ANSWERS TO
END-OF-CHAPTER QUESTIONS

CHAPTER 4: ENERGY, CHEMISTRY, AND SOCIETY

Emphasizing Essentials

1. a. List three fossil fuels.
b. What is the origin of fossil fuels?
c. Are fossil fuels a renewable resource?

Answer:

a. Coal, oil, and natural gas
b. Fossil fuels originated 150-300 million years ago from plant and animal matter.
c. No. The time required to form these fuels means they are not renewable.

2. The Calorie, used to express food heat values, is the same as a kilocalorie of heat energy. If you eat a chocolate bar from the United States with 600 Calories of food energy, how does the energy compare with eating a Swiss chocolate bar that has 3000 kJ of food energy? (Note: 1 kcal = 4.184 kJ)

Answer:

600 Calories is the same as 600 kcal of heat energy.

600 kcal × \frac{4.184 \text{kJ}}{1 \text{kcal}} = 2500 \text{kJ} \text{ in the U.S chocolate bar}

The Swiss chocolate bar contains more food energy.

3. A single serving bag of Granny Goose Hawaiian Style Potato Chips has 70 Cal. Assuming that all of the energy from eating these chips goes toward keeping your heart beating, how long can these chips sustain a heartbeat of 80 beats per minute? (Note: 1 kcal = 4.184 kJ, and each human heart beat requires approximately 1 J of energy)

Answer:

70 Cal × \frac{4.184 \text{kJ}}{1 \text{Cal}} × \frac{1000 \text{J}}{1 \text{kJ}} × \frac{1 \text{beat}}{1 \text{J}} × \frac{1 \text{min}}{80 \text{beats}} = 3700 \text{min}

4. Three power plants have been proposed that operate at these efficiencies.

<table>
<thead>
<tr>
<th>Plant</th>
<th>Power Plant Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>81</td>
</tr>
<tr>
<td>II</td>
<td>66</td>
</tr>
<tr>
<td>III</td>
<td>41</td>
</tr>
</tbody>
</table>

a. Calculate the overall efficiency of each plant (not the maximum theoretical efficiency) using the other efficiencies given in Table 4.1.
b. Identify the factors that affect the efficiency.
c. Discuss the practical limits that govern such efficiencies. Which plant would be most likely to be built? If plant III only costs half of plant I or II to operate, which would be most likely to be built?

**Answer:**

a. For each plant, the overall efficiency = the efficiency of (power plant) \times (boiler) \times (turbine) \times (electrical generator) \times (power transmission). The overall efficiencies are: Plant I: 46.7%; Plant II: 38.1%; Plant III: 23.7%.

b. The main factors affecting the efficiency are the various steps of energy transformation: the combustion of the fuel and boiling of the water (potential to kinetic), the turning of the turbine (kinetic to mechanical), and the operation of the generator (mechanical to electrical).

c. The second law of thermodynamics limits the efficiencies of each step. Heat can never completely be converted into work. With both the efficiency and operating costs of Plant I being twice that of Plant III, either of these would be equally likely to be built. One may be preferred if there were other factors such as environmental impacts or initial construction costs.

5. Equation 4.1 shows the complete combustion of methane.

a. By analogy, write a similar chemical equation using ethane, C₂H₆.

b. Represent this equation with Lewis structures.

**Answer:**

a. 2 C₂H₆ + 7 O₂ → 4 CO₂ + 6 H₂O

b. 

\[
\begin{align*}
\text{H} & \quad \text{H} \\
\text{C} & \quad \text{C} \\
\text{H} & \quad \text{H} \\
\end{align*}
\]

2 H\text{-C}-\text{C}-\text{H} + 7 \text{O}=\text{O} \rightarrow 4 \text{O}=\text{C}=\text{O} + 6 \text{H}\text{O}

6. The heat of combustion for ethane, C₂H₆, is 52.0 kJ/g. How much heat would be released if 1 mol of ethane undergoes complete combustion?

**Answer:**

\[
\frac{52.0 \text{ kJ}}{\text{1 g C}_2\text{H}_6} \times \frac{30.1 \text{ g C}_2\text{H}_6}{\text{1 mol C}_2\text{H}_6} = \frac{1570 \text{ kJ}}{\text{1 mol C}_2\text{H}_6}
\]

7. a. Write the chemical equation for the complete combustion of heptane, C₇H₁₆.

b. The heat of combustion for heptane is 4817 kJ/mol. How much heat would be released if 250 kg of heptane undergoes complete combustion?

**Answer:**

a. C₇H₁₆ + 11 O₂ → 7 CO₂ + 8 H₂O

b. 

\[
\begin{align*}
\text{250 kg C}_7\text{H}_{16} \times \frac{10^{3} \text{ g C}_7\text{H}_{16}}{\text{kg C}_7\text{H}_{16}} \times \frac{1 \text{ mol C}_7\text{H}_{16}}{100.2 \text{ g C}_7\text{H}_{16}} \times \frac{4817 \text{ kJ}}{1 \text{ mol C}_7\text{H}_{16}} = 1.2 \times 10^7 \text{ kJ}
\end{align*}
\]
8. Figure 4.7 shows energy differences for the combustion of hydrogen, an exothermic chemical reaction. The combination of nitrogen gas and oxygen gas to form nitrogen monoxide is an example of an endothermic reaction:

\[
180 \text{ kJ} + \text{N}_2(g) + \text{O}_2(g) \rightarrow 2\ \text{NO}(g)
\]

Sketch an energy diagram for this reaction.

**Answer:**

Note that in an endothermic reaction, the energy of the products is greater than the energy of the reactants. The opposite was true for an exothermic reaction.

![Energy Diagram for N₂ + O₂ → 2NO]

9. One way to produce ethanol for use as a gasoline additive is the reaction of water vapor with ethylene:

\[
\text{CH}_2\text{CH}_2(g) + \text{H}_2\text{O}(g) \rightarrow \text{CH}_3\text{CH}_2\text{OH}(l)
\]

**a.** Rewrite this equation using Lewis structures.

**b.** Is this reaction endothermic or exothermic?

**c.** In your calculation, was it necessary to break *all* the chemical bonds in the reactants to form the product ethanol? Explain your answer.
Answer:

\[
\begin{align*}
\text{b. Bonds broken in the reactants:} \\
1 \text{ mole C-to-C double bond} &= 1(598 \text{ kJ}) = 598 \text{ kJ} \\
1 \text{ mole O-to-H single bond} &= 1(467 \text{ kJ}) = 467 \text{ kJ} \\
\text{Total energy absorbed in breaking bonds} &= 1065 \text{ kJ}
\end{align*}
\]

\[
\begin{align*}
\text{Bonds formed in the products:} \\
1 \text{ mole C-to-C single bond} &= 1(356 \text{ kJ}) = 356 \text{ kJ} \\
1 \text{ mole C-to-H single bond} &= 1(416 \text{ kJ}) = 416 \text{ kJ} \\
1 \text{ mole C-to-O single bond} &= 1(336 \text{ kJ}) = 336 \text{ kJ} \\
\text{Total energy released in forming bonds} &= 1108 \text{ kJ}
\end{align*}
\]

Net energy change: \((1065 \text{ kJ}) + (-1108 \text{ kJ}) = -43 \text{ kJ}\)

Because the energy released in forming bonds is greater than the energy absorbed in breaking bonds, the net energy change is negative and the overall reaction is exothermic.

c. No, it is not necessary to break all of the bonds. There are four carbon-to-hydrogen single bonds on the reactant side, and they are also in the product, ethanol. One of the oxygen-to-hydrogen bonds in water remains intact in the product.

