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VCE Chemistry ½
Functional Groups in Organic Chemistry [2.7]
Workbook

Outline:

Learning Objectives:

- ☐ **CH12 [2.7.1]** - Apply IUPAC Conventions to Identify, Draw & Write IUPAC Names of Straight-chained & Branched Carboxylic Acids
- ☐ **CH12 [2.7.2]** - Write Condensation Reactions for the Formation of Esters & Relevant Catalysts/Conditions
- ☐ **CH12 [2.7.3]** - Apply IUPAC Conventions to Identify, Draw & Write IUPAC Names of Straight-chained Esters

Section A: Carboxyl Group

Sub-Section: Recap

Let's walk through first!

Question 1 Walkthrough.

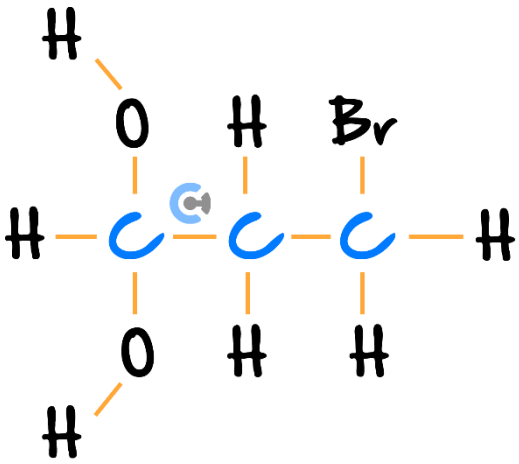
a. Draw the structural formula of 3-methylbutan-2-ol.

b. Write the semi-structural formula of but-2-en-1-ol.

_____

_____

c. Name the following molecule:

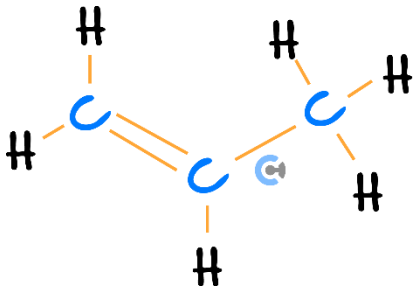


Your Turn!

Question 2

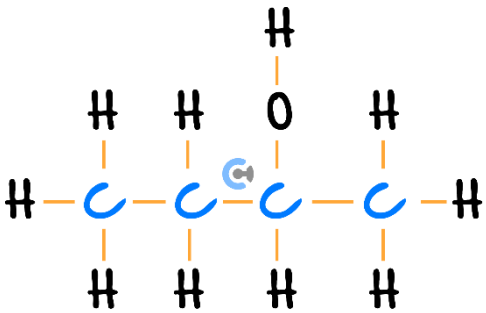
For each of the following molecules, provide the name for the functional group present, along with the name of the molecule.

a.



Functional Group Present	Name

b.

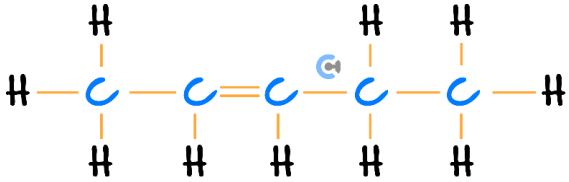


Functional Group Present	Name

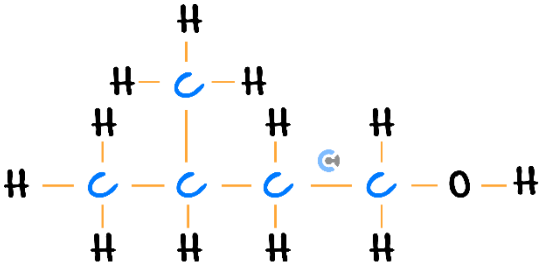
Question 3

Name the following molecules:

a.



b.



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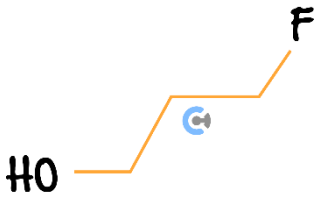
Question 4

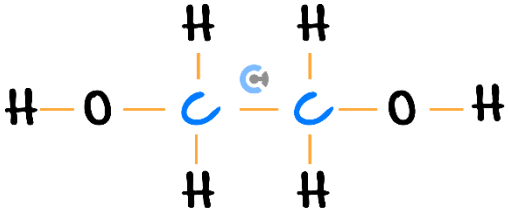
Name the following molecules:

a.

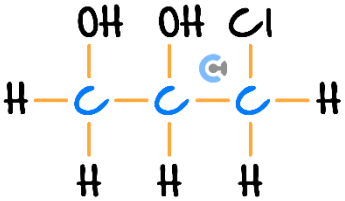
b.



c.



d.



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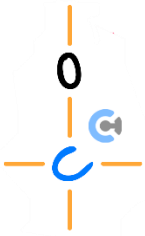
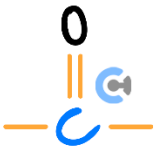
Sub-Section: Carbonyl Functional Group

Context

- **Before**: Oxygen forms **single** covalent bonds.
- **Now**: Oxygen forms a _____ covalent bond instead!

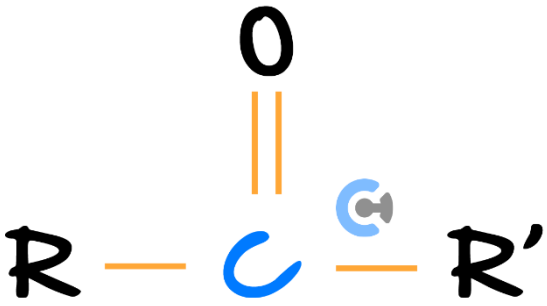




- C = O Name: _____ group.
- Semi-structural Formula: _____

Carbonyl Group

- **Definition**: A functional group consisting of a carbon double-bonded to an oxygen atom.
- **Structure**:



  - R – Stands for 'radical', which refers to the rest of the molecule!
- **Formula**:

$$C = O$$

NOTE: Carbonyl groups by themselves are not tested in VCE Chemistry ½, but other functional groups which contain them are!

Recall!

Active Recall: Draw the carbonyl functional group.

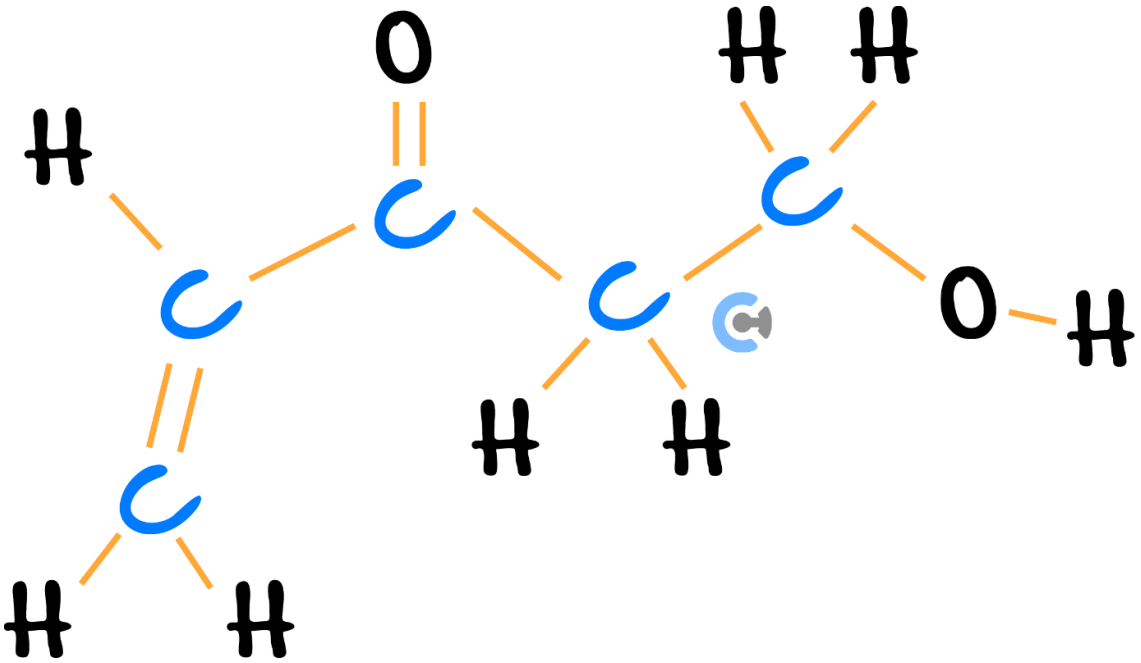
Structural Formula	Skeletal Structure

Space for Personal Notes

Your Turn!

