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

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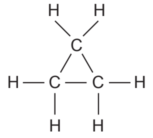
Understanding Concepts

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) $C_3H_{6(g)}$



3. (a) $CH_2 = CH—CH_3$
   (b) $CH_3—CH = CH—CH_3$
   (c)
$$\begin{array}{l} \qquad\quad CH_3 \qquad\quad CH_3 \\ \qquad\quad\;\; | \qquad\qquad\;\; | \\ CH_3—C = CH—CH—CH_3 \end{array}$$
Note: This compound should be named 2,4-dimethyl-**2**-pentene.
   (d) $CH \equiv C—CH_2—CH_3$
4. Both propene and propyne have only one possible location for their double and triple bond, respectively — no number is required to specify the location.
5. (a) 3,3-dimethyl-1-pentene
   (b) 3,3-dimethyl-1-pentene (same structure as 5(a) exactly)
   (c) 5-ethyl-4-methyl-2-heptyne
   Note: The text (evaluation copy) shows a double bond for this molecule, but counting carbons shows it should be a triple bond.
6. The **four** isomers of C_4H_8 are:

$CH_2 = CH—CH_2—CH_3$	1-butene
$CH_3—CH = CH—CH_3$	2-butene
$\begin{array}{l} \quad\;\; CH_3 \\ \quad\;\;\; \vert \\ CH_2 = C—CH_3 \end{array}$	methylpropene
$\begin{array}{ll} CH_2 — & CH_2 \\ \vert & \vert \\ CH_2 — & CH_2 \end{array}$	cyclobutane

7. (a) propene $CH_2 = CH—CH_3$
   (b) methylpropene
$$\begin{array}{l} \quad\;\; CH_3 \\ \quad\;\;\; | \\ CH_2 = C—CH_3 \end{array}$$

PRACTICE

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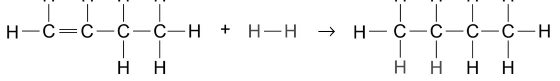
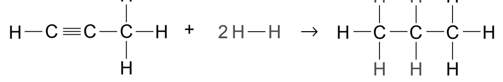
Understanding Concepts

8. (a) As aliphatic hydrocarbon molecular size increases, the boiling point of the substance increases.
   (b) For small molecules with equal numbers of carbon atoms, alkanes tend to have higher boiling points than alkenes.
9. Saturated hydrocarbons have only single bonds, so the total number of bonds (and hydrogens) is the maximum possible. Unsaturated hydrocarbons have at least one double or triple carbon-to-carbon bond.
10. Hydrocarbons that react quickly with bromine (as evidenced by colour disappearance) are unsaturated. Saturated hydrocarbons react very slowly.
    Hydrocarbons that react quickly with aqueous potassium permanganate (as evidenced by colour change) are unsaturated. Saturated hydrocarbons react very slowly.
11. cyclohexane



cyclohexene



Applying Inquiry Skills

12. **Evidence**

The reaction of cyclohexene with bromine is very quick, with the orange colour of bromine disappearing rapidly. There is no apparent reaction of cyclohexane with bromine; the orange colour of bromine does not change.

PRACTICE

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Understanding Concepts

13. cis-2-pentene

```
CH3     CH2—CH3
  \       /
   C = C
  /       \
H         H          trans-2-pentene
```

```
H         CH2—CH3
  \       /
   C = C
  /       \
CH3     H
```

14. (a) As shown below, 1-butene has identical structures on one side of the double bond, so exchanging them would result in an identical molecule. This means there are no (cis-trans) geometric isomers for any 1-alkene.

```
H         CH2—CH3
  \       /
   C = C
  /       \
H         H
```

(b) As shown below, trans-3-hexene has different structures on both sides of the double bond, so exchanging them on either side would result in a differently shaped molecule that would then be named cis-3-hexene.

```
          H         CH2—CH3
            \       /
             C = C
            /       \
CH3—CH2         H
```

(c) 4-hexene is not a possible name for an alkene, because a double bond on the fourth carbon of a six-carbon longest chain would have to be on the *second* carbon, if the chain were numbered in the other direction. The IUPAC rule requires numbering the chain from the end *closest* to the double bond.

