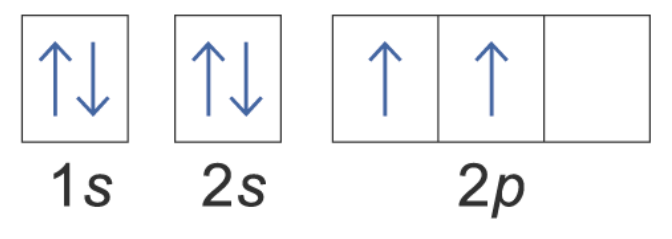
The Unique Nature of Carbon

Ability to form four strong covalent bonds

- Electronic configuration of carbon (ground state) : $1s^2 2s^2 2p^2$



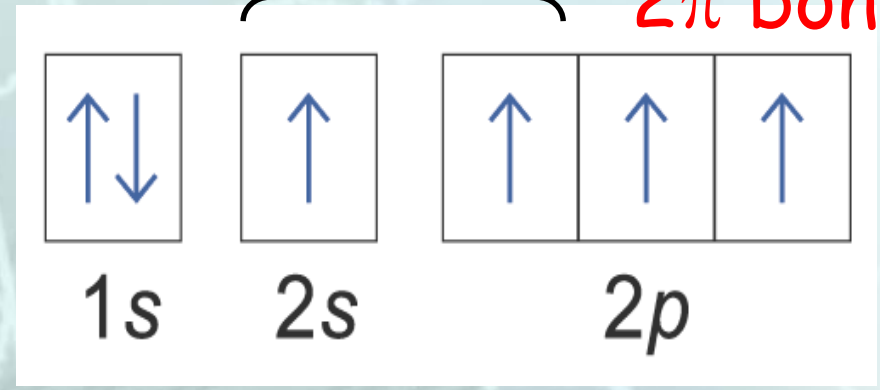
Carbon (ground state)

Ability to Form Multiple Bonds

sp^3 — 4σ bonds

sp^2 — 1π bond, 3σ bonds

sp — 2π bonds, 2σ bonds

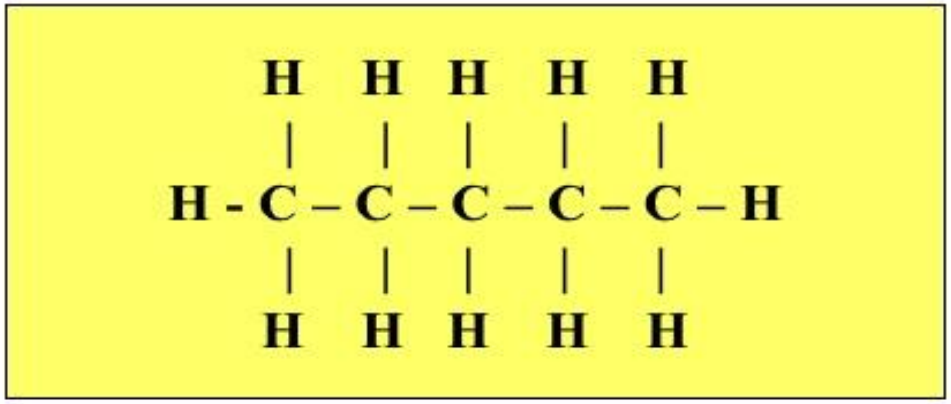


Carbon (excited state)

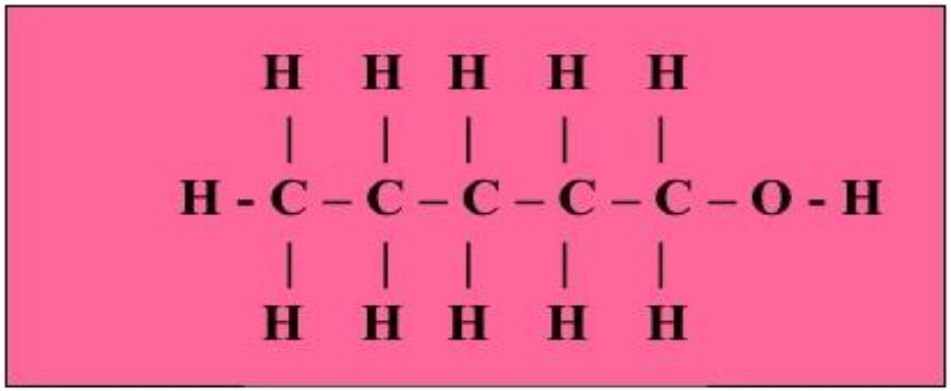
Ability to Catenate

- Carbon atoms link together to form chains of varying length, branched chains and rings of different sizes
- Catenation:

➔ Ability of atoms in forming stable bonds with itself, hence joining up into chains or rings

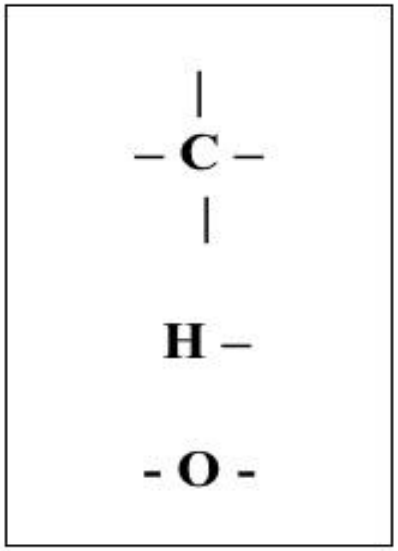


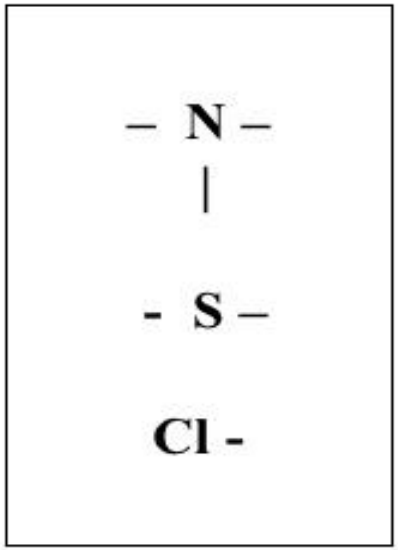
A carbon / hydrogen chain (organic)

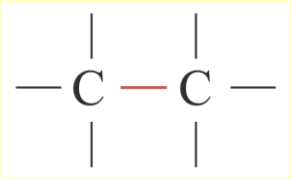
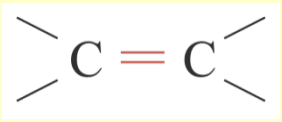
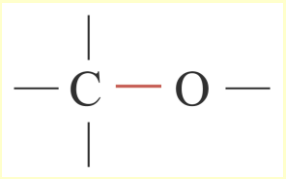
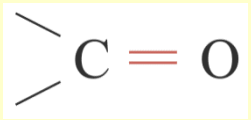
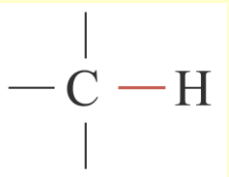
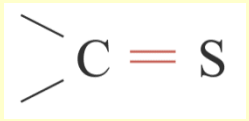
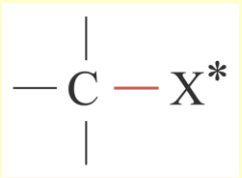
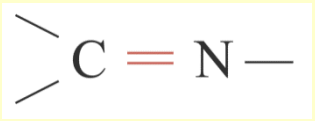
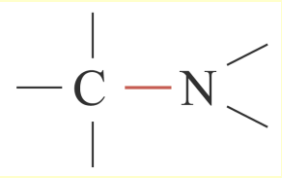
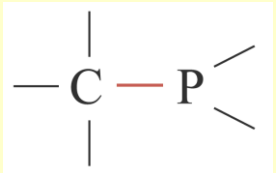


A carbon / hydrogen chain containing oxygen

Carbon can make four (4) bonds
Hydrogen can make one (1) bond
Oxygen can make two (2) bonds
Nitrogen can make three (3) bonds
Sulfur can make two (2) bonds
Halogens can make one (1) bond





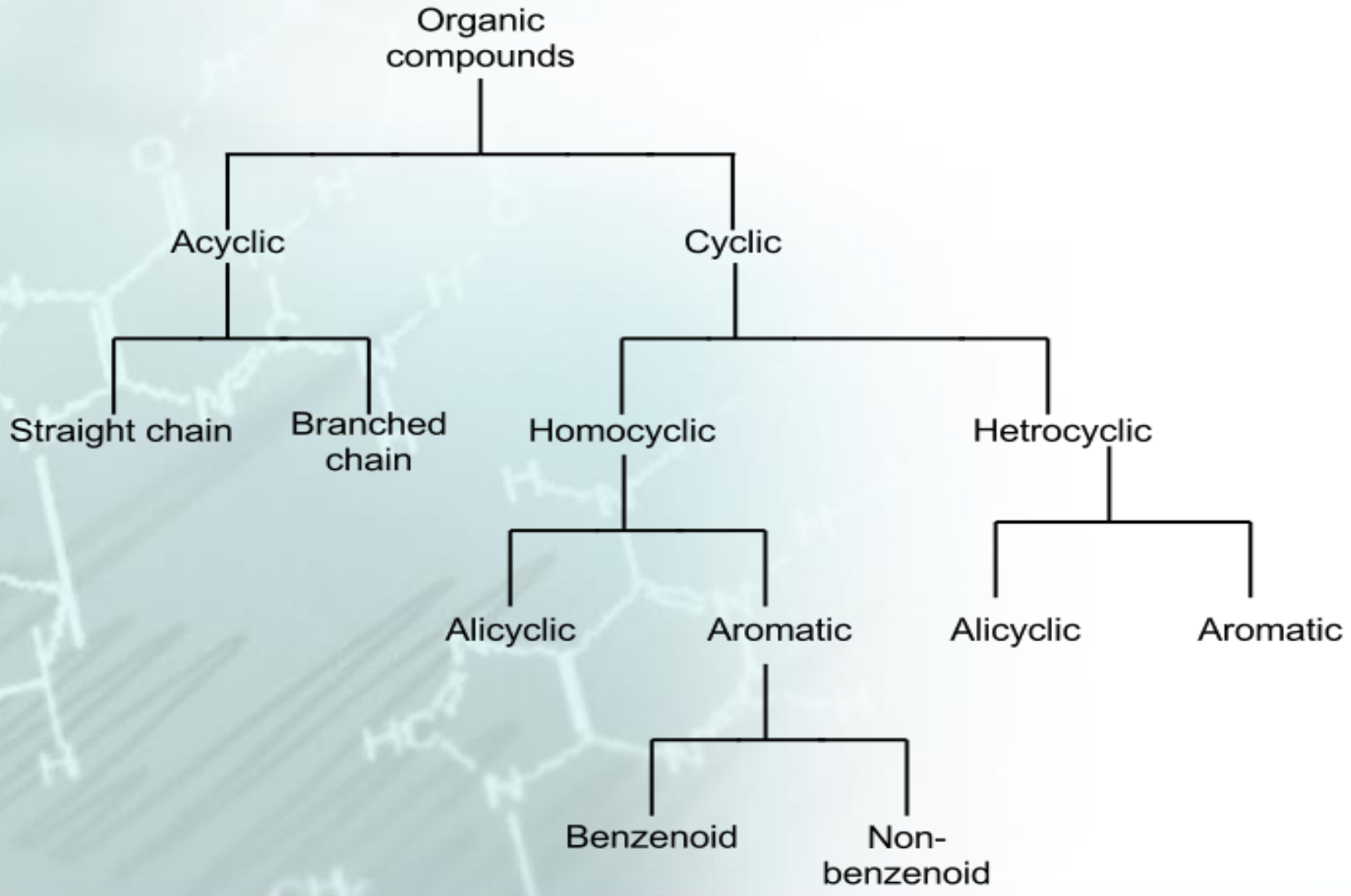
Single bond	Double bond	Triple bond
		
		
		
		
	* X = halogens	
		

Classification of Organic Compounds

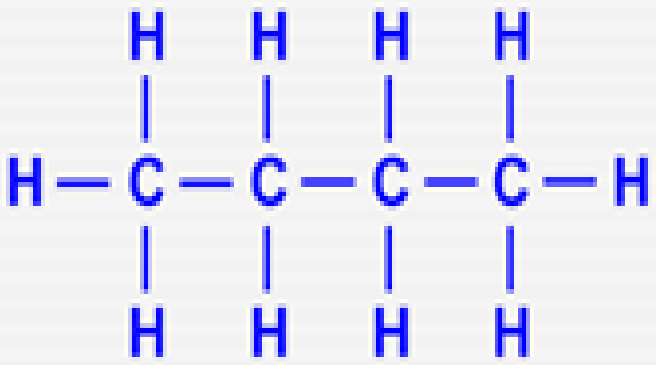
- Clasification according to Carbon Skeleton

- Clasification according to Functional Groups

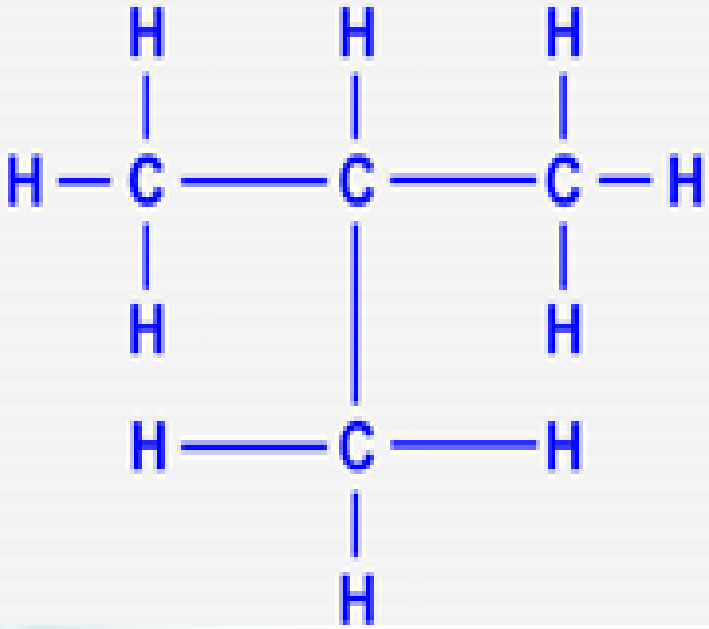
Clasification according to Carbon Skeleton



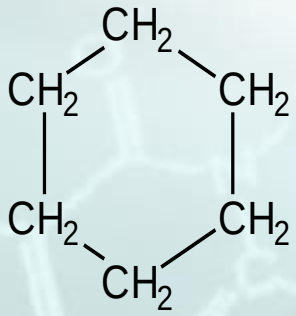
Straight Chain

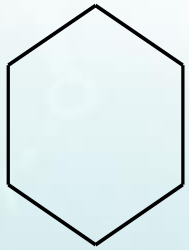


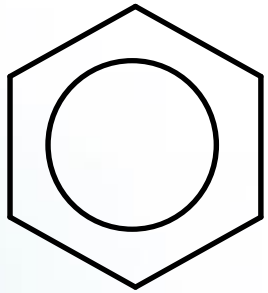
Branched Chain

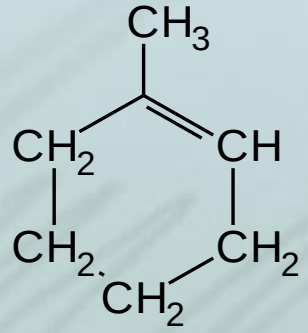


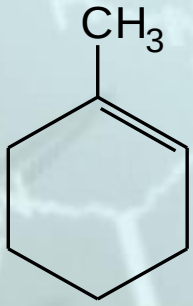
Cyclic compounds

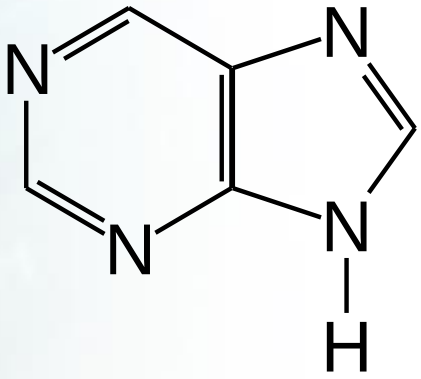












Clasification according to Functional Groups

- Organic compounds are classified by the presence of characteristic functional groups.

Functional Groups

A functional group is defined as an atom or a group of atoms that effectively determines the chemical properties of an organic compound.

Representing Functionality

Compounds containing the same functional group are called a family.

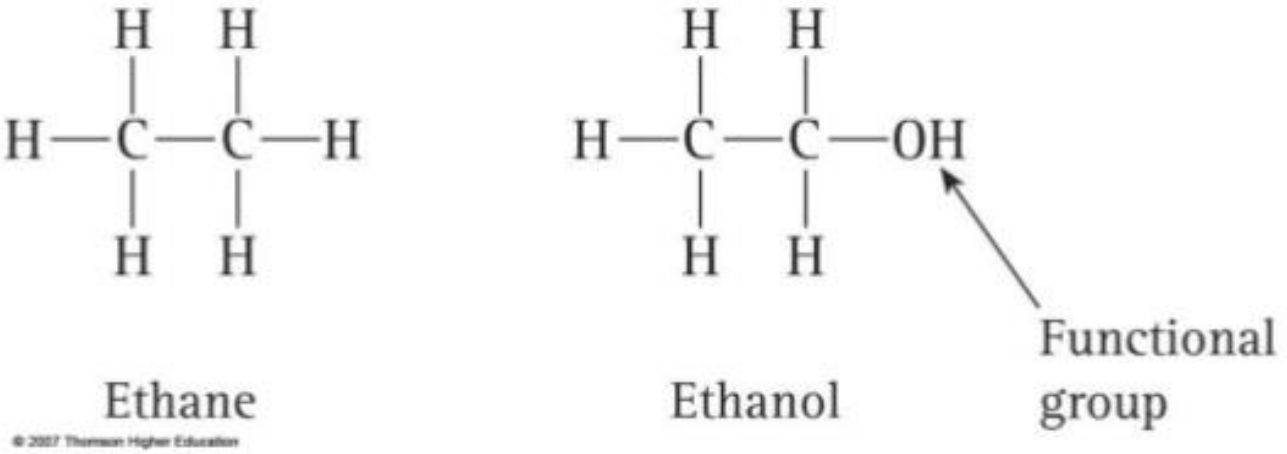
Generic symbolism is R-FG where R is the hydrocarbon part of the molecule and FG is the functional group.

R-OH symbolizes the alcohols.

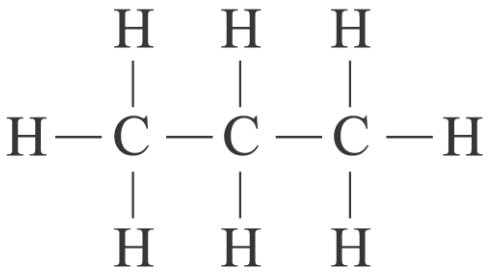
Functional groups help organize and classify organic compounds.

Functionalized Hydrocarbons

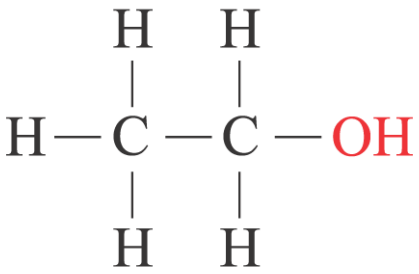
- Basic hydrocarbon structures form a foundation for a major grouping of organic compounds.
- Contain additional atoms or groups of atoms
- Insertion of functional groups to a hydrocarbon dramatically alters its properties.



