Temasek Junior College
Integrated Programme

Year 4 Chemistry

Topic 10.1:
Introduction to Organic Chemistry Notes

Name:

Class:

Date:

Learning objectives

At the end of this notes, you must be able to:

☐ **(a)** name natural gas, mainly methane, and crude oil as non-renewable sources of energy

☐ **(b)** describe crude oil as a mixture of hydrocarbons and its separation by fractional distillation to yield fractions which have competing uses as fuels and as a source of chemicals

☐ **(c)** describe biofuel (exemplified by bioethanol from sugarcane) as a renewable alternative to natural gas and crude oil

☐ **(d)** describe how biofuel, when compared to fossil fuels, can be more environmentally sustainable in terms of carbon dioxide emission

☐ **(e)** interpret, and use the nomenclature, general formulae and displayed formulae of the following classes of compounds:

(i) hydrocarbons (alkanes and alkenes)
(ii) halogen derivatives (halogenoalkanes)
(iii) alcohols
(iv) carboxylic acids and esters

☐ **(f)** interpret, and use the following terminology associated with organic reactions:

(i) functional group
(ii) addition, substitution, elimination, condensation, hydrolysis
(iii) oxidation and reduction

[in equations for organic redox reactions, the symbols [O] and [H] are acceptable]

☐ **(g)** describe constitutional (structural) isomerism

Useful references:

Books
1. A-level Chemistry (E. N. Ramsden)
2. A Self-Study Guide to the Principles of Organic Chemistry, Jiben Roy
3. GCE ‘O’ Level Chemistry Matters (Y.T. Tan, L. K. Chen, J. Sandler & E. Clare)

Websites
1. Virtual Text of Organic Chemistry (William Reusch, Michigan State University): https://www2.chemistry.msu.edu/faculty/reusch/virttxtjml/textindx.htm
2. Chemguide (Jim Clark): http://www.chemguide.co.uk/orgmenu.html
3. Basic IUPAC Organic Nomenclature (Ian Hunt, University of Calgary): http://www.chem.ucalgary.ca/courses/351/WebContent/orgnom/index.html

Topic Outline

1 Introduction

- Organic chemistry involves the study of the structures, reactions, syntheses and properties of **carbon-containing compounds**.

- **Hydrocarbons** are **organic compounds containing** ____________________________.

- Not all carbon-containing compounds, however, are classified as organic compounds; examples of such exceptions are the oxides of carbon (e.g. CO or CO_2), metal carbides (e.g. TiC) and carbonates (e.g. $CaCO_3$ or H_2CO_3).

1.1 Importance of Organic Chemistry

- It is a field of chemistry of immense importance to our daily lives and technology.

- Knowledge and application extend into domains such as the:
  - industrial manufacture of dyes, paints, plastics, fuels, drugs and polymers
  - understanding of organic and biological matter (e.g. carbohydrates, proteins and fats) in food
  - development of biochemistry and molecular biology

1.2 Unique Bonding Nature of Carbon

- Carbon is unique in its ability to form strong covalent bonds readily with other carbon atoms to form longer chains, rings and structures. This accounts for the presence of a vast number of organic compounds in nature.

- Carbon has an electronic configuration of _______________

- With 4 valence electrons, each carbon atom is able to form 4 covalent bonds where these can be **single, double or triple bonds**. Possibilities in a molecule include:

  - 4 single C–C bonds
  - 2 single C–C bonds and 1 double C=C bond
  - 1 single C–C bond and 1 triple C≡C bond
  - 2 double C=C bonds

2 Primary Sources of Organic Compounds

2.1 Crude Oil and Natural Gas

<u>Definition of fossil fuels</u>

Fossil fuels are fuels (including **<u>crude oil and natural gas</u>**) formed by natural resources such as buried dead organisms, due to heat and pressure acting on these organisms and anaerobic decomposition of these organisms.

Fossil Fuels

Crude oil | **Natural gas**

Crude oil is a liquid mixture of **different hydrocarbons** of different molecular weights (that is found in geologic formations beneath Earth's surface)

Natural gas is a naturally occurring hydrocarbon gas mixture, primarily consisting methane (impurities include carbon dioxide). It is typically found above the crude oil layer.

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For your information:

[DID YOU KNOW?] Singapore is committed to sustainable energy use with the aim of reducing our greenhouse gas emissions and adhering to our commitments under the Paris Agreement on climate change. To this end, we are constantly exploring innovative ways to reduce our carbon footprint. For instance, competition in the liberalised power generation sector has spurred power generation companies to switch from steam plants powered with fuel oil to more efficient Combined Cycle Gas Turbines (CCGTs) fuelled by <u>natural gas, the cleanest fossil fuel</u>.

[DID YOU KNOW?] Liquefied Natural Gas (LNG) enhances our energy security as it allows us to source for natural gas globally. To meet Singapore's gas demand, a two-stage Request for Proposal (RFP) was launched in June 2014 to appoint up to two new LNG importers to supply Singapore's next tranche of LNG. The appointment of two new LNG importers and the flexibility for any gas user to source LNG from the spot market contribute to the development of more competitive and dynamic gas and electricity markets in Singapore.