10. From personal experience, state whether these processes are endothermic or exothermic. Give a reason for each.

a. A charcoal briquette burns.

b. Water evaporates from your skin.

c. Ice melts.

d. Wood burns.

Answer:

a. Exothermic. A charcoal briquette releases heat as it burns.

b. Endothermic. Water absorbs the heat necessary for evaporation from your skin, and your skin feels cooler.

c. Endothermic. Ice absorbs the necessary heat from the environment to melt.

d. Exothermic. Wood releases heat as it burns.

11. Use the bond energies in Table 4.2 to explain why:

a. chlorofluorocarbons, CFCs, are so stable.

b. it takes less energy to release Cl atoms than F atoms from CFCs.

Answer:

a. CFCs are stable because it takes considerable energy to break carbon-to-chlorine and carbon-to-fluorine bonds.

b. The larger atomic size of Cl results in carbon-to-chlorine (327 kJ/mol) bonds being easier to break than carbon-to-fluorine bonds (485 kJ/mol).
12. Use the bond energies in Table 4.2 to calculate the energy changes associated with each of these reactions. Lewis structures of the reactants and products may be useful for determining the number and kinds of bonds. Label each reaction as endothermic or exothermic.

a. \( \text{N}_2(g) + 3 \text{H}_2(g) \rightarrow 2 \text{NH}_3(g) \)

b. \( 2 \text{C}_5\text{H}_{12}(g) + 11 \text{O}_2(g) \rightarrow 10 \text{CO}(g) + 12 \text{H}_2\text{O}(l) \)

c. \( \text{H}_2(g) + \text{Cl}_2(g) \rightarrow 2 \text{HCl}(g) \)

**Answer:**

**a.** Bonds broken in the reactants:

1 mol N-to-N triple bonds = 1(946 kJ) = 946 kJ
3 mol H-to-H single bonds = 3(436 kJ) = 1308 kJ

Total energy absorbed in breaking bonds = 2254 kJ

Bonds formed in the products:

6 mol N-to-H single bonds = 6(391 kJ) = 2346 kJ

Total energy released in forming bonds = 2346 kJ

Net energy change is (+2254 kJ) + (−2346 kJ) = −92 kJ

The overall energy change is negative, characteristic of an exothermic reaction.

**b.** Bonds broken in the reactants:

12 mol C-to-H single bonds = 12(416 kJ) = 4992 kJ
4 mol C-to-C single bonds = 4(356 kJ) = 1424 kJ
11 mol O-to-O double bonds = 11(498 kJ) = 5478 kJ

Total energy absorbed in breaking bonds = 11,894 kJ

Bonds formed in the products:

10 mol C-to-O triple bonds = 10(1073 kJ) = 10,730 kJ
24 mol O-to-H single bonds = 24(467 kJ) = 11,208 kJ

Total energy released in forming bonds = 21,938 kJ

Net energy change is (+11,894 kJ) + (−21,938 kJ) = −10,044 kJ

The overall energy change is negative, characteristic of an exothermic reaction.

**c.** Bonds broken in the reactants:

1 mol H-to-H single bonds = 1(436 kJ) = 436 kJ
1 mol Cl-to-Cl single bonds = 1(242 kJ) = 242 kJ

Total energy absorbed in breaking bonds = 678 kJ

Bonds formed in the products:

2 mol H-to-Cl single bonds = 2(431 kJ) = 862 kJ

Total energy released in forming bonds = 862 kJ
Net energy change is \((+678 \text{ kJ}) + (-862 \text{ kJ})\) \(= -184 \text{ kJ}\)
The overall energy change is negative, characteristic of an exothermic reaction.

13. Use the bond energies in Table 4.2 to calculate the energy changes associated with each of these reactions. Label each reaction as endothermic or exothermic.

**a.** \(2 \text{H}_2(g) + \text{CO}(g) \rightarrow \text{CH}_3\text{OH}(g)\)

**b.** \(\text{H}_2(g) + \text{O}_2(g) \rightarrow \text{H}_2\text{O}(g)\)

**c.** \(2 \text{BrCl}(g) \rightarrow \text{Br}_2(g) + \text{Cl}_2(g)\)

**Answer:**

**a.** \(2 \text{H}_2(g) + \text{CO}(g) \rightarrow \text{CH}_3\text{OH}(g)\)

Bonds broken in the reactants:
- 2 mol H-to-H single bonds \(= 2(436 \text{ kJ}) = 872 \text{ kJ}\)
- 1 mol C-to-O triple bonds \(= 1(1073 \text{ kJ}) = 1073 \text{ kJ}\)

Total energy absorbed in breaking bonds \(= 1945 \text{ kJ}\)

Bonds formed in the products:
- 1 mol C-to-O single bonds \(= 1(336 \text{ kJ}) = 336 \text{ kJ}\)
- 1 mol O-to-H single bonds \(= 1(467 \text{ kJ}) = 467 \text{ kJ}\)
- 3 mol C-to-H single bonds \(= 3(416 \text{ kJ}) = 1248 \text{ kJ}\)

Total energy released in making bonds \(= 2051 \text{ kJ}\)

Net energy change is \((+1945 \text{ kJ}) + (-2051 \text{ kJ})\) \(= -56 \text{ kJ}\)
The overall energy change is negative, characteristic of an exothermic reaction.

**b.** \(\text{H}_2(g) + \text{O}_2(g) \rightarrow \text{H}_2\text{O}(g)\)

Bonds broken in the reactants:
- 1 mol H-to-H single bonds \(= 1(436 \text{ kJ}) = 436 \text{ kJ}\)
- 1 mol O-to-O double bonds \(= 1(498 \text{ kJ}) = 498 \text{ kJ}\)

Total energy absorbed in breaking bonds \(= 934 \text{ kJ}\)

Bonds formed in the products:
- 2 mol O-to-H single bonds \(= 2(467 \text{ kJ}) = 934 \text{ kJ}\)

Total energy released in making bonds \(= 934 \text{ kJ}\)

Net energy change is \((+934 \text{ kJ}) + (-934 \text{ kJ})\) \(= 0 \text{ kJ}\)
The overall energy change is zero. The reaction is neither endothermic nor exothermic.

