Organic Chemistry

Introduction

Organic Chemistry

What do I need to know about *organic chemistry*?

Organic Chemistry

Overview

In the nineteenth century, chemists believed that all organic chemicals originated in tissues of living organisms. Friedrich Wohler, in 1828, challenged this belief and synthesised the organic compound urea, a compound found in urine, under laboratory conditions. His work led other chemists to attempt the synthesis of other organic compounds. In this section, students examine the sources of fuels, some basic concepts of organic chemistry such as homologous series, functional group, general formula and structural formula, and polymers. Students should be able to identify and name unbranched alkanes, alkenes, alcohols and carboxylic acids. They should recognise that materials such as plastics, detergents and medicines, and even the food that we eat are examples of organic compounds. Students should be able to value the need for assessing the impacts of the use of synthetic materials and the environmental issues related to the use of plastics.

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Learning Outcomes:

Candidates should be able to:

Fuels and Crude Oil

a) Name natural gas, mainly methane, and petroleum as sources of energy.
b) Describe petroleum as a mixture of hydrocarbons and its separation into useful fractions by fractional distillation.
c) Name the following fractions and state their uses:
- **i)** Petrol (gasoline) as a fuel in cars.
- **ii)** Naphtha as feedstock for the chemical industry.
- **iii)** Paraffin (kerosene) as a fuel for heating and cooking and for aircraft engines.
- **iv)** Diesel as a fuel for diesel engines.
- **v)** Lubricating oils as lubricants and as a sources of polishes and waxes.
- **vi)** Bitumen for making road surfaces.

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d) State that the naphtha fraction from crude oil is the main source of hydrocarbons used as the feedstock for the production of a wide range of organic compounds.

e) Describe the issues relating to the competing uses of oil as an energy source and as a chemical feedstock.

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Alkanes

a) Describe an homologous series as a group of compounds with a general formula, similar chemical properties and showing a gradation in physical properties as a result of increase in the size and mass of the molecules, *e.g.* melting and boiling points; viscosity; flammability.

b) Describe the alkanes as an homologous series of saturated hydrocarbons with the general formula C_nH_{2n+2}.

c) Draw the structures of branched and unbranched alkanes, C1 to C4, and name the unbranched alkanes, methane to butane.

d) Define isomerism and identify isomers.

e) Describe the properties of alkanes (exemplified by methane) as being generally unreactive except in terms of burning and substitution by chlorine.

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Alkenes

a) Describe the alkenes as an homologous series of unsaturated hydrocarbons with the general formula C_nH_{2n}.

b) Draw the structures of branched and unbranched alkenes, C2 to C4, and name the unbranched alkenes, ethene to butene.

c) Describe the manufacture of alkenes and hydrogen by cracking hydrocarbons and recognise that cracking is essential to match the demand for fractions containing smaller molecules from the refinery process.

d) Describe the difference between saturated and unsaturated hydrocarbons from their molecular structures and by using aqueous bromine.

e) Describe the properties of alkenes (exemplified by ethene) in terms of combustion, polymerisation and the addition reactions with bromine, steam and hydrogen.

f) State the meaning of polyunsaturated when applied to food products.

g) Describe the manufacture of margarine by the addition of hydrogen to unsaturated vegetable oils to form a solid product.

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Alcohols

a) Describe the alcohols as an homologous series containing the –OH group.

b) Draw the structures of alcohols, C1 to C4, and name the unbranched alcohols, methanol to butanol.

c) Describe the properties of alcohols in terms of combustion and oxidation to carboxylic acids.

d) Describe the formation of ethanol by the catalysed addition of steam to ethene and by fermentation of glucose.

e) State some uses of ethanol, *e.g.* as a solvent; as a fuel; as a constituent of alcoholic beverages.

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Carboxylic Acids

a) Describe the carboxylic acids as an homologous series containing the $–CO_2H$ group.

b) Draw the structures of carboxylic acids, methanoic acid to butanoic acid and name the unbranched acids, methanoic to butanoic acids.

c) Describe the carboxylic acids as weak acids, reacting with carbonates, bases and some metals.

d) Describe the formation of ethanoic acid by the oxidation of ethanol by atmospheric oxygen or acidified potassium dichromate(VI).

e) Describe the reaction of a carboxylic acid with an alcohol to form an ester, *e.g.* ethyl ethanoate.

f) State some commercial uses of esters, *e.g.* perfumes; flavourings; solvents.

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Macromolecules

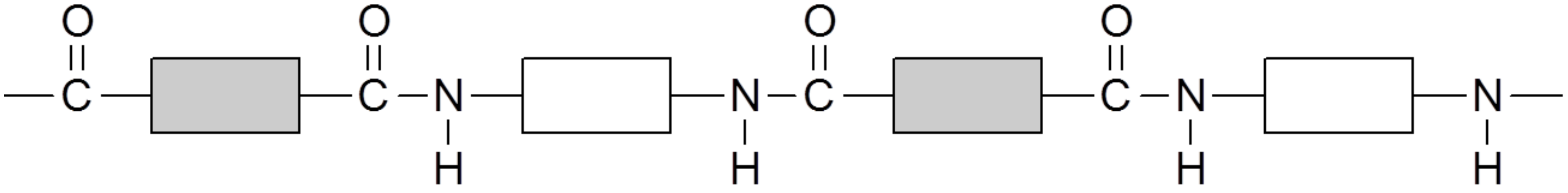
a) Describe macromolecules as large molecules built up from small units, different macromolecules having different units and/or different linkages.

b) Describe the formation of poly(ethene) as an example of addition polymerisation of ethene as the monomer.

c) State some uses of poly(ethene) as a typical plastic, *e.g.* plastic bags; clingfilm.

d) Deduce the structure of the polymer product from a given monomer and vice versa.

e) Describe nylon, a polyamide, and *Terylene*, a polyester, as condensation polymers, the partial structure of nylon being represented as:



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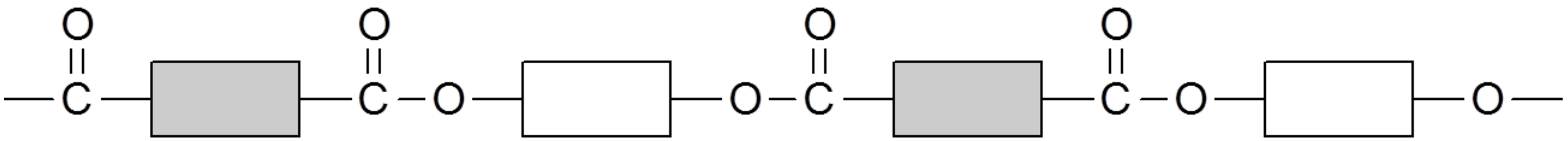
And the partial structure of *Terylene* as:



(Details of manufacture and mechanisms of these polymerisations are not required).

f) State some typical uses of man-made fibres such as nylon and *Terylene*, *e.g.* clothing; curtain materials; fishing line; parachutes; sleeping bags.

g) Describe the pollution problems caused by the disposal of non-biodegradable plastics.

Organic Chemistry

What is an *organic compound*?

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Organic	Inorganic
Citric Acid – $C_6H_8O_7$	Aluminium Oxide – Al_2O_3
Ethanoic Acid – CH_3COOH	Calcium Carbonate – $CaCO_3$
Ethanol – CH_3CH_2OH	Carbon Dioxide – CO_2
Glucose – $C_6H_{12}O_6$	Copper(II) Sulfate – $CuSO_4$
Methane – CH_4	Sodium Chloride – NaCl
Poly(ethene) – $(CH_2CH_2)_n$	Sulfuric Acid – H_2SO_4
Propane – C_3H_8	Water – H_2O

- Compare the organic compounds with the inorganic compounds. What are the differences?

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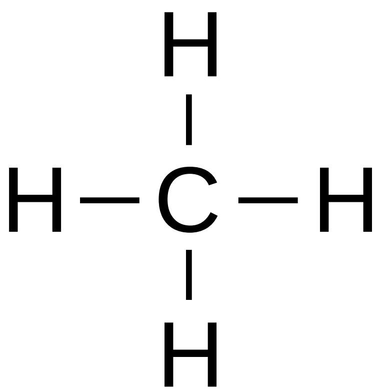
- An organic compound is a compound that contains *carbon covalently bonded to hydrogen*.

- Methane (formula CH_4) is *organic*.



- Carbon dioxide (formula CO_2) is *inorganic*.

O=C=O

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What is the nature of the *bonding* in organic compounds?

- Because only atoms of *non-metallic elements* are present, the bonding in organic compounds is *covalent*.

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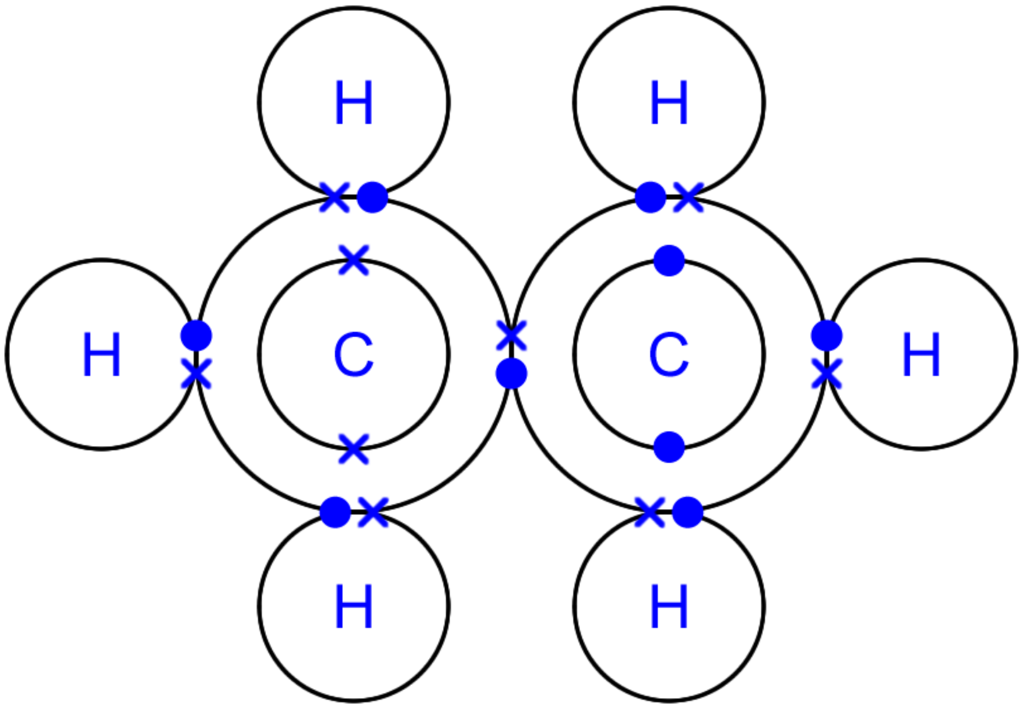
Bonding in Organic Compounds

Ethane – C_2H_6



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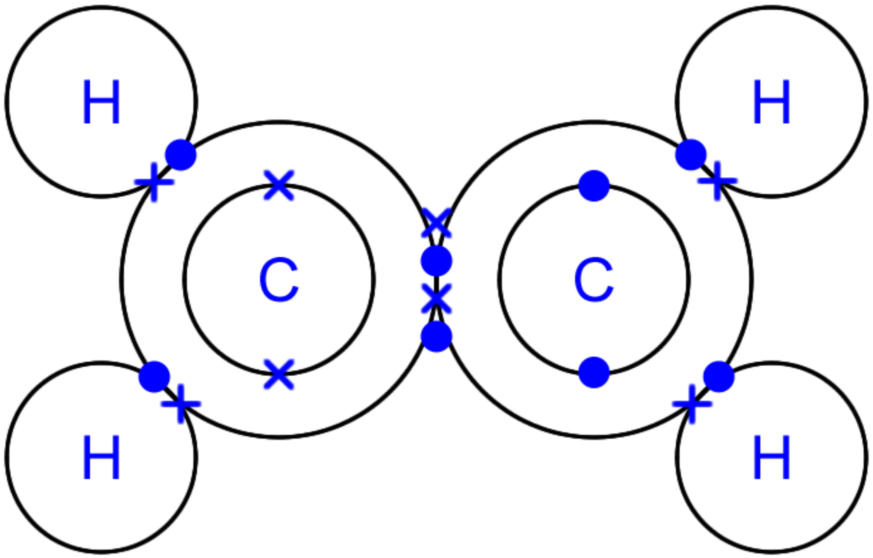
Bonding in Organic Compounds

Ethene – C_2H_4



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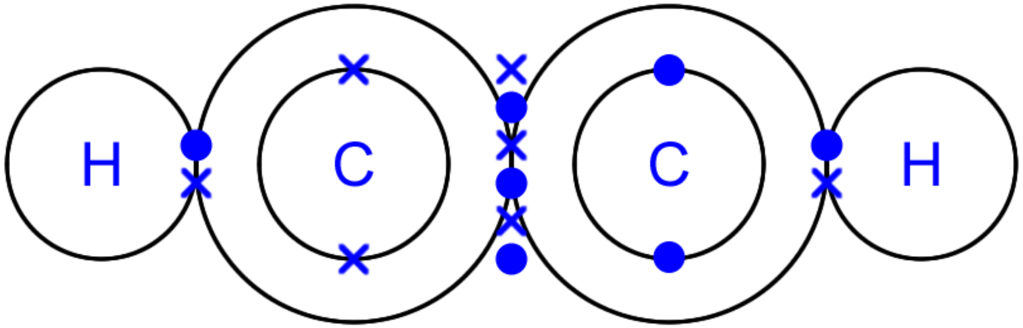
Bonding in Organic Compounds
Ethyne – C_2H_2



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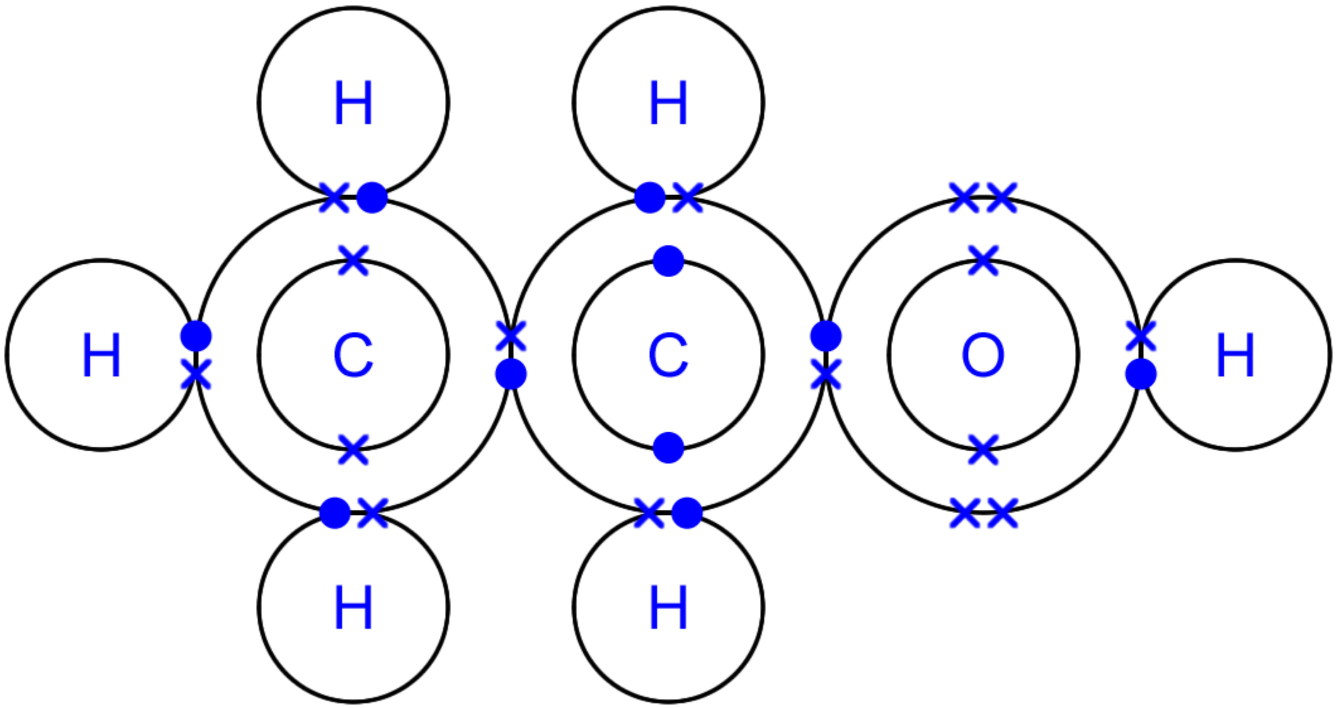
Bonding in Organic Compounds

Ethanol – CH_3CH_2OH



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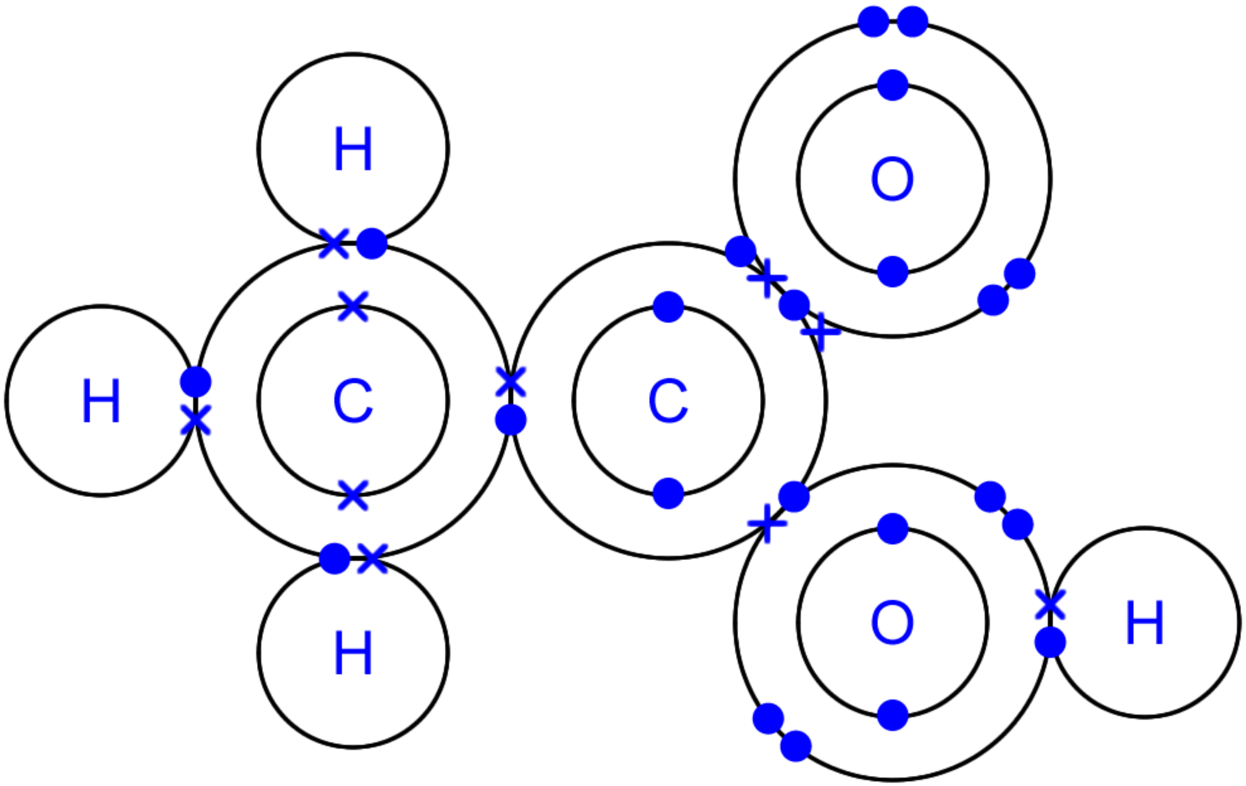
Bonding in Organic Compounds

Ethanoic Acid – CH_3COOH



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What *properties* of carbon make it such an important element?

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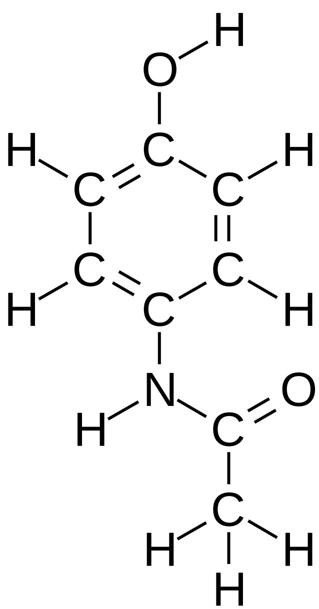
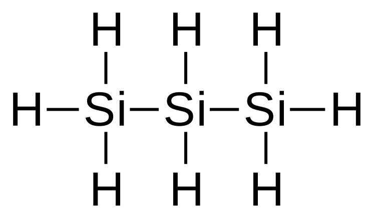
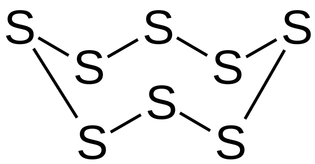
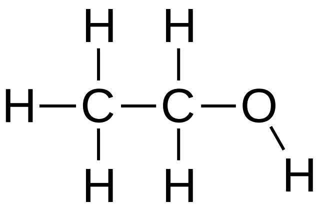
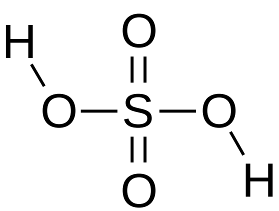
- Compare the bonding in the organic compounds with the bonding in the inorganic elements and compounds. What similarities and differences do you notice?

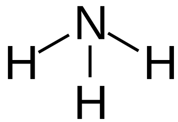


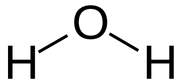


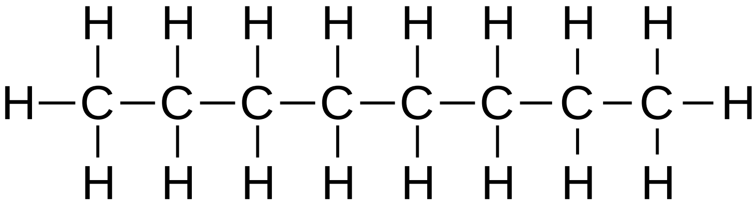


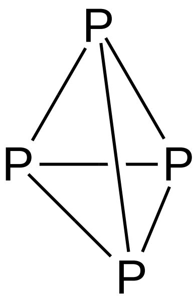












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- Compare the bond strengths between **i)** carbon atoms, **ii)** carbon atoms and other elements **iii)** other elements (excluding carbon). What similarities and differences do you notice?

