Addition Reactions Review

This review covers addition reactions from the Alberta Chem 30 organic chemistry unit perspective.

Adding Hydrogen Gas to an Ene

In **addition reactions**, only the second or third bond in an organic compound is broken.

Consider adding hydrogen gas (H_2) to ethene (C_2H_4). The second bond in ethene breaks, and one hydrogen atom is added to each side of the double bond.

The product will be two carbons with the four original carbon-hydrogen bonds, plus the two added hydrogen atoms. When the double bond breaks, each carbon gains one extra bonding capacity, and a hydrogen atom can then be added to each side. So, an **ene** turns into an **ane**.

$C_2H_4 + H_2 \rightarrow C_2H_6$

Since hydrogen gas is symmetric from right to left, it does not matter which hydrogen is added to which side; the same product is obtained.

Adding HCl to Ethene and Propene

When adding a molecule that is not symmetric from right to left, you have to consider the potential products that could be formed.

Consider adding HCl to ethene:

- The hydrogen (H) could add to either the left-hand carbon or the right-hand carbon, potentially giving two different products.
- However, in this case, adding the H to either side results in the same molecule: chloroethane.

If you switch the H and Cl around, you still have chloroethane, so you only need to show the molecule once.

Important: Do not draw the same molecule twice if it is, in fact, the same molecule just rotated or flipped.

Adding HCl to Propene

When adding HCl to propene, two different molecules with two different names are obtained. Therefore, both molecules must be drawn.

1. **First product**: Add the H from HCl to the left-hand side and the chlorine to the middle carbon, resulting in 2-chloropropane.
2. **Second product**: Add the chlorine to the terminal carbon and the hydrogen to the middle carbon, resulting in 1-chloropropane.

So, the two possible products are 2-chloropropane and 1-chloropropane.

You also need to balance the chemical reactions. For the chem 30 level, you only need to list the two potential products. In college or university-level chemistry, you will learn which one is more favored (the major product) and which one is the minor. Here, we are listing all possibilities.

$$2\ C_3H_6 + 2\ HCl \rightarrow C_3H_7Cl\ (2 - chloropropane) + C_3H_7Cl\ (1 - chloropropane)$$

You will need two of the propenes in order to make both of those products. You're going to need two HCl molecules in order to make those two products.

> **Addition Reaction** An addition reaction is a chemical reaction where atoms are added to an unsaturated organic compound (typically containing double or triple bonds), resulting in a saturated compound or a compound with fewer multiple bonds.

Substitution Reactions

This section reviews substitution reactions from the Alberta Chemistry 30 organic chemistry curriculum. In Chem 30, we focus on single substitutions, where one hydrogen atom is replaced by one bromine atom.

The Substitution Process

In a substitution reaction, one of the hydrogen atoms (H) is swapped out for one bromine atom (Br). The goal is to identify all the possible unique products that can result from this single switch. We do not consider scenarios where two or three bromine atoms are added to the same molecule.

For substitution reactions to occur, a **catalyst** is needed, typically in the form of high-energy or ultraviolet radiation. In many cases, **sunlight** can provide enough energy to drive the reaction.

Example: Substituting Propane

Let's consider a three-carbon chain (propane) and examine the products formed when one hydrogen atom is substituted with a bromine atom.

1. First Substitution: We start by substituting one of the hydrogen atoms. For example, we can replace one of the hydrogen atoms on the end carbon with a bromine atom.
2. Products: This substitution yields **1-bromopropane** and hydrogen bromide (HBr).
3. Identifying Equivalent Substitutions: We need to determine which other hydrogen atoms, if substituted, would yield the same product. In this case, substituting any of the hydrogen atoms on the far-left or far-right carbon atoms would result in 1-bromopropane.

Considering Other Possibilities

Now, consider what happens if the hydrogen atom on the middle carbon is replaced in a substitution reaction. This would yield **2-bromopropane**, a different organic product.

Final Products and Balancing

For the given example, only two unique organic products are possible: 1-bromopropane and 2-bromopropane. In addition, two inorganic products result: hydrogen bromide (HBr).

To complete the analysis, the chemical reaction must be balanced. For our specific reaction, two molecules of the original reactant (propane) and two diatomic bromine molecules are needed to carry out the substitution reaction.

Elimination Reactions

Elimination reactions are a type of chemical reaction where atoms or groups of atoms are removed from a molecule, leading to the formation of a **double bond (alkene)**.

Types of Elimination Reactions

There are two main types of elimination reactions:

- **Dehydration:** Removes water (H_2O).
- **Dehydrohalogenation:** Removes hydrogen and a halogen (HX).

Both types result in the formation of a double bond where the removed atoms/groups were located.

Dehydration of Alcohols

Dehydration involves the removal of water (H_2O) from an **alcohol**.

- Requires an **acid catalyst** (H^+). Catalysts are written above or below the reaction arrow. Catalysts are not consumed in the reaction.
- The acid catalyst attacks a lone pair on the **hydroxy group** (OH) of the alcohol.
- This forms a **leaving group** (H_2O).
- A double bond forms to either the right or left of the carbon that originally had the hydroxy group.
- The hydrogen that is lost replaces the H^+ from the acid.

Example: Dehydration of Butan-2-ol

Starting with butan-2-ol ($CH_3CH(OH)CH_2CH_3$), the H^+ catalyst facilitates the removal of water.

Two possible alkenes can form:

- But-2-ene ($CH_3CH=CHCH_3$)
- But-1-ene ($CH_2=CHCH_2CH_3$)

The overall reaction:

$2\ CH_3CH(OH)CH_2CH_3\ \xrightarrow{H^+}\ CH_3CH=CHCH_3\ +\ CH_2=CHCH_2CH_3\ +\ 2\ H_2O$

The key step is to:

1. Identify the carbon with the hydroxy group.
2. Form a double bond to the adjacent carbon on either side.
3. Remove a hydrogen from the carbon where the double bond is formed.

Dehydrohalogenation of Organic Halides

Dehydrohalogenation involves the removal of a **hydrogen** (H) and a **halogen** (X) from an organic halide.

- Requires **basic conditions**, typically using **hydroxide** (OH^-) as a **reactant**, not a catalyst.
- The hydroxide helps to remove a hydrogen, which facilitates the removal of the halogen and the formation of a double bond.
- The double bond forms to either the right or left of the carbon that originally had the halogen.

Example: Dehydrohalogenation of 2-Chlorobutane

Starting with 2-chlorobutane ($CH_3CHClCH_2CH_3$), the hydroxide reactant facilitates the removal of HCl.

Two possible alkenes can form:

- But-2-ene ($CH_3CH=CHCH_3$)
- But-1-ene ($CH_2=CHCH_2CH_3$)

The overall reaction:

$2\ CH_3CHClCH_2CH_3\ +\ 2\ OH^-\ \rightarrow\ CH_3CH=CHCH_3\ +\ CH_2=CHCH_2CH_3\ +\ 2\ H_2O\ +\ 2\ Cl^-$

In this reaction:

- The halogen leaves as a halide ion (Cl^-).
- The hydrogen removed by the hydroxide forms water (H_2O).

Spectator Ions

Sometimes, the hydroxide reactant is shown with a **spectator ion**, such as sodium (Na) in **sodium hydroxide** ($NaOH$).

> Spectator Ion: An ion that is present in the reaction mixture but does not participate in the actual chemical reaction.

The sodium ion does not affect the reaction and can be ignored for balancing purposes.

