Chemistry 500: Chemistry in Modern Living

Topic 9: The World of Plastics and Polymers

Polymer/Materials Science

Chemistry in Context, 2nd Edition: Chapter 10, Pages 319-350

Chemistry in Context, 3rd Edition: Chapter 9, Pages 337-374

Outline Notes by Dr. Allen D. Hunter, YSU Department of Chemistry, ©2000.
Outline

9A CARBON ALLOTROPES ................................................................. 3
9B THE PLASTIC ECONOMY .............................................................. 4
9C POLYMERS ................................................................................ 5
9D SOME NATURAL POLYMERS .................................................... 7
9E POLYETHYLENE ......................................................................... 8
9F HIGHER ORDER POLYMER STRUCTURES .................................. 9
9G THE BIG SIX ............................................................................... 10
9H ADDITION POLYMERIZATION .................................................. 13
9I CONDENSATION POLYMERIZATION .......................................... 14
9J POLYMER BONDS VS. DISCRETE MOLECULE BONDS ............... 15
9K THE STORY OF KEVLAR ........................................................... 16
9A Carbon Allotropes

- Allotropes are different chemical forms of the same Element
- Carbon is unique, especially in its tendency to form long chains
- Graphics from Text: Figures 10.2 and 10.3 in 2\textsuperscript{nd} Edition and 9.2a, b, c in 3\textsuperscript{rd} Edition, the allotropes of Carbon

- Diamond
  - All covalent bonds

- Graphite
  - Covalent bonds within layers (i.e., arene like)
  - Van der Waals bonds between layers

- Buckminsterfullerene
  - Covalent bonds within cages (i.e., arene like)
  - 5 and 6 membered rings
  - Van der Waals bonds between cages
9B The Plastic Economy

➤ Scale of Production

➤ Graphics from Text: Figure 10.4 in 2nd Edition and 9.5 in 3rd Edition, Annual US production (in billions of pounds)

➤ Approximately 100,000,000,000 pounds of plastics are produced in year in US

➤ Regularly increasing production

➤ Uses of plastics

➤ To replace other materials

➤ Lower cost and/or better performance

➤ Ask Students: What materials to plastics replace in consumer products

➤ Group Activity
9C Polymers

- Starting Materials for plastic production
  - Fossil Fuel Starting Materials
    - Petroleum
      - Graphics from Text: Figure 10.12 in 2nd Edition and 9.15 in 3rd Edition, the uses of a barrel of oil
  - Natural Gas
  - Coal

- Biological Starting Materials
  - Plant Materials
  - Bacterial Products
  - Animal Products
Monomers

- The small molecules from which plastics are made
- Must have a very low cost per pound (typically a few tens of cents)
- Relatively low molecular weights (typically from 28 to a hundred or so)
- Constant structures in pure samples
- Constant molecular weights in pure samples

Polymers

- Large molecules composed of many similar or identical Repeating Units
- Must have quite low prices or will be replaced by other materials
- Molecular Weights from thousands to millions
- Variable structures even in pure samples
- Variable molecular weights even in pure samples
9D Some Natural Polymers

➢ The bulk of living organisms (other than water) is composed of natural polymers

➢ Ask Students: What are some of the more common natural polymers?

➢ Group Activity
9E Polyethylene

- The most common plastic
  - Over 20,000,000 tons are produced each year in US
  - Found in plastic bags, construction materials, aircraft, etc.