Question 5

Circle and label the functional groups present in the following molecule below:



What functional groups can form from carbonyl groups?

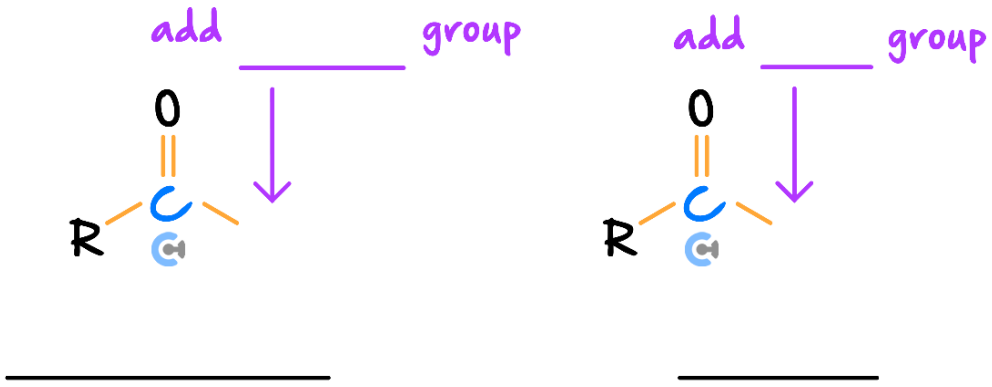
Space for Personal Notes

Sub-Section: Introduction to the Carboxyl Group

Return to the carbonyl group base!

Context

- Other **oxygen functional groups** that can be added carbonyl group:

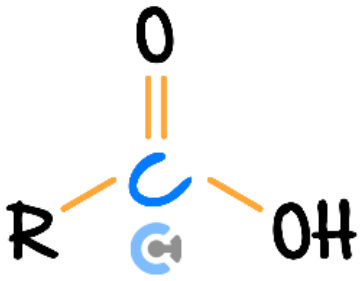


_____ _____

- **Result:**
  - If we add a hydroxyl group → _____ group.
  - If we add an ether group → _____ group.

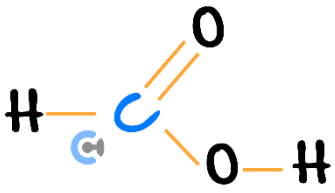
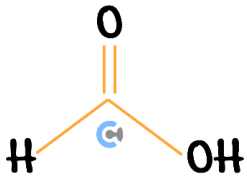
Carboxyl group

- **Definition**: A carboxyl group involves a carbonyl group ($C=O$) directly bonded to a hydroxyl group ($-OH$).
- **Functional group**: ($RCOOH$)



- Class of compound: _____
- Functional group name: _____
- Suffix: _____
- Priority: _____
- General Molecular Formula: _____.
- Data Book: Page 15

Exploration: Carboxylic acid

Number of carbons	1	2
Name		
Structural formula		
Semi-structural formula	$HCOOH$	
Skeletal formula		
Molecular formula	CH_2O_2	$C_2H_4O_2$

Space for Personal Notes

Let's have a look at more examples together!

Active Recall: How many covalent bonds does carbon form?

_____

Active Recall: What is the suffix for naming carboxyl groups? What is its numbering priority?

Suffix for carboxyl functional group	Numbering Priority
	[High] / [Medium] / [Low]

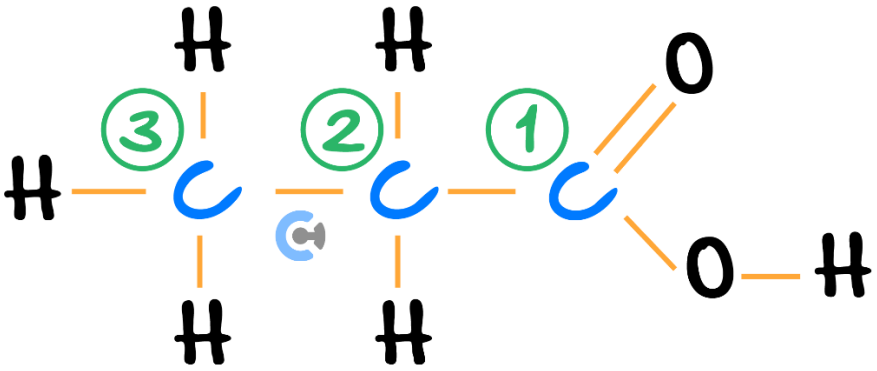
Active Recall: Draw a carboxyl group.

Structural Formula	Skeletal Structure

Space for Personal Notes

Exploration: Naming Carboxylic Acids

- Consider the following molecule:



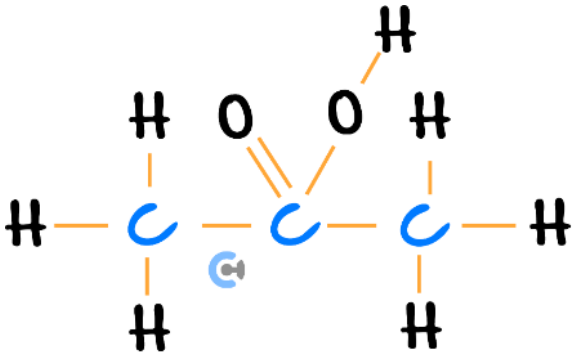
- Number the carbons according to their priority. *(Label Above)*
- **Carboxyl Group on Carbon Number:** _____
- **Name:** _____

Misconception

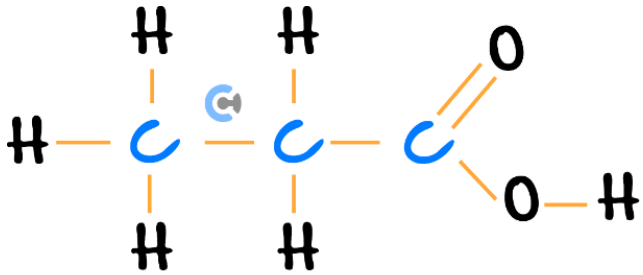
"The above molecule was called propan-1-oic acid:"

TRUTH:

- Could the carboxyl group be attached to the central carbon, like so?



- Bonds middle carbon has: _____
- Carboxyl group only position: _____ of molecule.



- **Name:** _____

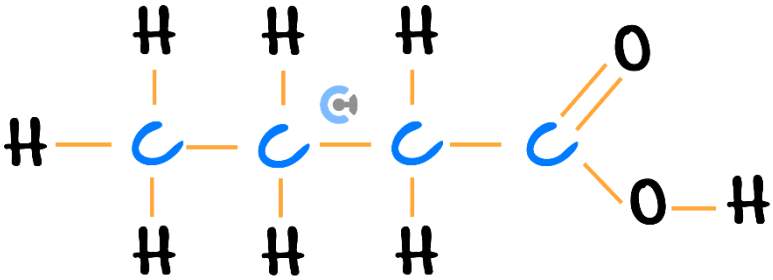
Naming the Carboxyl Group

- The location of the carboxyl group [does] / [does not] need to be specified!

Let's go through two more examples together!

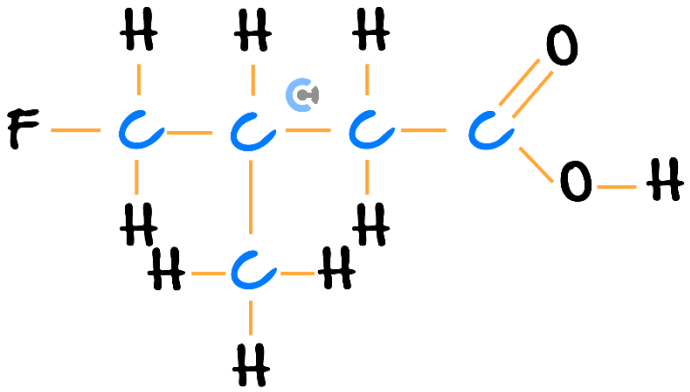
Question 6 Walkthrough.

a. Name the following molecule:



_____

b. For the following molecule:



i. Fill out the table:

Name	Semi-Structural Formula

ii. Draw the skeletal formula.