Example with the spectator ion:

$2 \ CH_3CHClCH_2CH_3 \ + \ 2 \ NaOH \ \rightarrow \ CH_3CH=CHCH_3 \ + \ CH_2=CHCH_2CH_3 \ + \ 2 \ H_2O \ + \ 2 \ NaCl$

Complete Combustion with Generic Formulas

Combustion is the rapid reaction between a substance with an oxidant, usually oxygen, to produce heat and light. Complete combustion of a hydrocarbon yields carbon dioxide and water vapor.

$Hydrocarbon \ + \ O_2(g) \ \rightarrow \ CO_2 \ + \ H_2O(g)$

To balance a combustion reaction, you must know the hydrogen:carbon ratio. The general formula for alkanes is C_nH_{2n+2}.

Example: Combustion of 2,2-dimethyl Decane

2,2-dimethyl Decane contains:

- Dec- Stem with 10 carbons.
- Two methyl groups, each with one carbon.

Total carbon count = 10 + 2(1) = 12, hence C_{12}.

Since it is an alkane, we use $2n+2$ to find the hydrogen count where $n = 12$:

$2(12) + 2 = 26$, hence H_{26}.

Our hydrocarbon is $C_{12}H_{26}$.

The balanced combustion reaction is:

$C_{12}H_{26} \ + \ \frac{37}{2}O_2(g) \ \rightarrow \ 12 \ CO_2 \ + \ 13 \ H_2O(g)$

Combustion Balancing Tips

When balancing combustion equations, remember that oxygen needs to be in pairs, or an even number. If you have an odd number of oxygen atoms because of an odd number of hydrogen atoms (e.g., 26 hydrogen atoms make 13 pairs, leading to an odd number of oxygen atoms), double the fuel to achieve an even number.

For example, if you have $C_{12}H_{26}$, doubling the fuel gives $2 * C_{12}H_{26}$. This results in 26 pairs of hydrogen atoms or 26 water molecules. With an even number, balancing becomes more straightforward.

In this case, $2 * 12 = 24$ carbons will yield 24 carbon dioxide molecules. The oxygen atoms on the product side include 48 from carbon dioxide ($24 * 2$) and 26 from water, totaling 74. Since 74 is divisible by 2 (37 pairs), you avoid fractional coefficients for oxygen. Without doubling, you would have obtained a fractional answer of $37/2$ for oxygen.

Incomplete Combustion

Incomplete combustion occurs when there is a **lack of oxygen** (O_2 is the limiting reagent). In this scenario, not every carbon atom can fully saturate with two oxygen atoms.

Products of Incomplete Combustion:

- **Carbon Dioxide (CO_2)**: A greenhouse gas.
- **Carbon Monoxide (CO)**: A toxic gas that is colorless and odorless. It binds to hemoglobin in the blood, preventing oxygen binding and leading to suffocation.
- **Carbon (Soot)**: Black soot, which is harmful to breathe in. High concentrations in the air can lead to poor air quality.
- **Water Vapor (H_2O)**: Not an environmental concern.

Review Guide Structure

Consider creating a review guide using the following structure for organic chemistry families:

Family	Characteristic/Functional Group	Example	Name of Example
Aromatics			
Cyclos			
Organic Halides			
Alcohols			
Carboxylic Acids			
Esters			

For reactions, a review can summarize the number of products and examples:

Reaction Type	Number of Products	Example(s)
Addition	One or Two	Symmetric addition, asymmetric addition
Esterification		Reaction between a carboxylate and an alcohol to make an ester
Elimination		Elimination of water, elimination of H and a halogen
Substitution		
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Elimination Reactions

Dehydration of Alcohols

- Involves the elimination of water (H_2O) from an alcohol to form an alkene.
- Requires an **acid catalyst** (e.g., H_2SO_4) for the reaction to occur. The acid catalyst helps in the removal of the hydroxyl group (OH) as water, which is a good leaving group.
- The acid catalyst is not consumed in the reaction; it is regenerated.

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Catalyst: A substance that increases the rate of a chemical reaction wit
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- A double bond forms between the carbon that was attached to the OH group and an adjacent carbon, with the concurrent elimination of a hydrogen atom.
- Generalized reaction:

$$Alcohol \xrightarrow{Acid\ Catalyst} Alkene + H_2O$$

Dehydrohalogenation of Organic Halides

- Involves the elimination of a **hydrogen halide** (e.g., HCl, HBr) from an organic halide to form an alkene.
- Requires **basic conditions**. The base is a reactant and is consumed in the reaction.
- The base (e.g., $NaOH$) assists in the removal of a proton (H^+), facilitating the formation of a double bond.
- Multiple possible alkene products may form, depending on the structure of the organic halide and the position of the halogen atom.
- Generalized reaction:

$$Organic\ Halide \xrightarrow{Base} Alkene + Halide\ Salt + Water$$

Factors Affecting Product Formation

When multiple alkene products are possible in dehydrohalogenation, consider the following:

- **Position of the Halogen Atom:** The location of the halogen on the carbon chain determines the possible positions for the double bond.
- **Possible Products:** Different alkenes can be formed depending on which adjacent carbon loses a hydrogen atom.
- **Example Scenario:** With a four-carbon chain organic halide (e.g. Chlorobutane), the double bond could form between carbon 1 and 2 (but-1-ene) or between carbon 2 and 3 (but-2-ene) after HCl elimination.

Reaction Conditions Comparison

Feature	Alcohol Dehydration	Organic Halide Dehydrohalogenation
Reaction Type	Elimination	Elimination
Reactant	Alcohol	Organic Halide
Reagent	Acid Catalyst	Strong Base
Role of Reagent	Catalyst (regenerated)	Reactant (consumed)
Byproducts	Water	Water and Halide Salt
Product	Alkene	Alkene

Ester Formation: Esterification

Esters are the last family of organic compounds we will study, focusing on their formation and naming conventions.

Ester Reaction Overview

Ester formation involves a reaction between an **organic compound derivative** (carboxylic acid) and another **hydrocarbon derivative** (alcohol).

- The reaction is unique due to the combination of these two types of reactants.
- Alcohols can undergo elimination reactions with acid catalysts, but esterification involves a **carboxylic acid** (containing a $-C=OOH$ group) reacting with an **alcohol** (containing a $-OH$ group).
- The products are an **ester** and **water**. It's crucial to remember the water byproduct.
- A **strong, concentrated acid** is required as a catalyst, such as sulfuric acid (H_2SO_4).

Example: Propanoic Acid + Methanol

Reacting **propanoic acid** with **methanol** in the presence of a strong acid yields an ester and water.

- The **carboxylic acid** is too weak to act as a catalyst itself.

Ester Formation Mechanism

While the detailed mechanism is beyond the scope of this course, understanding the basic connection is essential.

1. The alcohol's oxygen (with lone pairs of electrons) connects to the carbon in the carboxylic acid's carbonyl group ($C=O$).
2. This carbon is electron-deficient due to the polar carbon-oxygen bond.

> Electronegativity: Oxygen has a higher electronegativity than carbon, making the carbonyl carbon electron-poor and susceptible to nucleophilic attack by the alcohol oxygen.

3. During the reaction, the $-OH$ from the carboxylic acid and a hydrogen from the alcohol are eliminated, forming water.
4. The catalyst facilitates this process.

What is an Ester?

Esters are a distinct organic family characterized by a carbon bonded to an oxygen, which is then bonded to another carbon within the main chain. The general structure is $R-COO-R'$, where R and R' are hydrocarbon groups.