2.2 Separating Crude Oil via Fractional Distillation

Definition of fractional distillation

Fractional distillation is a **separation technique** that is used to separate a **liquid mixture** comprising of components with **different boiling points**.

Boiling points increase with increasing M_r due to the________________________________.
This leads to _______________and____.
Thus, ____________________is needed to **overcome these intermolecular forces of attraction** for larger alkanes during boiling.

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For your information:

[DID YOU KNOW?] In SG Green Plan 2030, under the Green Economy pillar, it was announced that Jurong Island, which is known for its refineries carrying out fractional distillation of crude oil, will become a sustainable energy and chemicals park. You can read more about this ambitious undertaking in the link here.

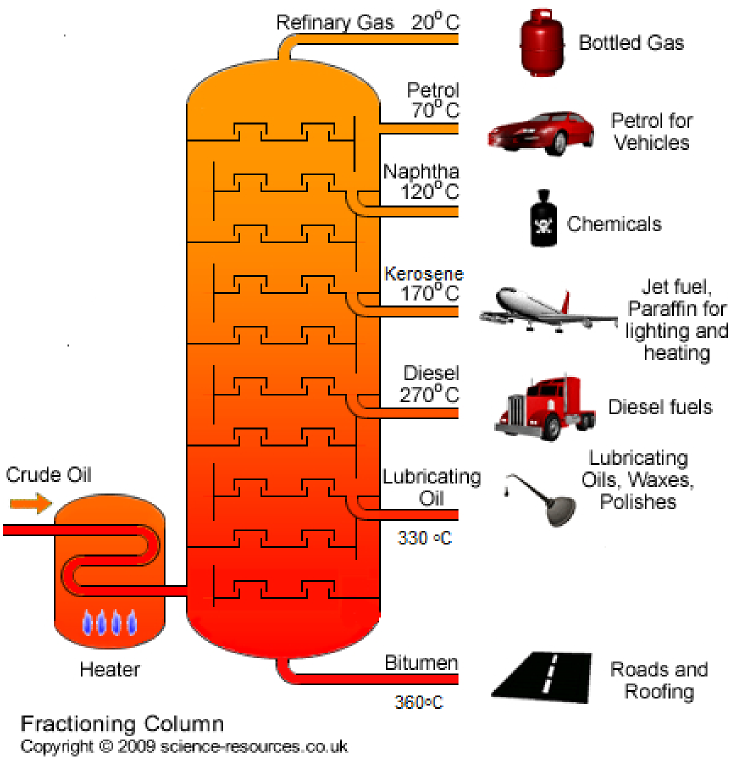
Question: ***Predict whether CH_4 or C_8H_{18} would have a higher boiling point. Explain why.***

Answer:

__Summary of processes in fractional distillation used to separate crude oil into the various components__

1. *At the bottom of the fractionating column, crude oil is heated into vapour.*
2. *The vapour is pumped into a fractionating column where it is cool at the top but hot at the bottom.*
3. *As the hot vapour rises, it cools down. The smaller hydrocarbons (i.e. the hydrocarbons with lower boiling points) are collected at the* ***__top__*** *of the fractionating column (as gases) while the larger hydrocarbons (i.e. the hydrocarbons with higher boiling points) are collected at the* ***__bottom__*** *of the column.*

Figure 1: Fractionating Column for Crude Oil Separation



Smaller hydrocarbon molecules with lower boiling point due to weaker intermolecular forces of attraction between molecules collect at the top of the fractionating column

Bigger hydrocarbon molecules with higher boiling point are collected at the bottom of the fractionating column

Teacher's note: Students should be aware that the data in the figure is a rough guide, and the temperature range varies from refinery to refinery. Also, the exact mixture composition of the crude oil may also affect what molecules make up each fraction.

View the following e-resource on the uses of the main fractions:
https://www.youtube.com/watch?v=JZdvsQzOKukv

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For your information:

One of the common fractions obtained from crude oil is diesel, which is used in transportation. However, diesel exhaust contains fine particles, nitrogen oxides, and other pollutants. In warm weather, hot sunlight bakes nitrogen oxides together with other pollutants which forms harmful smog.

[DID YOU KNOW?] In SG Green Plan 2030, under the Energy Reset pillar, in order to address diesel's harmful effects, new diesel car and taxi registrations are to cease from 2025, and all such registrations are to be of cleaner-energy models.

2.3 Catalytic Cracking

Definition of cracking:

Cracking is the **breaking down of long-chain (or bigger) hydrocarbons into smaller molecules**. This is usually done **under high temperature** (around 600 °C). A **catalyst** (e.g. Al_2O_3 or SiO_2) can be used to speed up the process (this is known as catalytic cracking).

Why is cracking important?

