

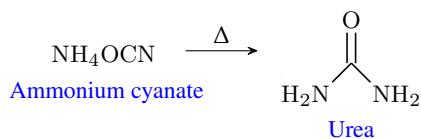


Ch. 1. Organic Chemistry

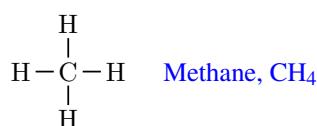
OORGANIC chemistry is a vast subject that studies the properties of carbon-based compounds, and organic compounds are chemicals based mostly on carbon as well as hydrogen. On one hand, organic chemistry plays a key role in the understanding of the functioning and composition of living cells. On the other hand, many products of industrial organic chemistry such as plastics, fuels, perfumes, or prescription drugs are an accepted part of our everyday lives. These types of compounds have common organic properties, from their smells to their powerful action. Key organic chemistry concepts are the naming of organic compounds and the properties of functional groups that give unique properties to molecules such as caffeine or even addictive drugs such as cocaine.

1.1 Organic and non-organic compounds

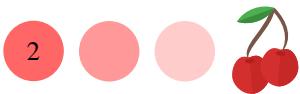
Organic compounds are chemicals mostly made of Carbon and Hydrogen, containing chains or rings of carbon atoms. Here a few examples of organic compounds: CH_4 , C_2H_6 , or C_6H_6 . Differently, inorganic compounds contain elements other than Carbon and Hydrogen. Examples of inorganic compounds are: NaCl , CO_2 , HCl , FeO or NaOH . Mind that carbonates (Na_2CO_3), carbon monoxide (CO) or carbon dioxide (CO_2) are not organic compounds. Originally the distinction between organic and inorganic compounds was made based on whether the chemical comes from a living system. Indeed organic compounds were thought of as synthesized only from living organisms. This belief was disregarded after Friedrich Wöhler was able to synthesize urea—a component of urine—from ammonium cyanate, an inorganic salt:



Alkanes are simple organic compounds made of Carbon and Hydrogen with all carbons connected using simple bonds—these are single lines representing the connections between atoms. The simplest alkane and the simplest organic compound is methane: CH₄, a fuel and the main constituent of natural gas.



Its structure is representative of organic compounds in general as it shows that each carbon atom in an organic molecule is connected to four different atoms.



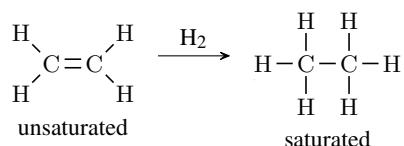
1.2 Alkanes

This first section will introduce organic chemistry, covering the simplest organic compounds: alkanes. Alkanes—also called hydrocarbons—are simply made of carbon and hydrogen with all C-C bonds being single bonds. First, you will be introduced to a few organic chemicals, and you will learn about a series of different organic formulas that can represent the same compound. Then, you will learn the basic naming rule of alkanes, which extends to other—more complex—organic chemicals. Hydrocarbons composed of single C-C bonds are called saturated hydrocarbons, whereas hydrocarbons containing multiple C-C bonds are described as being unsaturated. All carbons in a saturated hydrocarbon are bound to four atoms. You can produce saturated hydrocarbons by reacting an unsaturated hydrocarbon with hydrogen:

▼ Methane (CH_4) is used as a fuel for ovens, homes, water heaters.



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Molecular formula for alkanes The naming of alkanes results from the combination of a prefix and a suffix. On one hand, the suffix is always *ane*. On the other hand, the prefix depends on the number of carbons in the molecule. Table 1.1 shows a list of the different prefixes. For example, the alkane with a single carbon is called methane (CH_4). Other examples of alkanes are ethane which contains two carbons (C_2H_6) or propane with three carbons (C_3H_8). The molecular formula for an alkane with n carbon atoms is:

$$\text{C}_n\text{H}_{2n+2} \quad (1.1)$$

Hence, we have that the molecular formula for methane ($n = 1$) is CH_4 and the molecular formula for octane ($n = 8$) is C_8H_{18} . *Molecular formulas* represent only the molecular compositions, showing only the elements in the molecule.

Sample Problem 1

Write down the molecular formula for decane and pentane.

SOLUTION

Using Equation 1.1 we have that the molecular formula for decane ($n = 10$) would be: $C_{10}H_{22}$. Similarly, the molecular formula for pentane ($n = 5$) would be: C_5H_{12} .

► Answer: (decane) C₁₀H₂₂; (pentane) C₅H₁₂

STUDY CHECK

Name the alkane with formula C₇H₁₆ and give the molecular formula for nonane.

► Answer: heptane, C₉H₂₀.

▼ The octane rating of gas is a standard measure of the performance of engine fuels, originally determined by mixing a gasoline made entirely of heptane and 2,2,4-trimethylpentane (a highly branched octane).



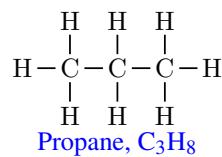
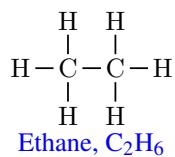
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Table 1.1 Prefixed for alkane naming

| # Carbons | prefix | # Carbons | prefix |
|-----------|--------|-----------|--------|
| 1 | Meth | 6 | Hex |
| 2 | Eth | 7 | Hepta |
| 3 | Prop | 8 | Octa |
| 4 | But | 9 | Nona |
| 5 | Pent | 10 | Deca |



Expanded structural formula for alkanes At this point, we have addressed the molecular formulas of three simple alkanes: methane (CH_4), ethane (C_2H_6), and propane (C_3H_8). However, these formulas do not inform about the molecular structure and how the atoms are connected. The structure of ethane and propane is shown below:

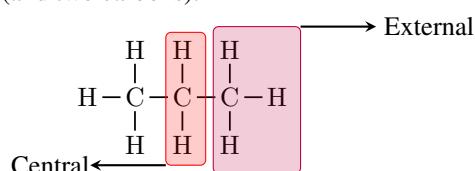


These structures show that each carbon connects to four different atoms, and each hydrogen connects to only one atom. The formulas presented above are called *expanded structural formulas* as all atoms and all bonds connecting these atoms are shown, representing the molecular structure.

