

# Structure 3.2

# Answers

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IB CHEMISTRY SL

<p>25 <b>Mn</b> Manganese 54.938045</p>	<p>16 <b>S</b> Sulfur 32.065</p>	<p><b>J</b></p>	<p>6 <b>C</b> Carbon 12.0107</p>	<p>2 <b>He</b> Helium 4.002602</p>	<p>25 <b>Mn</b> Manganese 54.938045</p>
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### Structure 3.2.1

#### Understandings:

- Organic compounds can be represented by different types of formulas. These include empirical, molecular, structural (full and condensed), stereochemical and skeletal.

#### Learning outcomes:

- Identify different formulas and interconvert molecular, skeletal and structural formulas.
- Construct 3D models (real or virtual) of organic molecules.

#### Additional notes:


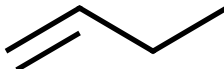
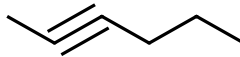
- Stereochemical formulas are not expected to be drawn, except where specifically indicated.

#### Linking questions:

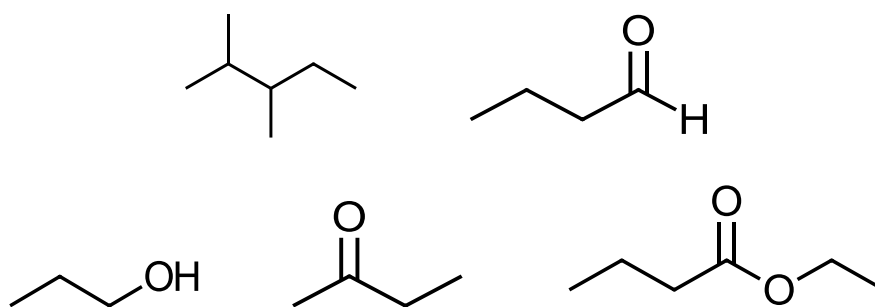
- Structure 2.2 What is unique about carbon that enables it to form more compounds than the sum of all the other elements' compounds?

#### Structural formulae

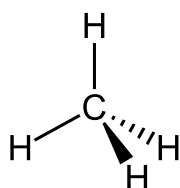
- The different types of formulas used in organic chemistry are shown below.

Compound	Molecular formula	Empirical formula	Full structural formula	Condensed structural formula	Skeletal formula
Butane	C <sub>4</sub> H <sub>10</sub>	C <sub>2</sub> H <sub>5</sub>	$\begin{array}{cccc} & \text{H} & \text{H} & \text{H} & \text{H} \\ &   &   &   &   \\ \text{H} & -\text{C} & -\text{C} & -\text{C} & -\text{C}-\text{H} \\ &   &   &   &   \\ & \text{H} & \text{H} & \text{H} & \text{H} \end{array}$	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>2</sub> CH <sub>3</sub>	
But-1-ene	C <sub>4</sub> H <sub>8</sub>	CH <sub>4</sub>	$\begin{array}{cccc} & \text{H} & \text{H} & \text{H} & \text{H} \\ &   &   &   &   \\ \text{H} & -\text{C} & =\text{C} & -\text{C} & -\text{C}-\text{H} \\ &   & &   &   \\ & \text{H} & & \text{H} & \text{H} \end{array}$	CH <sub>2</sub> CHCH <sub>2</sub> CH <sub>3</sub>	
Hex-2-yne	C <sub>6</sub> H <sub>10</sub>	C <sub>3</sub> H <sub>5</sub>	$\begin{array}{cccc} & \text{H} & & \text{H} & \text{H} & \text{H} \\ &   & &   &   &   \\ \text{H} & -\text{C} & -\text{C}\equiv\text{C} & -\text{C} & -\text{C} & -\text{C}-\text{H} \\ &   & &   &   &   \\ & \text{H} & & \text{H} & \text{H} & \text{H} \end{array}$	CH <sub>3</sub> CCCH <sub>2</sub> CH <sub>2</sub> CH <sub>3</sub>	

### Skeletal formulae



### Stereochemical formulae



- The two solid lines are in the plane of the paper.
- The wedge is coming out from the plane of the paper.
- The dashed line is going into the plane of the paper.

### **Structure 3.2.2**

#### **Understandings:**

- Functional groups give characteristic physical and chemical properties to a compound. Organic compounds are divided into classes according to the functional groups present in their molecules.

#### **Learning outcomes:**

- Identify the following functional groups by name and structure: halogeno, hydroxyl, carbonyl, carboxyl, alkoxy, amino, amido, ester, phenyl.

#### **Additional notes:**

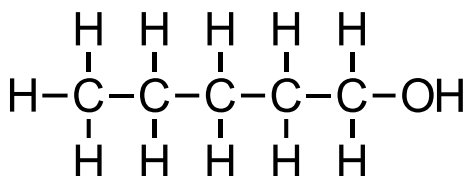
- The terms “saturated” and “unsaturated” should be included.

#### **Linking questions:**

- Structure 2.4 (HL) What is the nature of the reaction that occurs when two amino acids form a dipeptide?

## Functional groups

- A functional group is a group of atoms within a molecule that are responsible for the characteristic chemical reactions of the molecule.

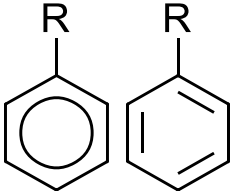
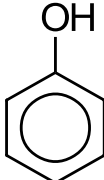