Naming Esters

Esters derive their names from the alcohol and carboxylic acid reactants. IUPAC nomenclature dictates the following:

1. Alcohol Portion: Named first, using the alkyl name (methyl, ethyl, propyl, butyl, etc.).
2. Carboxylic Acid Portion: Named second, using the alkane name derived from the acid's stem. Drop the "-e" and add "-oate".

Example: Ethanoic Acid + Propanol

Reacting ethanoic acid with propanol in the presence of a strong acid catalyst will produce an ester and water.

- The oxygen from propanol connects to the carbonyl carbon of ethanoic acid.

Naming the Product

1. Identify the alcohol and carboxylic acid fragments in the ester. The $C=O$ is a key indicator of the acid portion.
2. Name the alcohol portion:
    - Propanol (3 carbons) becomes "propyl".
3. Name the carboxylic acid portion:
    - Ethanoic acid (2 carbons) becomes "ethanoate".
4. Combine the names:
    - The ester's name is **propyl ethanoate**.

      The "-oate" suffix signifies the ester linkage ($C=O-O-$).

Practice

Let's test your understanding with an example:

Draw the structure of ethyl methanoate.

1. **Identify the alcohol and acid portions:**
    - Ethyl (alcohol portion)
    - Methanoate (acid portion)
2. **Draw the structure:**
    - Start with the ester linkage ($C=O-O-$).
    - Add the ethyl group (CH_2CH_3) to one side of the oxygen.
    - Add the methanoyl group (H) to the carbonyl carbon.

Reaction Types

Esterification is an important reaction to remember. Below is a table showing all the reactions studied in this course.

Reaction	Description
Addition	Two or more reactants combine to form a single product.
Substitution	An atom or group in a molecule is replaced by another atom or group.
Elimination	A molecule loses atoms or groups, often forming a double bond. Includes E1 and E2 mechanisms.
Combustion	A rapid reaction between a substance with an oxidant, usually oxygen, to produce heat and light. Can be complete (producing CO_2 and H_20) or incomplete (producing CO, C, and H_2O`).
Esterification	A reaction between a carboxylic acid and an alcohol to form an ester and water, catalyzed by a strong acid.

Naming Esters

Let's walk through naming esters with a few more examples. Remember, the key is to identify the alcohol and acid components.

Methyl Ethanoate Example

Consider methyl ethanoate. Here's how it's structured:

- Two line segments lead into the oxygen without any carbons.
- The carbons are located at three key points.

Butanoic Acid Example

Let's synthesize an ester from butanoic acid and ethanol.

- Butanoic acid has four carbons and a double-bonded oxygen (OOH).
- An acid catalyst is needed (strong, concentrated acid).
- The oxygen (O) from the alcohol's hydroxyl group connects to the carbonyl carbon.

The resulting ester will have the following structure:

- Four carbons with a double bond.
- An oxygen atom (O) from the alcohol.
- Two more carbons.

Don't forget the water molecule (H_2O) that is produced as a byproduct, important for balancing the equation.

Naming the Ester

1. Alcohol portion first: In this case, it's ethyl (two carbons).
2. Acid portion second: Butanoic acid becomes butanoate (four carbons). The "ane" is dropped and replaced with "oate".

So, the ester's name is ethyl butanoate. We are focusing on non-branched examples.

Benzoic Acid Example

One more example using benzoic acid.

- Benzoic acid: An aromatic hydrocarbon derivative with a carboxyl group ($COOH$) attached to a seventh carbon, not directly to the ring.
- The connection sequence remains the same.

The arrow goes from the alcohol oxygen to the carbon of the $C = O$ bond.

Reaction

The alcohol (e.g., methanol) reacts with the benzoic acid:

1. One carbon from the alcohol.
2. The black oxygen (O) stays.
3. Connects to a blue carbon with a double-bonded oxygen ($C = O$).
4. The blue oxygen (O) from the acid goes away as part of the water molecule (H_2O).
5. The aromatic ring remains.

Don't forget the water!

Naming

The alcohol part (methyl) comes first. Benzoic acid becomes benzoate by dropping the "oic acid" and adding "oate," resulting in methyl benzoate.

Ester Properties and Uses

Esters are formed through **esterification**.

> **Esterification**: A chemical reaction between an alcohol and an acid to form an ester and water.

- Methanol and benzoic acid have hydrogen bonding, making them soluble in water.
- Esters exhibit dipole-dipole forces but lack hydrogen bonding, so they aren't as soluble.

Esters tend to have distinct smells. They may smell like bananas, peaches, or have a more pungent odor like nail polish remover.

Hydrocarbon Cracking

One last topic.

> **Hydrocarbon Cracking**: Breaking long hydrocarbons into smaller, more valuable pieces by heating them under controlled conditions.

- Atom count must match on both sides of the reaction.
- For example, $C_{20}H_{42}$ can be broken into $C_9H_{20} + C_{11}H_{22}$

Context

Fractional distillation diagrams often appear on exams. Be aware that **hydrocarbon cracking** is often listed as a wrong answer choice when identifying fractional distillation.

Esterification Reactions

Esterification reactions involve the reaction between an alcohol and a carboxylic acid to produce an ester and water. This is unique in Alberta Chemistry 30 as it is the only reaction that requires two organic reactants.

Reaction Overview

During the reaction, the oxygen (O) from the alcohol connects to the carbon (C) that is double-bonded to an oxygen (O) – the carbonyl – and a hydroxyl group.

Visually, if ethanol (an alcohol) reacts with methanoic acid, the following occurs:

1. The oxygen from the ethanol connects to the carbon in the methanoic acid. The carbon to hydrogen bonds in the ethanol do not change.
2. The O-H bond in the alcohol breaks, allowing the alcohol to connect to the carbon from the methanoic acid.
3. The hydroxyl group (OH) from the methanoic acid is released.
4. The hydroxyl group combines with the hydrogen (H) from the alcohol to form water (H_2O).

$$Alcohol + CarboxylicAcid \rightarrow Ester + Water$$

Ester Uses

Esters are prevalent in the food industry due to their pleasant smells and are often synthesized to produce specific scents in products like gum.

Catalyst

To facilitate the reaction, an acid catalyst is required. Sulfuric acid is a common catalyst used in esterification reactions.

Naming Esters

Naming esters involves two parts: the alcohol component and the acid component.

1. **Alcohol Component**: The alcohol part is named first.
    - Identify the number of carbons in the alcohol.
    - Use the corresponding prefix (e.g., "eth-" for two carbons).
    - Add "-yl" to the prefix.
    - *Example:* If the alcohol has two carbons (ethanol), the first part of the ester's name is "ethyl."
2. **Acid Component**: The acid part is named second.
    - Identify the number of carbons in the acid.
    - Use the corresponding prefix (e.g., "meth-" for one carbon).
    - Drop the "-e" from the alkane name.
    - Add "-oate" to the stem.
    - *Example:* If the acid has one carbon (methanoic acid), the second part of the ester's name is "methanoate."
3. **Combining the Names**: Combine the names of the alcohol and acid components to form the ester's name.
    - *Example:* Ethyl methanoate.

Example

For the ester formed from ethanol and methanoic acid:

- The alcohol part (ethanol) has two carbons, so it becomes "ethyl."
- The acid part (methanoic acid) has one carbon, so it becomes "methanoate."
- The ester is named ethyl methanoate.

