

CHEM 2353
Fundamentals of Organic Chemistry

Chapter
1 Organic Compounds:
Alkanes

Organic and Biochemistry for Today (4th ed.)
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Organic chemistry nowadays almost drives me mad. To me it appears like a primeval tropical forest full of the most remarkable things, a dreadful endless jungle into which one does not dare enter, for there seems to be no way out.

Friedrich Wöhler

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What is Organic Chemistry?

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What Do We Mean By “Organic”?

- In everyday usage, the word **organic** can be found in several different contexts:
 - chemicals extracted from plants and animals were originally called “organic” because they came from living organisms.
 - organic fertilizers are obtained from living organisms.
 - organic foods are foods grown without the use of pesticides or synthetic fertilizers.
- In chemistry, the words “organic” and “organic chemistry” are defined a little more precisely:

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What is Organic Chemistry?

- **Organic chemistry** is concerned with the study of the structure and properties of compounds containing **carbon**.
 - All organic compounds contain carbon atoms.
 - Inorganic compounds contain no carbons. Most inorganic compounds are *ionic compounds*.
- Some carbon compounds are not considered to be organic (mostly for historical reasons), such as CO, CO₂, diamond, graphite, and salts of carbon-containing polyatomic ions (e.g., CO₃²⁻, CN⁻).
- **Inorganic chemistry** is the study of the other elements and non-carbon containing compounds.

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The Periodic Table

- There are 92 naturally occurring elements, and many artificial ones, in the (in)famous Periodic Table:

	IA																						VIII A	
1	H	II A																						He
2	Li	Be																	B	C	N	O	F	Ne
3	Na	Mg	III B		IV B	V B		VI B	VII B		III B			I B	II B	Al	Si	P	S	Cl	Ar			
4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr						
5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe						
6	Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn						
7	Fr	Ra	Ac	Rf	Db	Sg	Bh	Hs	Mt	Uun	Uuu	Uub		Uuq										

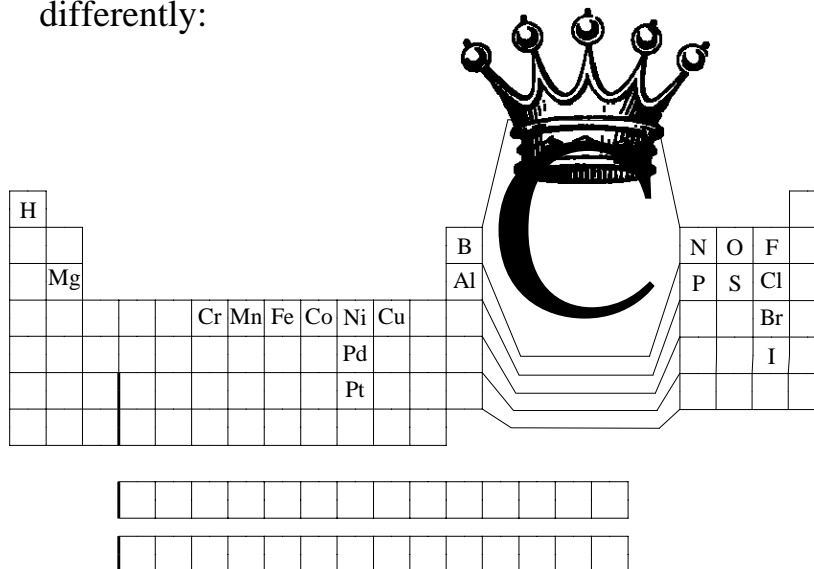
Lanthanides	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
-------------	----	----	----	----	----	----	----	----	----	----	----	----	----	----

Actinides	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr
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The Periodic Table of Organic Chemistry

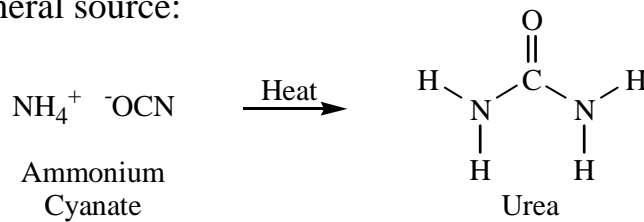
- Organic chemists look at the Periodic Table a little differently:



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Origins of Organic Chemistry

- Organic literally means “derived from living organisms” — organic chemistry was originally the study of compounds extracted from living organisms and their natural products.
- It was believed that only living organisms possessed the “vital force” necessary to create organic compounds (“vitalism”).
- This concept started to change in 1828 after Friedrich Wöhler showed that it was possible to make urea, a known “organic compound” from a mineral source:



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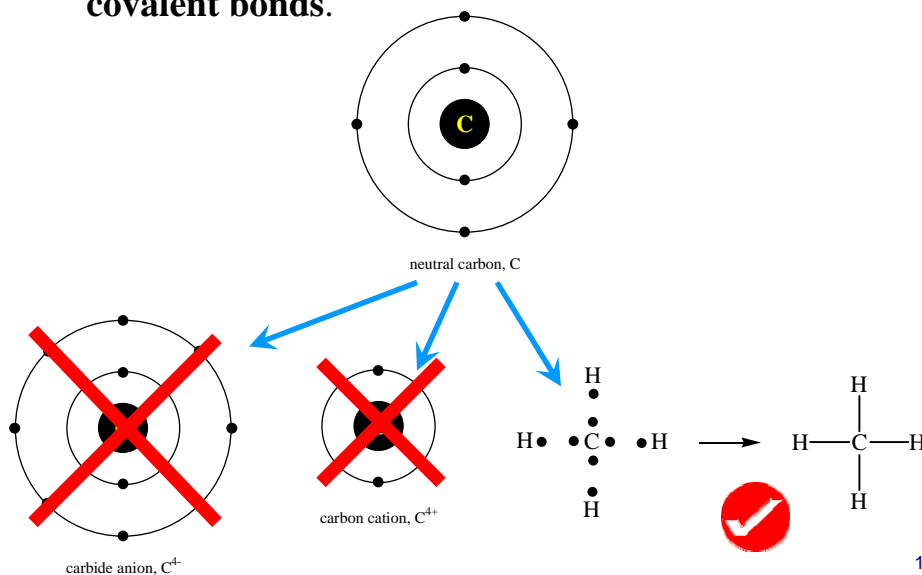
Origins of Organic Chemistry

- What this and later experiments showed was that “organic” molecules — even those made by living organisms — can be handled and synthesized just like minerals and metals
- What was special about these molecules was that *they contained the element **carbon**.*

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What's So Great About Carbon?

- Carbon atoms can be linked by strong, stable **covalent bonds**.



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What's So Great About Carbon?

- Carbon atoms can form **stable bonds to many other elements** (H, F, Cl, Br, I, O, N, S, P, etc.). Most organic compounds contain a few hydrogens, and sometimes oxygen, nitrogen, sulfur, phosphorus, etc.
- Carbon atoms can form **complex structures**, such as *long chains, branched chains, rings, chiral compounds* (having a particular “handedness”), *complex 3D shapes*, etc.
- Because of this variety in bonding and complexity, carbon atoms can form a **tremendous variety of compounds**. More than 16,000,000 organic compounds are known, as opposed to about 600,000 inorganic compounds.