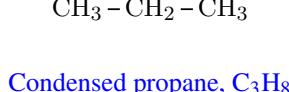
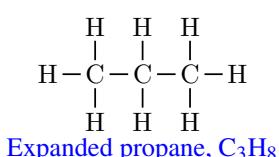
Table 1.2 Alkane names based on the number of carbons in the chain

| Number of Carbons | Name | Condensed Structural formula | Molecular formula |
|-------------------|---------|---|---------------------------|
| 1 | Methane | CH_4 | CH_4 |
| 2 | Ethane | CH_3-CH_3 | C_2H_6 |
| 3 | Propane | $\text{CH}_3-\text{CH}_2-\text{CH}_3$ | C_3H_8 |
| 4 | Butane | $\text{CH}_3-\text{CH}_2-\text{CH}_2-\text{CH}_3$ | C_4H_{10} |
| 5 | Pentane | $\text{CH}_3-\text{CH}_2-\text{CH}_2-\text{CH}_2-\text{CH}_3$ | C_5H_{12} |
| 6 | Hexane | $\text{CH}_3-\text{CH}_2-\text{CH}_2-\text{CH}_2-\text{CH}_2-\text{CH}_3$ | C_6H_{14} |
| 7 | Heptane | $\text{CH}_3-\text{CH}_2-\text{CH}_2-\text{CH}_2-\text{CH}_2-\text{CH}_2-\text{CH}_3$ | C_7H_{16} |
| 8 | Octane | $\text{CH}_3-\text{CH}_2-\text{CH}_2-\text{CH}_2-\text{CH}_2-\text{CH}_2-\text{CH}_2-\text{CH}_3$ | C_8H_{18} |
| 9 | Nonane | $\text{CH}_3-\text{CH}_2-\text{CH}_2-\text{CH}_2-\text{CH}_2-\text{CH}_2-\text{CH}_2-\text{CH}_2-\text{CH}_3$ | C_9H_{20} |

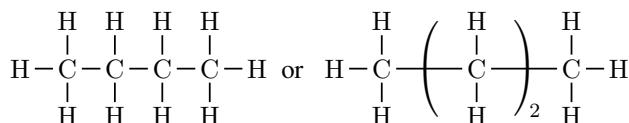
Condensed structural formula Let us analyze the formula of propane shown below. In this molecule, there are two different types of carbons: the end of the chain carbon, in the left and the right of the structure, and a central carbon. The external carbons are bound to three hydrogens (and one carbon), whereas the central carbons are bonded to two hydrogens (and two carbons).



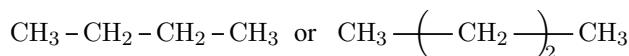
The extremes of the chain are indeed CH_3 units and the central carbon is a CH_2 unit. So, another way to represent propane would be:



This representation is called *condensed structural formula* or simple condensed structure, as the units of carbon and hydrogen are condensed into CH_2 and CH_3 units. Table ?? displays molecular formulas and condensed structures for different alkanes. For larger alkenes it is often convenient to use parenthesis to simplify the structure. For example, the expanded structure of butane can be written as:



Similarly, the condensed structure of butane can be written as:

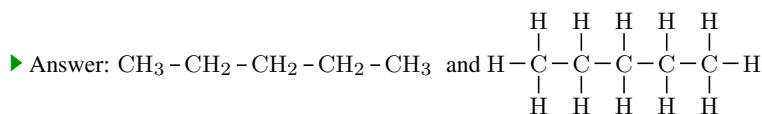


Sample Problem 2

Write down the condensed and expanded formulas for pentane.

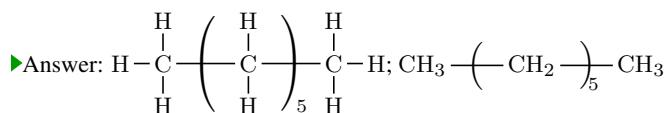
SOLUTION

Pentane has five carbons, hence its condensed formula will have two CH_3 units and three CH_2 units. On the other hand, the expanded formula for pentane should display all carbons and hydrogens:



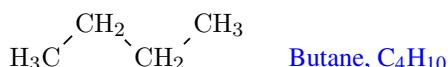
◆ STUDY CHECK

Write down the condensed and expanded formulas for heptane.



Skeletal structural formula Let us analyze the structure of butane again.

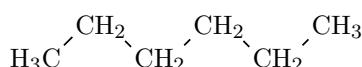
This molecule has four carbons in the form of a C-C chain such as C-C-C-C.



However, in reality, C-C chains with more than two carbons are not linear, and their structure resembles more a zig-zag rather than a line, since the tetrahedral C-C-C angle is 109.5° . So instead of representing butane as a line, it should be represented as:



This type of structural representation is called *skeletal structural formula* as you only represent the C-C skeleton of the molecule. Another example would be:



condensed formula of hexane



skeletal formula of hexane

The ending of a skeletal formula represents a CH_3 , and the points in between represent CH_2 . Hydrocarbons in which carbon atoms form a long, continuous string are called straight-chain (e.g. butane) or unbranched hydrocarbons, in contrast to branched hydrocarbons (e.g. isobutane).



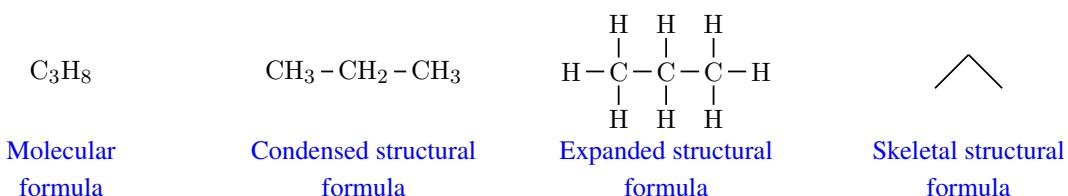
butane



isobutane



A review of the different structural formulas At this point, you have seen four different ways to represent organic molecules. Using propane as an example, here are all the formulas: We have that the *molecular formula* (e.g. C₃H₈ for propane) is mainly used to indicate the composition of the molecule in the form of Carbon and Hydrogen atoms. A second way to represent propane is using its *expanded structural formula*, that is by representing all atoms in the molecule and all atomic connections. A third molecular representation is the *condensed structural formula* that uses CH₃ and CH₂ units, only representing the C-C bonds. Finally, the *skeletal formula* is perhaps the most simplistic representation as only the C-C bonds are represented in the form of simple lines. It is important to understand that *all formulas are just different ways to represent the same molecule*.