NOTE: The carboxyl group has the highest priority when numbering, and thus is always assigned a number priority of 1!

REMINDER: Don't forget there are no spaces in any naming part so far, only in the '-oic acid' is there is a space!

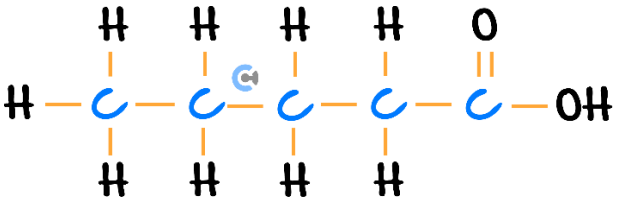
Space for Personal Notes

Your Turn!

Question 7

Fill in the table for the following molecules:

a.



Name	Skeletal structure

b.

Name	Semi-structural formula

c. $HCOOH$

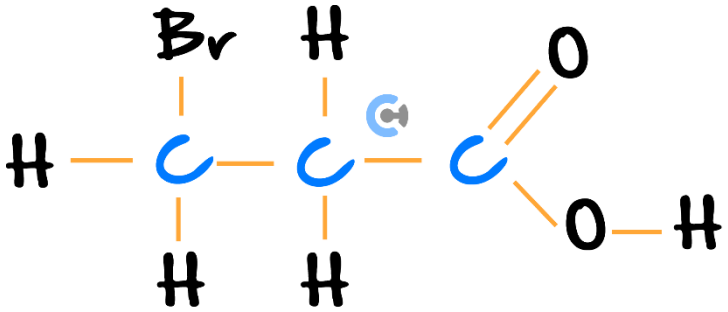
Name: _____

d. CH_3CH_2COOH

Name: _____

Question 8

For the following molecule:



a. Fill out the table:

Name	Semi-Structural Formula

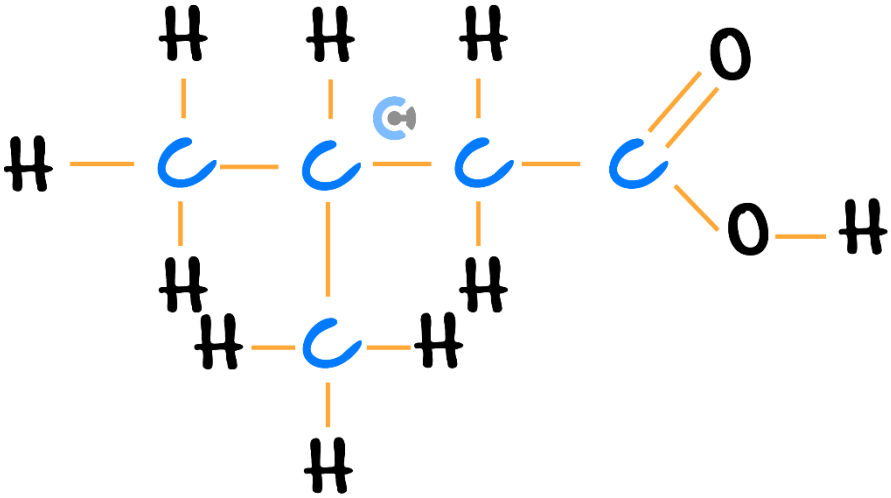
b. Draw the skeletal formula.

Space for Personal Notes

Try some more questions!

Question 9

For the following molecule:



a. Fill out the table:

Name	Semi-Structural Formula

b. Draw the skeletal formula.

Space for Personal Notes

Question 10

Draw the skeletal structure for all possible isomers of $C_5H_{10}O_2$, given that there is a known carboxyl group present (there are 4 total). Name them all.

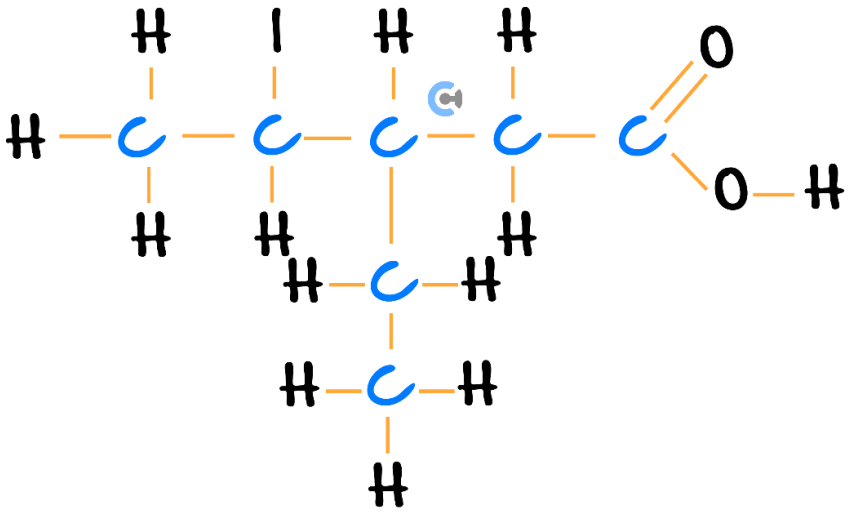
Isomer 1 Skeletal Structure: **Name**: _____	**Isomer 2 Skeletal Structure:** **Name**: _____
Isomer 3 Skeletal Structure: **Name**: _____	**Isomer 4 Skeletal Structure:** **Name**: _____

Space for Personal Notes

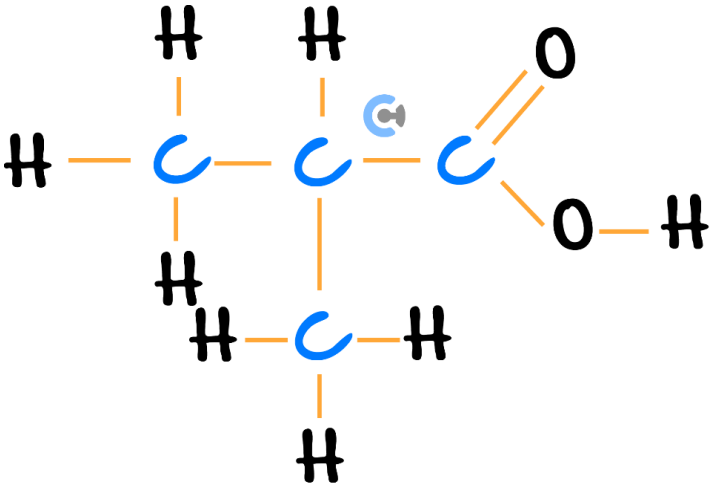
Question 11 Additional Question.

Name the following molecules:

a.



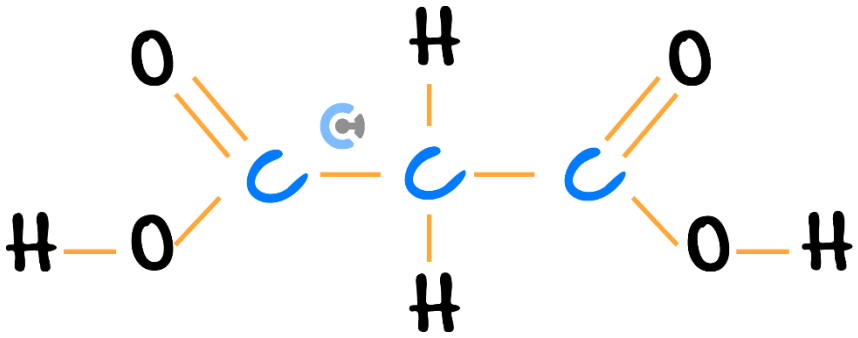
b.



NOTE: For the last molecule, as the methyl group can only be on the middle carbon, the number is omitted (redundant numbers)!

Sub-Section: Double-Ended Carboxylic Acids

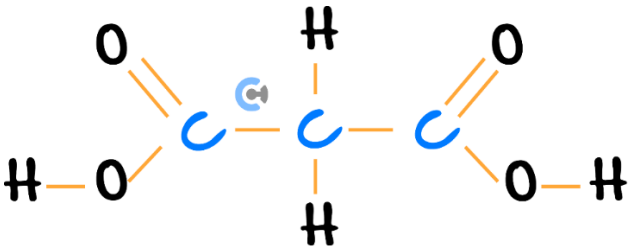
Discussion: What is the name of the following molecule?