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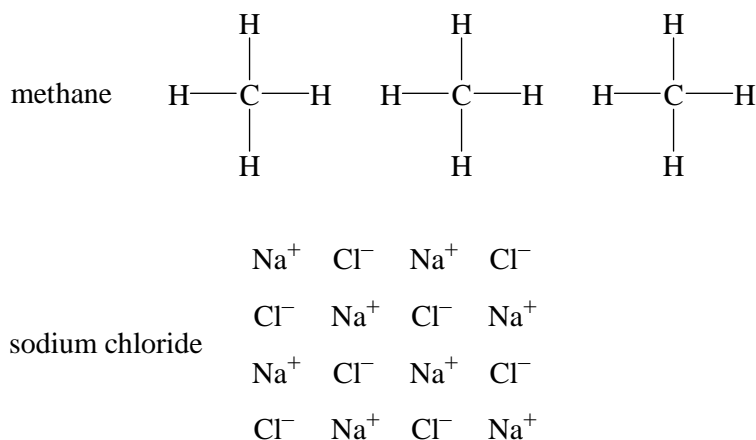
What's So Great About Carbon?

- Complex organic compounds can perform a number of **useful biological functions** (vitamins, carbohydrates, lipids, proteins, enzymes, ATP, DNA, RNA are all organic compounds) which are studied in **biochemistry**.
- Complex organic compounds are present in the **foods** we eat (carbohydrates, proteins, fats, etc.)
- Most **medicines**, whether they come from a chemical plant or a green plant, are organic compounds.
- Most **fuels** are organic compounds (wood, coal, natural gas, gasoline, kerosene, diesel fuel, oil, and other petroleum-based products).
- Complex organic compounds are also **useful in technology** (paints, plastics, rubber, textiles, etc.).

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Organic vs. Inorganic Compounds

- Organic compounds are held together by **covalent bonds**, while inorganic compounds are held together by **ionic bonds**.



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Organic vs. Inorganic Compounds

Table 1.1 Properties of typical organic and inorganic compounds.

Property	Organic	Inorganic
Bonding within molecules	Usually covalent	Often ionic
Forces between molecules	Generally weak	Quite strong
Normal physical state	Gases, liquids, or low melting-point solids	Usually high melting-point solids
Flammability	Often flammable	Usually nonflammable
Solubility in water	Often low	Often high
Conductivity of aqueous solutions	Nonconductor	Conductor

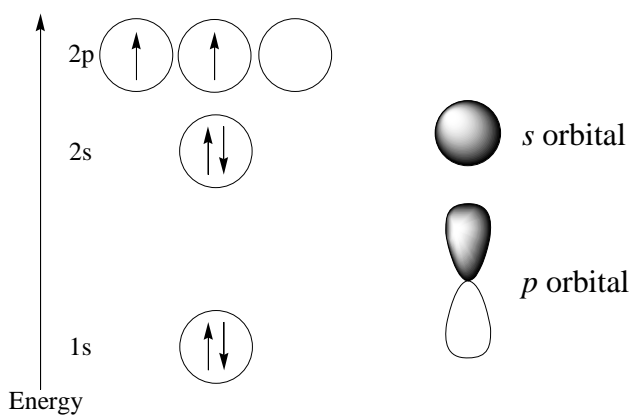
14

Bonding in Organic Compounds

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Atomic Orbitals on Carbon

- A carbon atom does not form ions easily, since it has four valence electrons ($1s^2 2s^2 2p^2$). It satisfies the octet rule in compounds by sharing electrons.

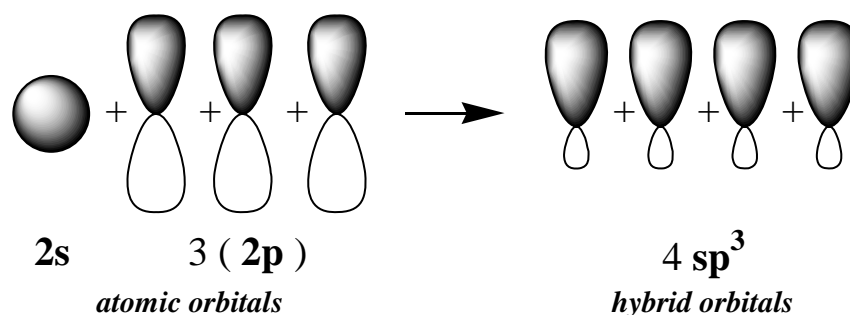


- These are the orbitals that exist on atomic carbon (not connected to anything).

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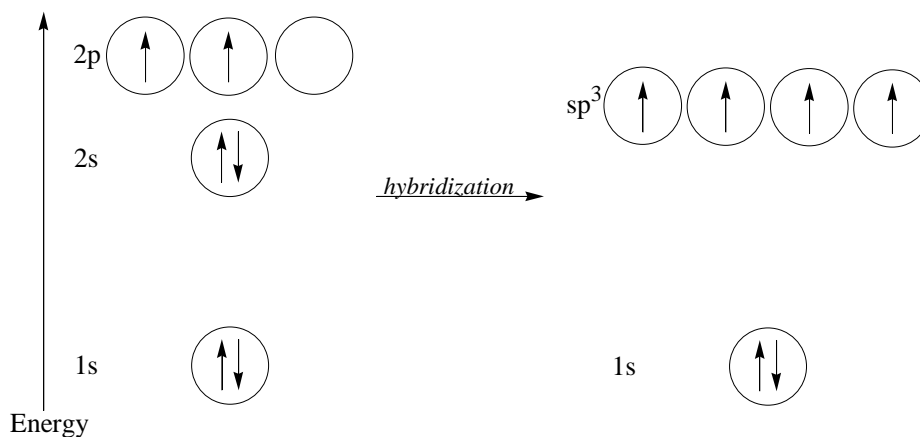
Hybrid Orbitals

- When carbon atoms form bonds with each other, we describe the resulting bonds using **hybrid orbitals**, which are formed by mixing (*hybridizing*) the carbon's atomic orbitals. (Linus Pauling, 1950s)
- When carbon atoms bond to 4 other atoms, the $2s$ and all three $2p$ orbitals in the valence shell combine to produce **four sp^3 orbitals**:



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Hybrid Orbitals

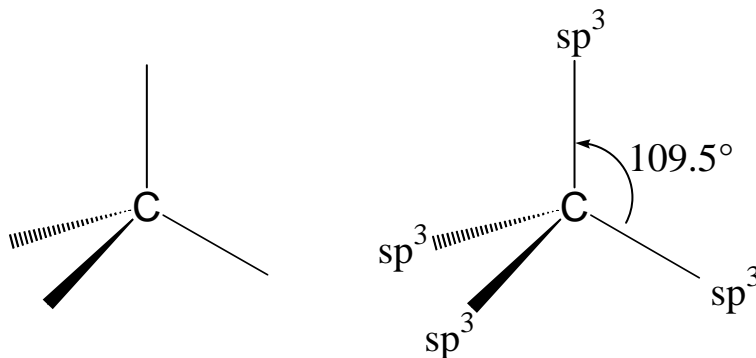


- All four sp^3 orbitals are at the same energy level, with one electron in each hybrid orbital.