Bond	ΔH kJ/mol
C – C	348
Si – Si	176
N – N	163
O – O	146
P – P	172
S – S	264
Cl – Cl	242

Bond	ΔH kJ/mol
C – H	412
Si – H	318
N – H	388
O – H	463
P – H	322
S – H	338
Cl – H	431

Bond	ΔH kJ/mol
C = C	612
C ≡ C	837
C – N	305
C = N	613
C ≡ N	890
C – O	360
C – Cl	338

Organic Chemistry

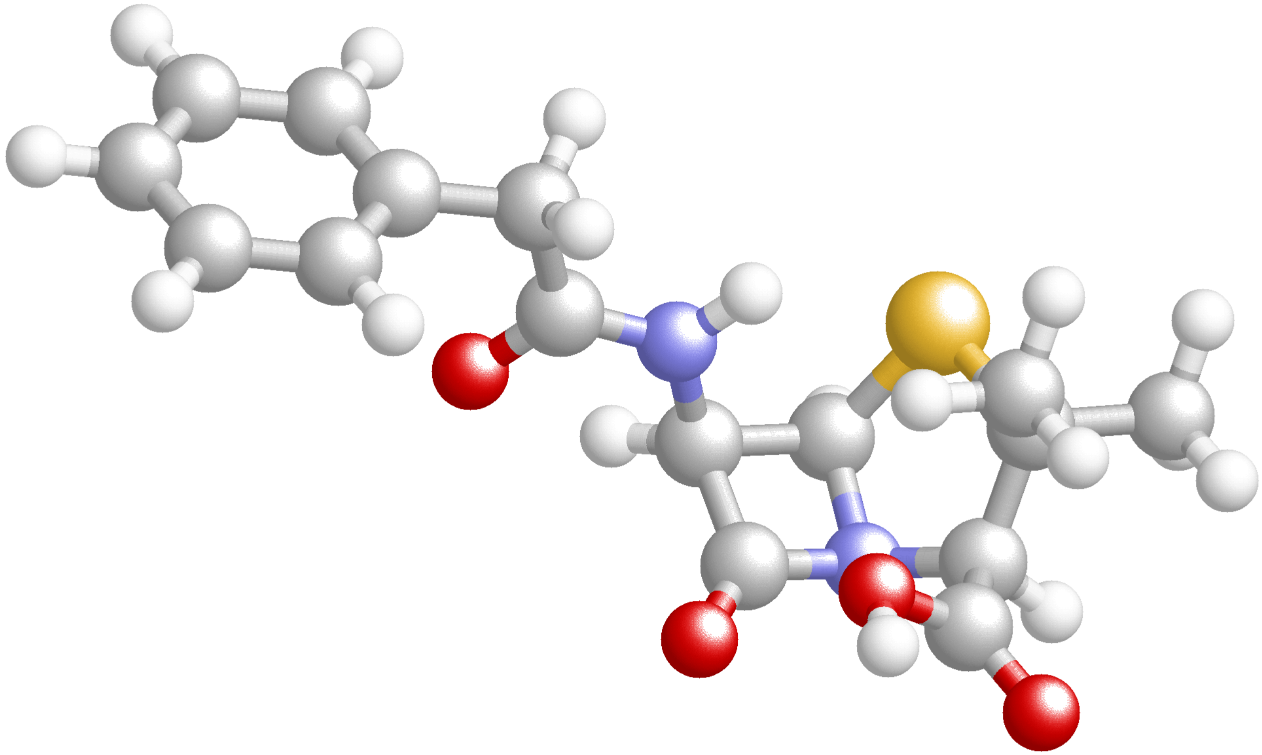
The Special Properties of carbon

- Carbon is in Group IV of the Periodic Table. It has four electrons in its valence shell and therefore makes four covalent bonds with atoms of other non-metallic elements.
Carbon is described as being *tetravalent*.

- The covalent bond between two carbon atoms is very strong. This allows carbon atoms to join together in large numbers to form long-chains and complex rings.
Carbon is said to *catenate*.

Organic Chemistry

The Special Properties of carbon



- The complex structure of the antibiotic *penicillin*.

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What is a *homologous series*?

Organic Chemistry

Homologous Series

- A *homologous series* of organic compounds is a group of molecules that possess the same *functional group*, share the same *general formula* and have similar names.

- A *functional group* is a group of atoms that are bonded together in a way that is unique to that particular homologous series. The functional group is responsible for a compound's characteristic *chemical properties*.

- Because they all possess the same functional group, members of the same homologous series will all *react in a similar way* to each other.

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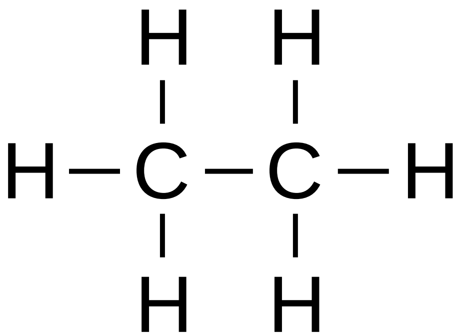
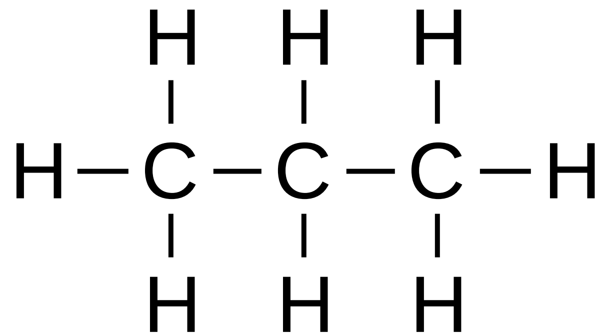
Homologous Series – Alkanes



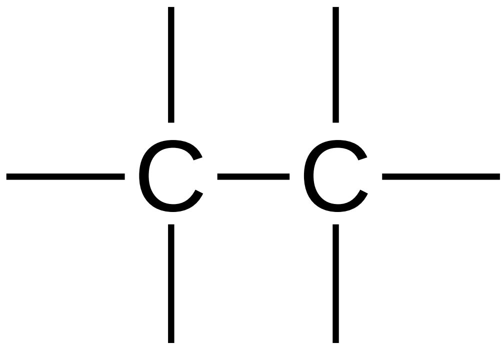
- Ethane



- Propane

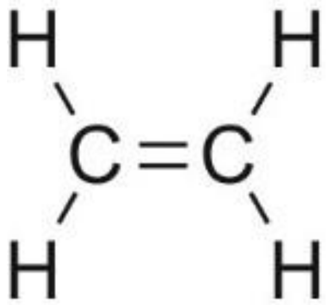
Organic Chemistry

Homologous Series – Alkanes

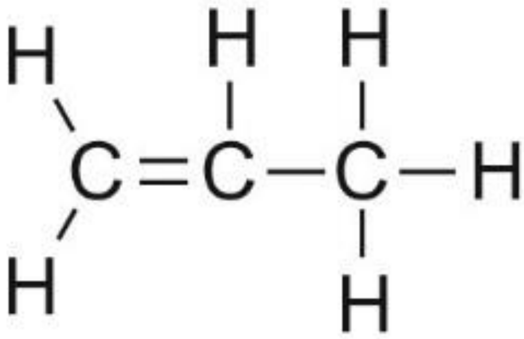
Functional Group	
General Formula	C_nH_{2n+2}
Name	-ane

Organic Chemistry

Homologous Series – Alkenes



- Ethene

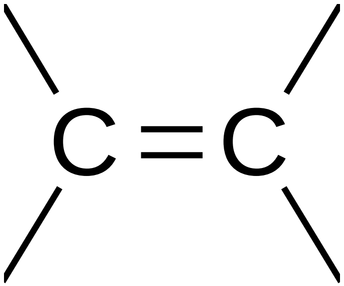


- Propene

Organic Chemistry

Homologous Series – Alkenes

Functional Group



General Formula

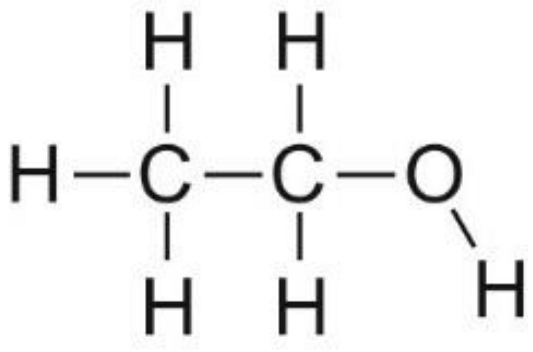
C_nH_{2n}

Name

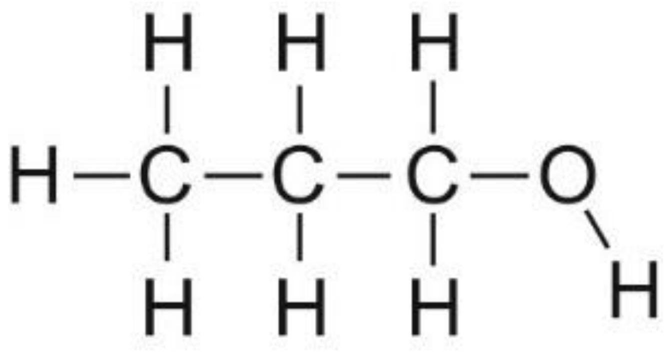
-ene

Organic Chemistry

Homologous Series – Alcohols



- Ethanol

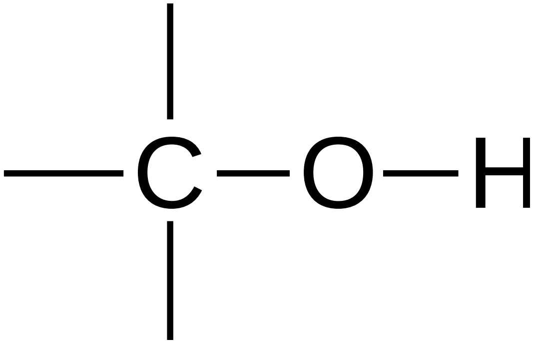


- Propan-1-ol

Organic Chemistry

Homologous Series – Alcohols

Functional Group
hydroxyl

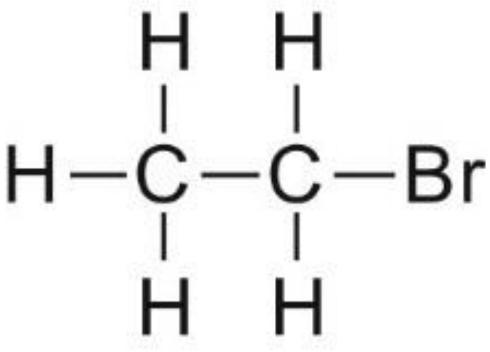


General Formula $C_nH_{2n+1}OH$

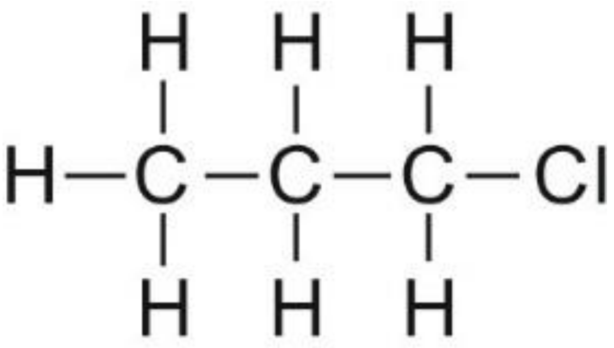
Name -ol

Organic Chemistry

Homologous Series – Halogenoalkanes



- Bromoethane

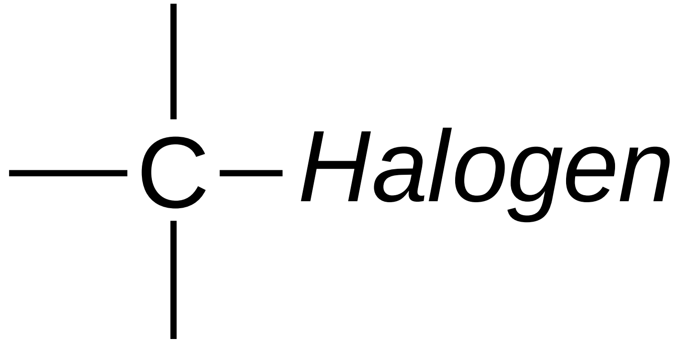


- 1-Chloropropane

Organic Chemistry

Homologous Series – Halogenoalkanes

Functional Group



General Formula

$C_nH_{2n+1}\mathit{Hal}$

Name

Bromo-

Chloro-

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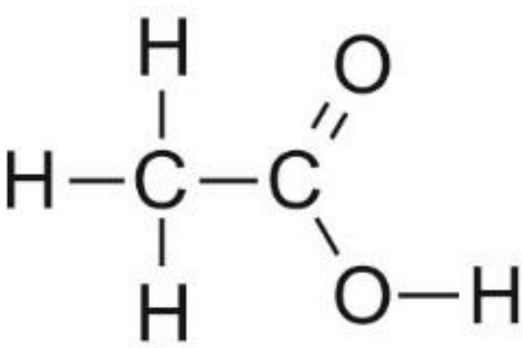
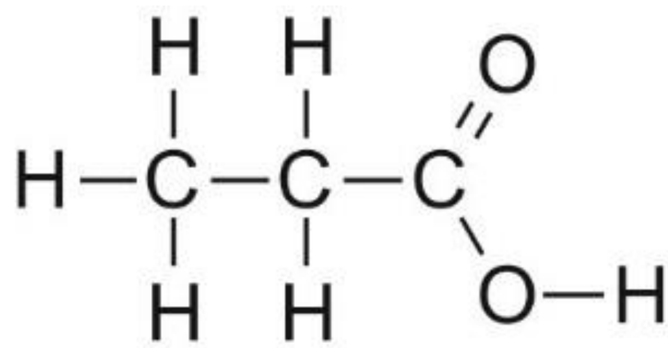
Homologous Series – Carboxylic Acids



- Ethanoic Acid

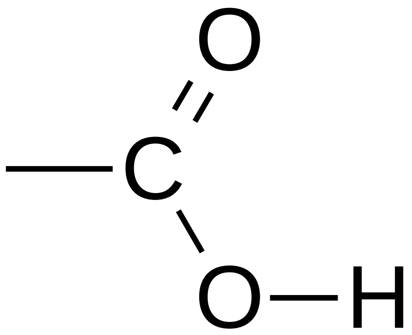


- Propanoic Acid

Organic Chemistry

Homologous Series – Carboxylic Acids

Functional Group
carboxyl



General Formula $C_nH_{2n}O_2$

Name -oic acid

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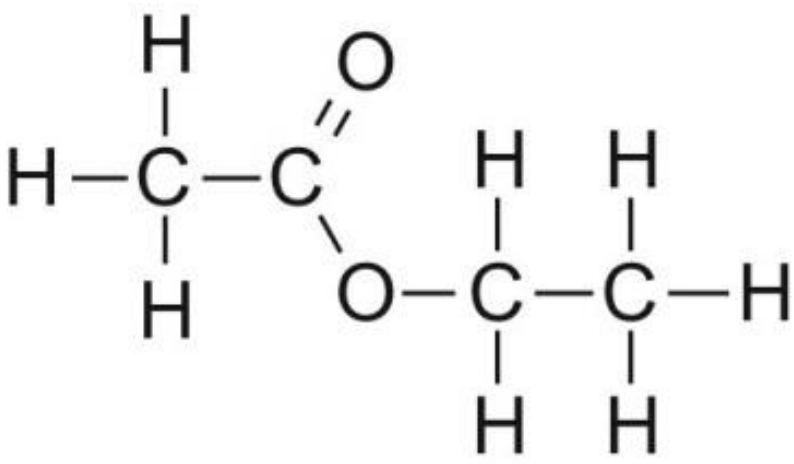
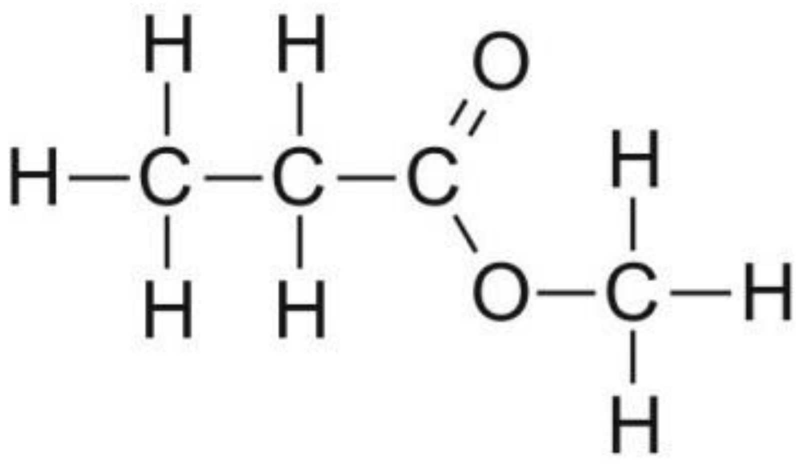
Homologous Series – Esters





- Ethyl Ethanoate
- Methyl Propanoate

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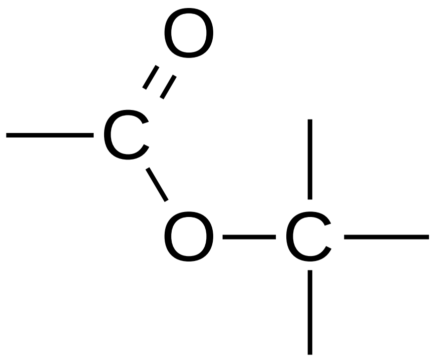
Homologous Series – Esters

Functional Group



General Formula $C_nH_{2n}O_2$

Name -yl -anoate

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What are the names and formulae of the *first 10 straight chain alkanes*?

Organic Chemistry

Naming Straight Chain Alkanes

- The alkanes are *saturated hydrocarbons* with the general formula C_nH_{2n+2}.

- *Saturated* means that the bonds between the carbon atoms are all *single covalent bonds*, there are no double or triple covalent bonds.

- *Hydrocarbon* means that the alkanes are composed only of the two elements *hydrogen* and *carbon*.

- General formula of C_nH_{2n+2}. For example, if n = 2, then $(2 \times 2) + 2 = 6$, so the formula of the alkane that contains two carbon atoms will be C_2H_6.

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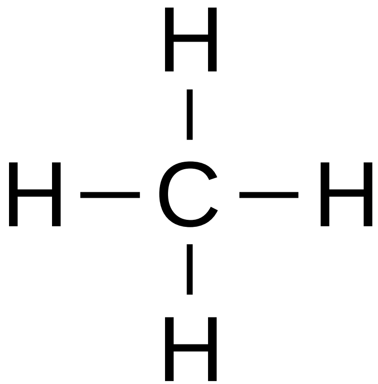
Naming Straight Chain Alkanes

Methane



CH_4

Melting Point = −182.5°C

Boiling Point = −161.6°C

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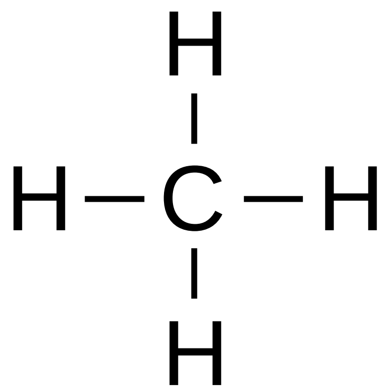
Naming Straight Chain Alkanes

Methane

Prefix:
Denotes the number of carbon atoms in the molecule.



Suffix:
Denotes the homologous series that the compound belongs to.