(d) 4-heptene is not a possible name for an alkene, because a double bond on the fourth carbon of a seven-carbon longest chain would have to be on the *third* carbon, if the chain were numbered in the other direction. The IUPAC rule requires numbering the chain from the end *closest* to the double bond.

15. As shown in the structures below, geometric isomers are only possible in compounds with double bonds, because the double bond is not free to rotate — thus fixing the shape of the molecule — and there are two possible structures that can bond to either carbon on either side of a double bond.

Single bonds in alkanes and cycloalkanes are all free to rotate, so "up" and "down" directions in a structural diagram are meaningless — they are identical in the actual molecule.

Triple bonds are not free to rotate, but the point is meaningless for geometric isomerism, because each carbon on each side of a triple bond can only bond to one more structure anyway — there is no second possibility.

(a)

$$\begin{array}{ccc} & & CH_3 \\ & & | \\ CH_3-CH-CH_3 & \text{is identical to} & CH_3-CH-CH_3 \\ | & & \\ CH_3 & & \end{array}$$

They are both named methylpropane.

(b)

$$\begin{array}{ccc} \begin{array}{ccc} H & & CH_3 \\ & \backslash\ \ / & \\ & C=C & \\ & /\ \ \backslash & \\ CH_3 & & H \end{array} & \qquad\qquad & \begin{array}{ccc} CH_3 & & CH_3 \\ & \backslash\ \ / & \\ & C=C & \\ & /\ \ \backslash & \\ H & & H \end{array} \\ \text{trans-2-butene} & & \text{cis-2-butene} \end{array}$$

These are not identical because one cannot be "rotated" into the other.

(c) $CH \equiv C{-}CH_2{-}CH_3$

Even if this molecule diagram could be "rotated" about the triple bond, it would be irrelevant — the molecule has a single possible shape.

(d)

$$\begin{array}{ccc} \begin{array}{ccc} CH_2 & - & CH_2 \\ | & & | \\ CH_2 & - & CH_2 \end{array} & \qquad\qquad & \begin{array}{ccc} CH & = & CH \\ | & & | \\ CH_2 & - & CH_2 \end{array} \\ \text{cyclobutane} & & \text{cyclobutene} \end{array}$$

Cycloalkanes are completely symmetrical around every bond, and cycloalkenes are symmetrical around their double bond, so only one geometric structure is possible in each case.

Note: This question is easily demonstrated using ball-and-stick models, so that bond rotation and molecular perspective can be readily visualized.

Making Connections

16. Students can learn a great deal from computer simulations of molecular structure as they offer many of the advantages of experimentation with models, and shorten the time required to examine various possibilities. Computer models aid visualization dramatically — a key to learning how to relate structural diagrams to actual molecular structure.

GO TO www.science.nelson.com, Chemistry 11, Teacher Centre.

ACTIVITY 11.5.1 STRUCTURES AND PROPERTIES OF ISOMERS

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Analysis

(a)

IUPAC Name C_4H_8	Structure	MP (°C)	BP (°C)
1-butene	$CH_2 = CH—CH_2—CH_3$	–185.3	–6.3
2-butene	H H \ / C=C / \ CH_3 CH_3	(cis) –138.9	3.7
	CH_3 H \ / C=C / \ H CH_3	(trans) –105.5	0.9
methylpropene	CH_3 | $CH_2=C—CH_3$	–140.3	–6.9
cyclobutane	$CH_2—CH_2$ | | $CH_2—CH_2$	–50	12
methylcyclopropane	CH_3 | CH / \ $CH_2—CH_2$	–117.2	4 to 5
C_4H_6			
1-butyne	$CH \equiv C—CH_2—CH_3$	–127.7	8.1
2-butyne	$CH_3—C \equiv C—CH_3$	–32.2	27
cyclobutene	$CH_2—CH_2$ | | CH = CH	2	–
methylcyclopropene	CH_3 | CH / \ CH = CH	(substance not known)	
1,2-butadiene	$CH_2=C=CH—CH_3$	–136.2	10.8
1,3-butadiene	$CH_2=CH—CH=CH_2$	–109.9	–4.4