Class: alcohol

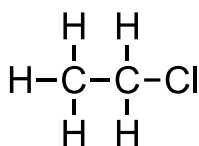
Functional group: hydroxyl group

Class	Functional group name	Structural formula	Example
Alkane		$  \begin{array}{cc}  \text{H} & \text{H} \\    &   \\  -\text{C} & -\text{C}- \\    &   \\  \text{H} & \text{H}  \end{array}  $	$  \begin{array}{cc}  \text{H} & \text{H} \\    &   \\  \text{H}-\text{C} & -\text{C}-\text{H} \\    &   \\  \text{H} & \text{H}  \end{array}  $ <p>Ethane <math>\text{CH}_3\text{CH}_3</math></p>
Alkene		$  \begin{array}{c}  \diagdown \quad \diagup \\  \text{C}=\text{C} \\  \diagup \quad \diagdown  \end{array}  $	$  \begin{array}{cc}  \text{H} & & \text{H} \\  & \diagdown & / \\  & \text{C}=\text{C} & \\  & / & \diagdown \\  \text{H} & & \text{H}  \end{array}  $ <p>Ethene <math>\text{C}_2\text{H}_4</math></p>
Alkyne		$  -\text{C}\equiv\text{C}-  $	$  \text{H}-\text{C}\equiv\text{C}-\text{H}  $ <p>Ethyne <math>\text{CHCH}</math></p>
Aldehyde	Carbonyl	$  \begin{array}{c}  \text{O} \\  // \\  \text{R}-\text{C} \\    \\  \text{H}  \end{array}  $ <p>R-CHO</p>	$  \begin{array}{c}  \text{O} \\  // \\  \text{H}_3\text{C}-\text{C} \\    \\  \text{H}  \end{array}  $ <p>Ethanal <math>\text{CH}_3\text{CHO}</math></p>
Ketone	Carbonyl	$  \begin{array}{c}  \text{O} \\  // \\  \text{R}-\text{C}-\text{R}'  \end{array}  $ <p>R-CO-R'</p>	$  \begin{array}{c}  \text{O} \\  // \\  \text{H}_3\text{C}-\text{C}-\text{CH}_3  \end{array}  $ <p>Propanaone <math>\text{CH}_3\text{COCH}_3</math></p>

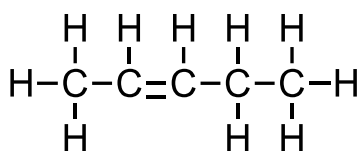
Class	Functional group name	Structural formula	Example
Alcohol	Hydroxyl	$R-OH$	$\begin{array}{c} H \\   \\ H-C-OH \\   \\ H \end{array}$ Methanol $CH_3OH$
Ester	Ester	$\begin{array}{c} O \\    \\ R-C-O-R' \end{array}$ $R-COO-R'$ $R-CO_2-R'$	$\begin{array}{c} O \\    \\ H-C-O-CH_3 \end{array}$ Methyl methanoate $HCOOCH_3$ or $HCO_2CH_3$
Ether	Ether	$R-O-R'$ $R-O-R'$	$H_3C-O-CH_3$ Methoxymethane $CH_3OCH_3$
Carboxylic acid	Carboxyl	$\begin{array}{c} O \\    \\ R-C \\   \\ OH \end{array}$ $R-COOH$ $R-CO_2H$	$\begin{array}{c} O \\    \\ H-C \\   \\ OH \end{array}$ Methanoic acid $HCOOH$ or $HCO_2H$

Class	Functional group name	Structural formula	Example
Amine	Amino	$\begin{array}{c} \text{H} \\   \\ \text{R}-\text{N} \\   \\ \text{H} \\ \text{R}-\text{NH}_2 \end{array}$	$\begin{array}{c} \text{H} \\   \\ \text{H}_3\text{C}-\text{N} \\   \\ \text{H} \\ \text{Methanamine} \\ \text{CH}_3\text{NH}_2 \end{array}$
Amide	Amido	$\begin{array}{c} \text{O} \\    \\ \text{R}-\text{C}-\text{NH}_2 \\ \text{R}-\text{CONH}_2 \end{array}$	$\begin{array}{c} \text{O} \\    \\ \text{H}_3\text{C}-\text{C}-\text{NH}_2 \\ \text{Methanamide} \\ \text{CH}_3\text{CONH}_2 \end{array}$
Arene	Phenyl	 $\text{C}_6\text{H}_5-$	 Phenol $\text{C}_6\text{H}_5\text{OH}$
Halogenoalkane	Fluoro- Chloro- Bromo- Iodo-  where X is a F, Cl, Br or I atom	$\text{R}-\text{X}$	$\begin{array}{c} \text{H} \\   \\ \text{H}-\text{C}-\text{Cl} \\   \\ \text{H} \\ \text{Chloromethane} \\ \text{CH}_3\text{Cl} \end{array}$

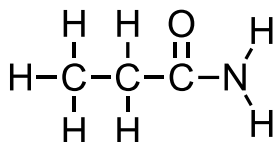
Answers:



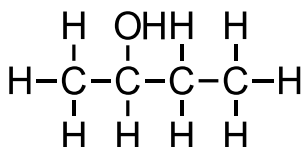
Class: **halogenoalkane**  
Functional group: **halogeno**



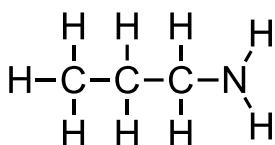
Class: **alkene**  
Functional group: **alkenyl**



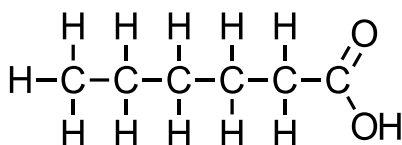
Class: **amide**  
Functional group: **amido**



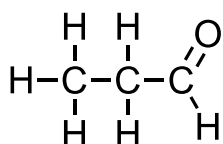
Class: **alcohol**  
Functional group: **hydroxyl**



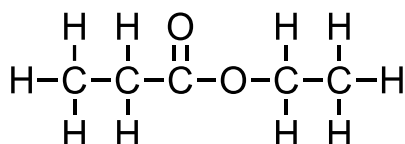
Class: **amine**  
Functional group: **amino**



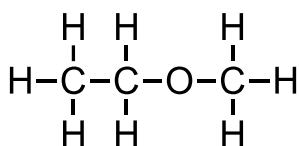
Class: **carboxylic acid**  
Functional group: **carboxyl**



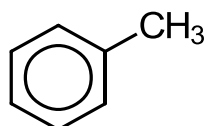
Class: **aldehyde**  
Functional group: **carbonyl**



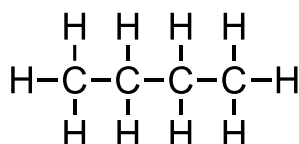
Class: **ester**  
Functional group: **ester**



Class: **ether**  
Functional group: **alkoxy**



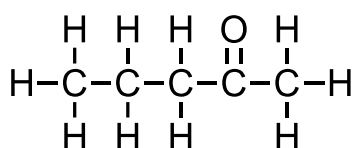
Class: **arene**  
Functional group: **phenyl**



Class: **alkane**  
Functional group:



Class: **alkyne**  
Functional group: **alkynyl**



Class: **ketone**  
Functional group: **carbonyl**



### Structure 3.2.3 and 3.2.4

#### Understandings:

- A homologous series is a family of compounds in which successive members differ by a common structural unit, typically CH<sub>2</sub>. Each homologous series can be described by a general formula (3.2.3).
- Successive members of a homologous series show a trend in physical properties (3.2.4).

