The increasingly large number of organic compounds identified with each passing day, together with the fact that many of these compounds are isomers of other compounds, requires that a systematic nomenclature system be developed. Just as each distinct compound has a unique molecular structure which can be designated by a structural formula, each compound must be given a characteristic and unique name. As organic chemistry grew and developed, many compounds were given trivial names, which are now commonly used and recognized. Some examples are:

<table>
<thead>
<tr>
<th>Name</th>
<th>Methane</th>
<th>Butane</th>
<th>Acetone</th>
<th>Toluene</th>
<th>Acetylene</th>
<th>Ethyl Alcohol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formula</td>
<td>CH(_4)</td>
<td>C(_4)H(_10)</td>
<td>CH(_3)COCH(_3)</td>
<td>CH(_3)C(_6)H(_5)</td>
<td>C(_2)H(_2)</td>
<td>C(_2)H(_5)OH</td>
</tr>
</tbody>
</table>

Such common names often have their origin in the history of the science and the natural sources of specific compounds, but the relationship of these names to each other is arbitrary, and no rational or systematic principles underly their assignments.

### The IUPAC Nomenclature System

A rational nomenclature system should do at least two things. First, it should indicate how the carbon atoms of a given compound are bonded together in a characteristic lattice of chains and rings. Second, it should identify and locate any functional groups present in the compound. Since hydrogen is such a common component of organic compounds, its amount and locations can be assumed from the tetravalency of carbon, and need not be specified in most cases.

The IUPAC nomenclature system is a set of logical rules devised and used by organic chemists to circumvent problems caused by arbitrary nomenclature. Knowing these rules and given a structural formula, one should be able to write a unique name for every distinct compound. Likewise, given a IUPAC name, one should be able to write a structural formula. In general, an IUPAC name will have three essential features:

- A root or base indicating a major chain or ring of carbon atoms found in the molecular structure.
- A suffix or other element(s) designating functional groups that may be present in the compound.
- Names of substituent groups, other than hydrogen, that complete the molecular structure.

As an introduction to the IUPAC nomenclature system, we shall first consider compounds that have no specific functional groups. Such compounds are composed only of carbon and hydrogen atoms bonded together by sigma bonds (all carbons are sp\(^3\) hybridized).

### Alkanes

Hydrocarbons having no double or triple bond functional groups are classified as **alkanes** or **cycloalkanes**, depending on whether the carbon atoms of the molecule are arranged only in chains or also in rings. Although these hydrocarbons have no functional groups, they constitute the framework on which functional groups are located in other classes of compounds, and provide an ideal starting point for studying and naming organic compounds. The alkanes and cycloalkanes are also
members of a larger class of compounds referred to as **aliphatic**. Simply put, aliphatic compounds are compounds that do not incorporate any **aromatic rings** in their molecular structure.

The following table lists the IUPAC names assigned to simple continuous-chain alkanes from C-1 to C-10. A common "ane" suffix identifies these compounds as alkanes. Longer chain alkanes are well known, and their names may be found in many reference and text books. The names **methane** through **decane** should be memorized, since they constitute the root of many IUPAC names. Fortunately, common numerical prefixes are used in naming chains of five or more carbon atoms.

<table>
<thead>
<tr>
<th>Name</th>
<th>Molecular Formula</th>
<th>Structural Formula</th>
<th>Isomers</th>
<th>Name</th>
<th>Molecular Formula</th>
<th>Structural Formula</th>
<th>Isomers</th>
</tr>
</thead>
<tbody>
<tr>
<td>methane</td>
<td>CH₄</td>
<td>CH₄</td>
<td>1</td>
<td>hexane</td>
<td>C₆H₁₄</td>
<td>CH₃(CH₂)₄CH₃</td>
<td>5</td>
</tr>
<tr>
<td>ethane</td>
<td>C₂H₆</td>
<td>CH₃CH₃</td>
<td>1</td>
<td>heptane</td>
<td>C₇H₁₆</td>
<td>CH₃(CH₂)₅CH₃</td>
<td>9</td>
</tr>
<tr>
<td>propane</td>
<td>C₃H₈</td>
<td>CH₃CH₂CH₃</td>
<td>1</td>
<td>octane</td>
<td>C₈H₁₈</td>
<td>CH₃(CH₂)₆CH₃</td>
<td>18</td>
</tr>
<tr>
<td>butane</td>
<td>C₄H₁₀</td>
<td>CH₃CH₂CH₂CH₂CH₃</td>
<td>1</td>
<td>nonane</td>
<td>C₉H₂₀</td>
<td>CH₃(CH₂)₇CH₃</td>
<td>35</td>
</tr>
<tr>
<td>pentane</td>
<td>C₅H₁₂</td>
<td>CH₃(CH₂)₃CH₃</td>
<td>3</td>
<td>decane</td>
<td>C₁₀H₂₂</td>
<td>CH₃(CH₂)₈CH₃</td>
<td>75</td>
</tr>
</tbody>
</table>