**c.** \(2 \text{BrCl}(g) \rightarrow \text{Br}_2(g) + \text{Cl}_2(g)\)

Bonds broken in the reactants:
- 2 mol Br-to-Cl single bonds \(= 2(217 \text{ kJ}) = 434 \text{ kJ}\)

Total energy absorbed in breaking bonds \(= 434 \text{ kJ}\)

Bonds formed in the products:
- 1 mol Br-to-Br single bonds \(= 1(193 \text{ kJ}) = 193 \text{ kJ}\)
- 1 mol Cl-to-Cl single bonds \(= 1(242 \text{ kJ}) = 242 \text{ kJ}\)

Total energy released in making bonds \(= 435 \text{ kJ}\)
Net energy change is \((+434 \text{ kJ}) + (-435 \text{ kJ}) = -1 \text{ kJ}\)

The overall energy change is negative, characteristic of an exothermic reaction.

14. Use Figure 4.9 to compare the sources of U.S. energy consumption. Arrange the sources in order of decreasing percentage and comment on the relative rankings.

Answer:
Currently, U.S. energy consumption follows the order oil > natural gas > coal > nuclear > hydropower > wood. This highlights the U.S. dependence on oil for its energy needs.

15. Table 4.3 lists the energy content of some fuels in kilojoules per gram (kJ/g). Calculate the fuel energy in kilojoules per mole (kJ/mol) for methane CH\(_4\), propane C\(_3\)H\(_8\), hydrogen H\(_2\), coal, and ethanol C\(_2\)H\(_6\)O. Make a generalization regarding the chemical composition of fuels and their respective energy contents. Visit Figures Alive! at the Online Learning Center for related activities.

Answer:

- Methane (CH\(_4\)):
  \[
  \text{mol} \times \frac{16 \text{ g}}{\text{mol}} = \frac{896 \text{ kJ}}{\text{mol}}
  \]

- Propane (C\(_3\)H\(_8\)):
  \[
  \text{mol} \times \frac{44 \text{ g}}{\text{mol}} = \frac{2244 \text{ kJ}}{\text{mol}}
  \]

- Hydrogen (H\(_2\)):
  \[
  \text{mol} \times \frac{2 \text{ g}}{\text{mol}} = \frac{280 \text{ kJ}}{\text{mol}}
  \]

- Coal (C\(_{135}\)H\(_{96}\)O\(_9\)NS):
  \[
  \text{mol} \times \frac{1906 \text{ g}}{\text{mol}} = \frac{59,086 \text{ kJ}}{\text{mol}}
  \]

- Ethanol (C\(_2\)H\(_6\)O):
  \[
  \text{mol} \times \frac{46 \text{ g}}{\text{mol}} = \frac{1380 \text{ kJ}}{\text{mol}}
  \]

16. Mercury is present in minor amounts (50–200 ppb) in coal. Use the amount of coal burned by a power plant in Your Turn 4.12 to determine how much Hg is released by that plant. Calculate the amount based on the lower (50 ppb) and higher (200 ppb) limits.

Answer:
A typical power plant burns 1.5 million tons of coal each year.

\[
\frac{x \text{ ton Hg}}{1.5 \times 10^9 \text{ ton coal}} = \frac{50 \text{ ton Hg}}{1 \times 10^9 \text{ ton coal}} \quad x = 0.75 \text{ ton Hg}
\]

\[
\frac{x \text{ ton Hg}}{1.5 \times 10^9 \text{ ton coal}} = \frac{200 \text{ ton Hg}}{1 \times 10^9 \text{ ton coal}} \quad x = 0.3 \text{ ton Hg}
\]

The plant releases between 0.075 and 0.3 ton Hg a year.
17. An energy consumption of 650,000 kcal per person per day is equivalent to an annual personal consumption of 65 barrels of oil or 16 tons of coal. Use this information to calculate the amount of energy available in each of these quantities.

- **a.** one barrel of oil
- **b.** 1 gal of oil (42 gal per barrel)
- **c.** one ton of coal
- **d.** a lb of coal (2000 lb per ton)

**Answer:**

\[
\frac{650,000 \text{ kcal}}{1 \text{ day}} \times \frac{365 \text{ day}}{1 \text{ yr}} = 2.4 \times 10^8 \text{ kcal} \\
\frac{1 \text{ yr}}{1 \text{ yr}} \times \frac{1 \text{ yr}}{65 \text{ barrel}} = 3.7 \times 10^6 \text{ kcal/ barrel}
\]

This value can be related to each of the energy sources.

- **a.** \( \frac{2.4 \times 10^8 \text{ kcal}}{1 \text{ yr}} \times \frac{1 \text{ yr}}{65 \text{ barrel oil}} \times \frac{1 \text{ barrel oil}}{42 \text{ gal}} = 8.8 \times 10^4 \text{ kJ/gal} \)
- **b.** \( \frac{2.4 \times 10^8 \text{ kcal}}{1 \text{ yr}} \times \frac{1 \text{ yr}}{65 \text{ barrel oil}} \times \frac{1 \text{ barrel oil}}{42 \text{ gal}} = 8.8 \times 10^4 \text{ kJ/gal} \)
- **c.** \( \frac{2.4 \times 10^8 \text{ kcal}}{1 \text{ yr}} \times \frac{1 \text{ yr}}{16 \text{ ton coal}} \times \frac{1 \text{ ton coal}}{2000 \text{ pound}} = 7.5 \times 10^3 \text{ kcal/pound of coal} \)
- **d.** \( \frac{2.4 \times 10^8 \text{ kcal}}{1 \text{ yr}} \times \frac{1 \text{ yr}}{16 \text{ ton coal}} \times \frac{1 \text{ ton coal}}{2000 \text{ pound}} = 7.5 \times 10^3 \text{ kcal/pound of coal} \)

18. Use the information in question 17 to find the ratio of the quantity of energy available in 1 lb of coal to that in 1 lb of oil. *Hint: One pound of oil has a volume of 0.56 qt.*

**Answer:**

\[
\frac{8.8 \times 10^4 \text{ kcal}}{1 \text{ gallon oil}} \times \frac{1 \text{ gallon}}{4 \text{ quarts}} \times \frac{0.56 \text{ quarts}}{1 \text{ pound oil}} = 1.2 \times 10^4 \text{ kcal/pound oil}
\]

\[
\frac{8.8 \times 10^4 \text{ kcal}}{1 \text{ gallon oil}} \times \frac{1 \text{ gallon}}{4 \text{ quarts}} \times \frac{0.56 \text{ quarts}}{1 \text{ pound oil}} = 1.2 \times 10^4 \text{ kcal/pound oil}
\]

\[
\frac{1.2 \times 10^4 \text{ kcal}}{1 \text{ pound coal}} \times \frac{1 \text{ pound coal}}{7.5 \times 10^3 \text{ kcal}} = 1.6
\]

There is 1.6 times as much energy in a pound of coal as there is in a pound of oil.