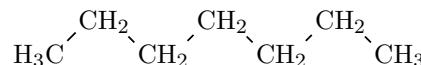


Sample Problem 3

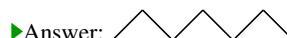
Write down the condensed and skeletal formulas for heptane.

SOLUTION

Heptane has seven carbons, hence its condensed formula will have two CH₃ units and five CH₂ units:



The skeletal formula for would be:



◆ STUDY CHECK

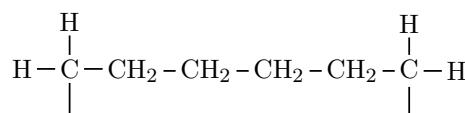
Draw the skeletal formula of decane.



1.3 Cycloalkanes

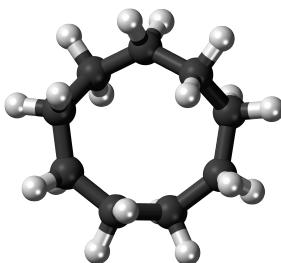
Alkanes are perfect examples of hydrocarbons, with C-C chains and all carbon atoms saturated with hydrogen. Cycloalkanes are simply alkanes with a cyclic structure. We will cover the molecular, condensed, and skeletal formulas for these chemicals.

Cyclic alkanes Consider the expanded structure of hexane. A cycloalkane results from removing the left and right hydrogen while connecting the molecule in the form of a cycle:



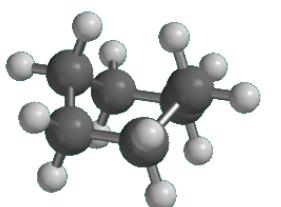


▼3D representation of Cyclononane



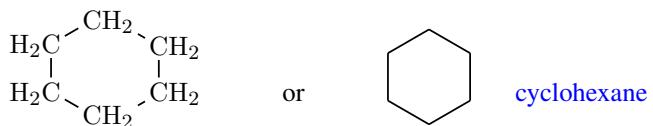
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▼3D representation of Cyclohexane with the shape of a chair.



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As the most stable structure for six lines is the hexagon, the resulting structure of cyclohexane would be:



Naming cycloalkanes The naming of alkanes and cycloalkanes is very similar. You just need to add the cyclo prefix to the name. For example, the alkane with five carbons is called pentane, whereas the corresponding cycloalkane is called cyclopentane:



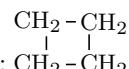
Sample Problem 4

Write down the condensed structure and name the following cycloalkane:



SOLUTION

The cycloalkane has four carbons and its name is cyclobutane. Its condensed structure is



►Answer: CH_2-CH_2

◆ STUDY CHECK

Write down the condensed structure and name the following cycloalkane:



►Answer: cyclopropane, CH_2-CH_2

Molecular formulas for cycloalkanes The molecular formula for a general cycloalkane with n carbon atoms is:

$$\text{C}_n\text{H}_{2n} \quad (1.2)$$

As an example, the formula for cyclobutane ($n = 4$) is C_4H_8 and the formula for cyclooctane ($n = 8$) is C_8H_{16} .

Sample Problem 5

Write down the molecular formula for cyclodecane and cyclopentane.

SOLUTION

Using Equation 1.2 we have that the molecular formula for cyclodecane ($n = 10$) would be: $\text{C}_{10}\text{H}_{20}$. Similarly, the molecular formula for cyclopentane ($n = 5$) would be:

►Answer: C_5H_{10} .





STUDY CHECK

Name the alkane with formula C₇H₁₄ and give the formula for cyclononane.

► Answer: cycloheptane, C₉H₁₈.

1.4 Alkanes with substituents

Oftentimes alkanes have other groups of atoms called substituents attached to the hydrocarbon chain. This section covers the naming of alkanes with substituents. Here is an example of an alkane and an alkane with a substituent:



Propane

Nitropropane

In the substituted molecule, a nitro group has replaced a hydrogen atom.

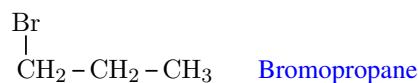
Substituents There are many different substituents—also called groups—that can be found attached to an alkane chain. Their names are indicated in Table ???. The easiest substituents are halogens; atoms of chlorine (Cl —), bromine (Br —) or iodine (I —) can replace hydrogen atoms in an alkane. The name of these substituents—chloro, bromo, and iodo—resembles the name of the corresponding atom. Other substituents can contain carbon, like a methyl (CH₃ —) or a ethyl (CH₃CH₂ —). There are even more complex substituents such as tert-butyl in which a central carbon atom is connected to three different methyl groups. The name of substituents (methyl) comes from the name of the alkane (methane) by replacing the *-ane* suffix with *-yl*.

Alkanes with a single substituent Let us consider the following example.

The condensed formula for propane is



Now, this would be propane with a substituent:

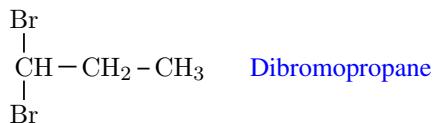


As you can see a bromine atom substitutes one of the hydrogen atoms of the second first of the molecule (starting from the left). The name simply results from the combination of the substituent group and the alkane name

**Table 1.3 Substituent name**

| Substituents | name | Substituents | name | | |
|---|---------|--|-----------|---|-----------|
| CH ₃ — | Methyl | F — | Fluoro | CH ₂ = CH — | Vinyl |
| CH ₃ CH ₂ — | Ethyl | Cl — | Chloro | NO ₂ — | Nitro |
| CH ₃ CH ₂ CH ₂ — | Propyl | Br — | Bromo | NH ₂ — | Amino |
| CH ₃ CH ₂ CH ₂ CH ₂ — | Butyl | I — | Iodo | H ₃ C — — CH — CH ₂ CH ₃ | sec-Butyl |
| $\begin{array}{c} \\ \text{H}_3\text{C} - \text{C} - \text{CH}_3 \\ \\ \text{CH}_3 \end{array}$ | t-butyl | $\begin{array}{c} \\ \text{H}_3\text{C} - \text{CH} - \text{CH}_3 \end{array}$ | Isopropyl | CH ₃ CH ₂ CH ₂ — | Propyl |

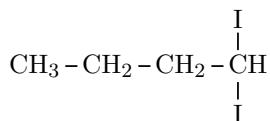
Alkanes with two or more equal substituents In the same way, as when you have a single bromo substituent attached to propane, you can also have two Br —. In this case, you need to use the prefix *di* to indicate there are two identical bromos. For example, the name of the following molecule would be:



Similarly, you should use the prefix *tri* and *tetra* for three equal substituents.