It is a necessary process in the petrochemical industry to produce useful fractions from less useful ones, for example:

1. to produce petrol (long-chain hydrocarbons are less flammable).
2. to produce short-chain alkenes (which can be used to manufacture other compounds, e.g. plastics).
3. to produce hydrogen (source of clean fuel) e.g. Toyota fuel cell cars

Examples of cracking

1. $C_{10}H_{22} \xrightarrow[\text{in the presence of } SiO_2 \text{ catalyst}]{\text{high heat}} C_3H_6 + C_7H_{16}$

2. $C_{12}H_{26} \xrightarrow[\text{in the presence of } SiO_2 \text{ catalyst}]{\text{high heat}} \_\_\ C_4H_8 + \_\_\ C_2H_6 + \_\_\ C_2H_4$

Principle of conservation of mass:
Total number of C and H atoms in reactants = Total no. of C and H atoms in the products

Quick-check

Nonane, C_9H_{20} undergoes cracking to form propene (C_3H_6), ethene (C_2H_4) and **Y** as the products.

Deduce the molecular formula of product **Y** hence write a balanced equation for the cracking process. You may use molecular formulae in your equation.

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2.4 Usage of Fossil Fuels

Fossil fuels are **non-renewable** energy sources, which are energy sources that are **finite**. Fossil fuels are non-renewable because it takes millions of years to be produced. Therefore, we will need to use energy more efficiently (i.e. conserve energy) in the use of fossil fuels to ensure that its depletion takes place at a slower pace.

The world is still heavily dependent on fossil fuels, especially crude oil, because of the competing uses of petrochemical feedstock and fuel. About 10% of crude oil is used as petrochemical feedstock (raw materials, usually naphtha) in the manufacture of plastics, medicines, synthetic rubber; the remaining is used as fuel.

2.5 Biofuel as Alternative Fuels

With fossil fuels being non-renewable and contributing to global warming, biofuels are increasingly being considered as a possible alternative for the future. Biofuels are produced from natural products, often plant biomass containing carbohydrates. As biofuels are produced from plants, they are renewable and theoretically carbon neutral.

Some biofuels are produced by using microorganisms to anaerobically ferment carbohydrate in the plant material, for example, bioethanol. When ethanol is made by fermentation, sugar is converted into ethanol and carbon dioxide if conditions are anaerobic. Single-celled fungi, called yeast, contain enzymes that are natural catalysts for making this process happen. One source of carbohydrate is sugarcane, which can be directly fermented into bioethanol. For other sources like maize, enzymes must be used to break down the starch into sugar first. Other common biofuels are biodiesel and biogas which are produced via different processes.

Advantages of biofuel

- Carbon neutral, renewable and sustainable if crops and trees are replanted
- Reduces greenhouse emissions and pollution
- Biofuel production could provide money for less developed countries as they have the space to grow the crops required
- Provides jobs in the agriculture and energy sectors

Disadvantages of biofuel

- Many developed countries don't have the space to be able to produce enough plants to make biofuels because the land is needed for food production
- For bioethanol to be burnt in a car engine, some engine modification is needed, although (most) modern petrol engines can use petrol containing up to ten per cent ethanol without needing any modifications
- Although biofuels are in theory themselves carbon neutral, this does not take into account the carbon dioxide emissions associated with growing, harvesting and transporting the crops, or producing the ethanol from them

3 Classes of Organic Compounds

3.1 Saturated and Unsaturated Compounds

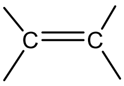
- **Saturated** compounds have only ______________ (C–C) bonds between their atoms.
- **Unsaturated** compounds have ______________ bonds between their atoms.

  Examples: These could include presence of:
  - C=C (in alkenes)
  - C=O (in carboxylic acids and esters)

3.2 Functional Groups and Homologous Series

Functional group

A functional group is an **atom or group of atoms** common to a series of organic compounds that **determines the chemical properties** of the series.

Example:  (alkene functional group), –OH (alcohol functional group)

Homologous series

A homologous series is a series of compounds with the **same functional group** and **same general formula**.

In general, members in the **same** homologous series:
- can be represented by a **general molecular formula**, (e.g. C_nH_{2n} for alkenes)
- differ in formula by a **constant –CH_2– unit**
- exhibit ____________ **chemical** properties
- exhibit ______________ **physical** properties

Example of a homologous series

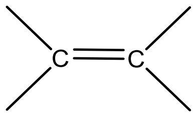
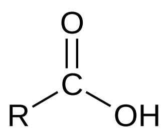
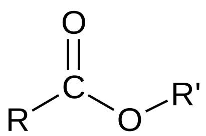
Homologous series	:	Alcohol
General formula	:	$C_nH_{2n+1}OH$ (or **R**–OH)
Functional group	:	Alcohol
Members	:	CH_3OH, CH_3CH_2OH, $CH_3CH_2CH_2OH$, etc.

