Summary and Notes for Exam Preparation: Hydrocarbons

Alkanes and Homologous Series

Key Concepts:

- Alkanes are hydrocarbons with the general formula C_nH_{2n+2}
- They form a homologous series with similar chemical properties but gradually changing physical properties

Characteristics of Homologous Series:

1. Same general formula (C_nH_{2n+2})
2. Differ by CH_2 unit between consecutive members
3. Similar chemical properties
4. Gradual change in physical properties (e.g., boiling point, melting point)

First 10 Members of Alkane Series:

Name	Formula	Molecular Structure
Methane	CH_4	Single C atom with 4 H atoms
Ethane	C_2H_6	2 C atoms with 6 H atoms
Propane	C_3H_8	3 C atoms chain
Butane	C_4H_{10}	4 C atoms chain
Pentane	C_5H_{12}	5 C atoms chain

Hexane	C6H14	6 C atoms chain
Heptane	C7H16	7 C atoms chain
Octane	C8H18	8 C atoms chain
Nonane	C9H20	9 C atoms chain
Decane	C10H22	10 C atoms chain

Physical Properties Trends:

1. Boiling Point:
    - Increases with molecular mass
    - Due to stronger van der Waals forces
    - Example: Methane (-161.5°C) < Ethane (-88.6°C) < Propane (-42.1°C)
2. Physical State at Room Temperature:
    - C1 to C4: Gases
    - C5 to C17: Liquids
    - C18 and above: Solids

2. Sources of Alkanes

Natural Sources:

1. Crude Oil (Petroleum)
    - Primary source
    - Complex mixture of hydrocarbons
    - Formed from ancient marine organisms
2. Natural Gas
    - Mainly methane (85-95%)
    - Small amounts of ethane, propane, butane
3. Coal Bed Methane
    - Trapped in coal seams
    - Extracted during mining

Industrial Sources:

1. Cracking of Larger Hydrocarbons

    - Thermal cracking
    - Catalytic cracking Example: C10H22 → C5H12 + C5H10 (decane → pentane + pentene)
2. Hydrogenation of Alkenes Example: C2H4 + H2 → C2H6 (ethene + hydrogen → ethane)

3. Fractional Distillation of Crude Oil

Process Overview:

1. Crude oil is heated to 350-400°C
2. Hydrocarbons vaporize
3. Vapors rise in fractionating column
4. Different fractions condense at different temperatures

Column Structure:

- Tall tower with decreasing temperature from bottom to top
- Multiple collection trays at different heights
- Temperature gradient: 400°C (bottom) to 20°C (top)

Main Fractions (from top to bottom):

1. Gases (< 20°C)
    - C1 to C4
    - Uses: cooking gas, fuel
2. Petroleum Spirit/Naphtha (20-60°C)
    - C5 to C7
    - Use: petrol/gasoline
3. Kerosene (150-250°C)
    - C10 to C14
    - Use: jet fuel, heating
4. Diesel Oil (250-350°C)
    - C15 to C18
    - Use: diesel engines
5. Lubricating Oil (350-400°C)
    - C19 to C25
    - Use: machinery lubrication
6. Residue (>400°C)
    - C25+
    - Use: bitumen, road surfacing

Trends in Fractions:

1. As temperature increases:
    - Carbon chain length increases
    - Viscosity increases

- Volatility decreases
- Color darkens

4. Saturated vs Unsaturated Hydrocarbons

Saturated Hydrocarbons (Alkanes):

1. Characteristics:
   - Single bonds only
   - Maximum number of hydrogen atoms
   - General formula C_nH_{2n+2}
2. Chemical Properties:
   - Less reactive
   - Undergo substitution reactions Example: $CH_4 + Cl_2 \rightarrow CH_3Cl + HCl$ (methane + chlorine → chloromethane + hydrogen chloride)

Unsaturated Hydrocarbons:

1. Alkenes (C_nH_{2n}):
   - Contains C=C double bond
   - More reactive than alkanes
   - Undergo addition reactions Example: $C_2H_4 + Br_2 \rightarrow C_2H_4Br_2$ (ethene + bromine → dibromoethane)
2. Alkynes (C_nH_{2n-2}):
   - Contains C≡C triple bond
   - Very reactive
   - Multiple addition reactions possible

Testing for Saturation:

1. Bromine Water Test:
   - Saturated: Remains brown/orange
   - Unsaturated: Decolorizes from brown to colorless
2. Potassium Permanganate Test:
   - Saturated: Remains purple
   - Unsaturated: Decolorizes from purple to colorless