Sample Problem 6

Name the following hydrocarbon:



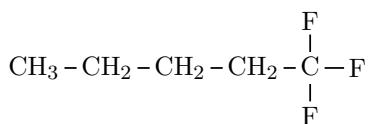
SOLUTION

The carbon chain has four carbons and hence the ending of the name would be: butane. Also there are two iodines (iodo substituents) attached to the carbon chain. As there are two of the same iodo atoms, we need to use the prefix *di*. The full name would be:

►Answer: Dioiodobutane.

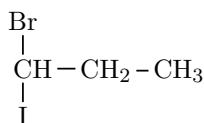
◆ STUDY CHECK

Name the following hydrocarbon:



►Answer: Trifluoropentane.

Alkanes with different substituents Now imagine you have two different halogens as substituents: Br — and I — like in next example



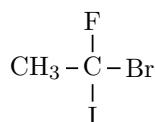
As both substituents have different names you cannot use the prefix *di*. Still, when you indicate the names of the substituents you need to order them alphabetically. So Bromo goes first in the name and Iodo after. You also need to separate the different substituents with a hyphen ('-'). The final name of the hydrocarbon above would be Bromo-Iodopropane.

Naming rules for alkanes Overall, the rules for naming alkanes are:

- 1 **Step one:** The number of carbon atoms in the chain will give the ending name of the molecule (e.g. four carbons would be butane).
- 2 **Step two:** Number the main chain starting at the end closest to the substituents so that the numbers for the substituents are small.
- 3 **Step three:** Name the substituents with their position and order them alphabetically (di, tri, etc. do not count in the alphabetic order).

Sample Problem 7

Name the following hydrocarbon:



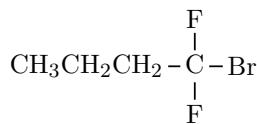
SOLUTION

The carbon chain has two carbons and hence the ending of the name would be: ethane. Also there are three different substituents: iodine (ido substituents), bromine (bromo substituents) and fluorine (fluoro substituents). We need to order them according to the *abc*, hence the order would be: bromo, then fluoro and finally iodo. The full name of the alkane would be:

►Answer: Bromo-Fluoro-Iodoethane.

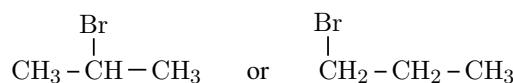
◆ STUDY CHECK

Name the following hydrocarbon:



►Answer: Bromodifluorobutane.

Numbering the chain Substituents are atoms or groups of atoms that replace hydrogens in alkane chains. You could envision attaching substituents at different points of the chain. For example:



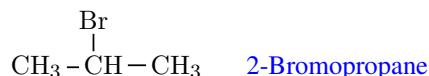
In the right example, Br is plugged into the left C atom, whereas in the left example, C is plugged into the middle carbon. Hence, it is important first, to learn how to number a hydrocarbon chain. Let us use propane—a molecule with three atoms—as an example. To



number the chain, you start by selecting the extreme that is the closest to the substituent using this carbon as number one. Next carbon would be carbon number two and so on until you arrive at carbon number three.

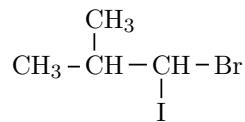


As the Br atom in the carbon number one, the name of the molecule would be 1-bromopropane or simply bromopropane. Differently, when the substituent is in a carbon different than one, you need to indicate that location. For example:



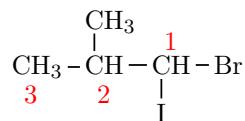
Sample Problem 8

Name the following hydrocarbon:



SOLUTION

First we find the ending of the name: as the molecule has three carbons in the main chain, the ending of the name would be: propane. Then we need to number the chain so that the number one carbon is the closest to the substituents:

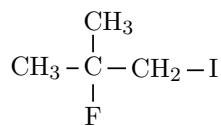


A methyl is connected to carbon two, and two halogens, a iodo and a bromo are connected to carbon number one. The substituents are: 2-methyl, 1-bromo, 1-iodo. If we order them: 1-bromo-1-iodo-2-methyl. And the final name would be:

►Answer: 1-bromo-1-iodo-2-methylpropane.

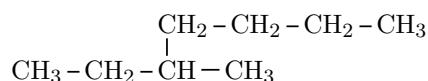
◆ STUDY CHECK

Name the following hydrocarbon:



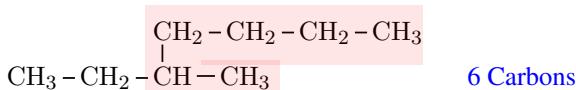
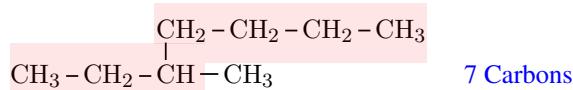
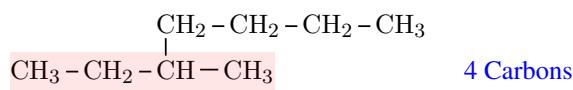
►Answer: 1-iodo-2-fluoro-2-methylpropane.

Finding the longest chain Alkanes are complex molecules often containing more than one hydrocarbon chain. Therefore, one can envision several ways to number the chain. However, the rule is to first locate the longest chain. Let us use the following hydrocarbon. How many chains can you find, and which is the longest chain?

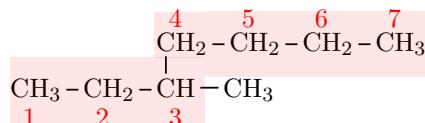




The answer should be three chains. Let me highlight the three different possibilities and the number of atoms in each chain:



As the longest chain has seven carbons, the name of the molecule would be heptane. Still, you need to add the substituents to the name. Hence, after you locate the longest chain, you need to number the chain so that the substituents are located the closest to the carbon number one possible:



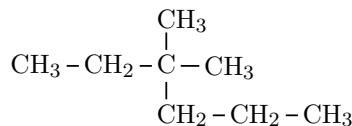
As there is a methyl in carbon number three the final name of the molecule would be: 3-methylheptane.

Naming rules for branched alkanes Overall, the rules to name branched alkanes are:

- 1 **Step one:** Look for the longest carbon-carbon chain that will give the ending name of the molecule (e.g. four carbons would be butane).
- 2 **Step two:** Number the main chain starting at the end closest to the substituents so that the numbers for the substituents are small.
- 3 **Step three:** Name the substituents with their position and order them alphabetically.