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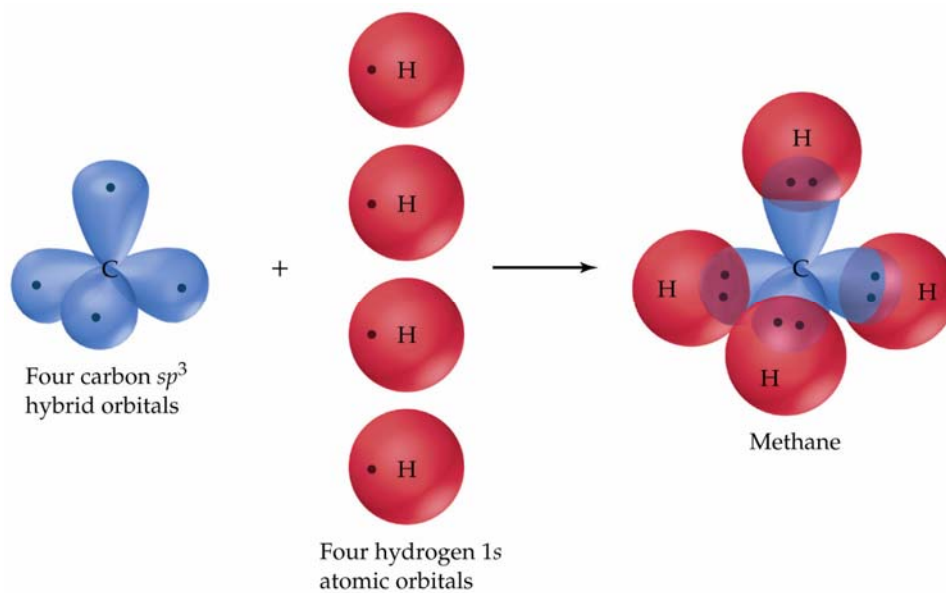
The Shape of an sp^3 Carbon

- In order to get as far away from each other as possible (thus minimizing electron-electron repulsions), the sp^3 orbitals are arranged in the shape of a **tetrahedron** around the central carbon atom, with bond angles of **109.5°**.



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The Shape of an sp^3 Carbon



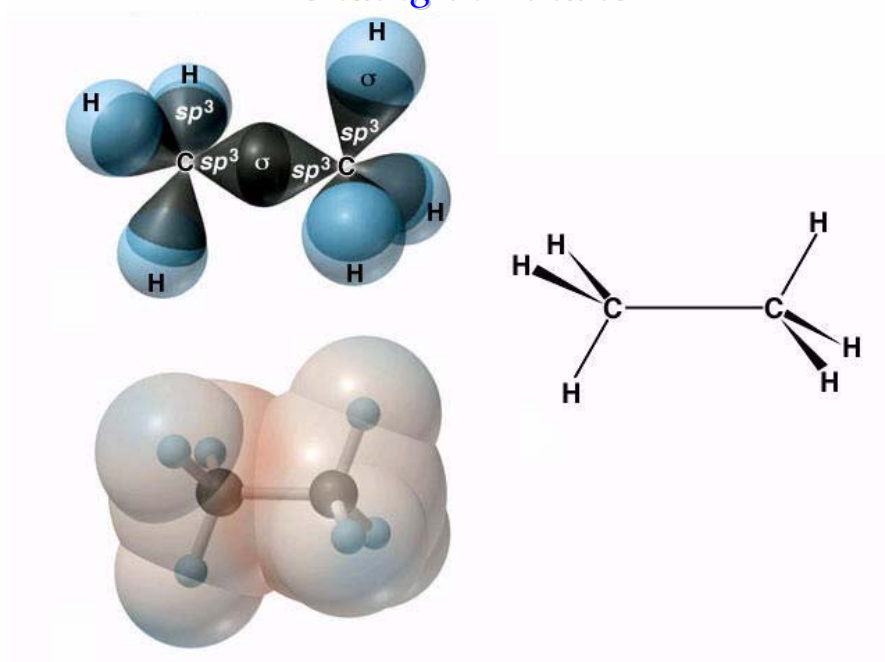
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Bonding in Ethane

- Bonds arise from the **overlap** of orbitals on adjacent atoms.
 - End-on-end overlap of sp^3 orbitals produces a **σ -bond (sigma bond)**.
 - All single bonds are σ -bonds.
 - *Free rotation* is possible around σ -bonds.
- Each carbon in the ethane molecule, CH_3CH_3 , is sp^3 -hybridized and tetrahedral in shape. Free rotation is possible around the C—C bond. (*See next slide*)

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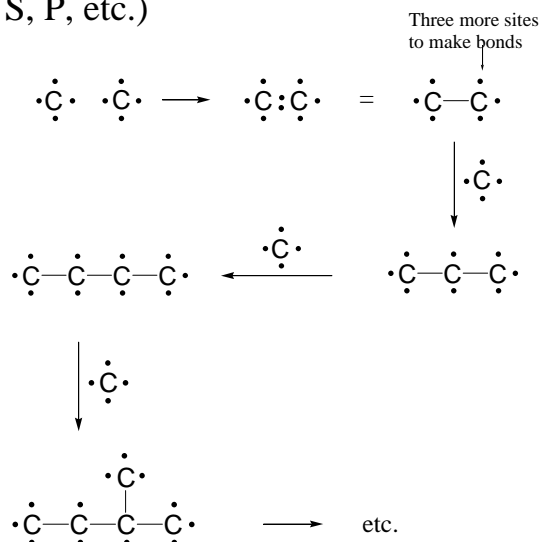
Bonding in Ethane



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Carbon Chains

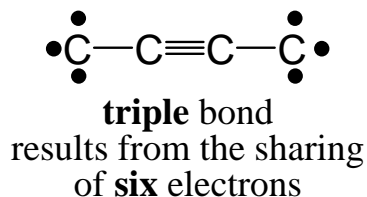
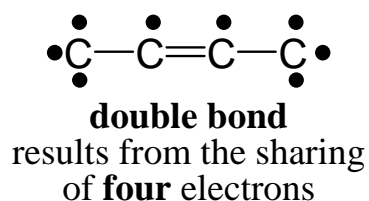
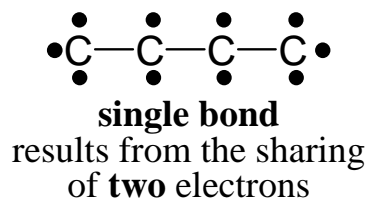
- Each carbon atom can form **four bonds**, either to other carbon atoms, or to different atoms (such as H, O, N, S, P, etc.)



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Multiple Bonds

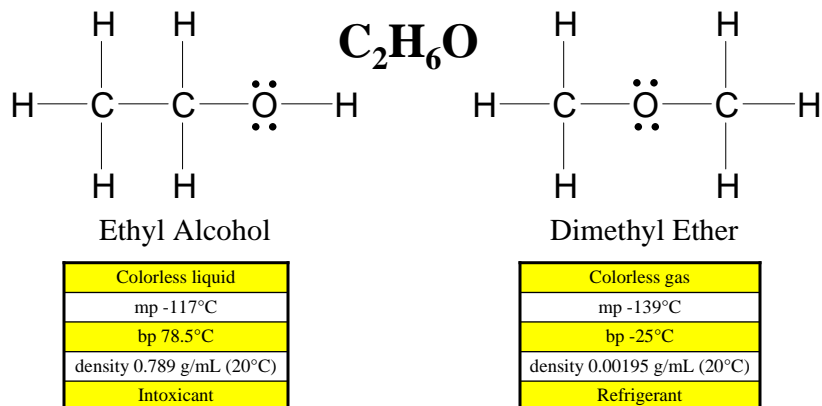
- Carbon atoms form four bonds to other things, but sometimes those bonds are **multiple bonds** (*double* or *triple* bonds):



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Isomers

- **Isomers** — compounds having identical molecular formulas, but different arrangements of atoms.
- **Structural Isomers** — the atoms in each molecule are connected in a different order.