- Name: _____

Misconception

"The following molecule is called propane-1,3-dioic acid"



TRUTH:

- Where must the two carboxyl groups be located on a molecule? _____.
- Do the numbers need to be specified? [Yes] / [No]
- **Actual Name:** _____

Naming Double-ended carboxylic acids

- As carboxyl groups must always be at the end, numbers [do] / [do not] need to be specified!

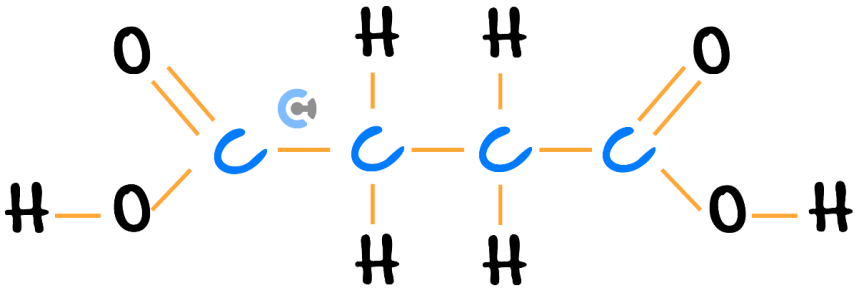
NOTE: The 'e' needs to be added whenever there's a prefix such as 'di-', 'tri-' or 'tetra-'!

Try some questions!

Question 12

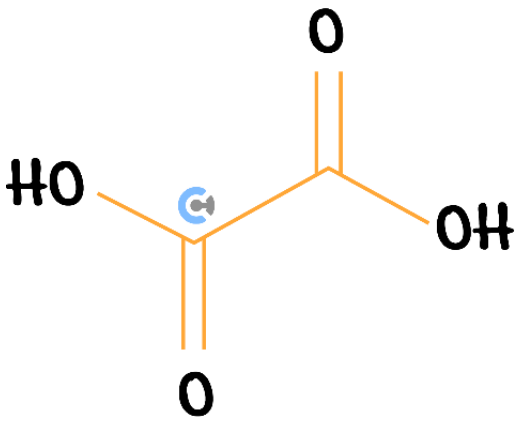
Fill in the table with the relevant information for the following molecules:

a.



Name	Molecular formula

b.

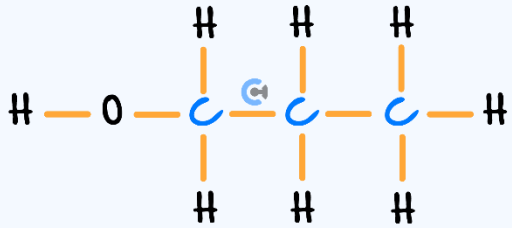
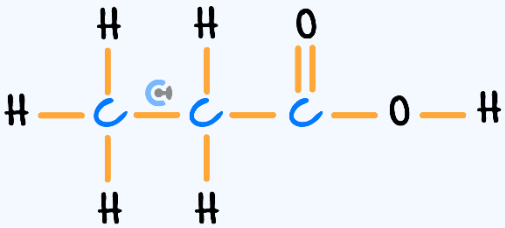


Name: _____

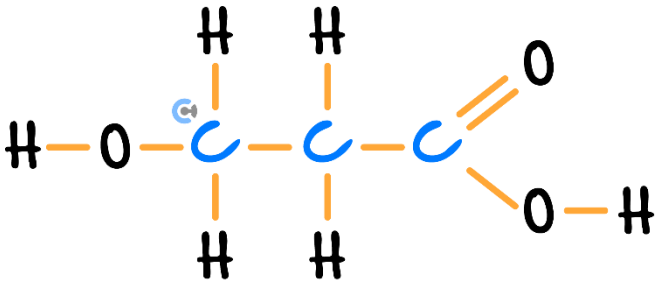
Sub-Section: Multiple Functional Groups

What happens if there is a hydroxyl group and a carboxyl group?

Exploration: Hydroxyl and carboxyl groups

Molecule #1	Molecule #2
	
Name:	Name:

What if a molecule has both functional groups?



- Functional groups present & their suffixes: *(Label Above)*
- Organic molecules can have how many suffixes? _____
- Functional group with priority: [Hydroxyl group (-ol)] / [Carboxyl group (-oic acid)]
- Primary functional group: [Hydroxyl group (-ol)] / [Carboxyl group (-oic acid)]
- Functional group which gets suffix: [Hydroxyl group (-ol)] / [Carboxyl group (-oic acid)]

How do we name the hydroxyl group?

- Instead of "-ol", hydroxyl groups are named via: _____
- Carbon number hydroxyl group on: _____
- **Name**: _____

Misconception

"The name of the above molecule is 3-hydroxylpropanoic acid "

TRUTH:

Multiple Functional Groups Naming Steps

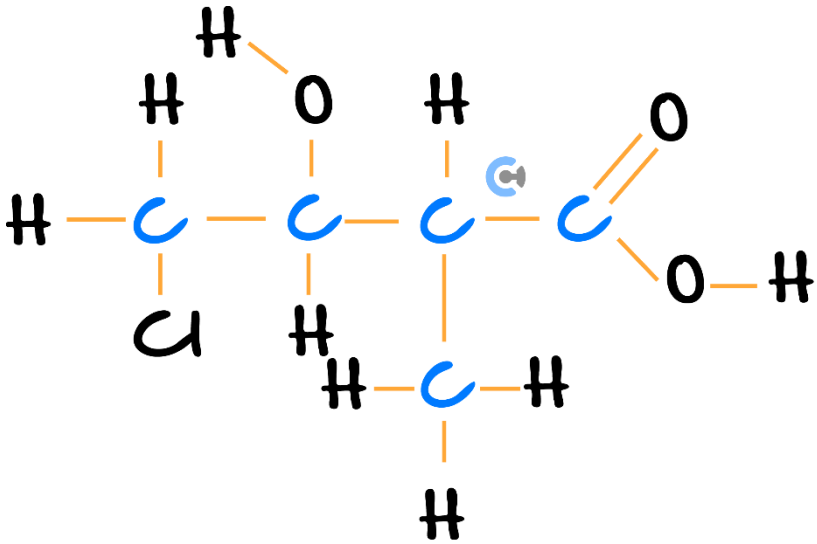
1. **Find** the **primary functional group** first (highest on the table in the Databook).
2. Primary functional group assigned: [prefix] / [suffix] naming.
3. Other functional groups assigned: [prefix] / [suffix] naming.

Space for Personal Notes

Let's have a look at a question together!

Question 13 Walkthrough.

For the following molecule:



a. Provide the IUPAC name.

_____

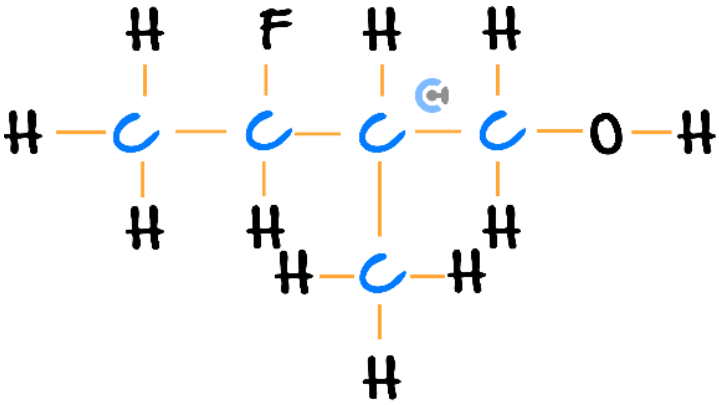
b. Draw the skeletal structure.

REMINDER: Don't forget that 'hydroxy-' has no 'l' at the end!

Your turn!