PRACTICE

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Understanding Concepts

17. (a) $C_2H_{6(g)} \rightarrow C_2H_{6(l)}$ (at very low temperature and high pressure)
    (b) $CH_3—CH_3 \quad \rightarrow \quad CH_2 = CH_2 \quad + \quad H—H$
    (c) $CH_2 = CH_2 \quad + \quad CH_2 = CH_2 \quad + \quad CH_2 = CH_2 \quad + \quad \cdots$
    $\rightarrow \quad \cdots —CH_2—CH_2—CH_2—CH_2—CH_2—CH_2— \cdots$
18. Products made from polyethene (polyethylene) are incredibly varied. Answers may include food containers, woven waterproof fabrics, insulating coatings, toys, automobile parts, clear sheet for vapour barriers, drop "cloths" for painting, and innumerable small "plastic" tools.

Making Connections

19. Polypropene (polypropylene) is used for packaging films; moulded parts for autos, appliances, and housewares; artificial turfs; plastic pipe; clothing; surgical casts; and disposable filters, among many other things.

    Polybutene (polybutylene) is used for hot-melt adhesives, sealing tapes, caulking compounds, cable insulation, and as an additive to lubricating oils, among many other things.

    Obviously, our society depends on the availability and use of polymers. The greatest objection to their use is that they are so unreactive that they do not readily biodegrade. When disposed of, they will stay in the environment unchanged for an extremely long time.

PRACTICE

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Making Connections

20. A typical answer might be:

    A petrochemical plant operator performs work that controls the actual industrial process. An operator in an ethylene plant, for instance, that makes ethylene from the ethane that is extracted from natural gas, will normally work shifts. The job involves controlling and monitoring the operation of huge pressure and reaction vessels and pipes.

    Employers generally want applicants for operator positions to have a diploma from an accredited school of technology, showing that they have course work and practical training in this area. Such a course of study is normally three years, postsecondary.

    The petrochemical industry is worldwide, and growing, so opportunities for trained operators are available. Working conditions are generally good, especially in newer plants, which are designed to more rigorous specifications, particularly concerning the release of products to the environment. The DOW Chemical hydrocarbons plant in Fort Saskatchewan, Alberta, for example, is completely surrounded by a greenbelt wildlife conservation zone, and discharges no water to the environment, except as vapour from cooling towers.

    Salary, vacations, and benefits for operators are excellent in Canada. Trained and experienced operators can make salaries on the order of \$60 000–\$80 000, plus overtime. Benefit packages usually include full medical, dental, vision, and disability coverage at quite reasonable rates, as the employee group is usually very large.

    GO TO www.science.nelson.com, Chemistry 11, Teacher Centre.

SECTION 11.5 QUESTIONS

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Understanding Concepts

1. (a) alkanes, C_nH_{2n+2} alkenes, C_nH_{2n} alkynes, C_nH_{2n-2}
   (b) Alkanes have only single carbon-to-carbon bonds, alkenes have at least one double carbon-to-carbon bond, and alkynes have at least one triple carbon-to-carbon bond.
   (c) Every increase in the number of electrons shared between carbon atoms means fewer available for sharing with hydrogen atoms. Consequently, alkenes and alkynes have lower H/C ratios than alkanes of the same C number.

2. Alkenes can form geometric isomers as well as the structural isomers that alkanes form. Also, the varying position of the double bond produces more possible isomers than for alkanes of the same C number.
3. All hydrocarbons have quite similar physical properties.
4. Alkenes and alkynes are much more chemically reactive than alkanes.
5. The first member of the alkenes is ethene (ethylene), which is used primarily to make a wide variety of petrochemicals.