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Examples: Isomers

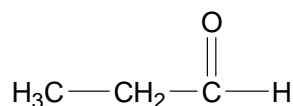
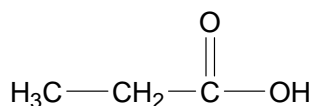
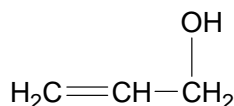
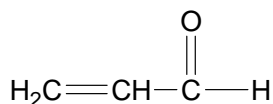
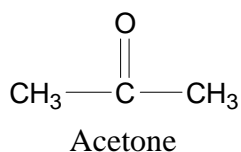
- Draw all possible structures having the formulas C_4H_{10} , C_5H_{12} , and C_6H_{14} .

C_7H_{16} 9 isomers
 C_8H_{18} 13 isomers
 C_9H_{20} 35 isomers
 $\text{C}_{10}\text{H}_{22}$ 75 isomers
 $\text{C}_{20}\text{H}_{42}$ 366,319 isomers
 $\text{C}_{30}\text{H}_{62}$ 4,111,846,763 isomers!
 $\text{C}_{40}\text{H}_{82}$ 62,481,801,147,341 isomers!

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Examples: Isomers

- Which of the following molecules is a structural isomer of acetone?




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Functional Groups

- Organic molecules are often organized by structures called **functional groups**, which are characteristic arrangement of atoms which define many of the physical and chemical properties of a class of organic compounds.
 - The simplest of the functional groups are the **hydrocarbons**, which include the **alkanes**, **alkenes**, **alkynes**, and **aromatic hydrocarbons**.
 - Many functional groups contain oxygen atoms, such as **alcohols**, **ethers**, **aldehydes**, **ketones**, **carboxylic acids**, and **esters**.
 - Some other functional groups contain nitrogen atoms, such as the **amines** and **amides**.
- Molecules with the same functional group tend to share similar chemical and physical properties.

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Table 1.2 Classes and functional groups of organic compounds

Class	Functional Group	Example of expanded structural formula	Example of condensed structural formula	IUPAC / Common name
Alkane	None	$\begin{array}{c} \text{H} & \text{H} \\ & \\ \text{H}-\text{C} & -\text{C}-\text{H} \\ & \\ \text{H} & \text{H} \end{array}$	CH_3CH_3	ethane
Alkene	$\begin{array}{c} \diagup & \diagdown \\ & \text{C}=\text{C} \\ \diagdown & \diagup \end{array}$	$\begin{array}{c} \text{H} & \text{H} \\ & \diagdown & \diagup \\ & \text{C}=\text{C} \\ & \diagup & \diagdown \\ \text{H} & \text{H} \end{array}$	$\text{H}_2\text{C}=\text{CH}_2$	ethene (ethylene)
Alkyne	$-\text{C}\equiv\text{C}-$	$\text{H}-\text{C}\equiv\text{C}-\text{H}$	$\text{HC}\equiv\text{CH}$	ethyne (acetylene)
Aromatic	$\begin{array}{c} \diagup & & \diagdown \\ & \text{C}=\text{C} & \\ \diagdown & & \diagup \\ & \text{C}=\text{C} & \\ \diagup & & \diagdown \end{array}$	$\begin{array}{c} \text{H} & & \text{H} \\ & \diagdown & \diagup \\ & \text{C}=\text{C} & \\ & \diagup & \diagdown \\ \text{H}-\text{C} & & \text{C}-\text{H} \\ & \diagdown & \diagup \\ & \text{C}=\text{C} & \\ & \diagup & \diagdown \\ \text{H} & & \text{H} \end{array}$		benzene
Alcohol	$\begin{array}{c} \\ -\text{C}-\text{O}-\text{H} \\ \end{array}$	$\begin{array}{c} \text{H} & \text{H} \\ & \\ \text{H}-\text{C} & -\text{C}-\text{O}-\text{H} \\ & \\ \text{H} & \text{H} \end{array}$	$\text{CH}_3\text{CH}_2\text{OH}$	ethyl alcohol
Ether	$\begin{array}{c} & \\ -\text{C}-\text{O}-\text{C}- \\ & \end{array}$	$\begin{array}{c} \text{H} & & \text{H} \\ & & \\ \text{H}-\text{C} & -\text{O}- & \text{C}-\text{H} \\ & & \\ \text{H} & & \text{H} \end{array}$	CH_3OCH_3	methoxymethane (dimethyl ether)

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Table 1.2 Classes and functional groups of organic compounds

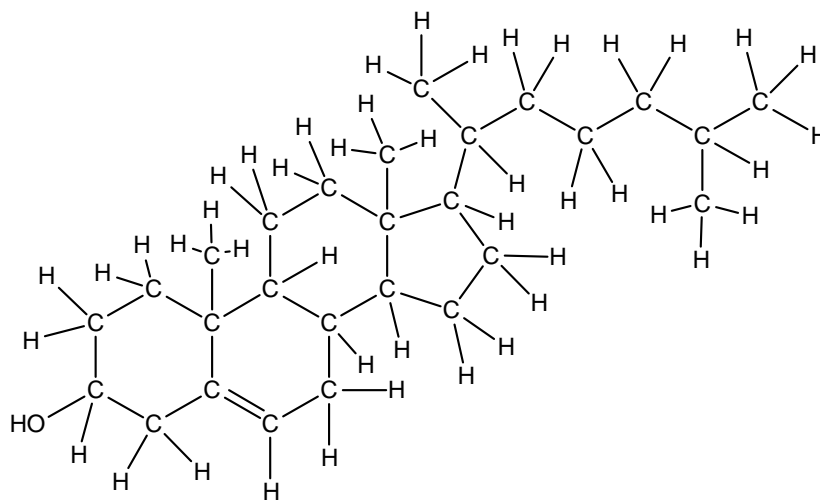
Class	Functional Group	Example of expanded structural formula	Example of condensed structural formula	IUPAC / Common name
Aldehyde	$\begin{array}{c} \text{O} \\ \\ -\text{C}-\text{H} \end{array}$	$\begin{array}{c} \text{H} & \text{O} \\ & \\ \text{H}-\text{C} & -\text{C}-\text{H} \\ \\ \text{H} \end{array}$	$\begin{array}{c} \text{O} \\ \\ \text{CH}_3\text{CH} \end{array}$	ethanal (acetaldehyde)
Ketone	$\begin{array}{c} & \text{O} & \\ & & \\ -\text{C} & -\text{C} & -\text{C}- \\ & & \end{array}$	$\begin{array}{c} \text{H} & \text{O} & \text{H} \\ & & \\ \text{H}-\text{C} & -\text{C} & -\text{C}-\text{H} \\ & & \\ \text{H} & & \text{H} \end{array}$	$\begin{array}{c} \text{O} \\ \\ \text{CH}_3\text{CCH}_3 \end{array}$	2-propanone (acetone)
Carboxylic acid	$\begin{array}{c} \text{O} \\ \\ -\text{C}-\text{O}-\text{H} \end{array}$	$\begin{array}{c} \text{H} & \text{O} \\ & \\ \text{H}-\text{C} & -\text{C}-\text{O}-\text{H} \\ \\ \text{H} \end{array}$	$\begin{array}{c} \text{O} \\ \\ \text{CH}_3\text{COH} \end{array}$	ethanoic acid (acetic acid)
Ester	$\begin{array}{c} \text{O} & \\ & \\ -\text{C}-\text{O}-\text{C}- \\ & \end{array}$	$\begin{array}{c} \text{H} & \text{O} & \text{H} \\ & & \\ \text{H}-\text{C} & -\text{C}-\text{O}- & \text{C}-\text{H} \\ & & \\ \text{H} & & \text{H} \end{array}$	$\begin{array}{c} \text{O} \\ \\ \text{CH}_3\text{COCH}_3 \end{array}$	methyl ethanoate (methyl acetate)
Amine	$\begin{array}{c} \text{H} \\ \\ -\text{N}-\text{H} \end{array}$	$\begin{array}{c} \text{H} & \text{H} \\ & \\ \text{H}-\text{C} & -\text{N}-\text{H} \\ \\ \text{H} \end{array}$	CH_3NH_2	methylamine
Amide	$\begin{array}{c} \text{O} \\ \\ -\text{C}-\text{N}- \\ \end{array}$	$\begin{array}{c} \text{H} & \text{O} \\ & \\ \text{H}-\text{C} & -\text{C}-\text{N}-\text{H} \\ & \\ \text{H} & \end{array}$	$\begin{array}{c} \text{O} \\ \\ \text{CH}_3\text{CNH}_2 \end{array}$	ethanamide (acetamide)