#### Learning outcomes:

- Identify the following homologous series: alkanes, alkenes, alkynes, halogenoalkanes, alcohols, aldehydes, ketones, carboxylic acids, ethers, amines, amides and esters (3.2.3).
- Describe and explain the trend in melting and boiling points of members of a homologous series (3.2.4).

#### Additional notes:

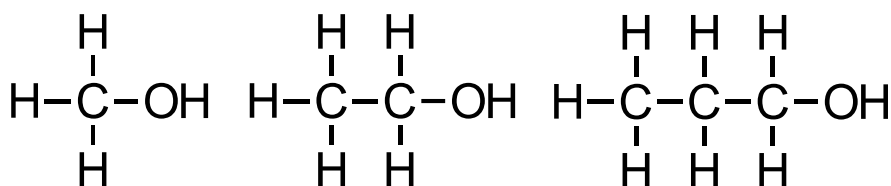
- The terms “saturated” and “unsaturated” should be included.

#### Linking questions:

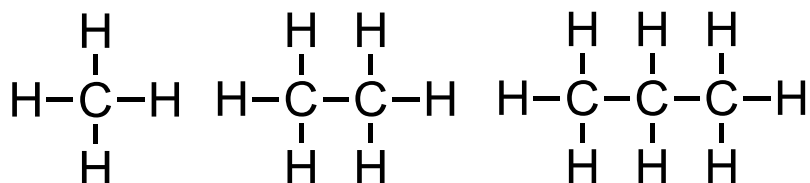
- Structure 2.4 (HL) What is the nature of the reaction that occurs when two amino acids form a dipeptide?
- Structure 2.2 What is the influence of the carbon chain length, branching and the nature of the functional groups on intermolecular forces?

#### Homologous series

- A homologous series is a series of organic compounds of the same family which differ by a common structural unit (CH<sub>2</sub>).



- Functional group: hydroxyl (OH) – each member differs by a CH<sub>2</sub> group.
- Members of a homologous series have similar chemical properties.



- Members of a homologous series show a gradation in physical properties (such as the increasing boiling point of the alkanes).
- They also have the same general formula.

**Summary:** Members of a homologous series:

- differ by a  $\text{CH}_2$
- have the same general formula
- have similar chemical properties
- show a gradation (gradual increase) in physical properties such as boiling point
- have the same functional group

## Factors that affect the boiling points of organic compounds

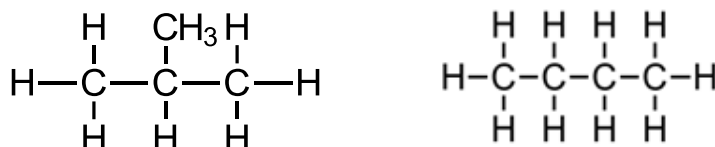
### Molar mass and boiling point

alkane	molar mass ( $\text{g mol}^{-1}$ )	boiling point ( $^{\circ}\text{C}$ )
methane	16	-164
ethane	30	-89
propane	44	-42
butane	58	-0.5
pentane	72	36
hexane	86	69
heptane	100	98
octane	114	125
nonane	128	151
decane	142	174

- As the molar mass of the compound increases, the boiling point increases.
- As the molar mass increases, the strength of the London dispersion forces between the molecules increases (the molecules have more electrons and are more easily polarisable).
- More energy is required to overcome the London dispersion forces between the molecules, therefore, the boiling point increases.

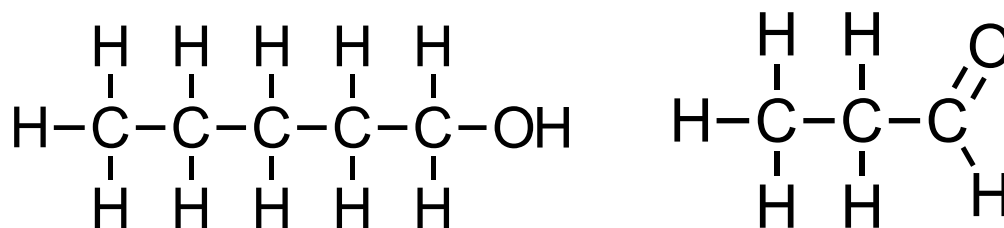
### Branched chain isomers vs straight chain isomers

- Branched-chain isomers have lower boiling points than straight-chain isomers.
- The branches reduce the contact surface area between the molecules which reduces the strength of the London dispersion forces between the molecules and lowers the boiling point.
- The structures of 2-methylpropane (boiling point  $-11.7^{\circ}\text{C}$ ) and butane (boiling point  $-1^{\circ}\text{C}$ ) are shown below.

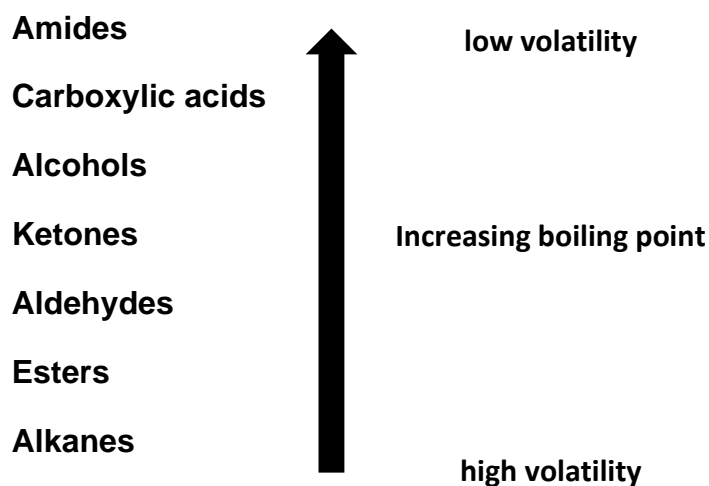


- 2-methylpropane, a branched alkane, has a lower boiling than butane.
- The branches result in a lower contact surface area between the molecules.