19. Consider the data for three hydrocarbons shown in the table.

<table>
<thead>
<tr>
<th>Compound, formula</th>
<th>Melting Point (°C)</th>
<th>Boiling Point (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pentane, C₅H₁₂</td>
<td>-130</td>
<td>36</td>
</tr>
<tr>
<td>Triacontane, C₃₀H₆₂</td>
<td>66</td>
<td>450</td>
</tr>
<tr>
<td>Octane, C₈H₁₈</td>
<td>-57</td>
<td>125</td>
</tr>
</tbody>
</table>

Predict the physical state (solid, liquid, or gas) of each hydrocarbon at a temperature of 25 °C.
Pentane should be a liquid at room temperature because room temperature is below its boiling point but above its melting point. Triacontane should be solid at room temperature because room temperature is below its melting point. Octane should be a liquid at room temperature for the same reason as pentane.

20. Table 4.5 shows the structural formulas of alkanes containing one to eight carbons.
   a. Draw the structural formula for decane, C\(_{10}\)H\(_{22}\).
   b. Use Table 4.5 to predict the structural formulas for nonane, the alkane with 9 carbons, and dodecane, the alkane with 12 carbons.
   c. The structural formulas in Table 4.5 are two-dimensional. Use the bond angle information in Chapter 3 to predict the C-to-C-to-C and H-to-C-to-H bond angles in decane.

   Answer:
   a. Decane:
   
   \[
   \begin{align*}
   &\text{H} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{H} \\
   &\text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \\
   &\text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \\
   &\text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \\
   
   \end{align*}
   \]

   b. nonane:
   
   \[
   \begin{align*}
   &\text{H} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{H} \\
   &\text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \\
   &\text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \\
   &\text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \\
   &\text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \\
   
   \end{align*}
   \]

   dodecane:
   
   \[
   \begin{align*}
   &\text{H} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{H} \\
   &\text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \\
   &\text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \\
   &\text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \\
   &\text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \\
   
   \end{align*}
   \]

c. All the carbon atoms in saturated hydrogens are forming single bonds only. Thus the geometry around the carbon is tetrahedral and the bond angles are approximately 109.5°.

21. Consider this equation representing the process of cracking.

   $$C_{16}H_{34} \rightarrow C_5H_{12} + C_{11}H_{22}$$

   a. Which bonds are broken and which bonds are formed in this reaction? Use Lewis structures to help answer this question.
   b. Use the information from part a and Table 4.2 to calculate the energy change during this cracking reaction.

   Answer:
   a. $C_{16}H_{34} \rightarrow C_5H_{12} + C_{11}H_{22}$
b. Bonds broken in the reactants:

- 1 mol C-to-C single bonds = 1(356 kJ) = 356 kJ
- 1 mol C-to-H single bonds = 1(416 kJ) = 416 kJ

Total energy absorbed in breaking bonds = 772 kJ

Bonds formed in the products:

- 1 mol C-to-H single bonds = 1(416 kJ) = 416 kJ
- 1 mol C-to-C double bonds = 1(598 kJ) = 598 kJ

Total energy released in forming bonds = 1014 kJ

Net energy change is (+772 kJ) + (–1014 kJ) = –242 kJ

The overall energy change has a negative sign, characteristic of an exothermic reaction.

22. This is the ball-and-stick representation of one isomer of butane (C₄H₁₀).

a. Draw the Lewis structure for this isomer. Hint: Show how atoms are linked, but not their spatial arrangement.

b. Draw the Lewis structure for each additional isomer, being careful not to repeat isomers.

c. What is the total number of isomers of C₄H₁₀?

Answer:

a. 

b. 

c. There are only the two shown in a and b.

23. A premium gasoline available at most stations has an octane rating of 92. What does that tell you about:

a. the knocking characteristics of this gasoline?

b. whether the fuel contains oxygenates?
Answer:

**a.** Gasoline with an octane rating of 92 has the same knocking characteristics as a mixture composed of 92% isoctane and 8% heptane. In essence, this is a blend that is resistant to knocking.

**b.** The octane rating does not give you any additional information about whether or not the fuel contains oxygenates. Other labels around the pump should reveal this information.

**Concentrating on Concepts**

24. How might you explain the difference between temperature and heat to a friend? Use some practical, everyday examples.

**Answer:**

Wouldn’t you rather spill a drop of hot coffee on you than the whole cupful at the same temperature? Although the drop and the cup full of coffee may initially have the same temperature, you will receive a bigger burn from the bigger volume of coffee because it has the higher heat content. Heat is a form of energy. In contrast, temperature is a measurement that indicates the direction heat will flow. Heat always flows from an object at high temperature to an object at lower temperature. This means that if hot coffee is added to cold coffee, heat will flow from the hot liquid to the cold liquid, and the final temperature of the mixture will be between the original temperatures of the two individual solutions. Heat depends on the temperature and on how much material is present.

25. Write a response to this statement: “Because of the first law of thermodynamics, there can never be an energy crisis.”

**Answer:**

The first law of thermodynamics states that energy is neither created nor destroyed; it only changes form. Energy can be transformed, but the total energy in the world is constant. However, this statement does not take into effect our ability to capture and use energy in all of its forms. The energy of fossil fuels is stored in the form of chemical bonds. When we burn fossil fuels, we release some of the energy stored. Wind and solar power derive their energy from the Sun. An energy crisis arises when demand exceeds supply. Unless we are better able to capture energy from sources other than fossil fuels, we will indeed have an energy crisis – not due to a shortage of absolute energy but a shortage in our ability to use the energy available.

26. Candle wax, a hydrocarbon, is composed of straight-chain hydrocarbons with about 50 carbon atoms.

**a.** Make a general statement describing how the number of carbon atoms affects the physical state of normal hydrocarbons.

**b.** Write a chemical formula for the alkane having 50 carbon atoms.

**Answer:**

**a.** The physical state of straight-chain hydrocarbons depends on the molar mass (which in
turn depends on the number of carbon atoms). Hydrocarbons with lower molar masses (such as methane and ethane) are gases. Pentane is a liquid, and higher molar mass hydrocarbons such as candle wax are solids.

**b.** \(\text{C}_{50}\text{H}_{102}\)

27. A friend tells you that hydrocarbons containing larger molecules are better fuels than those containing smaller ones.