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Drawing Organic Compounds

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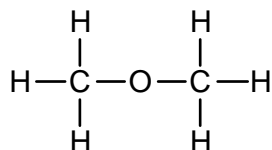
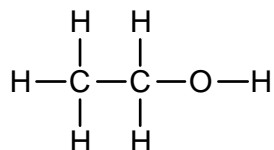
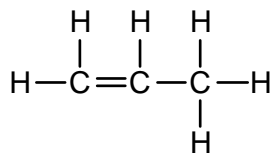
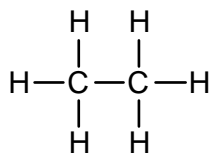
A Moderately Complex Organic Molecule



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Expanded Structural Formulas

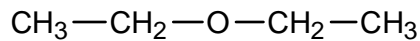
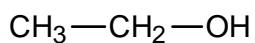
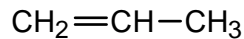
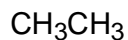
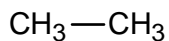
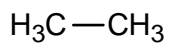
- In **expanded structural formulas** (Lewis formulas, Lewis structures), *all* atoms and bonds are shown:



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Condensed Structural Formulas

- In **condensed structural formulas**, only specific bonds are shown; this is useful in reducing the number of C—H bonds that must be drawn.



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Line Drawings

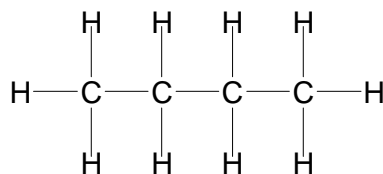
- In **line drawings** (line-angle formulas, skeletal structures, stick figures), bonds are represented by lines; everywhere two lines meet or a line begins or ends is a C atom. H's on C's are not shown (except for emphasis); H's on other atoms *must* be shown.



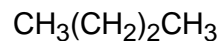
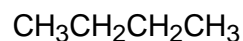
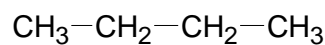
35

Drawing Organic Molecules

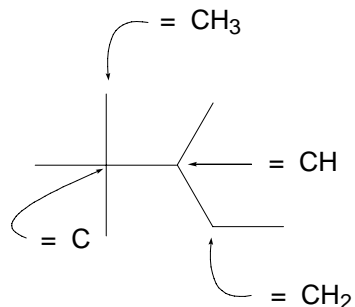
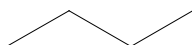
Expanded structural formula
(Lewis structure)



Condensed structural formulas



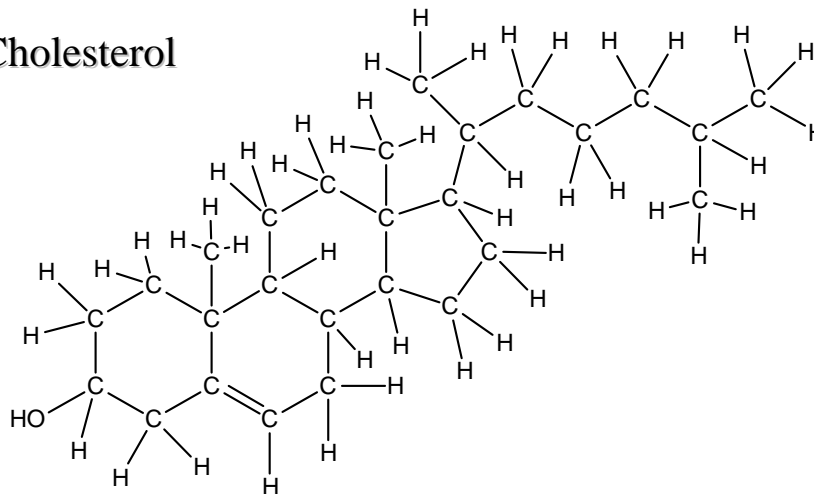
Line drawing



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Drawing Organic Molecules

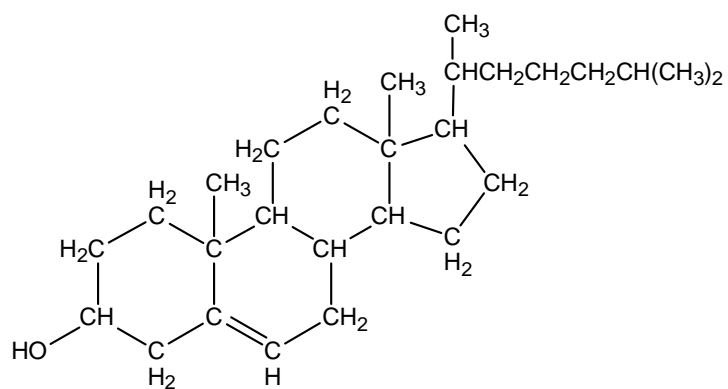
Cholesterol



Expanded Structural Formula

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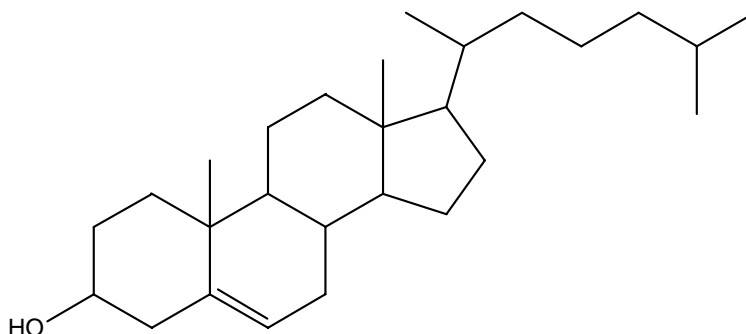
Drawing Organic Molecules



Condensed Structure

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Drawing Organic Molecules

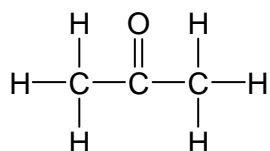
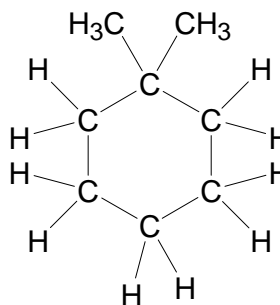
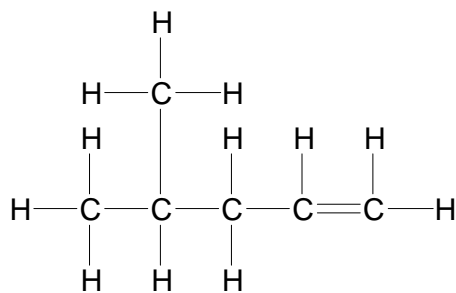


Line Drawing

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Examples: Drawing Organic Molecules

- Draw acceptable condensed structures and line drawings associated with the following expanded structural formulas.