CH_4

Melting Point = −182.5°C
Boiling Point = −161.6°C

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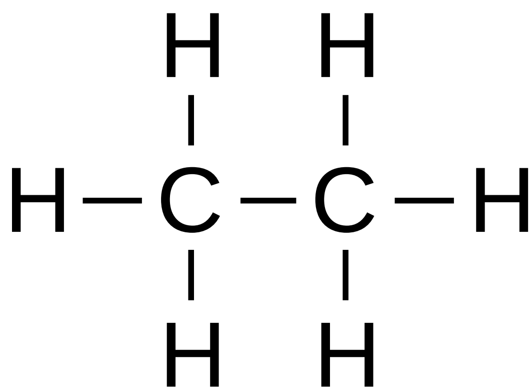
Naming Straight Chain Alkanes

Ethane



C_2H_6

Melting Point = −181.8°C

Boiling Point = −89.0°C

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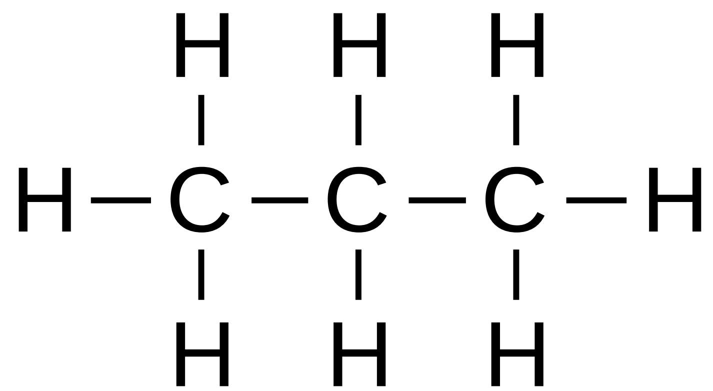
Naming Straight Chain Alkanes

Propane



C_3H_8

Melting Point = −187.7°C

Boiling Point = −42.1°C

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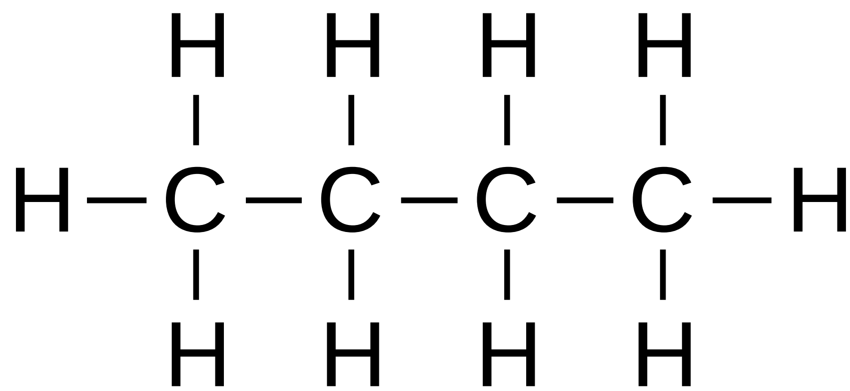
Naming Straight Chain Alkanes

Butane



$$C_4H_{10}$$

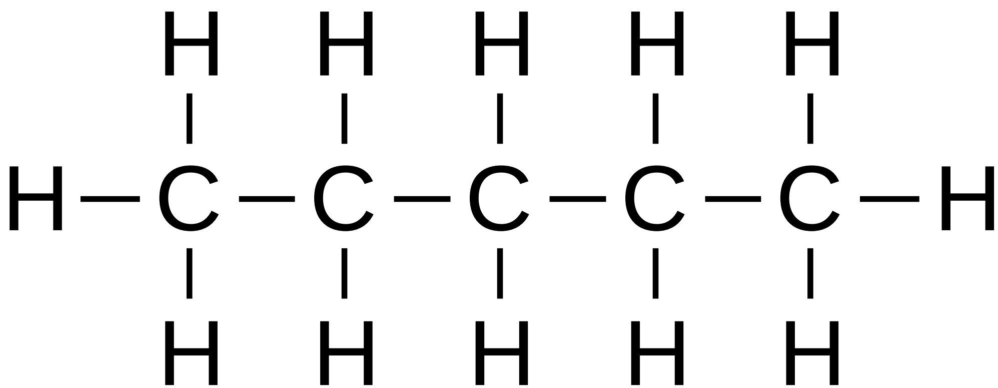
Melting Point = −138.4°C

Boiling Point = −0.5°C

Organic Chemistry

Naming Straight Chain Alkanes

Pentane



$$C_5H_{12}$$

Melting Point = −129.8°C

Boiling Point = 36.1°C

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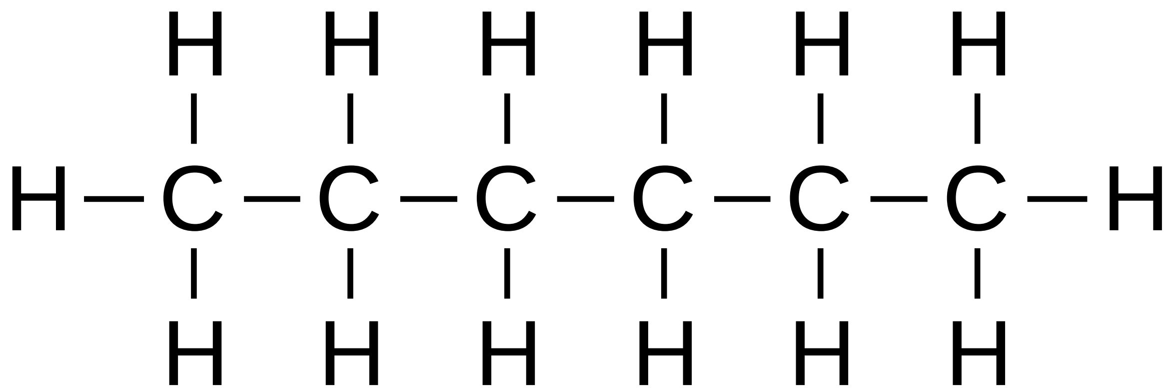
Naming Straight Chain Alkanes

Hexane



$$C_6H_{14}$$

Melting Point = −95.3°C

Boiling Point = 68.7°C

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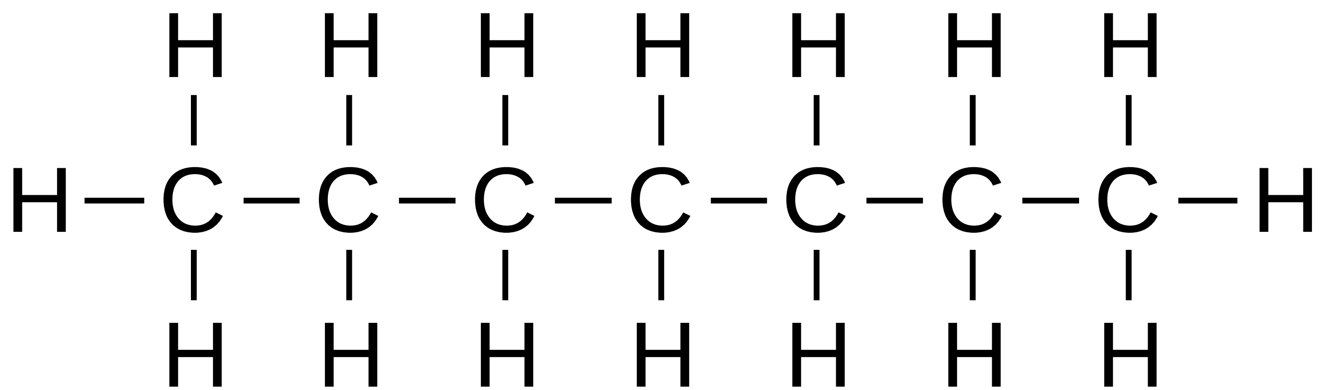
Naming Straight Chain Alkanes

Heptane



$$C_7H_{16}$$

Melting Point = −90.6°C

Boiling Point = 98.4°C

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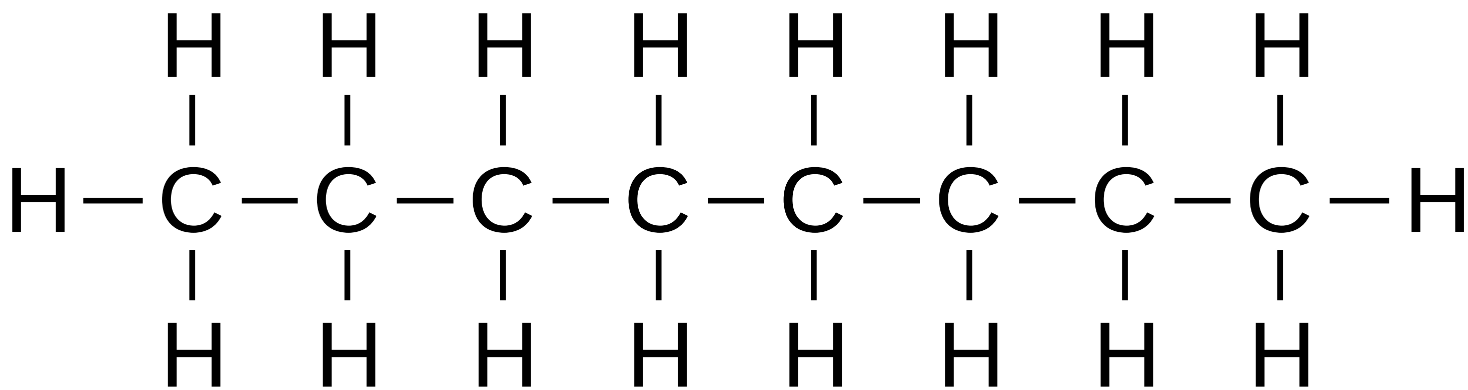
Naming Straight Chain Alkanes

Octane



$$C_8H_{18}$$

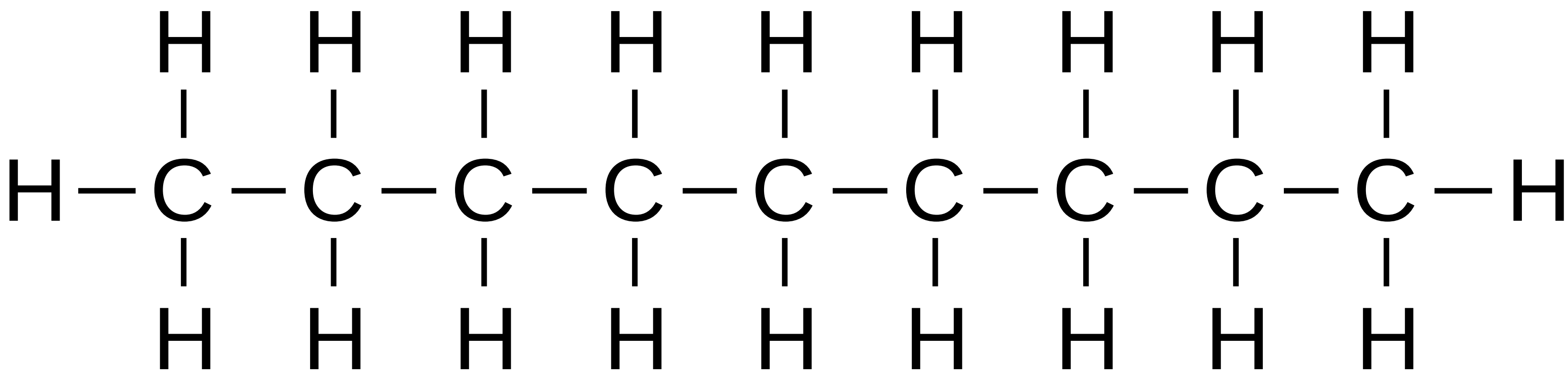
Melting Point = −57.0°C

Boiling Point = 125.5°C

Organic Chemistry

Naming Straight Chain Alkanes

Nonane



C_9H_{20}

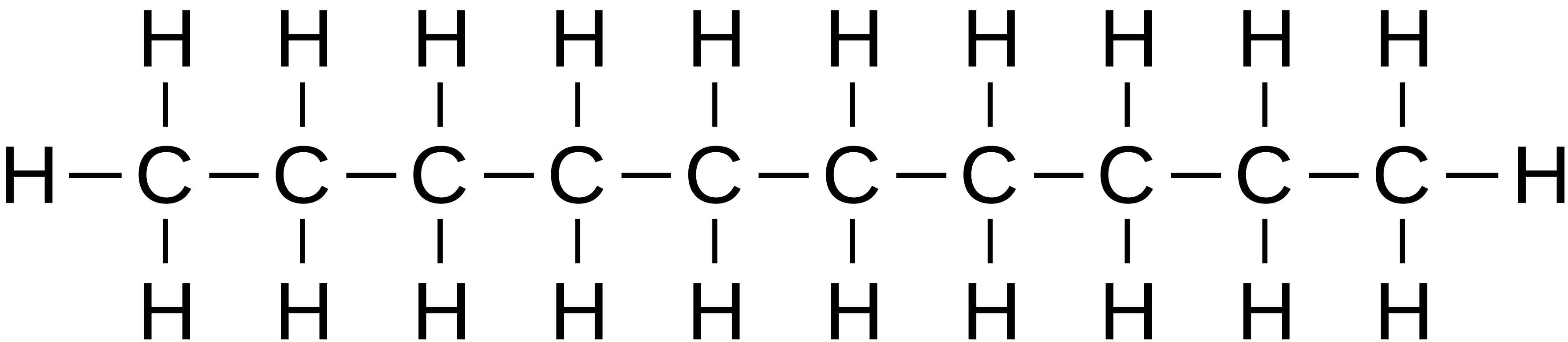
Melting Point = −53.0°C

Boiling Point = 151.0°C

Organic Chemistry

Naming Straight Chain Alkanes

Decane



$$C_{10}H_{22}$$

Melting Point = −27.9°C

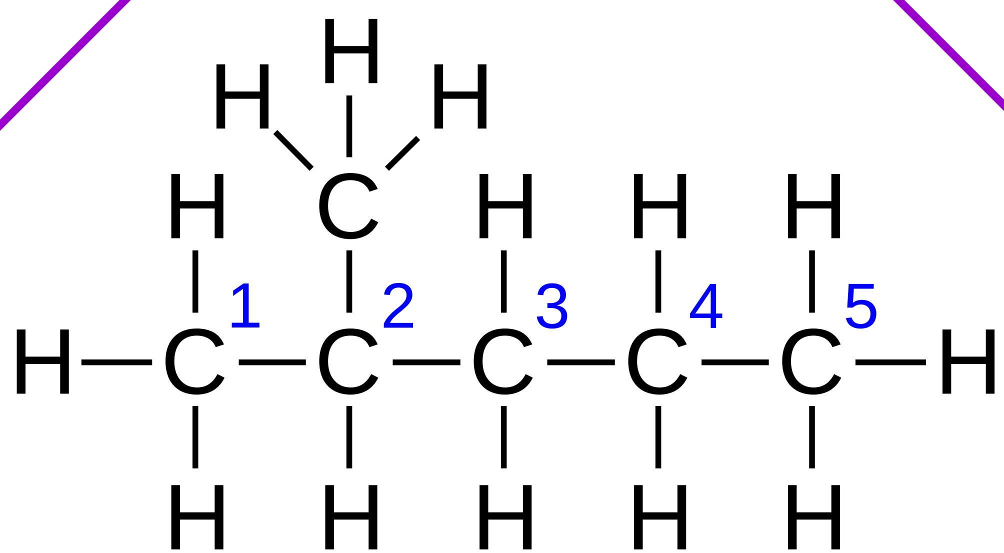
Boiling Point = 174.1°C

Organic Chemistry

Naming Branched Chain Alkanes

2-Methylpentane

Methyl group ($–CH_3$) bonded to carbon Nº. 2 of the longest carbon chain.



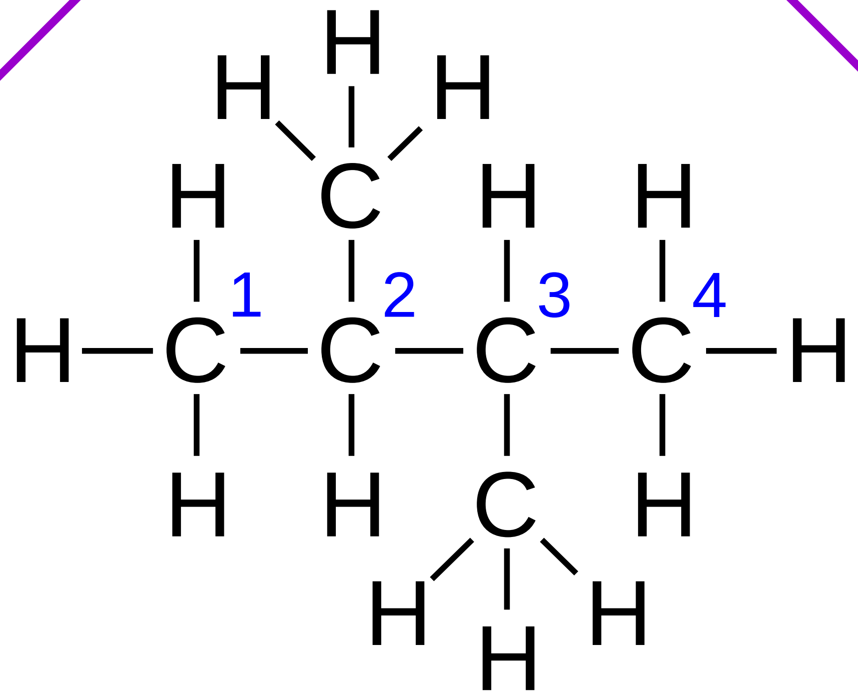
Indicates the longest carbon chain. Five carbon atoms = pentane.

Organic Chemistry

Naming Branched Chain Alkanes

2,3-Dimethylbutane

Two methyl groups ($–CH_3$), one bonded to carbon Nº. 2, and one bonded to carbon Nº. 3 of the longest carbon chain.



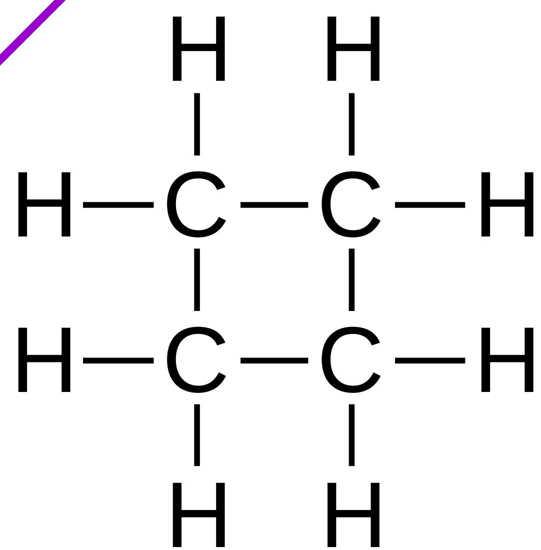
Indicates the longest carbon chain. Four carbon atoms = butane.

Organic Chemistry

Naming Cyclic Alkanes

Cyclobutane

The prefix *cyclo*– indicates that the carbon atoms are arranged in a *ring*.



Indicates the longest carbon chain. Four carbon atoms = butane.

Organic Chemistry

Naming Straight Chain Alkanes

Name	Formula	Relative Molecular Mass	m.p. / °C	b.p. / °C
Methane	CH_4	16	–182.5	–161.6
Ethane	C_2H_6	30	–181.8	–89.0
Propane	C_3H_8	44	–187.7	–42.1
Butane	C_4H_{10}	58	–138.4	–0.5
Pentane	C_5H_{12}	72	–129.8	36.1
Hexane	C_6H_{14}	86	–95.3	68.7
Heptane	C_7H_{16}	100	–90.6	98.4
Octane	C_8H_{18}	114	–57.0	125.5
Nonane	C_9H_{20}	128	–53.0	151.0
Decane	$C_{10}H_{22}$	142	–27.9	174.1

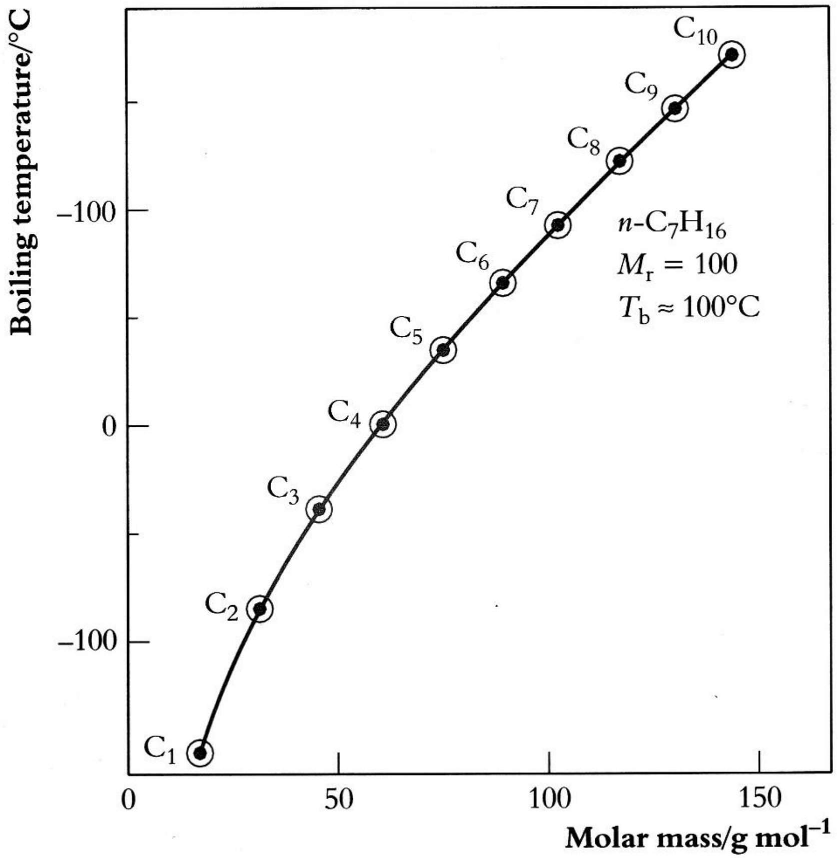
Organic Chemistry

Naming Straight Chain Alkanes

- The melting points and boiling points of the alkanes increases as the *length of the carbon chain* increases.
- The melting points and boiling points of the alkanes increases as *relative molecular mass* increases.
- A complex mixture of alkanes can be separated by *fractional distillation*.
- On an industrial scale, the complex mixture of alkanes in crude oil is separated by fractional distillation in an *oil refinery*.

Organic Chemistry

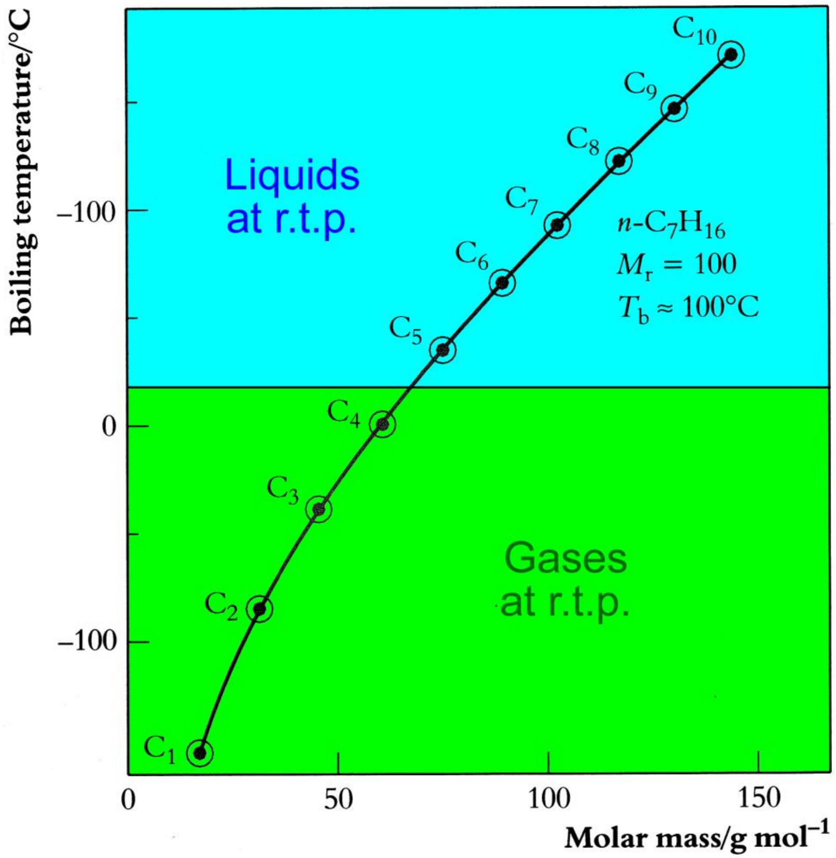
Naming Straight Chain Alkanes



- The melting points and boiling points of the alkanes increases as relative molecular mass increases. This is because the *surface area* of the molecules *increases*, hence *intermolecular forces of attraction* (Van der Waals forces) become *stronger*. More energy is required to weaken the force of attraction between the molecules.

