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

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Outline

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 2nd Edition and 9.2a, b, c in 3rd 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

$$H_2C{=}CH_2 + \text{Catalyst} \rightarrow \text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}$$

Is equivalent to saying

$$H_2C{=}CH_2 + \text{Catalyst} \rightarrow \text{-}[CH_2\text{-}CH_2]_n\text{-}$$

  - At high temperatures the reaction can reverse
    - Depolymerization
  - Occurs because π-bonds are stronger than σ-bonds

9F 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