Exam Preparation Tips:

1. Practice drawing structural formulas
2. Memorize the first 10 alkanes and their formulas
3. Understand trends in physical properties
4. Know the different fractions from fractional distillation and their uses
5. Practice writing balanced equations for reactions
6. Remember tests for saturation/unsaturation

Example Exam Questions:

Question: "Draw the structural formula for butane and show its combustion reaction." Answer: Structural formula: CH3-CH2-CH2-CH3
Combustion: $C_4H_{10} + 6.5O_2 \rightarrow 4CO_2 + 5H_2O$
Question: "Explain why pentane has a higher boiling point than ethane." Answer: Pentane (C_5H_{12}) has more carbon atoms than ethane (C_2H_6), resulting in stronger van der Waals forces between molecules. This requires more energy to overcome, leading to a higher boiling point.
Question: "Name the process that converts longer chain hydrocarbons into shorter ones." Answer: Cracking (either thermal or catalytic).
Example: $C_{10}H_{22} \rightarrow C_6H_{14} + C_4H_8$

Reactions of Alkanes

Key Characteristics:

- Alkanes are generally unreactive due to strong C-C and C-H bonds
- Require high temperatures or UV light for reactions
- Main reaction types: combustion and substitution

Types of Reactions:

1. Combustion (complete and incomplete)
2. Free radical substitution
3. Cracking (thermal and catalytic)

2. Combustion of Alkanes

Complete Combustion:

- Requires excess oxygen
- Products: CO_2 and H_2O
- General equation: $C_nH_{2n+2} + (3n+1)/2\ O_2 \rightarrow nCO_2 + (n+1)H_2O$

Examples:

1. Methane: $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
2. Ethane: $C_2H_6 + 3.5O_2 \rightarrow 2CO_2 + 3H_2O$
3. Propane: $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$

Incomplete Combustion:

- Limited oxygen supply
- Products: CO, C (soot), and/or H_2O
- Example: $2CH_4 + 3O_2 \rightarrow 2CO + 4H_2O$

Applications of Combustion:

1. Domestic Uses:
    - Cooking (natural gas stoves)
    - Heating (gas furnaces)
    - Hot water systems
2. Industrial Applications:
    - Power generation
    - Industrial furnaces
    - Manufacturing processes
3. Transportation:
    - Internal combustion engines
    - Jet engines
    - Rocket fuel

3. Pollution from Hydrocarbon Fuels

Major Pollutants:

1. Carbon Dioxide (CO_2):
    - Greenhouse gas
    - Contributes to global warming
    - Source: Complete combustion
2. Carbon Monoxide (CO):
    - Toxic gas
    - Binds to hemoglobin
    - Source: Incomplete combustion
3. Sulfur Dioxide (SO_2):
    - Acid rain formation
    - Respiratory irritant
    - Source: Sulfur impurities in fuel
4. Nitrogen Oxides (NO_x):
    - Photochemical smog
    - Acid rain formation
    - Source: High-temperature combustion
5. Particulate Matter:
    - Respiratory problems
    - Reduced visibility
    - Source: Incomplete combustion

Environmental Effects:

1. Global Warming:
    - Increased average temperatures
    - Sea level rise
    - Climate change
2. Acid Rain:

- Building damage
- Soil acidification
- Aquatic ecosystem damage

4. Catalytic Converters

Function:

- Converts harmful exhaust gases into less harmful substances
- Operates at high temperatures (300-600°C)
- Contains precious metal catalysts (Pt, Pd, Rh)

Structure:

1. Ceramic honeycomb structure
2. Washcoat (Al2O3)
3. Catalyst particles

Chemical Processes:

1. Oxidation of CO:

   2CO + O2 → 2CO2

2. Oxidation of unburned hydrocarbons:

   CxHy + O2 → CO2 + H2O

Reduction of NOx:

2NO + 2CO → N2 + 2CO2

3. 2NO + 2H2 → N2 + 2H2O

Applications:

1. Automotive vehicles
2. Industrial emissions control
3. Power plant emissions

5. Substitution Reactions of Alkanes

Overview:

- Replacement of H atoms with halogen atoms

- Requires UV light or high temperature
- Follows free radical mechanism

Free Radical Mechanism:

1. Initiation:

- UV light breaks halogen molecule
- Forms halogen radicals

$Cl_2 \rightarrow 2Cl^{\bullet}$

2. Propagation:

- Two-step chain reaction
- Creates new radicals

Step 1: $CH_4 + Cl^{\bullet} \rightarrow CH_3^{\bullet} + HCl$

Step 2: $CH_3^{\bullet} + Cl_2 \rightarrow CH_3Cl + Cl^{\bullet}$

3. Termination:

- Radicals combine
- Chain reaction ends

$Cl^{\bullet} + Cl^{\bullet} \rightarrow Cl_2$

$CH_3^{\bullet} + Cl^{\bullet} \rightarrow CH_3Cl$

$CH_3^{\bullet} + CH_3^{\bullet} \rightarrow C_2H_6$

Example with Propane:

1. Initiation:
   Cop
   $Cl_2 \rightarrow 2Cl^{\bullet}$

Propagation:

$CH_3CH_2CH_3 + Cl^{\bullet} \rightarrow CH_3CH_2CH_2^{\bullet} + HCl$

2. $CH_3CH_2CH_2^{\bullet} + Cl_2 \rightarrow CH_3CH_2CH_2Cl + Cl^{\bullet}$

3. Termination:

   $CH_3CH_2CH_2^{\bullet} + Cl^{\bullet} \rightarrow CH_3CH_2CH_2Cl$

6. Practice Problems

Problem 1:

Write balanced equations for the complete combustion of: a) Butane (C_4H_{10}) b) Pentane (C_5H_{12})

Solution: a) $C_4H_{10} + 6.5O_2 \rightarrow 4CO_2 + 5H_2O$ b) $C_5H_{12} + 8O_2 \rightarrow 5CO_2 + 6H_2O$

Problem 2:

For the chlorination of methane: a) Write the initiation step b) Write both propagation steps c) Write three possible termination steps

Solution: a) Initiation: $Cl_2 \rightarrow 2Cl^{\bullet}$ b) Propagation:

- $CH_4 + Cl^{\bullet} \rightarrow CH_3^{\bullet} + HCl$
- $CH_3^{\bullet} + Cl_2 \rightarrow CH_3Cl + Cl^{\bullet}$ c) Termination:
- $Cl^{\bullet} + Cl^{\bullet} \rightarrow Cl_2$
- $CH_3^{\bullet} + Cl^{\bullet} \rightarrow CH_3Cl$
- $CH_3^{\bullet} + CH_3^{\bullet} \rightarrow C_2H_6$

Problem 3:

Explain why the following equation represents incomplete combustion: $2C_3H_8 + 7O_2 \rightarrow 4CO + 2CO_2 + 8H_2O$

Solution:

- This is incomplete combustion because:
  1. CO is produced instead of CO_2 for some carbon atoms
  2. Insufficient oxygen was available for complete oxidation
  3. Complete combustion would require $10O_2$ and produce only CO_2

Problem 4:

Calculate the volume of oxygen needed for complete combustion of $50cm^3$ of propane.

Solution:

Equation: $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$

Ratio of $C_3H_8:O_2 = 1:5$
Therefore, $50cm^3$ of propane needs $250cm^3$ of oxygen

The Alkenes

Characteristics:

- General formula: C_nH_{2n}
- Contains C=C double bond
- Unsaturated hydrocarbons
- More reactive than alkanes

First Six Members:

Name	Formula	Structure
Ethene	C_2H_4	$CH_2=CH_2$
Propene	C_3H_6	$CH_3-CH=CH_2$
Butene	C_4H_8	$CH_3-CH_2-CH=CH_2$
Pentene	C_5H_{10}	$CH_3-(CH_2)_2-CH=CH_2$
Hexene	C_6H_{12}	$CH_3-(CH_2)_3-CH=CH_2$

Physical Properties:

- Lower boiling points than equivalent alkanes
- Slightly polar due to electron density in double bond
- Generally insoluble in water

2. Oil Refineries and Cracking

Oil Refinery Process:

1. Fractional Distillation
2. Cracking

3. Treatment processes

Cracking Methods:

1. Catalytic Cracking:

- Temperature: 450-500°C
- Pressure: Moderate
- Catalyst: Zeolites
- Produces more branched alkanes and alkenes

Process:

```
Long-chain alkane → shorter-chain alkane + alkene

C15H32 → C8H18 + C7H14
```

Advantages:

- Lower temperature than thermal cracking
- Better yield of useful products
- More selective process

2. Thermal Cracking:

- Temperature: 700-900°C
- No catalyst
- Produces mixture of alkanes and alkenes

Example:

```
C10H22 → C6H14 + C4H8

Decane → hexane + but-1-ene
```

Catalytic Cracker Components:

1. Reactor vessel
2. Regenerator
3. Fractionating column
4. Catalyst recycling system

3. Addition Reactions of Alkenes

1. Addition of Hydrogen (Hydrogenation):

- Conditions: Ni/Pt/Pd catalyst, 150°C
- Products: Alkanes

```
CH2=CH2 + H2 → CH3-CH3

Ethene → Ethane
```

2. Addition of Steam (Hydration):

- Conditions: H3PO4 catalyst, 300°C, 60 atm
- Products: Alcohols

```
CH2=CH2 + H2O → CH3CH2OH

Ethene → Ethanol
```

3. Addition of Hydrogen Halides:

- Room temperature
- Products: Haloalkanes

```
CH3CH=CH2 + HBr → CH3CHBrCH3

Propene → 2-bromopropane
```

Markovnikov's Rule:

- H attaches to C with more H atoms
- X attaches to C with fewer H atoms

4. Addition of Halogens:

- Room temperature
- Products: Dihalogenoalkanes

```
CH2=CH2 + Br2 → CH2Br-CH2Br

Ethene → 1,2-dibromoethane
```

4. Electrophilic Addition Mechanism

Steps:

1. Formation of electrophile
2. Attack by π electrons
3. Formation of carbocation
4. Attack by nucleophile

Example with HBr:

```
Step 1: H-Br → H+ + Br-

Step 2: CH3CH=CH2 + H+ → CH3CH+CH3

Step 3: CH3CH+CH3 + Br- → CH3CHBrCH3
```

5. Oxidation of Alkenes

1. Cold Oxidation (Mild):

- Reagent: Cold KMnO4 or K2Cr2O7
- Products: Diols

CH2=CH2 + [O] + H2O → CH2OH-CH2OH

2. Hot Oxidation (Vigorous):

- Reagent: Hot KMnO4
- Products: Carboxylic acids

CH3CH=CH2 + [O] → CH3COOH + CO2 + H2O

6. Addition Polymerization

Process:

- Involves unsaturated monomers
- Double bonds break
- Monomers join to form long chains

Examples:

1. Polyethene from ethene:

n(CH2=CH2) → [-CH2-CH2-]n

2. Polypropene from propene:

n(CH3-CH=CH2) → [-CH2-CH(CH3)-]n

Types of Polyethene:

1. HDPE (High Density):
    - Linear chains
    - Higher density
    - Stronger
2. LDPE (Low Density):
    - Branched chains
    - Lower density
    - More flexible

7. Environmental Considerations

Disposal Methods:

1. Landfill:
    - Non-biodegradable
    - Long-term environmental impact
    - Space issues
2. Incineration:
    - Produces energy
    - Potential toxic emissions
    - Requires proper filtering
3. Recycling:
    - Mechanical recycling
    - Chemical recycling
    - Energy recovery

Environmental Issues:

1. Plastic Pollution
2. Microplastic contamination
3. Marine ecosystem damage
4. Greenhouse gas emissions

8. Exam Preparation

Tackling Polymer Questions:

1. Identifying Repeat Units:

- Look for the double bond in monomer
- Break the double bond
- Connect monomers

Example:

```
Monomer: CH2=CH-Cl

Repeat unit: [-CH2-CHCl-]
```

2. Identifying Monomers:

- Look for repeating pattern
- Add double bond
- Check valencies

Example:

```
Polymer: [-CH2-CH(CH3)-]

Monomer: CH2=CH-CH3
```

Practice Problems:

1. Draw the structure of the polymer formed from: a) CH2=CHCl b) CH2=C(CH3)2

Solution: a) [-CH2-CHCl-]n b) [-CH2-C(CH3)2-]n

2. Identify the monomer used to make: [-CH2-CH(C6H5)-]n

Solution: CH2=CH-C6H5 (styrene)

3. For the reaction between propene and HBr: a) Draw the mechanism b) Name the product c) Explain why this product forms

Key Points to Remember:

1. Always show all bonds clearly
2. Use curly arrows correctly in mechanisms
3. Apply Markovnikov's Rule
4. Remember polymerization conditions
5. Consider environmental impacts

Common Exam Questions:

1. Drawing mechanisms
2. Identifying products
3. Naming monomers/polymers
4. Environmental discussions
5. Industrial applications

Writing Tips:

- Use precise chemical terminology
- Show working clearly
- Include relevant equations
- Explain mechanisms step by step
- Link structure to properties