Organic Chemistry

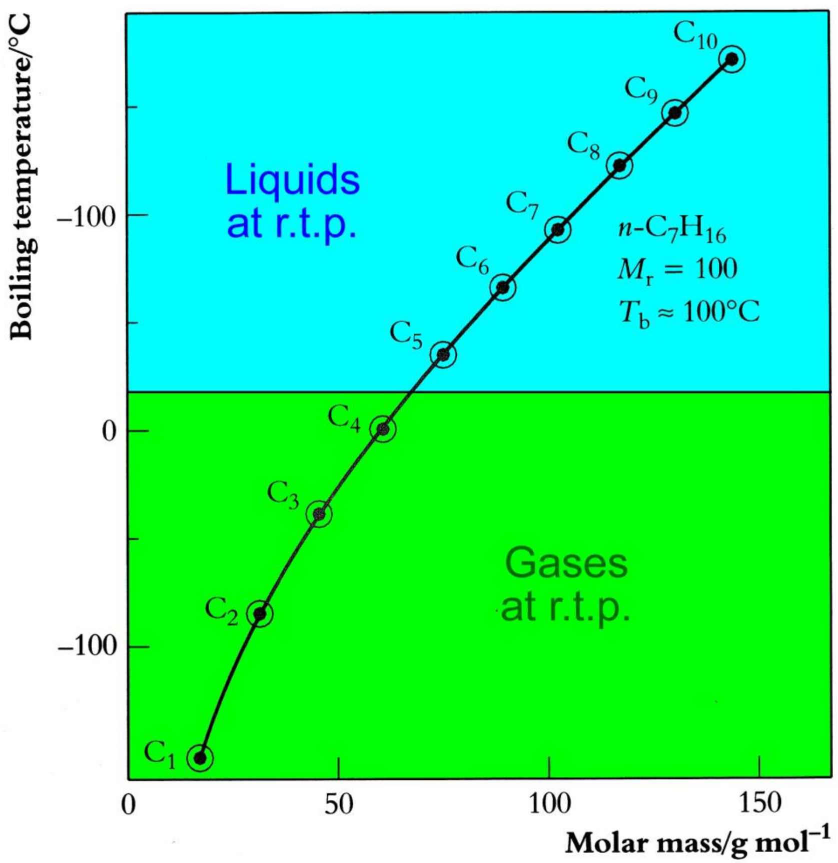
Naming Straight Chain Alkanes



- The melting points and boiling points of the alkanes increases as relative molecular mass increases. This is because the *surface area* of the molecules *increases*, hence *intermolecular forces of attraction* (Van der Waals forces) become *stronger*. More energy is required to weaken the force of attraction between the molecules.

Organic Chemistry

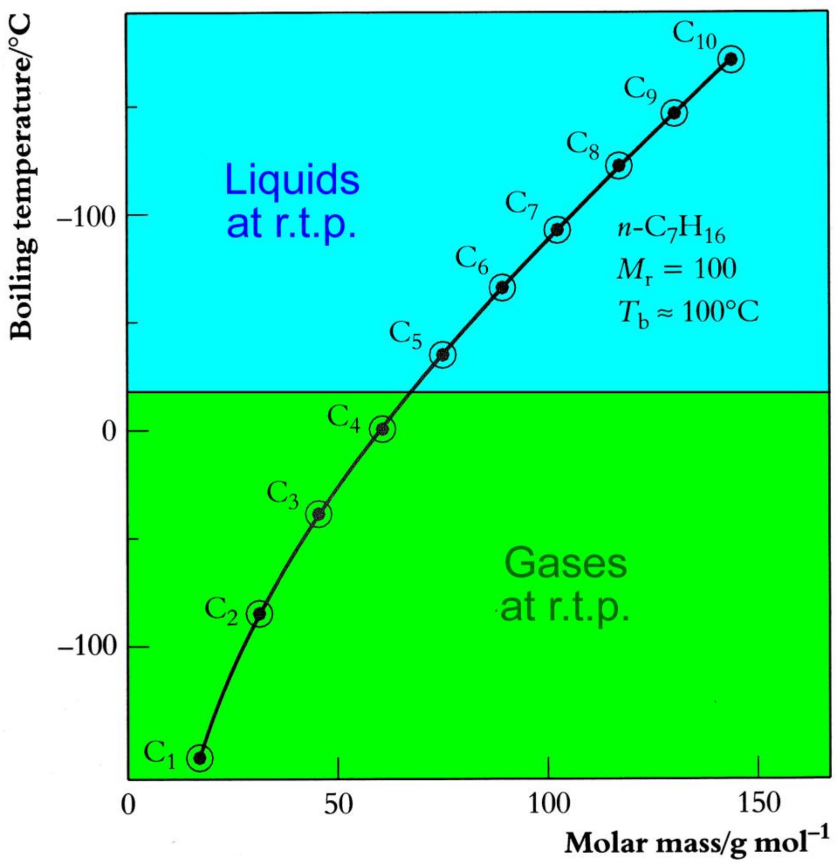
Naming Straight Chain Alkanes



- As relative molecular mass increases, the liquid alkanes become *more viscous*. This is because the length of the hydrocarbon chain increases and hence their *surface area increases*. Consequently, *intermolecular forces* of attraction (Van der Waals forces) become *stronger* and the molecules are unable to slip and slide over each other as easily.

Organic Chemistry

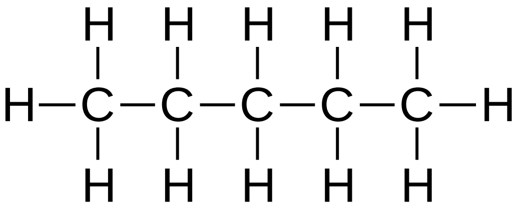
Naming Straight Chain Alkanes



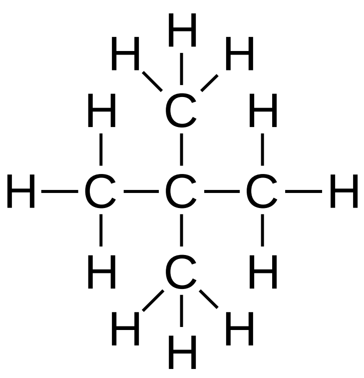
- As relative molecular mass increases, the alkanes become *less flammable*. As the surface area of the molecules increases, the intermolecular forces of attraction (Van der Waals forces) also increase and the alkanes become *less volatile*. Alkanes burn when gaseous. The less likely an alkane is to be gaseous, the less likely it is to ignite and burn.

Organic Chemistry

Naming Straight Chain Alkanes



pentane



2,2-dimethylpropane
(or just dimethylpropane)

- Pentane and 2,2-dimethylpropane are *isomers*, *i.e.* they share the same molecular formula (C_5H_{12}), but have different structural formulae. Pentane boils at *31.6 ℃*, while 2,2-dimethylpropane boils at *9.50 ℃*. The difference in boiling points is due to the difference in their surface areas. The larger surface area of pentane results in stronger intermolecular forces of attraction (Van der Waals forces) between the molecules, which require more energy to overcome, hence increasing the boiling point.

Organic Chemistry

How do I name the *alkenes*, *halogenoalkanes*, *alcohols* and *carboxylic acids*?

Organic Chemistry

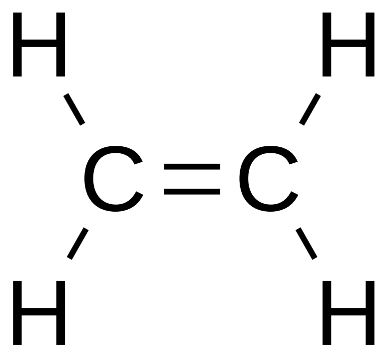
Naming Alkenes

- The alkenes are *unsaturated hydrocarbons* with the general formula C_nH_{2n}.
- *Unsaturated* means that the molecule contains at least one *carbon-to-carbon double covalent bond*.
- *Hydrocarbon* means that the alkenes are composed only of the two elements *hydrogen* and *carbon*.
- General formula of C_nH_{2n}. For example, if $n = 3$, then $2 \times 3 = 6$, so the formula of the alkene that contains three carbon atoms will be C_3H_6.

Organic Chemistry

Naming Alkenes

Ethene



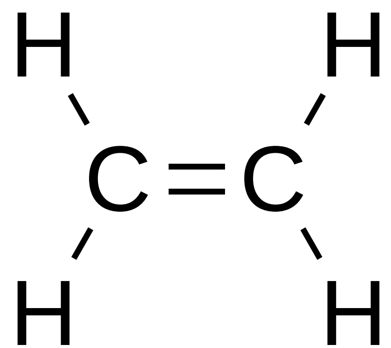
C_2H_4

Organic Chemistry

Naming Alkenes

Ethene

Prefix:
Denotes the number of carbon atoms in the molecule.



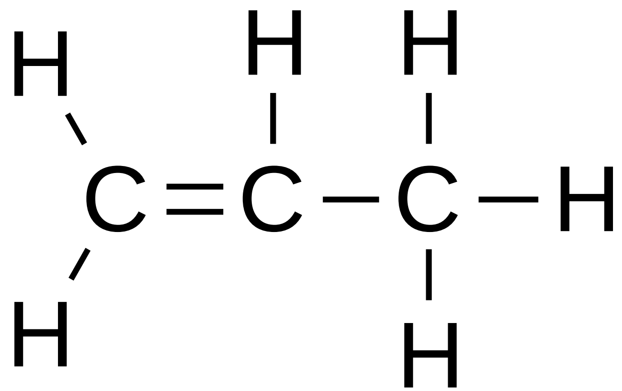
Suffix:
Denotes the homologous series that the compound belongs to.

C_2H_4

Organic Chemistry

Naming Alkenes

Propene

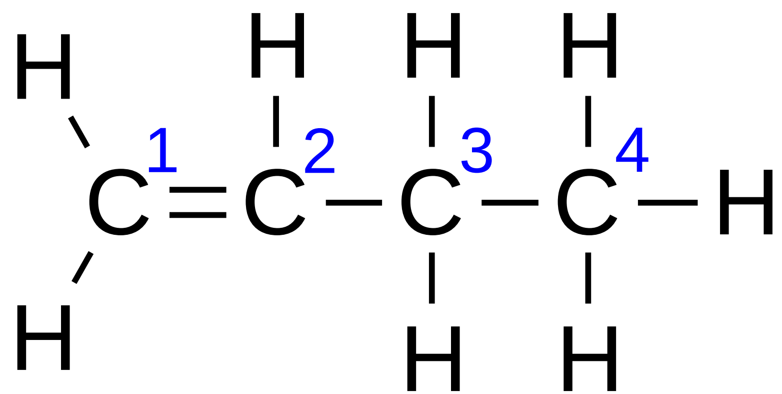


C_3H_6

Organic Chemistry

Naming Alkenes

But-1-ene

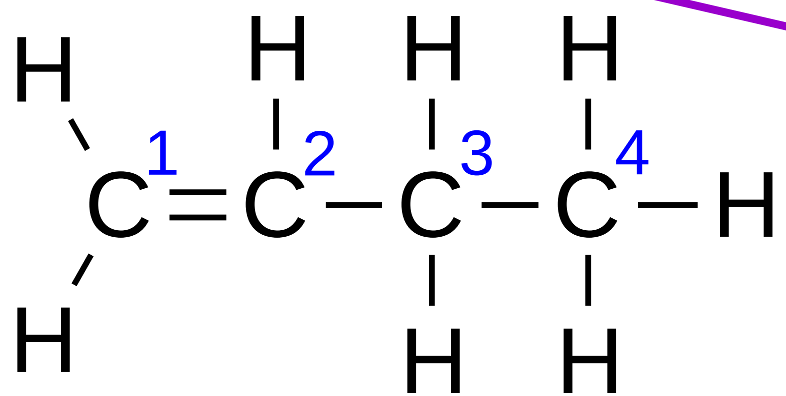


$$C_4H_8$$

Organic Chemistry

Naming Alkenes

But-1-ene



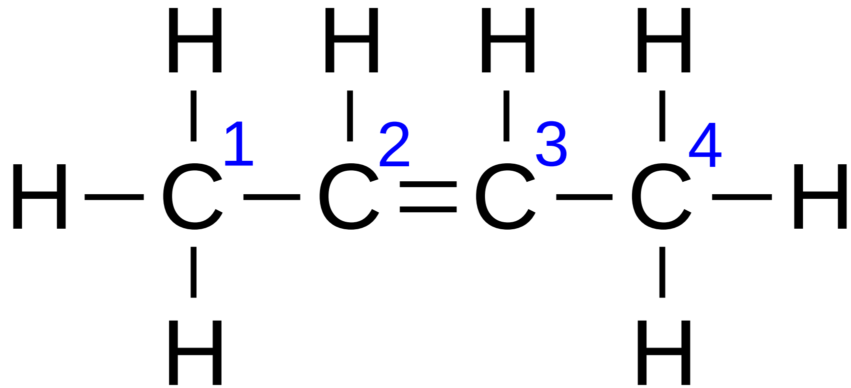
Number: Indicates the location of the C=C bond within the molecule.

C_4H_8

Organic Chemistry

Naming Alkenes

But-2-ene

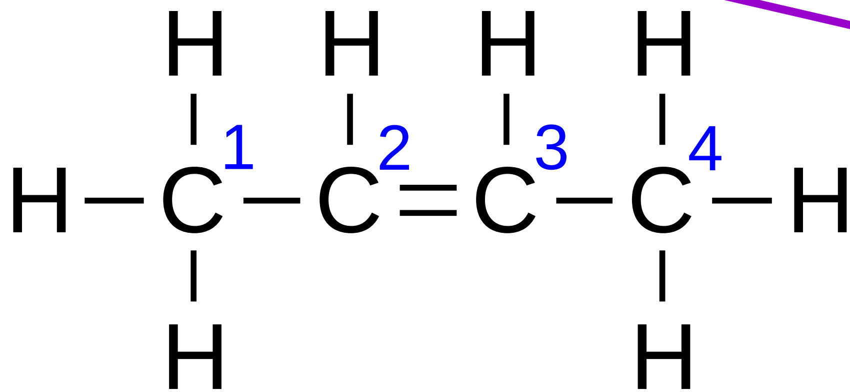


C_4H_8

Organic Chemistry

Naming Alkenes

But-2-ene



Number: Indicates the location of the C=C bond within the molecule.

C_4H_8

Organic Chemistry

Naming Halogenoalkanes

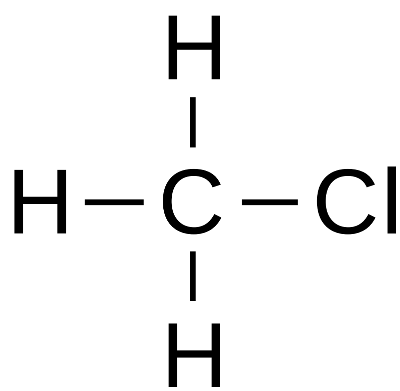
- The halogenoalkanes are alkanes in which at least one of the hydrogen atoms has been substituted by a *halogen* (*Group VII element*).

- The general formula of the halogenoalkanes is $C_nH_{2n+1}Hal$, where *Hal* is the symbol of a Group VII element (*i.e.* F, Cl, Br, I). For example, if n = 4, then $(2 \times 4) + 1 = 9$, so the formula of the halogenoalkane that contains four carbon atoms and chlorine will be C_4H_9Cl.

Organic Chemistry

Naming Halogenoalkanes

Chloromethane



$$CH_3Cl$$

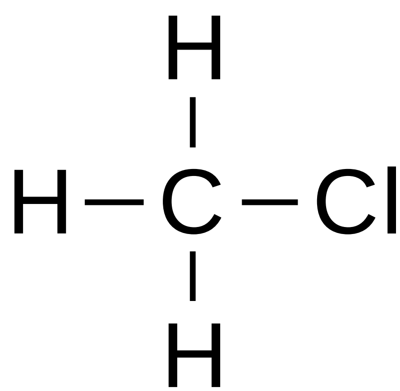
Organic Chemistry

Naming Halogenoalkanes

Chloromethane

Prefix:
Indicates the Group VII element that is present in the compound,

F = fluoro-
Cl = chloro-
Br = bromo-
I = Iodo-



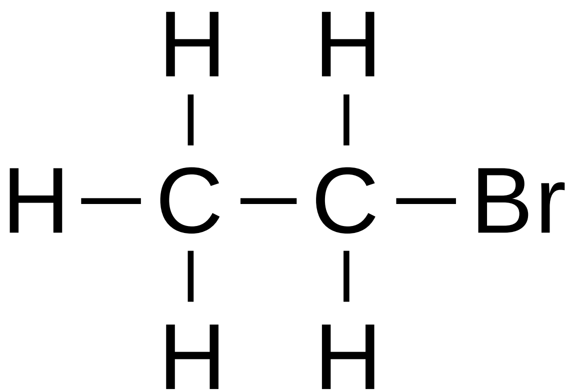
CH_3Cl

Suffix:
Denotes the number of carbon atoms in the molecule.

Organic Chemistry

Naming Halogenoalkanes

Bromoethane

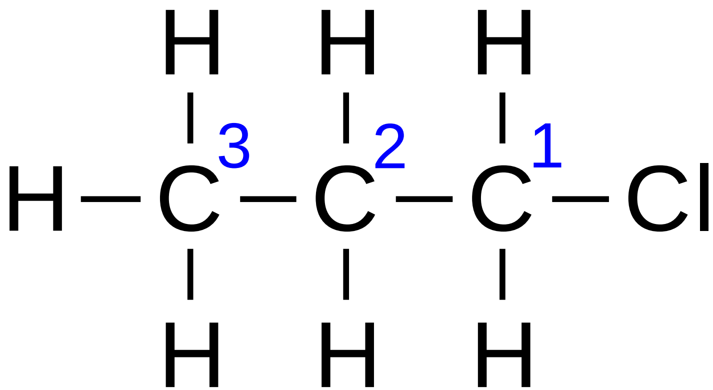


$$C_2H_5Br$$

Organic Chemistry

Naming Halogenoalkanes

1-Chloropropane

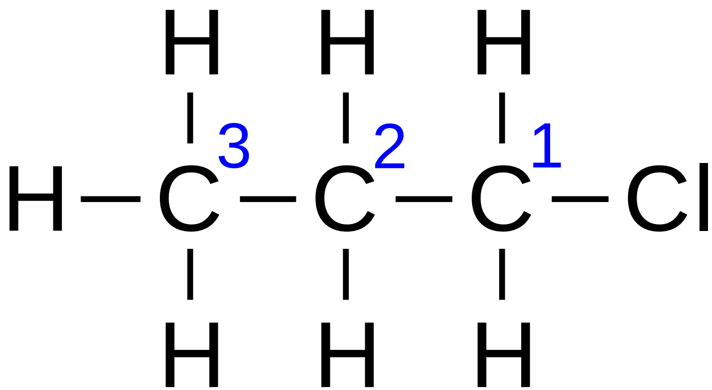


C_3H_7Cl

Organic Chemistry

Naming Halogenoalkanes

1-Chloropropane



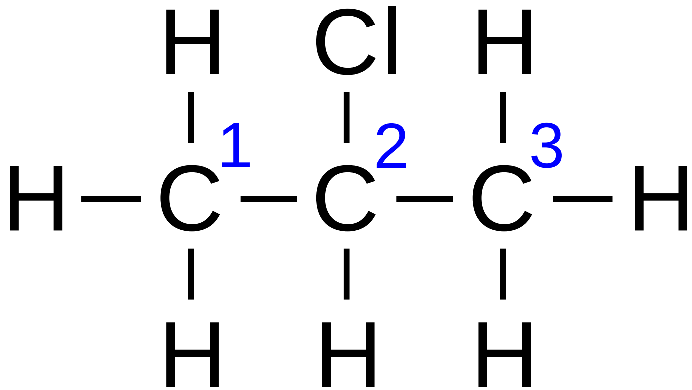
Number:
Indicates the location of the chlorine atom within the molecule.

C_3H_7Cl

Organic Chemistry

Naming Halogenoalkanes

2-Chloropropane

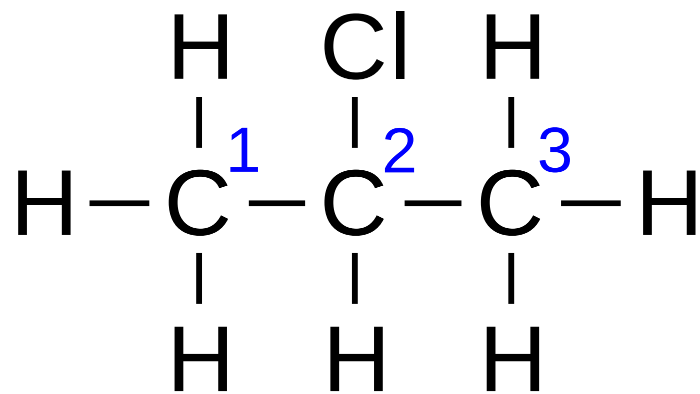


C_3H_7Cl

Organic Chemistry

Naming Halogenoalkanes

2-Chloropropane



Number: Indicates the location of the chlorine atom within the molecule.

C_3H_7Cl

Organic Chemistry

Naming Alcohols

- The alcohols are alkanes in which at least one of the hydrogen atoms has been substituted by a *hydroxyl group*, O–H.