## Effect of functional group



- Compounds with functional group containing H bonded to O or N have hydrogen bonding between their molecules.
- Compounds with functional group containing carbonyl group (C=O) have dipole-dipole forces between their molecules.
- Alcohols, amides and carboxylic acids have higher boiling points as they are able to form hydrogen bonds between their molecules.
- Aldehydes, ketones, and esters have dipole-dipole forces between their molecules.
- Alkanes, alkenes and alkynes have London dispersion forces between their molecules.



## Exercises:

1. Methane and heptane belong to the same class (the alkanes). Predict and explain which compound has a higher boiling point.

Heptane has a larger molar mass than methane and therefore stronger London dispersion forces between the molecules and a higher boiling point.

2. Explain the difference in boiling point between the structural isomers pentane and 2-methylbutane.

2-methylbutane, a branched alkane, has a lower boiling point than pentane. Branched alkanes have weaker London dispersion forces between the molecules and lower boiling points because of the lower contact surface area.

3. Ethanol and propane have similar molar masses but different boiling points. Predict and explain which compound has the highest boiling point.

Although they have similar molar masses, ethanol is able to form hydrogen bonds between its molecules whereas propane only has weaker London dispersion forces between the molecules and a lower boiling point.

### **Structure 3.2.5**

#### **Understandings:**

- IUPAC nomenclature refers to a set of rules used by the International Union of Pure and Applied Chemistry to apply systematic names to organic and inorganic compounds.

#### **Learning outcomes:**

- Apply IUPAC nomenclature to saturated or mono-unsaturated compounds that have up to six carbon atoms in the parent chain and contain one type of the following functional groups: halogeno, hydroxyl, carbonyl, carboxyl.

#### **Additional notes:**

- Include straight-chain and branched-chain isomers.

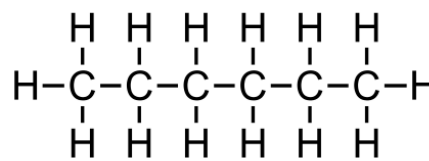
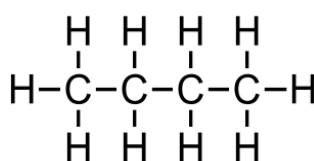
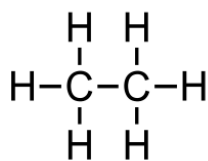
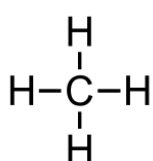
## Naming organic compounds

- Students are required to name organic compounds with up to 6 carbon atoms in the longest chain.

number of carbon atoms	root / stem
1	meth-
2	eth-
3	prop-
4	but-
5	pent-
6	hex-

## Alkanes

- General formula  $C_nH_{2n+2}$
- Alkanes are saturated hydrocarbons (C-C single bonds).



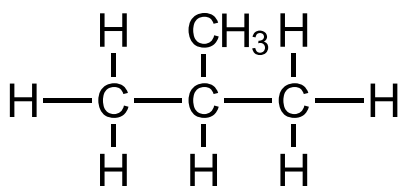
**Methane**

**Ethane**

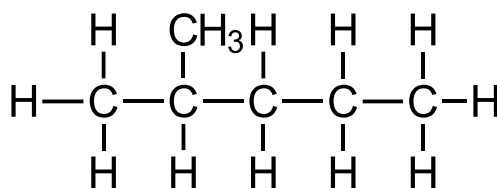
**Butane**

**Hexane**

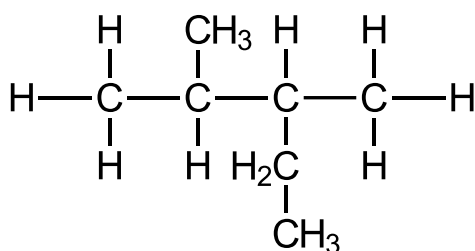
## Branched-chain alkanes



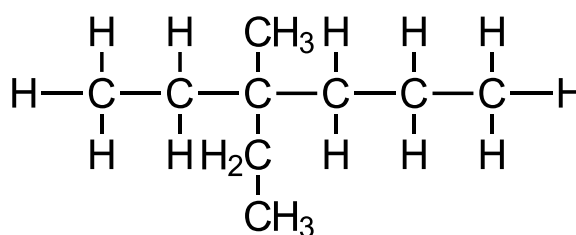
**2-methylpropane**



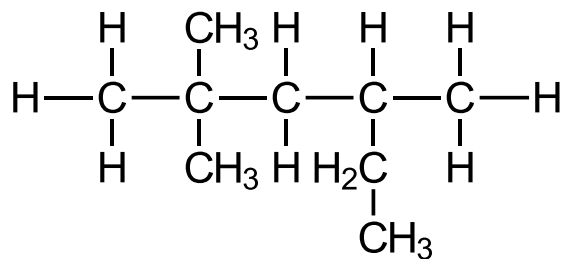
**2-methylpentane**



**2,3-dimethylpentane**



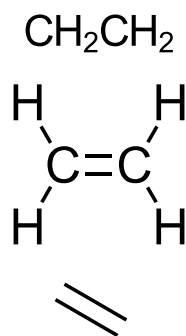
**3-ethyl-3-methylhexane**



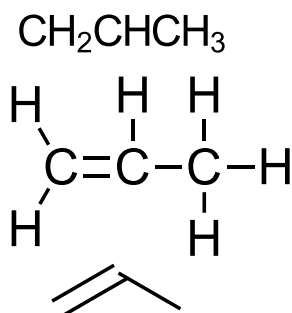
**2,2,4-trimethylhexane**

### Alkenes

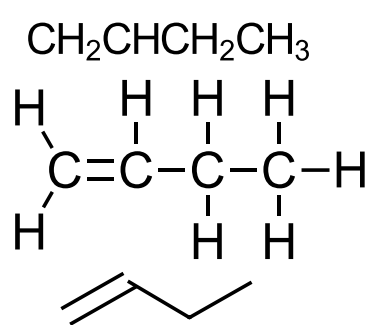
- General formula  $C_nH_{2n}$
- Alkenes are unsaturated hydrocarbons (C=C double bond).