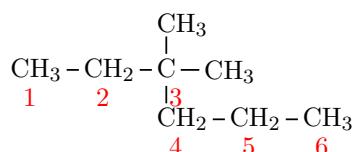
Sample Problem 9

Name the following hydrocarbon:



SOLUTION

First we locate the longest chain. We have five possible chains, and the longest one has six carbons. Hence the name of the hydrocarbon would be hexane. Now we need to number the carbons so that we start numbering the closest to the substituents the possible.



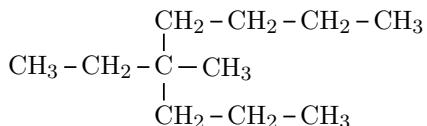


We have two methyl connected to carbon number three. Hence the final name will be:

►Answer: 3-dimethylhexane.

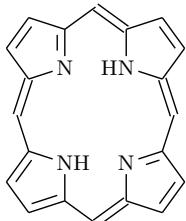
◆ STUDY CHECK

Name the following hydrocarbon:

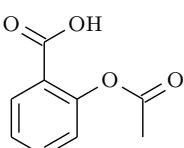


►Answer: 4-ethyl-4-methyloctane.

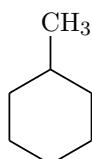
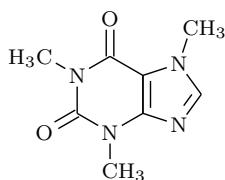
▼Porphyrin has several amine groups.



▼Aspirin contains an aromatic cycle, a carboxylic acid and a ester.

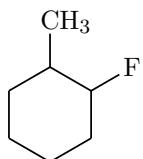


▼Caffeine contains amides and amines

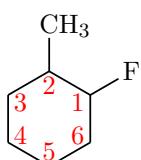


this is a cyclohexane connected to a methyl substituent. As there is only one substituent, there is no need to number the carbon chain. Hence the name would be simply methylcyclohexane.

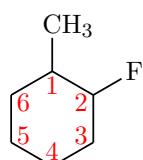
Cycloalkanes with two substituents Let us look at the following cycloalkane:



this is a cyclopentane connected to two different substituents: a methyl and a fluoro. In order to name this molecule, we need to number the carbons first, and there are two different ways to number the cyclopentane ring:



1-Fluoro-2-methylcyclopentane

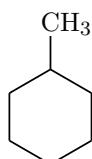


Fluoro-1-methylcyclopentane

1.5 Cycloalkanes with substituents

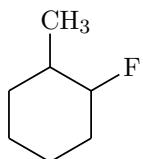
The naming rules for cycloalkanes are the same as the rules for naming linear alkanes. This means first you will find the ending of the name by counting the number of carbons in the cycle. Then you will locate each substituent and number the carbon chain so that the position numbers are small. Finally, all substituents should be ordered alphabetically.

Cycloalkanes with one substituent Let us take a look at the following cycloalkane:

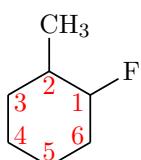


this is a cyclohexane connected to a methyl substituent. As there is only one substituent, there is no need to number the carbon chain. Hence the name would be simply methylcyclohexane.

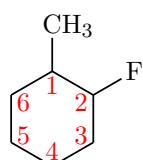
Cycloalkanes with two substituents Let us look at the following cycloalkane:



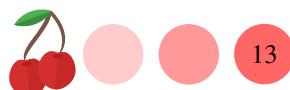
this is a cyclopentane connected to two different substituents: a methyl and a fluoro. In order to name this molecule, we need to number the carbons first, and there are two different ways to number the cyclopentane ring:



1-Fluoro-2-methylcyclopentane

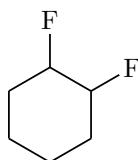


Fluoro-1-methylcyclopentane

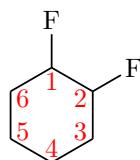


we will choose the name that gives the lowest numbers: 1-Fluoro-2-methylcyclohexane.

Cycloalkanes with repeated substituents Let us look at the following cycloalkane, which has two repeated fluorine substituents:



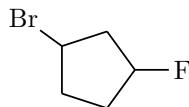
After numbering the chain:



The name would be: 1,2-difluorocyclohexane.

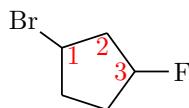
Sample Problem 10

Name the following hydrocarbon:



SOLUTION

The molecule is a cyclopentane with two substituents: fluoro and bromo. I will start numbering in bromo and continue until bromo. This way I will have small numbers and follow the abc rule:

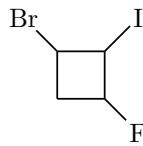


And the name of the molecule would be:

►Answer: 1-bromo-3-fluorocyclopentane.

❖ STUDY CHECK

Name the following hydrocarbon:

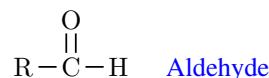


►Answer: 1-bromo-3-fluoro-2-bromocyclobutane.

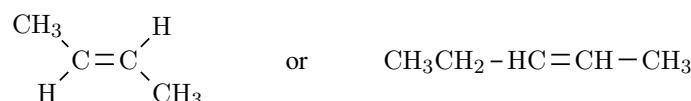


You have certainly taken painkillers for a headache or over-the-counter drugs to get over a cold. Maybe you drink coffee and perhaps you like tea. All these substances contain active organic molecules. These active molecules are hydrocarbon derivatives and differ from plain hydrocarbons, which are simply made of carbon and hydrogen. Active molecules contain functional groups such as alcohol, ethers, carboxylic acids, amines, amides, or aromatic groups. These groups of atoms have a specific function and give activity to the molecule. The goal of this section is simply to identify the different groups.