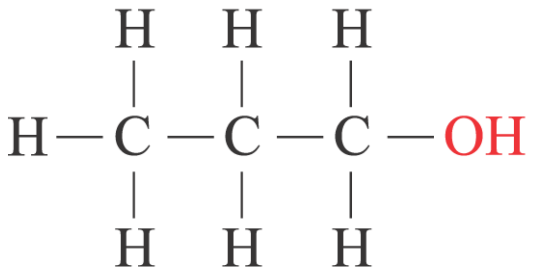
Functional Groups



Propane

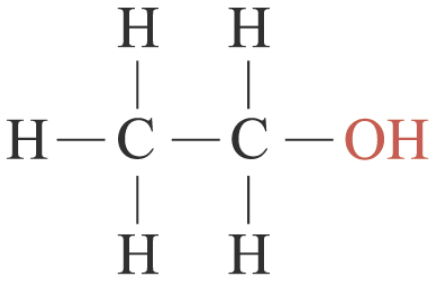


Ethanol



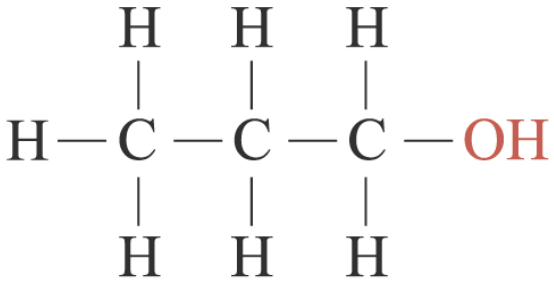
Propan-1-ol

Functional Groups



Ethanol

and

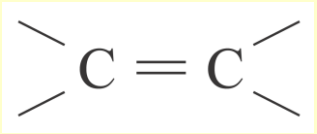
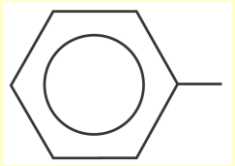


Propan-1-ol

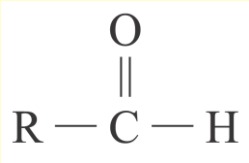
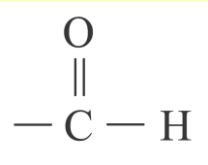
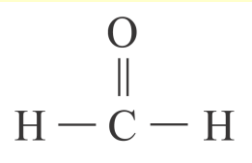
- have similar chemical properties

➔ they contain the same functional group –OH

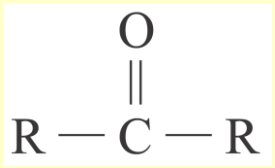
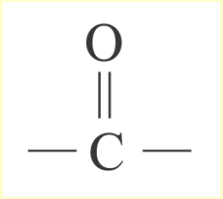
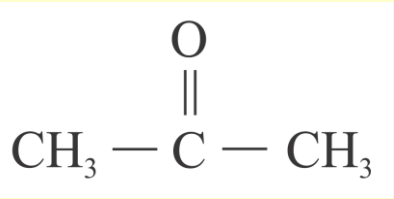
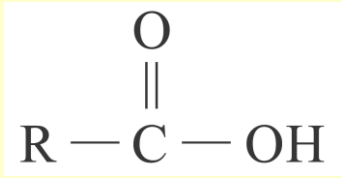
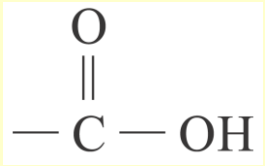
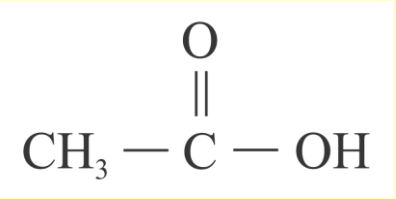
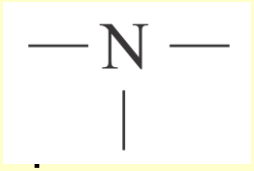
➔ they are classified into the same homologous series — alcohols

Family	General formula	Functional group	Example	
			Formula	IUPAC name
Alkane	RH	(Nil)	CH_3CH_3	Ethane
Alkene	$RCH = CH_2$ $RCH = CHR$ $R_2C = CHR$ $R_2C = CR_2$	 Carbon-carbon double bond	$CH_2 = CH_2$	Ethene
Alkyne	$RC \equiv CH$ $RC \equiv CR$	$– C \equiv C –$ Carbon-carbon triple bond	$HC \equiv CH$	Ethyne
Aromatic hydrocarbon	ArH	 Phenyl group		Benzene

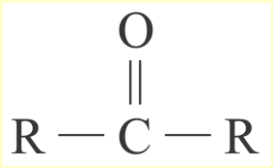
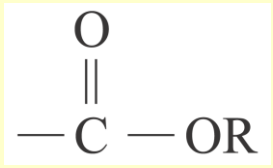
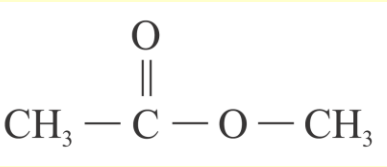
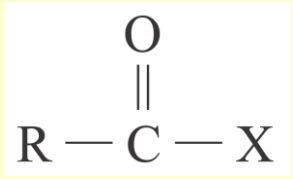
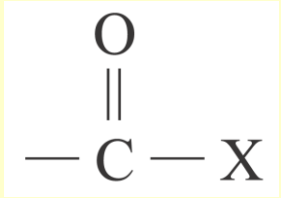
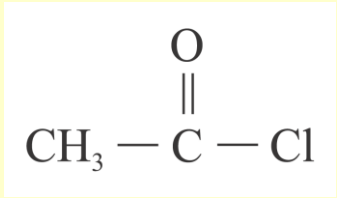
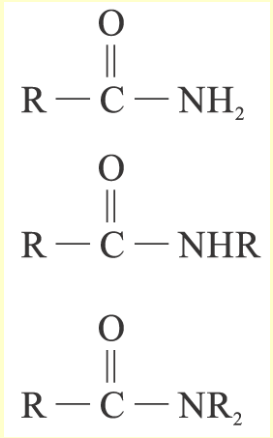
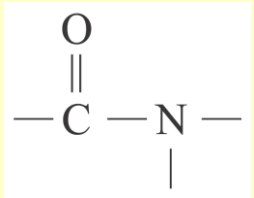
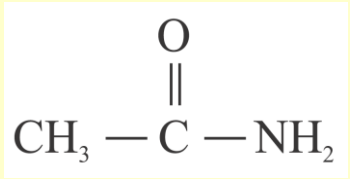
$R = C_nH_{2n+1} –$

Family	General formula	Functional group	Example	
			Formula	IUPAC name
Haloalkane	RX	— X halo group	CH_3Cl	Chloromethane
Alcohol	ROH	— OH hydroxyl group	CH_3OH	Methanol
Ether	R—O — R	— O — oxy group	$CH_3–O–CH_3$	Methoxymethane
Aldehyde		 carbonyl group		Methanal

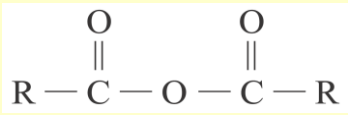
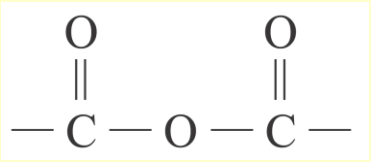
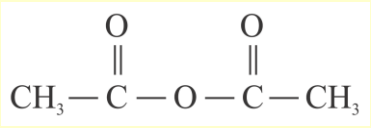
$R = C_nH_{2n+1}–$

Family	General formula	Functional group	Example	
			Formula	IUPAC name
Ketone		 carbonyl group		Propanone
Carboxylic acid		 carboxyl group		Ethanoic acid
Amine	RNH_2 R_2NH R_3N	 amino group	CH_3NH_2	Methylamine
Nitrile	$RC{\equiv}N$	$-C \equiv N$ nitrile group	CH_3CN	Ethanenitrile

$R = C_nH_{2n+1}-$

Family	General formula	Functional group	Example	
			Formula	IUPAC name
Ester		 ester group		Methyl ethanoate
Acyl halide		 acyl halide group		Ethanoyl chloride
Amide		 amide group		Ethanamide

$R = C_nH_{2n+1}-$

Family	General formula	Functional group	Example	
			Formula	IUPAC name
Acid anhydride		 acid anhydride group		Ethanoic anhydride

$$R = C_nH_{2n+1}-$$

Alcohols

- General formula: R-OH
- Additional of the –OH makes alcohols polar.
- Increased intermolecular attractive forces makes alcohols liquids.
- Naming involves modifying the hydrocarbon name with an ending of –ol.

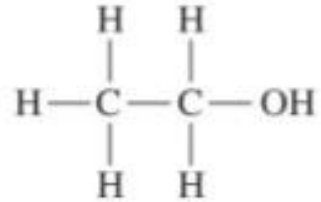
Ethanol

- Alcoholic beverages
- Gasoline additive
- Sugar fermentation

$$C_6H_{12}O_6 \rightarrow 2\ CH_3CH_2OH + 2\ CO_2$$

- CNS depressant
- Adverse health effects

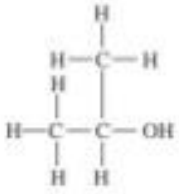
Ethanol



Other Alcohols

- Isopropyl alcohol is commonly known as rubbing alcohol.

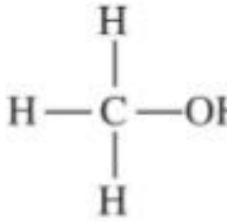
Isopropyl alcohol



CH_3CHOH

- Methanol is toxic to the human liver.
- Ethanol is administered as an antidote.

Methanol

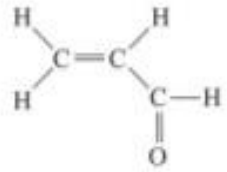


CH_3OH

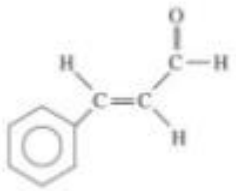
Aldehydes and Ketones

- Commonly found in pleasant flavors and aromas
- Contain the carbonyl group: Carbon double bonded to an oxygen atom

Acrolein



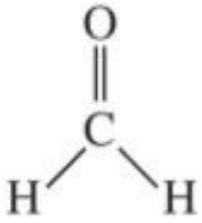
Cinnamaldehyde



Formulas

- Aldehydes
  - General formula: RCHO, includes carbonyl group
  - Named according to length carbon chain with the ending of –al or –aldehyde
  - Methanal or formaldehyde

Formaldehyde

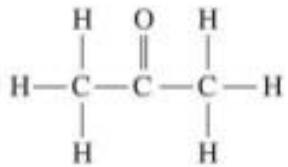


- Preservation of biological specimens

Formulas

- Ketones
  - Similar to aldehydes but have two R groups with the carbonyl
  - Names end in –one
  - Acetone is the simplest ketone.

Acetone

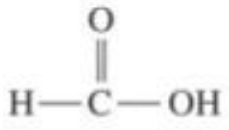


- Nail polish removal

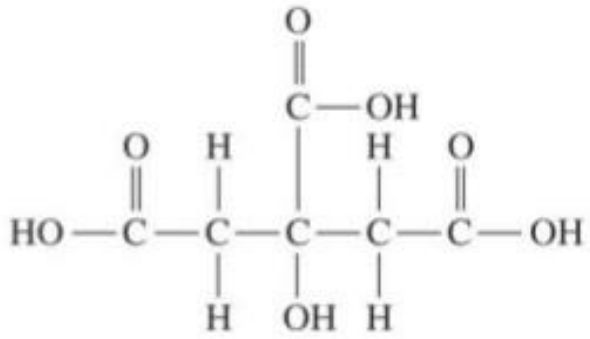
Carboxylic Acids

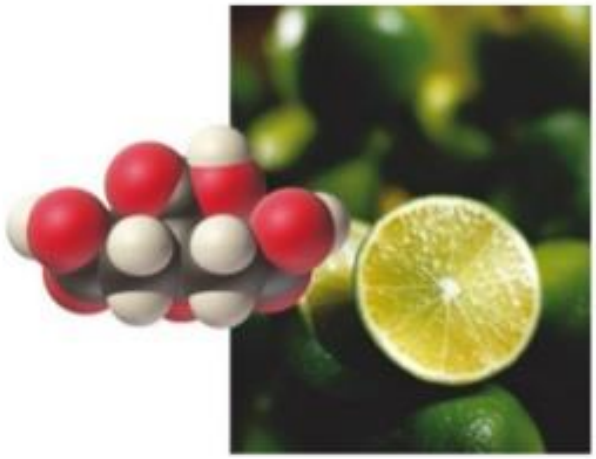
- Commonly found in sour foods
- General formula: RCOOH
- One of these oxygen atoms is bonded as a carbonyl group, as in aldehydes and ketones.

Formic acid

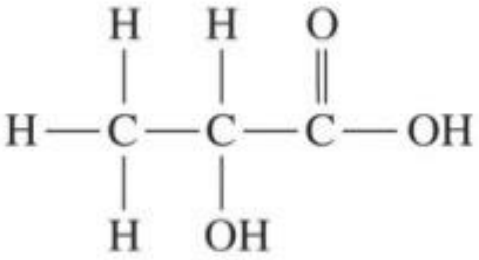


Citric acid





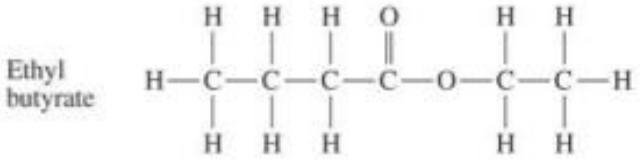
Lactic acid



Esters

- Esters have pleasant odors.
- General formula: RCOOR
- Named according to the relevant R groups and ending with –ate

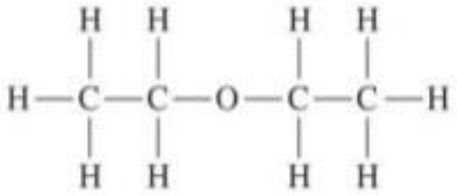
Ethyl butyrate



Ethers

- Ethers contain the functional group –O-
- General formula: ROR
- Named according to the two R groups and given the ending ether

Diethyl ether

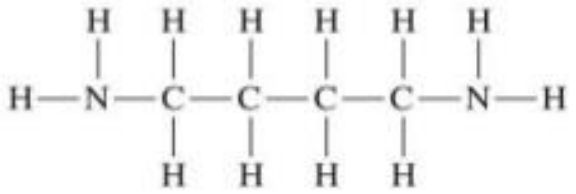


- Formerly used as an anesthetic

Amines

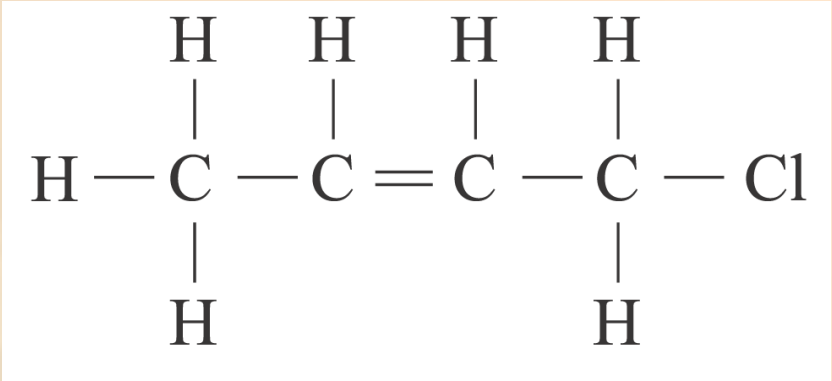
- Amines are organic compounds that contain nitrogen.
- General formula: NR_3
- Notable for disagreeable odors
- Named for R groups present and ending in –amine

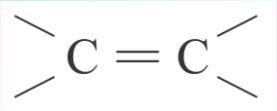
Putrescine

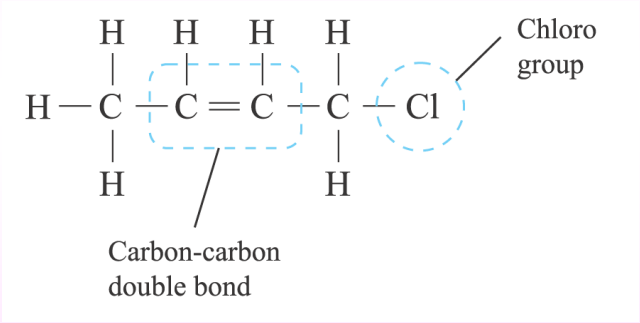


Identify the functional group(s) in the following compounds:

(a)



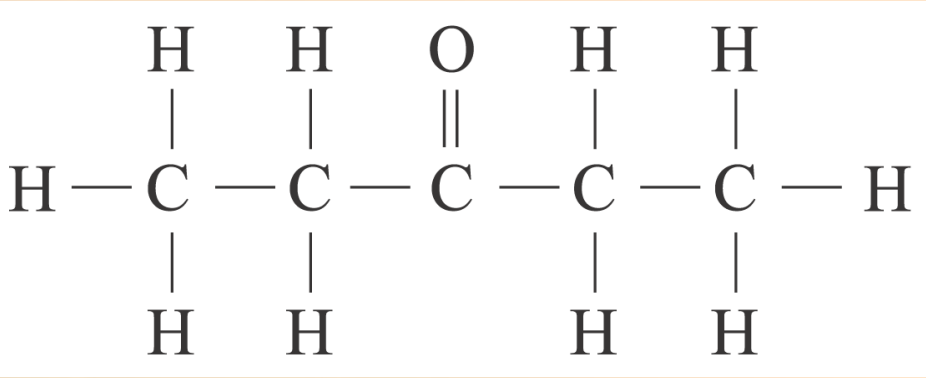
(a) Carbon-carbon double bond () and chloro group (—Cl)



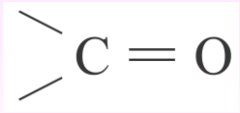
Answer

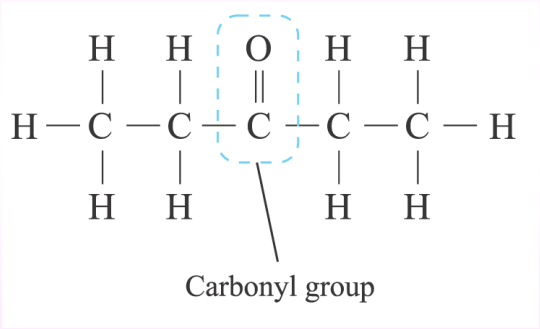
Identify the functional group(s) in the following compounds:

(b)



Answer

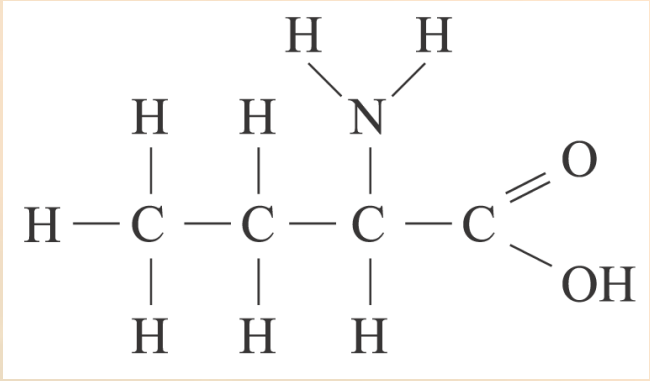
(b) Carbonyl group ()

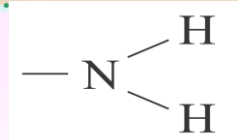
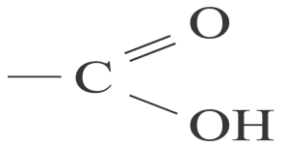


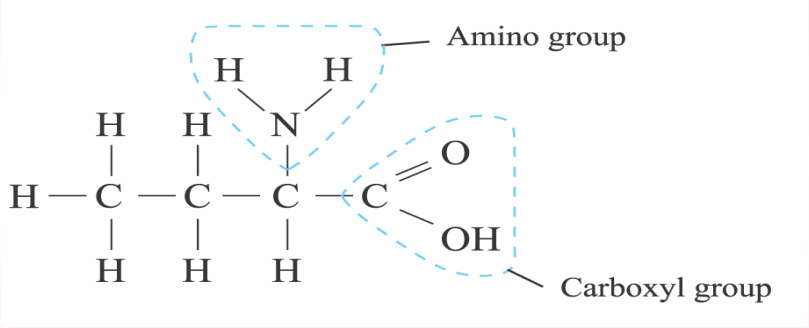
Identify the functional group(s) in the following compounds:

Answer

(c)

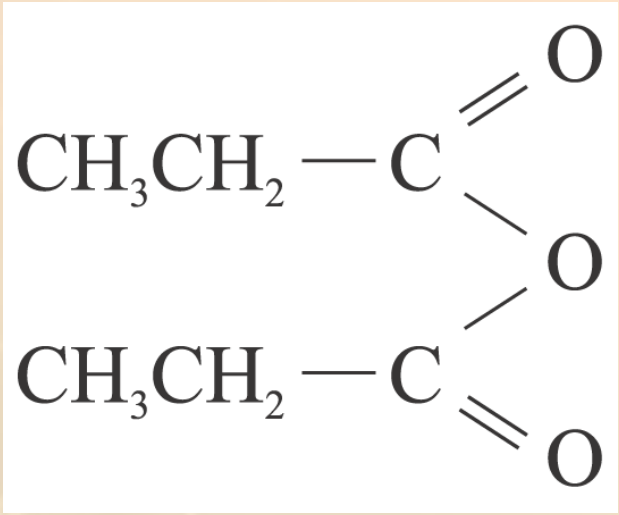


(c) Amino group () and carboxyl group ()



To which homologous series does each of the following compounds belong?

(c)

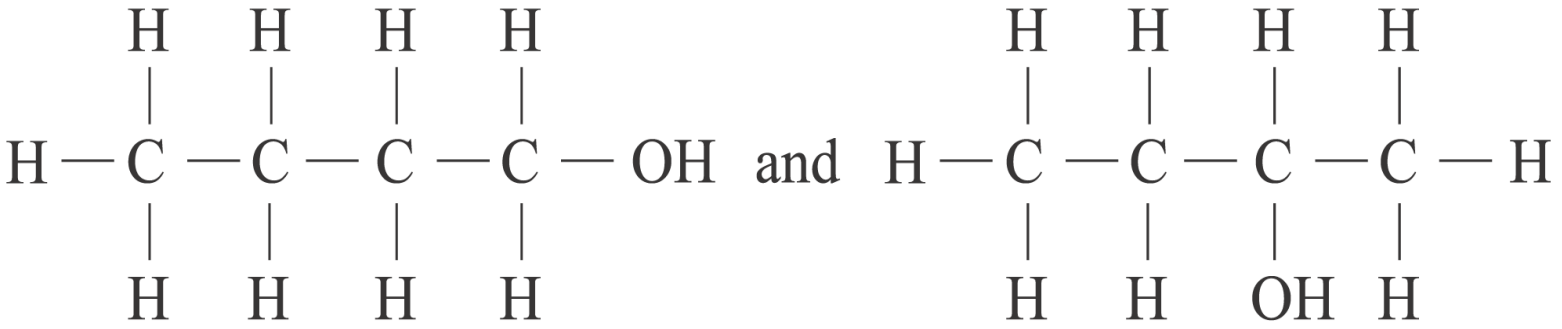


(c) Acid anhydride

Answer

State whether each of the following pairs of compounds belongs to the same homologous series. Explain your answer.

(b)

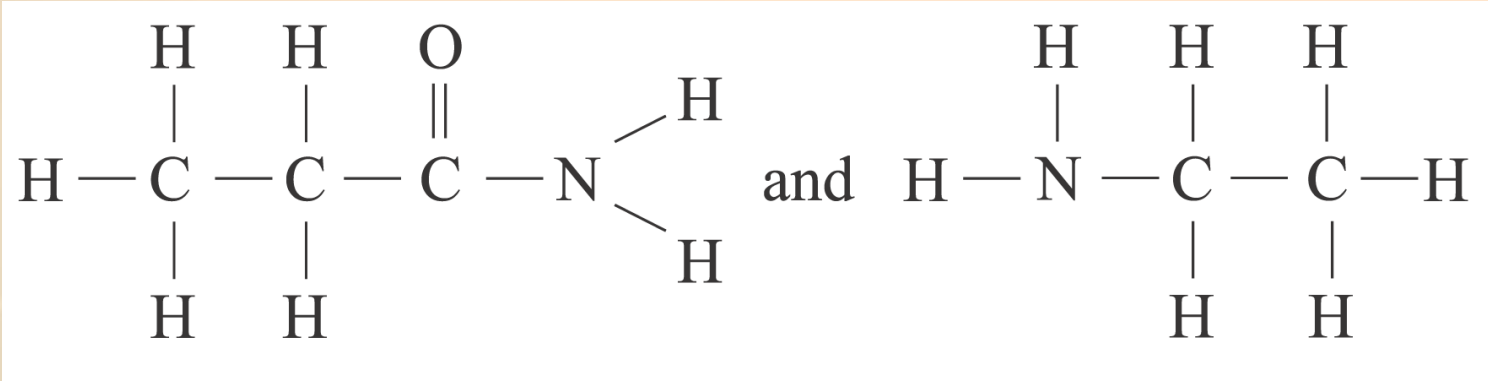


(b) Yes, both of them are alcohols.

Answer

State whether each of the following pairs of compounds belongs to the same homologous series. Explain your answer.

(c)



Answer

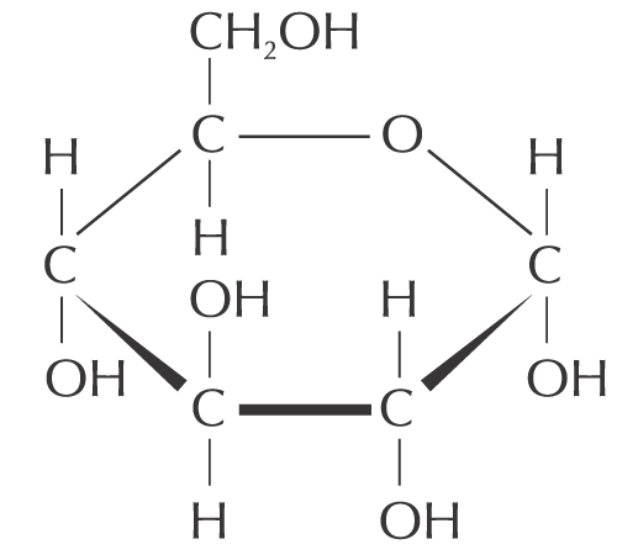
(c) No, the first one is an amide and the second one is an amine.