Hydrocarbon Combustion Reactions

Complete Combustion

- This type of combustion is not new and has been covered in previous science courses.
- A **hydrocarbon fuel**, such as methane (CH_4), reacts with **oxygen** (O_2).
- Requires **sufficient** or **excess** oxygen.
- Produces **carbon dioxide gas** (CO_2) and **water vapor** (H_2O).
- Both carbon dioxide and water vapor are **greenhouse gases**.
    - Water vapor is often overlooked in discussions about greenhouse gases.
- Example of a balanced equation:

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$$

Incomplete Combustion

- Occurs when **oxygen is the limiting reagent**.
- The ratios of products depend on how limiting the oxygen is.
- Observed in vehicles, such as transport trucks emitting black smoke when going uphill or accelerating, indicating incomplete combustion.
- Balancing incomplete reactions will not be assessed.
- Focus is on the products and their environmental effects.
- The products of incomplete combustion are:
    - **Carbon dioxide** (CO_2): A greenhouse gas.
    - **Carbon monoxide** (CO):

        A deadly, odorless, and tasteless gas. Carbon monoxide detectors are essential in homes to alert occupants of leaks, commonly from furnaces.
    - **Pure Carbon** (C):

        Soot that can be seen in fireplaces, barbecues, or emitted from transport truck smokestacks.
    - **Water Vapor** (H_2O)

Comparison of Combustion Types

Feature	Complete Combustion	Incomplete Combustion
Oxygen Supply	Sufficient or excess	Limiting reagent
Products	Carbon dioxide, water vapor	Carbon dioxide, carbon monoxide, pure carbon (soot), water vapor
Unique Products	None	Carbon monoxide, soot
Repeating Products	Carbon dioxide, water vapor	Carbon dioxide, water vapor

Polymerization

In this lesson, we're shifting our perspective to understand **polymers**, which are ginormous molecules unlike the other families we've studied.

Basic Polymer Terminology

Here's some key terminology for understanding polymers:

- **Monomers**: These replace the term "reactants." A *mono*mer is one unit that turns into *many* units.
- **Polymers**: This term replaces "product." Polymers are the result of many monomers joining together.

Polymers often have masses of millions of grams per mole, forming long chains that weave around each other, giving plastics their flexibility. Because of the complexity, we use a shorthand to represent these molecules.

Addition Polymerization

Addition polymerization involves breaking a double bond to create connections.

- The second bond in a double bond is a π bond, which is easily broken.
- Breaking the π bond frees up a connection on each side. Instead of adding small molecules, another monomer connects to each end.
- Each connection frees up another end, allowing continuous growth.

Combining Ethene Monomers

Let's look at what happens when we put two **ethene** monomers together. The π bond breaks, creating bonding spots, and the carbons at the end of the double bond connect.

You can stop the process of building a polymer by adding a chemical $like chlorine$ that terminates the chain, but that's not covered in this lesson.

Typically, we draw polymers with "n" repeating units, where n can be any whole number. The dashes show the connections coming in and out of the bracket.

Naming Convention

The naming convention for polymers involves adding "poly" in front of the monomer name. For example, the polymer made from ethene is called **polyethene**. The "ene" comes from the double bond that used to exist in the monomer, but there's no double bond in the polymer itself.

Everyday Examples

Recycling codes 2 and 4 are both forms of polyethylene, with 4 being high-density polyethylene $HDPE$, often used in milk jugs.

Polypropene Example

If we start with **propene**, we get **polypropene**.

Here's how it works:

1. The double bond breaks.
2. The carbon at the end of the double bond connects to another carbon at the end of the double bond.
3. The CH_3 group remains unaffected.

This results in a branched polymer structure that is more complex than polyethylene. The repeating pattern is shown "n" times.

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Whenever you break the double bond, there are always four connections around t
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Recycling code 5 is polypropylene, often found in water bottles.

Polystyrene

Using **styrene** as a monomer, which has a benzene ring, we create **polystyrene**.

Here's the repeating pattern:

- Two carbons that were part of the double bond
- No double bond anymore
- Three connections are H's
- One connection is a phenol side group

Polystyrene is a very common plastic, often marked with recycling code 6. It can be found in two forms:

- **Styrofoam**: Air is pumped in during production, making it light and fluffy.
- **Hard and Dense**: No air is added, resulting in a denser material, like the brown Tim Hortons cups.

Mixing Monomers

Chemists and companies like DuPont are always experimenting with mixing different monomers to create new products with mass market appeal. Many times, these discoveries are accidental.

One example is Scotch tape. The glue was originally intended to be permanent, but it ended up being removable, which proved to be a useful property.

Example: Bromoethene and Tetrachloroethene

If we mix **bromoethene** and **tetrachloroethene** together, we get a repeating unit with one of each. If mixed in the right ratio, it will keep alternating. The repeating pattern will be BrH followed by CCl_2.

Polymerization Reactions

Backwards Testing

Alberta Education has started testing students on polymers by showing them a **polymer** and asking what **monomer** created it. Students must understand the bonds well enough to identify the family or draw the structure of the monomers. For example, a question might present a polymer and ask which of the multiple-choice answers shows the correct monomer that makes up the polymer.

Addition Polymerization

In addition polymerization, a **double bond** is broken to connect monomers.

- The **monomer** must be an **-ene**, not an **-ane**, because the double bond is essential for the reaction.
- It is possible to be asked what two monomers make a given polymer, requiring careful examination of the repeating pattern.

Condensation Polymers

Condensation polymers undergo a **dehydration reaction**, similar to ester formation, but are categorized differently because the reaction repeats extensively.

- What sets them apart from ester chemistry is all of the monomers have two functional groups, allowing connection on both sides.

> **Dehydration Reaction:** A chemical reaction that involves the removal of a water molecule from a reactant.

Process

1. **Di-functional acid** and **di-functional alcohol** monomers react.
2. An **alcohol** can react on one side of a **carboxylic acid** and extend the chain, while another **carboxyl group** on the other side can also grow the chain to the right.
3. The **hydroxyl group** on the alcohol can grow to the left and right, creating a polymer instead of just an ester.

During esterification, the alcohol connects to a carbon atom, and a hydroxyl group is removed, initiating the connection.

$C = O$

The hydroxyl group that comes off connects to the carbon.

Visualizing Polymers

Imagine the process happening repeatedly, growing the polymer chain.

Model Representation

$Acid - Alcohol - Acid - Alcohol...$

Polyesters and Trademarked Names

In general, anything that is condensation polymerization that is bi-functional, you will make a **polyester**.

- **Polyester** is a general term for polymers made this way.
- **Nylon** is a trademarked name by DuPont for a specific type of polyester.

Byproducts

Two water molecules are produced as byproducts, one from each end of the reaction. Balancing these reactions is typically not required.

Flammability of Polyesters

Polyester materials are highly flammable and should be kept away from heat sources.

Biological Polymers

After discussing synthetic polymers, we can transition to biological polymers.

- Amino acids make up DNA.
- Starches are polymers made out of sugar.

Biological Molecules

Tri-Fatty Acids

- **Tri-fatty acids** are a type of biological molecule.
- They involve a polyester type of chemistry occurring three times.

> **Glycerol**: A three-carbon alcohol with an -OH group on each carbon, allowing it to form ester linkages through reactions with carboxylic acids. The length of the acid piece can vary.

- The product has three carbons from the alcohol, each with an ester linkage.
- **Tri-fatty acid** is the polymer, while **glycerol** and **fatty acids** are the monomers.