- Equation for synthesis

\[
\text{H}_2\text{C} = \text{CH}_2 + \text{Catalyst} \rightarrow -\text{CH}_2-\text{CH}_2-\text{CH}_2-\text{CH}_2-\text{CH}_2-
\]

Is equivalent to saying

\[
\text{H}_2\text{C} = \text{CH}_2 + \text{Catalyst} \rightarrow -[\text{CH}_2-\text{CH}_2]_n-
\]

- At high temperatures the reaction can reverse
  - Depolymerization

- Occurs because \(\pi\)-bonds are stronger than \(\sigma\)-bonds
Higher Order Polymer Structures

- **Backbone Structure**
  - The structure of the repeating units that link polymers together

- **Side Chains**
  - Occur in variable frequency depending on synthetic methods
  - Occur in variable lengths depending on synthetic methods

- **Cross Links**
  - Connect adjacent chains

- **High Density Polyethylene, HDPE**
  - Long relatively straight chains

- **Low Density Polyethylene, LDPE**
  - Highly branched Structures
9G The Big Six

- Five have long chains of carbon atoms in their backbones (i.e., they are giant alkanes)
- Graphics from Text: Table 10.1 and Figure 10.9 in 2nd Edition and Table 9.1 and Figure 9.11 in 3rd Edition, The Big Six
- LDPE prepared from Ethylene

- HDPE prepared from Ethylene
Polyvinyl Chloride, PVC, prepared from Vinyl Chloride

Polystyrene, PS, prepared from Styrene
Polypropylene, PP, prepared from Propylene

Polyethylene Terephthalate, PETE, prepared from Ethylene Glycol and Terephthalic Acid, Polyester

Ask Students: List at least three uses for each of these classes of polymers

Group Activity
9H Addition Polymerization

➢ Addition Polymerization reactions occur without the loss of mass

➢ Thus, the weight of monomer you start with equals the weight of polymer isolated

➢ No wastage of mass

➢ Addition Polymerizations typically occur via a type of reaction called Chain Growth

➢ This involves rapid increases in molecular weight and highly reactive intermediates

➢ Leads to polymers with very high molecular weights

➢ Examples include: LDPE, HDPE, PVC, PS, and PP
9I Condensation Polymerization

- Condensation Polymerization reactions occur with the loss of mass (most commonly water is lost).
- Thus, the weight of monomer you start with is greater than the weight of polymer isolated.
- Wastage of mass.

- Condensation Polymerizations typically occur via a type of reaction called Step Growth.
- This involves slow increases in molecular weight and no highly reactive intermediates.
- Leads to polymers with lower molecular weights.

- Examples include: PETE.
  - Reaction for PETE synthesis.
9J  Polymer Bonds vs. Discrete Molecule Bonds

- Same types of covalent bonds

- Alkane type C-C single bonds
  - Ethane vs. Polyethylene

- Ether Linkages
  - Diethyl Ether vs. Polyethylene Glycol, PEG

- Ester Linkages
  - Ethyl Acetate vs. PETE

- Amide Linkages
  - Methyl Acetamide vs. Nylon
9K The Story of Kevlar

- Polyphenylene Terephthalamide = Kevlar
- Reaction for Synthesis

- Structure

- Purification

- Properties
Index of Vocabulary and Major Topics

A
Addition Polymerization ............................................ 13
alkanes ........................................................................ 10
Allotropes ..................................................................... 3
Amide Linkages ............................................................ 15
Animal Products ........................................................... 5
Annual US production ................................................ 4
Ask Students ............................................................ 4, 7, 12

B
Backbone Structure..................................................... 9
Bacterial Products ........................................................ 5
barrel of oil .................................................................... 5
Biological Starting Materials ........................................ 5
branched Structures ...................................................... 9
Buckminsterfullerene .................................................. 3

C
Carbon ......................................................................... 3
Carbon Allotropes ........................................................ 3
Catalyst ......................................................................... 8
C-C single bonds .......................................................... 15
Chain Growth .............................................................. 13
Coal .............................................................................. 5
common natural polymers ............................................ 7
Condensation Polymerization ...................................... 14
Constant molecular weights ......................................... 6
Constant structures ....................................................... 6
covalent bonds ............................................................. 15
Covalent bonds ............................................................ 3
Cross Links .................................................................... 9

D
Depolymerization ...................................................... 8
Diamond ........................................................................ 3
Diethyl Ether ............................................................... 15