(a) Name the homologous series of organic compounds that contain oxygen atoms in their functional groups.

Answer

(a) Alcohol, ether, aldehyde, ketone, carboxylic acid, ester, acyl halide, amide and acid anhydride

(b) Identify and name the functional groups in glucose which has the following structure.

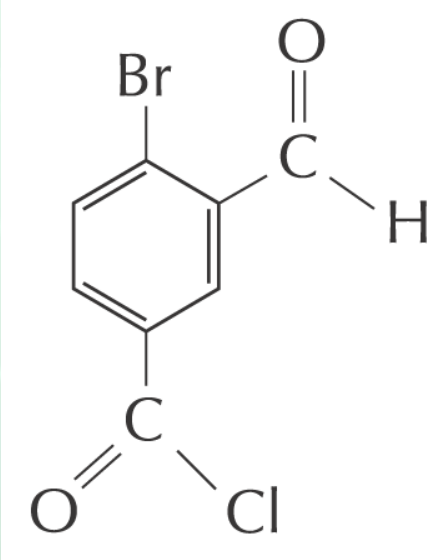


(b) —OH (hydroxyl group)
and — O — (oxy group)

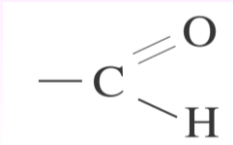
Answer

(c) Identify and name the functional groups in the following compounds:

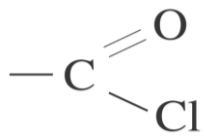
Answer



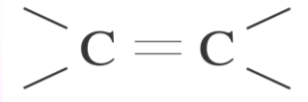
(c) —Br (bromo),



(aldehyde),



(acyl chloride),



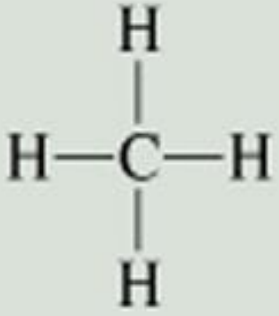
(carbon-carbon double bond) groups

Nomenclature of Organic Compounds

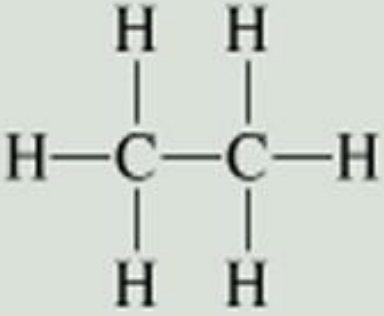
Alkanes

Alkanes are the simplest type of

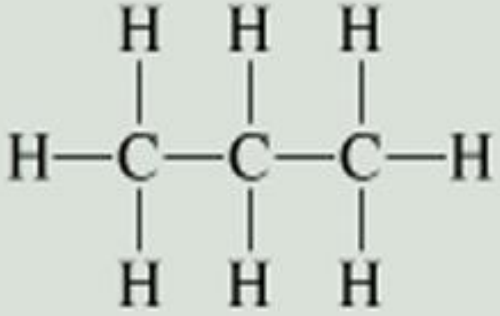
Hydrocarbons



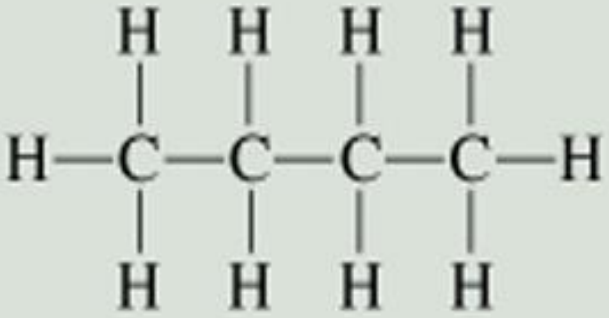
Methane



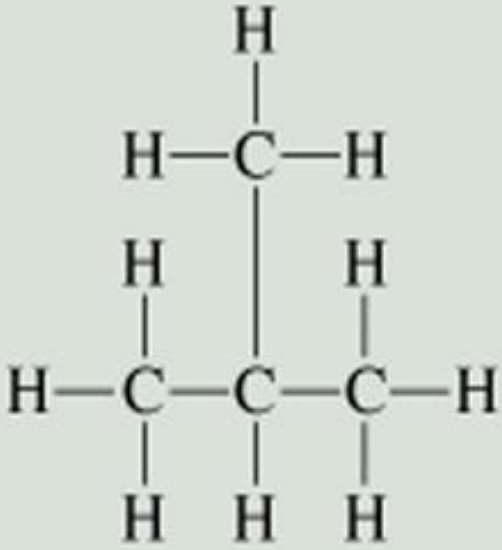
Ethane



Propane



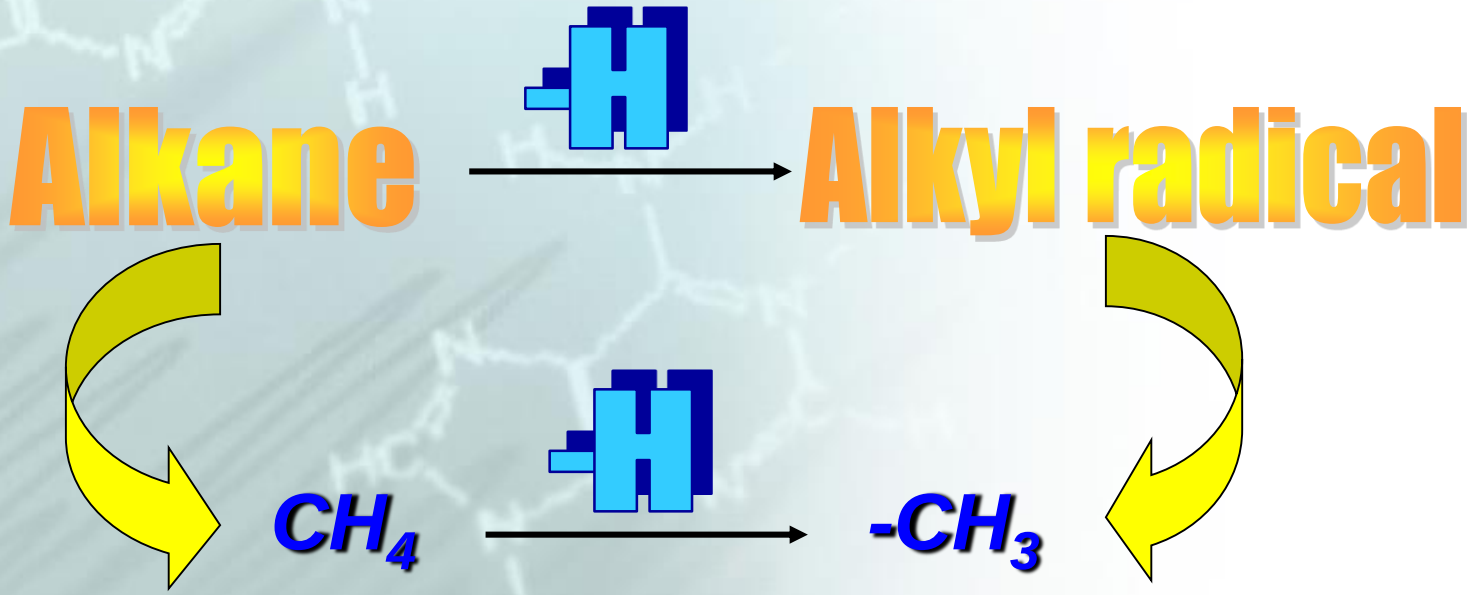
n-Butane



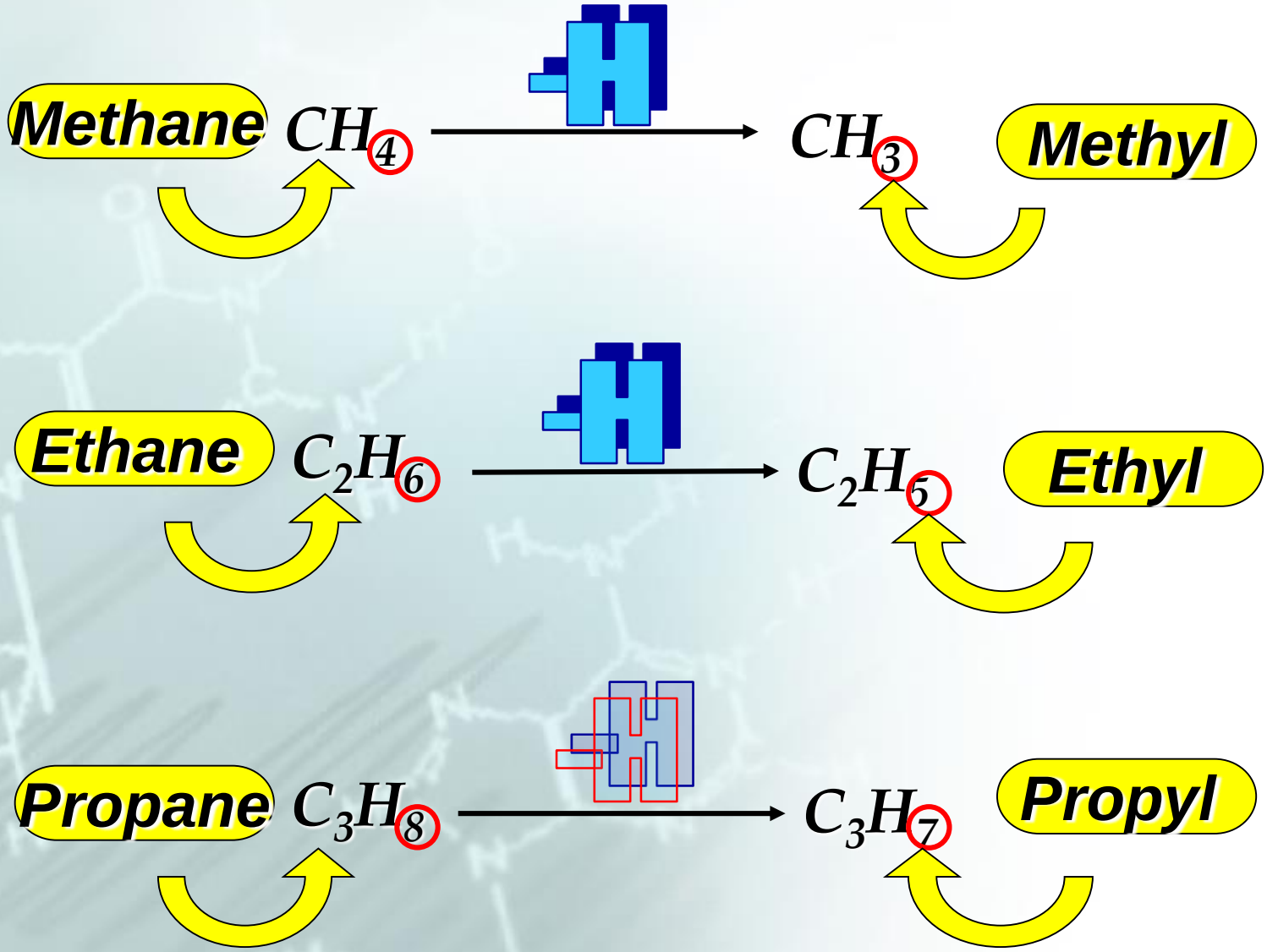
Isobutane

Alkyl Radicals

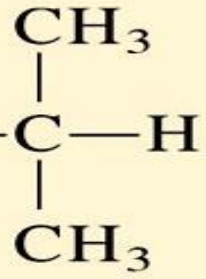
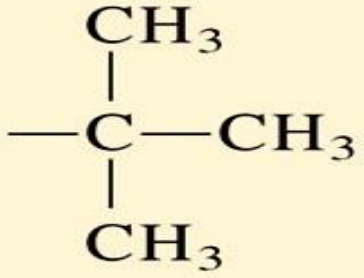
When a hydrogen atom is removed from an alkane the remaining group of atoms is called alkyl group or alkyl radical.



Alkyl group

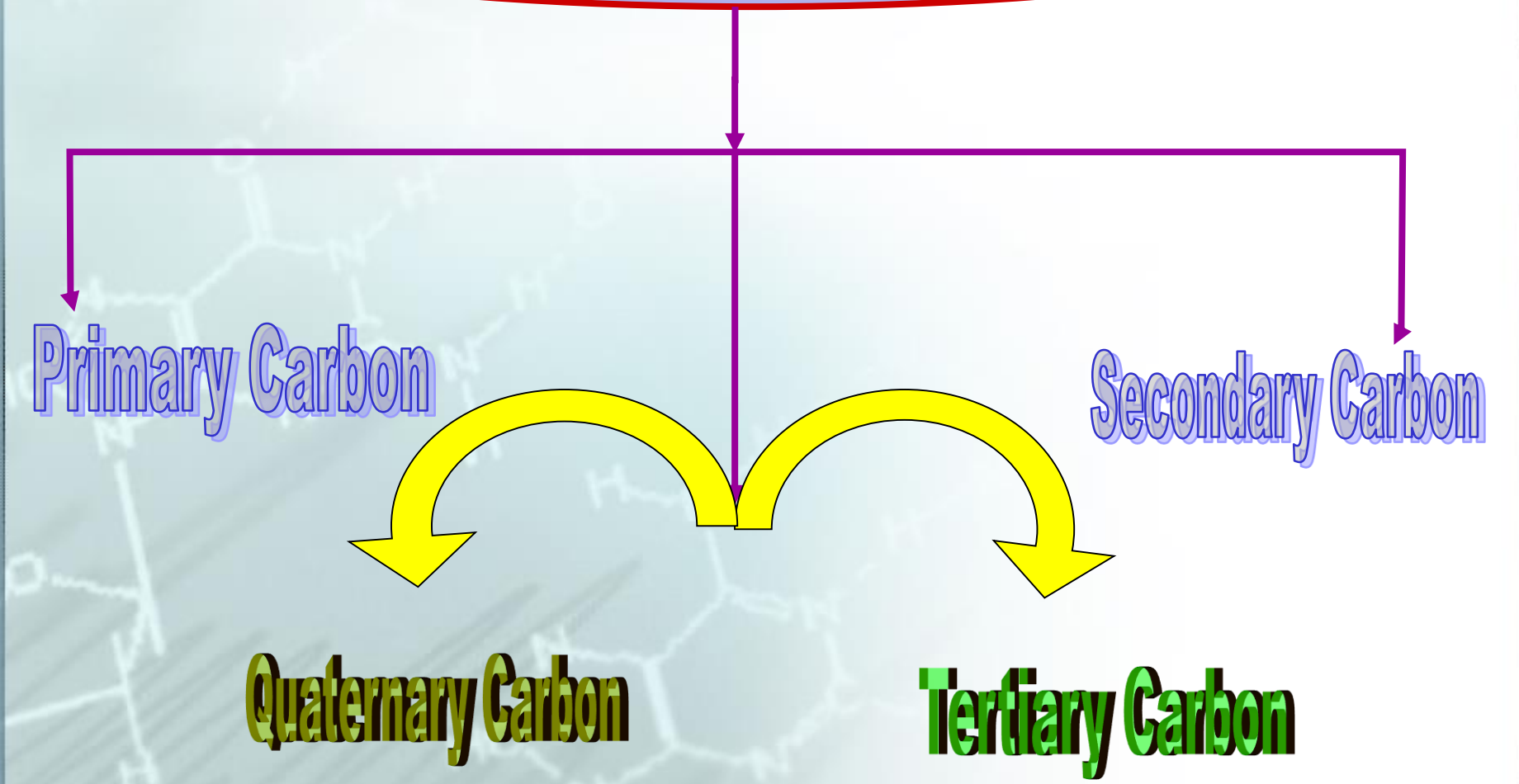

Methane
CH_4
CH_3
Methyl
Ethane
C_2H_6
C_2H_5
Ethyl
Propane
C_3H_8
C_3H_7
Propyl

Common Alkyl Groups

Name	Formula
Methyl	$-CH_3$
Ethyl	$-CH_2-CH_3$
n-Propyl	$-CH_2-CH_2-CH_3$
n-Butyl	$-CH_2-CH_2-CH_2-CH_3$
Isopropyl	
t-Butyl*	

*The letter *t* stands for tertiary.

Classification of Carbon Atoms



Primary Carbon

A carbon atom attached to one other carbon atom

Secondary Carbon

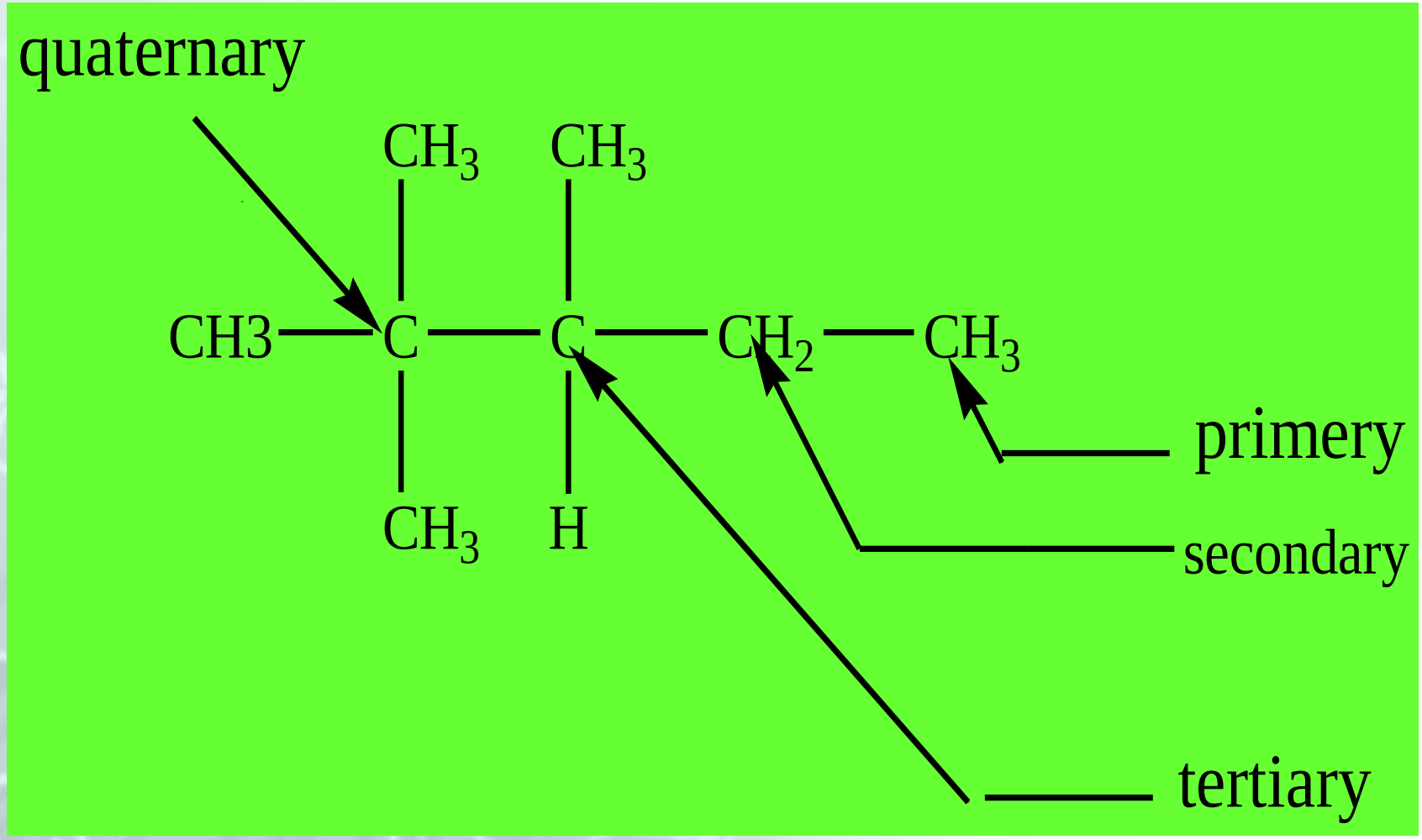
A carbon atom attached *to two other carbon atoms*

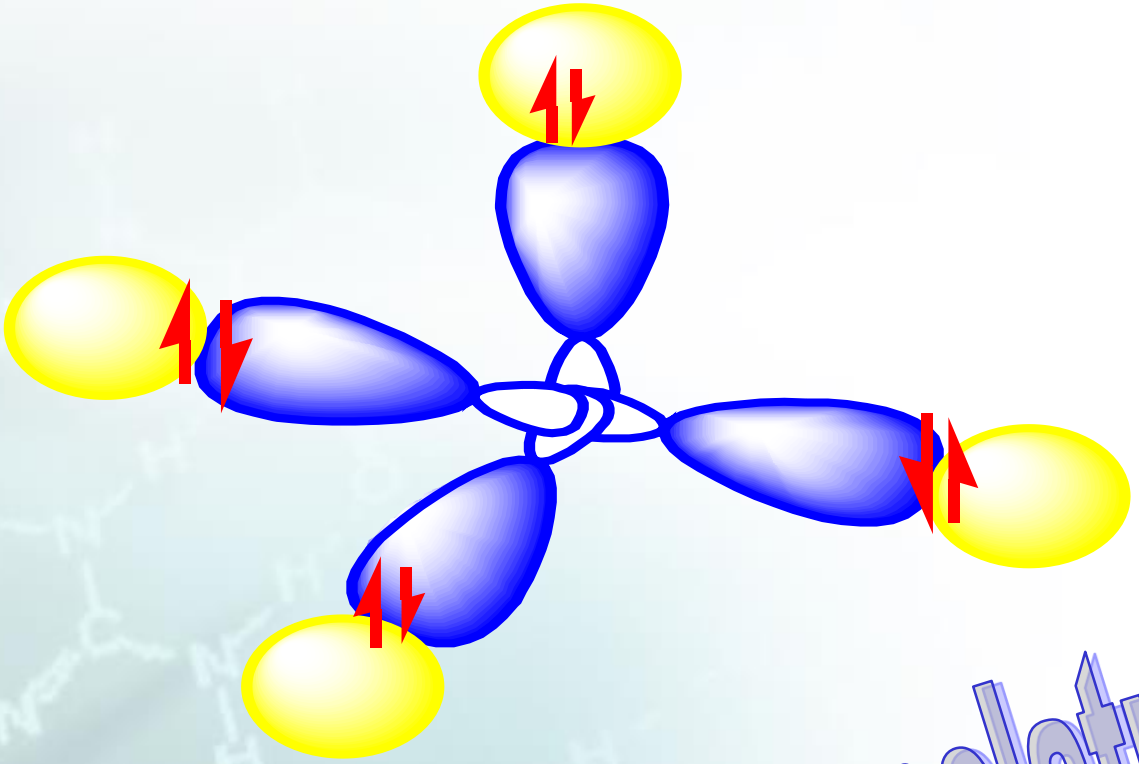
A carbon atom attached to four other carbon atoms

A carbon atom attached to three other carbon atoms

Quaternary Carbon

Tertiary Carbon


quaternary
CH3
CH3
CH3
C
C
CH2
CH3
CH3
H
primery
secondary
tertiary



Organic Nomenclature

Common or Trivial System

Compound	Common name
CH_4	Methane
$H_3CCH_2CH_2CH_3$	*n*-Butane
$(H_3C)_2CHCH_3$	Isobutane
$(H_3C)_4C$	Neopentane
$H_3CCH_2CH_2OH$	*n*-Propyl alcohol
$HCHO$	Formaldehyde
$(H_3C)_2CO$	Acetone
$CHCl_3$	Chloroform
CH_3COOH	Acetic acid
C_6H_6	Benzene
$C_6H_5OCH_3$	Anisole
$C_6H_5NH_2$	Aniline
$C_6H_5COCH_3$	Acetophenone
$CH_3OCH_2CH_3$	Ethyl methyl ether

This method of nomenclature was used before 1892.