- Draw an acceptable expanded structure and line drawing for the molecule $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$.

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Examples: Drawing Organic Molecules

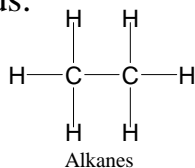
- Draw acceptable expanded structures, condensed structures, and line drawings for the following molecules:
 - isopropyl alcohol, $\text{CH}_3\text{CH}(\text{OH})\text{CH}_3$
 - acetic acid, CH_3COOH
 - acetaldehyde, CH_3CHO
 - acetone, CH_3COCH_3

Hydrocarbons and Alkane Nomenclature

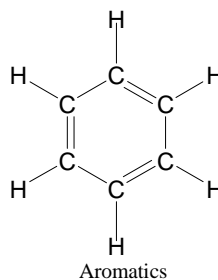
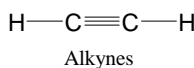
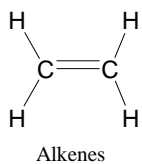
43

Hydrocarbons

- **Hydrocarbons** — compounds that contain only carbon and hydrogen.
- **Saturated Hydrocarbons** — contain only carbon-carbon single bonds.



- **Unsaturated Hydrocarbons** — contain carbon-carbon double or triple bonds.



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Alkanes

- **Alkanes** are *saturated hydrocarbons* — each carbon holds the maximum number of hydrogen atoms).
 - Alkanes contain only carbon-carbon single bonds.
 - General formula: C_nH_{2n+2} (no rings).
- Most chemical reactions require a functional group “handle” to proceed. Since alkanes don’t really have functional groups, they aren’t very useful in many biologically important processes.
 - Since alkanes undergo combustion easily, they are a good source of energy (e.g., gasoline).
 - Alkanes also provide the raw materials for the production of many other more complex substances (plastics, etc.).

45

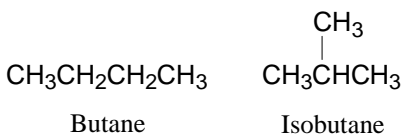
Some Common Alkanes

- **Methane, CH_4**
 - major component of natural gas (~85%), which is produced by bacterial decomposition of organisms in the absence of oxygen (marsh gas, cow flatulence).
 - burns cleanly, so is useful for cooking.
 - odorless — ethanethiol is added to make natural gas leaks detectable.
- **Ethane, CH_3CH_3 (C_2H_6)** — a minor component of natural gas (~10%).
- **Propane, $CH_3CH_2CH_3$ (C_3H_8)** — used as an industrial fuel, and in home heating and cooking.

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Some Common Alkanes

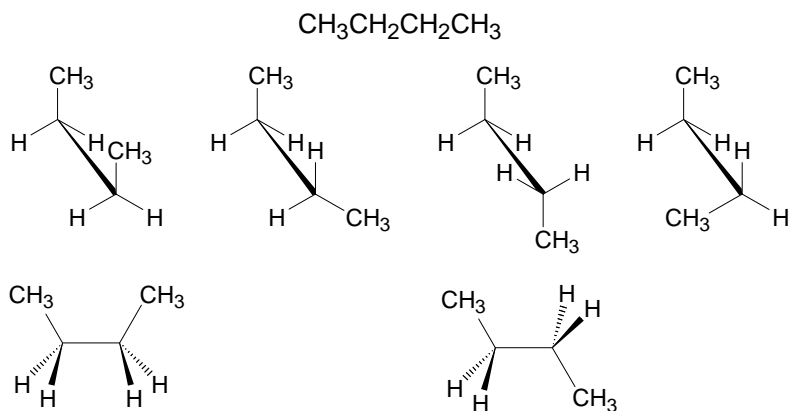
- **Butane**, $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3$ (C_4H_{10})
 - cigarette lighters
 - Butane is an **unbranched (normal) alkane**.
There is also a **branched alkane** with the formula C_4H_{10} , having a three-carbon chain with a one-carbon group connected to the middle.
 - We must give the other isomer a different name: $\text{CH}_3\text{CH}(\text{CH}_3)\text{CH}_3$ [or $\text{CH}_3\text{CH}(\text{CH}_3)_2$] is named **isobutane** (or 2-methylpropane).
 - Butane and isobutane are structural isomers of each other.



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Conformations of Alkanes

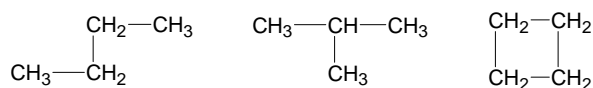
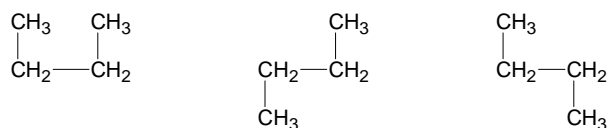
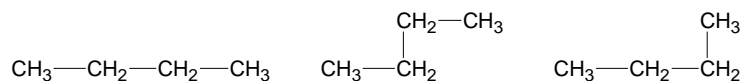
- **Conformation** — the different arrangements of atoms in space achieved by rotation about single bonds.
- Structures which are related to each other by rotation around a single bond are *the same molecule*.



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Examples: Conformations and Isomers

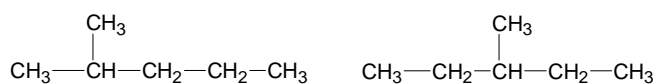
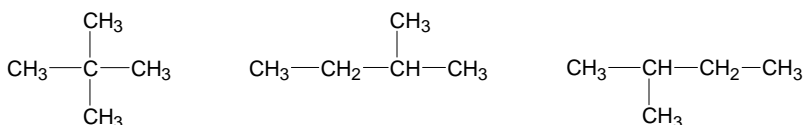
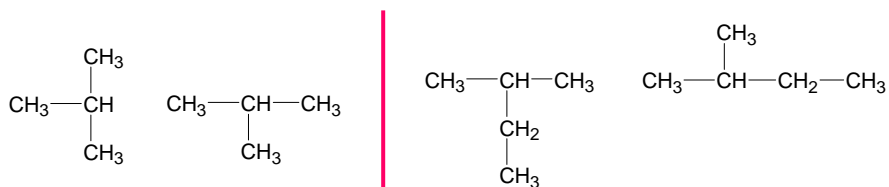
- Which of the following groups represent structural isomers, and which are simply the same compound?