**Some important behavior trends and terminologies**

1. The formulas and structures of these alkanes increase uniformly by a \((\text{CH}_2)\) increment.
2. A uniform variation of this kind in a series of compounds is called homologous.
3. These formulas all fit the \((C_nH_{2n+2})\) rule. This is also the highest possible H/C ratio for a stable hydrocarbon.
4. Since the H/C ratio in these compounds is at a maximum, we call them saturated (with hydrogen).

Beginning with butane (C₄H₁₀), and becoming more numerous with larger alkanes, we note the existence of alkane isomers. For example, there are five C₆H₁₄ isomers, shown below as abbreviated line formulas (A through E):

![Isomers](image)

Although these distinct compounds all have the same molecular formula, only one (A) can be called hexane. How then are we to name the others?

The **IUPAC** system requires first that we have names for simple unbranched chains, as noted above, and second that we have names for simple alkyl groups that may be attached to the chains. Examples of some common **alkyl groups** are given in the following table. Note that the "ane" suffix is replaced by "yl" in naming groups. The symbol **R** is used to designate a generic (unspecified) alkyl group.
IUPAC Rules for Alkane Nomenclature

1. Find and name the longest continuous carbon chain.
2. Identify and name groups attached to this chain.
3. Number the chain consecutively, starting at the end nearest a substituent group.
4. Designate the location of each substituent group by an appropriate number and name.
5. Assemble the name, listing groups in alphabetical order.

The prefixes di, tri, tetra etc., used to designate several groups of the same kind, are not considered when alphabetizing.

Halogen substituents are easily accommodated, using the names: fluoro (F-), chloro (Cl-), bromo (Br-) and iodo (I-).

Example 1: Halogen Substitution

For example, (CH₃)₂CHCH₂CH₂Br would be named 1-bromo-3-methylbutane. If the halogen is bonded to a simple alkyl group an alternative "alkyl halide" name may be used. Thus, C₂H₅Cl may be named chloroethane (no locator number is needed for a two carbon chain) or ethyl chloride.

For the above isomers of hexane the IUPAC names are: B 2-methylpentane C 3-methylpentane D 2,2-dimethylbutane E 2,3-dimethylbutane

Cycloalkanes

Cycloalkanes have one or more rings of carbon atoms. The simplest examples of this class consist of a single, unsubstituted carbon ring, and these form a homologous series similar to the unbranched alkanes. The IUPAC names of the first five members of this series are given in the following table. The last (yellow shaded) column gives the general formula for a cycloalkane of any size. If a simple unbranched alkane is converted to a cycloalkane two hydrogen atoms, one from each end of the chain, must be lost. Hence the general formula for a cycloalkane composed of n carbons is CₙH₂n. Although a cycloalkane has two fewer hydrogens than the equivalent alkane, each carbon is bonded to four other atoms so such compounds are still considered to be saturated with hydrogen.

<table>
<thead>
<tr>
<th>Name</th>
<th>Cyclopropane</th>
<th>Cyclobutane</th>
<th>Cyclopentane</th>
<th>Cyclohexane</th>
<th>Cycloheptane</th>
<th>Cycloalkane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molecular Formula</td>
<td>C₃H₆</td>
<td>C₄H₈</td>
<td>C₅H₁₀</td>
<td>C₆H₁₂</td>
<td>C₇H₁₄</td>
<td>CₙH₂n</td>
</tr>
</tbody>
</table>
Substituted cycloalkanes are named in a fashion very similar to that used for naming branched alkanes. The chief difference in the rules and procedures occurs in the numbering system. Since all the carbons of a ring are equivalent (a ring has no ends like a chain does), the numbering starts at a substituted ring atom.

**IUPAC Rules for Cycloalkane Nomenclature**

1. For a monosubstituted cycloalkane the ring supplies the root name (table above) and the substituent group is named as usual. A location number is unnecessary.
2. If the alkyl substituent is large and/or complex, the ring may be named as a substituent group on an alkane.
3. If two different substituents are present on the ring, they are listed in alphabetical order, and the first cited substituent is assigned to carbon #1. The numbering of ring carbons then continues in a direction (clockwise or counter-clockwise) that affords the second substituent the lower possible location number.
4. If several substituents are present on the ring, they are listed in alphabetical order. Location numbers are assigned to the substituents so that one of them is at carbon #1 and the other locations have the lowest possible numbers, counting in either a clockwise or counter-clockwise direction.
5. The name is assembled, listing groups in alphabetical order and giving each group (if there are two or more) a location number. The prefixes di, tri, tetra etc., used to designate several groups of the same kind, are not considered when alphabetizing.