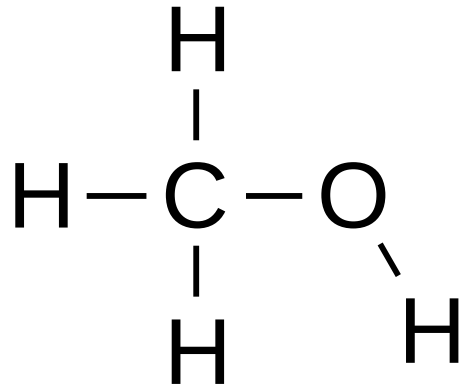
- The general formula of the alcohols is $C_nH_{2n+1}OH$. For example, if n = 5, then $(2 \times 5) + 1 = 11$, so the formula of the alcohol that contains five carbon atoms will be $C_5H_{11}OH$.

Organic Chemistry

Naming Alcohols

Methanol

Prefix:
Denotes the number of carbon atoms in the molecule.



Suffix:
Denotes the homologous series that the compound belongs to.

CH_3OH

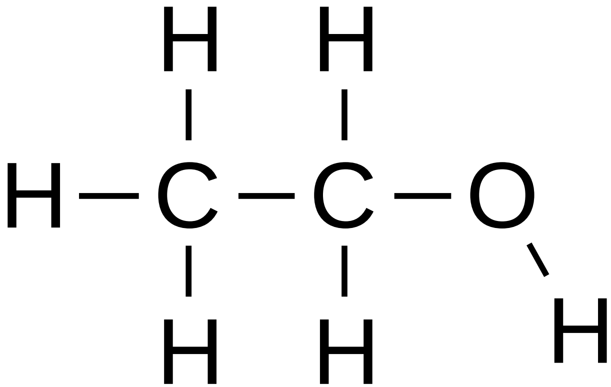
Melting Point = –97.6 °C

Boiling Point = 64.7 °C

Organic Chemistry

Naming Alcohols

Ethanol



C_2H_5OH

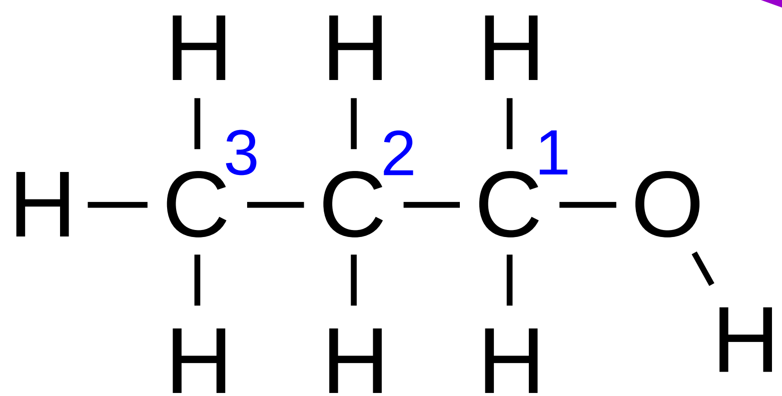
Melting Point = –114 °C

Boiling Point = 78.2 °C

Organic Chemistry

Naming Alcohols

Propan-1-ol



Number: Indicates the location of the O–H group within the molecule.

C_3H_7OH

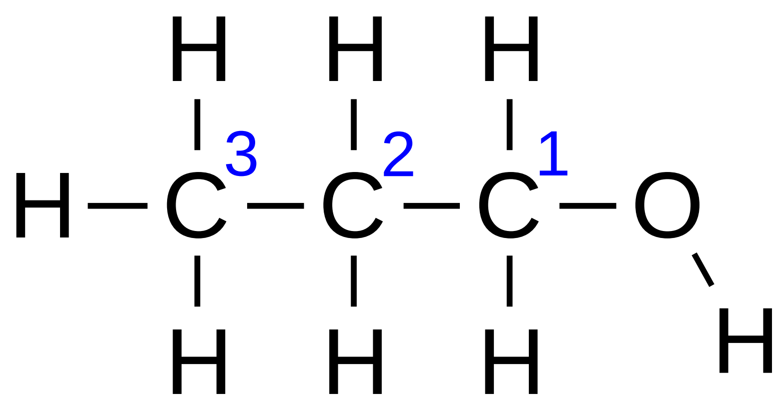
Melting Point = –126 °C

Boiling Point = 97.5 °C

Organic Chemistry

Naming Alcohols

Propan-1-ol

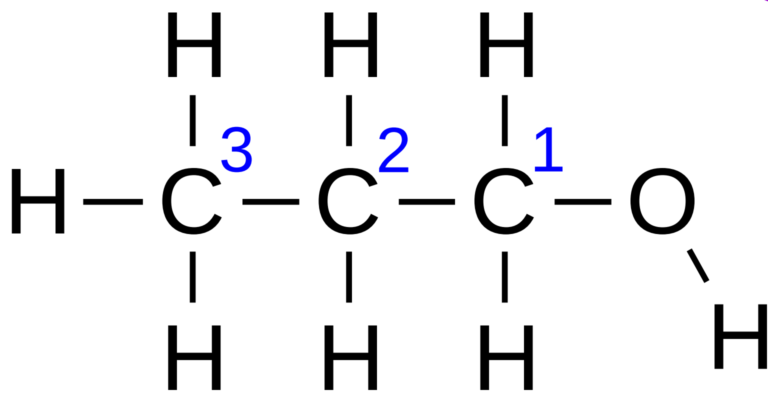


$$C_3H_7OH$$

Organic Chemistry

Naming Alcohols

Propan-1-ol



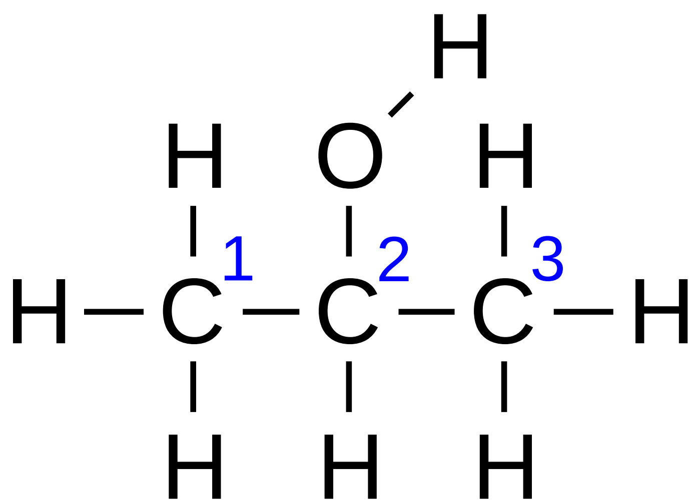
Number: Indicates the location of the O–H group within the molecule.

$$C_3H_7OH$$

Organic Chemistry

Naming Alcohols

Propan-2-ol

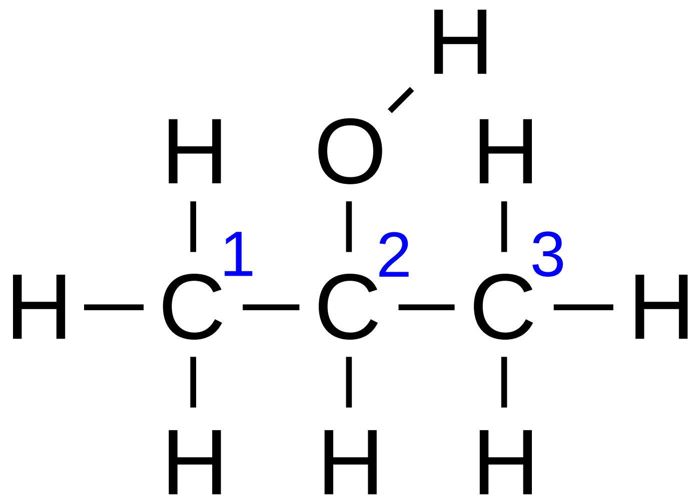


C_3H_7OH

Organic Chemistry

Naming Alcohols

Propan-2-ol



Number:
Indicates the location of the O–H group within the molecule.

C_3H_7OH

Organic Chemistry

Naming Carboxylic Acids

- The general formula of the carboxylic acids is $C_nH_{2n}O_2$. For example, if n = 6, then 2 × 6 = 12, so the formula of the carboxylic acid that contains six carbon atoms will be $C_6H_{12}O_2$.

Note: The carboxylic acid functional group is COOH (*carboxyl*). This is normally written separately in the formula, so $C_6H_{12}O_2$ is re-written as $C_5H_{11}COOH$.

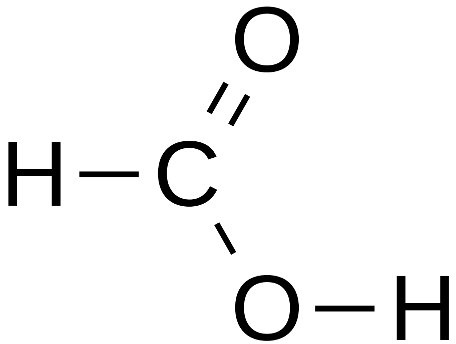
- Remember, the carboxylic acids are *weak acids*, *i.e.* they only partially ionise when dissolved in water.

$$CH_3COOH \rightleftharpoons CH_3COO^- + H^+$$

Organic Chemistry

Naming Carboxylic Acids

Methanoic Acid



CHOOH

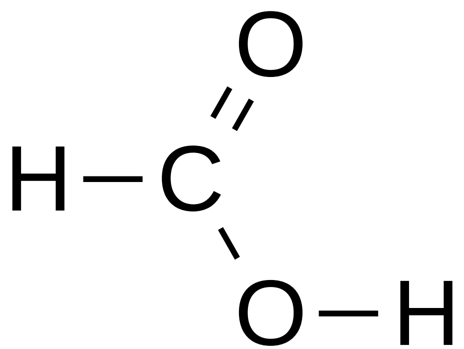
By default, the **C** of **C**OOH is always N^{o}. 1.

Organic Chemistry

Naming Carboxylic Acids

Methanoic Acid

Prefix:
Denotes the number of carbon atoms in the molecule.



Suffix:
Denotes the homologous series that the compound belongs to.

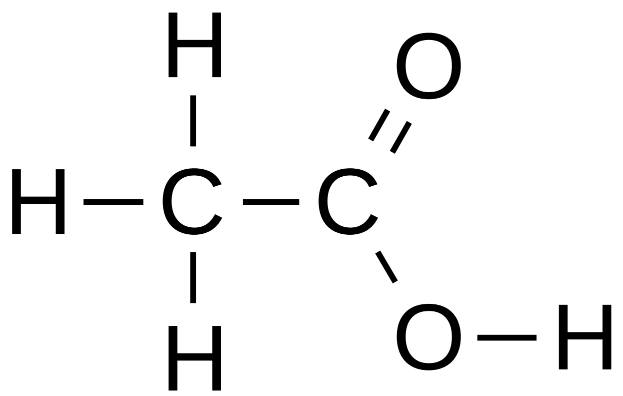
CHOOH

By default, the **C** of **C**OOH is always Nº. 1.

Organic Chemistry

Naming Carboxylic Acids

Ethanoic Acid



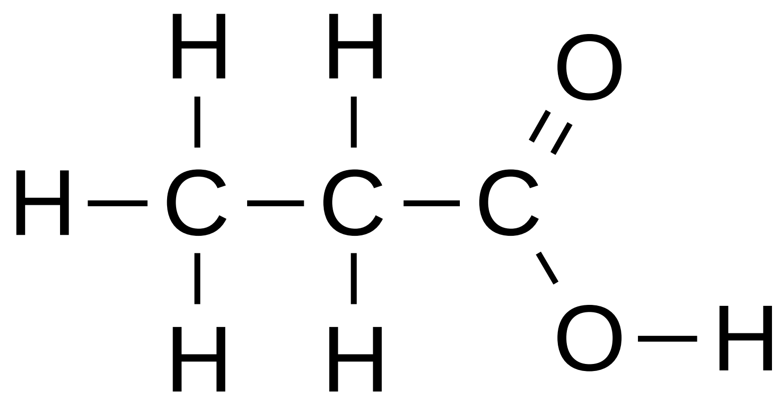
CH_3COOH

By default, the **C** of **C**OOH is always Nº. 1.

Organic Chemistry

Naming Carboxylic Acids

Propanoic Acid



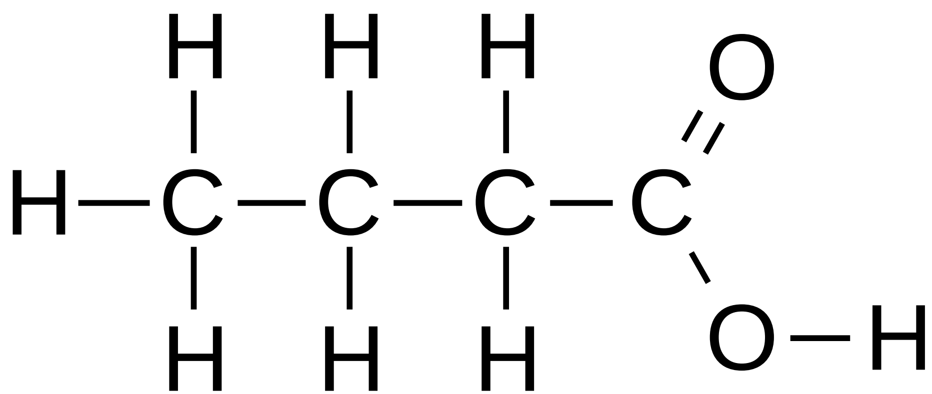
$$C_2H_5COOH$$

By default, the **C** of **C**OOH is always N^{o}. 1.

Organic Chemistry

Naming Carboxylic Acids

Butanoic Acid



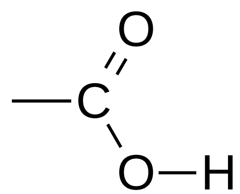
C_3H_7COOH

By default, the **C** of **C**OOH is always Nº. 1.

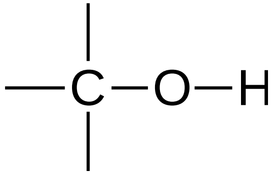
Organic Chemistry

Hierarchy of Functional Groups in Naming Compounds

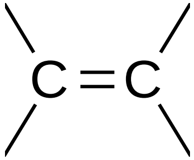
- Higher Priority



- Carboxylic Acid

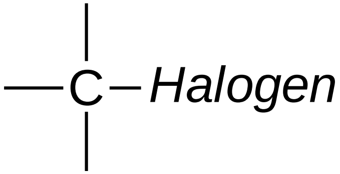


- Alcohol



- Alkene

- Lower Priority



- Halogenoalkane

- Higher priority groups have lower numbers assigned to them when naming.

Organic Chemistry

Hierarchy of Functional Groups in Naming Compounds

$CHCl_2–CH_2–CH_2–CH_2OH$

4,4-dichlorobutan-1-ol *not* 1,1-dichlorobutan-4-ol

- The hydroxyl group of the alcohol is given the priority of having the lower number.

$CHCl_2–CH_2–CH=CH_2$

4,4-dichlorobut-1-ene *not* 1,1-dichlorobut-3-ene

- The carbon-to-carbon double covalent bond of the alkene is given the priority of having the lower number.

Organic Chemistry

Hierarchy of Functional Groups in Naming Compounds

$CH_2Cl–CHCl–CH_2–COOH$

3,4-dichlorobutanoic acid *not* 1,2-dichlorobutan-4-oic acid

- The carbon of the carboxylic acid group (carboxyl group) is given the priority of having the lower number.

$CH_2=CH–CH_2–CH_2–COOH$

pent-4-enoic acid *not* pent-1-en-5-oic acid

- The carbon of the carboxylic acid group (carboxyl group) is given the priority of having the lower number.

Organic Chemistry

What is the *origin* of the organic compounds that are used by chemists?

Organic Chemistry

Organic Chemistry

Origin of Crude Oil (Petroleum)

- Millions of years ago, tiny sea creatures and plants sank to the seabed when they died. The dead sea creatures and plants were slowly covered by mud and sand.

- Heat from the Earth and pressure from the mud and sand acted on these organisms over millions of years, eventually producing *crude oil* (*petroleum*) and *natural gas*.

- Petroleum and natural gas are often found in underground deposits hundreds, or thousands, of metres below the surface of the Earth. Deep wells have to be drilled to extract them.

Organic Chemistry

Origin of Crude Oil (Petroleum)

Organic Chemistry

Origin of Crude Oil (Petroleum)

- Crude oil (petroleum) is a very *complex mixture* of organic compounds.

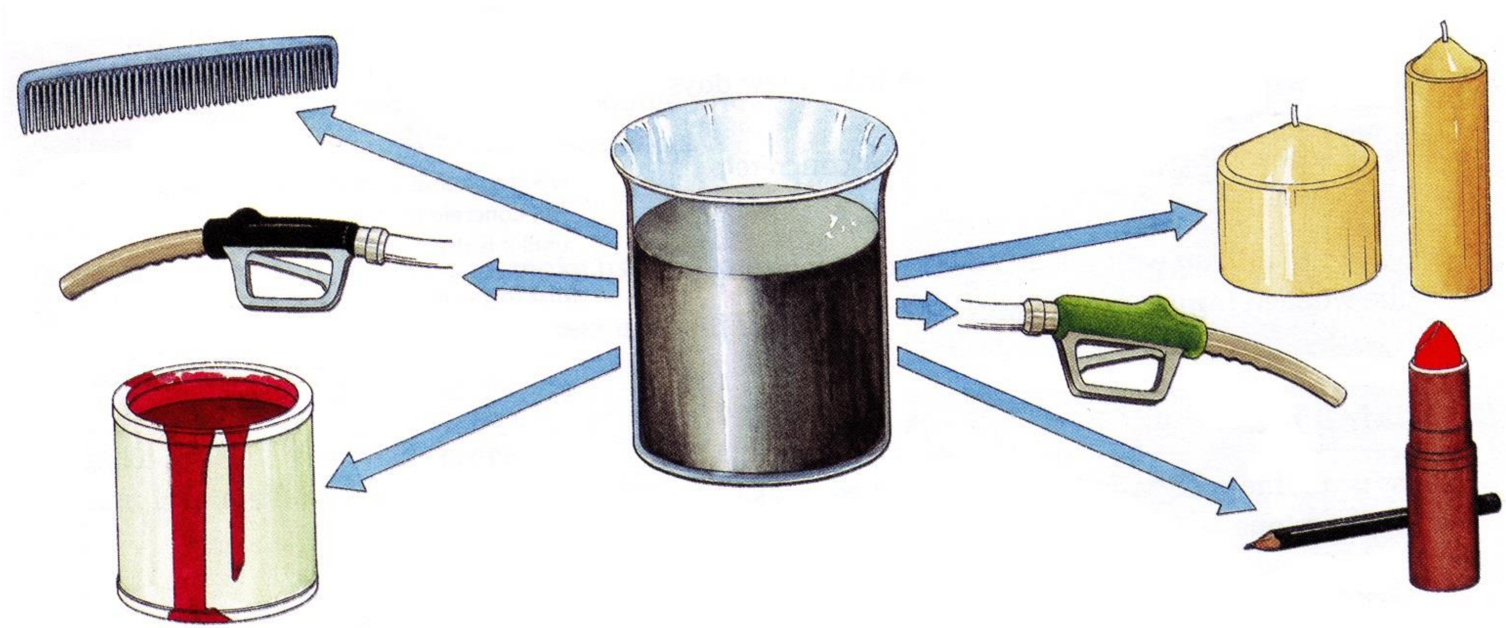
- Crude oil is a dark brown, toxic, foul smelling and viscous liquid.

- Crude oil can be separated into useful fractions by *fractional distillation*.

- Each crude oil fraction is a mixture of hydrocarbons that boils over a certain temperature.
  $\rightarrow$ Lighter fractions consist of smaller hydrocarbons.
  $\rightarrow$ Heavier fractions consist of larger hydrocarbons.

Organic Chemistry

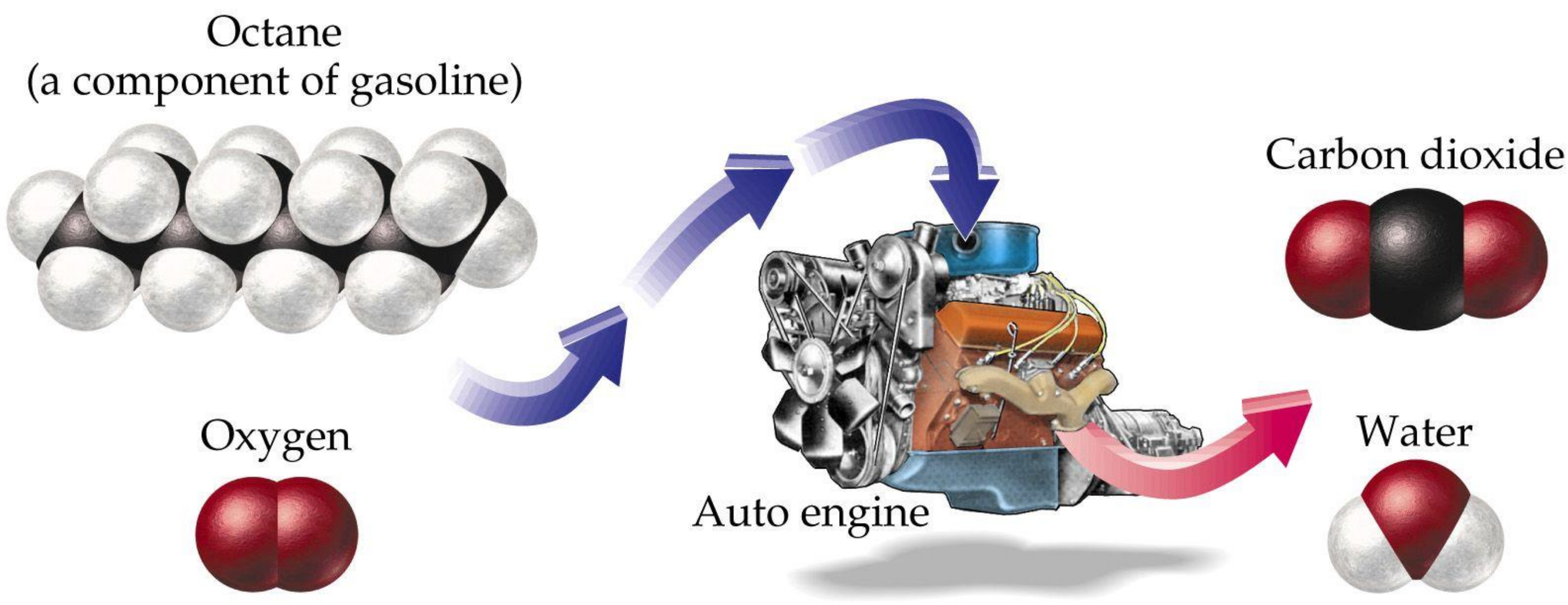
Fractional Distillation of Crude Oil (Petroleum)



- Diagram to illustrate some uses of the different fractions that are separated from crude oil.