Note: **R** is known as an ***alkyl group***. The general formula of **R** is $\mathbf{C_nH_{2n+1}}$

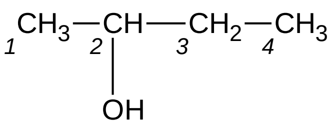
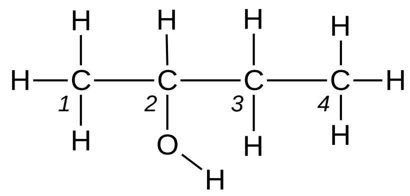
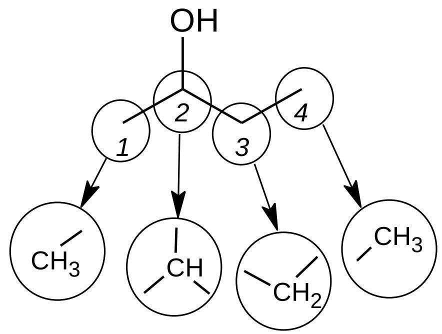
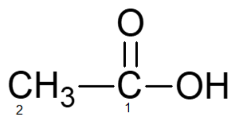
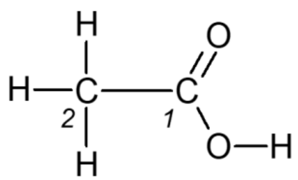
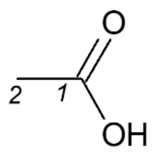
Example: n = 1, –CH_3 *methyl* group

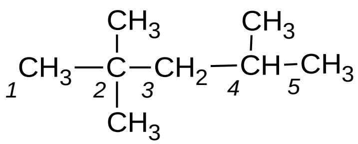
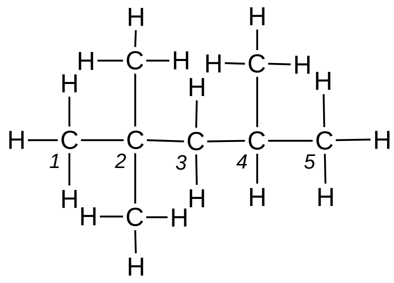
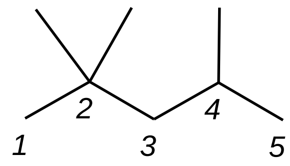
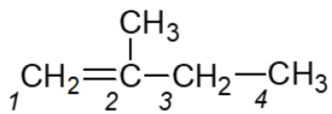
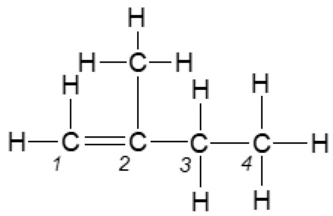
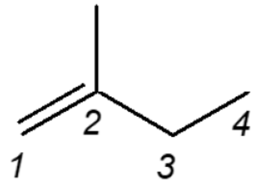
n = 2, –C_2H_5 *ethyl* group

Examples of common homologous series covered in IP Chemistry

Homologous series	General formula	Functional group	Example (name)
Alkanes	C_nH_{2n+2}	None	$CH_3CH_2CH_3$ (propane)
Alkenes	C_nH_{2n}	 **alkene** functional group	$CH_3CH{=}CH_2$ (propene)
Halogenoalkane	$C_nH_{2n+1}X$ where X is –C*l*, –Br or –I	R–X **halogenoalkane** functional group	CH_3Cl (chloromethane)
Alcohols	$C_nH_{2n+1}OH$	R–OH **alcohol** functional group	$CH_3CH_2CH_2OH$ (propan-1-ol)
Carboxylic acids	$C_nH_{2n+1}COOH$	 **carboxylic acid** functional group	CH_3COOH (ethanoic acid)
Esters	RCOOR’	 **ester** functional group	$CH_3COOCH_2CH_3$ (ethyl ethanoate)

4 Representations of Organic Compounds

Organic Compound	Empirical Formula	Molecular Formula	Structural Formula		
			Structural Formula	**Displayed Formula (Full Structural Formula)**	**Skeletal Formula**
Definition	States the **<u>simplest ratio</u>** of the elements in the compound	States the **<u>actual</u> number of atoms** of each element present in the compound. (empirical formula)$_n$	Shows the **sequence in which the atoms are bonded to each other**, for an <u>unambiguous</u> structure.	Detailed structure of molecule showing the **relative placing of all atoms and number of bonds between the atoms** in the molecule. **All bonds would have to be shown clearly.**	Derived from the structural formula by removing the H and C atoms, leaving just the carbon-carbon bonds in the skeleton and the associated functional groups.
Example 1: **Butan-2-ol**	$C_4H_{10}O$	$C_4H_{10}O$	*1 2 3 4* $CH_3CH(OH)CH_2CH_3$ or 		
Example 2: **Ethanoic acid**	CH_2O	$C_2H_4O_2$	CH_3COOH or 	 Note: the carbon containing the carboxylic acid functional group should be labelled as carbon no 1	

Organic Compound	Empirical Formula	Molecular Formula	**Structural Formula**		
			Structural Formula	**Displayed Formula (Full Structural Formula)**	**Skeletal Formula**
Example 3: **2,2,4-trimethylpentane**	C_4H_9	C_8H_{18}	$(CH_3)_3CCH_2CH(CH_3)_2$ or 		
Example 4: **2-methylbut-1-ene**	CH_2	C_5H_{10}	$CH_2{=}C(CH_3)CH_2CH_3$ or 		

5 Nomenclature (Naming) of Organic Compounds

- The name of an organic compound depends on:
  (a) the <u>number of carbon atoms</u> it has
  (b) the <u>homologous series</u> it belongs to

- **IUPAC Nomenclature** is a system of naming chemical substances developed by the International Union of Pure and Applied Chemistry (IUPAC).