*In this system of nomenclature, the compounds were named on the basis of their **history, such as source of origin** etc.*

IUPAC

SYSTEM

A method known as the Geneva system was suggested in 1892 by the International Chemical Congress at Geneva for naming organic compounds.

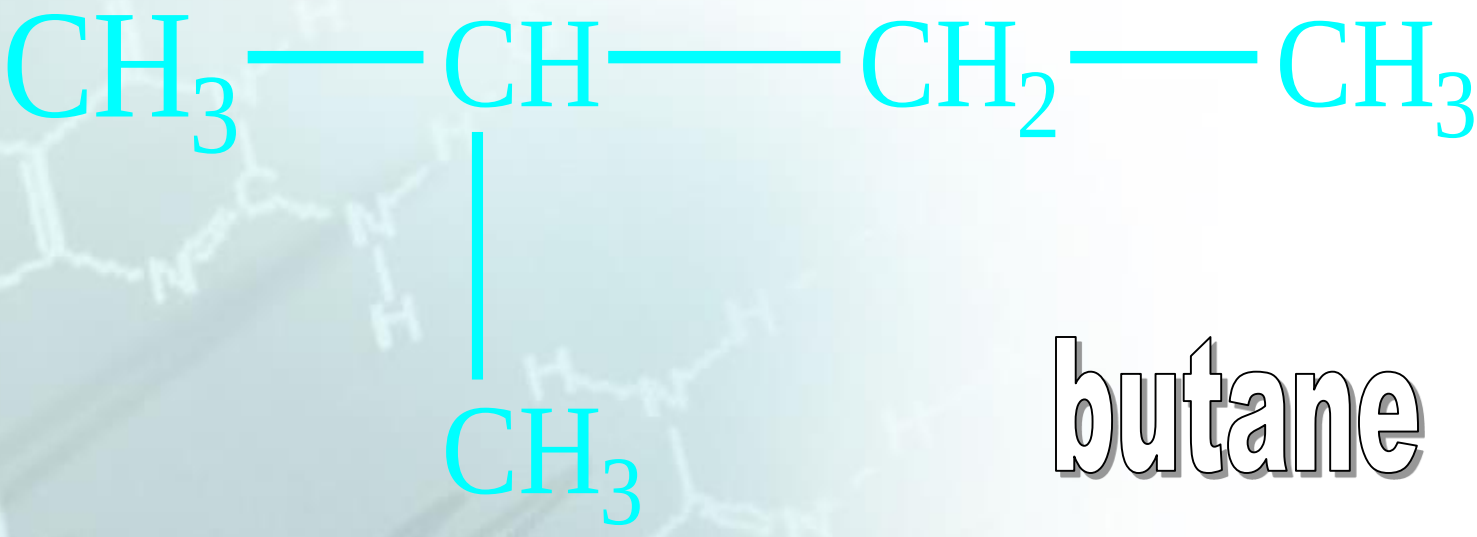
*Later the **International Union of Chemistry at Liege (Belgium)** developed it into **IUPAC** system of nomenclature in 1930.*

*In **1958**, the **IUPAC system** was modified by the International Union of Pure and Applied Chemistry **(IUPAC)** into the present day IUPAC system of nomenclature.*

Rules for naming alkanes

Rule 1:

Select the longest continuous chain of carbon atoms as the parent chain and name the hydrocarbon.

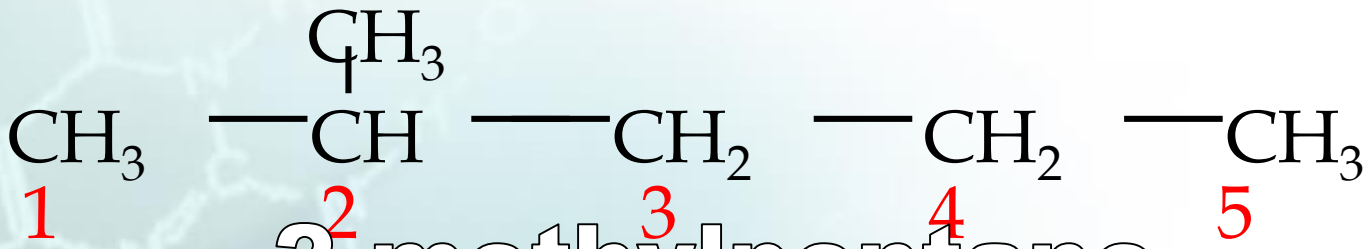


butane

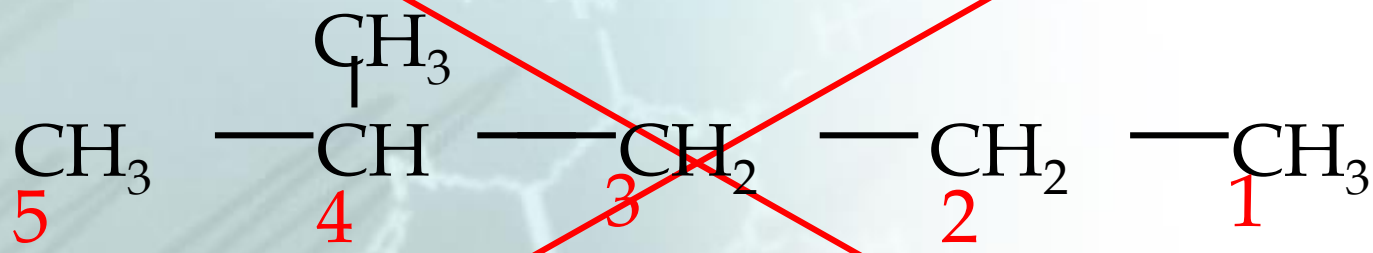
The longest continuous chain has four carbon atoms, thus the compound is named as butane.

Rule 2:

Number the carbon atoms in the longest continuous chain in such a way as to give lowest possible number to carbons atoms carrying substituents.

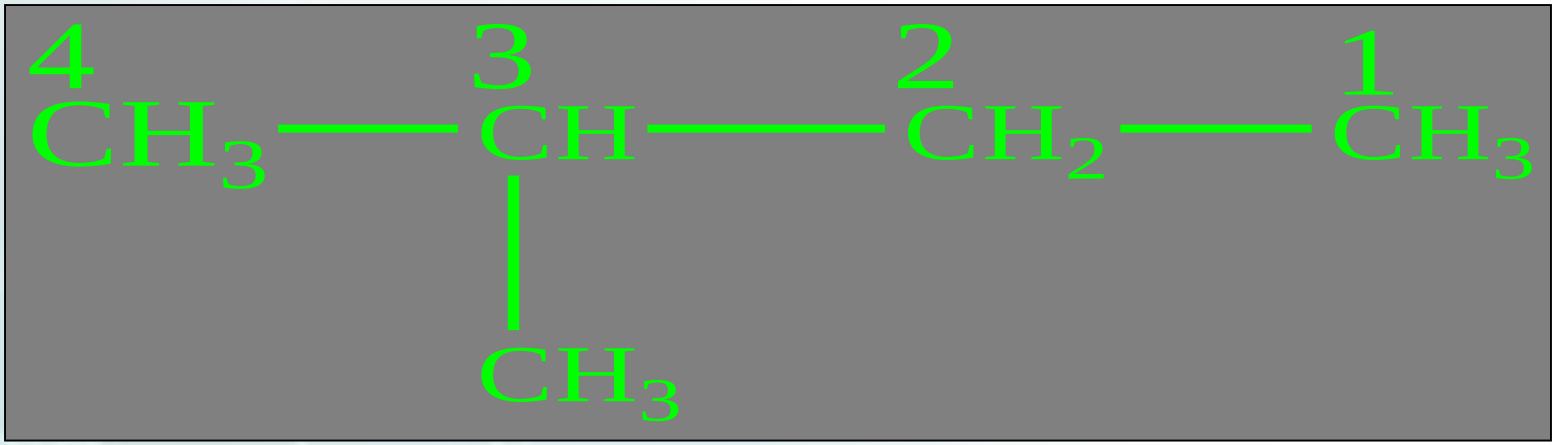


2-methylpentane

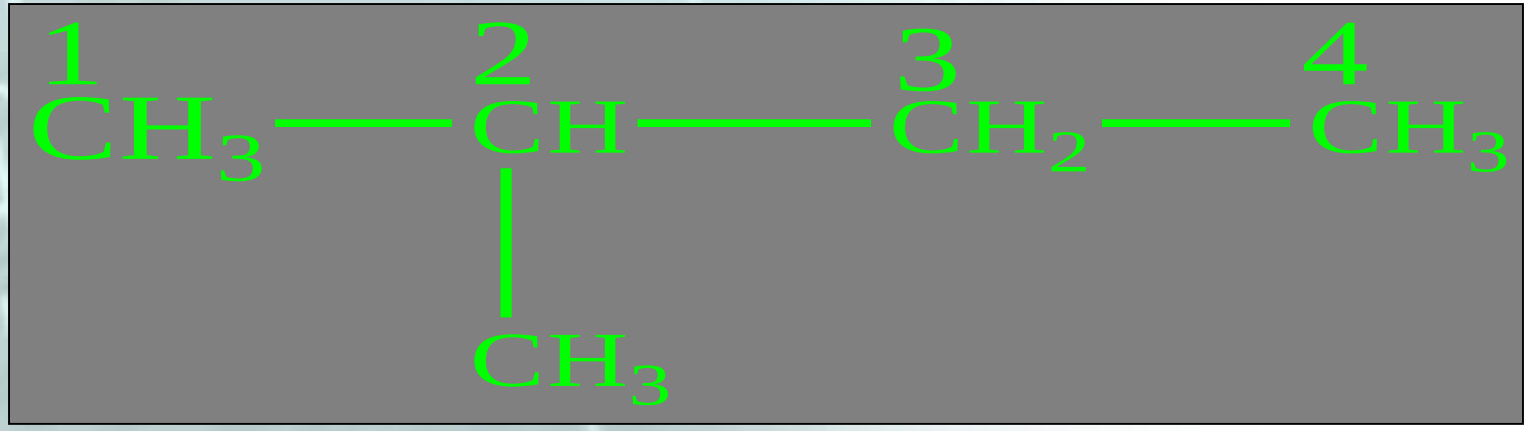


4-methylpentane

Incorrect numbering

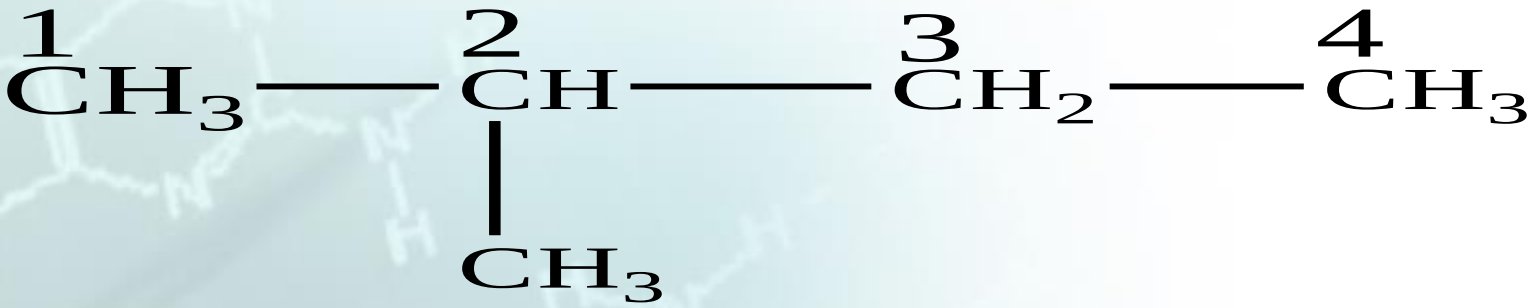


Correct numbering



Rule 3:

Name the substituent.
Indicate its position by the number of the carbon atom to which it is attached.



The attached group is located on carbon 2 of the chain, and it is a

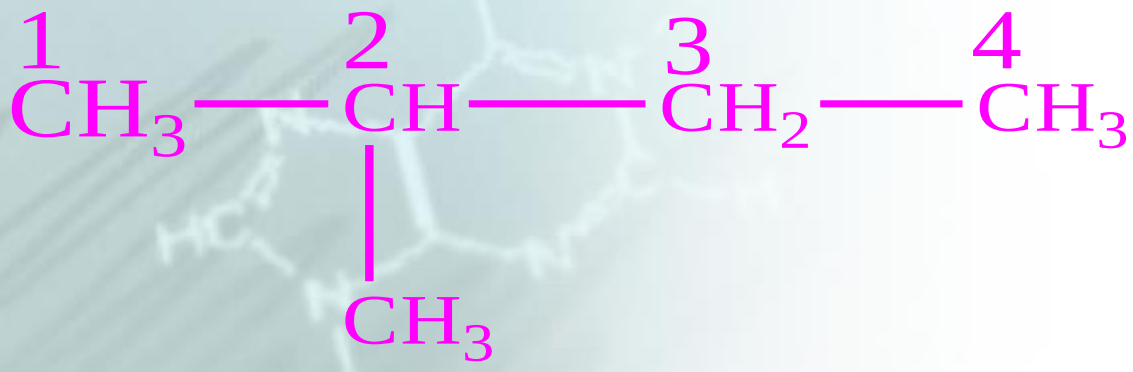
methyl group

Rule 4:

***Prefix** the **position number and name of the substituent** onto the **parent name**.*

The whole name is written as one word.

Note that the number and name of the substituent are separated by a hyphen.



2-

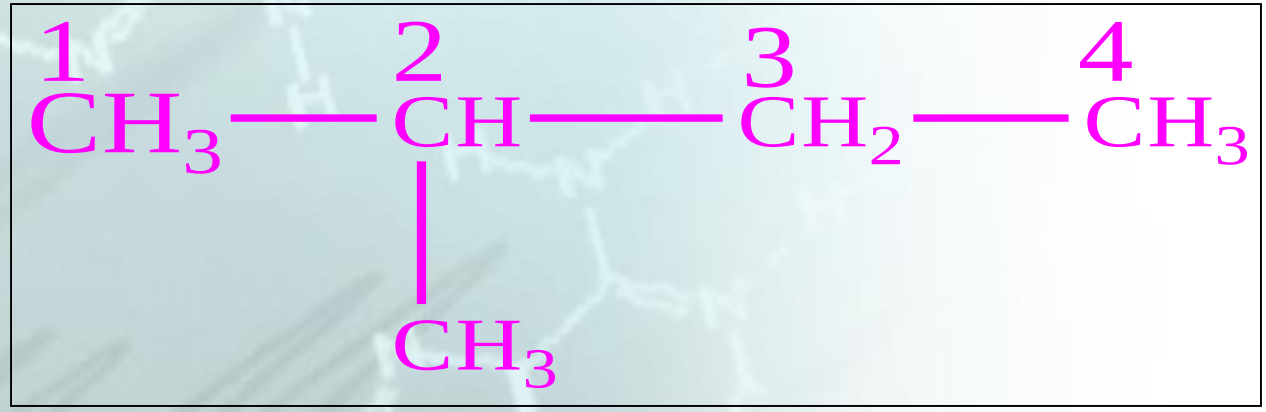
Methyl

Butane

Attached alkyl group

Longest chain

Position of alkyl group

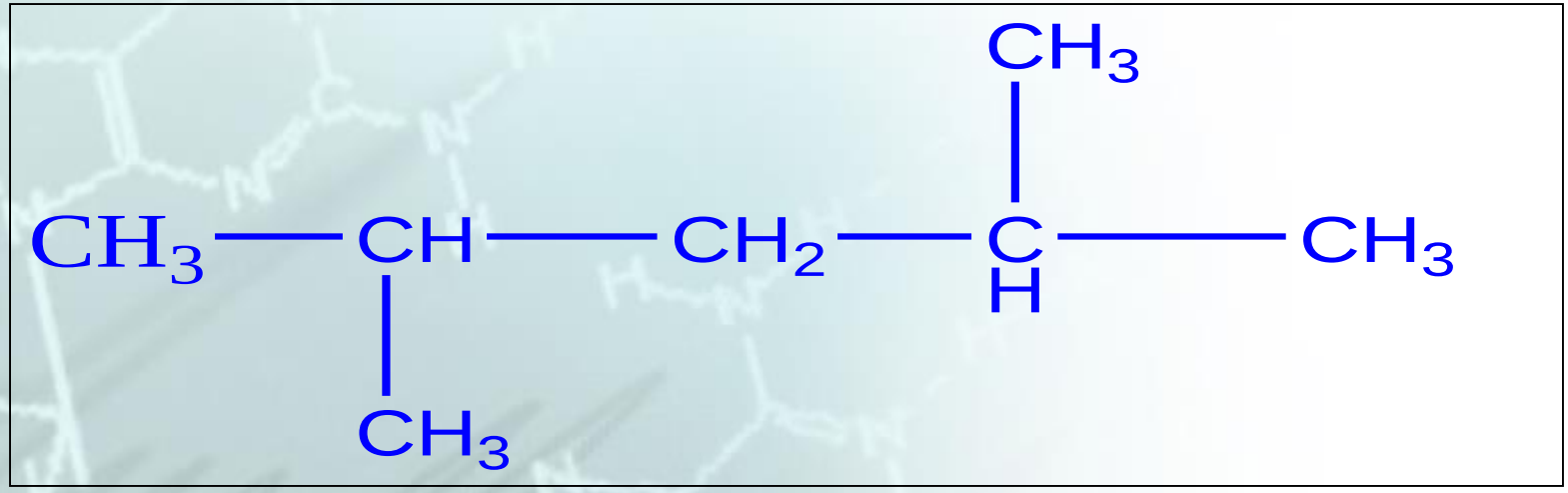


2-Methylbutane

Rule 5:

If identical substituents are present more than once in the molecule, then use prefixes di- tri-tetra-,penta-,

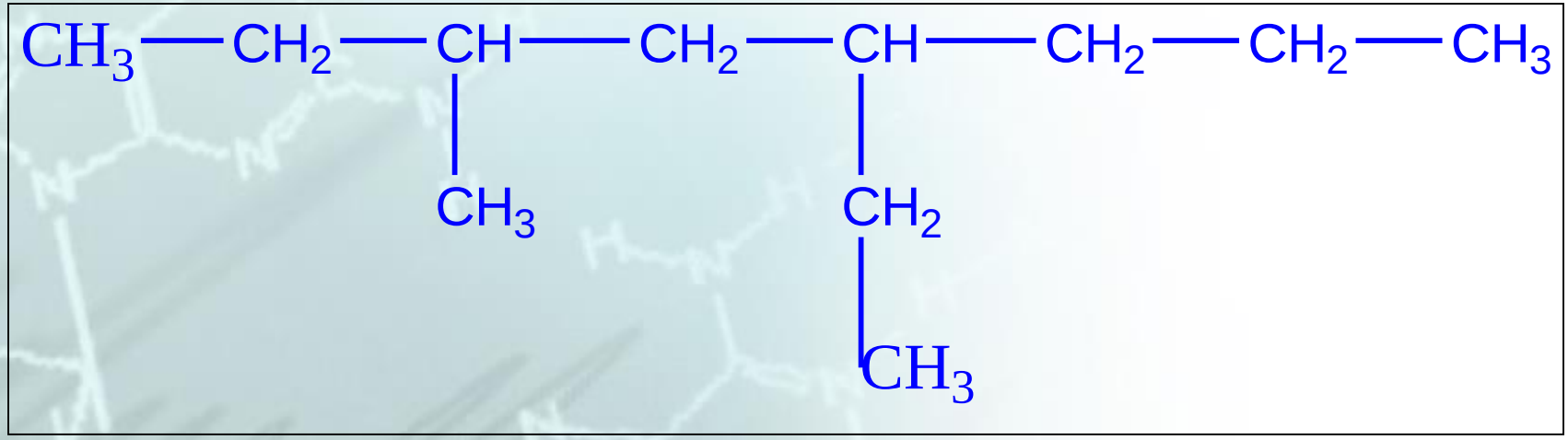
Position of each substituent is indicated by a separate number.