**a.** Use these data, together with appropriate calculations, to discuss the merits of this statement.

<table>
<thead>
<tr>
<th>Hydrocarbon</th>
<th>Heat of Combustion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Octane, (\text{C}<em>8\text{H}</em>{18})</td>
<td>5450 kJ/mol</td>
</tr>
<tr>
<td>Butane, (\text{C}<em>4\text{H}</em>{10})</td>
<td>2859 kJ/mol</td>
</tr>
</tbody>
</table>

**b.** Considering your answer to part a, do you expect the heat of combustion per gram of candle wax, \(\text{C}_{25}\text{H}_{52}\), to be more or less than the heat of combustion per gram of octane? Do you expect the molar heat of combustion of candle wax to be more or less than the molar heat of combustion of octane? Justify your predictions.

**Answer:**

**a.** Looking only at the molar heats of combustion, octane, with more atoms and more chemical bonds, has a greater heat of combustion than butane. However, comparisons should be based on a common base of measurement, such as the heat per gram of substance. Using the molar masses of each hydrocarbon, these are the calculated heats.

\[
\frac{5450 \text{ kJ}}{1 \text{ mol C}_8\text{H}_{18}} \times \frac{1 \text{ mol C}_8\text{H}_{18}}{114.2 \text{ g C}_8\text{H}_{18}} = \frac{47.7 \text{ kJ}}{\text{g C}_8\text{H}_{18}}, \text{ the heat released per gram octane burned.}
\]

\[
\frac{2859 \text{ kJ}}{1 \text{ mol C}_4\text{H}_{10}} \times \frac{1 \text{ mol C}_4\text{H}_{10}}{58.1 \text{ g C}_4\text{H}_{10}} = \frac{49.2 \text{ kJ}}{\text{g C}_4\text{H}_{10}}, \text{ the heat released per gram butane burned.}
\]

Here the values are much closer and with just two data points, it is not possible to establish a trend. Notice, however, that the smaller hydrocarbon gives slightly more heat per gram than the larger one. Because heat comparisons should be made based on a common unit, you will have to educate your friend on this point.

**b.** Candle wax is composed of high molar mass hydrocarbons. Looking at the values from part a, the heat of combustion per gram is expected to be slightly smaller and the heat of combustion per mole is expected to be larger.

28. Halons are synthetic chemicals similar to CFCs, but they also include bromine. Although halons are excellent materials for fire fighting, they more effectively deplete ozone than CFCs. Here is the Lewis structure for halon-1211.
a. Which bond in this compound is broken most easily? How is that related to the ability of this compound to interact with ozone?

b. C₂HClF₄ is a compound being considered as a replacement for halons as a fire extinguisher. Draw the Lewis structure for this compound and identify the bond broken most easily. How is the structure related to the ability of this compound to interact with ozone?

**Answer:**

a. The C-to-F single bond requires 485 kJ/mol, the C-to-Cl single bond requires 327 kJ/mol, and the C-to-Br single bond requires 285 kJ/mol to break the bond. The C-to-Br bond is the weakest. Thus bromine atoms would be likely to form and react with ozone, much like chlorine does.

b. 

The C-to-Cl bond is broken most easily in this structure, and chlorine free radicals can be released. Such free radicals can catalyze the destruction of ozone.

29. The Fischer–Tropsch conversion of hydrogen and carbon monoxide into hydrocarbons and water was given in Equation 4.12:

\[ n \text{ CO} + (2n + 1) \text{ H}_2 \rightarrow \text{C}_n\text{H}_{2n+2} + n \text{ H}_2\text{O} \]

a. Determine the heat evolved by this reaction when \( n = 1 \).

b. Without doing a calculation, do you think that more or less energy will be given off in the formation of larger hydrocarbons (\( n > 1 \))? Explain your reasoning.

**Answer:**

a. When \( n = 1 \), the balanced equation is

\[ \text{CO} + 3 \text{H}_2 \rightarrow \text{CH}_4 + \text{H}_2\text{O} \]

To calculate the heat evolved we use the same method as in Problem 4.13.

Bonds broken in the reactants:

- 1 mol C-to-O triple bonds = 1(1073 kJ) = 1073 kJ
- 3 mol H-to-H single bonds = 3(436 kJ) = 1308 kJ

Total energy absorbed in breaking bonds = 2381 kJ

Bonds formed in the products:

- 4 mol C-to-H single bonds = 4(416 kJ) = 1664 kJ
- 2 mol O-to-H single bonds = 2(467 kJ) = 934 kJ

Total energy released in forming bonds = 2598 kJ

Net energy change is (+2381 kJ) + (−2598 kJ) = −217 kJ
b. Reactions with \( n \) greater than 1 will release more energy as \( n \) becomes larger, assuming that we are viewing the energy per mole of the hydrocarbon formed (not per gram). There will always be \( n \) C-to-O triple bonds to break and \((2n + 1)\) H-to-H single bonds to break. The number of C-to-H bonds forming will be \((2n + 2)\), and the number of O-to-H bonds forming is \(2n\). As \( n \) becomes larger, more and more energy will be released.

30. During the distillation of petroleum, kerosene and hydrocarbons with 12–18 carbons used for diesel fuel will condense at position C marked on this diagram.

![Distillation Diagram](image)

a. Separating hydrocarbons by distillation depends on differences in a specific physical property. Which one?
b. How will the number of carbon atoms in the hydrocarbon molecules separated at A, B, and D compare with those separated at position C? Explain your prediction.
c. How will the uses of the hydrocarbons separated at A, B, and D differ from those separated at position C? Explain your reasoning.

**Answer:**
a. Hydrocarbons separate due to differences in their boiling points.
b. Hydrocarbons separated at positions A and B have lower boiling points and are more volatile than the hydrocarbons separated at position C. The hydrocarbons separated at positions A and B have fewer carbons in their structures than those separated at position C. The hydrocarbons at position D will be less volatile or not volatile at all, compared to those at position C. The hydrocarbons separated at position D have more carbon atoms than the hydrocarbons separated at C.
c. The hydrocarbons separated at A will be gases, and can be used as fuels and starting materials for manufacturing. Those separated at B will be liquids, and can be used as motor fuels and as industrial solvents. Position D contains residue material that is rich in many complex compounds as well as many hydrocarbons. In addition to waxes and asphalt, these tars can be further separated into other useful compounds. The hydrocarbons separated at C are used as kerosene or diesel fuel or may be cracked.

31. Imagine you are at the molecular level, looking at what happens when liquid ethylene, \( \text{C}_2\text{H}_4 \), boils. Consider a collection of four ethylene molecules.

\[
\text{C}_2\text{H}_4 = \text{Structure Image}
\]

a. Draw a representation of ethylene in the liquid state and then in the gaseous state. How will the two differ?
b. Estimate the temperature at which the transition from liquid to gas is taking place. What is the basis for your estimation?