- A chemical name has three parts in the IUPAC system: **prefix, stem, suffix**.

  The name of a compound can be arranged in the order:

  Prefix(es) – Stem – Suffix

  Example: 3-methylbutan-1-ol

  3-methyl | butan - | 1 − ol

  prefix **stem** **suffix**

<u>Stem</u>

✓ The **<u>stem</u>** gives the <u>number of carbon atoms</u> in the **<u>longest continuous chain</u>** that **<u>contains the principal functional group</u>**.

✓ In the **aliphatic straight chain** system, the stem is named **according to the number of C atoms** as shown in Table 2.

Table 2: Naming of Stem

No. of C atoms in the longest continuous chain	Stem
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	

Aliphatic hydrocarbon: Carbon atoms joined in an unbranched or branched chains.

Cyclic hydrocarbon: Carbon atoms joined to form a <u>ring</u>.

Suffix

- ✓ The suffix indicates the **principal functional group** that is present in the compound.
- ✓ A number is added to show the position of the functional group, if necessary.
- ✓ If more than one functional group is present, the one with the highest priority is assigned as the principal functional group and that will be the one named in the suffix.

(higher priority) carboxylic acid, alcohol, alkene (lower priority)

Table 3: Common suffixes for IP Chemistry

Homologous series	Suffix	Example
Alkane	–ane	$CH_3CH_2CH_3$ Prop**ane**
Alkene (unsaturated hydrocarbon, C=C)	–ene	$CH_3CH{=}CH_2$ Prop**ene**
Alkyne (unsaturated hydrocarbon, C≡C) *	–yne	$CH_3C{\equiv}CH$ Prop**yne**
Alcohol (–OH)	–ol	$CH_3CH_2CH_2OH$ Propan-1-**ol**
Carboxylic acid (–COOH)	–oic	CH_3CH_2COOH Propan**oic acid**

**not included as one of the homologous series to learn in IP or JC Chemistry*

Prefix

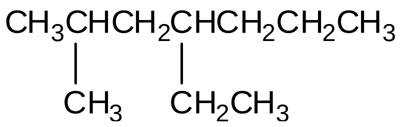
- ✓ The prefix denotes the **substituent** (*atom or group of atoms substituted in place of a hydrogen atom on the parent chain of a hydrocarbon*) present in an organic compound.
  - Placed in alphabetical order if there is more than 1 prefix.
  - For multiple prefix for the same type, use di, tri, tetra etc.
  - Add number(s) to show the position(s) of the substituent(s), if necessary.

Table 4: Common Prefixes

Substituent Group	Name as Prefix
$–CH_3$	
$–CH_2CH_3$	
$–CH_2CH_2CH_3$	
–F	
–C*l*	
–Br	
–I	

<u>Steps to naming organic compounds:</u>

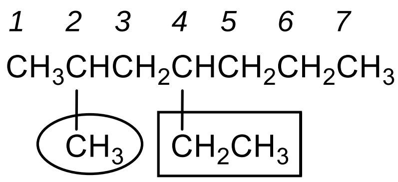
(1) Identify the **parent chain**, which is the **<u>longest continuous chain</u>** of carbon atoms **<u>containing the principal functional group</u>**.



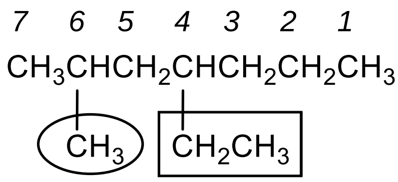
- Longest continuous chain has **7** carbon atoms
  ⇒ parent chain (stem) is **hept–**
- No principal functional group present: an **alkane**
  ⇒ suffix is **–ane**

(2) The parent chain is numbered so that the **<u>lowest possible number</u>** is given for the substituents.

Correct ☑

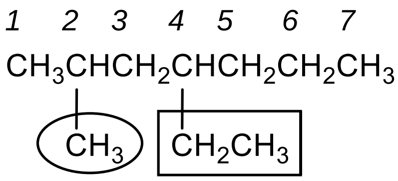


Incorrect ☒



Substituent alkyl groups are at positions **2** & **4** (instead of positions 4 & 6).

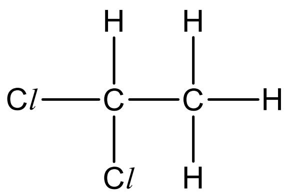
(3) Name each **substituent** and indicate its position by the **number of the carbon atom to which it is attached**.



- At carbon position no. **2**
  ⇒ prefix methyl substituent ($–CH_3$ group)
- At carbon position no. **4**
  ⇒ prefix ethyl substituent ($–CH_2CH_3$ group)

IUPAC name: ___________________________________

(4) **If the carbon chain is substituted by the same group more than once**, the number of identical groups is indicated by affixing **di, tri, tetra, etc.** in front.