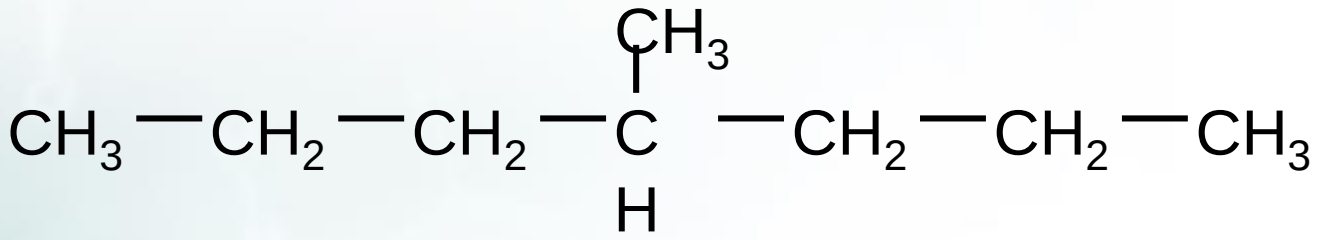
2,4-Dimethylpentane

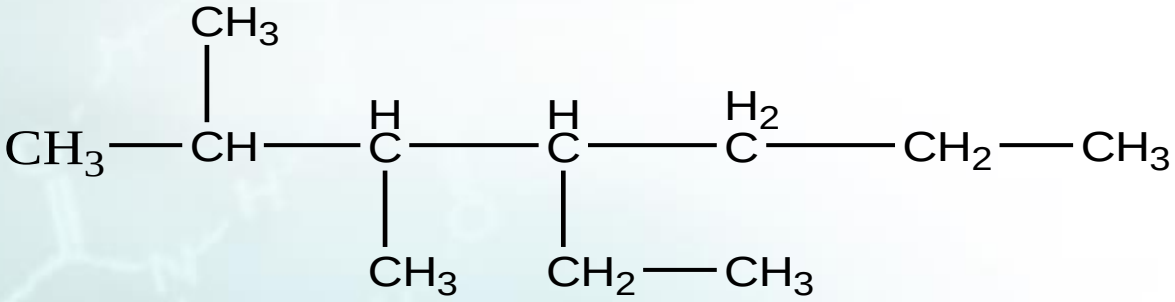
Rule 6:

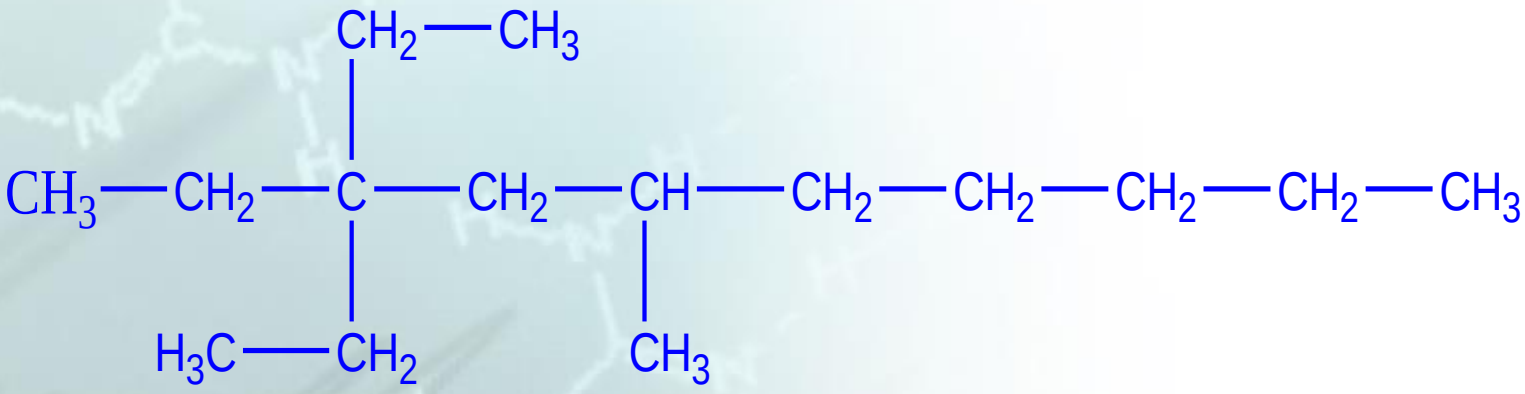
When two or more different substituents are present, their names are arranged in alphabetic order and added to the name of the parent alkane, again as one word.

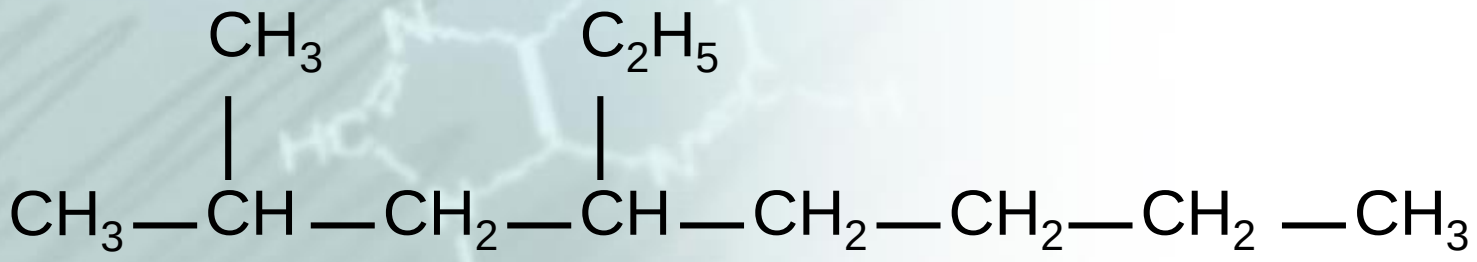


5-Ethyl-3-methyloctane

1. 

2. 

3. 

4. 

Always remember

- ***Numbers are separated from each other by commas;***

- *Numbers are separated from names by hyphens;*

- ***Prefixes di-, tri-, are not taken into account in alphabetizing substituent names.***

Structural formulas from the IUPAC names

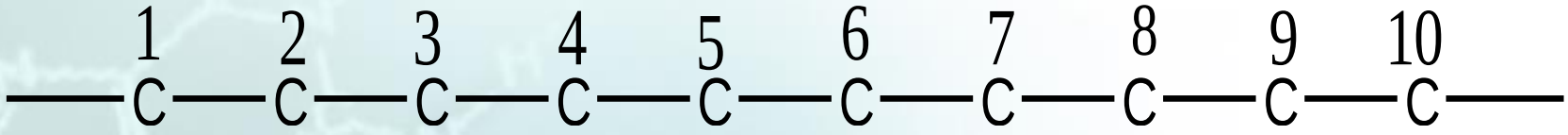
Step-by-step procedure to draw structural formulas from the IUPAC names.

Consider the following IUPAC name:

3,3-Diethyl-5-methyldecane

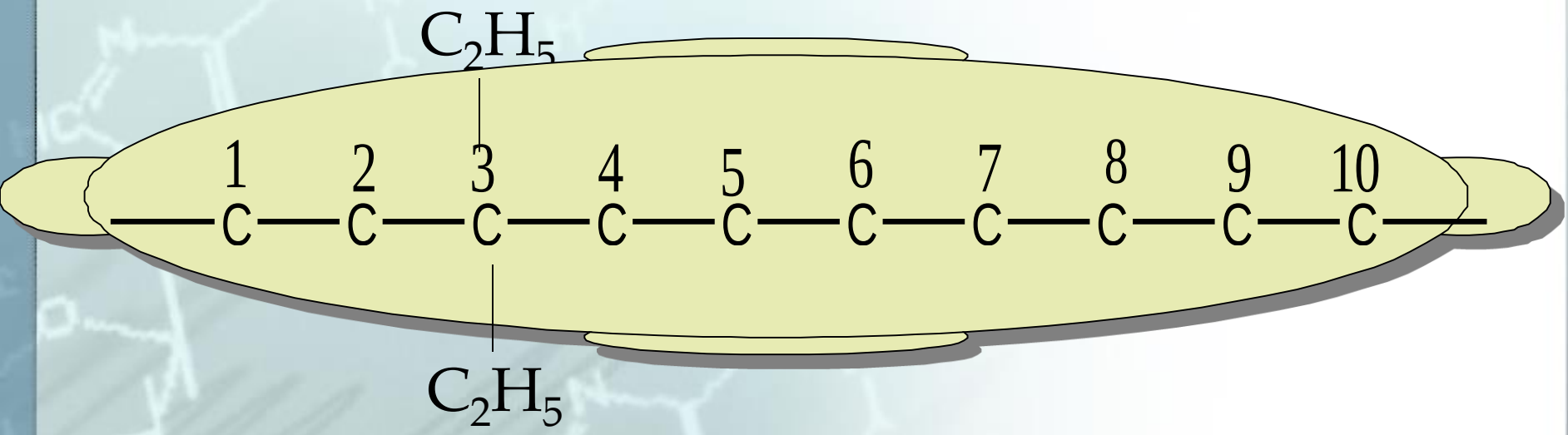
Step1

Draw a decane skeleton and number it.



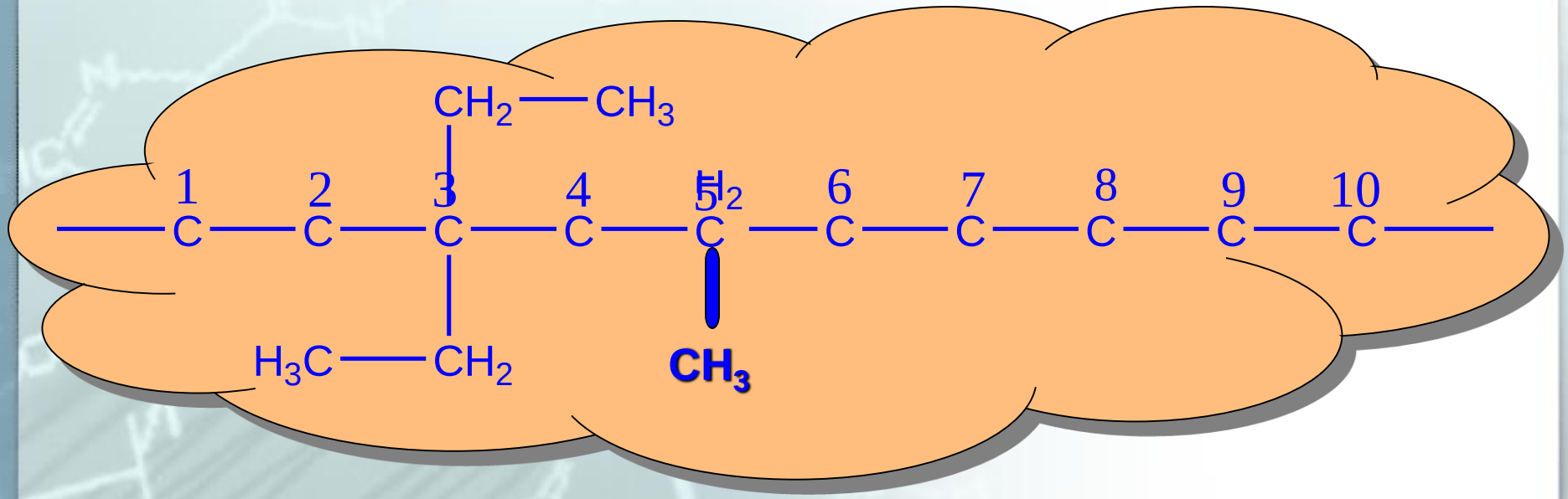
Step 2

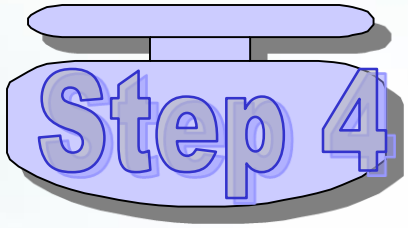
Attach two ethyl groups at C-3



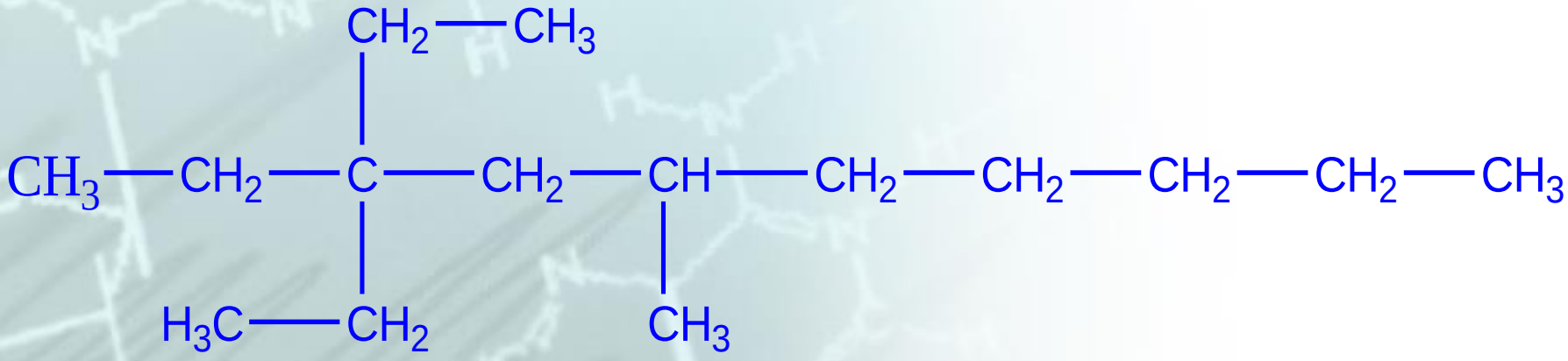
Step 3:

Attach a methyl group at C.5





Supply hydrogen atoms so that each carbon atom has four bonds.



Draw structural formulas for the following compounds

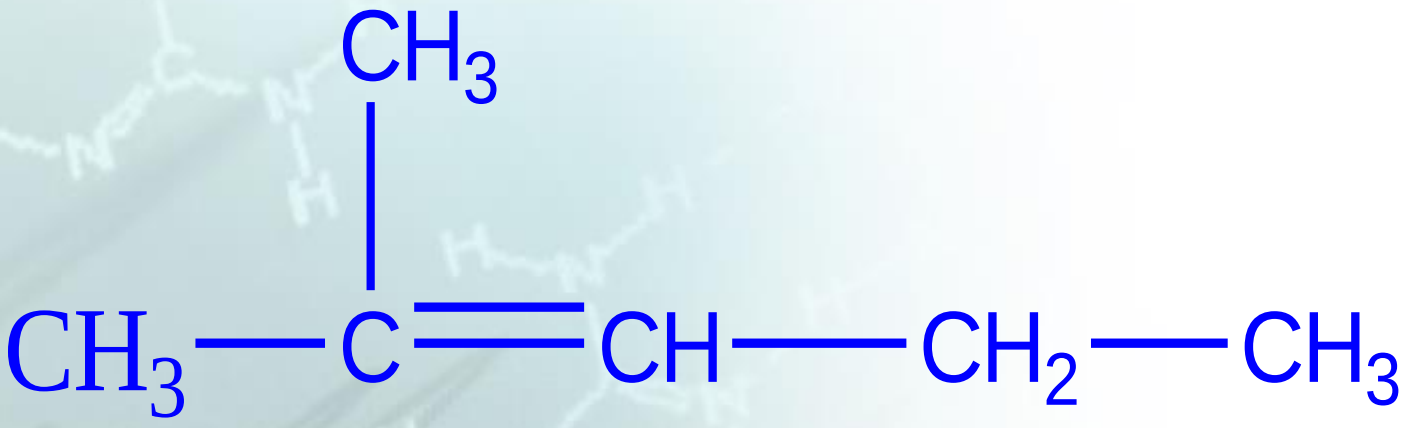
1. 2,3-dimethylhexane
2. 3,3-dimethylhexane
3. 2-bromo-3-nitrobutane
4. 1-amino-3-nitrobutane
5. 2,4-dimethylhexane?

IUPAC

Rules for Naming Alkenes

Rule 1

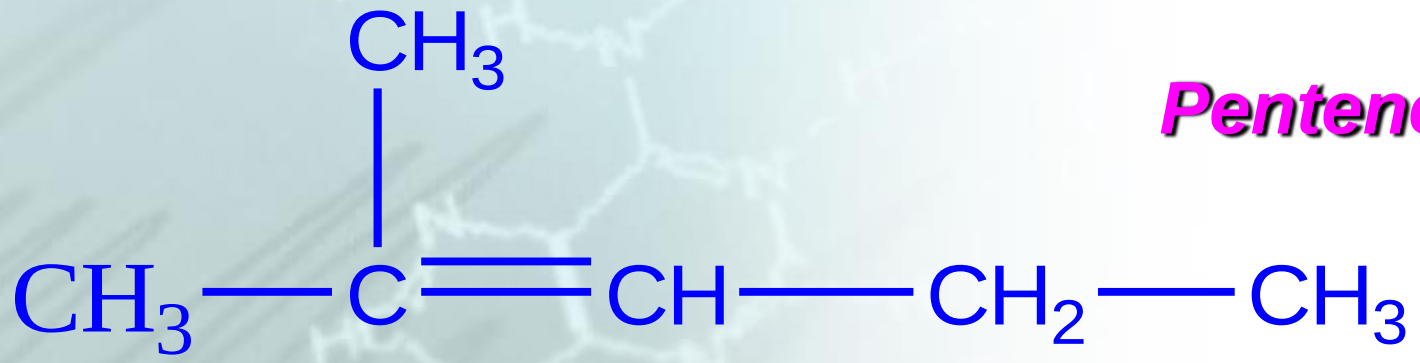
Select the longest continuous chain of carbon atoms containing the double bond, as the parent chain.



Rule 2

Name the longest chain. The name is obtained by replacing "ane" of alkane with "ene".

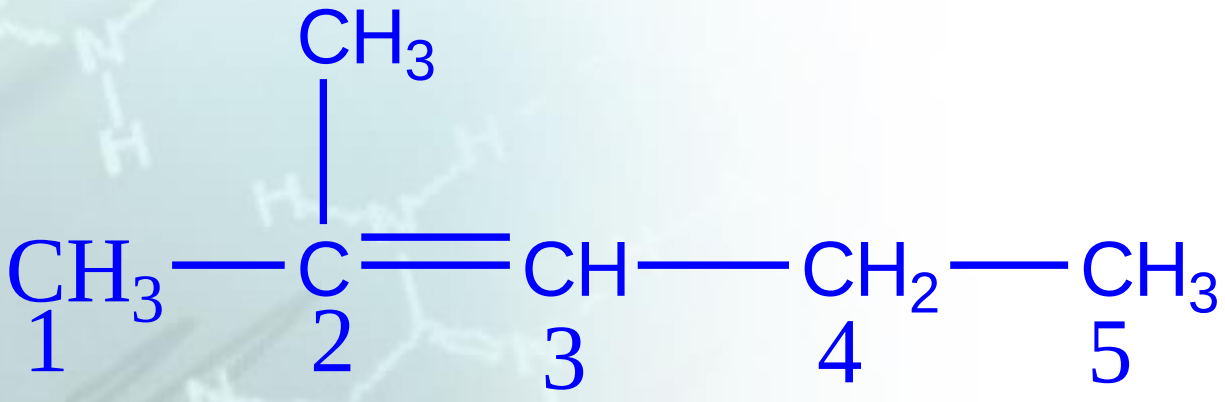
Alkane —(*-ane* / *+ene*)→ **Alkene**



Pentene

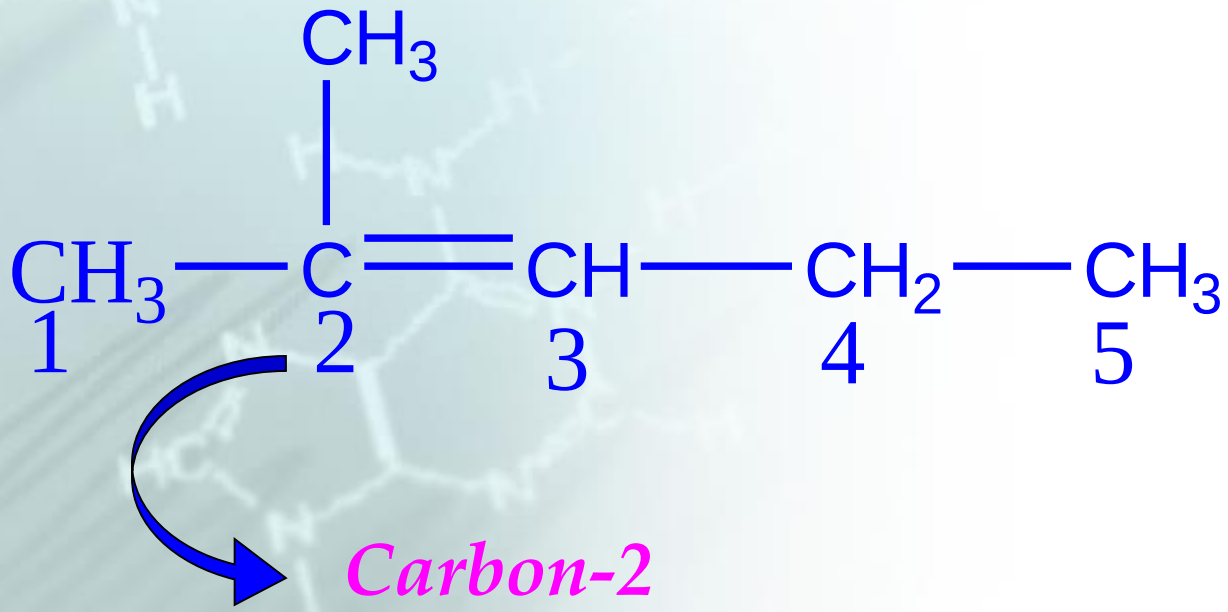
Rule 3

Number the chain from the end closer to the double bond.



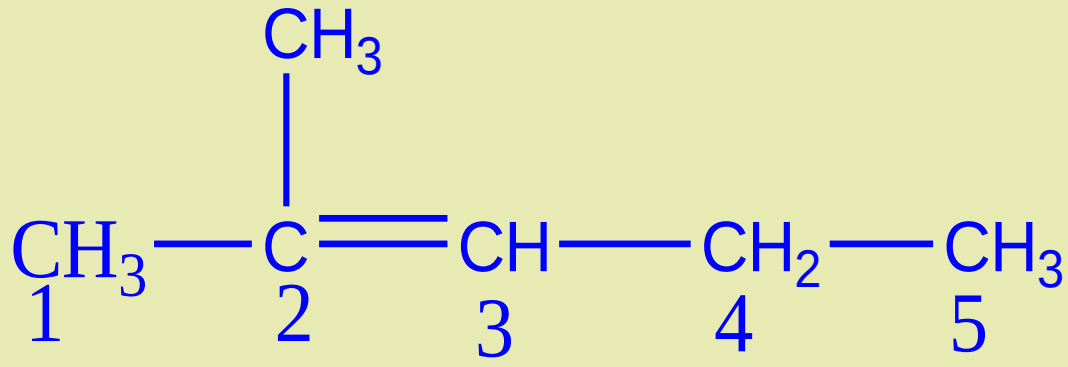
Rule 4

Indicate the position of the double bond by the number of the first (lowest numbered) carbon atom involved in the double bond.



Rule 5

Alkyl groups and other substituent's are numbered , named and placed as prefixes in alphabetical order.