Question 14

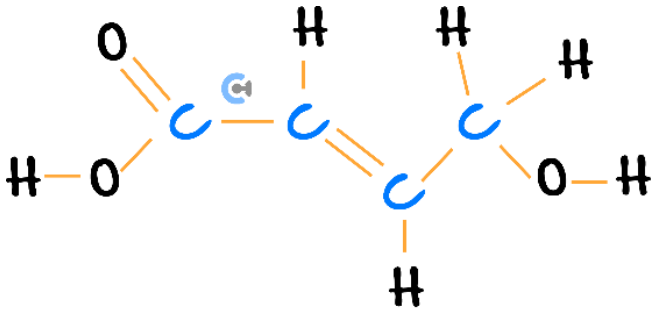
Name the following molecule:



_____

Question 15

Fill out the following information for the molecule below:

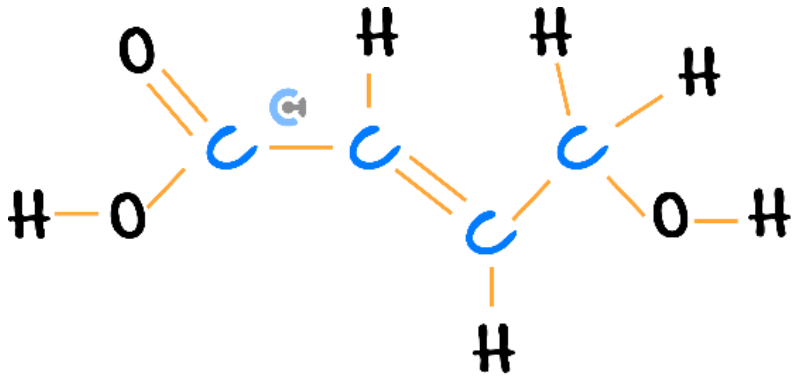


Name: _____

Skeletal Structure:

Question 16 Additional Question.

Name the following molecule:



Section B: Esters

Sub-Section: Esterification Condensation Reaction

Now that we've covered carboxyl groups in depth, let's look at the last functional group, which are esters!

Context

- Ever thought about where fruits get their smells from?

- Esters are responsible for their smell.

Active Recall: What is condensation?

_____

Condensation Reaction

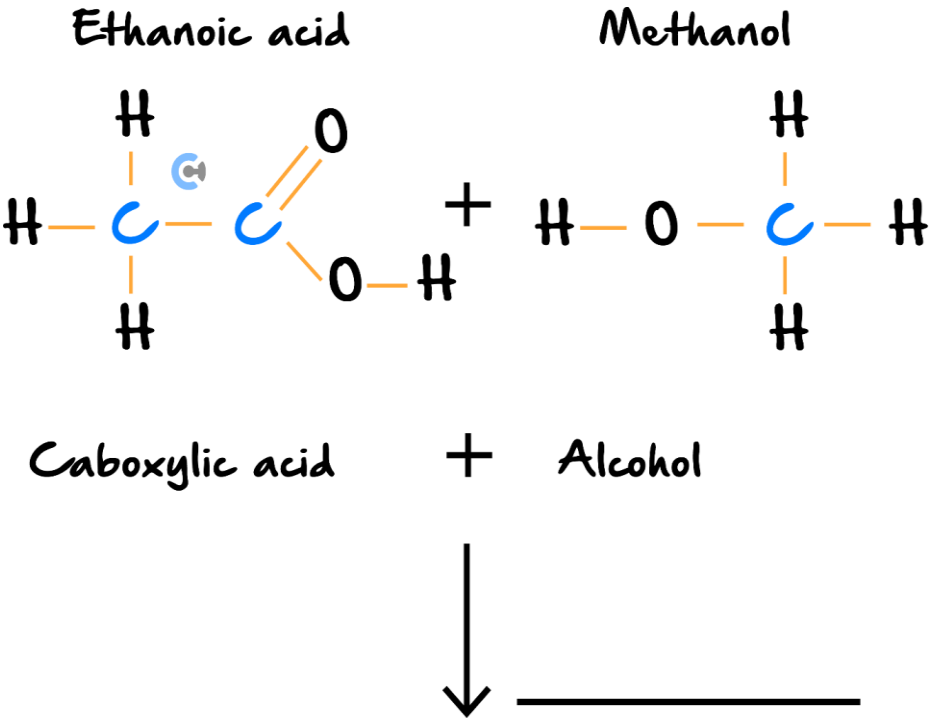
- **Definition**: The combination of two molecules, which results in the **elimination of** _____ or another simple molecule.

Space for Personal Notes

Let's have a look at the esterification reaction!

Exploration: Esterification Condensation Reaction

- **Esterification reaction considered:** _____ **reaction.**
- Consider a carboxylic acid (e.g., ethanoic acid) and an alcohol (e.g., methanol) reacting together:

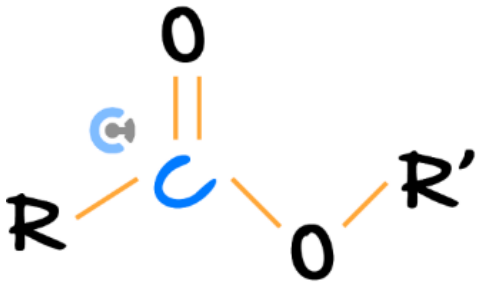


$$\textit{Carboxylic Acid} + \textit{Alcohol} \rightarrow \textit{Ester} + \textit{Water}$$

- Products:
  - _____.
  - _____.
- Reaction uses organic **highly concentrated** acidified catalyst sulphuric acid (H_2SO_4). *(Label Above.)*

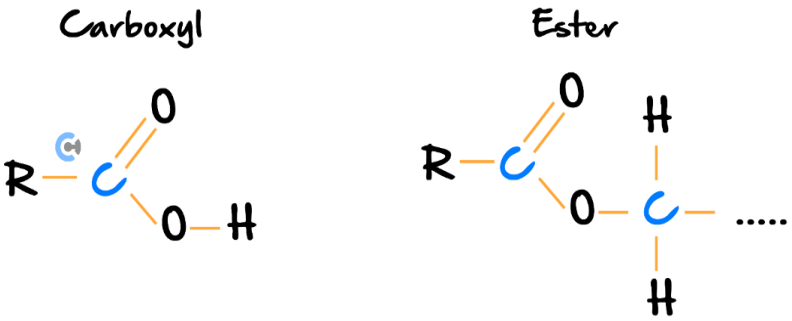
Ester Functional Group

- **Definition**: A carbonyl group ($C = O$) which is attached to an oxygen then another carbon.
- **Special Feature:** There must be at least one carbon attached to either side of the ester functional group!
- **Structure**:



- **Semi-Structural Structure**: $R - COO - R'$.

TIP: Think about an ester group as a carboxyl group with the hydrogen replaced with a carbon chain!



Space for Personal Notes

Let's look at a question together!

Question 17 Walkthrough.

For the esterification reaction that occurs between ethanol and propanoic acid:

a. Draw structural formulae reaction.

b. Draw the semi-structural formulae reaction between propan-1-ol and ethanoic acid.

_____

_____

TIPS: When writing a semi-structural formula, the ester will be a '$COOCH_2$'.

- Always write the **carboxylic acid first**!
- Align the hydroxyl groups ($-OH$) to each other!

NOTE: For esterification reactions, all states are **liquid**!

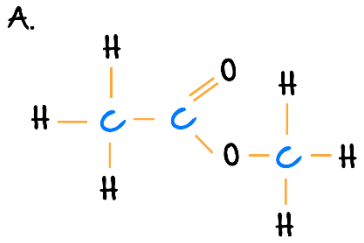
ALSO NOTE: The sulphuric acid $(H_2SO_4(l))$ is also liquid in state! Don't forget to add water (H_2O) as the by-product!

Your Turn!

Question 18

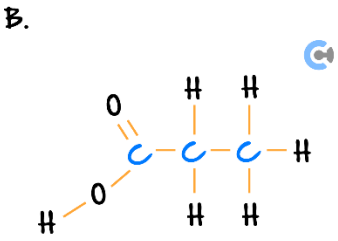
Circle and label the primary functional group, identifying if it is a carboxyl or ester functional group.

a.



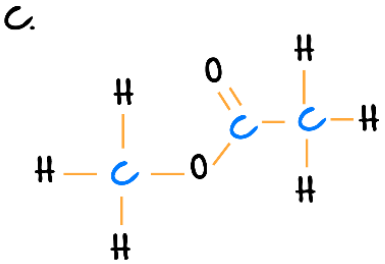
[carboxyl] / [ester] functional group

b.



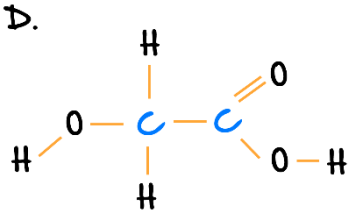
[carboxyl] / [ester] functional group

c.



[carboxyl] / [ester] functional group

d.



[carboxyl] / [ester] functional group

Space for Personal Notes

Question 19

For the esterification reaction that occurs between ethanoic acid and ethanol:

a. Draw structural formulae reaction.

b. Circle and name the primary functional group in the product formed.