Organic Chemistry

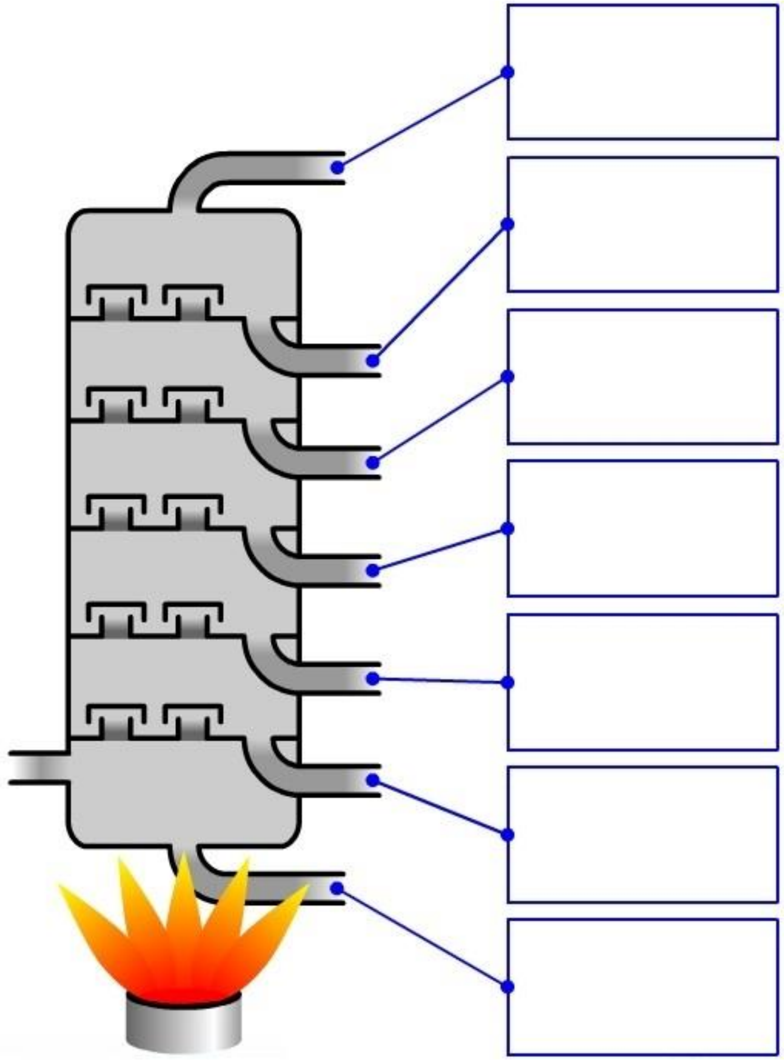
Fractional Distillation of Crude Oil (Petroleum)



- Petrol – C_5H_{12} to $C_{10}H_{22}$ – is an important fraction that is separated from crude oil by *fractional distillation*.

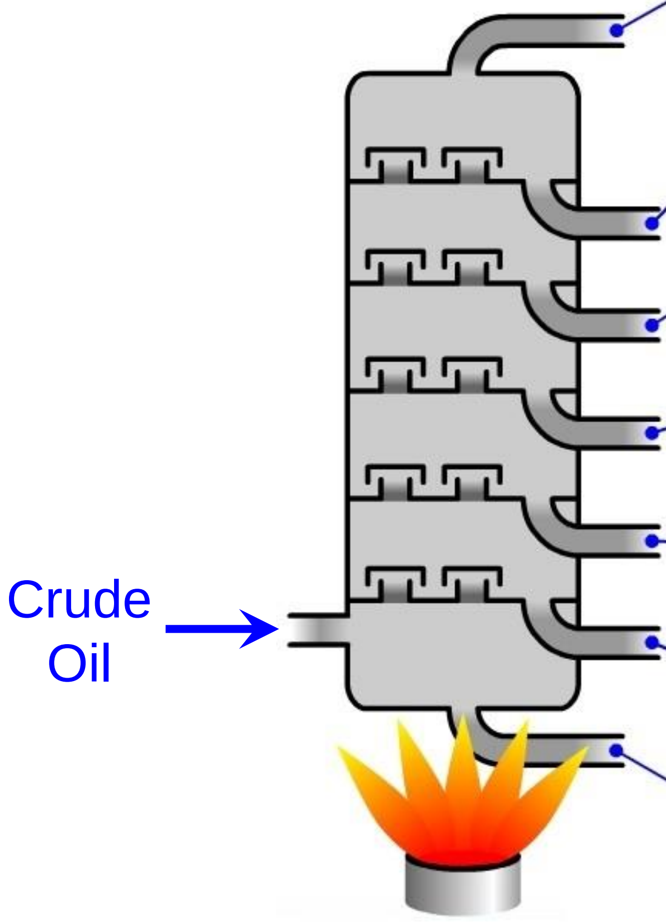
Organic Chemistry

Fractional Distillation of Crude Oil (Petroleum)



Organic Chemistry

Fractional Distillation of Crude Oil (Petroleum)



Petroleum Gas	$C_1 – C_4$	b.p. = < 40 °C
Petrol	$C_5 – C_{10}$	b.p. = 40 – 75 °C
Naphtha	$C_7 – C_{14}$	b.p. = 90 – 150 °C
Paraffin (Kerosene)	$C_9 – C_{16}$	b.p. = 150 – 240 °C
Diesel Oil	$C_{15} – C_{25}$	b.p. = 220 – 250 °C
Lubricating Oil	$C_{20} – C_{35}$	b.p. = 300 – 350 °C
Bitumen	$> C_{70}$	b.p. = > 350 °C

Organic Chemistry

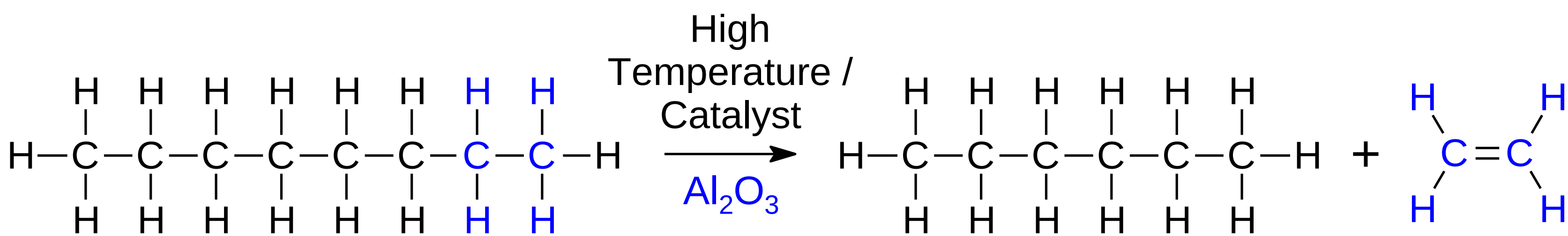
Fractional Distillation of Crude Oil (Petroleum)

Name of Fraction	Number of Carbon Atoms	Boiling Point / °C	Use of Fraction
Petroleum Gas	$C_1 – C_4$	< 40	Fuel for cooking and heating.
Petrol	$C_5 – C_{10}$	40 – 75	Fuel for motorcars.
Naphtha	$C_7 – C_{14}$	90 – 150	Feedstock for the chemical industry.
Paraffin (Kerosene)	$C_9 – C_{16}$	150 – 240	Fuel for aircraft, cooking and heating.
Diesel Oil	$C_{15} – C_{25}$	220 – 250	Fuel for buses, lorries and trains.
Lubricating Oil	$C_{20} – C_{35}$	300 – 350	For lubricating machines.
Bitumen	$> C_{70}$	> 350	For making road surfaces and roofing.

Organic Chemistry

Fractional Distillation of Crude Oil (Petroleum)

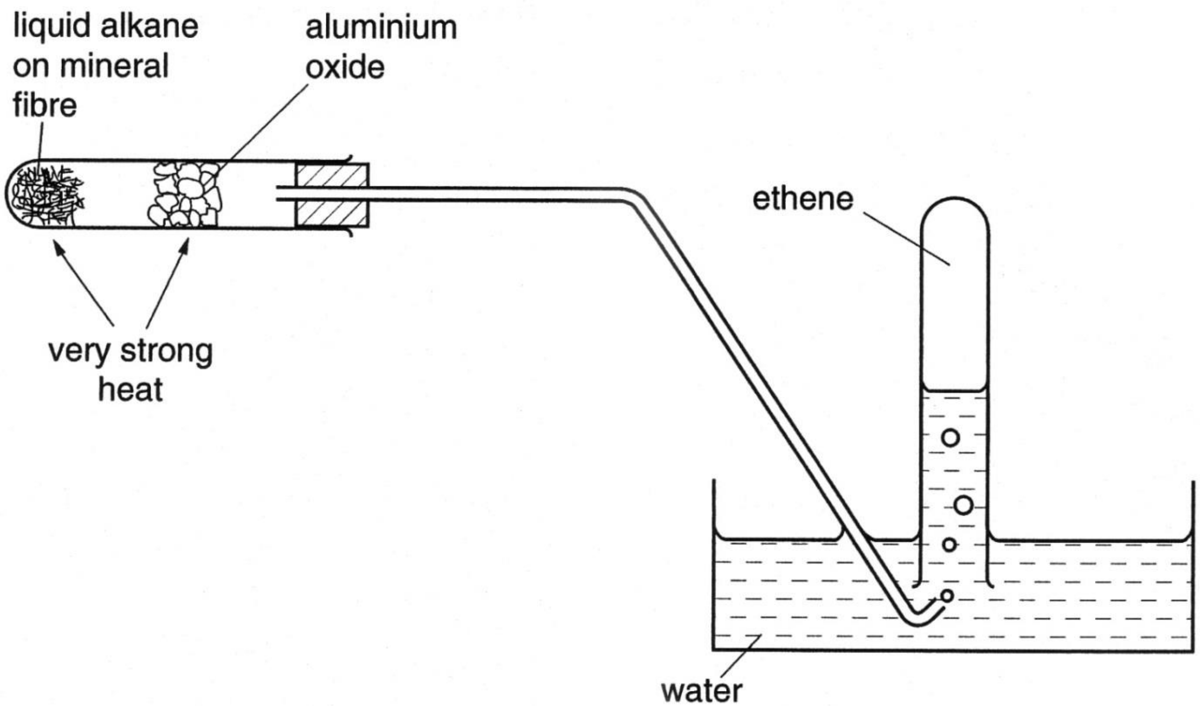
The catalytic cracking of long-chain alkanes produces short-chain alkanes and alkenes as reaction products. Short-chain alkanes tend to be more useful than long-chain alkanes, and alkenes can be used in organic synthesis.



Octane Hexane Ethene

Organic Chemistry

Fractional Distillation of Crude Oil (Petroleum)



- An experiment to *crack* a long-chain hydrocarbon in the lab. Note that the insoluble ethene gas is collected by the *downward displacement of water*.

Organic Chemistry

Fractional Distillation of Crude Oil (Petroleum)

Organic Chemistry

Fractional Distillation of Crude Oil (Petroleum)

- Accidents during the transport of crude oil can lead to environmental disasters.
- The non-polar hydrocarbon molecules in crude oil are immiscible with the polar solvent water.
- Crude oil is less dense than water.
- The crude oil coats plants and animals with a thick, viscous layer of toxic chemicals which will eventually kill them if not removed.

Organic Chemistry

Fractional Distillation of Crude Oil (Petroleum)

Organic Chemistry

Fractional Distillation of Crude Oil (Petroleum)

- Crude oil, coal and natural gas are *fossil fuels*. They are *non-renewable* sources of energy, and will eventually run out.
- It is important to develop alternative sources of *clean* and *renewable energy*.

Organic Chemistry

Fractional Distillation of Crude Oil (Petroleum)

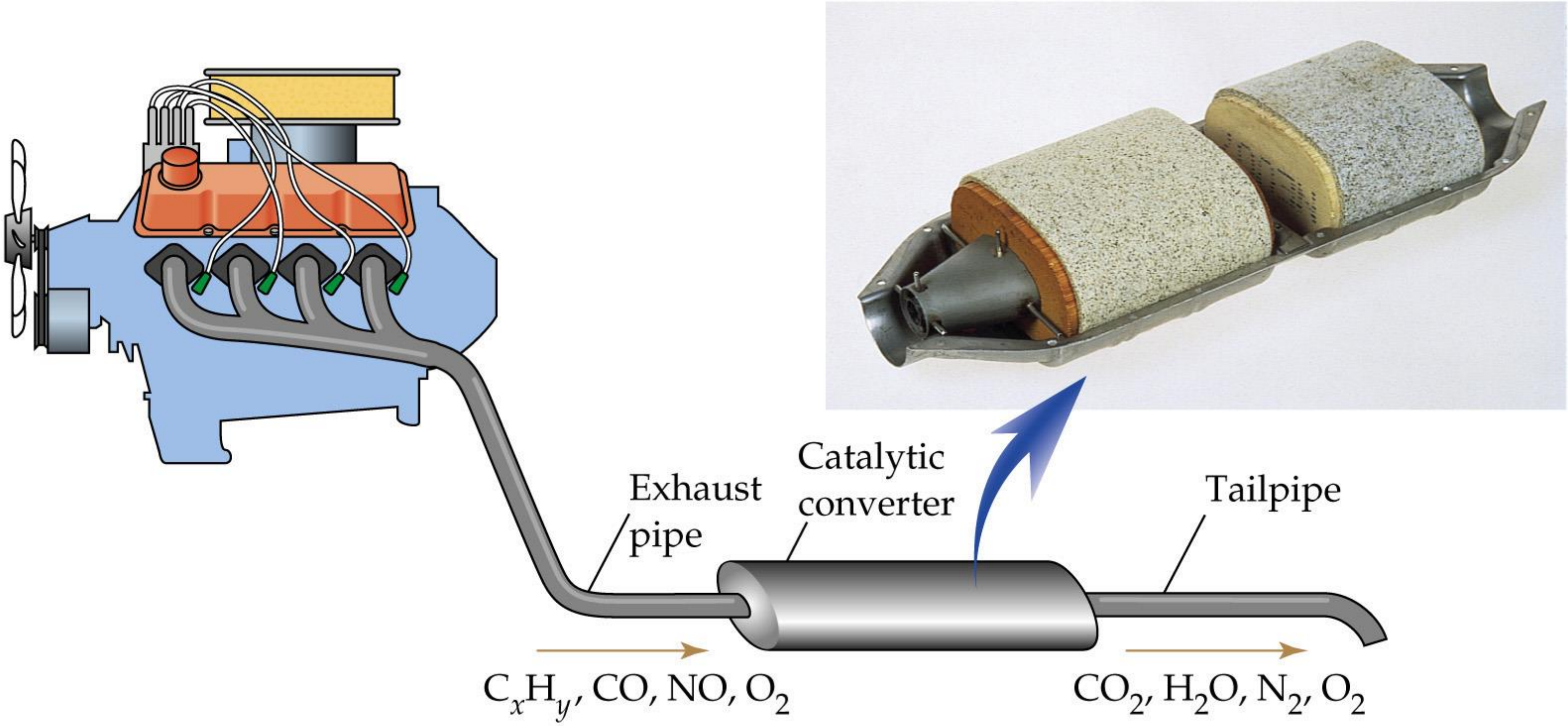
Organic Chemistry

Fractional Distillation of Crude Oil (Petroleum)

- The combustion of fossil fuels produce pollutants such as:
- Carbon dioxide → causes global warming.
- Carbon monoxide → toxic.
- Oxides of nitrogen → irritant, causes acid rain.
- Sulfur dioxide → irritant, causes acid rain.
- Unburned hydrocarbons → cause cancer.

Organic Chemistry

Fractional Distillation of Crude Oil (Petroleum)



- Pollutants can be removed from car exhaust fumes using *catalytic converters*.

Organic Chemistry

What are *isomers*?

Organic Chemistry

Isomers

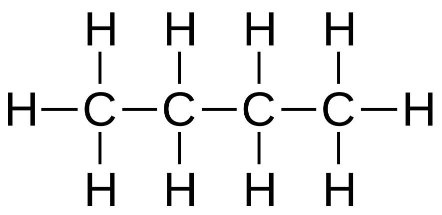
- Isomers are compounds that share the same molecular formula, but have different structural formulas (arrangement of atoms).
- Isomers may or may not belong to the same homologous series.
- Isomers have different names.

Organic Chemistry

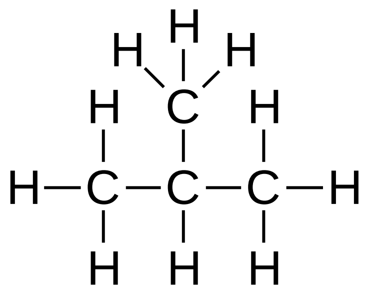
There are Two Isomers of C_4H_{10}:

Organic Chemistry

There are Two Isomers of C_4H_{10}:



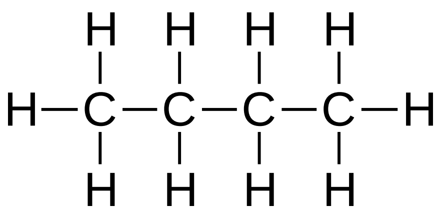
butane



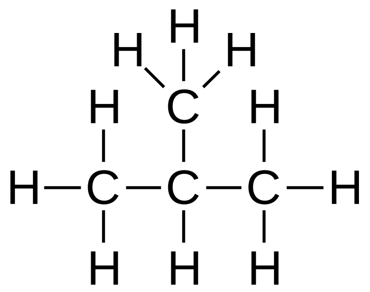
2-methylpropane
(or just methylpropane)

Organic Chemistry

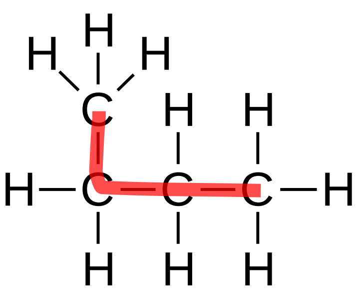
There are Two Isomers of C_4H_{10}:



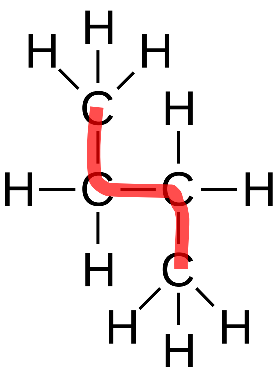
butane



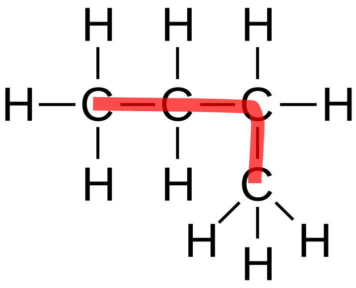
2-methylpropane
(or just methylpropane)



This is butane *not*
1-methylpropane



This is butane *not*
1,2-dimethylethane



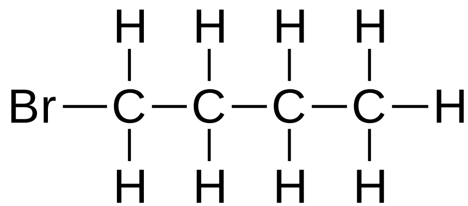
This is butane *not*
1-methylpropane

Organic Chemistry

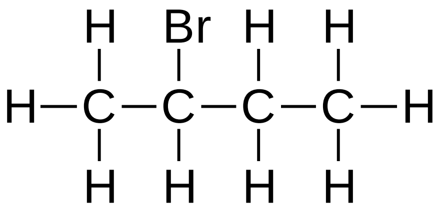
What are the Isomers of C_4H_9Br?

Organic Chemistry

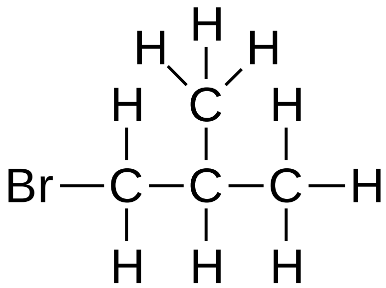
What are the Isomers of C_4H_9Br?



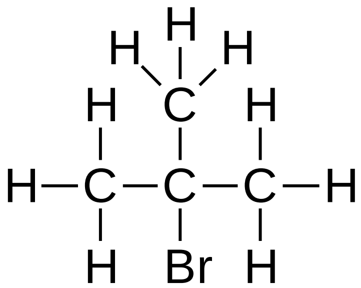
1-bromobutane



2-bromobutane



1-bromo-2-methylpropane
(or just 1-bromomethylpropane)



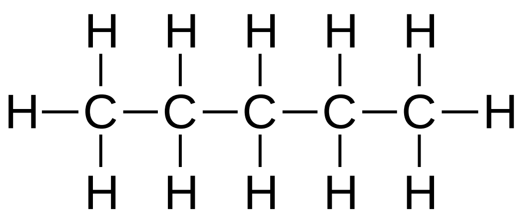
2-bromo-2-methylpropane
(or just 2-bromomethylpropane)

Organic Chemistry

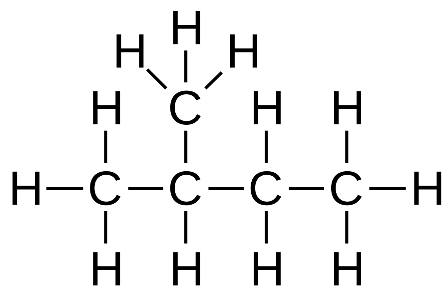
What are the Isomers of C_5H_{12}?