Small rings, such as three and four membered rings, have significant angle strain resulting from the distortion of the sp³ carbon bond angles from the ideal 109.5° to 60° and 90° respectively. This angle strain often enhances the chemical reactivity of such compounds, leading to ring cleavage products. It is also important to recognize that, with the exception of cyclopropane, cycloalkyl rings are not planar (flat). The three dimensional shapes assumed by the common rings (especially cyclohexane and larger rings) are described and discussed in the [Conformational Analysis Section](#).

Hydrocarbons having more than one ring are common, and are referred to as **bicyclic** (two rings), **tricyclic** (three rings) and in general, **polycyclic** compounds. The molecular formulas of such compounds have H/C ratios that decrease with the number of rings. In general, for a hydrocarbon composed of **n carbon atoms** associated with **m rings** the formula is: $C_nH_{(2n + 2 - 2m)}$. The structural relationship of rings in a polycyclic compound can vary. They may be separate and independent, or they may share one or two common atoms. Some examples of these possible arrangements are shown in the following table.

<table>
<thead>
<tr>
<th>Structural Formula</th>
<th>Line Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>(CH₂)n</td>
<td>(CH₂)₁₃</td>
</tr>
<tr>
<td>H₂C—CH₃</td>
<td>△</td>
</tr>
<tr>
<td>H₂C—CH₃</td>
<td>□</td>
</tr>
<tr>
<td>H₂C—CH₃</td>
<td>⊙</td>
</tr>
<tr>
<td>H₂C—CH₃</td>
<td>⊙</td>
</tr>
<tr>
<td>H₂C—CH₃</td>
<td>⊙</td>
</tr>
<tr>
<td>(CH₂)n</td>
<td>(CH₂)₁₃</td>
</tr>
</tbody>
</table>

**Table 4: Examples of Isomeric \(C_{8}H_{14}\) Bicycloalkanes**

<table>
<thead>
<tr>
<th>Isolated Rings</th>
<th>Spiro Rings</th>
<th>Fused Rings</th>
<th>Bridged Rings</th>
</tr>
</thead>
</table>

---
Alkenes and Alkynes

Alkenes and alkynes are hydrocarbons which respectively have carbon-carbon double bond and carbon-carbon triple bond functional groups. The molecular formulas of these unsaturated hydrocarbons reflect the multiple bonding of the functional groups:

- **Alkane**: \( R-\text{CH}_2-\text{CH}_2-R \) \( \text{C}_n\text{H}_{2n+2} \)
  - This is the maximum H:C ratio for a given number of carbon atoms.
  - Each double bond reduces the number of hydrogen atoms by 2.

- **Alkene**: \( R-\text{CH}═\text{CH}-R \) \( \text{C}_n\text{H}_{2n} \)
  - Each double bond reduces the number of hydrogen atoms by 2.

- **Alkyne**: \( R-\text{C}≡\text{C}-R \) \( \text{C}_n\text{H}_{2n-2} \)
  - Each triple bond reduces the number of hydrogen atoms by 4.

As noted earlier in the Analysis of Molecular Formulas section, the molecular formula of a hydrocarbon provides information about the possible structural types it may represent. For example, consider compounds having the formula \( \text{C}_5\text{H}_8 \). The formula of the five-carbon alkane pentane is \( \text{C}_5\text{H}_{12} \) so the difference in hydrogen content is 4. This difference suggests such compounds may have a triple bond, two double bonds, a ring plus a double bond, or two rings. Some examples are shown here, and there are at least fourteen others!
IUPAC Rules for Alkene and Cycloalkene Nomenclature

1. The **ene** suffix (ending) indicates an alkene or cycloalkene.
2. The longest chain chosen for the root name must include both carbon atoms of the double bond.
3. The root chain must be numbered from the end nearest a double bond carbon atom. If the double bond is in the center of the chain, the nearest substituent rule is used to determine the end where numbering starts.
4. The smaller of the two numbers designating the carbon atoms of the double bond is used as the double bond locator. If more than one double bond is present the compound is named as a diene, triene or equivalent prefix indicating the number of double bonds, and each double bond is assigned a locator number.
5. In cycloalkenes the double bond carbons are assigned ring locations #1 and #2. Which of the two is #1 may be determined by the nearest substituent rule.
6. Substituent groups containing double bonds are:

   - H₂C=CH– Vinyl group
   - H₂C=CH–CH₂– Allyl group

IUPAC Rules for Alkyne Nomenclature

1. The **yne** suffix (ending) indicates an alkyne or cycloalkyne.
2. The longest chain chosen for the root name must include both carbon atoms of the triple bond.
3. The root chain must be numbered from the end nearest a triple bond carbon atom. If the triple bond is in the center of the chain, the nearest substituent rule is used to determine the end where numbering starts.
4. The smaller of the two numbers designating the carbon atoms of the triple bond is used as the triple bond locator.
5. If several multiple bonds are present, each must be assigned a locator number. Double bonds precede triple bonds in the IUPAC name, but the chain is numbered from the end nearest a multiple bond, regardless of its nature.
6. Because the triple bond is linear, it can only be accommodated in rings larger than ten carbons. In simple cycloalkynes the triple bond carbons are assigned ring locations #1 and #2. Which of the two is #1 may be determined by the nearest substituent rule.
7. Substituent groups containing triple bonds are:

   - HC≡C– Ethynyl group
   - HC≡CH–CH₂– Propargyl group

Benzene Derivatives

The nomenclature of substituted benzene ring compounds is less systematic than that of the alkanes, alkenes and alkynes. A few mono-substituted compounds are named by using a group name as a prefix to "benzene", as shown by the combined names listed below. A majority of these compounds, however, are referred to by singular names that are
unique. There is no simple alternative to memorization in mastering these names.

Two commonly encountered substituent groups that incorporate a benzene ring are phenyl, abbreviated Ph-, and benzyl, abbreviated Bn-. These are shown here with examples of their use. Be careful not to confuse a phenyl (pronounced fenyl) group with the compound phenol (pronounced feenol). A general and useful generic notation that complements the use of R- for an alkyl group is Ar- for an aryl group (any aromatic ring).

When more than one substituent is present on a benzene ring, the relative locations of the substituents must be designated by numbering the ring carbons or by some other notation. In the case of disubstituted benzenes, the prefixes ortho, meta & para are commonly used to indicate a 1,2- or 1,3- or 1,4- relationship respectively. In the following examples, the first row of compounds show this usage in red. Some disubstituted toluenes have singular names (e.g. xylene, cresol & toluidine) and their isomers are normally designated by the ortho, meta or para prefix. A few disubstituted benzenes have singular names given to specific isomers (e.g. salicylic acid & resorcinol). Finally, if there are three or more substituent groups, the ring is numbered in such a way as to assign the substituents the lowest possible numbers, as illustrated by the last row of examples. The substituents are listed alphabetically in the final name. If the substitution is symmetrical (third example from the left) the numbering corresponds to the alphabetical order.
Alkyl halides

One of the simplest functional groups is the alkyl halide. In an alkyl halide, one of the hydrogen atoms in an alkane has been replaced by a halogen. Alkyl halides are easy to name. The name of the alkane is preceded by the number of the carbon on which the halogen is substituted and the name of the halogen, modified so that -ine is replaced by -o (e.g. 2-bromopropane). Alkyl halides are treated the same as alkyl substituents; if a molecule contains both, they are ranked to give the lowest possible number to a substituent and then listed in alphabetical order. If a molecule contains an alkyl halide and a multiple bond, numbers are assigned to give the lowest number to the first functional group. In the event of a tie, the lowest number goes to the multiple bond.

Alcohols

The alcohol is a very common functional group and a very easy one to name. The molecule is named as if it were an alkane (or alkene or alkyne), except that the suffix -ane is replaced by -ol and the number of the carbon atom on which the -OH group is located is placed before the name of the compound (e.g. 2-butanol). The alcohol functional group takes precedence over alkyl substituents, multiple bonds, and halides and always gets the lowest number.

Ethers

An ether is a molecule consisting of two alkyl groups connected to an oxygen atom. Ethers are named by considering one alkyl group (the shorter one) plus the oxygen atom to be a substituent and the other alkyl group (the longer one) to be an alkane. The alkyl group plus oxygen atom is called an "alkoxy" substituent and is named by replacing -ane suffix from the alkane with -oxy (e.g. methane becomes methoxy). The allkoxy substituent gets priority over alkyl and halide substituents, but not over alcohols, which will get the lower number.

Amines

An amine is a derivatives of the molecule ammonia, NH₃, in which one or more of the hydrogens has been replaced by an alkyl substituent (R group). Amines are named by replacing the suffix -ane with -amine, like in alcohols. If there are further substituents attached to the nitrogen atom, they are preceded by N-. The amine gets the lowest number.

Contributors

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