REMINDER: Don't forget to write the carboxylic acid first!

Space for Personal Notes

Question 20

For the esterification reaction that occurs between propan-1-ol and methanoic acid:

Draw structural formulae reaction.

Space for Personal Notes

Now, practice writing the semi-structural formula reactions!

Question 21

For each of the following, write the semi-structural formula reaction when the specified chemicals react together.

a. Methanoic acid and propan-1-ol

_____

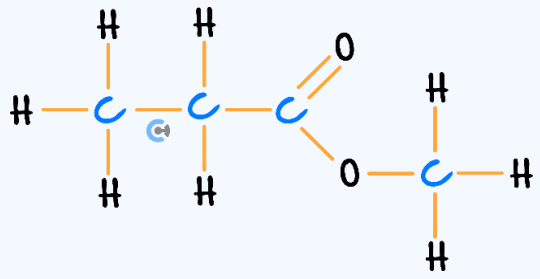
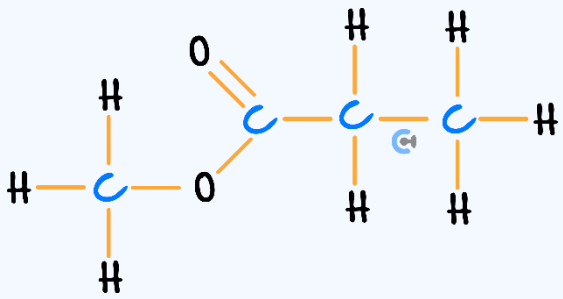
_____

b. Ethanol and propanoic acid

_____

_____

NOTE: Esters are written differently forwards and backwards.

Arrangement #1	Arrangement #2
	
Name: _____	Name: _____

- However, try to **avoid** using the **second**, 'backwards' formation to avoid confusion!

How do we name esters?

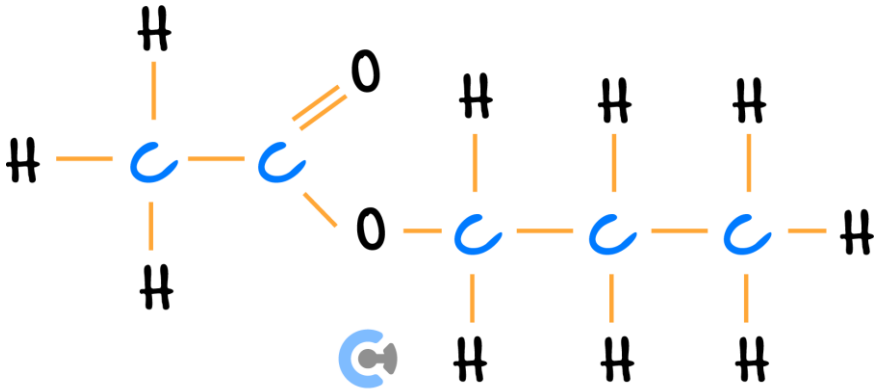
Sub-Section: Naming Esters

Active Recall: Which two classes of molecules combine to form ester?

Molecule #1	Molecule #2

Exploration: Naming Esters

- If we consider the following ester, where is the ester functional group? *(Label Below.)*



_____ _____

- Carboxyl and Alcohol Portions: *(Label Above.)*
- Segment with higher priority: [Carboxylic acid] / [Alcohol]
- Esters split into a **main chain** and a **side chain**.

- Main chain and Side chain portions: *(Label Below.)*

- Length of each chain:

Main Chain	Side Chain

- Esters are named with the suffix _____.
- **Name**: _____.

Naming Esters

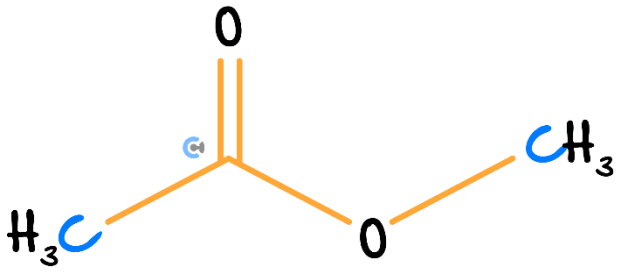
- Esters split into **two** portions:

Main Chain	Side Chain
Originally [carboxylic acid] / [alcohol] end	Originally [carboxylic acid] / [alcohol] end
Naming: [Prefix] / [Suffix] of _____	**Naming:** [Prefix] / [Suffix] like alkyl groups

Let's look at a question together!

Question 22 Walkthrough.

Name the following ester.



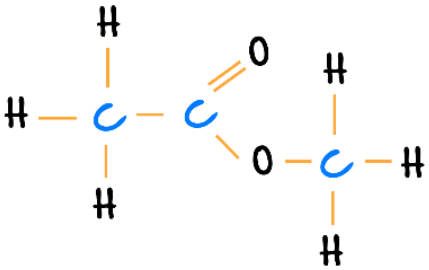
_____

Try some questions!

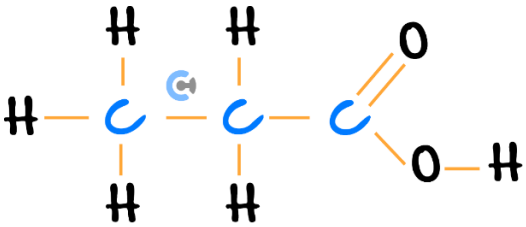
Question 23

Circle and label the primary functional group in each of the following molecules.

a.



b.



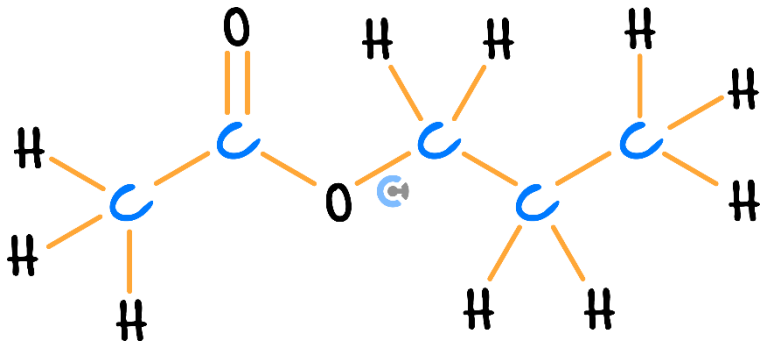
c. What type of isomers are the above two molecules?

_____

Question 24

Provide the systematic IUPAC name for each of the following molecules.

a.

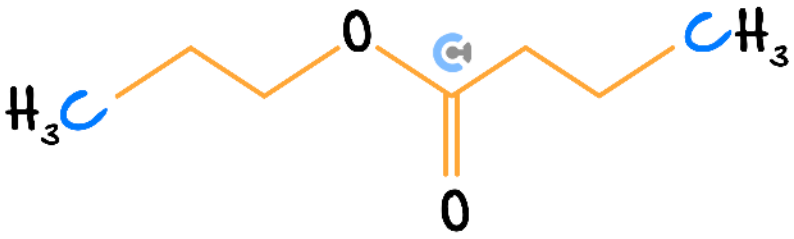


b. Write the systematic name for the following molecule.

$$CH_3CH_2CH_2COOCH_2CH_2CH_3$$

Question 25

The name of the molecule shown below is:



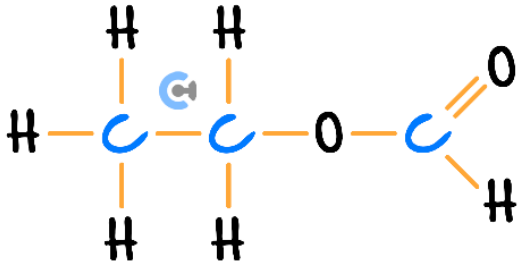
A. Butyl butanoate

B. Propyl propanoate

C. Butyl propanoate

D. Propyl butanoate

Question 26



The systematic IUPAC name for the molecule shown above is:

A. Ethyl propanoate

B. Propanal

C. Propanoic acid

D. Ethyl methanoate

Space for Personal Notes

Sub-Section: Drawing Ester from Name

Exploration: Deriving Structure of Ester from Name

- What does the ester look like?

Ethyl methanoate

Semi-Structural Formula	Skeletal Diagram

NOTE: Ester groups will always be by themselves – molecules with ester groups and other functional groups in addition will not be tested!