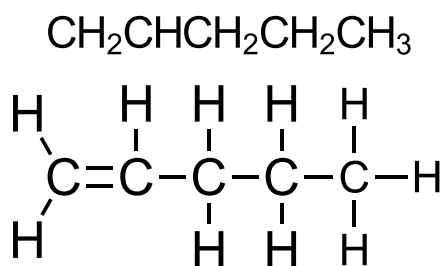
**Ethene**



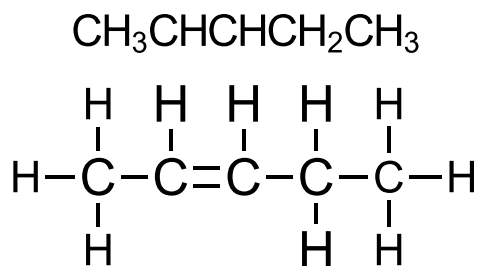
**Propene**



**But-1-ene**



**Pent-1-ene**

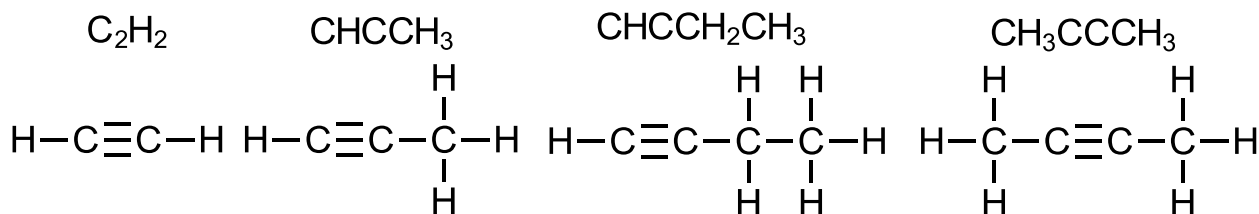


**Pent-2-ene**



## Alkynes

- General formula  $C_nH_{2n-2}$
- Alkynes are unsaturated hydrocarbons (C to C triple bond).