   The first member of the alkynes is ethyne (acetylene), which is used commonly as a very high-energy heating fuel in oxyacetylene welding.
6. “Unsaturated” is a term that, applied to a hydrocarbon, means it has at least one multiple bond.
7. The five acyclic structural isomers of C_5H_{10} are:

$$CH_2 = CH\text{—}CH_2\text{—}CH_2\text{—}CH_3 \qquad \text{1-pentene}$$

$$CH_3\text{—}CH = CH\text{—}CH_2\text{—}CH_3 \qquad \text{2-pentene}$$

$$\begin{array}{ccccccc} & & CH_3 & & & & \\ & & | & & & & \\ CH_2 & = & C & \text{—} & CH_2 & \text{—} & CH_3 \end{array} \qquad \text{2-methyl-1-butene}$$

$$\begin{array}{ccccccc} & & & & CH_3 & & \\ & & & & | & & \\ CH_2 & = & CH & \text{—} & CH & \text{—} & CH_3 \end{array} \qquad \text{3-methyl-1-butene}$$

$$\begin{array}{ccccccc} & & CH_3 & & & & \\ & & | & & & & \\ CH_3 & \text{—} & C & = & CH & \text{—} & CH_3 \end{array} \qquad \text{2-methyl-2-butene}$$

8. (a) Pentane has no geometric isomers.
   (b) 2-pentene has two geometric isomers:

$$\begin{array}{ccccl} H & & & & CH_2\text{—}CH_3 \\ & \backslash & & / & \\ & C & = & C & \\ & / & & \backslash & \\ CH_3 & & & & H \end{array} \qquad\qquad \begin{array}{ccccl} CH_3 & & & & CH_2\text{—}CH_3 \\ & \backslash & & / & \\ & C & = & C & \\ & / & & \backslash & \\ H & & & & H \end{array}$$

trans-2-pentene   cis-2-pentene

   (c) 1-pentyne has no geometric isomers.
   (d) 1-butene has no geometric isomers.
   (e) 4-methyl-2-pentene has two geometric isomers, shown below.

$$\begin{array}{ccccl} & & & & CH_3 \\ & & & & | \\ H & & & & CH\text{—}CH_3 \\ & \backslash & & / & \\ & C & = & C & \\ & / & & \backslash & \\ CH_3 & & & & H \end{array} \qquad\qquad \begin{array}{ccccl} & & & & CH_3 \\ & & & & | \\ CH_3 & & & & CH\text{—}CH_3 \\ & \backslash & & / & \\ & C & = & C & \\ & / & & \backslash & \\ H & & & & H \end{array}$$

trans-4-methyl-2-pentene   cis-4-methyl-2-pentene

9. An alicyclic isomer of 1-butyne, $CH \equiv C\text{—}CH_2\text{—}CH_3$, is

$$\begin{array}{lll} CH & = & CH\ , \\ | & & | \\ CH_2 & \text{—} & CH_2 \end{array} \qquad \text{cyclobutene.}$$

10. The acyclic isomers of C_4H_6 are:
2-butyne, $CH_3—C \equiv C—CH_3$, and
1-butyne, $CH \equiv C—CH_2—CH_3$

Note: Students may discover independently (or with guidance) that there exist two different dienes that are also acyclic isomers of C_4H_6. These are

$$\begin{array}{ccc} & & CH_3 \\ & & / \\ & C = C & \\ // & & \backslash \\ CH_2 & & H \end{array} \qquad\qquad \begin{array}{cccc} H & & & CH_2 \\ & \backslash & & // \\ & C & — & C \\ & // & & \backslash \\ CH_2 & & & H \end{array}$$

1,2-butadiene and 1,3-butadiene,
but students will not have a nomenclature system for these, yet.

11. (a)

$$\begin{array}{c} \qquad\qquad\qquad\quad CH_3 \\ \qquad\qquad\qquad\quad | \\ CH_3—CH = C—CH—CH_3 \\ \qquad\quad | \\ \qquad\qquad\quad CH_2—CH_3 \end{array}$$

(b)

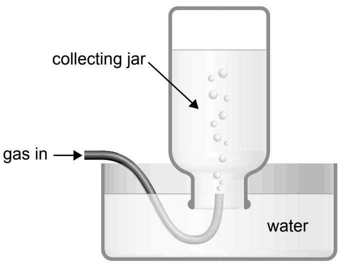
$$\begin{array}{ccccccccccc} & & CH_3 & & & & CH_2—CH_3 & & & & \\ & & | & & & & | & & & & \\ CH_3 & — & C & — & C \equiv C & — & CH & — & CH & — & CH_3 \\ & & | & & & & & & | & & \\ & & CH_3 & & & & & & CH_3 & & \end{array}$$

12. 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.
13. Polypropene is made from the monomer, propene (propylene), C_3H_6.
14. $CH_2CHCl + CH_2CHCl + CH_2CHCl + \cdots$
$\rightarrow \cdots —CH_2—CHCl—CH_2—CHCl—CH_2—CHCl— \cdots$

Note: This example writes C_2H_3Cl as CH_2CHCl for clarity about the structure of the polymer.