**Answer:**
a. The molecules in the liquid state should appear closer together than the molecules in the gas state. The molecules themselves remain intact, as no chemical bonds are broken in changing from ethylene\(l\) to ethylene\(g\).
b. Ethylene is a small hydrocarbon and is likely to have a boiling point similar to other small hydrocarbons. For example, if you knew the boiling points of methane, ethane, and propene, most likely the boiling point would be in this same range. The actual boiling point is \(-103.7\) °C.

32. Explain why cracking is necessary in the refinement of crude oil.

**Answer:**
Cracking is necessary because the demand for the mid-range hydrocarbons found in gasoline exceeds the amount produced by the distillation of crude oil.

33. Catalysts speed up cracking reactions in oil refining and allow them to be carried out at lower temperatures. What other examples of catalysts were given in the first three chapters of this text?

**Answer:**
Section 1.11 described the catalytic converters in automobiles. Section 2.9 described the catalytic destruction of ozone by chlorine free radicals.

34. Octane ratings of several substances are listed in Table 4.6.
a. What evidence can you give that the octane rating is or is not a measure of the energy content of a gasoline?
b. Octane ratings are measures of a fuel’s ability to minimize or prevent engine knocking. Why is the prevention of knocking important?
c. Why are higher octane rating gasolines more expensive than lower ones?

**Answer:**
a. Chapter 4 notes that both octane and isooctane have nearly identical heats of combustion, so the octane rating is not a measure of the energy content of a gasoline.
c. The industrial process (requiring catalysts) is more costly to produce higher octane gasolines.

35. The octane rating describes a fuel’s resistance to preignition. Considering Figure 4.19, how do the activation energies for combustion of \(n\)-octane and isooctane compare? Explain.

**Answer:**
The heats of combustion for \(n\)-octane and isooctane are nearly identical, but the more
compact shape of the isooctane molecule allows it to burn more smoothly in the engine. The activation energy of isooctane is greater (100) than that for \( n \)-octane (−10).

36. The combustion of ethanol produces about 40% less energy per gram than normal hydrocarbon fuels. In 2006, the Indy car racing circuit will begin to use engines that have been modified to run on pure ethanol, replacing the current engines that run on methanol, \( \text{CH}_3\text{OH} \). Why do you think these high-performance vehicles are switching to ethanol?

Answer:

The decision to switch to 100% ethanol was an agreement between Team Ethanol, the IndyCar Series, Rahal Letterman Racing (RLR), and the Ethanol Promotion and Information Council (EPIC). The partners in the agreement report that their primary motivation was to support a fuel derived from biomass, which can be produced domestically.

37. One risk of depending on foreign oil is periodic gasoline shortages due to unfavorable international events. Does a gasoline shortage affect only individual motorists? Name some ways that a gasoline shortage could affect your life.

Answer:

A gasoline shortage would affect far more than just individual motorists. For example, gasoline is needed for the production and transportation of food and many other goods to consumers, and for the removal of garbage and other waste.

38. These three structures have the chemical formula \( \text{C}_8\text{H}_{18} \). The hydrogen atoms and C-to-H bonds have been omitted for simplicity.

\[
\text{C} \quad \text{C} \quad \text{C} \\
\text{C} \quad \text{C} \quad \text{C} \\
\text{C} \quad \text{C} \quad \text{C} \\
\text{C} \quad \text{C} \quad \text{C} \\
\text{C} \quad \text{C} \quad \text{C} \\
\]

structure 1  structure 2  structure 3

a. Fill in the missing hydrogen atoms and C-to-H bonds and confirm that these structures all represent \( \text{C}_8\text{H}_{18} \).
b. Are any of these representations identical isomers? If so, which ones?
c. Obtain a model kit and construct one of the structures. What are the C-to-C-to-C bond angles?
d. If you were to build a different one, would the C-to-C-to-C bond angles change? Explain?
e. Draw the structural formula of two more isomers of \( \text{C}_8\text{H}_{18} \).
Answer:

a. Each structure has the formula C₈H₁₈.
b. Yes; structures 2 and 3 have exactly the same order of linkage.
c. Each C-to-C-to-C bond angle is 109.5°, because the geometry of the bonds around each carbon atom is tetrahedral.
d. No, the bond angle will not change. In every isomer of C₈H₁₈, each carbon atom has four bonds and therefore the geometry is tetrahedral.
e. Several other isomers are possible. Be sure the linkage is different from the given isomers.

39. A ball-and-stick model of ethanol, C₂H₆O, is shown here. Dimethyl ether also has the formula C₂H₆O. Rearrange the atoms in ethanol to draw the Lewis structure of dimethyl ether. Hint: Remember to complete the octet for the carbon and oxygen atoms.

Answer:

The Lewis structure for dimethyl ether is:

```
H:C:O:C:H
H     H
```

40. How is the growth in oxygenated gasolines related to:

a. restrictions on the use of lead in gasoline?

b. federal and state air quality regulations?

Answer:

a. Eliminating the use of tetraethyl lead as an octane booster in part led to the rise of oxygenates as octane boosters.
b. Cities in the U.S. that do not meet federal air quality standards are required by the Clean Air Act of 1990 to use oxygenated fuels. Check the EPA website (for example, [http://www.epa.gov/mtbe/gas.htm](http://www.epa.gov/mtbe/gas.htm)) for more information.

41. Do oxygenated fuels have a higher energy content than nonoxygenated fuels? Use the bond energies in Table 4.2 to calculate the heat of combustion of MTBE.

Answer:

Typically oxygenated fuels have a lower energy content than hydrocarbons. To determine the heat of combustion of MTBE, we first need the balanced combustion reaction.

\[
C_5H_{12}O(l) + \frac{15}{2} O_2(g) \rightarrow 5 CO_2(g) + 6 H_2O(g)
\]

We determine the heat of combustion in the usual way.

Bonds broken in the reactants:

- 3 mol C-to-C single bonds = 3(356 kJ) = 1068 kJ
12 mol C-to-H single bonds = 12(416 kJ) = 4992 kJ
2 mol C-to-O single bonds = 2(336 kJ) = 672 kJ
$\frac{15}{2}$ mol O-to-O double bonds = $(\frac{15}{2})(498$ kJ) = 3735 kJ
Total energy absorbed in breaking bonds = 10,467 kJ

Bonds formed in the products:
10 mol C-to-O double bonds = 10(803 kJ) = 8030 kJ
12 mol O-to-H single bonds = 12(467 kJ) = 5604 kJ
Total energy released in forming bonds = 13,634 kJ

Net energy change is (+10,467 kJ) + (−13,634 kJ) = −3167 kJ

42. Your neighbor is shopping for a new family vehicle. The salesperson identified a van to be of interest as a flexible fuel vehicle (FFV).
   a. Explain what is meant by FFV to your neighbor.
   b. What does it mean for the van to be able to use E85 fuel?
   c. Would your neighbor and his family be particularly interested in using E85 fuel depending on what region of the country they live?