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Deriving Structure of Ester from Name

Beginning Portion of name ending with '-yl'	Ending Portion of name ending with '-oate'
[Main] / [Side] chain	[Main] / [Side] chain
Attached to side with $[C=O]$ / $[-O-]$	Attached to side with $[C=O]$ / $[-O-]$

Let's try a question together!

Question 27 Walkthrough.

Write the semi-structural formula of ethyl methanoate.

_____

Your Turn!

Question 28

Draw the skeletal structure of butyl methanoate.

Question 29

Draw the semi-structural formula of pentyl ethanoate.

_____

_____

Question 30 Additional Question.

Write the molecular formula of methyl propanoate.

_____

_____

Space for Personal Notes

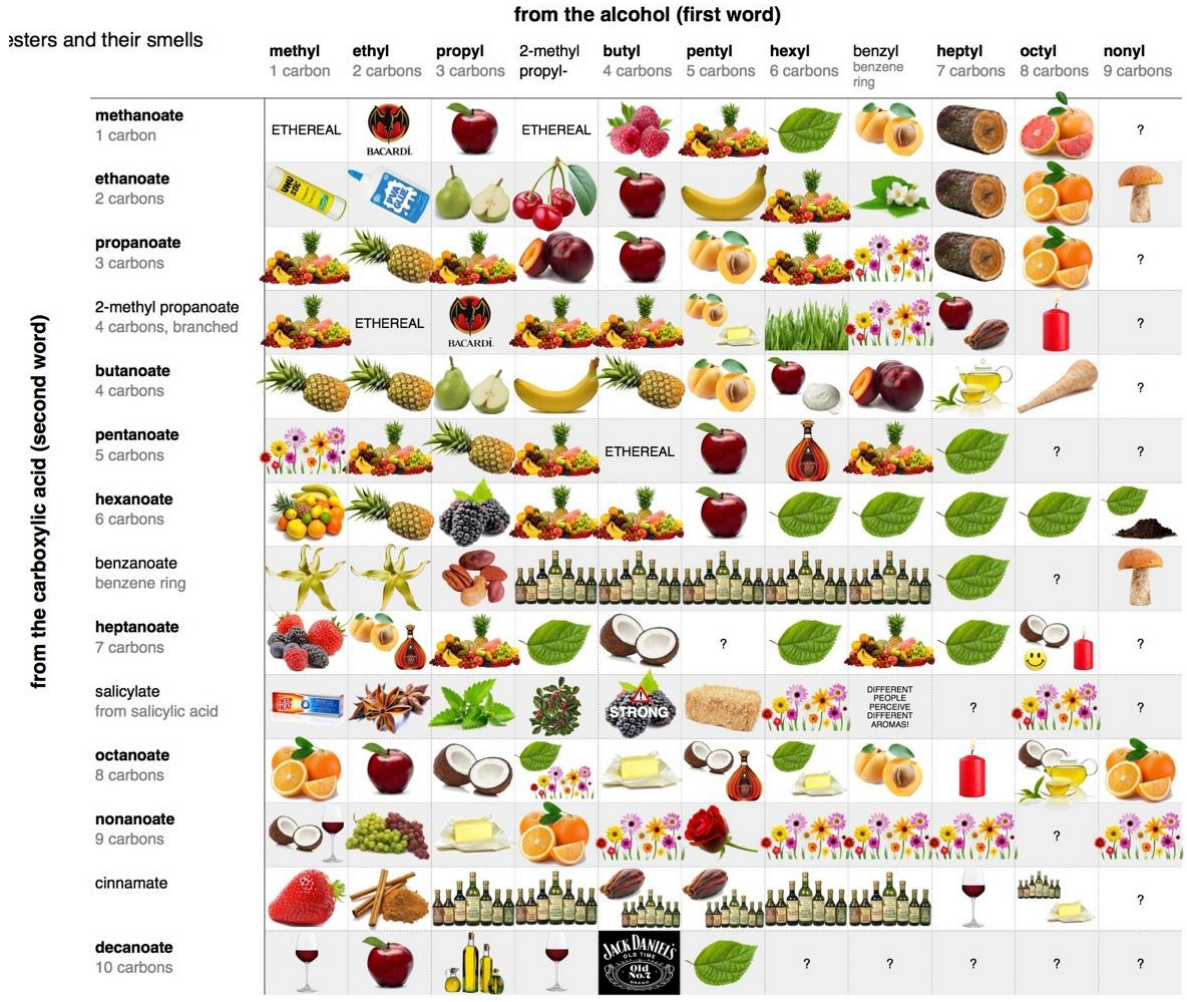
Sub-Section: Ester Smells

Context

- Ester Smell: _____.
- Smell dictated by: _____ of main/side chain.

Ester Smells

- Consider the table below.



NOTE: This table does not need to be memorised and will be provided if a question refers to it!

Let's try a question together!

Question 31 Walkthrough.

State which esters give off a coconut smell, referring to the table provided on the previous page.

_____

_____

Your Turn!

Question 32

For each of the following questions, state the smell the ester gives off, referring to the table provided on the previous page.

a. Ethyl hexanoate	**b.** Butyl proponate

Question 33

Name one ester which gives off a smell of wine, referring to the table provided on the previous page.

_____

Space for Personal Notes

Section C: Isomers

Sub-Section: Ester Isomers

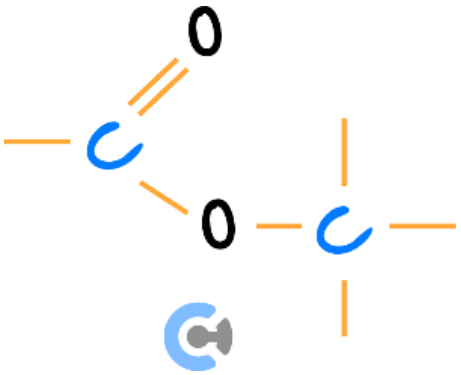
Context

- As esters have both a main chain and a side chain, it is very easy to form different chain isomers!

Let's have a look at an example together!

Exploration: Isomers of esters

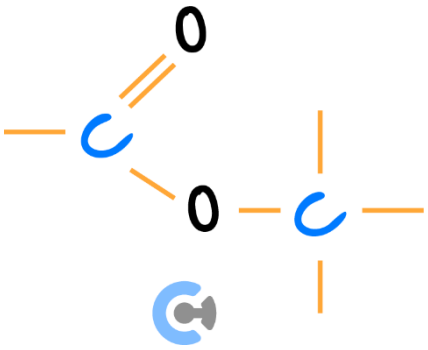
- Consider esters with molecular formula: $C_4H_8O_2$
- **Baseline Structure:**



- Already has **two** carbons.

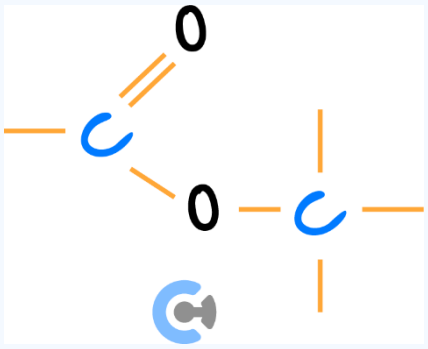
- Possible Isomers:

Isomer 1 Structure:



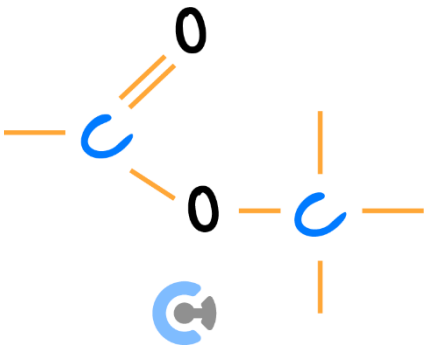
Name: _____.

Isomer 2 Structure:



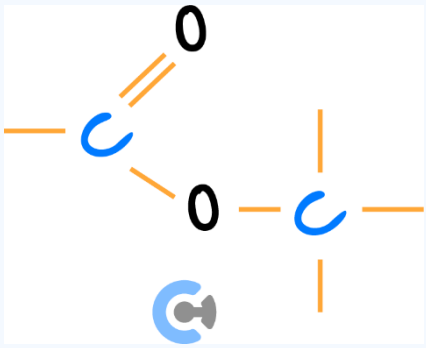
Name: _____.

Isomer 3 Structure:



Name: _____.