E
Element ......................................................................... 3
Ester Linkages ............................................................. 15
Ethane .......................................................................... 15
Ether Linkages ............................................................ 15
Ethyl Acetate ............................................................... 15
Ethylene ....................................................................... 10
Ethylene Glycol ........................................................... 12

F
Fossil Fuel Starting Materials ...................................... 5

G
Graphics from Text .................................................... 3, 4, 5, 10
Graphite ......................................................................... 3
Group Activity ............................................................. 4, 7, 12

H
H₂C=CH₂ ..................................................................... 8
HDPE ......................................................................... 9, 10, 13
Higher Density Polyethylene ......................................... 9
Higher Order Polymer Structures ................................ 9

K
Kevlar .......................................................................... 16

L
LDPE ............................................................................ 9, 10, 13
Low Density Polyethylene ........................................... 9

M
Methyl Acetamide ..................................................... 15
molecular weights ......................................................... 6
monomer ..................................................................... 13, 14
Monomers ..................................................................... 6

N
Natural Gas ................................................................. 5
Nylon ............................................................................. 15

P
PEG .............................................................................. 15
PETE ............................................................................ 12, 14, 15
Petroleum ...................................................................... 5
Plant Materials ............................................................. 5
Polyester ........................................................................ 8, 15
Polyethylene Glycol ..................................................... 15
Polyethylene Terephthalate ........................................... 12
Polymer Bonds vs. Discrete Molecule Bonds .............. 15
Polymers ...................................................................... 5, 6
Polyphenylene Terephthalamide .................................. 16
Polypropylene ............................................................. 12
Polystyrene ................................................................. 11
Polyvinyl Chloride ...................................................... 11
PP ................................................................................ 12, 13
Propylene ................................................................. 12
PS .............................................................................. 11, 13
PVC ............................................................................. 11, 13

©2000, Dr. Allen D. Hunter, Department of Chemistry, Youngstown State University
<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Story of Kevlar</td>
<td>16</td>
</tr>
<tr>
<td>Uses of plastics</td>
<td>4</td>
</tr>
<tr>
<td>Van der Waals bonds</td>
<td>3</td>
</tr>
<tr>
<td>Variable molecular weights</td>
<td>6</td>
</tr>
<tr>
<td>Variable structures</td>
<td>6</td>
</tr>
<tr>
<td>Vinyl Chloride</td>
<td>11</td>
</tr>
<tr>
<td>(\pi)-bonds</td>
<td>8</td>
</tr>
<tr>
<td>(\sigma)-bonds</td>
<td>8</td>
</tr>
<tr>
<td>(\pi)-bonds</td>
<td>8</td>
</tr>
<tr>
<td>(\sigma)-bonds</td>
<td>8</td>
</tr>
<tr>
<td>R repeating units</td>
<td>9</td>
</tr>
<tr>
<td>Scale of Production</td>
<td>4</td>
</tr>
<tr>
<td>Side Chains</td>
<td>9</td>
</tr>
<tr>
<td>Some Natural Polymers</td>
<td>7</td>
</tr>
<tr>
<td>Starting Materials for plastic production</td>
<td>5</td>
</tr>
<tr>
<td>Step Growth</td>
<td>14</td>
</tr>
<tr>
<td>Styrene synthesis</td>
<td>11</td>
</tr>
<tr>
<td>(\pi)-bonds</td>
<td>8</td>
</tr>
<tr>
<td>(\sigma)-bonds</td>
<td>8</td>
</tr>
<tr>
<td>Terephthalic Acid</td>
<td>12</td>
</tr>
<tr>
<td>The Big Six</td>
<td>10</td>
</tr>
<tr>
<td>The Plastic Economy</td>
<td>4</td>
</tr>
<tr>
<td>(U) Uses of plastics</td>
<td>4</td>
</tr>
<tr>
<td>(V) Van der Waals bonds</td>
<td>3</td>
</tr>
<tr>
<td>(\pi)-bonds</td>
<td>8</td>
</tr>
<tr>
<td>(\sigma)-bonds</td>
<td>8</td>
</tr>
</tbody>
</table>