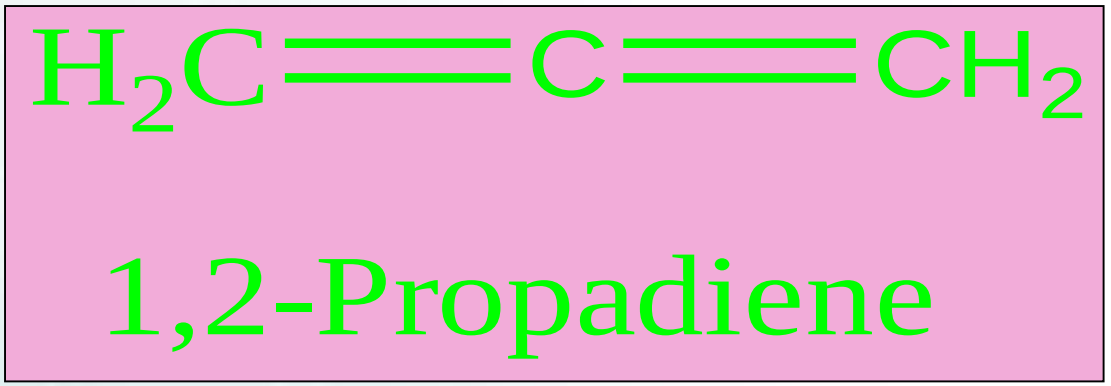
2-Methyl-2-pentene or 2-Methylpent-2-ene

Rule 6

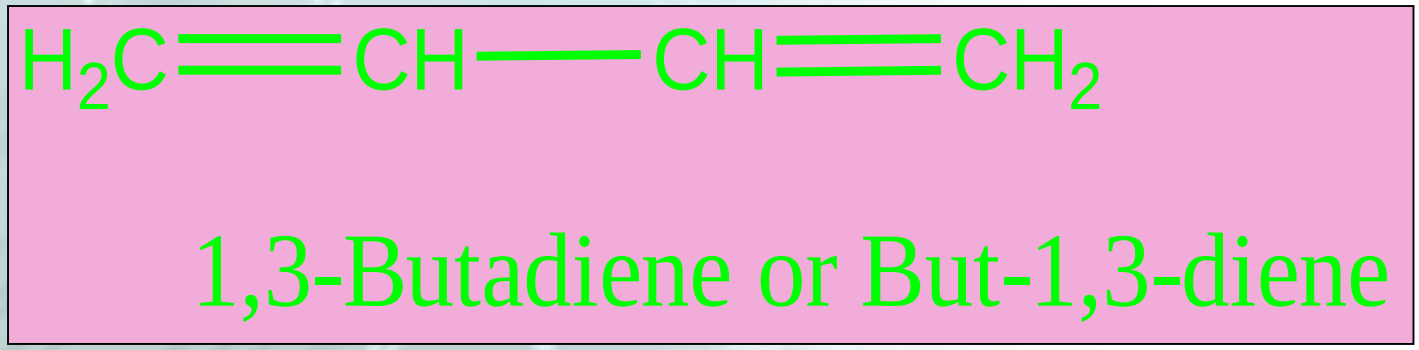
If more than one double bonds are found then use the prefixes di,tri,tetra,for 2,3 and 4.

Alkenes containing two double bonds are named as

Alkadienes



1,2-Propadiene

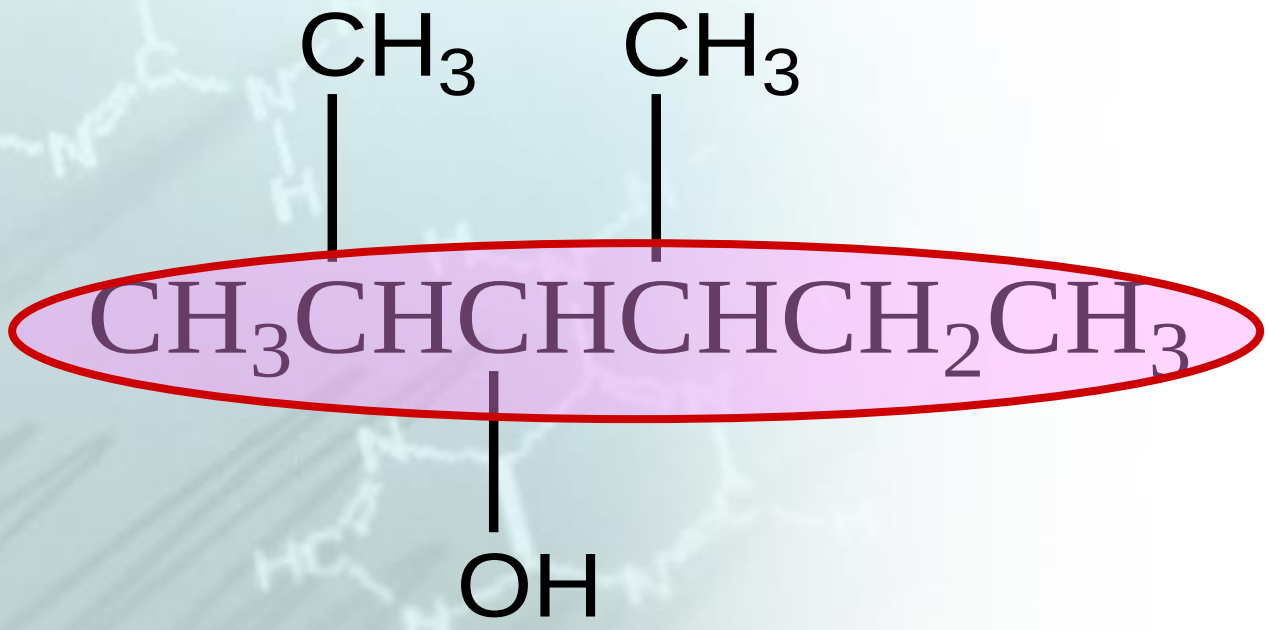


1,3-Butadiene or But-1,3-diene

IUPAC Rules for naming Alcohols.

Rule 1

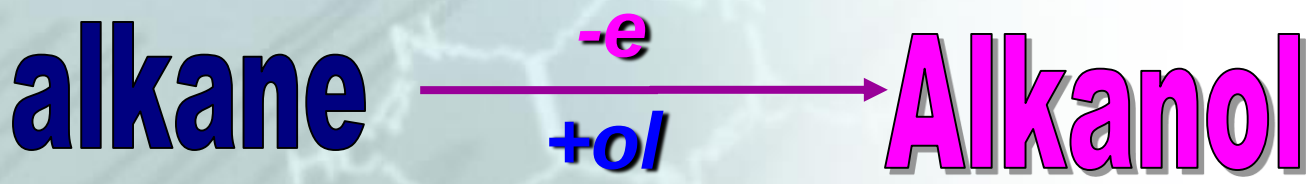
Select the longest continuous carbon chain to which the hydroxyl group is attached as the parent chain.



Rule 2

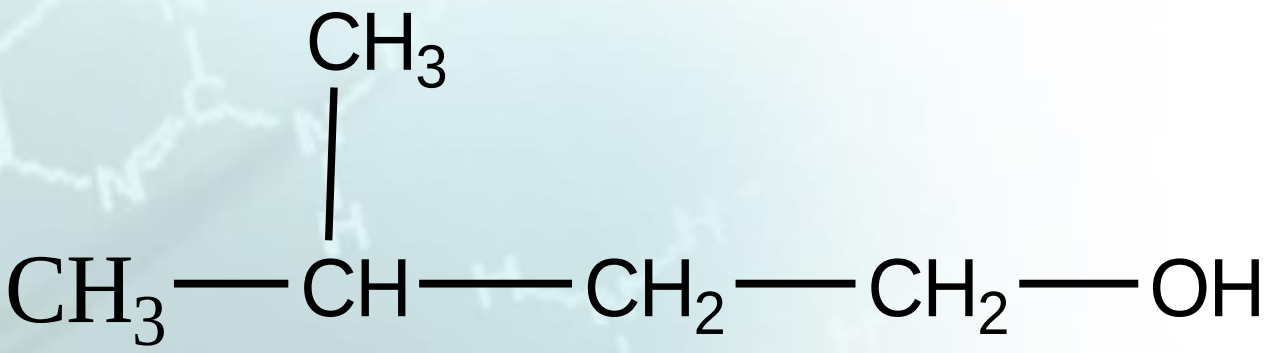
Name the longest chain

The name is obtained by replacing the final -e with- ol.



Rule 3

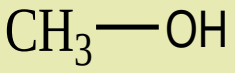
Number the chain to give the lowest number to carbon attached to the hydroxyl group.



3-Methyl-1-butanol or 3-Methyl-but-1-ol

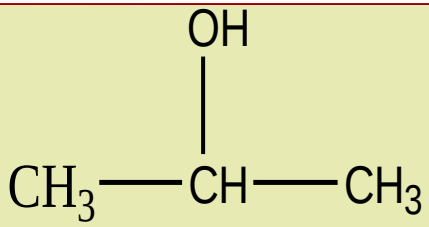
Rule 4

Other substituents are numbered, named, and placed as prefixes in alphabetic order. For example:

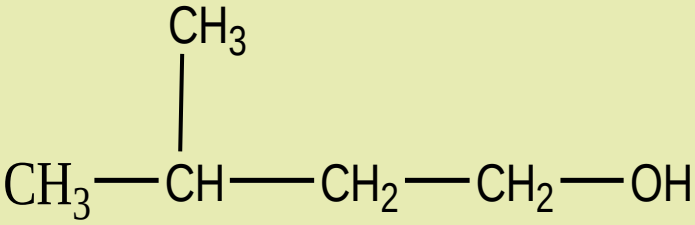


Methanol

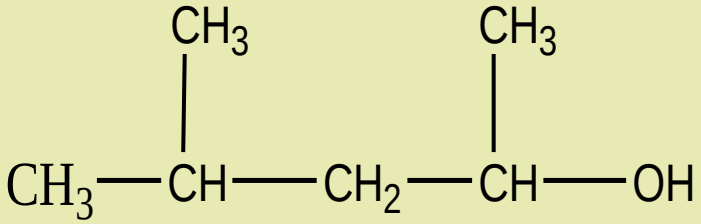
Ethanol



2-Propanol



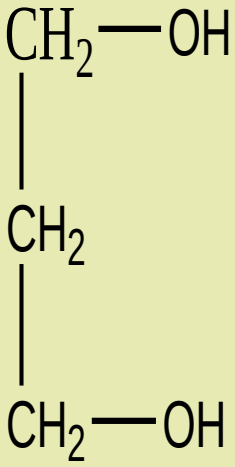
3-Methyl-1-butanol or 3-Methyl-but-1-ol



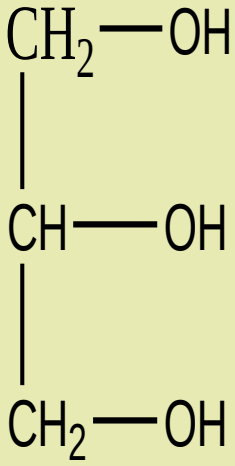
4-Methyl-2-butanol or 4-Methyl-but-2-ol

Rule 5

Alcohols containing two or three –OH groups are named as Alkanediols and Alkanetriols respectively. Note that "–e" of the corresponding alkane name is retained.



1,3-Propranediol or Propan-1,3-diol

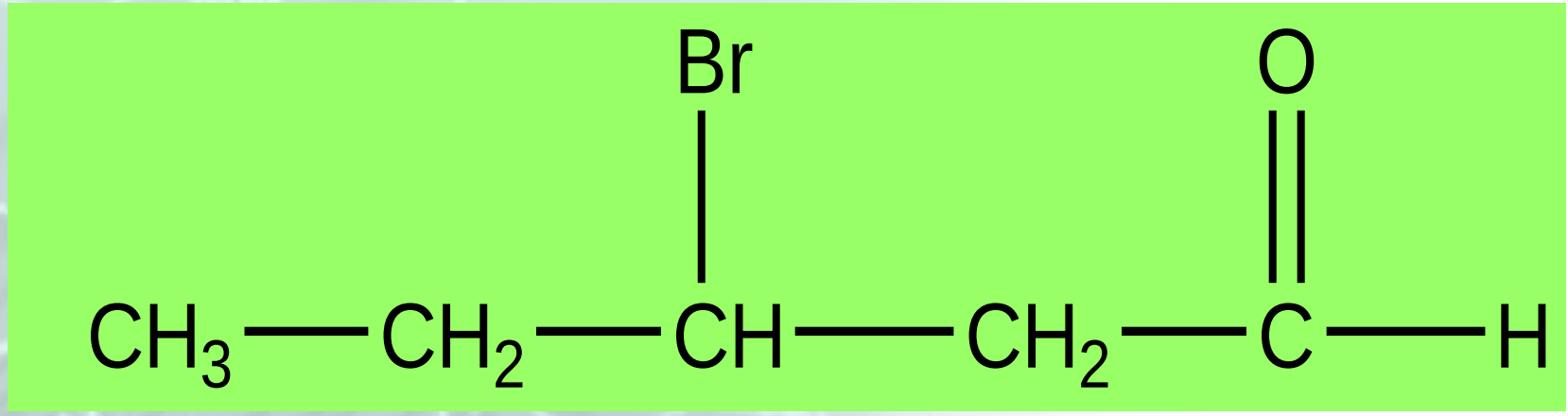


1,2,3-Propanetriol or propan-1,2,3-triol

IUPAC Rules for Naming Aldehydes

Rule 1

Select the longest chain containing the aldehyde group.

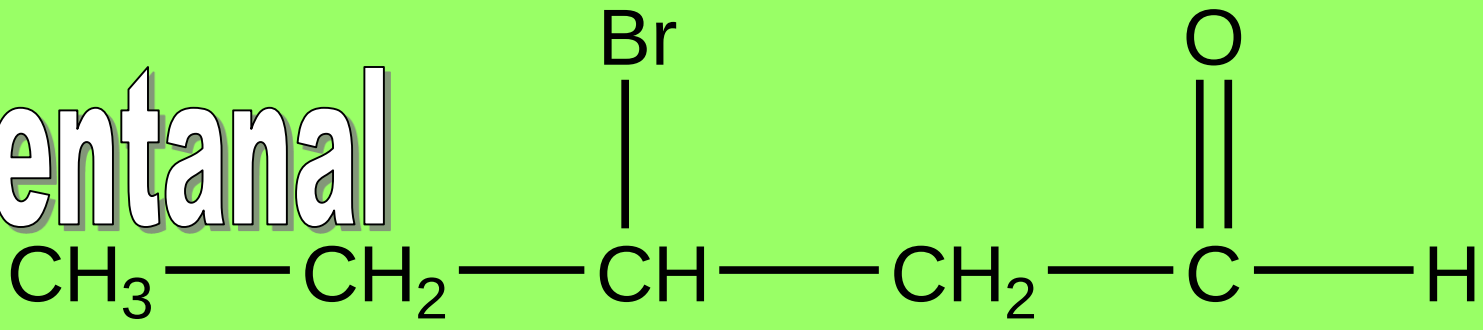


Rule 2

Name the longest chain.
***The name is obtained by dropping the final "-e" from the name of the corresponding alkane, and adding "-al" to* the end.**

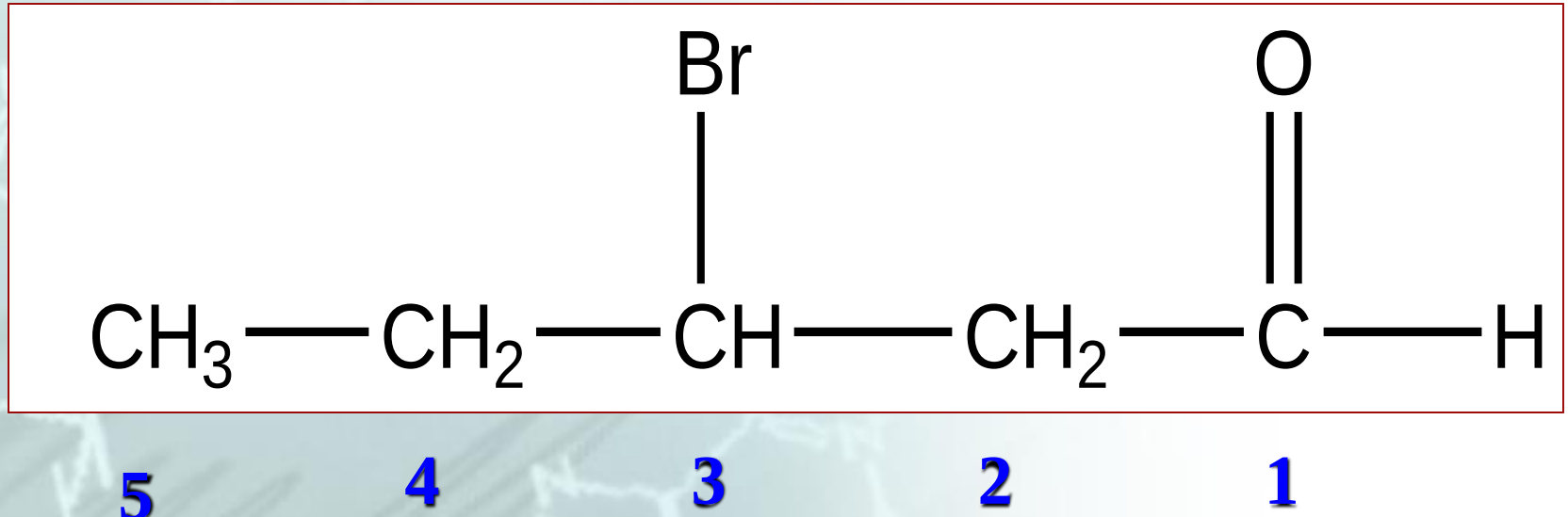
Alkane -e + al = Alkanal

Pentanal



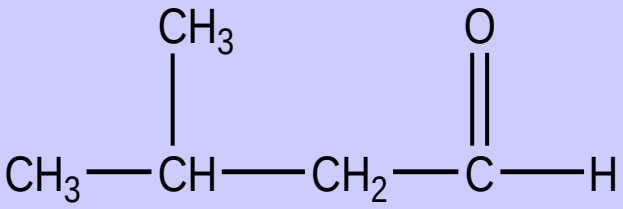
Rule 3

Number the chain by assigning the number 1 to the aldehyde carbon.

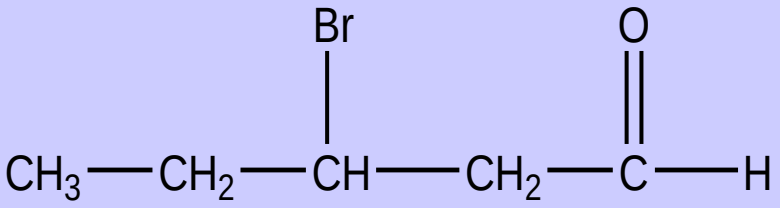


Rule 4

Other substituents are numbered, named, and placed as prefixes in alphabetic order.



3-Methyl

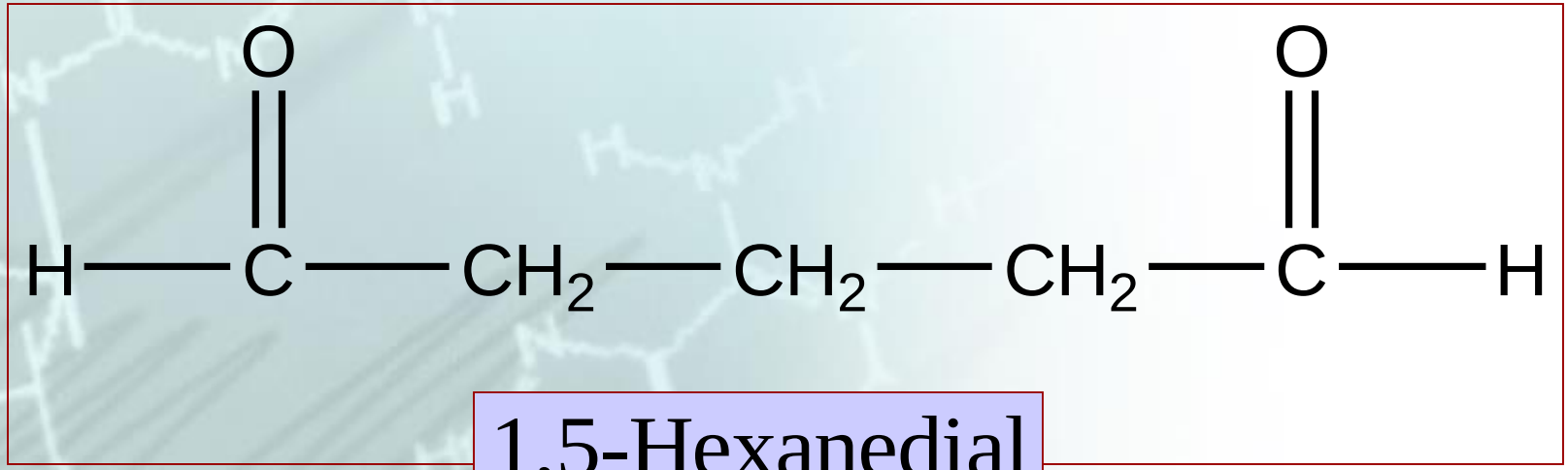


3-Bromo

Rule 5

When there are two aldehyde groups in a molecule, it is named as "Alkanedial".

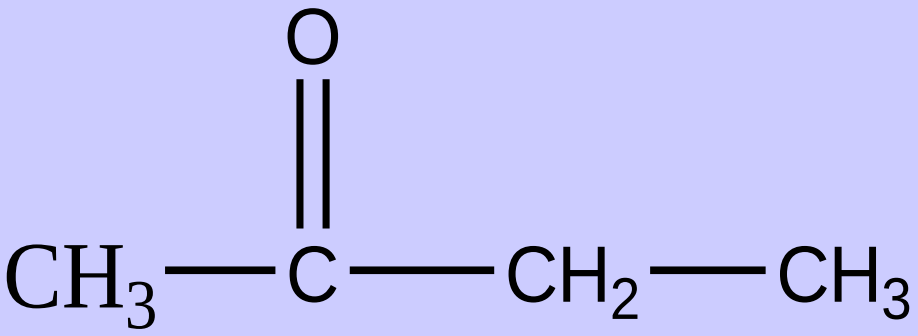
Note that "-e" of the corresponding alkane name is retained.



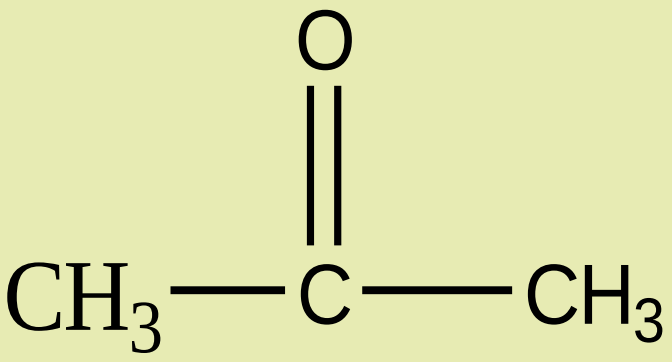
1,5-Hexanedial

Ketones

Ketones are compounds in which carbonyl group (C=O) is bonded to two organic groups.



Butanone



Propanone

IUPAC Rules for naming Ketones

Rule 1

Select the longest chain containing the carbonyl carbon atom.

