Chemistry 1500: Chemistry in Modern Living

Topic 4: Energy, Chemistry, and Society

Thermodynamics, Kinetics, and Fossil Fuels

Chemistry in Context, 2nd Edition: Chapter 4, Pages 113-148
Chemistry in Context, 3rd Edition: Chapter 4, Pages 137-182
Chemistry in Context, 4th Edition: Chapter 4, Pages 149-195
Chemistry in Context, 5th Edition: Chapter 4, Pages 170-217

The Figure, Table, & Problem numbers in these notes are taken from the 4th edition of the text unless otherwise noted.


➤ Graphics from Text: Figure 4.0, Freeway

Motor vehicles in the U.S. use prodigious amounts of energy daily from burning gasoline.
### Outline

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| 4B | ENERGY CONSUMPTION PATTERNS | 5 |
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4A  Heat, Temperature, and Energy

- **Heat**: at a chemical level can be thought of as atomic and molecular motion
- **Temperature**: a measure of the degree of heat in a substance, a scale
- **Energy**: the capacity to do work

- **Units of energy**
  - A calorie, cal, is the amount of energy required to raise one gram of water 1 °C
  - A calorie also equals 4.184 joules (J, metric)
  - A kJ is a kilojoule (1,000 joules)
  - A Calorie (in food) is really 1,000 calories = 1 kcal

- Graphics from Text: Figure 4.1, Calorie Labels
Heat Capacity: a measure of the amount of heat energy that a substance can hold

Discuss:

- Fire walking
- Oven burns

First Law of Thermodynamics

- Also called the law of conservation of energy
- Energy can neither be created nor destroyed
4B  Energy Consumption Patterns

- Graphics from Text: Figure 4.2, Annual per capita energy consumption levels of selected countries

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- Ask Students: Explain the origins of the observed differences in total energy consumption between different countries.

- Group Activity

- Ask Students: Using these same factors, predict how the energy consumption in the valley has changed in the last 30 years.

- Group Activity
Discuss the origins of the trends for:

- Wood
- Coal
- Oil
- Natural Gas
- Nuclear Fission
Graphics from Text: Figure 4.4, Sources of US vs. World Energy Consumption

(a)

(b)

(Source of data: Department of Energy/EIA.)

Ask Students: Why does the US pattern differ from other countries

Group Activity
4C  Energy: Where From and How Much?

➢ Exothermic Reactions
  ➢ Reactions that give off heat

➢ Endothermic Reactions
  ➢ Reaction that consume heat

➢ Examples

\[ \text{CH}_4 + 2 \text{O}_2 \rightarrow \text{CO}_2 + 2 \text{H}_2\text{O} + \text{Energy} \quad \text{(Exothermic)} \]

\[ \text{CO}_2 + 2 \text{H}_2\text{O} + \text{Energy} \rightarrow \text{CH}_4 + 2 \text{O}_2 \quad \text{(Endothermic)} \]

➢ Example Calculation

➢ Methane Oxidation produces approximately 800 kJ/mole

➢ If one has 1 g of Methane, how much total heat will be produced

\[
800 \text{ kJ/mole} \times 1 \text{ g} / 16 \text{ g/mole} = 50 \text{ kJ/g}
\]
Graphics from Text: Figure 4.5, Bomb Calorimeter

Graphics from Text: Figure 4.6, Energy Differences in an Exothermic Reaction
➢ Where does this energy come from / go to?

➢ Changes in Bond Energy

➢ If the total of all the bond strengths in the products are stronger than the bonds in the starting material than the reaction will “want” to proceed and energy will be given off

➢ If the total of all the bond strengths in the products are weaker than the bonds in the starting material than the reaction will not “want” to proceed and energy will be consumed
Graphics from Text: Table 4.1, Table of Bond Energies

Table 4.1

<table>
<thead>
<tr>
<th></th>
<th>H</th>
<th>C</th>
<th>N</th>
<th>O</th>
<th>S</th>
<th>F</th>
<th>Cl</th>
<th>Br</th>
<th>I</th>
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<tbody>
<tr>
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<td></td>
<td></td>
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<tr>
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<td>N</td>
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<td>O</td>
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<td>336</td>
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<td>146</td>
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<td>F</td>
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<td>234</td>
<td>213</td>
<td></td>
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<td>193</td>
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<td>I</td>
<td>299</td>
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<td>201</td>
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<td>209</td>
<td>180</td>
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<td>C≡C</td>
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<tr>
<td>N≡N</td>
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</tbody>
</table>