Answer:
   a. Vehicles designed to operate on E85 are called Flexible Fuel Vehicles (FFVs) and can function on conventional gasoline, ethanol, or a combination of the two within the same tank.
   b. E85 is a blend of 85 percent ethanol and 15 percent gasoline.
   c. The neighbor might be more interested in using E85 if she was from a corn producing state or from California where oxygenated fuels are in regular use.

43. Find information about the availability of biodiesel fuel distributors in the United States.
   a. Why are a majority of the distributors located where they are?
   b. According the National Biodiesel Board, their distributors will ship the fuel anywhere in the country, particularly to operators of fleets of trucks or cars. Would trucking companies in Florida and Oklahoma both be equally interested? List factors that would be important in such a decision.

Answer:
   a. Biodiesel fuel distributors are located primarily in the Midwest agricultural areas.
While Oklahoma does not have many distributors, it is still fairly close to a large number of distributors. Trucks might be able to refuel while on the road and delivery to Oklahoma might be inexpensive. Florida is a great distance from the Midwest, so delivery costs would be higher.

44. China’s large population has increased energy consumption as the standard of living increases.
   a. Report on China’s increasing number of automobiles over the last 10 years.
   b. What evidence suggests that the increase in the number of vehicles has affected air quality? What interventions, if any, does the Chinese government have underway?

Answer:
   a. China's auto production had been growing by 15 per cent a year on average in the last decade. According to Beijing Traffic Administration, the number of registered motor vehicles in Beijing has doubled in a mere seven years, between 1997 and 2003. In 1950, the city had 1,757 vehicles, and reached 1 million in 1997. Asia Times reports that Beijing’s car population was growing at a rate of 1,000 cars per day through 2005. The number of cars in the city in August, 2007 stood at more than three million.
   b. Automobiles are creating pollution because of poor road infrastructure, old vehicle technology, and emission standards similar to those in the U.S. in the early 1970s. Health effects and poor crop yields are being attributed to the pollution created by this drastic increase in automobile use. The Chinese government has already begun taking steps to try to reduce the pollution by attempting to reduce emissions in the automotive population. They are doing this with aid from foreign manufacturers. General Motors is aiding the Chinese government in developing proper vehicle emission standards. The government is also pursuing the electric car market with assistance from Peugeot. They are hoping to produce 5,000 electric cars per year. The city of Beijing in particular is planning to reduce air pollution during the 2008 Olympic Games by restricting the number of private vehicles on the roads.
Exploring the Extensions

45. The concept of entropy and disorder is used in games like poker. Describe how the rank of hands (from a simple high card to a royal flush) is related to entropy.

Answer:
A royal flush is an ace, king, queen, jack, and ten of the same suit. It is a highly improbable hand in poker. It exhibits a higher level of order and is more highly valued than a simple high card (a lower level of order). The most ordered state is the winning hand!

46. Another claim in the Scientific American article by Lovins referenced in Section 4.11 was that replacing an incandescent bulb (75 W) with a compact fluorescent bulb (18 W) would save about 75% in the cost of electricity. Electricity is generally priced per kilowatt-hour (kwh). Using the price of electricity where you live, calculate how much money you would save over the life of one compact fluorescent bulb (about 10,000 hr).

Answer:
Answers will vary depending on the current cost of electricity. However, the “75% less energy” claim can be easily validated.

Over the lifetime of a compact fluorescent, 180 kWh of electricity are used.
10,000 hours x 0.018 kW = 180 kWh

Over the same amount of time, a standard light bulb will use 750 kWh of electricity.
10,000 hours x 0.075 kW = 750 kWh

Over 10,000 hours, the compact fluorescent uses 24% of the electricity of a standard bulb.
180/750 = 24%

47. Section 4.9 states that RFGs burn more cleanly by producing less carbon monoxide than nonoxygenated fuels. What evidence supports this statement?

Answer:
RFGs are oxygenates. This means that these fuels contain oxygen in addition to carbon and hydrogen. With more oxygen present in the fuel itself, it is more likely that the fuel will burn completely to produce carbon dioxide. Carbon monoxide production should be minimized.

48. Another type of catalyst used in the combustion of fossil fuels is the catalytic converter that was discussed in Chapter 1. One of the reactions that these catalysts speed up is the conversion of NO(g) to N₂(g) and O₂(g).

a. Draw a diagram of the energy of this reaction similar to the one shown in Figure 4.19.

b. Why is this such an important reaction? Hint: See Sections 1.9 and 1.11.

Answer:
a. The sketch shows that the catalyzed pathway requires less activation energy than the uncatalyzed pathway.
b. In Chapter 1, catalysts were discussed in connection with reducing NO from automobile exhaust. Nitrogen oxide can react with oxygen to form NO₂, a criteria pollutant. NO is also involved in forming ozone in the troposphere and contributes to acid rain. To reduce pollution, it is important to reduce NO emissions.

49. Chemical explosions are very exothermic reactions. Describe the relative bond strengths in the reactants and products that would make for a good explosion.

**Answer:**

Consider a natural gas (methane) explosion:

\[ \text{CH}_4 + 2 \text{O}_2 \rightarrow \text{CO}_2 + 2 \text{H}_2\text{O} \]

The bond energies involved are:
- C-to-H single bond, 416 kJ/mole
- O-to-O double bond, 498 kJ/mole
- H-to-O single bond in water, 467 kJ/mole
- C-to-O double bond, 803 kJ/mole

The bond energies of the products are larger than those of the reactants. This will lead to a negative net energy change indicating a large exothermic reaction.

50. Bond energies such as those in Table 4.2 are sometimes found by “working backward” from heats of reaction. A reaction is carried out, and the heat absorbed or evolved is measured. From this value and known bond energies, other bond energies can be calculated. For example, the energy change associated with the combustion of formaldehyde (H₂CO) is \(-465\) kJ.

\[ \text{H}_2\text{CO}(g) + \text{O}_2(g) \rightarrow \text{CO}_2(g) + \text{H}_2\text{O}(g) \]

Use this information and the values found in Table 4.2 to calculate the energy of the C-to-O double bond in formaldehyde. Compare your answer with the C-to-O bond energy in CO₂.
and speculate on why there is a difference.

Answer:

\[ \text{H}_2\text{CO}(g) + \text{O}_2(g) \rightarrow \text{CO}_2(g) + \text{H}_2\text{O}(g) \]

Let \( x \) represent the C-to-O bond energy in CO\(_2\).