49

Examples: Conformations and Isomers

- Which of the following groups represent structural isomers, and which are simply the same compound?



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Alkane Nomenclature

- Straight-chain alkanes are named by combining a **prefix** which indicates the *number of carbon atoms in the chain*, and a **suffix** indicating the *functional group* of the molecule.

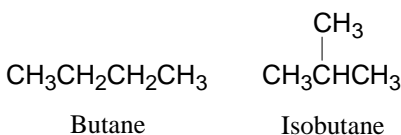
No. of C's	Prefix
1	meth-
2	eth-
3	prop-
4	but-
5	pent-
6	hex-
7	hept-
8	oct-
9	non-
10	dec-

Functional Group	Suffix
Alkane	-ane
Alkene	-ene
Alkyne	-yne

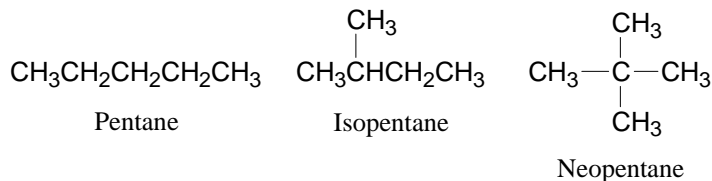
51

Alkane Nomenclature

- When alkanes are branched, things get more complex. Remember there are two isomers of C_4H_{10} :



- There are three isomers of C_5H_{12} :

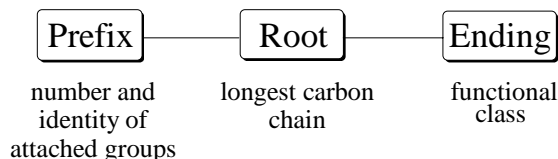


- There are 75 isomers of $C_{10}H_{22}$!
- We need a way to name molecules that doesn't require memorizing a huge number of prefixes.

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IUPAC System of Chemical Nomenclature

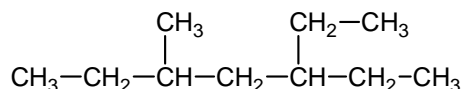
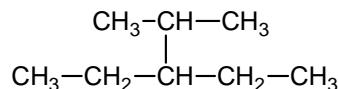
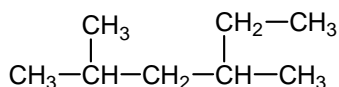
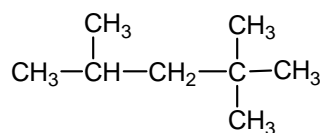
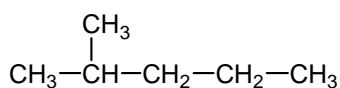
- The system of nomenclature used to name organic compounds was developed by the **International Union of Pure and Applied Chemistry (IUPAC)**.
 - A **root** identifies the **longest continuous chain of carbon atoms**.
 - A **suffix** identifies the **main functional group** in the molecule.
 - A set of **prefixes** identifies the numbers and positions of the **substituents** (groups which are attached to the longest chain). (**Alkyl groups** are substituents which contain a carbon chain.)



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IUPAC Nomenclature of Alkanes

- **Step 1.** Identify and name the **longest continuous chain** of C atoms (#C + **-ane** for alkanes).



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IUPAC Nomenclature of Alkanes

- **Step 2. Number the atoms** in the longest chain.
 - Number consecutively from the end that will give the lower number to any C to which a group is attached.
 - If two or more alkyl groups are attached to the longest chain, use the numbering path that gives the lowest number for the first point of difference.
 - If two different alkyl groups are attached at the same distance from either end of the chain, the one that comes first in alphabetical order has the highest priority.
 - If there is more than one way to get a certain number of atoms in the longest chain, go with the way that gives more substituents.

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IUPAC Nomenclature of Alkanes

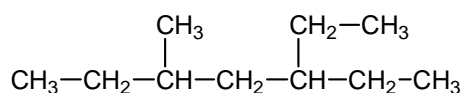
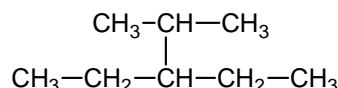
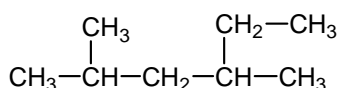
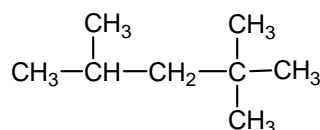
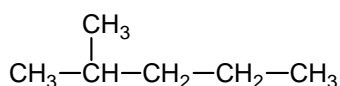
- **Step 3.** Name the **alkyl groups (#C + -yl) and other substituents** connected to the longest chain. In front of each alkyl group name, put the number of the carbon the group is attached to, separated from the name by a dash (e.g., 2-methyl).
- **Step 4.** If there is more than one of a particular substituent, **combine them into a single word using the appropriate counting prefix** (di-, tri-, tetra-, etc.). Include all of the carbon numbers which the groups are attached to, separated by commas (e.g., 2,2,3-trimethyl).

No. of Groups	Prefix	No. of Groups	Prefix
1	—	6	hexa-
2	di-	7	hepta-
3	tri-	8	octa-
4	tetra-	9	nona-
5	penta-	10	deca-

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IUPAC Nomenclature of Alkanes

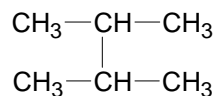
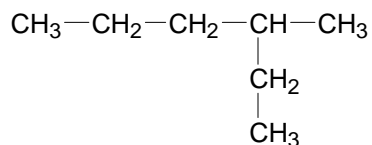
- **Step 5. Arrange the alkyl groups in front of the parent name in alphabetical order** (ignoring counting prefixes). Always separate numbers by commas, and numbers from words by dashes.



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Examples: Alkane Nomenclature

- Draw structural formulas and give the correct names for all of the possible structural isomers of butane.
- Draw structural formulas and give the correct names for all of the possible structural isomers of pentane.
- Draw structural formulas and give the correct names for all of the possible structural isomers of hexane.
- Provide acceptable IUPAC names for the following molecules:



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Common Substituents

Common Alkyl Groups

methyl	—CH_3	butyl	$\text{—CH}_2\text{CH}_2\text{CH}_2\text{CH}_3$
ethyl	$\text{—CH}_2\text{CH}_3$		
propyl	$\text{—CH}_2\text{CH}_2\text{CH}_3$	<i>sec</i> -butyl	$\begin{array}{c} \text{CH}_3 \\ \\ \text{—CH—CH}_2\text{—CH}_3 \end{array}$
isopropyl	$\begin{array}{c} \text{CH}_3 \\ \\ \text{—CH—CH}_3 \end{array}$	isobutyl	$\begin{array}{c} \text{CH}_3 \\ \\ \text{—CH}_2\text{—CH—CH}_3 \end{array}$
		<i>tert</i> -butyl	$\begin{array}{c} \text{CH}_3 \\ \\ \text{—C—CH}_3 \\ \\ \text{CH}_3 \end{array}$