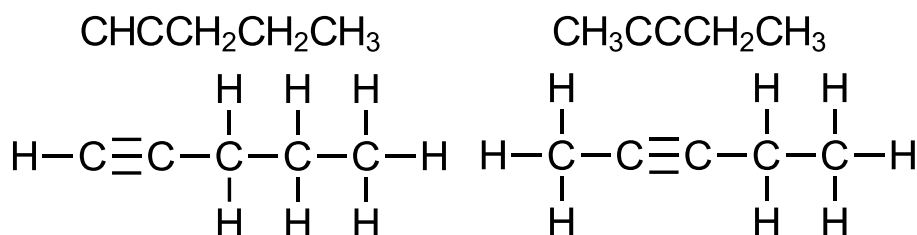


**Ethyne**

**Propyne**

**But-1-yne**

**But-2-yne**

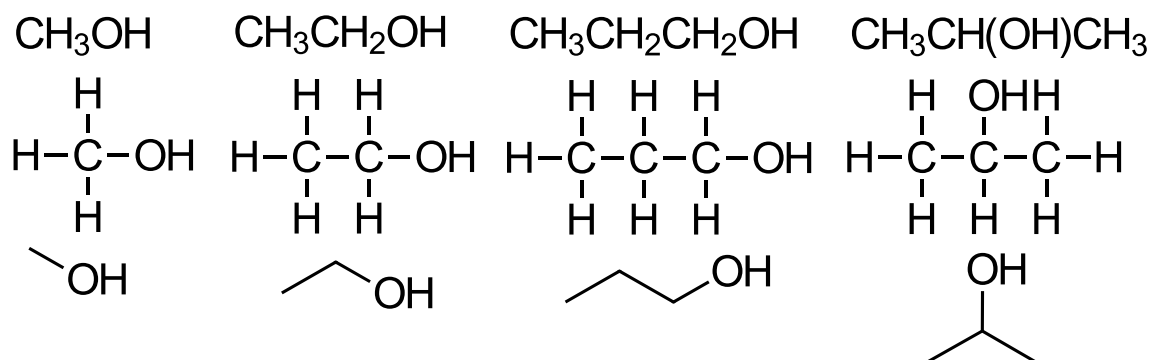


**Pent-1-yne**

**Pent-2-yne**

## Alcohols

- General formula  $C_nH_{2n+1}OH$

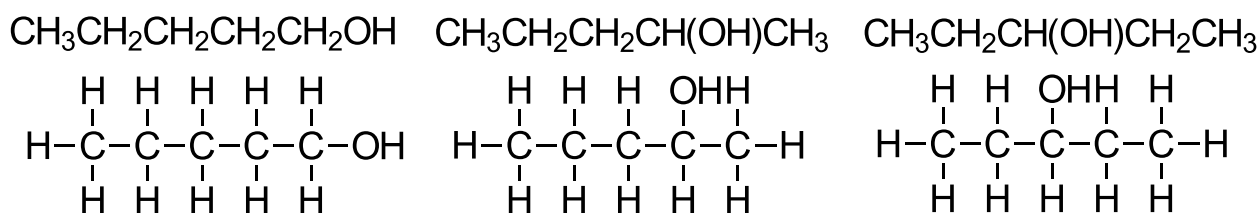


**Methanol**

**Ethanol**

**Propan-1-ol**

**Propan-2-ol**

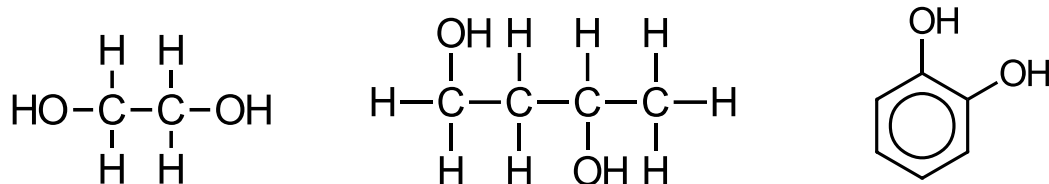


**Pentan-1-ol**

**Pentan-2-ol**

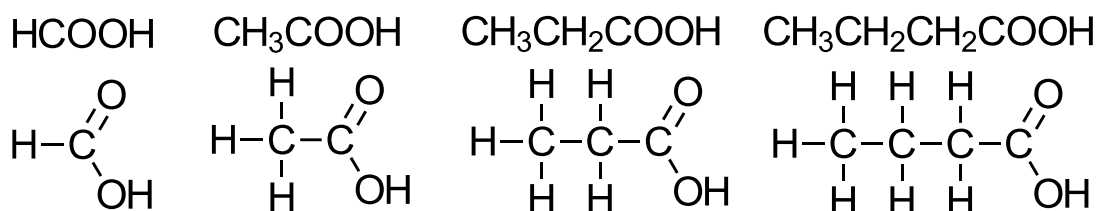
**Pentan-3-ol**

## Diols (compounds with two OH groups)



## Carboxylic acids (COOH or CO<sub>2</sub>H)

- General formula C<sub>n</sub>H<sub>2n+1</sub>COOH

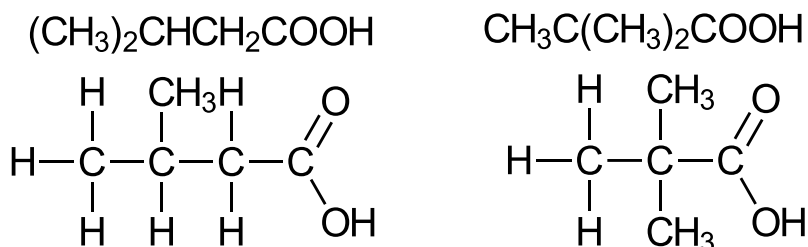


**Methanoic acid**

**Ethanoic acid**

**Propanoic acid**

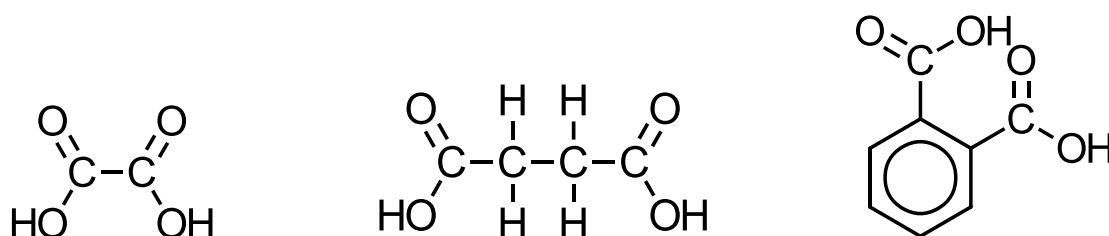
**Butanoic acid**



**3-methylbutanoic acid**

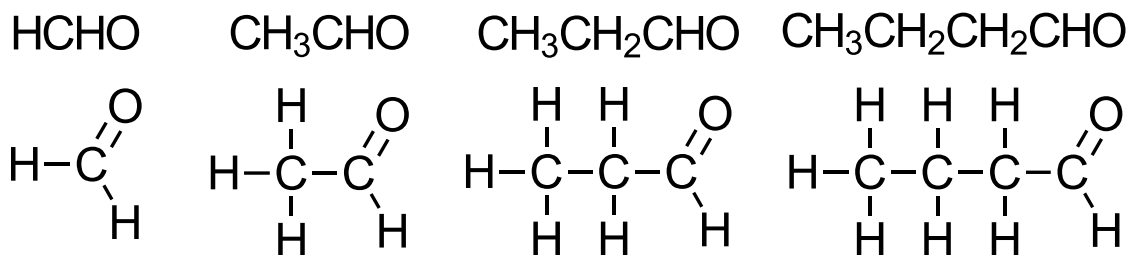
**2,2-dimethylpropanoic acid**

## Dicarboxylic acids (compounds with two carboxyl groups)



## Aldehydes

- General formula  $C_nH_{2n}O$



**Methanal**

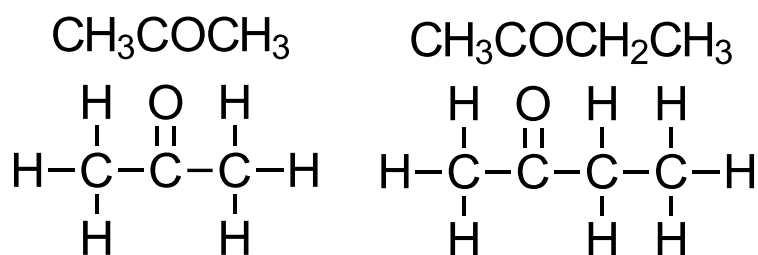
**Ethanal**

**Propanal**

**Butanal**

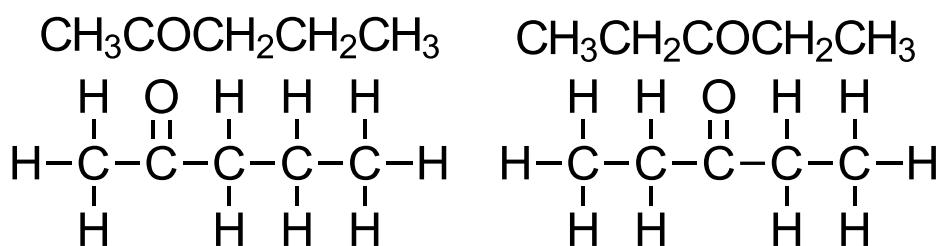
## Ketones

- General formula  $C_nH_{2n}O$



**Propanone**

**Butanone**

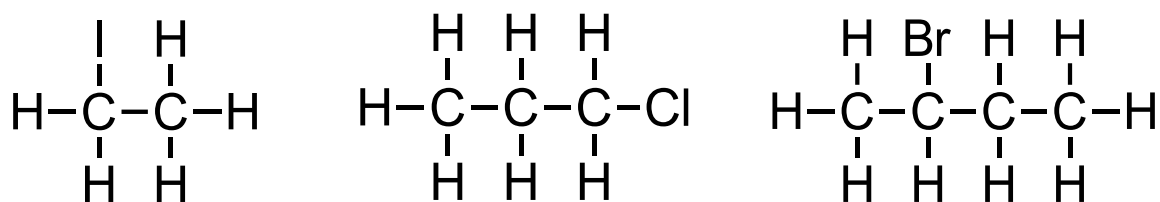


**Pentan-2-one**

**Pentan-3-one**

## Halogenoalkanes

- Halogenoalkanes contain an atom of fluorine, chlorine, bromine or iodine.
- General formula  $C_nH_{2n+1}X$



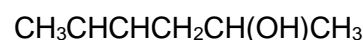
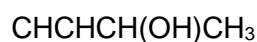
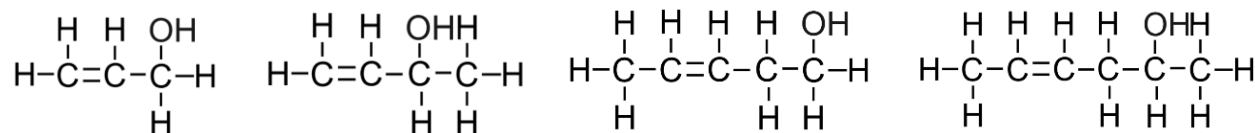
**Iodoethane**