Amino Acids, DNA, and RNA

- **Amino acids** can be linked together to form **dipeptides** (two amino acids) or **polypeptides** (many amino acids).
- There are 20 different amino acids that serve as the building blocks of life.
- Important monomer-polymer pairs to be familiar with:
    - DNA
    - RNA

Carbohydrates and Sugars

- When eating sugars, you're consuming **carbohydrates** and **cellulose**.
- **Monosaccharides** are the monomers.
  - Putting two sugars together creates a **disaccharide**.
  - Putting many together forms **polysaccharides**.
- Examples of monosaccharides include **glucose** and **fructose**.
- Examples of polysaccharides:
  - **Carbohydrates** that humans can consume.
  - **Celluloses** (grasses) that cows can break down but humans can't.
  - **Complex carbohydrates** (like pastas) take longer for our bodies to break down, providing energy more slowly.
- Connect the monomers and polymers:
  - **Glucose** (monomer) and **carbohydrate** (polymer).

Cracking

Hydrocarbon Cracking

- **Cracking** is a process of breaking down compounds, crucial for the Alberta energy industry.
- Often, what comes out of the ground isn't what customers want, necessitating the breaking down of compounds.

> **Cracking**: A reaction where a large molecule is broken into two or more smaller molecules using heat and pressure.

- Example: a large molecule $C_{20}H_{42}$ is broken into $C_{11}H_{22}$ (diesel fuel or gasoline) and C_9H_{20}.
- When cracking, you get varying pieces, not uniform results.
- Essential for taking what comes out of the ground and making it sellable, especially in Alberta's oil sands, which contain longer-chained hydrocarbons.
- Cracking is less necessary for light sweet oil from places like Saudi Arabia, which already contains more smaller chains.

Introduction to Polymers

In organic chemistry, we're moving into a section focused on **polymers**. These are large structures, and instead of using the term "reactants," we'll use "**monomer**" to describe the single unit that builds up into the larger structure.

> A **monomer** is a single unit that can join together with other monomers to form a larger structure called a polymer.

The resulting products are called "**polymers**," consisting of many repeating units (tens of thousands or even hundreds of thousands). The molar mass of polymers can reach into the millions per mole. Polymers are flexible and are the plastics we use daily.

> A **polymer** is a large molecule made up of many repeating subunits called monomers.

IUPAC Naming Conventions

Monomers are named following standard organic chemistry nomenclature. Polymer IUPAC names indicate the type of polymer but not its exact size.

For example:

- `poly(monomer_name)`

This is a general classification, indicating that many monomers have come together.

Addition Polymerization

Addition polymerization is our first type, where monomers add to each other. Think of it like the addition reactions you've learned, where a double bond breaks. Let's start with two monomers and then expand to many.

Ethene Example

Consider **ethene** (two carbons with a double bond) as our monomer. In addition chemistry, the second, weaker bond breaks, allowing monomers to link up via carbon-carbon connections.

$$CH_2 = CH_2 + CH_2 = CH_2 \rightarrow -[CH_2 - CH_2 - CH_2 - CH_2]-$$

At each end, another monomer can add. To represent a large number of monomers, we can show a repeating pattern.

If we have ten ethene molecules, the extra bond breaks, and connections form. At each side of the monomer where the double bond used to be, future connections can occur. To show this repeated unit, we use square brackets with lines coming out, indicating repetition *n* number of times.

$$-[CH_2 - CH_2]_n-$$

This polymer's common name is **polyethylene**. It is used in number two and number four recycling plastic codes, commonly found in milk jugs and containers.

Propene Example

Next, consider **propene** (three carbons with a double bond). We can create **polypropene** from it.

Starting with two propene monomers:

- There are always four substituents around the double bond.
- These substituents will show up in our repeating unit.

When two units come together, the monomer propene makes the polymer polypropene. This is the number three plastic code.

The typical exam representation is one unit with *n* of those:

$$-[CH_2 - CH(CH_3)]_n-$$

Styrene Example

Styrene is the monomer used to create **polystyrene** (styrofoam). Styrene contains a benzene ring.

When you break the double bonds of styrene and link the units together, you get polystyrene.

Two styrene units connecting:

$$-[CH_2 - CH(C_6H_5)]_n-$$

These are your number six plastics. The density can vary, resulting in styrofoam packing chips or Tim Horton's lids, which are denser forms of polystyrene.

Creative Examples

Let's consider a more creative example with bromine and chlorine atoms. Suppose we have monomers with bromine and chlorine in the molecule, creating an alternating pattern.

If we have two carbons in the repeating unit, with a Cl, H, and H, we can deduce that we need an alkene to have made this polymer. For example, 1-bromo-2-chloroethene.

Condensation Polymerization

Condensation polymers involve the same chemistry as ester reactions, but the monomers have two functional groups that can form ester linkages. This involves two carboxyl groups in the acid and two hydroxyl groups in the alcohol.

You add a large amount of each monomer, and the hydroxyl group in the carboxylic acid connects to the carbon in the alcohol, forming an ester linkage.

In this reaction, water is produced. This reaction occurs at both ends, creating a repeating pattern on each side. This results in a repeating chain of acid-alcohol-acid-alcohol.

Polyesters: Building Blocks and Decoding

Let's explore how to identify the monomers that make up a polyester, working backward from the polymer structure.

Identifying Monomers in Polyesters

1. **Locate the Oxygen in the Backbone**: The "O" in the repeating backbone pattern is key. This helps identify the **acid** and **alcohol** pieces that combined to form the ester linkage.

2. **Find the Carbonyl Group**: Look for the carbonyl group (C=O). This is the **acid side**. The other side connected to the oxygen will be the **alcohol side**.

Building Back the Monomers

Let's consider a polyester with a repeating unit represented as "rocket" repeating n times.

$$[rocket]_n$$

To decode this polyester, we need to identify the acid and alcohol monomers that formed it.

1. **Acid Component**: If the acid portion has two carbons, construct a full carboxyl group on both sides of those two carbons to complete the acid component.
2. **Alcohol Component**: On the alcohol side, determine the number of carbons and ensure you identify the correct number of hydroxyl groups (-OH). Wrong answer choices on a test might have the correct carbon count but an incorrect number of hydroxyl groups.

Example

Imagine our polyester repeating unit has a two-carbon acid component and a one-carbon alcohol component. The monomers would be:

- **Acid**: A two-carbon diacid (i.e., an acid with carboxyl groups on both ends).
- **Alcohol**: A one-carbon dialcohol (i.e., an alcohol with two hydroxyl groups).

Key Vocabulary

> **Monomer**: A molecule that can bond to other identical molecules to form a polymer.
>
> **Polymer**: A substance or material consisting of very large molecules, or macromolecules, composed of many repeating subunits.

Polyester: A polymer containing ester functional groups in its main chain.

Carbonyl Group: A functional group composed of a carbon atom double-bonded to an oxygen atom (C=O).

Hydroxyl Group: A functional group consisting of an oxygen atom bonded to a hydrogen atom (-OH).

Polymer Skills

- Predicting polymers from monomers.
- Predicting monomers from polymers (working backward).

No need to worry about drawing these structures for the test. Focus on being able to interpret diagrams, work forward and backward, and name the compounds involved.

Introduction to Polymers

Which of the following monomers is used to create polystyrene, commonly known as styrofoam?

A
Ethene
B
Propene
C
Styrene
D
Polyethylene

Styrene is the monomer used to create polystyrene, which is commonly known as styrofoam and is plastic code number six.

Which of the following polymers is formed through condensation polymerization, producing water as a byproduct?

A
Polyethylene
B
Polystyrene
C
Polyester
D
Polypropene

Polystyrene is made from styrene monomers through addition polymerization. This process involves breaking the double bonds and linking the styrene units directly, without the production of water.

Polyesters are formed via condensation polymerization, a process analogous to ester reactions, where monomers with two functional groups form ester linkages and produce water as a byproduct.