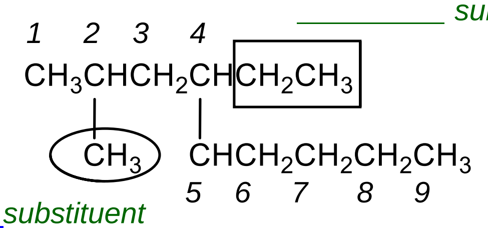
Note: In naming organic compounds,
- a dash (–) is used between numbers and letters
- a comma (,) is used between numbers

IUPAC name: _________________________________

(5) If there are two or more substituents, they should be named in **<u>alphabetical order</u> (<u>excluding</u> di, tri, tetra, etc.)**

<u>Example</u>

_________ *substituent*



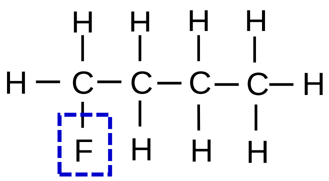
________ *substituent*

IUPAC name: ______________________________

<u>Quick Check</u>

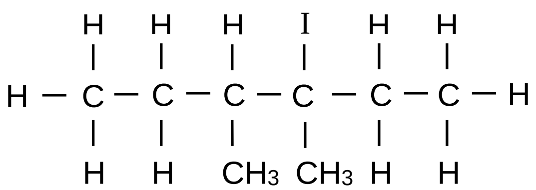
Name the following compounds.

1.



IUPAC name: _________________________

2.



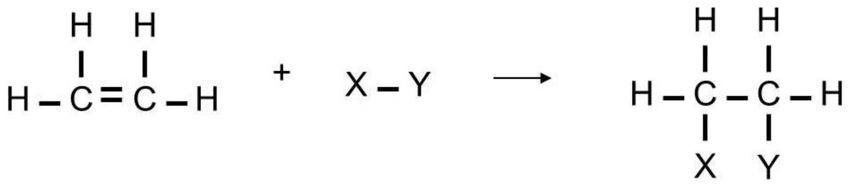
IUPAC name: ___________________________

6 Types of Organic Reactions

(a) Addition reaction

Reaction where **two reagents react to form a single product**. Usually, an unsaturated functional group (e.g. alkene) is involved as the reactant.

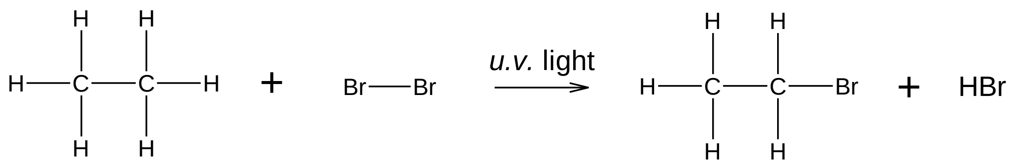
Example: Addition reaction involving ethene, an alkene



(b) Substitution reaction

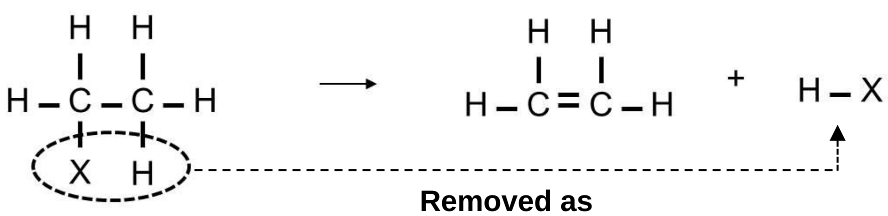
Reaction where **one atom or a group of atoms is substituted** by another atom, group of atoms, or ion.

Example: Substitution reaction between ethane and $Br_2(g)$



(c) Elimination reaction

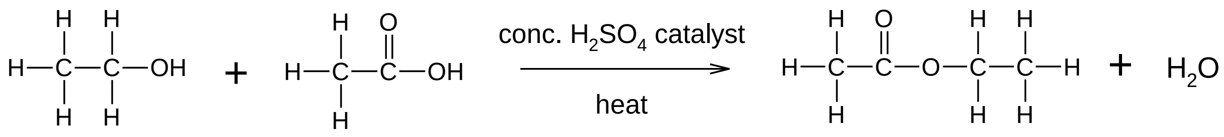
Reaction involving the **removal (elimination) of an atom or group of atoms from a single reactant molecule**. Usually, an unsaturated functional group (e.g. alkene) is formed as the product.



(d) Condensation reaction

Reaction **involving two or more reactants** **to yield a product**, with the **formation of water or some other small molecule** (e.g. HC*l*).

Example: Condensation reaction between ethanoic acid (carboxylic acid) and ethanol (alcohol) to yield ethyl ethanoate (ester)

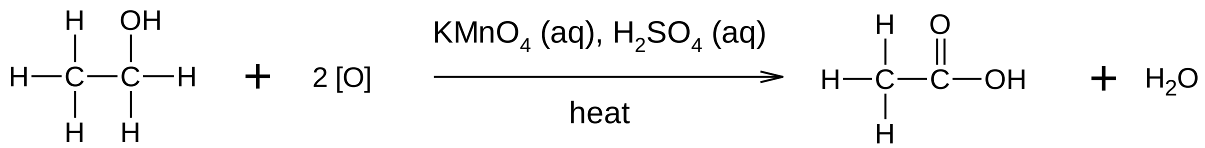


(e) Reduction and Oxidation (Redox)

Organic compounds can be oxidised or reduced. For organic redox reaction, the focus is on the "transformation" of the organic compounds, hence formulae of oxidising and reducing agents are usually left out in the chemical equations.