- Practice reading the values off of the table for different bond types
- General Trends - Single Bonds are Weaker than Double Bonds which are Weaker than Triple Bonds
Graphics from Text: Figure 4.8, Combustion of \( \text{H}_2 \) by \( \text{O}_2 \) to Give Water

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

Breaking 1 mole of \( \text{O} = \text{O} \) bonds
\[= +498 \text{ kJ}\]

Breaking 2 moles of \( \text{H} - \text{H} \) bonds
\[= 2(436 \text{ kJ}) = +872 \text{ kJ}\]

Forming 4 moles of \( \text{H} - \text{O} \) bonds
\[= 4(-467 \text{ kJ}) = -1868 \text{ kJ}\]

Net energy change
\[= -498 \text{ kJ}\]

Energy (kilojoules)
Graphics from Text: Figure 4.9, The Hindenburg - Lakehurst, NJ, 1937

Graphics from Text: Figure 4.10, Methane Combustion
4D Activation Energy

- Graphics from Text: Figure 4.11, Energy - Reaction Pathway

Diagram

- Analogy with Mountain Passes and Valleys

- Energy of Activation
➢ The energy required by the reagents before the reaction can proceed

➢ A barrier that must be surmounted to go from starting materials to product

➢ Net Energy Change of Reaction

➢ The net energy given off or consumed by a reaction

➢ For a reaction to occur quickly, need the correct collision energy, collision orientation, and number of collisions
Exothermic Reaction Pathway Diagram

Thermoneutral Reaction Pathway Diagram

Endothermic Reaction Pathway Diagram
4E The Nature of a Flame (Optional Topic 4.1)

- Discussion of what a candle flame looks like
- Homework!!

- What burns: Solids, Liquids, and/or Gasses?

- Diagram: Fuel, Charred Fuel, Pyrolysis Zone, Transport Zone, Combustion Zone
  - Role of Free Radicals in combustion
  - Nature of Fuel Molecules

- How to make something fireproof
  - Slow Pyrolysis, Slow Combustion, Remove Heat
  - Fireproofing strategies
  - Halons and fire extinguishers
➢ Ask Students: What is it that actually kills people in fires?

➢ Group Activity

➢ What is Flashover?
4F  King Coal

➤ What is the structure of coal?

➤ Organic

➤ Mineral / Inorganic

➤ Scale Effects

➤ How was Coal Formed?

➤ Plants

➤ Anaerobic Decomposition

➤ Heat and Pressure
Rank of Coal

Peat
↓
Brown Coal
↓
Sub-bituminous Coal
↓
Bituminous Coal
↓
Anthracite Coal

- Due to differences in age and heating history
- Changes of elemental composition with time
- Changes in appearance
- Typical Formula: $C_{135}H_{96}O_{9}NS$, Extremely Variable
Graphics from Text: Table 4.2 from Text, Classification, Composition, and Fuel Values of various North American coals

### Table 4.2
Fuel Value of Various U.S. Coals

<table>
<thead>
<tr>
<th>Type of Coal</th>
<th>State of Origin</th>
<th>Heat Content (kJ/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anthracite</td>
<td>PA</td>
<td>30.5</td>
</tr>
<tr>
<td>Bituminous</td>
<td>MD</td>
<td>30.7</td>
</tr>
<tr>
<td>Subbituminous</td>
<td>WA</td>
<td>24.0</td>
</tr>
<tr>
<td>Lignite (brown coal)</td>
<td>ND</td>
<td>16.2</td>
</tr>
<tr>
<td>Peat</td>
<td>MS</td>
<td>13.</td>
</tr>
<tr>
<td>Wood</td>
<td>—</td>
<td>10.4–14.1</td>
</tr>
</tbody>
</table>
Sulfur content of coal

- Organic Sulfur
- Inorganic Sulfur

US regional trends in Sulfur content

- Clean Coal Desulfurization Initiative
- Combustion

Coal (S) + Oxygen $\Rightarrow$ CO$_2$ + H$_2$O + Energy + SO$_2$ / SO$_3$

Coal Mining

- Underground mining
- Open pit mining

Pollution (air, water, radiation)

Safety (100,000 deaths in US since 1900)
4G Refining Petroleum

- Water Distillation diagram
- The process of moon shining
  - Corn mash, fermentation, distillation

- Petroleum Production
  - Graphics from Text: Figure 4.12, US Petroleum Production & Imports
Graphics from Text: Figure 4.13, Regional Sources of US Petroleum Imports

(Source of data: National Energy Policy Development Group Report, figure 8.3.)