Consider the two main types of polymerization discussed: addition and condensation. Addition polymerization involves direct linking of monomers, while condensation polymerization involves the formation of a small molecule, such as water, as a byproduct. Recall which type involves ester linkages.

A polymer is represented by the structure -[CH2-CH(Cl)]n-. Which monomer was used to create this polymer?

A
Chloroethene
B
Ethene
C
Propene
D
Styrene

The polymer -[CH2-CH(Cl)]n- is formed from chloroethene (also known as vinyl chloride). During polymerization, the double bond in chloroethene breaks, allowing the monomers to link together.

Consider the structure of the repeating unit in the polymer. What functional group is attached to the carbon backbone? Focus on the smallest repeating unit and identify the corresponding monomer that would yield this structure through addition polymerization.

A chemist is trying to create a polymer similar to polyethylene but with slightly different properties. Which monomer would be most suitable for creating a polymer with a repeating unit of -[CH(CH3)-CH2]n-?

A

Ethene

B

Propene

Propene (CH3CH=CH2) would result in a polymer with a repeating unit of -[CH(CH3)-CH2]n- after polymerization occurs at the double bond.

C

Styrene

D

1-bromo-2-chloroethene

Remember that in addition polymerization, the double bond in the monomer breaks, allowing monomers to link up. Consider the structure of each monomer and how it would contribute to the repeating unit of the polymer. Ask yourself: Which of these monomers contains a methyl group (CH3) that could be present in the repeating unit shown?

A polymer has the repeating unit -[CH2-CH(C6H5)]n-. What monomer is used to create this polymer, and what is the common name of the resulting polymer?

A

Ethene; Polyethylene

B

Propene; Polypropene

C

Styrene; Polystyrene

The repeating unit -[CH2-CH(C6H5)]n- corresponds to polystyrene, which is created from the monomer styrene, containing a benzene ring (C6H5).

D

1-bromo-2-chloroethene; Poly(1-bromo-2-chloroethene)

Think about the structure that includes a benzene ring. Consider what monomer results in polystyrene. Review the examples of polymers and monomers in the text to match the repeating unit.

A scientist discovers a new polyester with a repeating unit containing a three-carbon acid component and a two-carbon alcohol component. Which combination of monomers would form this polyester?

A

A three-carbon diacid and a two-carbon dialcohol.

A polyester is formed from a diacid and a dialcohol. A three-carbon diacid provides the acid portion, while a two-carbon dialcohol provides the alcohol portion of the repeating unit in the polyester.

B

A three-carbon monoacid and a two-carbon monoalcohol. wrong

C

A two-carbon diacid and a three-carbon dialcohol.

D

A two-carbon monoacid and a three-carbon monoalcohol.

A polyester requires two functional groups on each monomer (a diacid and a dialcohol) to enable the polymerization process at both ends, creating a repeating pattern. → wrong

Which of the following polymers is created through addition polymerization?

A
Polyester

Polyesters are formed through condensation polymerization, where monomers link by forming ester bonds and releasing water as a byproduct. This process is distinct from addition polymerization.

B
Polyethylene

Polyethylene is formed from the addition polymerization of ethene monomers, where the double bond breaks and monomers link together directly without the loss of any atoms or molecules.

C
A polymer formed from a diacid and a dialcohol

D
A polymer with ester linkages in the main chain

A new polymer is synthesized with the repeating unit -[CH2-CH(Br)]n-. What is the IUPAC name of the monomer used to create this polymer?

A
poly(bromoethene)

B
poly(ethene bromide)

C
poly(1-bromoethene)

The monomer used is 1-bromoethene, which polymerizes to form poly(1-bromoethene). The '1-' indicates that the bromine atom is attached to the first carbon in the ethene molecule.

D
poly(2-bromoethene)

A scientist is analyzing a polymer sample and identifies the repeating unit as -[CH2-CH(CH2CH3)]n-. What monomer was used to synthesize this polymer?

A
Propene

B
Butene

The repeating unit -[CH2-CH(CH2CH3)]n- indicates that butene (four carbons with one double bond) was the monomer used. During polymerization, the double bond breaks, allowing butene monomers to link together, forming the polymer.

C
Ethene

D
Styrene

A chemist aims to synthesize a polymer similar to polystyrene but using a monomer with an ethyl group (CH2CH3) attached to the carbon instead of a benzene ring (C6H5). What would be the repeating unit of this new polymer?

A
-[CH2-CH(CH2CH3)]n-

The ethyl group (CH2CH3) replaces the benzene ring (C6H5) on the carbon atom, creating the repeating unit -[CH2-CH(CH2CH3)]n-.

B
-[CH2-CH(C6H5)]n-

C
-[CH(CH3)-CH2]n-

D
-[CH2-CH(Br)]n-

Consider how the structure of styrene relates to polystyrene. Remember, the substituent attached to the carbon in the monomer will also be present in the repeating unit of the polymer. Then consider how the ethyl group should replace the benzene ring on the carbon.

A scientist is trying to synthesize a new polymer using 1-chloroethene ($CH2=CHCl$) as the monomer. What would be the repeating unit of the resulting polymer, assuming it undergoes addition polymerization?

A

-[CH2-CHCl]n-

B

-[CH2-CH2]n-

C

-[CHCl-CHCl]n-

D

-[CH3-CHCl]n-

Think about addition polymerization and how the double bond in the monomer breaks to form single bonds to connect with other monomers. Consider what atoms will be directly attached to the carbon atoms in the repeating unit based on the structure of 1-chloroethene (CH2=CHCl).

Consider a polymer formed from the monomer 2-chloro-1,3-butadiene ($CH_2 = CCl - CH = CH_2$). If this monomer undergoes *addition polymerization*, what would be the repeating unit of the resulting polymer?

A -[CH2-CCl=CH-CH2]n-

In addition polymerization, the double bonds break, and the monomers link together. For 2-chloro-1,3-butadiene, the repeating unit is -[CH2-CCl=CH-CH2]n- where the double bond shifts to between the second and third carbon atoms.

B -[CH2-CH=CCl-CH2]n-

C -[CH3-CCl=CH-CH2]n-

D -[CH2-CCl=CH-CH3]n-

Remember that addition polymerization involves the breaking of double bonds in the monomer and the formation of single bonds to create a repeating unit. In the monomer 2-chloro-1,3-butadiene, the double bonds will break, allowing the monomers to link. Think about where the chlorine atom is located and how the double bonds rearrange to create the repeating unit. Review the ethene example.

Which of the following is NOT a typical characteristic of polymers?

A

Composed of repeating monomer units.

B

Formed through addition or condensation reactions.

C

Low molar mass compared to monomers.

Polymers have a very high molar mass due to their large size, resulting from the many repeating monomer units, not low.

D

Can be flexible, like many plastics.

A scientist discovers a new polyester and determines its repeating unit includes a carbonyl group (C=O) connected to a two-carbon chain, which then connects to an oxygen atom linked to a one-carbon chain. What monomers are most likely used to create this polyester?

A

Ethanoic acid and methanol.

B

A two-carbon diacid and a one-carbon dialcohol.

In polyester formation, the repeating unit includes an acid component and an alcohol component. The acid contributes the carbonyl group (C=O) and connects to a carbon chain, while the alcohol provides the oxygen linkage. A two-carbon diacid means there are carboxyl groups on both ends of the two-carbon chain, while a one-carbon dialcohol means there are two hydroxyl groups on the single carbon.

C

A two-carbon dialcohol and a one-carbon diacid.

D

Propanal and ethanol.