To balance such equations, **symbols [O] and [H] are used for oxidation and reduction respectively**.

Example: Oxidation of ethanol to ethanoic acid using acidified potassium manganate(VII)

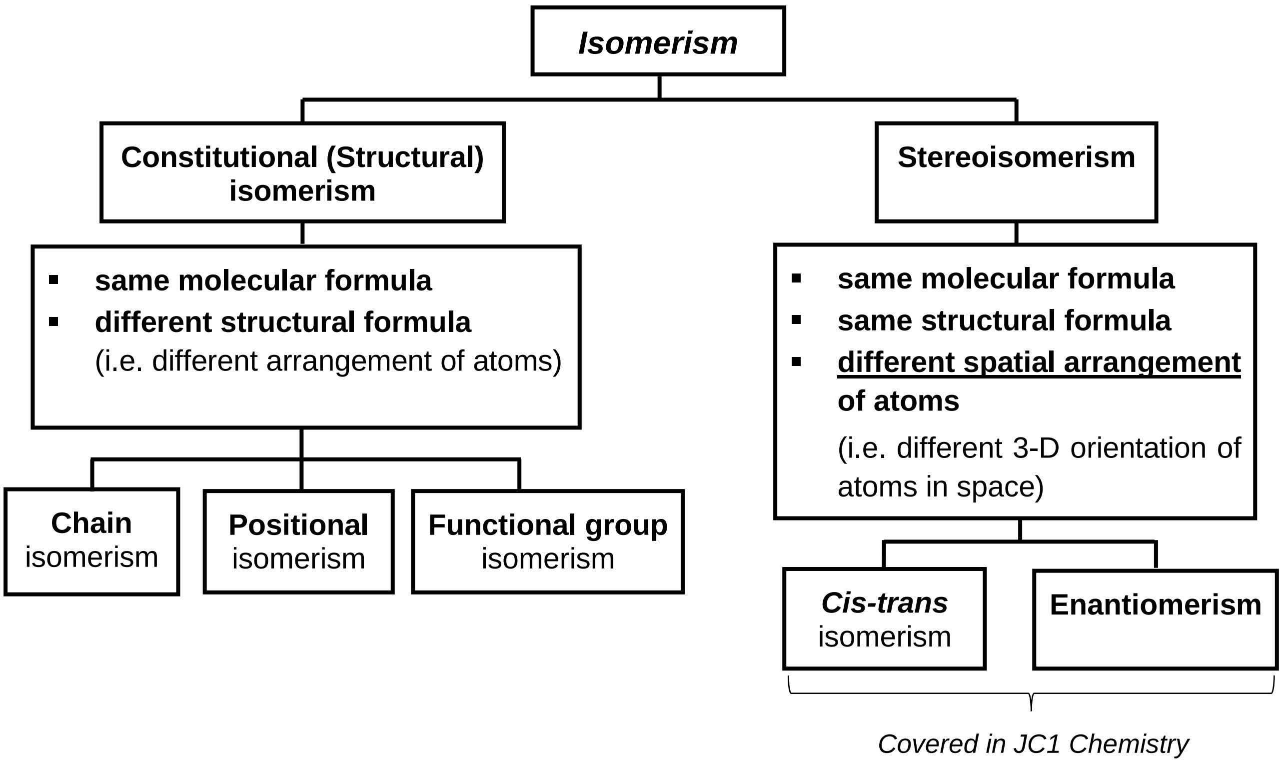


7 Isomerism

Definition:

Isomers are compounds that have the **<u>same molecular formula</u>** but **<u>different structural formula</u>**.

There are two classes of isomerism:



7.1 Constitutional Isomerism

There are 3 types of **constitutional isomerism**:

(1) **Chain** isomerism

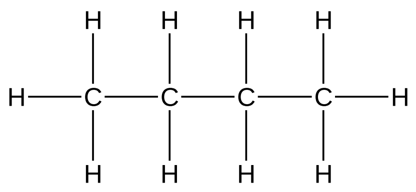
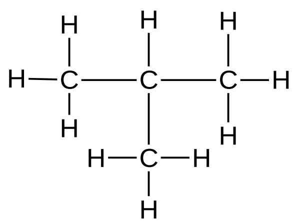
(2) **Positional** isomerism

(3) **Functional** group isomerism

7.1.1 Chain Isomerism

Definition:	**<u>Different arrangement of carbon chain</u>**.

