & CH_3 & & & & & & \\ & & | & & & & & & \\ CH_3 & — & CH & — & CH_2 & — & CH_2 & — & CH_3 \end{array}$$
2-methylpentane

$$\begin{array}{ccccccccc} & & & & CH_3 & & & & \\ & & & & | & & & & \\ CH_3 & — & CH & — & CH_2 & — & CH_2 & — & CH_3 \end{array}$$
3-methylpentane

$$\begin{array}{ccccccc} & & CH_3 & & CH_3 & & \\ & & | & & | & & \\ CH_3 & — & CH & — & CH & — & CH_3 \end{array}$$
2,3-dimethylbutane

4. (a)

$$\begin{array}{ccccccccccc} & & CH_3 & & & & CH_3 & & & & \\ & & | & & & & | & & & & \\ 2\ CH_3 & — & C & — & CH_2 & — & CH & — & CH_3 + 25\ O{=}O \rightarrow 16\ O{=}C{=}O\ +\ 18\ H & — & O \\ & & | & & & & & & & & | \\ & & CH_3 & & & & & & & & H \end{array}$$

2,2,4-trimethylpentane reacts with oxygen to form carbon dioxide and water.

Note: In this question water can be shown as H—O—H, but the bent form is preferable, since the bonds are at an angle, and students should know that by now.

(b)

$$\begin{array}{ccccccccc} & & CH_3 & & & & & & H \\ & & | & & & & & & | \\ CH_3 & — & CH & — & CH_2 & — & CH_3 \ +\ 8\ O{=}O \ \rightarrow\ 5\ O{=}C{=}O\ +\ 6\ H & — & O \end{array}$$

Methylbutane reacts with oxygen to form carbon dioxide and water.

Note: It is not incorrect to name the first compound 2-methylbutane, but the methyl group has only one possible location, so the “2” is not required.

5. (a) $CH_4 \ + \ CH_3—CH_2—CH_2—CH_3 \ \rightarrow$
$CH_3—CH_2—CH_2—CH_2—CH_3 \ + \ H–H$
reforming

(b) $CH_3—CH_2—CH_3 \ + \ CH_3—CH_2—CH_2—CH_2—CH_3 \ \rightarrow$
$CH_3—CH_2—CH_2—CH_2—CH_2—CH_2—CH_2—CH_3 \ + \ H–H$
reforming

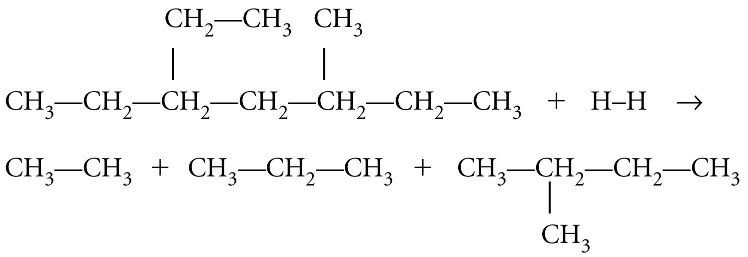
(c) $CH_3—CH_2—CH_2—CH_3 \ + \ O{=}O \ \rightarrow \ O{=}C{=}O + H–O–H$
combustion

(d) $CH_3—CH_2—CH_2—CH_2—CH_2—CH_2—CH_2—CH_2—CH_2—CH_3 \ 1 \ H–H$

$\rightarrow \ CH_3—CH_2—CH_2—CH_2—CH_2—CH_2—CH_3 \ + \ CH_3—CH_2—CH_3$

cracking

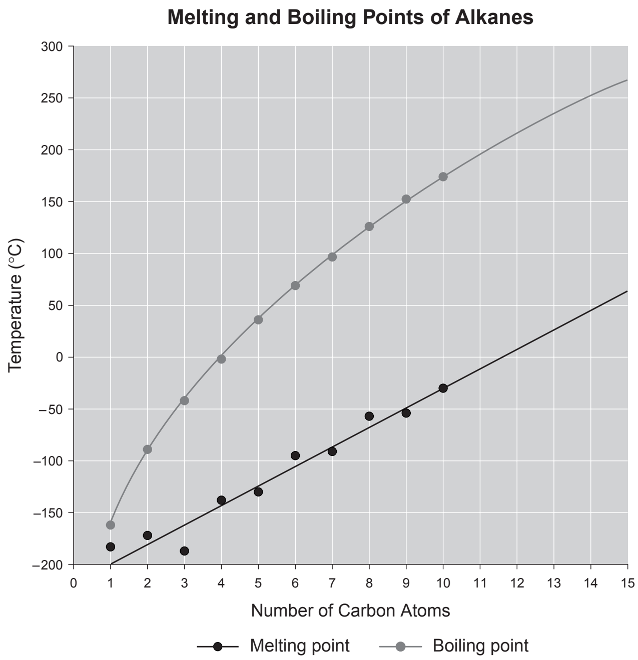
(e)