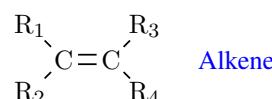
Alkene group: double bonds Ketones and aldehydes both contain a C=O group. Still, these are two different groups, and ketones have a C=O group bounded to two different carbon atoms



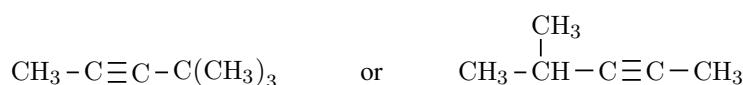
whereas aldehydes have the same C=O group but this time bound to a carbon and a hydrogen. Alkenes contain at least one double bond between carbons. An example would be:



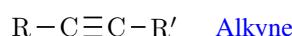
Double bonds are also called unsaturations. Hence, we say alkenes are unsaturated. Both extremes of an alkene chain can be connected to different hydrocarbons. We normally represent this as:



where R and R' represent any hydrocarbon chain. For Example R and R' can be CH₃— or CH₃CH₂—. Alkynes contain at least one triple bond between carbons. An example would be:

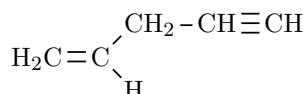


Again, we could use R and R' to represent any hydrocarbon chain:



Sample Problem 11

Identify the alkene and alkyne groups in the molecule:



SOLUTION

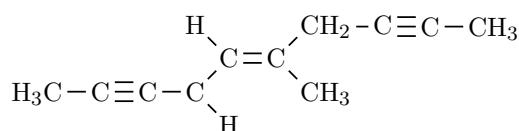
A double bond is carbon atoms sharing two pairs of electrons, whereas a triple bond is a pair of atoms sharing three pairs of electrons. They are represented with a double and triple line, respectively.

►Answer: (left) alkene; (right) alkyne

❖ STUDY CHECK

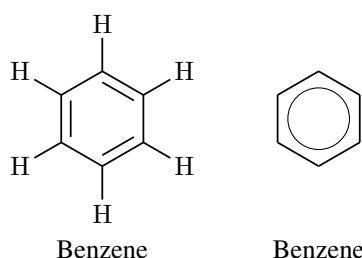


Identify the alkene and alkyne groups in the molecule:



► Answer: (center) alkene; (right, left) alkyne

Aromatic group Aromatic groups are based on benzene, a carcinogenic cyclohexane-like molecule with a series of alternating double bonds, which is often represented as a circle for simplicity:



Examples of molecules containing aromatic groups are:

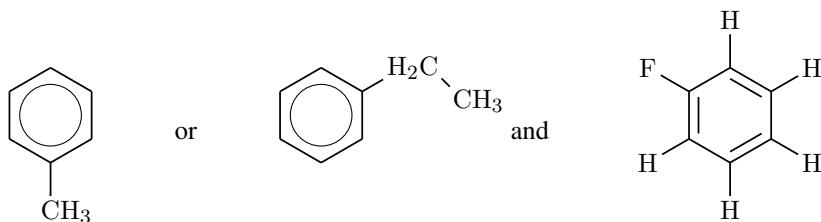


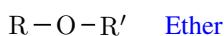
Table 1.4 Names of several functional groups

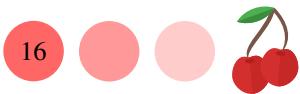
| Functional group | Name | Functional group | Name | Functional group | Name |
|---|-----------------|--|----------|-----------------------------------|---------|
| $\begin{array}{c} \text{R}_1 \\ \\ \text{C} = \text{C} \\ \\ \text{R}_2 \end{array}$ | Alkene | $\begin{array}{c} \text{O} \\ \\ \text{R} - \text{C} - \text{R}' \end{array}$ | Ketone | $\text{R} - \text{OH}$ | Alcohol |
| $\text{R} - \text{C} \equiv \text{C} - \text{R}'$ | Alkyne | $\begin{array}{c} \text{O} \\ \\ \text{R} - \text{C} - \text{H} \end{array}$ | Aldehyde | $\text{R} - \text{SH}$ | Thiol |
| $\begin{array}{c} \text{O} \\ \\ \text{R} - \text{C} - \text{OH} \end{array}$ | Carboxylic acid | $\begin{array}{c} \text{R}' \\ \\ \text{R} - \text{N} - \text{R}'' \end{array}$ | Amine | $\text{R} - \text{O} - \text{R}'$ | Ether |
| $\begin{array}{c} \text{O} \\ \\ \text{R} - \text{C} - \text{O} - \text{R}' \end{array}$ | Ester | $\begin{array}{c} \text{O} \quad \text{R}'' \\ \quad \\ \text{R} - \text{C} - \text{N} - \text{R}' \end{array}$ | Amide | | Phenyl |

Alcohol, ether and thiol group Alcohols contain an –OH group attached to a carbon.



Whereas ethers have oxygen atoms attached to two carbon atoms:





Examples of alcohols and ether are:



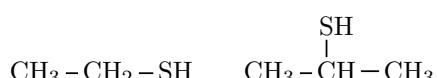
alcohol

ether

Thiols contain a $-SH$ group attached to a carbon. They are equivalent to alcohols but based on sulfur:



Examples of thiols are:



Thiols are responsible for the characteristic smell of rotten eggs and burned hair.

Sample Problem 12

Classify the following molecules as alcohol or ether.



SOLUTION

The OH groups is an alcohol, and we find this group in the left molecule. Differently, the right molecule is an ether as it contains the R – O – R' group.

► Answer: (left) alcohol; (right) ether.

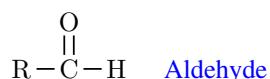
STUDY CHECK

Classify the following molecules as alcohol or ether.

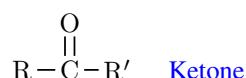


► Answer: (left) ether; (right) alcohol.

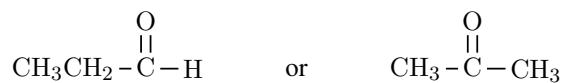
Aldehydes and ketones Ketones and aldehydes both contain a C=O group. Still, these are two different groups, and ketones have a C=O group bounded to two different carbon atoms



whereas aldehydes have the same C=O group but this time bound to a carbon and a hydrogen.



Examples of aldehydes and ketones are:



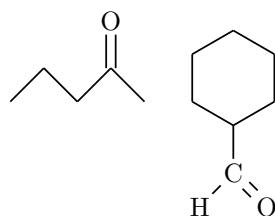
Aldehyde

Ether

Ketones are good solvents. For example, acetone is commonly found in nail polish removers for example. Aldehydes have strong smells. For example, vanillin is an aldehyde responsible for the vanilla smell. Cinnamaldehyde is responsible for the cinnamon odor.

Sample Problem 13

Classify the following molecules as an aldehyde or ketone



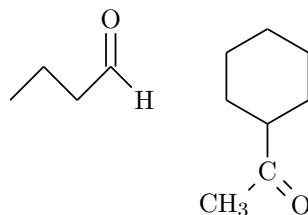
SOLUTION

The left molecule is a ketone as the carbonyl group ($\text{C}=\text{O}$) is connected to a CH_3 and a CH_2 . Differently, the right molecule is an aldehyde as the carbonyl group is connected to a cycloalkane but also to a hydrogen.