**1-chloropropane**

**2-bromobutane**

## Naming unsaturated compounds

### Alcohols



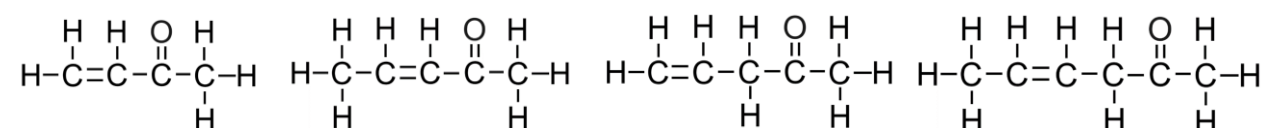
**Prop-2-en-1-ol**

**But-3-en-2-ol**

**Pent-3-en-1-ol**

**Hex-4-en-2-ol**

### Ketones



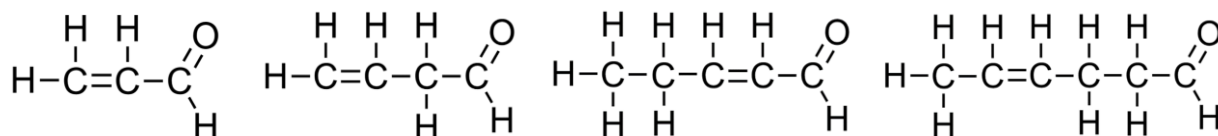
**But-3-en-2-one**

**Pent-3-en-2-one**

**Pent-4-en-2-one**

**Hex-4-en-2-one**

### Aldehydes



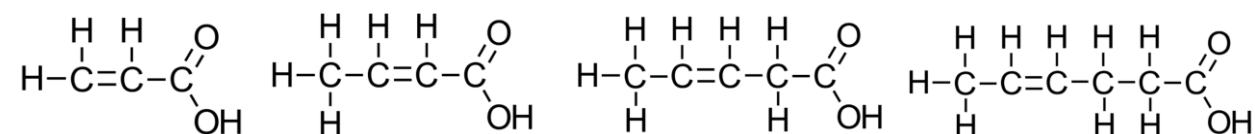
**Prop-2-enal**

**But-3-enal**

**Pent-2-enal**

**Hex-4-enal**

### Carboxylic acids



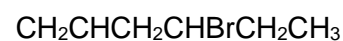
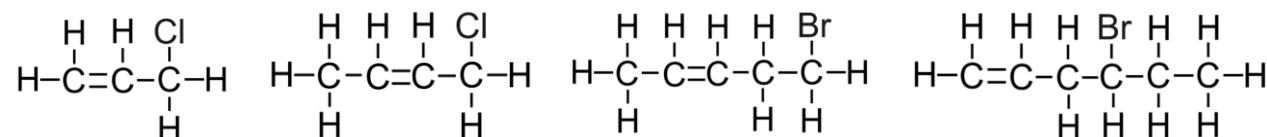
**Prop-2-enoic acid**

**But-2-enoic acid**

**Pent-3-enoic acid**

**Hex-4-enoic acid**

### Halogenoalkanes



**3-chloroprop-1-ene**

**1-chlorobut-2-ene**

**5-bromopent-2-ene**

**4-bromohex-1-ene**

### Structure 3.2.6

#### Understandings:

- Structural isomers are molecules that have the same molecular formula but different connectivities.

#### Learning outcomes:

- Recognise isomers, including branched, straight-chain, position and functional group isomers.

#### Additional notes:

- Primary, secondary and tertiary alcohols, halogenoalkanes and amines should be included.

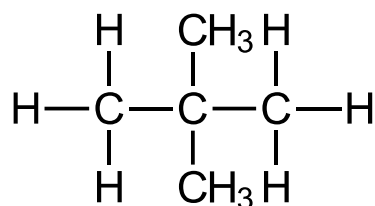
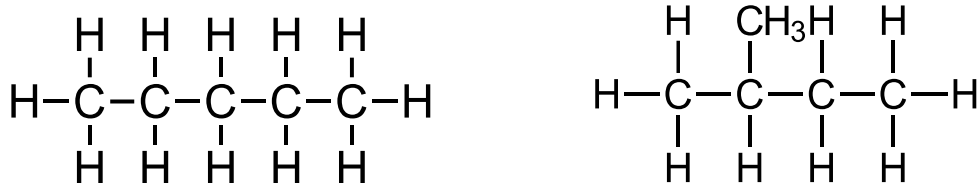
#### Linking questions:

- Structure 2.2 (HL) How does the fact that there are only 3 isomers of dibromobenzene support the current model of benzene's structure?

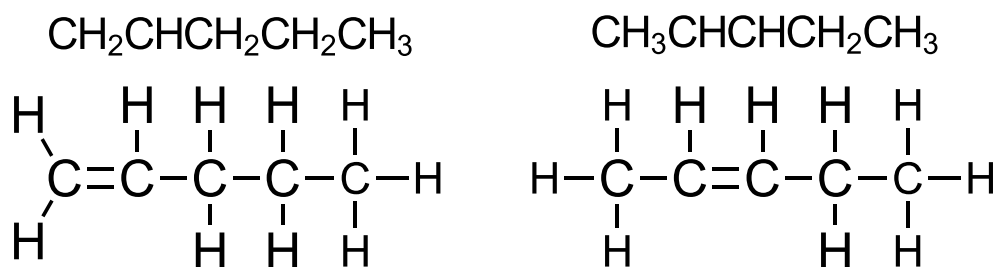
### Structural isomers

- Structural isomers are compounds with the same molecular formula but different arrangements of atoms.
- They can be divided into branched, straight-chain, position and functional group isomers.