Organic Chemistry

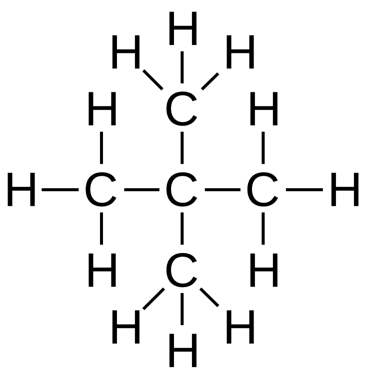
What are the Isomers of C_5H_{12}?



pentane



2-methylbutane
(or just methylbutane)



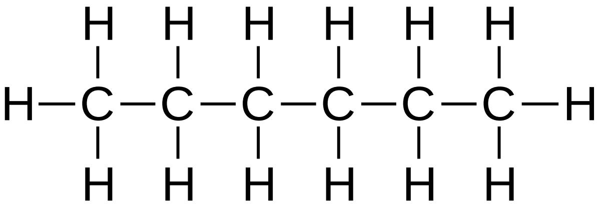
2,2-dimethylpropane
(or just dimethylpropane)

Organic Chemistry

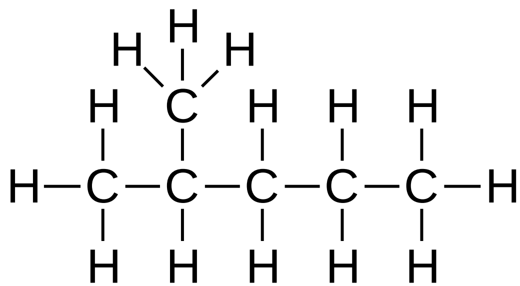
What are the Isomers of C_6H_{14}?

Organic Chemistry

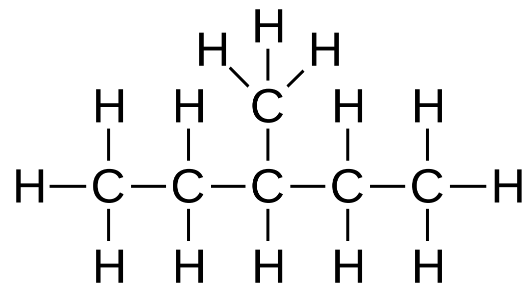
What are the Isomers of C_6H_{14}?



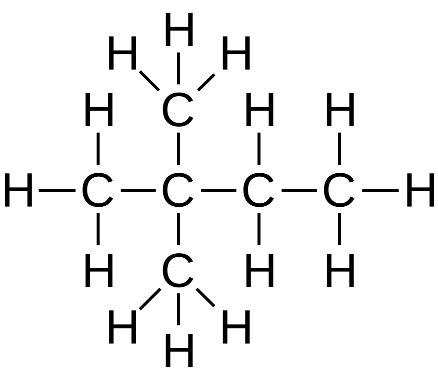
hexane



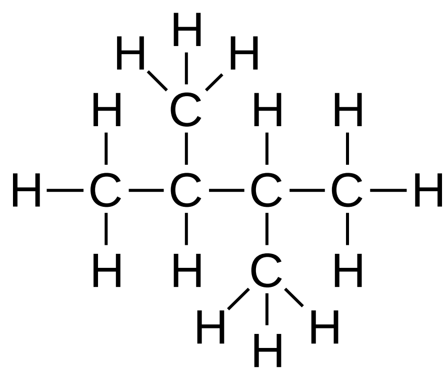
2-methylpentane



3-methylpentane



2,2-dimethylbutane



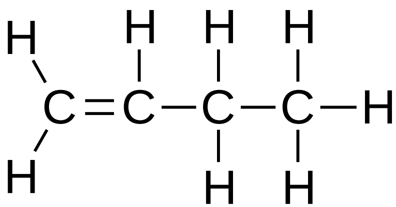
2,3-dimethylbutane

Organic Chemistry

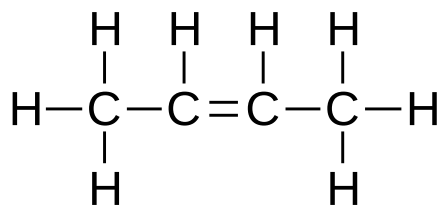
What are the Isomers of C_4H_8?

Organic Chemistry

What are the Isomers of C_4H_8?

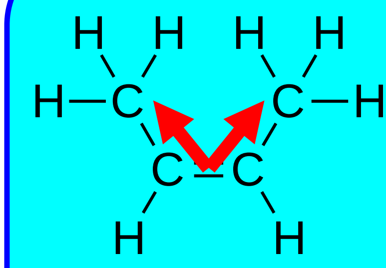


but-1-ene

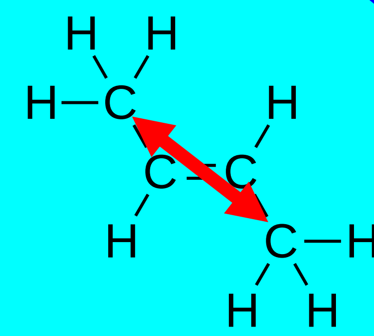


but-2-ene

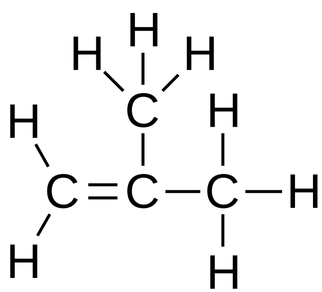
Geometric Isomers!



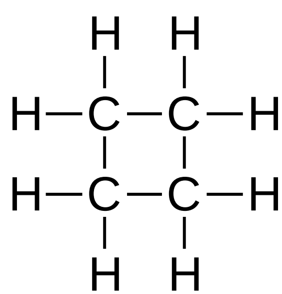
cis-but-2-ene



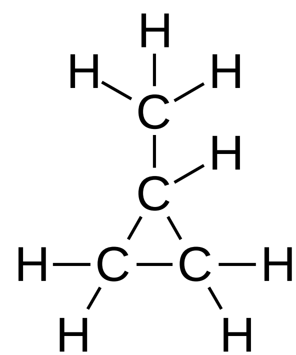
trans-but-2-ene



2-methylprop-1-ene
(or just methylpropene)



cyclobutane



methylcyclopropane

Organic Chemistry

How do I *calculate the formula* of an organic compound from its percentage composition?

Organic Chemistry

Calculation of Formula from Percentage Composition

- Calculate the empirical formula of the hydrocarbon that has the following percentage composition:

C = 85.7% H = 14.3 %

- Given that the relative molecular mass of the hydrocarbon is 42.0, calculate the molecular formula of the hydrocarbon.

- This hydrocarbon has two isomers. Give the structural formulae and names of the two isomers.

Organic Chemistry

Calculation of Formula from Percentage Composition

Step 1: Divide each element's percentage by the element's relative atomic mass.

- For carbon: 85.7 ÷ 12.0 = 7.14
- For hydrogen: 14.3 ÷ 1.0 = 14.3

How does this calculation work? Imagine that you had 100 g of the hydrocarbon. 85.7 g of the compound would be carbon, and 14.3 g would be hydrogen. Remember, mass in grams divided by relative atomic mass gives number of moles as the answer. So, 85.7 ÷ 12.0 = 7.14 moles of carbon and 14.3 ÷ 1.0 = 14.3 moles of hydrogen. The simple mole ratio of elements in a compound gives us the empirical formula of the compound.

Organic Chemistry

Calculation of Formula from Percentage Composition

Step 2: Divide each one of the answers by the smallest answer.

- For carbon: 7.14 ÷ 7.14 = 1.00
- For hydrogen: 14.3 ÷ 7.14 = 2.00

Organic Chemistry

Calculation of Formula from Percentage Composition

Step 3: This gives the compound's empirical formula which is the most simple ratio of elements in the compound.

$$CH_2$$

Organic Chemistry

Calculation of Formula from Percentage Composition

Step 4: Calculate the relative molecular mass of the compound's empirical formula.

$$= C + (2 \times H)$$

$$= 12.0 + (2 \times 1.0)$$

$$= 14.0$$

Organic Chemistry

Calculation of Formula from Percentage Composition

Step 5: Divide the relative molecular mass of the compound's molecular formula by the relative molecular mass of the compound's empirical formula.

$$= 42.0 \div 14.0$$

$$= 3.00$$

Organic Chemistry

Calculation of Formula from Percentage Composition

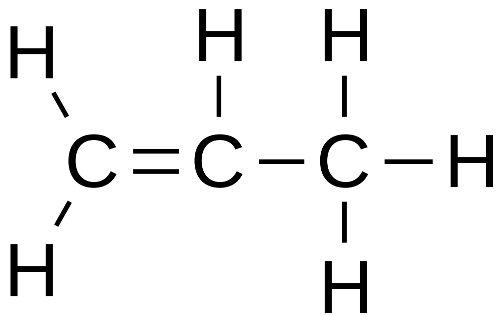
Step 6: Multiply the empirical formula by the answer to Step 5 to determine the compound's molecular formula.

$= CH_2 \times 3.00$

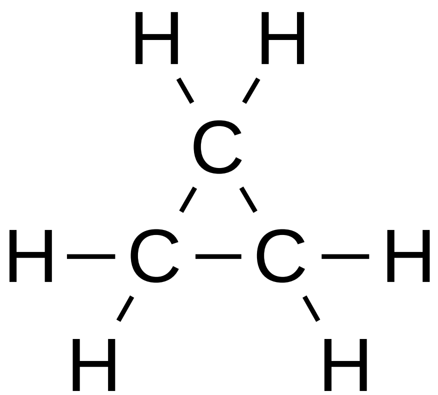
C_3H_6

Organic Chemistry

Calculation of Formula from Percentage Composition



Propene



Cyclopropane

Organic Chemistry

How are the reactions of organic compounds *classified*?

Organic Chemistry

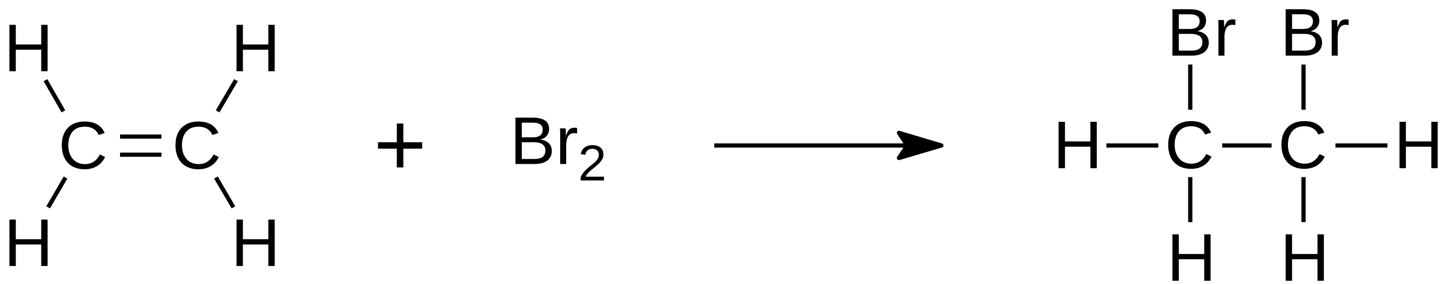
Classification of Organic Reactions

Organic reactions can be classified into (at least) three main types:

- Addition.
- Elimination.
- Substitution.