Petroleum Distillation

Graphics from Text: Figure 4.14, Oil Refinery
Graphics from Text: Figure 4.15, Diagram of a distillation tower

- Contains hydrocarbons of 1–4 carbon atoms.
- Used as fuel, starting material for plastics, gasoline additives.

- Contains hydrocarbons of 5–12 carbon atoms.
- Used as motor fuel, industrial solvents.

- Contains hydrocarbons of 12–16 carbon atoms.
- Used as fuel for lamps, stoves, tractors, diesel engines; starting material for the cracking process.

- Contains hydrocarbons of 15–18 carbon atoms.
- Used as starting material for cracking and for heating oils for industry, and for diesel fuel.

- Contains hydrocarbons of 16–20 carbon atoms.
- Used as lubricants.

- Residue material. Contains hydrocarbons of more than 20 carbon atoms that do not vaporize at 370°C. Contains paraffin, waxes, asphalt, coke.
- Can be separated further to produce other products.
Fractions Obtained from Typical Crude Oil

- Gasoline (C5 to C12), Pavement (C20 or greater), etc.
- Relationships to boiling point / volatility
- Relative values of fractions as a function of molecular weight
- “Oil Shortages” as “fraction shortages”
- Relative compositions of different oils

Graphics from Text: Figure 4.16, Fractional End Uses for 1 Barrel (42 gallons) of Crude Oil
➢ Improving the Yield, Cracking

➢ Synthetic process to break complex molecules into smaller / simpler ones that have a higher value

\[ \text{C}_{16}\text{H}_{34} \Rightarrow \text{C}_{8}\text{H}_{18} + \text{C}_{8}\text{H}_{16} + \text{etc.} \]

➢ Octane Ratings

➢ Graphics from Text: Figure 4.17, Knocking

➢ Graphics from Text: Table 4.3, Representative Octane Ratings

<table>
<thead>
<tr>
<th>Compound</th>
<th>Octane Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Octane</td>
<td>−20</td>
</tr>
<tr>
<td>Heptane</td>
<td>zero</td>
</tr>
<tr>
<td>Isooctane</td>
<td>100</td>
</tr>
<tr>
<td>Methanol</td>
<td>107</td>
</tr>
<tr>
<td>Ethanol</td>
<td>108</td>
</tr>
<tr>
<td>MTBE</td>
<td>116</td>
</tr>
</tbody>
</table>
“Synthetic Oils”

- Costs of production vs. importing oil
- Capital costs high
- Cracking, Hydrogenation, Reforming, …

Heavy Oil

- Steam / Surfactant Injection

Shale Oil in Colorado

Tar Sands in Alberta

- $10 - 15 a barrel production cost
- Environmental costs
4H Alcohol Fuels

- Fuels
  - Grains, harvest residues, garbage, etc.

- Graphics from Text: Figure 4.20, Gasohol

- Fermentation to give Ethanol
  
  \[ \text{Sugar (C}_6\text{H}_{12}\text{O}_6) + \text{Yeast} \Rightarrow 2 \text{C}_2\text{H}_5\text{OH} + 2 \text{CO}_2 \]

- Concentration

- Byproducts

- Distillation
  - Gives 95% ethanol

- Energy cost (Reverse osmosis)

- Gasohol = Gasoline + Ethanol + Blending Agent (MTBE)
4I  Electricity from Heat

➢ Graphics from Text: Figure 4.22, Diagram of any heat powered plant for electricity generation
Graphics from Text: Figure 4.23, Conversions of types of energy in power plants

Potential Energy (Chemical Bonds) ↓
Heat Energy ↓
Mechanical Energy ↓
Electrical Energy

➤ Energy lost at each stage
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