Applying Inquiry Skills

15. If the substance is tested by adding bromine, and the colour disappears quickly, then the substance probably contains molecules with double and/or triple bonds.
16.



Gases produced by chemical reactions may be collected easily by the downward displacement of water with relatively simple equipment as shown above. If measurement of the gas volume is required, a graduated cylinder may be substituted for the collecting jar. However, this process only works for gases that are negligibly soluble in water.

Making Connections

17. Acetylene becomes very reactive if compressed greatly, causing the gas to react violently with itself, forming hydrogen, carbon, and great heat, and exploding the container.
    For commercial use the gas is stored under lower relative pressure in cylinders containing fabric pads soaked with liquid acetone, $CH_3COCH_{3(l)}$. When not more than 100 volumes of acetylene are dissolved in 1 volume of acetone, the substance may be handled without danger.
18. A typical answer might be:
    Polyethylene's greatest use is as insulation for electrical wiring. Fabrics can be used for the same purpose (and were, historically), but they are nowhere near as durable, and are poorer insulators.
    The main problem with polyethylene has to do with its presence in waste material. It does not degrade significantly over time, so it persists in the environment.
19. Economic:
    Fossil fuels provide very inexpensive energy.
    Petrochemicals will become very expensive if fossil fuels become scarce.

    Social:
    Cheap energy from fossil fuels makes social improvements possible.
    Society has become dangerously dependent on fossil fuel energy.

    Environmental:
    Burning fossil fuels produces far fewer pollutants than burning wood.
    Burning fossil fuels produces greenhouse gas pollutants.

    Ethical:
    Burning fossil fuels improves the living standard of almost everyone.
    People should not use up a resource and thus deny it to future generations.

CHAPTER 11 REVIEW

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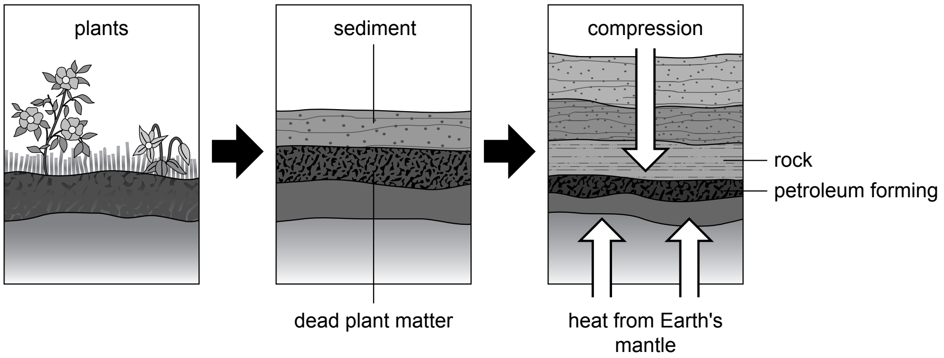
Understanding Concepts

1.



    Currently accepted belief is that fossil fuels are formed when deposits of dead biological material are sealed in by sedimentary layers, and over geologic time are subjected to great pressure and high temperature deep beneath the Earth's surface.
2. The two fractions of raw petroleum are crude oil and natural gas — distinguished by their physical state on site — liquids and gases, respectively.
3. Fractionation is the principal physical process in petroleum refining.
4. Cracking and reforming are the principal chemical processes in petroleum refining.
5. Hydrocarbons are used technologically for fuels, and to manufacture petrochemical products.
6. Scientists suspect that organic compounds found on other planets might indicate non-earthly forms of life.