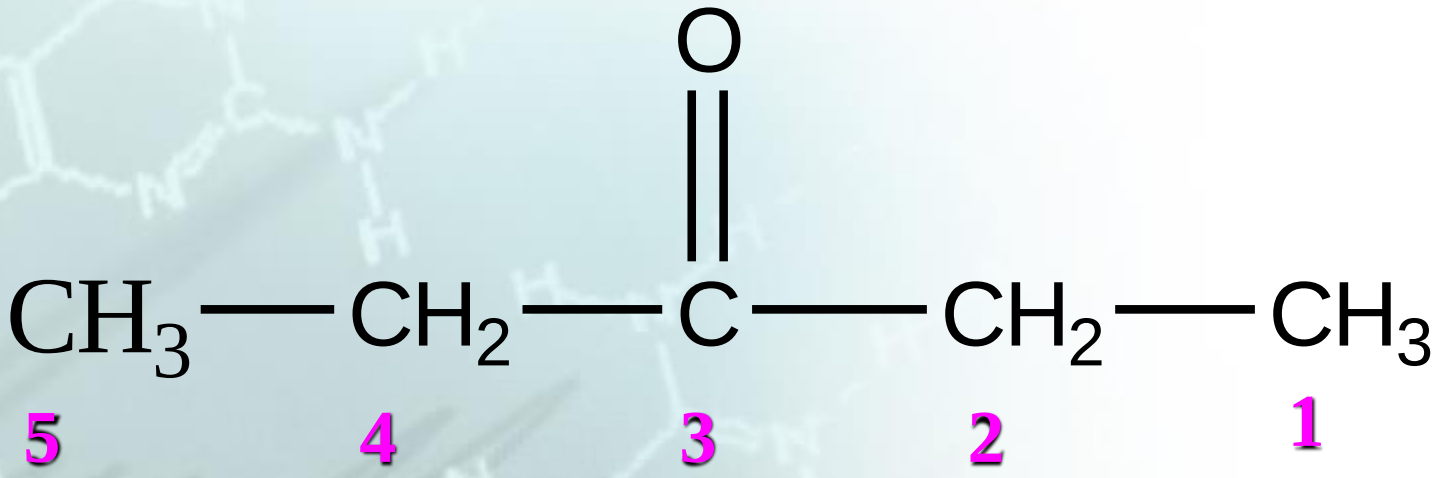
Rule 2

Name the longest chain by dropping "-e" from the name of the corresponding alkane, and Adding "-one" at the end.

Alkane -e + one = Alkanone

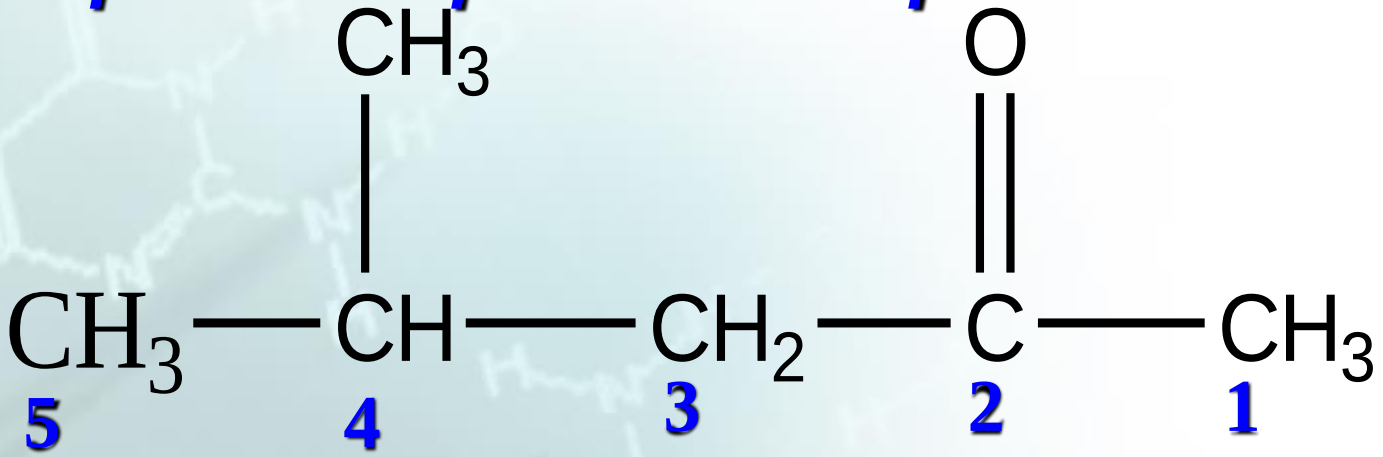
Rule 3

Number the chain to give the lowest number to the carbonyl carbon.



Rule 4

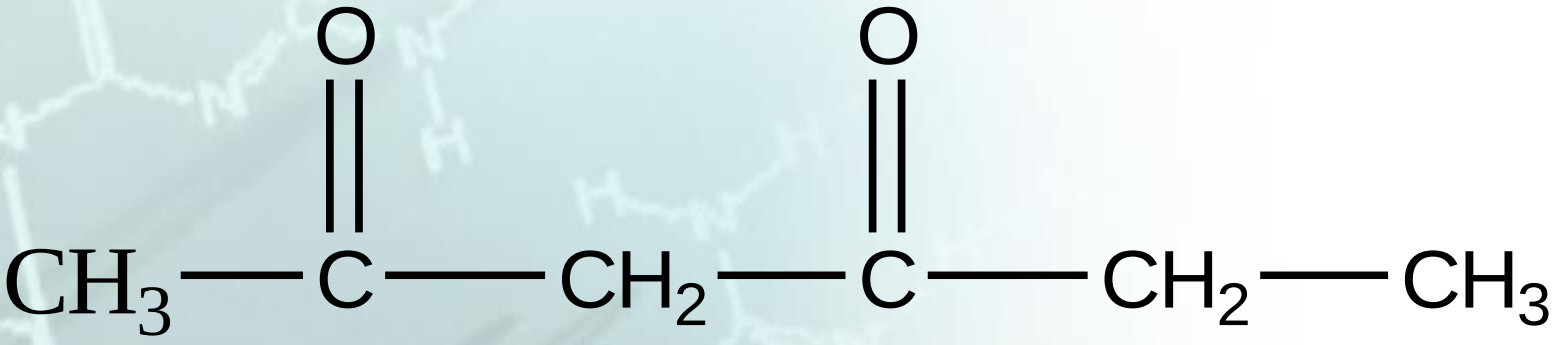
Other substituent's are numbered, named, and placed as prefixes in alphabetic order.



4-Methyl-2-pentanone OR 4-Methyl pentan-2-one

Rule 5

When there are two carbonyl groups in a molecule, it is named as Alkanedione.



2,4-Hexanedione

IUPAC Rules for naming Carboxylic acids

1. ***Select the longest chain containing the acid group -COOH.***
2. ***Start numbering from the end where the –COOH group is.***
3. ***Remove "-e" from the parent alkane and add "_oic acid".***

Eg.:-

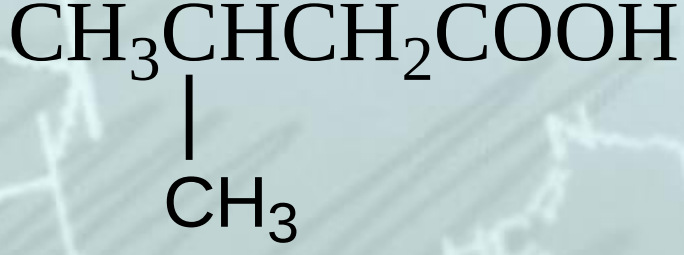
CH_3CH_2COOH Propanoic acid

4. If two carboxylic acid groups are present, it should be named as alkanedioic acid

Eg.:-

$HOOC\text{-}CH_2\text{-}CH_2\text{-}COOH$ Butanedioic acid

Other substituents are numbered, named, and placed as prefixes in alphabetic order.



3-Methylbutanoic acid

Esters

They are the condensation products of alcohols and acids.

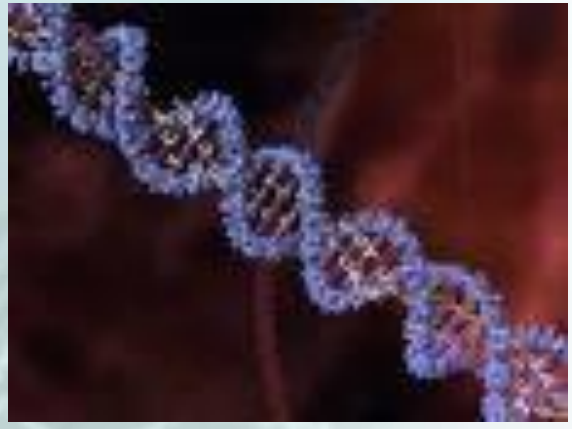
Fraction contains –COO- group will have the name end with "ate".

Fraction carries no –COO- group will have the name end with "yl" and will be written first.

The molecule is Ethyl propanoate

Chemistry of Life Part I

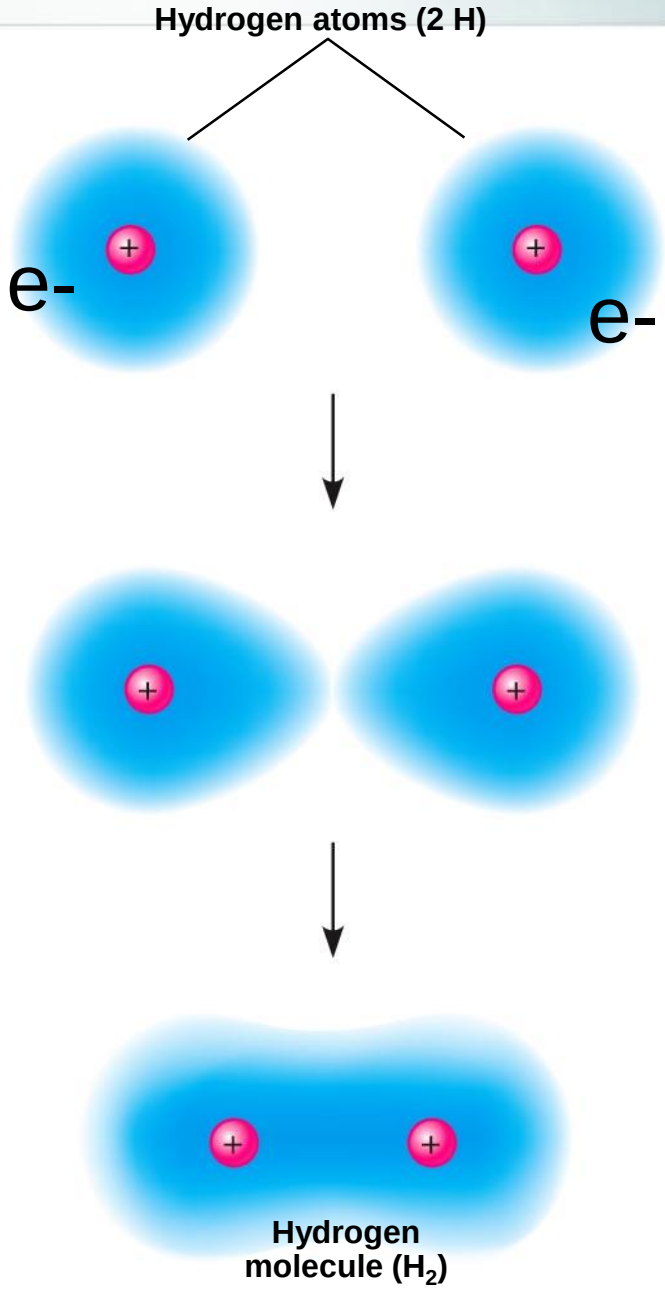
Common Constituents and Bonds



Covalent Bonds

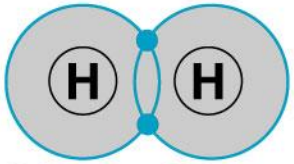
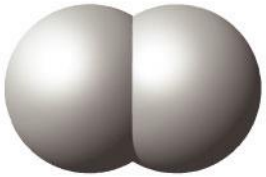
- the sharing of a pair of valence electrons by two atoms

LE 2-10

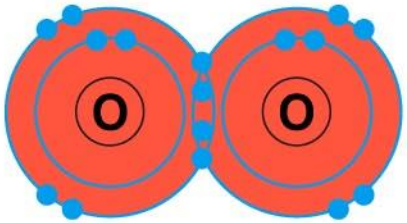
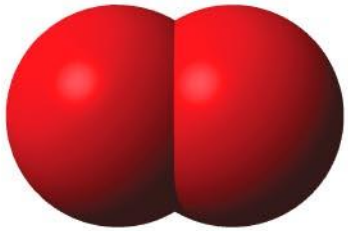


- A single covalent bond, or single bond, is the sharing of one pair of valence electrons
- A double covalent bond, or double bond, is the sharing of two pairs of valence electrons
- Covalent bonds can form between atoms of the same element or atoms of different elements
- A molecule is two or more covalently bonded atoms

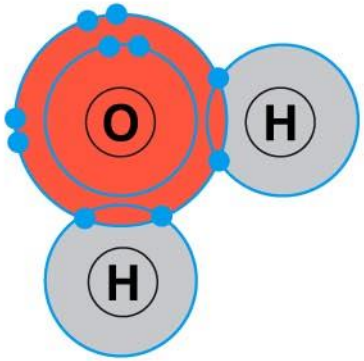
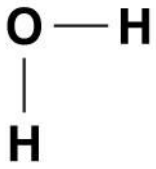
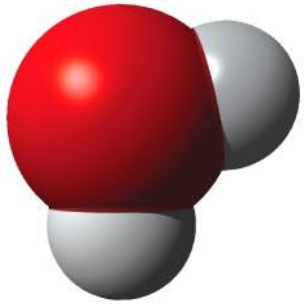
<u>Strong bond</u>

Name (molecular formula)	Electron-shell diagram	Structural formula	Space-filling model
(a) Hydrogen (H_2)		H — H	

LE 2-11b

Name (molecular formula)	Electron-shell diagram	Structural formula	Space-filling model
(b) Oxygen (O_2)		O═O	

LE 2-11c

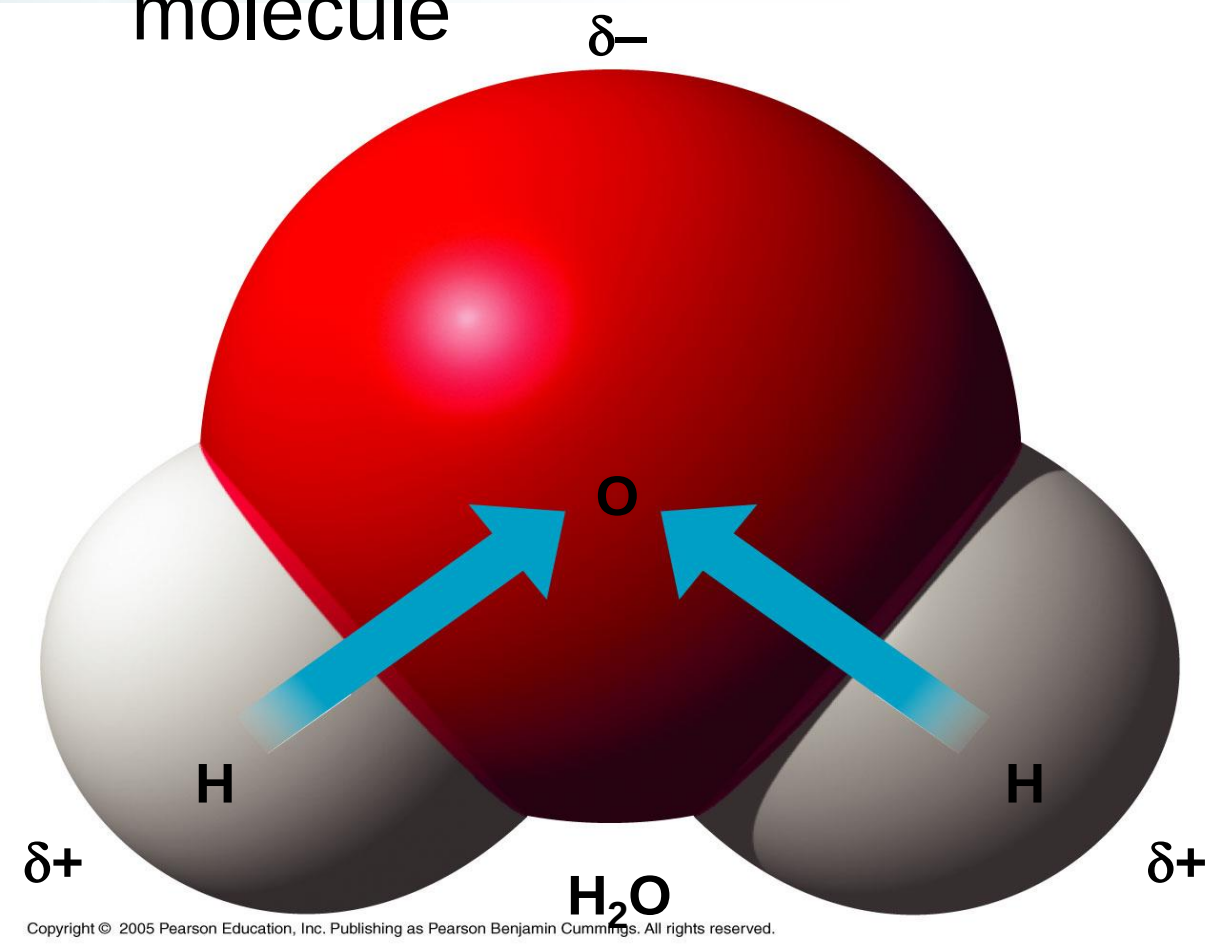
Name (molecular formula)	Electron-shell diagram	Structural formula	Space-filling model
(c) Water (H_2O)			

- Electronegativity
  - an atom's attraction for the electrons in a covalent bond

  Examples: Oxygen and nitrogen are highly electronegative

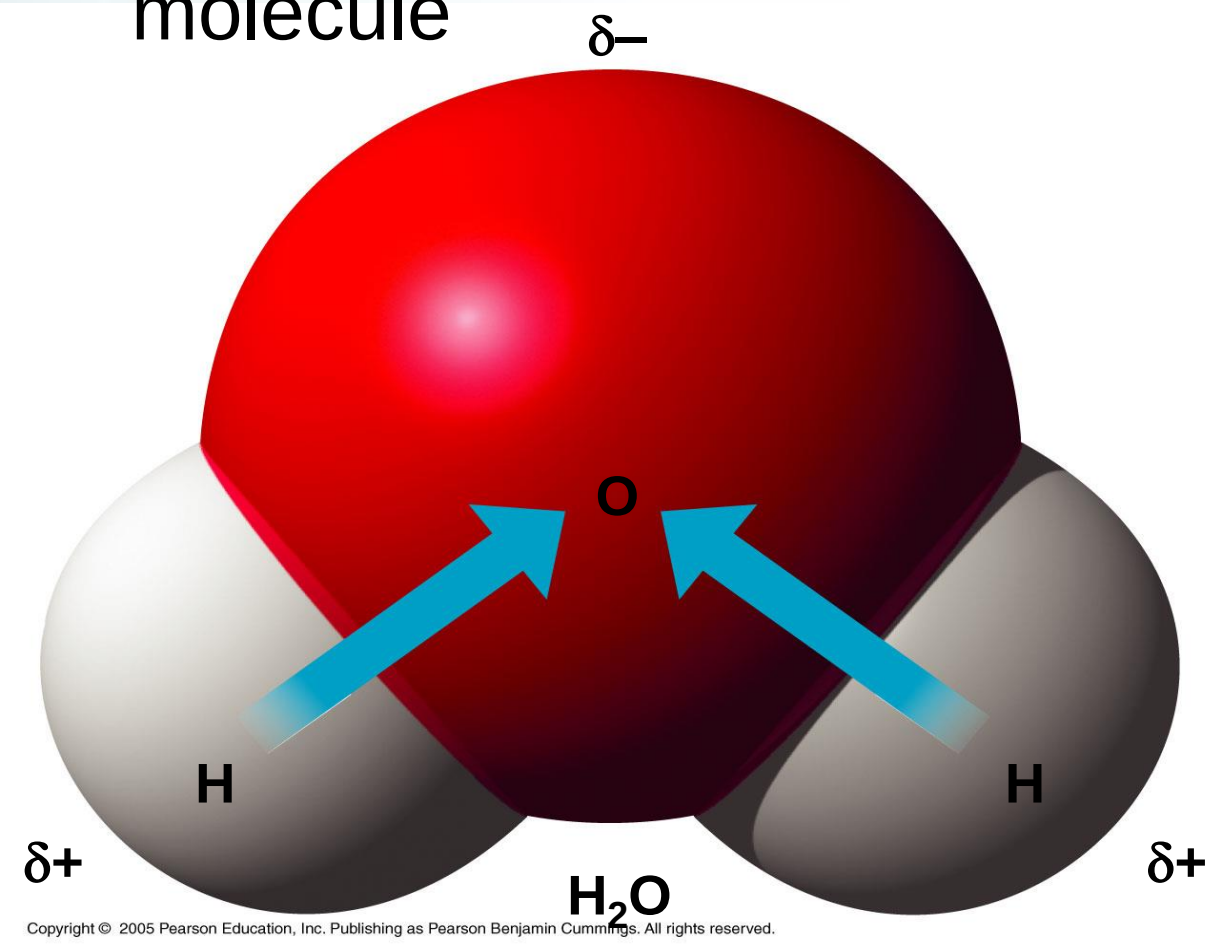
- The more electronegative an atom, the more strongly it pulls shared electrons toward itself

H_2O: Polar covalent molecule



- Polar covalent bond
  - one atom is more electronegative
  - the atoms do not share the electron equally
  - Partial negative and positive charges

H_2O: Polar covalent molecule

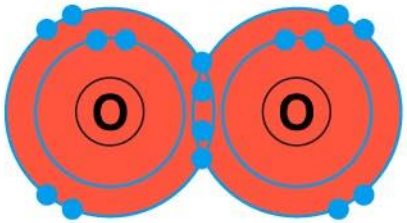
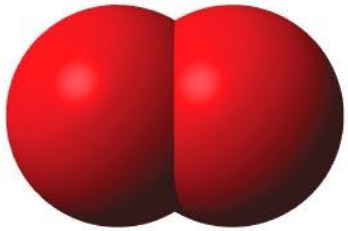


- Nonpolar covalent bond
  - the atoms share the electron equally

-molecule has no charge (neither positive nor negative)

LE 2-11b

Molecular Oxygen

Name (molecular formula)	Electron-shell diagram	Structural formula	Space-filling model
(b) Oxygen (O_2)		O═O	