Isomer 4 Structure:



Name: _____.

NOTE: While you will not be asked to name esters with alkyl groups on the main/side chain, you need to know of their existence!

TIP: Start with all the carbons on the main chain and slowly move the carbons across!

Ester Isomers Steps:

1. Start with the baseline structure.
2. Add carbons on either side.

Space for Personal Notes

Your Turn!

Question 34

Draw all potential isomers of a molecule with the molecular formula of $C_3H_6O_2$, given that it is known to have an ester functional group.

Question 35 Additional Question.

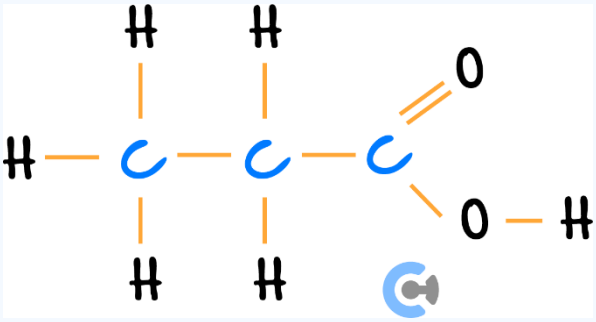
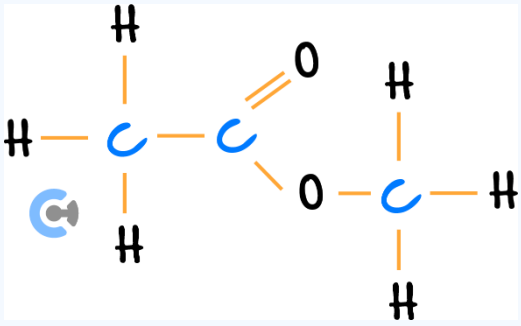
State the number of isomers of esters possible with the molecular formula of $C_2H_4O_2$.

_____

Space for Personal Notes

Sub-Section: Functional Isomers

Exploration: Carboxyl and Ester Functional Groups

Ethanoic Acid	Methyl Methanoate
	
Molecular Formula: _____.	Molecular Formula: _____.

- **Observation**: Ethanoic acid and methyl methanoate have the same molecular formula.
- **Conclusion**: They are _____ of each other.
- **Type of Isomers:** _____.

Functional Isomer

- **Definition**: Compounds that have the same molecular formula, but **different functional groups**.

Space for Personal Notes

Let's have a look at an example together!

Exploration: Isomers of $C_2H_4O_2$

- Consider molecules with molecular formula: $C_2H_4O_2$
- **Carboxyl** isomers: **(Isomer 1)**

- **Ester** isomers: **(Isomer 2)**

- Another functional group with oxygen in it: _____.
- Amount of functional group is needed: _____.
- **Hydroxyl Isomers: (Isomer 3 & 4)**

NOTE: As hydroxyl groups do not contain a $C=O$ double bond, they end up having more hydrogens! We 'remove' these hydrogens by including a $C=C$ double bond!

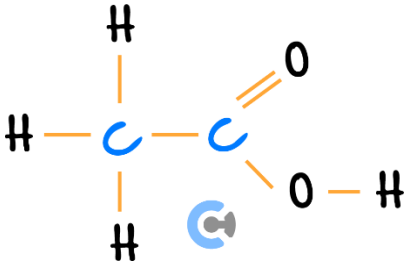
What type of isomers are these to each other?

Definition

Isomers with Oxygen

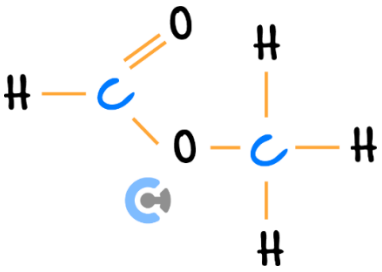
- Molecules with the formula $C_2H_4O_2$ have four different isomers:

Isomer 1 Structure:



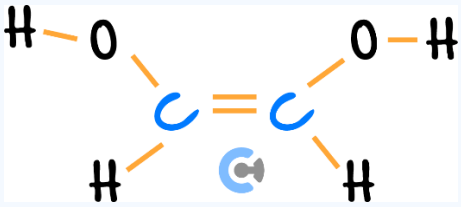
Name: Ethanoic acid

Isomer 2 Structure:



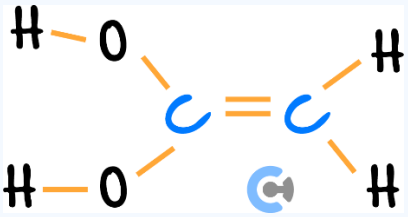
Name: Methyl methanoate

Isomer 3 Structure:



Name: Ethene-1,2-diol

Isomer 4 Structure:



Name: Ethene-1,1-diol

- Isomer 1 and Isomer 2 are _____ isomers.
- Isomer 1 and Isomer 3 are _____ isomers.
- Isomer 3 and Isomer 4 are _____ isomers.
- Carboxylic acids and esters have the same molecular formula.

NOTE: While exists, generally, try to find the carboxyl and ester isomers first before filling in the hydroxyl isomers with an alkenyl group!

Your Turn!

Question 36

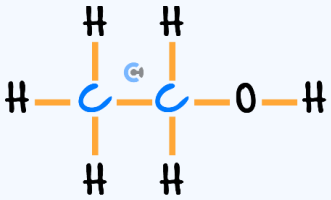
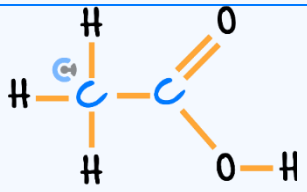
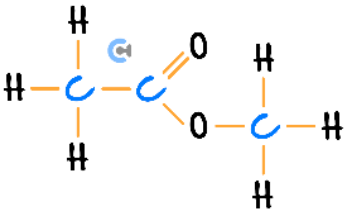
Draw three potential isomers of molecules with a molecular formula of $C_3H_6O_2$.

Space for Personal Notes

Contour Check

- Learning Objective: [2.7.1] - Apply IUPAC conventions to identify, draw & write IUPAC names of straight-chained & branched carboxylic acids

Key Takeaways

Structural Formula	Functional Group	Class of Molecule	Prefix / Suffix
			
			
			

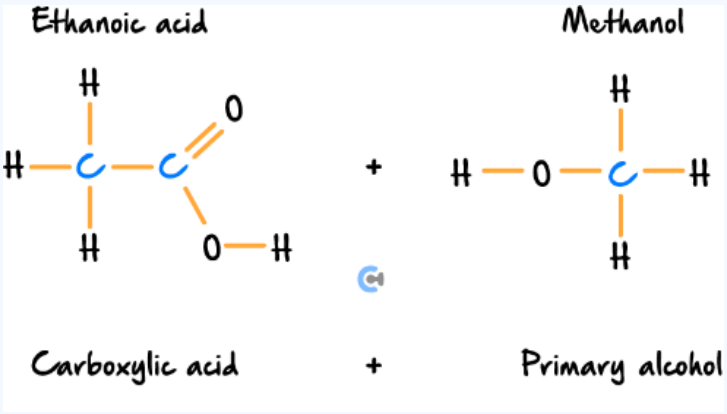
- As carboxyl groups must always be at the end, numbers [do] / [do not] need to be specified!
- Multiple Functional Groups Naming Steps

1. **Find** the **primary functional group** first (highest on the table in the databook).
2. Primary functional group assigned: [Prefix] / [Suffix] naming.
3. Other Functional Groups assigned: [Prefix] / [Suffix] naming.

Learning Objective: [2.7.2] - Write condensation reactions for the formation of esters & relevant catalysts / conditions

Key Takeaways

- Condensation Reaction Produces:



  - Ester Name:

☐ Learning Objective: [2.7.3] - Apply IUPAC conventions to identify, draw & write IUPAC names of straight-chained esters

Key Takeaways

☐ Naming Esters

Main Chain	Side Chain
Originally [carboxylic acid] / [alcohol] end	Originally [carboxylic acid] / [alcohol] end
Naming: [Prefix] / [Suffix] of _____	**Naming:** [Prefix] / [Suffix] like alkyl groups

☐ Drawing Esters from Name

Beginning Portion of name ending with '-yl'	Ending Portion of name ending with '-oate'
[Main] / [Side] chain	[Main] / [Side] chain
Attached to side with [C = O] / [−O −]	Attached to side with [C = O] / [−O −]

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