Organic Chemistry

Classification of Organic Reactions



Ethene

1,2-Dibromoethane

Unsaturated

Saturated

Organic Chemistry

Classification of Organic Reactions

Ethene

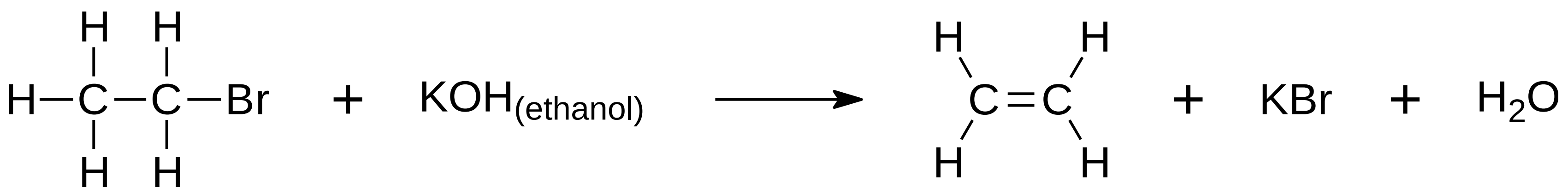
1,2-Dibromoethane

Unsaturated

Saturated

Organic Chemistry

Classification of Organic Reactions



Bromoethane

Ethene

Saturated

Unsaturated

Organic Chemistry

Classification of Organic Reactions

Bromoethane

Ethene

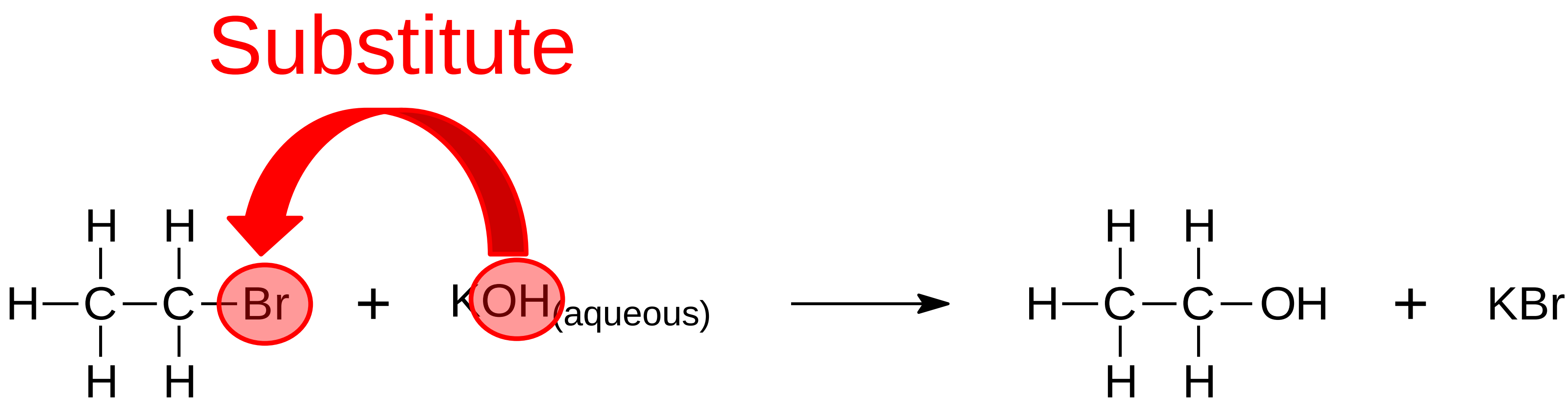
Elimination

Saturated

Unsaturated

Organic Chemistry

Classification of Organic Reactions

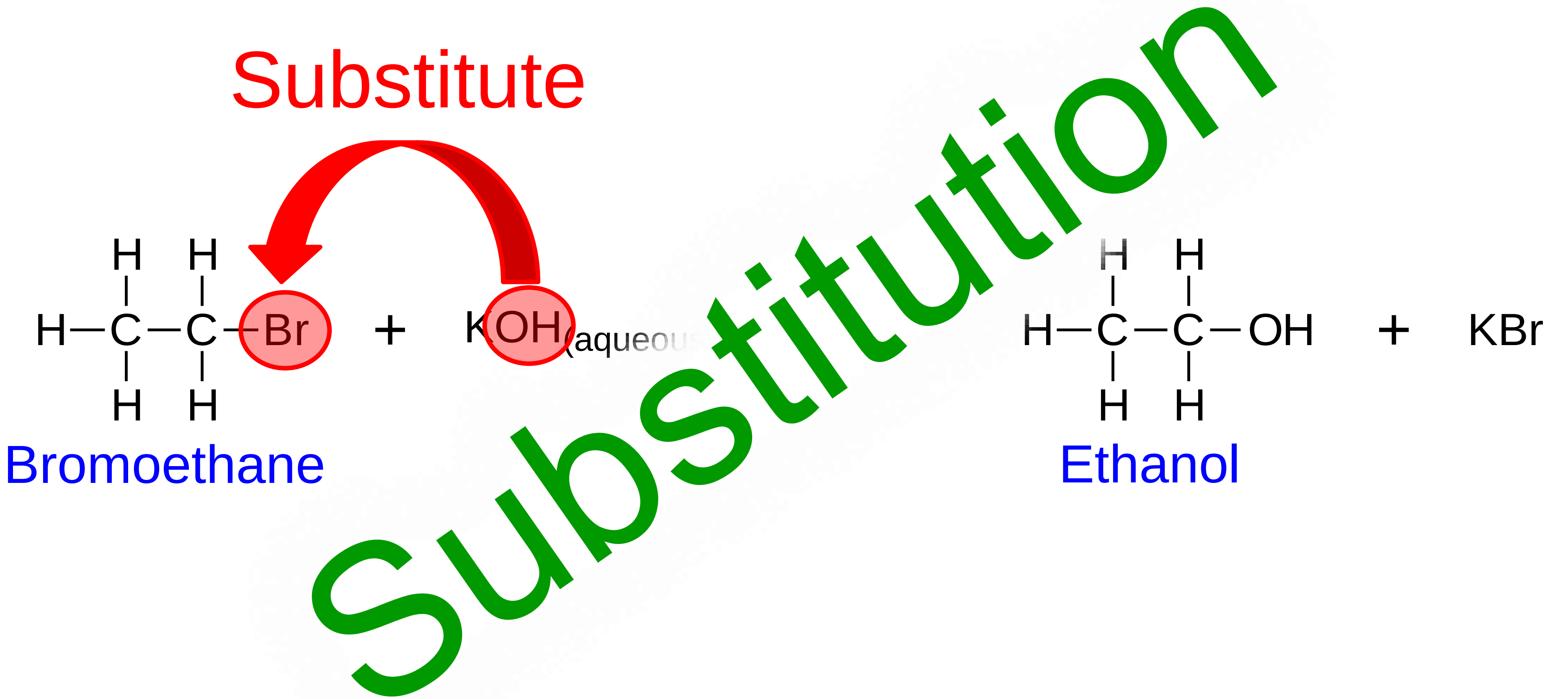


Bromoethane

Ethanol

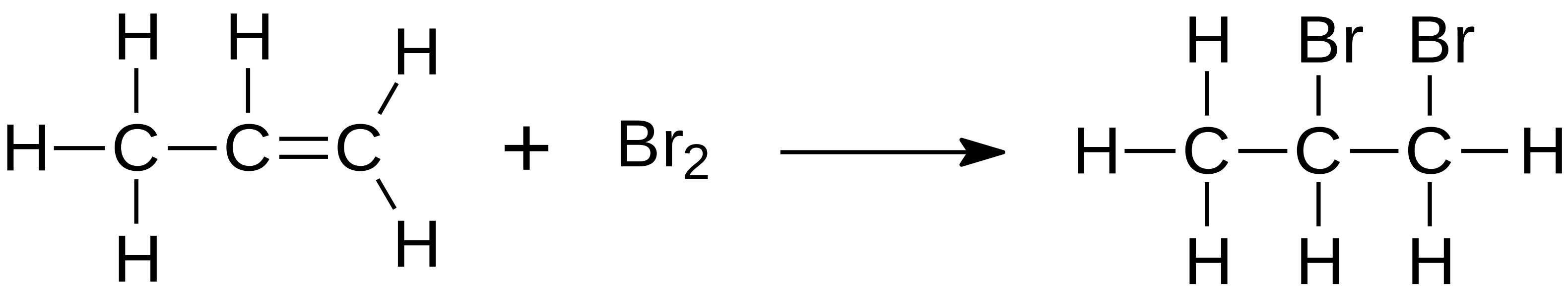
Organic Chemistry

Classification of Organic Reactions



Organic Chemistry

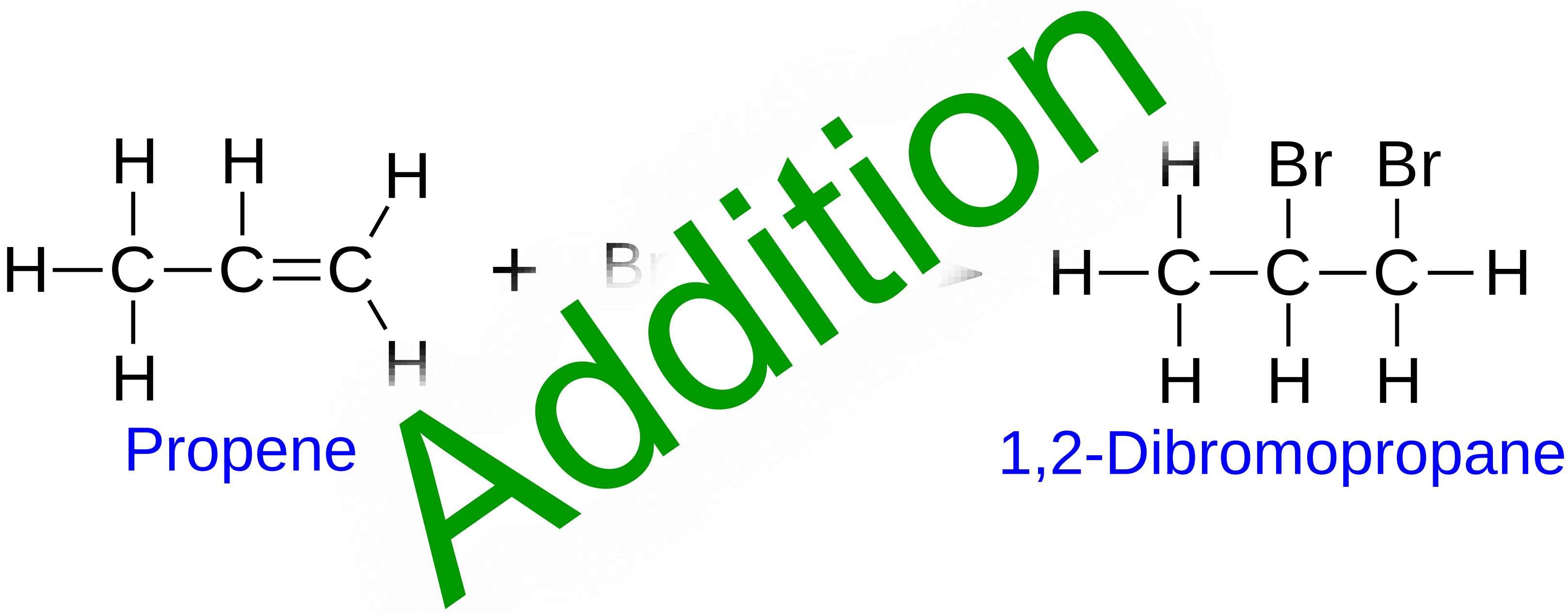
Classification of Organic Reactions



Propene 1,2-Dibromopropane

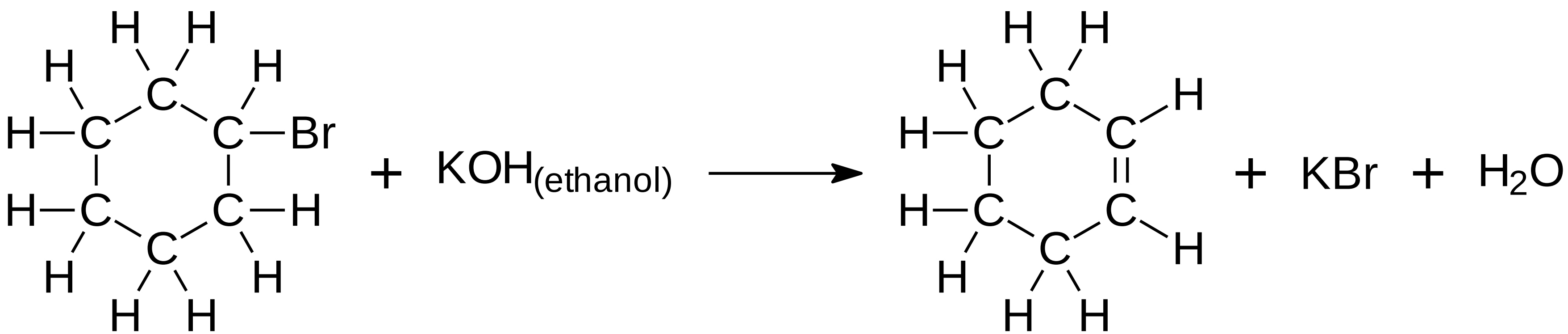
Organic Chemistry

Classification of Organic Reactions



Organic Chemistry

Classification of Organic Reactions



Bromo-cyclohexane

Cyclohexene

Organic Chemistry

Classification of Organic Reactions

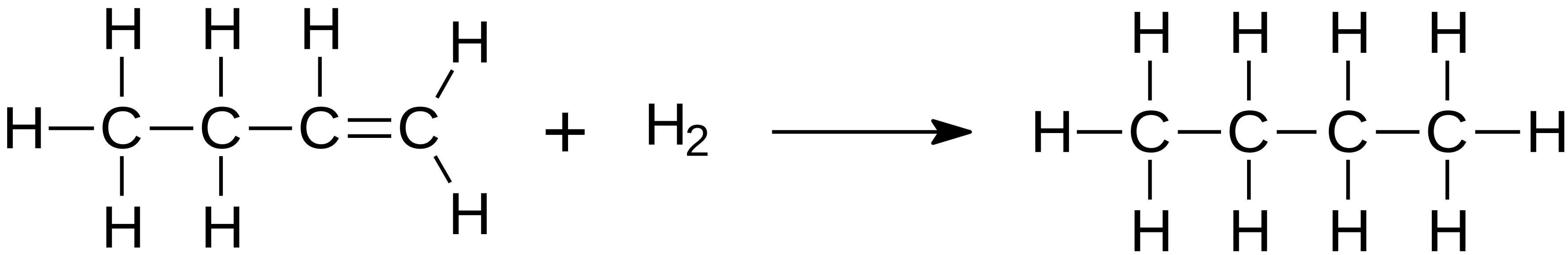
Bromo-
cyclohexan

Cyclohexene

Elimination

Organic Chemistry

Classification of Organic Reactions



But-1-ene

Butane

Organic Chemistry

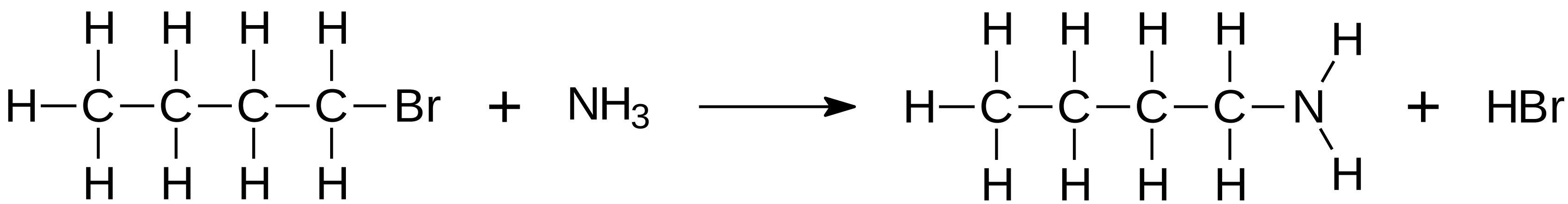
Classification of Organic Reactions

But-1-ene

Butane

Organic Chemistry

Classification of Organic Reactions



1-Bromobutane

Butyl-1-amine

Organic Chemistry

Classification of Organic Reactions

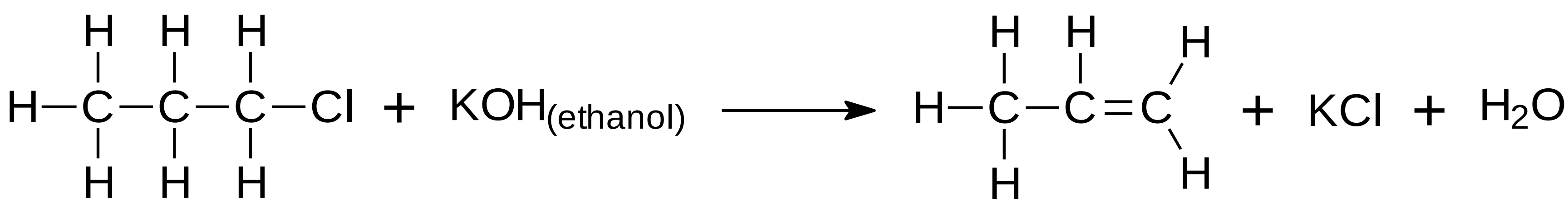
Substitution

1-Bromobutane

Butyl-1-amine

Organic Chemistry

Classification of Organic Reactions



1-Chloropropane

Propene

Organic Chemistry

Classification of Organic Reactions

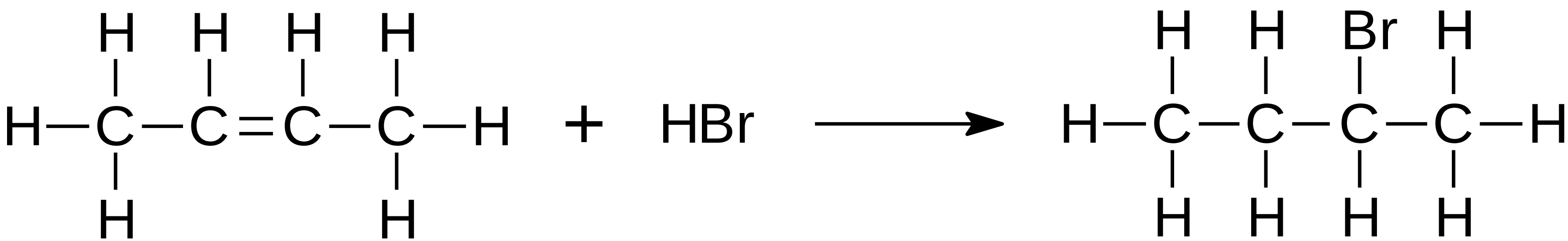
1-Chloropropane

Propene

Elimination

Organic Chemistry

Classification of Organic Reactions



But-2-ene

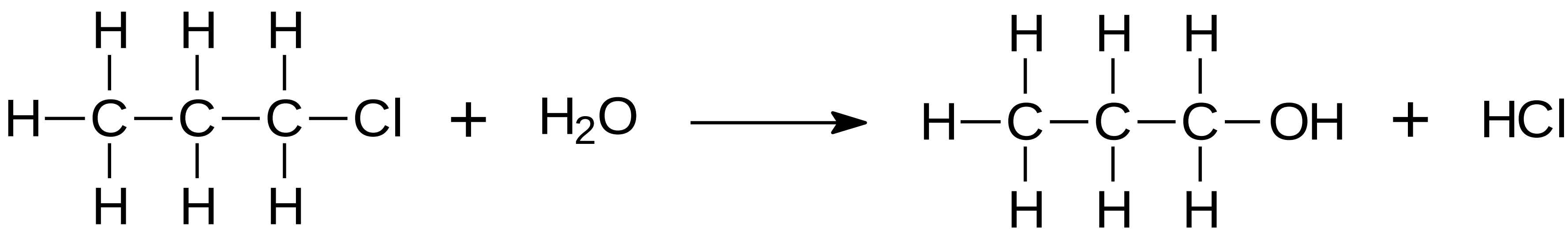
2-Bromobutane

Organic Chemistry

Classification of Organic Reactions

Organic Chemistry

Classification of Organic Reactions



1-Chloropropane

Propan-1-ol

Organic Chemistry

Classification of Organic Reactions

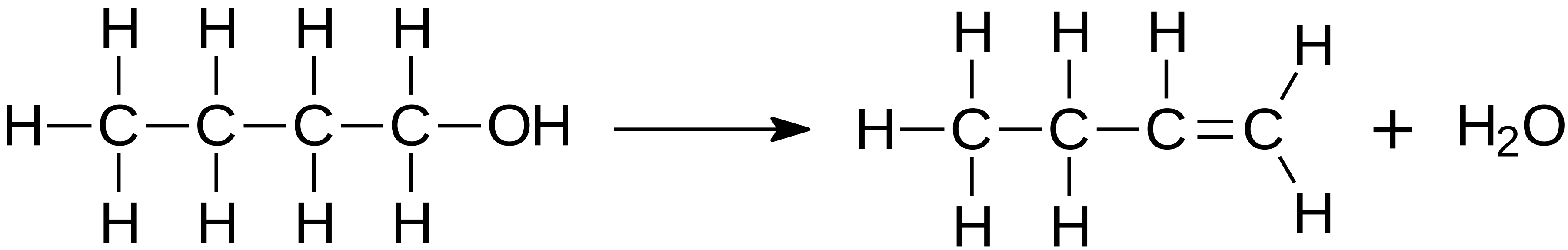
1-Chloropropane

Propan-1-ol

Substitution

Organic Chemistry

Classification of Organic Reactions



Butan-1-ol

But-1-ene

Organic Chemistry

Classification of Organic Reactions

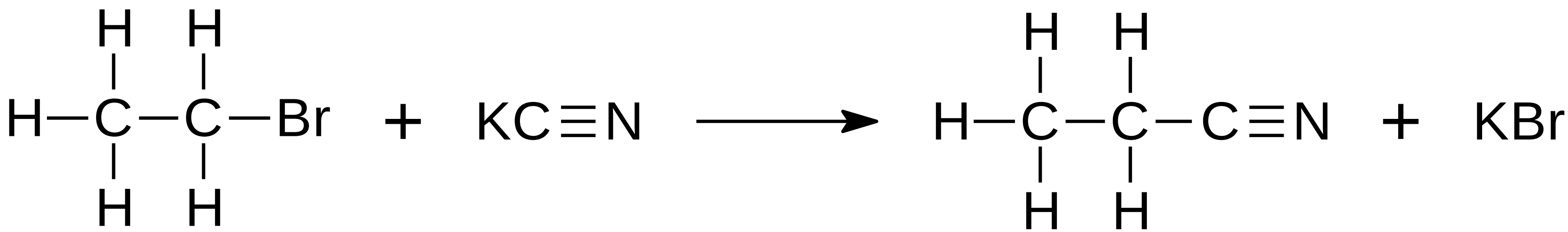
Butan-1-ol

But-1-ene

Elimination

Organic Chemistry

Classification of Organic Reactions



Bromoethane

Propanenitrile

Organic Chemistry

Classification of Organic Reactions

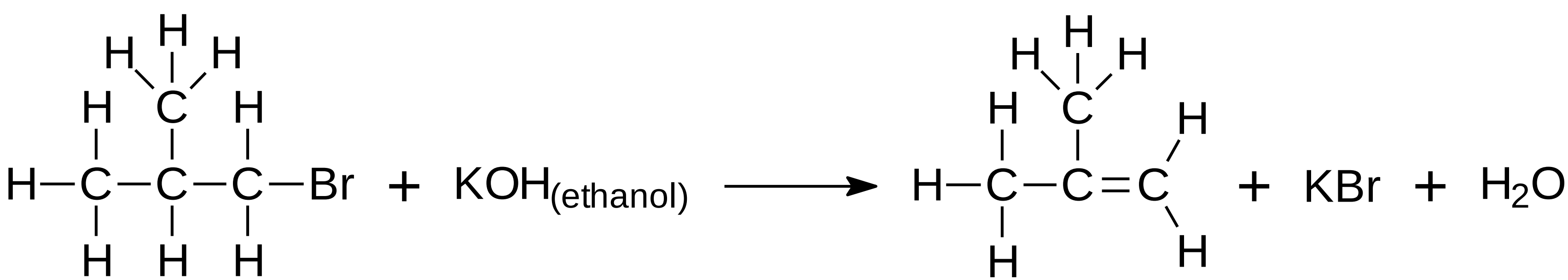
Bromoethane

Propanenitrile

Substitution

Organic Chemistry

Classification of Organic Reactions



1-Bromo-2-methylpropane
or
1-Bromo-methylpropane

2-Methylpropene
or Methylpropene

Organic Chemistry

Classification of Organic Reactions

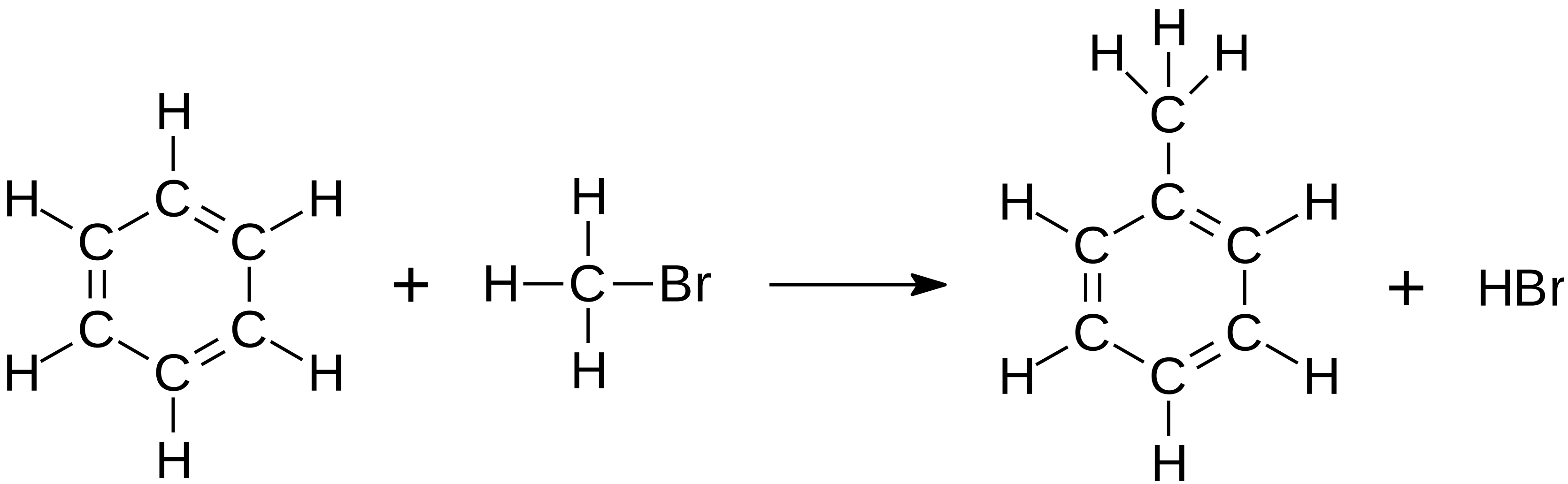
Elimination

1-Bromo-2-
methylprop
or
1-Bromo-
methylpropane

2-Methylpropene
or Methylpropene

Organic Chemistry

Classification of Organic Reactions

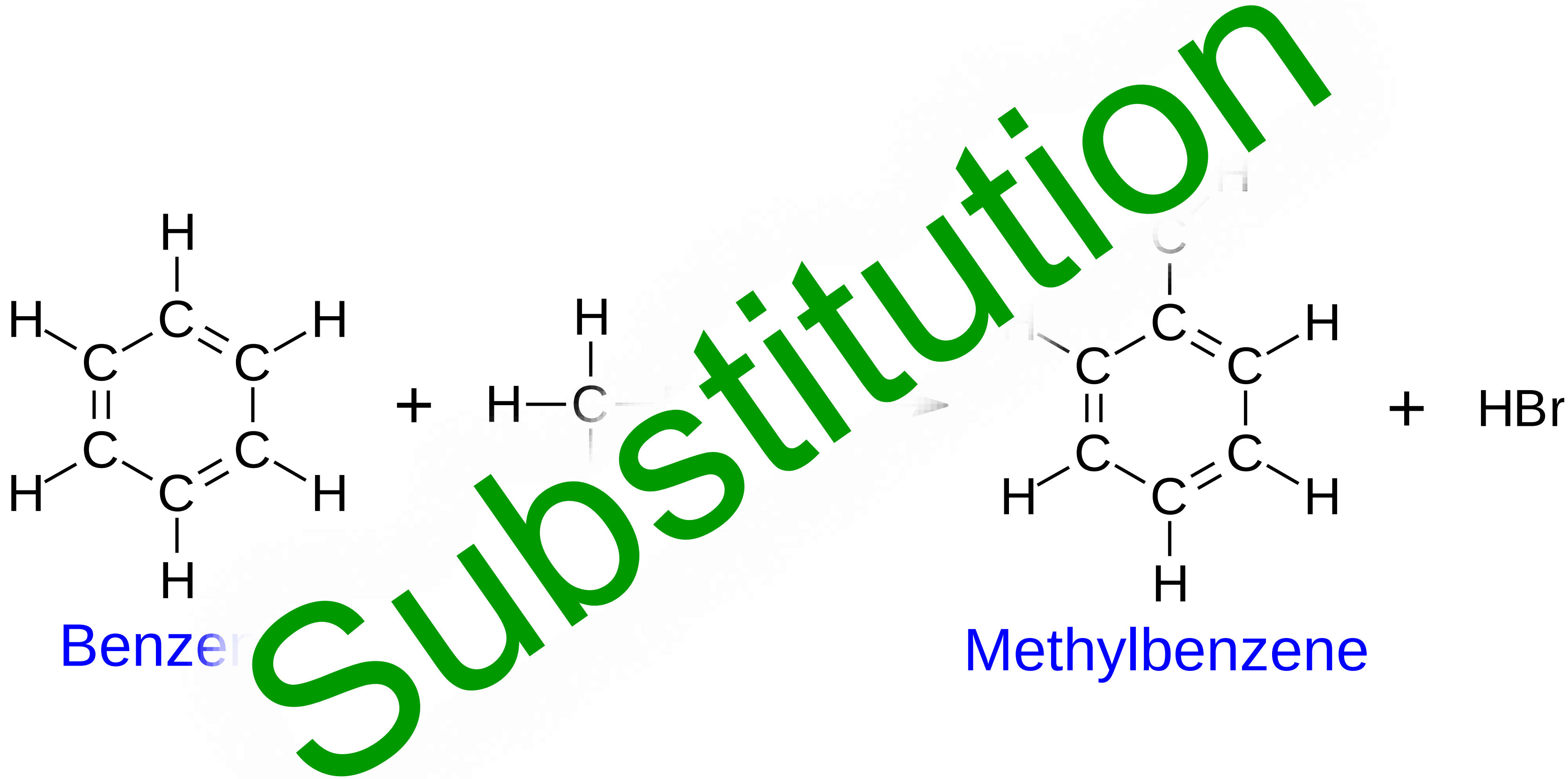


Benzene

Methylbenzene

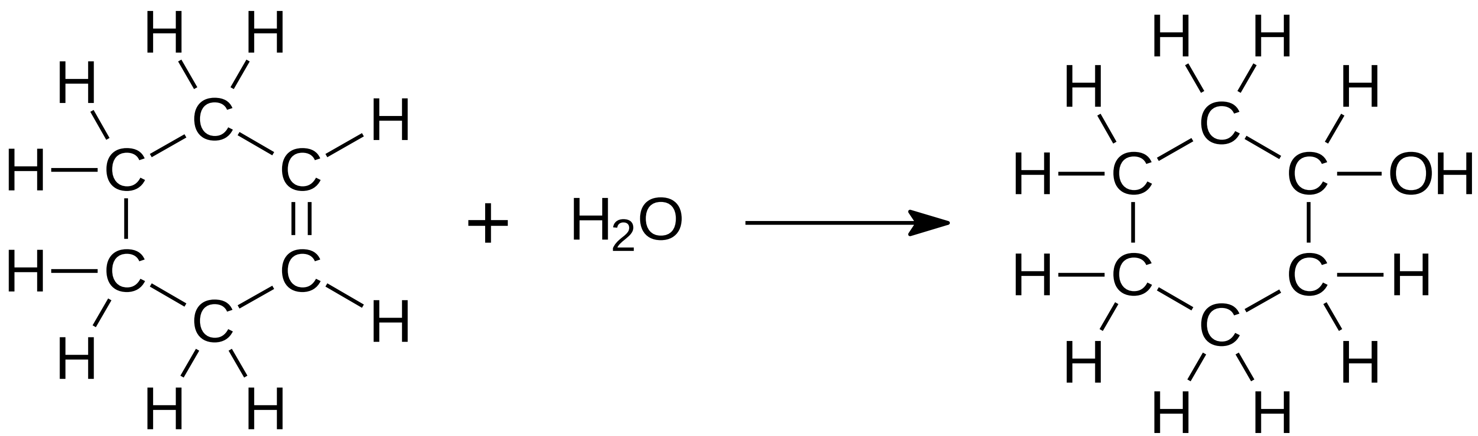
Organic Chemistry

Classification of Organic Reactions



Organic Chemistry

Classification of Organic Reactions



Cyclohexene

Cyclohexanol

Organic Chemistry

Classification of Organic Reactions

Cyclohexene

Cyclohexanol

Organic Chemistry

Presentation on
Organic Chemistry
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