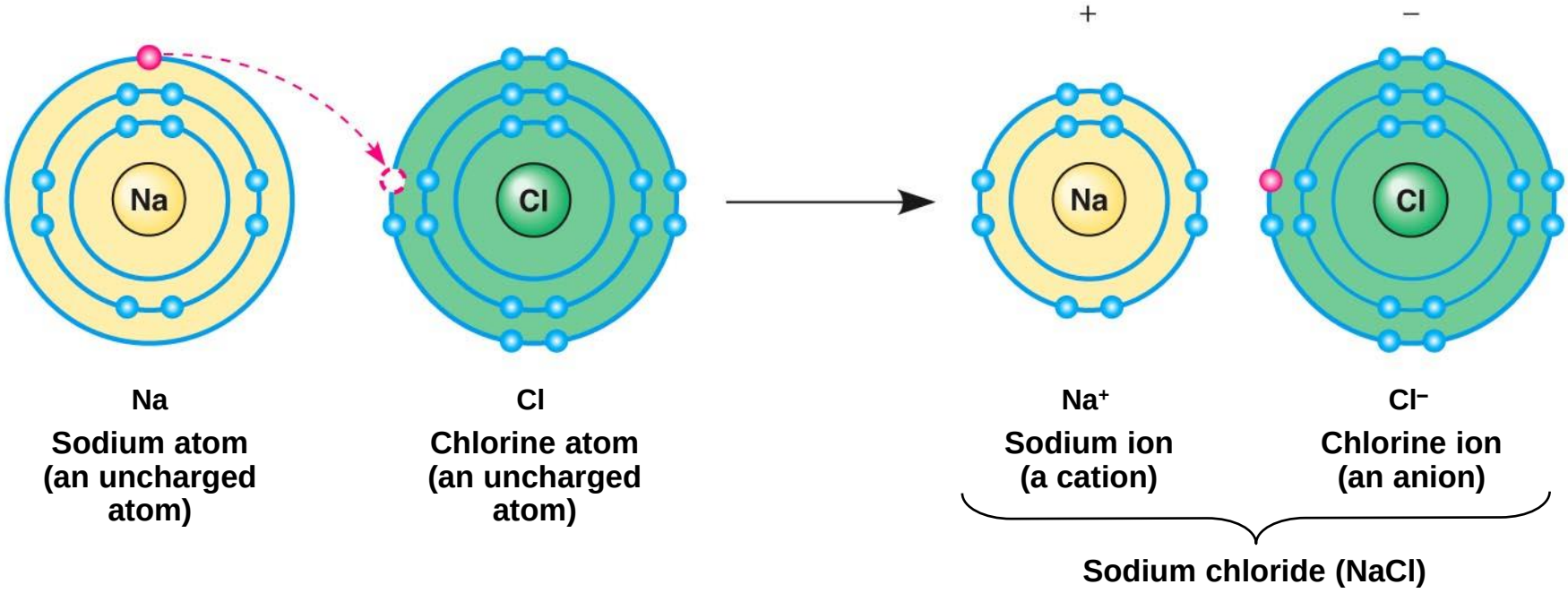
Nonpolar covalent molecule
Neutral

Ionic Bonds

- Formed by the transfer of electrons from one atom to another
- After transfer, both atoms charged
- A charged atom (or molecule) is called an ion
- Weaker than covalent bond

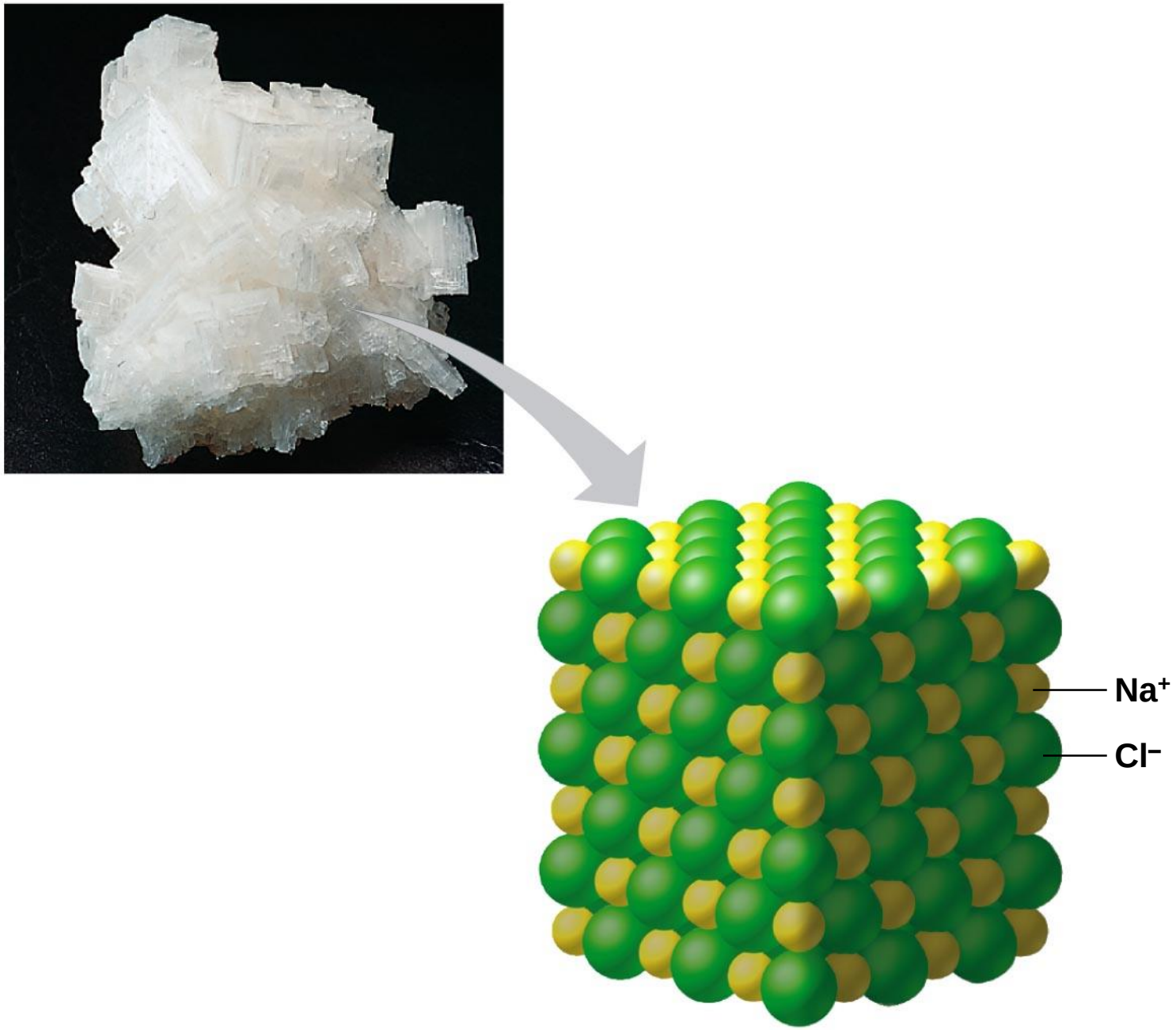
- Anion
  - negatively charged ion
- Cation
  - positively charged ion
- Ionic bond
  - attraction between an anion and a cation

LE 2-13



- Ionically bonded atoms
  - ionic compounds, or salts e.g. NaCl
- often crystals

LE 2-14



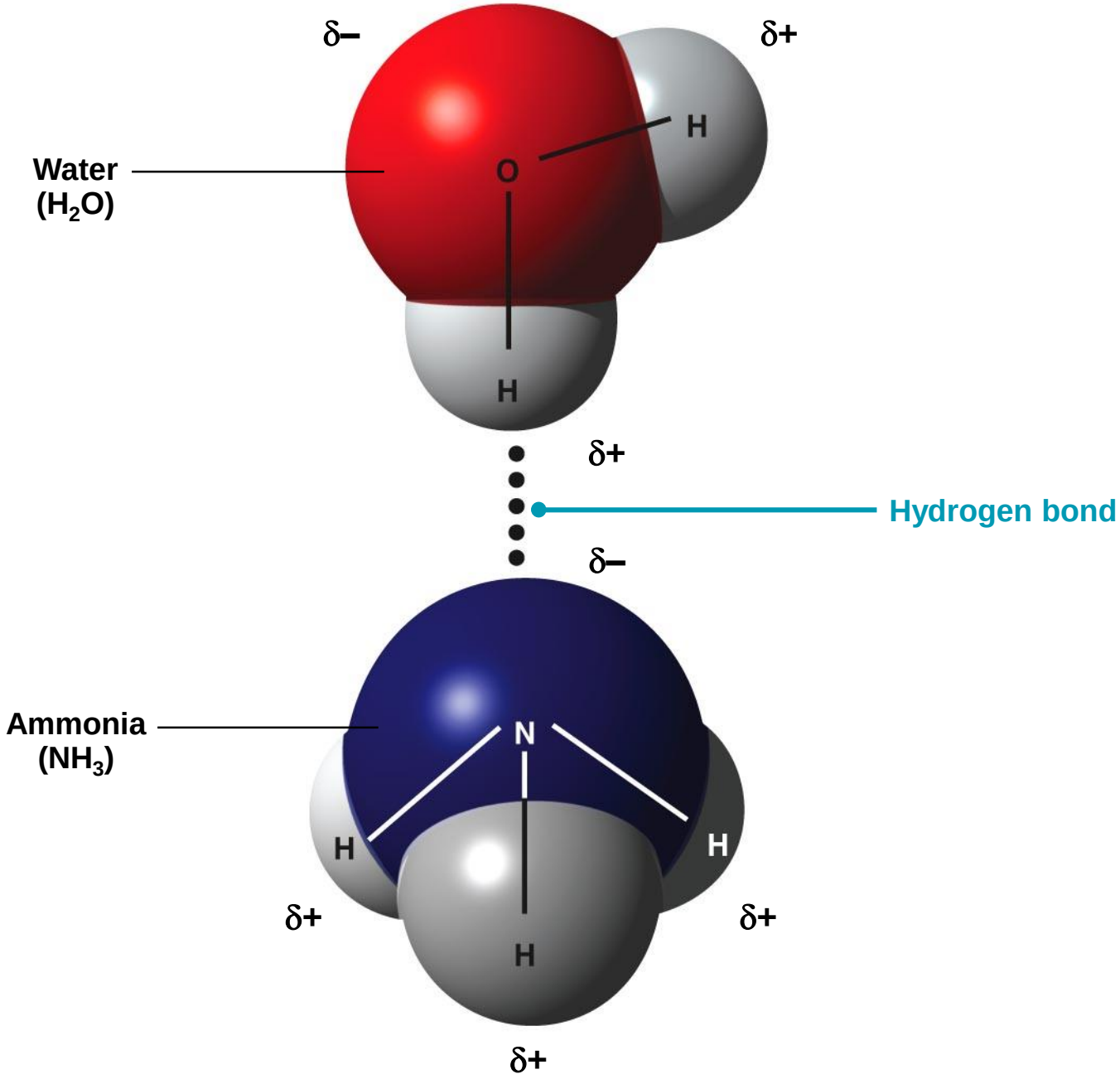
Hydrogen Bonds

- when a hydrogen atom, covalently bonded to one electronegative atom, is attracted to another electronegative atom

- Example: water (H_2O)

- Weak, but many together are strong

LE 2-15



Do H-bonds form between water molecules?

o, illustrate by drawing the interaction of 2 water molecu

Van der Waals Interactions

- Attraction between adjacent atoms by fleeting charge differences
- Very weak
- Collectively, can be strong
- Example: molecules of a gecko's toe hairs and a wall surface

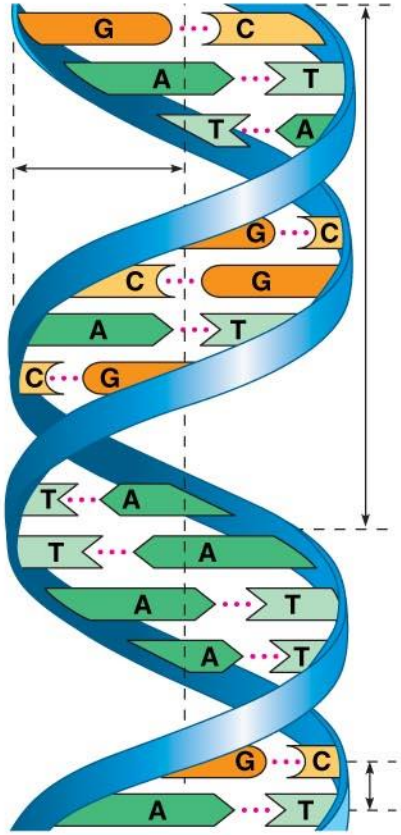
Order of Relative Bond Strength

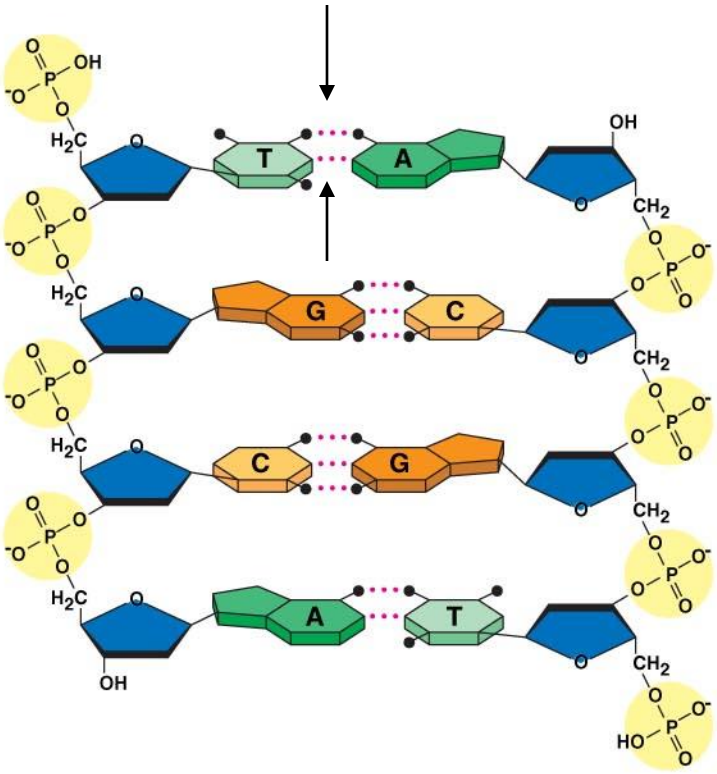
Covalent >ionic> hydrogen> van der waals

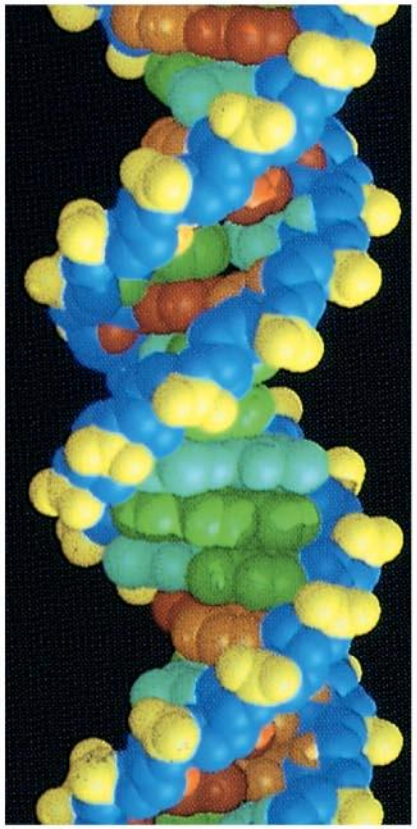
In biological systems, often many weak bonds collectively are strong and help stabilize structures.

Example: DNA double helix: held together through H-bonds

2 H-bonds







(a) (b) (c)

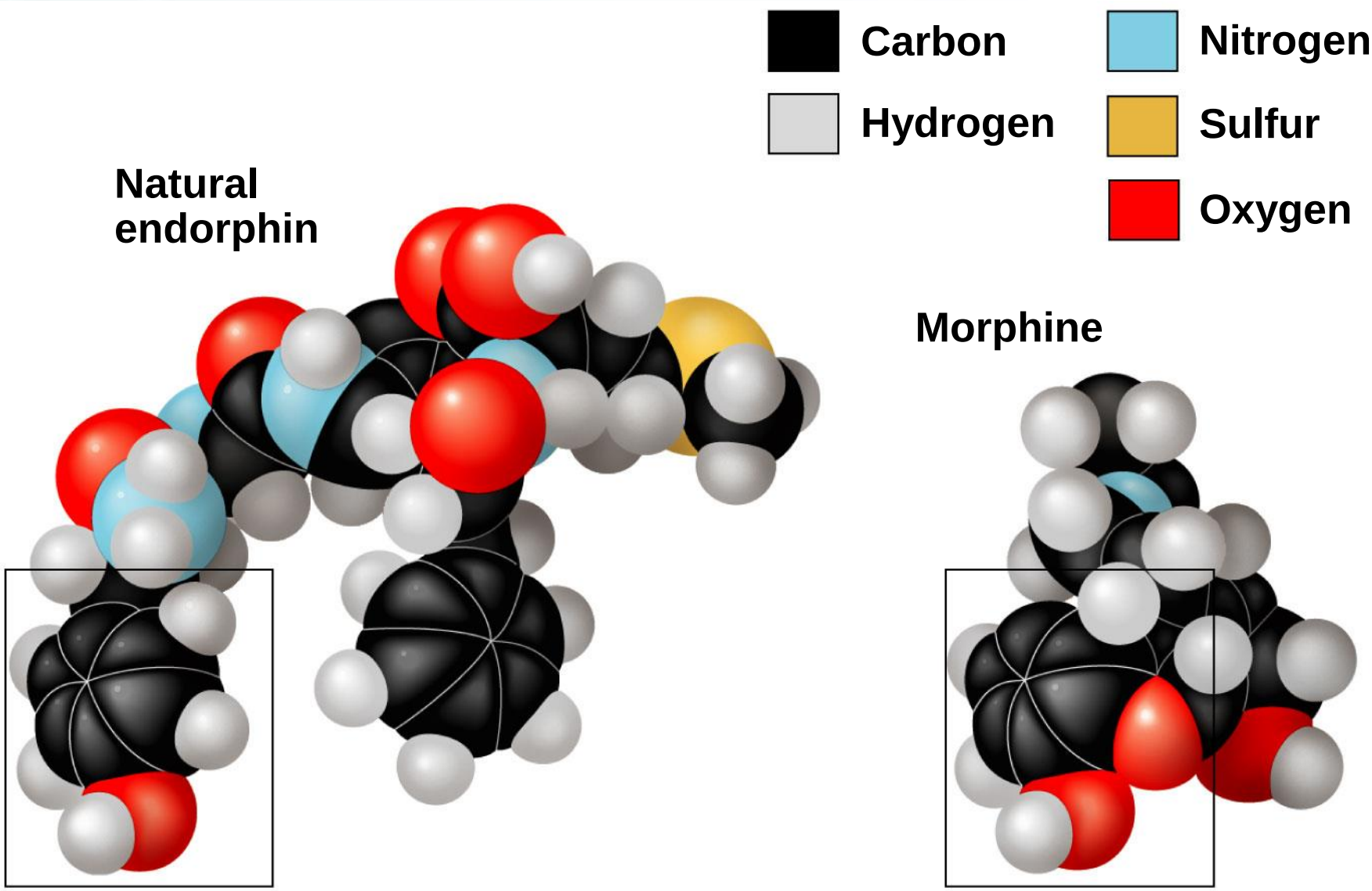
In biochemical systems

molecular structure is crucial

For example

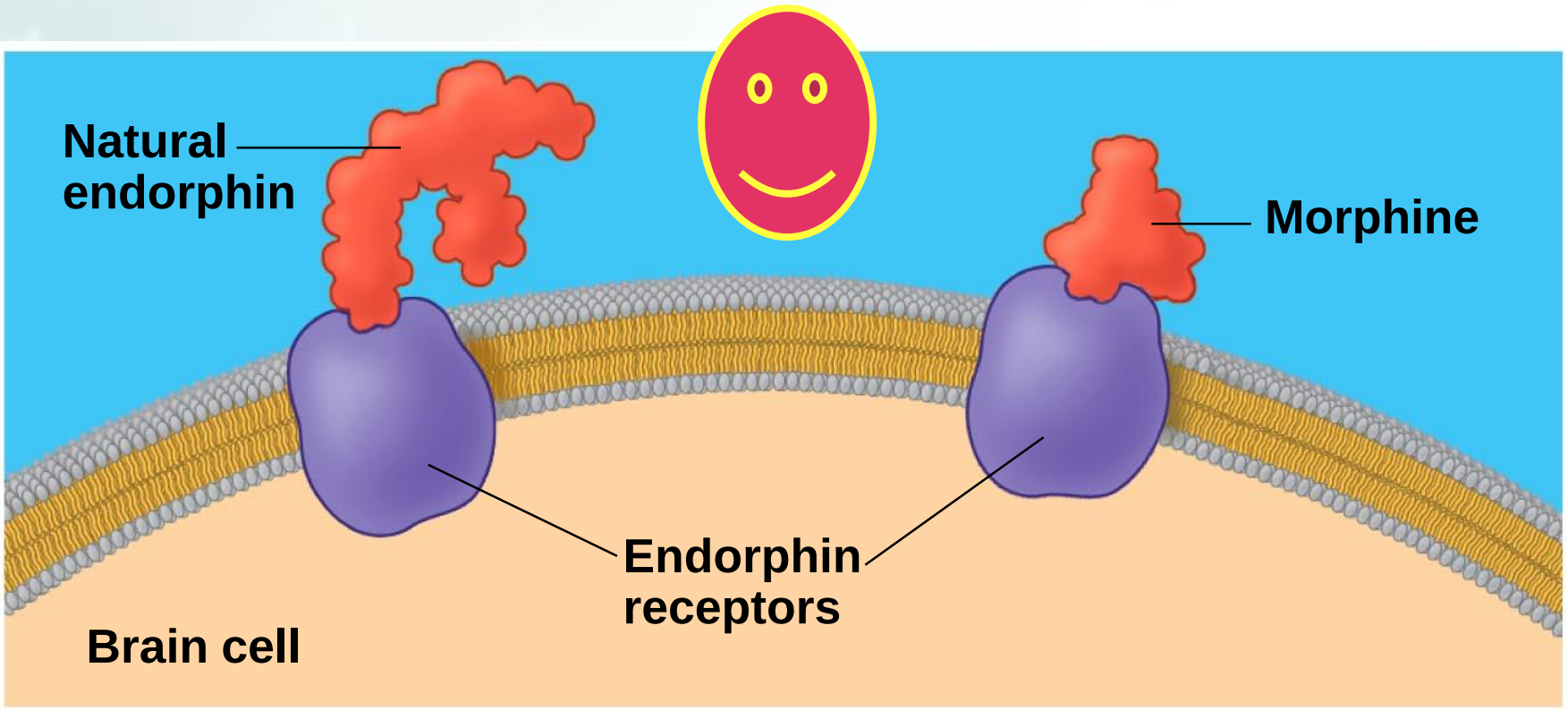
between hormone and hormone receptor

LE 2-17a



(a) Structures of endorphin and morphine

LE 2-17b



(b) Binding to endorphin receptors

Cells are composed of various elements, mostly C,H,N,O,P,S

Chemical bonds combine atoms together to form a variety of molecules.

Molecular structure contributes to biochemical and biological function.

The END