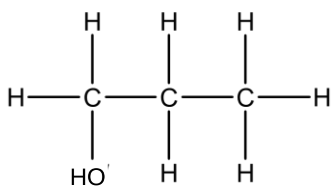
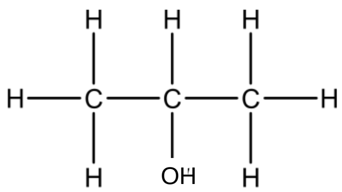
Example: C_4H_{10}

Structural formula	Name	Remarks
	butane	
	2–methylpropane	

7.1.2 Positional Isomerism

Definition:	**<u>Different positions of the same functional group</u>** on a carbon chain.

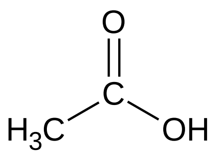
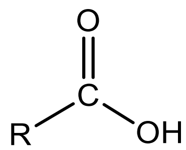
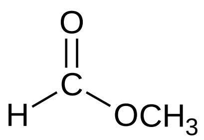
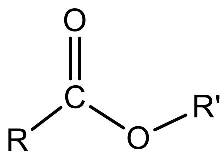
Example: C_3H_7OH

Structural formula	Name
	**propan–1–ol**
	**propan–2–ol**

7.1.3 Functional Group Isomerism

Definition:	<u>**Different functional groups**</u> present

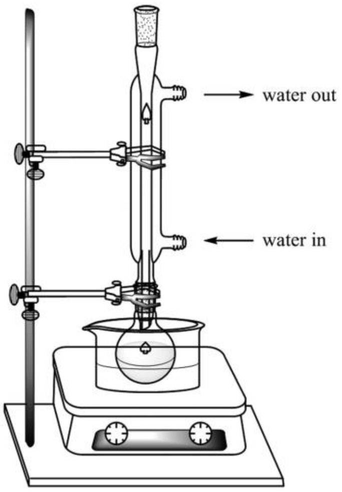
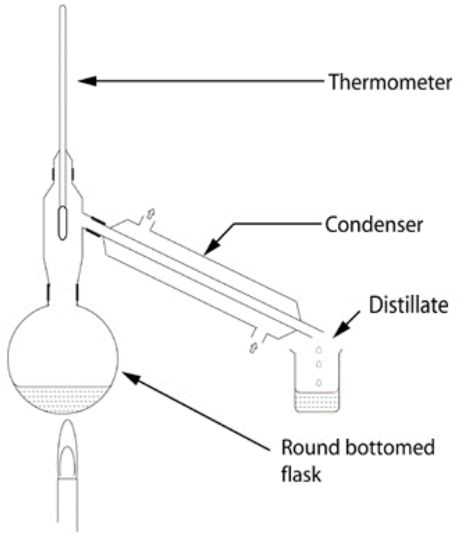
Example: $C_2H_4O_2$

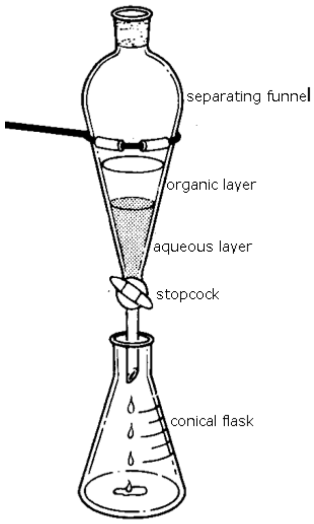
Structural formula	Name	Functional group
	ethanoic acid	 carboxylic acid
	methyl methanoate	 ester

In general, <u>carboxylic acids and esters</u> are functional group isomers.

Annex [Self-directed learning]

Common Laboratory Techniques in Organic Reactions

Technique + Labelled diagram	Description
Technique: **Heating under reflux** Labelled diagram:  	This technique is used: 1. To <u>minimise loss of reactants (organic reactants are often volatile) due to vapourisation.</u> 2. To carry out heating to achieve a reasonable rate of reaction **Details:** • A water condenser is connected vertically to a reaction flask. • During the heating process, vapour formed will condense at the cool surface of the condenser and the liquid flows back into the reaction flask.
Technique: **Distillation** Labelled diagram:  	This technique is used for separation when the desired <u>organic compound (product) is more volatile than the reactants</u> (i.e. the <u>components have different boiling points)</u> **Details:** • The reaction mixture is heated to its boiling point and the vapourised product enters the condenser. • At the cool surface of the condenser, the vapour condenses and is collected in the flask placed at the other end of the condenser.

Technique + Labelled diagram	Description
Technique: **Extraction using separatory funnel** Labelled diagram:  	This technique is used when the product is soluble in one solvent while the reactants/impurities are soluble in another solvent, and that <u>the two solvents are immiscible.</u> **Details:** • The two layers of solvents are separated by adjusting the stopcock of the separatory funnel. • To recover the desired organic compound (product) from the solvent, recrystallisation may be used.
Technique: **Recrystallisation**	This technique is used: 1. as a purification technique to obtain a pure sample of organic compound. 2. when the <u>compounds in a particular solvent have different solubilities</u>. **Details** • The impure substance is first dissolved in a suitable solvent that had been heated. • Filtration is then carried out. • The filtrate is cooled to allow the dissolved organic compound to crystallise. • A second filtration is carried out to collect the crystals, and washed with a small amount of the solvent before being dried.