►Answer: (left) ketone; (right) aldehyde.

◆ STUDY CHECK

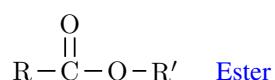
Classify the following molecules as an aldehyde or ketone



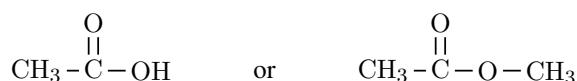
Carboxylic acids and esters Carboxylic acids contain a carbonyl group ($\text{C}=\text{O}$) connected to both a hydrocarbon chain and an alcohol group:



Esters have the same $\text{C}=\text{O}$ group but this time bounded to a carbon (R) and an ether group ($-\text{O}-\text{R}'$).



Examples of carboxylic acids and esters are:



Carboxylic acid

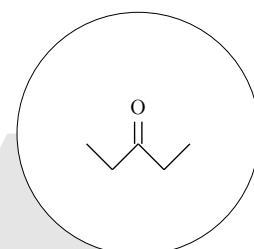
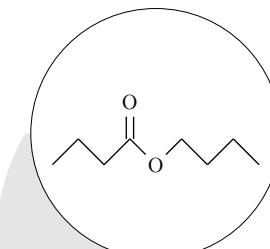
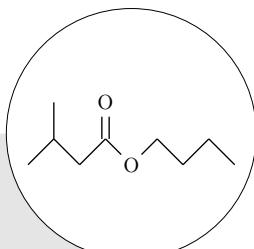
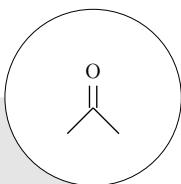
Esters

▼ Acetone, the smallest ketone, is also known as nail polish remover.

▼ Ethyl isovalerate is an ester that flavors apples.

▼ Butyl butyrate is an ester that flavors pineapple.

▼ Diethyl ether was formerly used as a general anesthetic, until non-flammable drugs were developed.



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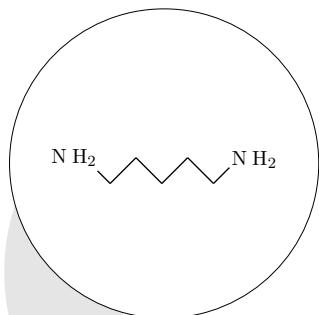


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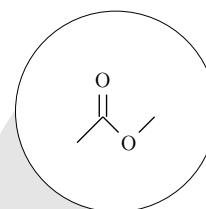
▼ Amines are responsible of the bad smell of decaying meat.

▼ Esters are found in soaps

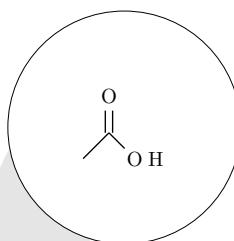
▼ Vinegar contains acetic acid, the smallest carboxylic acid.



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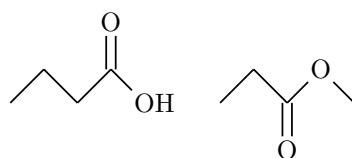


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Figure 1.1 Some examples of functional groups with applications to real life.

Sample Problem 14

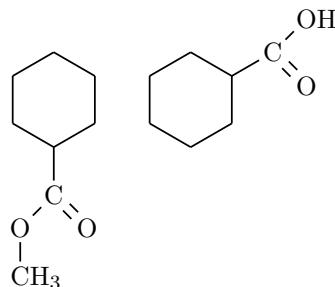
Classify the following molecules as an carboxylic acid or ester:

**SOLUTION**

The molecule in the left is a carboxylic acid as the carbonyl group ($\text{C}=\text{O}$) is connected to an alcohol $-\text{OH}$. Differently, the molecule in the right is an ester as the carbonyl group is connected to a $-\text{O}-\text{CH}_3$ group.

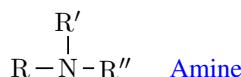
◆ STUDY CHECK

Classify the following molecules as an carboxylic acid or ester:

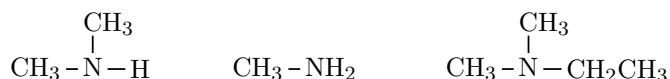


►Answer: (left) ester; (right) acid.

Amines and amides Amines and amides are groups containing nitrogen. Amines are derivative of ammonia (NH_3) with one or more of the hydrogen atoms being replaced by a hydrocarbon



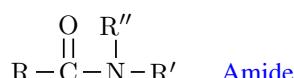
All these molecules are amines:



Amines have very strong and unpleasant odors often associated with the smell of decaying flesh:



Amides, on the other hand, contain a carbonyl group ($\text{C}=\text{O}$) connected to an amine group (—N—)



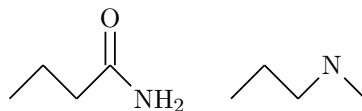
Examples of amides are:





Sample Problem 15

Classify the following molecules as an amide or amine:

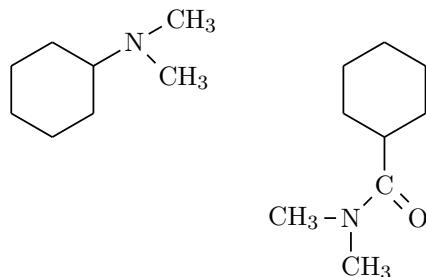
**SOLUTION**

The molecule in the left is a amide as the carbonyl group ($\text{C}=\text{O}$) is connected to a nitrogen atom. Differently, the molecule in the right is an amine as the nitrogen group is not connected to any carbonyl group.

►Answer: (left) amide; (right) amine.

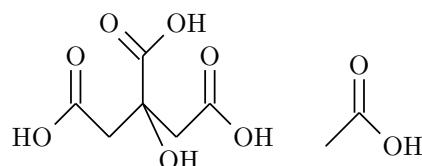
◆ STUDY CHECK

Classify the following molecules as an amide or amine:



►Answer: (left) amine; (right) amide.