A chemist is analyzing a polymer and discovers that it contains ester linkages in the main chain. Which type of polymer is the chemist most likely analyzing?

A

An addition polymer.

B

A condensation polymer.

Condensation polymers, such as polyesters, are formed through the reaction of monomers containing two functional groups, leading to the creation of ester linkages and the release of a small molecule, such as water. Therefore, the presence of ester linkages indicates a condensation polymer.

C

A polymer made from alkenes.

D

A polymer with carbon-carbon double bonds.

- polyester is formed through condensation, where water gets produced as a byproduct.

Which of the following polymers is formed via *addition polymerization* from the monomer vinyl chloride ($CH_2 = CHCl$)?

- ✓ $[-CH_2 - CHCl-]_n$
- $[-CH_2 - CH = CH - CHCl-]_n$
- $[-CH_2 - CHBr-]_n$
- $[-CHOH - CHOH-]_n$

Explanation

Correct. In *addition polymerization*, the double bond breaks and the monomers link up. Therefore, $CH_2 = CHCl$ becomes $[-CH_2 - CHCl-]_n$ when it polymerizes.

Which of the following monomers would result in a polymer with the repeating unit -[$CH_2 - CH(CH_2CH_3)$]-*n*-, assuming *addition polymerization* occurs?

- Butane
- ✓ Butene
- Cyclobutane
- 2-Butene

Explanation

Correct. Butene (specifically, 1-butene) has a double bond that can break during *addition polymerization*, allowing it to form the repeating unit -[$CH_2 - CH(CH_2CH_3)$]-*n*-.

Name ________________________________

Chapter 20 Naming Carboxylic Acids Practice Worksheet

Carboxylic Acids:

Carboxylic Acids are named by counting the number of carbons in the logest continuous chain including the carboxyl group (—COOH)and by replacing the suffix '**-ane**' of the corresponding alkane with '**-anoic acid**.' If there are two —COOH groups, the suffix is expanded to include a prefix that indicates the number of —COOH groups present (**-anedioic acid** – there should not be more than 2 of these croups on the parent chain as they must occur at the ends). It is not necessary to indicate the position of the —COOH group because this group will be at the end of the parent chain and its carbon is automatically assigned as C-1.

$CH_3 — CH_2 — C(=O) — OH$

propanoic acid

$CH_3 — CH(CH_3) — CH_2 — C(=O) — OH$

3-methylbutanoic acid

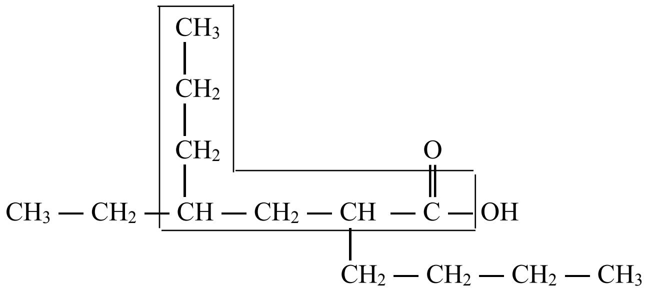
1. Complete the exercise below by entering the formulas and condensed structural formulas of the first ten aldehydes.

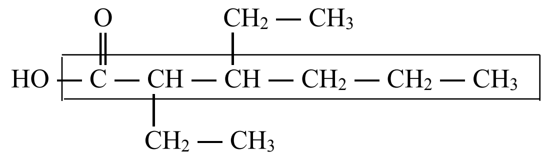
	Carboxylic Acid Name	*Condensed Structural Formula*	
a.	methanoic acid	COOH (O=)	CHO_2
2 b.	Ethanoic acid	$H_3C — C(=O) — O — H$	$C_2H_4O_2$
3 c.	propanoic acid	$CH_3 — CH_2 — C(=O) — OH$	$C_3H_6O_2$
d.	butanoic acid	CH_3-CH_2-CH_2-COOH	$C_4H_8O_2$
e.	Pentanoic acid	CH_3-CH_2-CH_2-CH_2 —COOH	$C_5H_{10}O_2$
f.	Hexanoic acid	$C_6H_{12}O_2$	
g.	Heptanoic acid	$C_7H_{14}O_2$	
h.	Octanoic acid	$C_8H_{16}O_2$	
i.	Nonanoic acid	$C_9H_{18}O_2$	
j.	Decanoic acid	$C_{10}H_{20}O_2$	

Name ____________________

IUPAC Rules for Naming Carboxylic Acids:

<u>RULE 1</u>: The carboxyl group takes precedence over alkyl groups and halogen substituents, as well as double bonds, in the number of the parent chain.

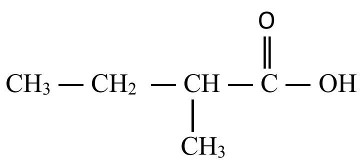




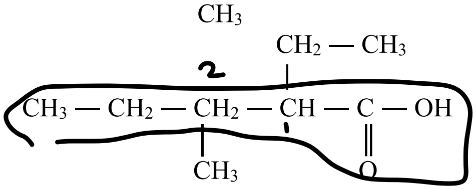
2,3-diethylhexanoic acid

4-ethyl-2-butylheptanoic acid

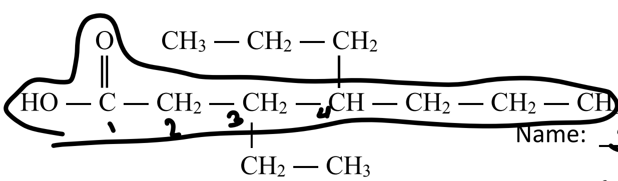
2. For the following compounds, draw a box around the longest continuous carbon chain and name each molecule. Number the carbons in the longest chain so that the alkyl group(s) will be on the <u>lowest</u> numbered carbons. The first one is done for you.

a. 

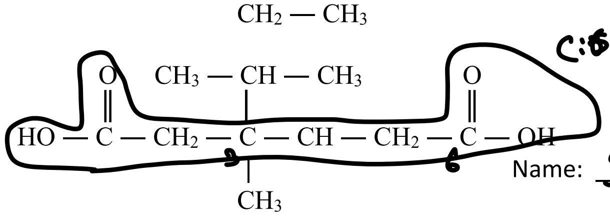
Name: 2-methylbutanoic acid

b. 

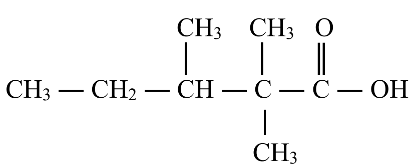
Name: 1-ethyl, 2-methyl, pentanoic acic

c. 

Name: 3-ethyl, 4-propyl, heptanoic acid

d. 

Name: 3-methyl, 3-propyl hexanedioic acid.

e. 

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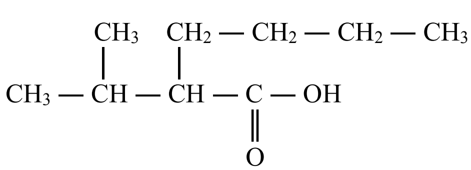
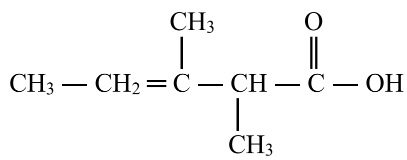
f. 

Name: ____________________

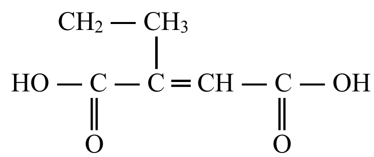
 Name ________________________________

RULE 2: If the carboxyl group is attached to a ring, the parent ring is named and the suffix **–carboxylic acid** is added.