6. (a) 3,3-dimethylpentane
   (b) 2,3,4-trimethylhexane
   (c) 3,3,5-trimethyloctane
   (d) 1-methyl-4-propylcyclohexane
7. Cyclopentane should be negligibly soluble in water because its molecules have only London intermolecular forces and are nonpolar, whereas water molecules have van der Waals forces and hydrogen bonding, and are strongly polar.
8. Methane, octane, and paraffin (pentacosane) illustrate the fact that London intermolecular forces increase in proportion to molecular size.
9. Eicosane should be solid at room temperature, soluble in gasoline, negligibly soluble in water, less dense than water, and combustible in air if heated enough to vaporize.
10. Pentane molecules must “pack” together better, with more surface area closer, than the molecules in its methylbutane isomer. This is evident because the intermolecular attractive forces must be stronger in pentane, since it has a higher boiling point.

Applying Inquiry Skills

11.



From the graph, the predicted melting point for tetradecane, $C_{14}H_{30}$, (with 14 carbon atoms) is about 30°C, or 303 K, and the boiling point should be about 250°C, or 523 K.

Note: These predicted values will vary significantly with the care taken to construct the graph, particularly the extrapolation of the line, and should be taken as typical examples only.

From a reference, the melting point for tetradecane is 6°C, or 279 K, and the boiling point is 254°C, or 527 K.

Evaluation

Note: Temperatures must be in kelvins to be compared numerically. The points for the melting point curve are much more erratic than those for the boiling point curve.

Melting point accuracy

$$\text{difference} = |303 - 279|\text{ K} = 24\text{ K}$$

$$\%\text{ difference} = \frac{24\ \cancel{\text{K}}}{279\ \cancel{\text{K}}} \times 100\% = 8.6\ \%$$

Boiling point accuracy

$$\text{difference} = |523 - 527|\text{ K} = 4\text{ K}$$

$$\%\text{ difference} = \frac{4\ \cancel{\text{K}}}{527\ \cancel{\text{K}}} \times 100\% = 0.8\ \%$$

The boiling point can be predicted very accurately, within 1%, but the melting point prediction is much less accurate, only within 9%. This indicates that the melting point of an alkane is probably affected significantly by factors other than molecular size.

Making Connections

12. An oil spill means that a "slick" forms on the surface, as alkanes are less dense than water and will not dissolve. This coats anything floating, and also the entire shore area if it drifts there. Most of the damage done is physical, because alkanes are not very reactive.

13. (a) $M_{CH_4} = 16.05$ g/mol

$V_{CH_4} = 24.8$ L/mol (SATP)

$$\text{density}_{CH_4} = \frac{16.05\text{ g}}{1\ \cancel{\text{mol}}} \times \frac{1\ \cancel{\text{mol}}}{24.8\text{ L}}$$

$$\text{density}_{CH_4} = 0.647\text{ g/L}$$

The SATP density of methane is 0.647 g/L.

(b) Propane-powered vehicles may not park in underground lots because of the danger of any possible fuel leak. Propane is denser than air, and so will collect in low areas and persist for a long time before dissipating, which poses a great explosion hazard. Natural gas is much lighter than air, so in the event of a fuel leak the gas will rise and dissipate quickly.

(c) Gasoline-powered vehicles may park in underground lots because the risk of fuel leaks is extremely small. Gasoline hydrocarbons are liquids at SATP, and so are under negligible pressure in the steel gas tank. As well, the flammable liquid, if ignited, will burn gradually at the surface of the liquid and will not explode all at once, as would a mixture of propane gas and air.

11.5 ALKENES AND ALKYNES

PRACTICE

(Page 547)

Understanding Concepts

1. (a) $C_2H_{4(g)}$ is an alkene.
   (b) $C_3H_{8(g)}$ is an alkane.
   (c) $C_4H_{6(g)}$ may be an alkyne, or a cycloalkene.
   (d) $C_5H_{10(l)}$ may be an alkene, or a cycloalkane.
2. (a) $C_3H_{8(g)}$ $CH_3—CH_2—CH_3$
   (b) $C_3H_{6(g)}$ $CH_2 = CH—CH_3$
   (c) $C_3H_{4(g)}$ $CH \equiv C—CH_3$
   (d) $C_3H_{6(g)}$