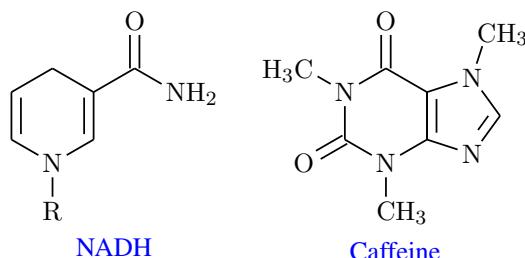
Identifying organic acids and bases Acid organic molecules, in general, contain one or more carboxylic acid groups. An example would be vinegar and citric acid, the acid found in citrus.

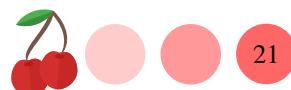


Citric acid

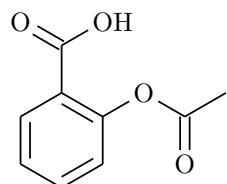
Acetic Acid

Bases contain one or more amine groups. Examples of bases are NADH, a coenzyme found in all living cells, or caffeine, a base found in coffee.

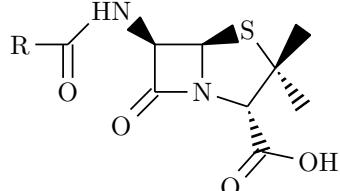


**Sample Problem 16**

Classify the following molecules as an acid or base:



Aspirin



Penicillin

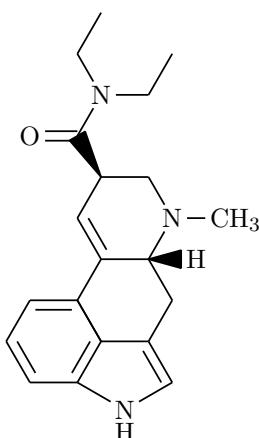
SOLUTION

Aspirin contains an acid group and hence it will be acidic. Penicillin contains both acidic and amine groups and hence will be both acidic and basic.

►Answer: (left) acid; (right) both.

◆ STUDY CHECK

Classify the following molecules as an carboxylic acid or base:



LDS

►Answer: base

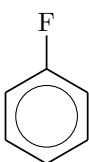
1.7 Aromatic hydrocarbons

Aromatic compounds are a special type of unsaturated hydrocarbons. Benzene represents the simplest of all aromatic compounds. In this molecule, all carbon atoms are equivalent. On one hand, the localized electron model justifies this equivalence through the existence of several equivalent resonant structures. On the other hand, the orbitals model described each carbon using two sp^2 orbitals that form σ C-H and C-C bonds; the remaining $2p$

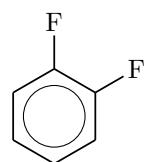


atomic orbital is used to π delocalized orbitals, represented by a circle inside the ring. This electronic delocalization makes benzene behave very differently than plan cyclohexane or simple alkenes. This section will address on one hand the unique reactivity of aromatic hydrocarbons, but also their nomenclature.

Nomenclature The standard nomenclature—the naming rules—for benzene derivatives are very similar to the ones for substituted alkanes. For benzenes with more than one substituent, we follow the abc rule and we use numbers to indicate the location of each substituent. See examples below:

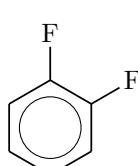


Fluorobenzene

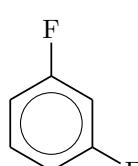


1,2-difluorobenzene

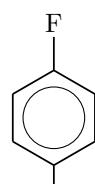
There is an alternative, but extensively used, nomenclature that uses the prefixes *ortho*, *meta*, and *para* to describe the location of double-substituted benzene. *Ortho o-* is used when the substituents are adjacents (1,2 location), whereas *meta m-* is used when there is a carbon in between the two substituents (1,3 location). *Para p-* is used when there are two carbons in between the two substituents (1,4 location). Below you can see this alternative nomenclature in use:



o-difluorobenzene

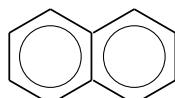


m-difluorobenzene

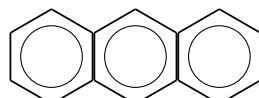


p-difluorobenzene

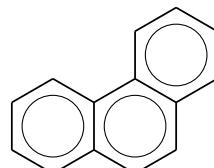
Complex aromatic systems Benze is the simplest of all aromatic hydrocarbons. Benzene rings can fuse, hence forming complex aromatic rings. Some examples are given below. These chemicals are used for the manufacturing of mothballs (naphthalene) or dyes (anthracene) to synthetic drugs (phenanthrene). Another derivative such as 3,4-benzpyrene is an active carcinogen found in smoke and smog.



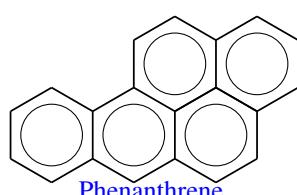
Naphthalene



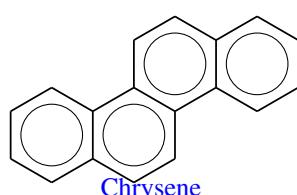
Anthracene



Phenanthrene



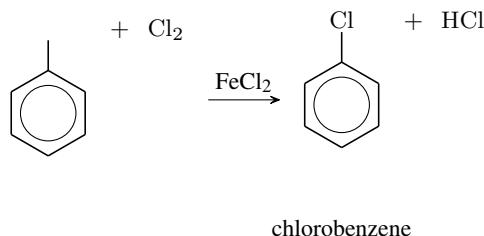
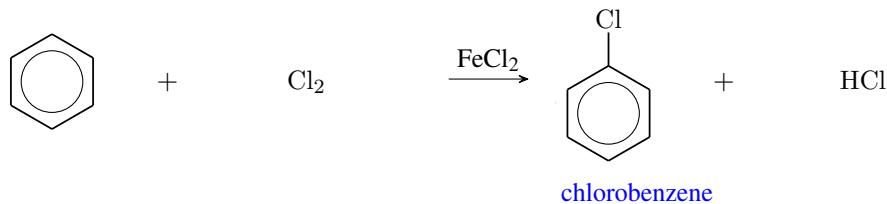
Phenanthrene



Chrysene



Reactivity The reactivity of benzene is very different from the one of unsaturated hydrocarbons. Unsaturated hydrocarbons undergo an addition reaction in which external atoms add to double bonds. Differently, saturated hydrocarbons undergo substitution reactions in which hydrogen atoms are replaced by other atoms. For example, chlorine can add to benzene forming chlorobenzene.



Further, nitric acid reacts with benzene forming nitrobenzene.

Finally, chloromethane reacts with benzene to give toluene, methylbenzene