RULE 3: When both double bonds and carboxyl groups are present, the **–en** suffix follows the parent chain directly and the **–oic acid** suffix follows the –en suffix (notice that the e is left off, **-en** instead of –ene). The location of the double bond(s) is(are) indicated before the parent name as before, and the –oic acid suffix follows the –en suffix directly. Remember it is not necessary to specify the location of the carboxyl group because it will automatically be carbon #1. See below for examples. Again, the carboxyl gets priority in the numbering of the parent chain.

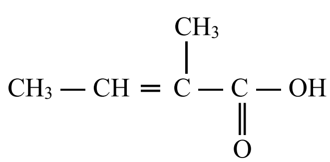


2,3-dimethyl-3-pentenal

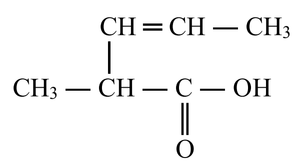


2-ethyl-2-butenedioic acid

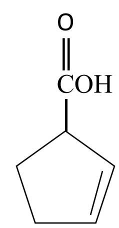
RULE 4: If there is a choice in numbering not previously covered, the parent chain is numbered to give the substituents the **lowest** number at the **first point of difference**.



2-methyl-2-butenoic acid

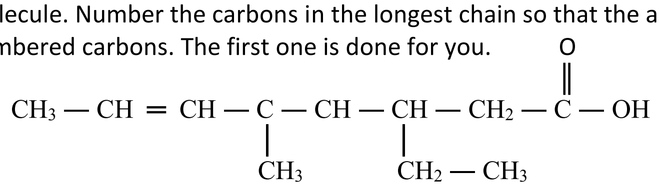


2-methyl-3-pentenoic acid

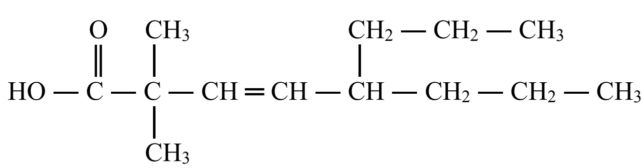


2-cyclo-3-pentenoic acid

3. For the following compounds, draw a box around the longest continuous carbon chain and name each molecule. Number the carbons in the longest chain so that the alkyl group(s) will be on the lowest numbered carbons. The first one is done for you.

a. 

Name: 3-ethyl-5-methyl-6-octenoic acid

b. 

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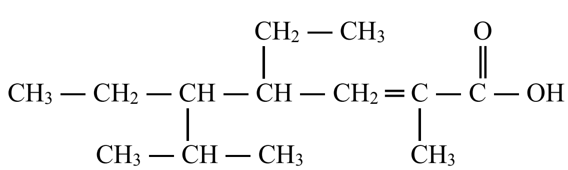
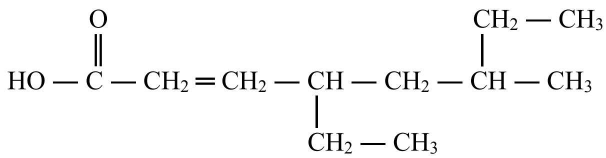
c. 

Name: ________________________________

Name ____________________

d. 

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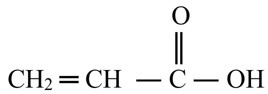
e. 

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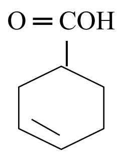
f. 

Name: ____________________

4. Draw the following compounds.

a. 4-methylhexanoic acid

b. 3-methylbutanoic acid

c. 2,6-dimethylheptanoic acid

d. 2-methyl-3-isopropylpentanoic acid

e. 3-ethyl-6-methyl-3-octenoic acid

f. 4-methyl-2-pentenoic acid

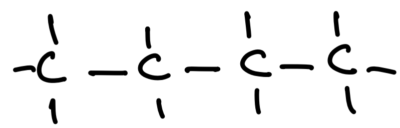
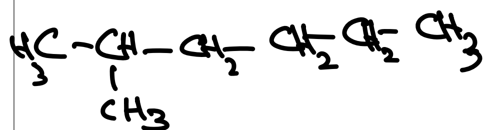
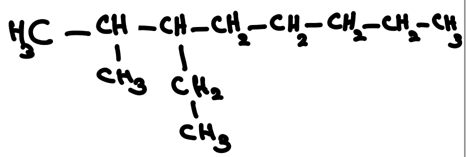
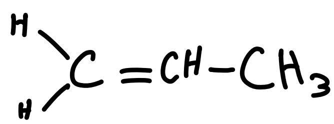
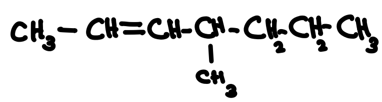
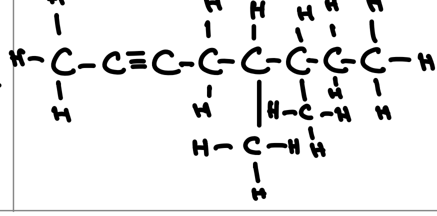
g. 3-ethyl-5-nonenoic acid

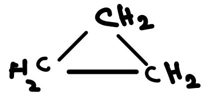
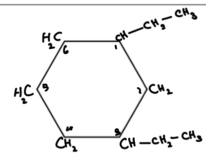
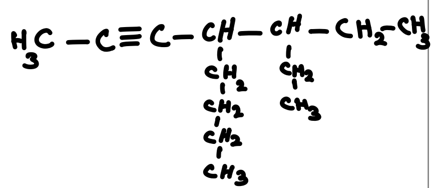
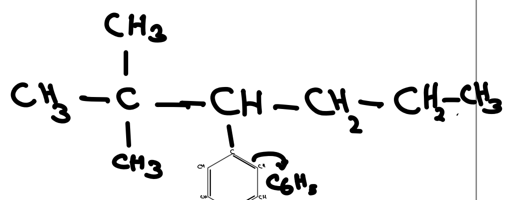
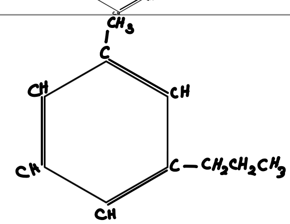
h. 3-ethyl-2-cyclopentanoic acid

Name: ____________________________ Date: ____________________

Organic Chemistry - HYDROCARBONS WORKSHEET

Draw the complete structural formula and condensed molecular formula for each compound.

IUPAC Name	Complete Structural Formula	Condensed Formula
Single butane C_4H_{10} 4C n 2n+2		C_4H_{10}
Single bond alkane: ← 2-methylhexane CH_3 C_6		C_7H_{16}
CH_3 3-ethyl-2-methylnonane $-CH_2-CH_3$ C_9		$C_{12}H_{26}$
alkene: double bond propene 3		C_3H_6
double bond 4-methyl-2-heptene CH_3 7	 H:16	C_8H_{16}
alkyne: triple bond ethyne 2	$H-C \equiv C-H$	C_2H_2 n 2n-2
2 triple 5,6-dimethyl-2-octyne CH_3 8		$C_{10}H_{18}$

cyclopropane		C_3H_6
1,3-diethylcyclohexane		$C_{10}H_{20}$
5-ethyl-4-propyl-2-heptyne		$C_{12}H_{22}$
2,2-dimethly-3-phenylhexane		$C_{14}H_{22}$
1-methyl-3-propylbenzene		$C_{10}H_{14}$

Draw structural formulae and give the names for the five possible (noncyclic) isomers of C_6H_{14}.