Bonds broken in the reactants:

\[
\begin{align*}
2 \text{ mol C-to-H single bonds} &= 2(416 \text{ kJ}) = 823 \text{ kJ} \\
1 \text{ mol C-to-O double bonds} &= 1(x \text{ kJ}) = x \text{ kJ}
\end{align*}
\]

Total energy absorbed by breaking bonds = \((823 + x) \text{ kJ}\)

Bonds formed in the products:

\[
\begin{align*}
2 \text{ mol O-to-H single bonds} &= 2(467 \text{ kJ}) = 934 \text{ kJ} \\
1 \text{ mol C-to-O double bonds} &= 1(803 \text{ kJ}) = 803 \text{ kJ}
\end{align*}
\]

Net energy change: \((+823 + x \text{ kJ}) - (1737 \text{ kJ}) = -465 \text{ kJ}\)

Rearranging the equation:

\[
x \text{ kJ} = -465 + 1737 - 823 \text{ kJ}
\]

\[x = 449 \text{ kJ}\]

This value is 354 kJ less than the bond energy for C-to-O double bonds in carbon dioxide reported in Table 4.2. The C-to-O double bonds in carbon dioxide are much stronger than the C-to-O double bond in formaldehyde.

51. You may have seen some General Motors advertisements using the slogan “Live Green by Going Yellow” for their FlexFuel vehicles that can use E85 gasoline. To what do the colors in this slogan refer?

Answer:

Living “green” refers to living in an environmentally conscious way. GM is encouraging people to use E85 gasoline to reduce consumption of fossil fuels. The ethanol used in E-85 gasoline in the U.S. is derived from corn, which is yellow.

52. Explain why a distillation tower can separate a mixture of hydrocarbons into different fractions, but it is not possible to separate seawater, also a complex mixture, into all of its different fractions in the same manner.

Answer:

Hydrocarbons are separated into fractions based on their boiling points. Seawater contains mainly dissolved salts and water. Only two fractions could normally be separated - the water, and all the nonvolatile salts mixed together. The water can be distilled from seawater at a temperature of 100 °C, but the salts mixed together are left behind. They are not volatile at the temperatures in a distillation column.

53. Section 4.8 states that both \(n\)-octane and isooctane have essentially the same heat of combustion. How is that possible if they have different structures? Explain.
Answer:

The same number and type of bonds will be broken and formed when either isomer undergoes combustion. Therefore, there is essentially the same amount of heat released for this exothermic reaction.

54. Why do you think that countries are willing to go to war over energy issues, but not over other environmental issues? Write a brief op-ed piece for your school newspaper discussing this issue.

Answer:

One point is that fuel is perceived as more essential to the economic well-being of a country and its citizens than are most environmental issues. Note: Nations also have gone to war over water rights.

55. Since the inception of reformulated gasoline requirements, MTBE has been preferred over ethanol by oil companies. One reason for this is the infrastructure requirements. MTBE can be blended with gasoline at the refinery, whereas ethanol must be shipped separately and mixed with the fuel at the filling station. Why the difference? Hint: A detailed look at solubility will be given in the next chapter.

Answer:

Here are the Lewis structures for ethanol and MTBE. Both contain oxygen, a highly electronegative atom. The O-H bond is polar; the C-O bond also is polar, but less so. Ethanol is soluble both in water (a polar solvent) and in gasoline (a nonpolar solvent). MTBE also dissolves in both water and gasoline, but is more soluble in gasoline. Because of the difference in solubility in gasoline, the more soluble MTBE can be blended at the refinery with no danger of its separating out en route. In contrast, ethanol needs to be blended right where it is pumped into your automobile.

56. What relative advantages and disadvantages are associated with using coal and with using oil as energy sources? Which do you see as the better fuel for the 21st century? Give reasons for your choice.

Answer:

Coal is more widely available across the globe, though mining coal is dangerous work and strip mining is harmful to the land. Coal can contain mercury and other heavy metals which are released when the coal is burned. Traces of sulfur in coal produce SO\textsubscript{x} upon combustion.

Oil is easily converted to gasoline and usually is cleaner burning than coal. Oil is found in more limited regions of the world, though it is convenient to transport via oil tankers and pipelines. Oil can be harmful to the environment if spilled from oil tankers or off shore drilling platforms.
57. What are the advantages and disadvantages of replacing gasoline with renewable fuels such as ethanol? Indicate your personal position on the issue and state your reasoning.

Answer:
Ethanol derived from plant matter is a renewable energy source which does not deplete fossil fuel reserves. Ethanol burns more cleanly than gasoline. However, widespread use of ethanol as automobile fuel could divert millions of acres of cropland from producing food to producing fuel. Cars using ethanol are less fuel efficient than when using gasoline, and ethanol use may cause engine problems in some vehicles. Personal positions may depend heavily on location and the current prices of gasoline and ethanol-based fuels.

58. According to the EPA, driving a car is “a typical citizen’s most ‘polluting’ daily activity."
   a. Do you agree? Why or why not?
   b. What pollutants do cars emit?
   Hint: Information on automobile emissions provided by the EPA (together with the information in this text) can help you fully answer this question.
   c. RFGs play a role in reducing emissions. Where in the country are RFGs required? Check the current list published on the Web by the EPA.
   d. Explain which emissions RFGs are supposed to lower.

Answer:
   a. Students who agree may cite the small number of people who use public transportation or the low fuel efficiencies of most vehicles. Students who disagree may point out that many people, especially those who live in metropolitan areas, use public transit and may not even own a car.
   b. Cars emit CO₂, CO, particulate matter, and NO via their exhaust pipes.
   c. Information on RFGs can be found at the EPA website. For example, try: http://www.epa.gov/otaq/gasoline.htm.
   d. RFGs contain oxygenates that are intended to reduce CO emissions.

59. It was stated in Section 4.11 that the Three Gorges Dam in China is a controversial project. Use the resources of the Web to investigate some of the major issues concerning this dam.

Answer:
This major project has both drawbacks and benefits. The benefits include hydroelectric power and flood control on the Chang Jiang (Yangzi) River. The drawbacks include the loss of the fertile land and the 1 million plus people who had to be relocated.

Environmental issues also are being debated. Some people predict that industrial waste will accumulate in the reservoir formed behind the dam. Others say that the hydroelectric power will take the place of millions of tons of coal that would have been mined otherwise, thereby
saving the country from the environmental damage caused by mining. Archaeologists are concerned about the loss of ancient sites.

60. C. P. Snow, a noted scientist and author, wrote an influential book called *The Two Cultures*, in which he stated: “The question, ‘Do you know the second law of thermodynamics?’ is the cultural equivalent of ‘Have you read a work of Shakespeare’s?’” How do you react to this comparison? Discuss these questions in light of your own educational experiences.

**Answer:**

At least one of the authors of this text does not like this comparison. She feels that neither of these questions necessarily means anything in and of itself. A person might be able to recite the second law of thermodynamics. Similarly, a person might have read a play by William Shakespeare. A more meaningful comparison across *The Two Cultures* could require a higher level of engagement. For example, consider wanting to communicate something about an important societal topic – say global climate change in some part of the planet. One way to do this might be to draft an environmental statement. Another could be to create some form of art to convey the complexities of the climate.