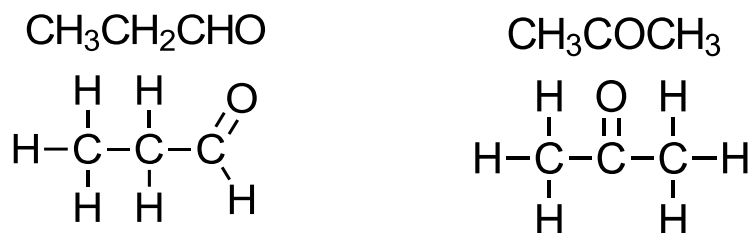
### Structural isomers of C<sub>5</sub>H<sub>12</sub> (chain isomers)



### Structural isomers of C<sub>5</sub>H<sub>10</sub> (position isomers)

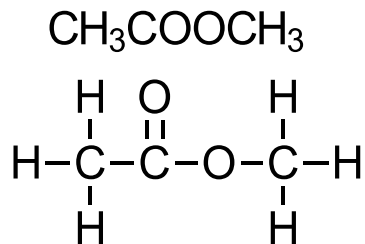
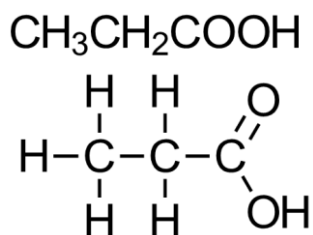


### Structural isomers of C<sub>3</sub>H<sub>6</sub>O (functional group isomers)



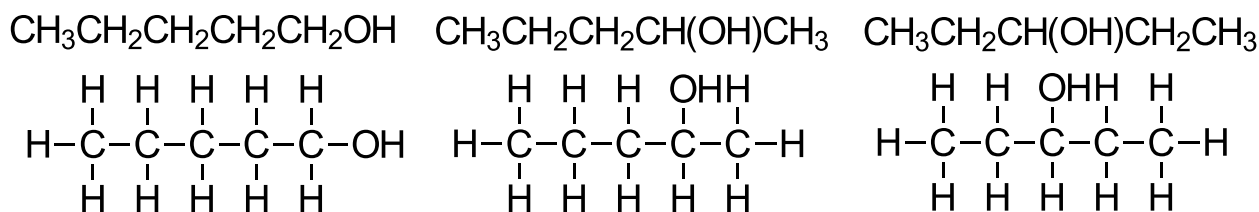
**Exercise:** Identify the type of isomerism shown by the following compounds.

1. Structural isomers of  $C_3H_6O_2$



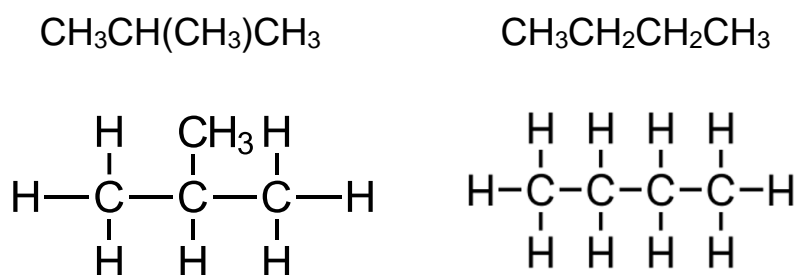
**Propanoic acid and methyl ethanoate are functional group isomers.**

2. Structural isomers of  $C_5H_{12}O$



**Pentan-1-ol, pentan-2-ol and pentan-3-ol are position isomers.**

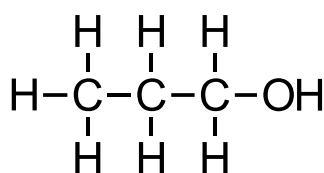
3. Structural isomers of  $C_4H_{10}$



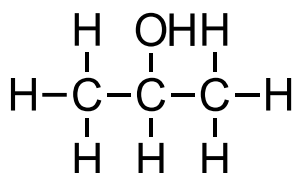
**2-methylpropane and butane are chain isomers.**

## Classification of organic compounds

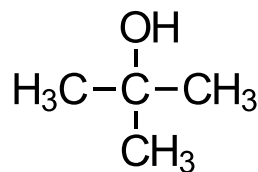
- Alcohols, amines and halogenoalkanes can be classified as primary, secondary or tertiary depending on how many carbon atoms are bonded to the carbon atom that is bonded directly to the functional group.



**Ethanol (primary)**



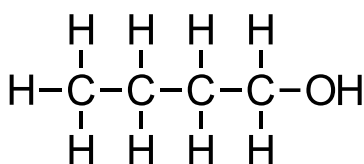
**Propan-2-ol (secondary)**



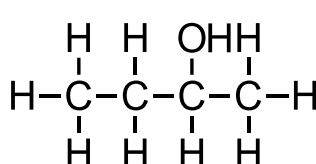
**2-methylpropan-2-ol (tertiary)**

### Exercise:

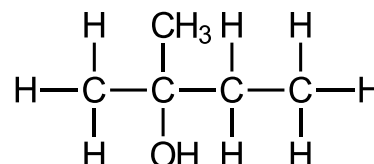
- Name and classify the following alcohols as primary, secondary or tertiary.



**Butan-1-ol**  
**Primary alcohol**

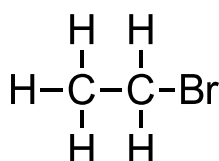


**Butan-2-ol**  
**Secondary alcohol**

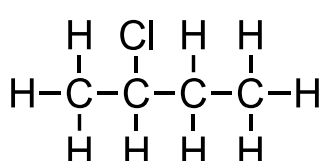


**2-methylbutan-2-ol**  
**Tertiary alcohol**

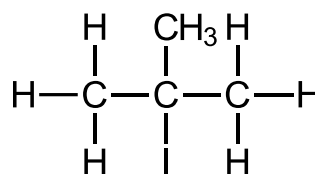
- Name and classify the following halogenoalkanes as primary, secondary or tertiary.



**Bromoethane**  
**Primary halogenoalkane**

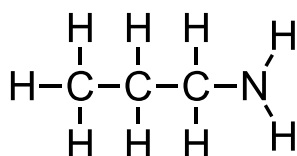


**2-chlorobutane**  
**Secondary halogenoalkane**

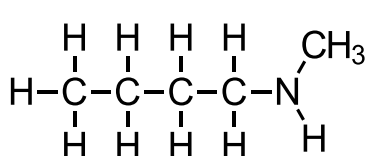


**2-iodo-2-methylpropane**  
**Tertiary halogenoalkane**

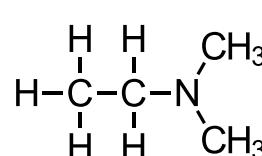
- Classify the following amines as primary, secondary or tertiary.



**Propanamine**  
**Primary amine**



**N-methylbutanamine**  
**Secondary amine**



**N,N-dimethylethanamine**  
**Tertiary amine**