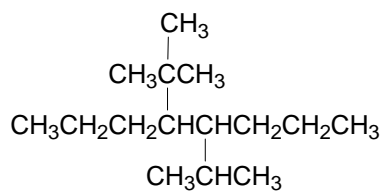
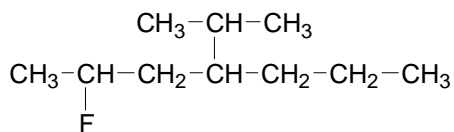
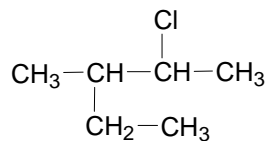
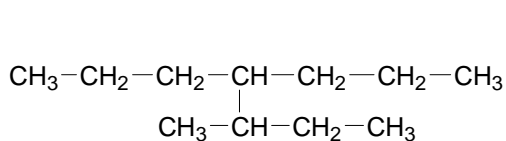
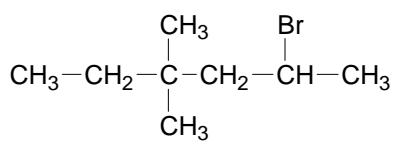
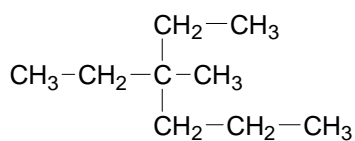
Common Nonalkyl Groups

fluoro	—F	iodo	—I
chloro	—Cl	nitro	—NO_2
bromo	—Br	amino	—NH_2

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Examples: Alkane Nomenclature

- Provide acceptable IUPAC names for the following molecules:



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Examples: Alkane Nomenclature

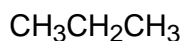
- Draw condensed structural formulas or line drawings for each of the following compounds:
 - 3-ethylpentane
 - 2,2-dimethylbutane
 - 3-ethyl-2-methylhexane
 - 4-isopropyloctane
 - 6-*sec*-butyl-7-ethyl-2,2,5,8-tetramethylnonane
- The following names have been assigned incorrectly. Draw the structure corresponding to the name, and assign the correct IUPAC name.
 - 3-*sec*-butylpentane
 - 2-ethyl-2,6-dimethylhexane



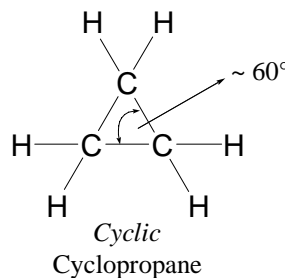
61

Cycloalkanes

- Alkanes may also possess **cyclic** structures in addition to the straight- and branched-chain **acyclic** molecules we have already seen.
- General formula: C_nH_{2n} (for one ring)



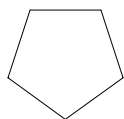
Acyclic
Propane



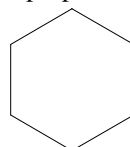
Note that these
molecules are
not structural
isomers of
each other!



cyclobutane



cyclopentane



cyclohexane



cyclooctane

62

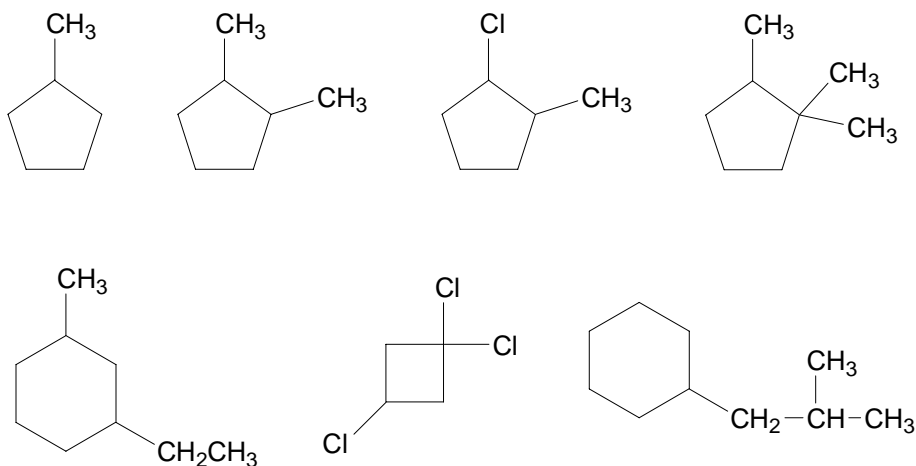
Cycloalkane Nomenclature

- When naming cycloalkanes, the ring is taken to be the longest chain; the prefix **cyclo-** is added to the normal root + -suffix.
- When mono-substituted cycloalkanes are named, it is not necessary to specify the position number, since all positions in the ring are equivalent.
- When more than one substituent is located on a ring, the numbering begins at the carbon to which the group is attached which comes first in alphabetical order, and then proceeds in a direction which gives the lowest possible number to the next attached group.

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Examples: Cycloalkane Nomenclature

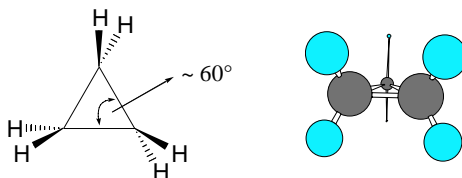
- Provide acceptable IUPAC names for the following molecules:



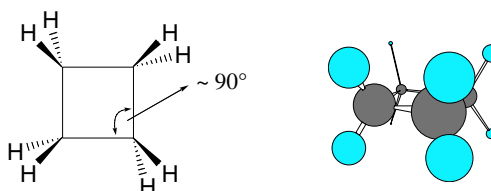
64

The Shape of Cycloalkanes

- Cyclopropane has bond angles of 60° , which is bent far away from the “normal” 109.5° bond angles of straight-chain alkanes. It is a flat molecule.



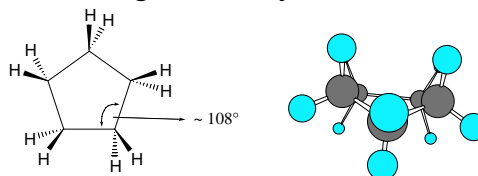
- Cyclobutane has bond angles of about 90° ; it is also less stable than a “normal” alkane. It is mostly flat, but there is some slight puckering of the ring.



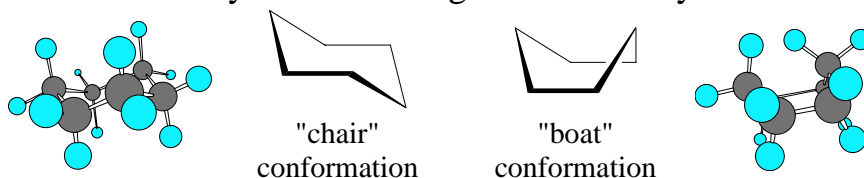
65

The Shape of Cycloalkanes

- Cyclopentane has bond angles of about 108° ; it forms a mostly flat but slightly puckered ring. Cyclopentane rings are very common in nature.



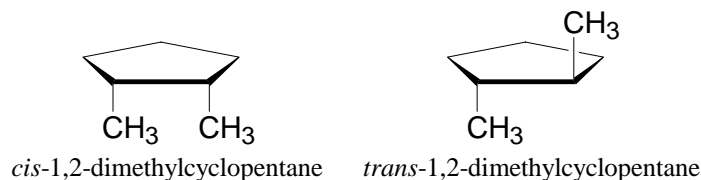
- If cyclohexane were flat, the bond angles would be about 120° ; but this molecule can adopt a “chair” or “boat” conformation in which the bond angles are 109.5° . Cyclohexane rings are extremely common.



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Stereoisomers of Cycloalkanes

- The molecules below are different molecules because *there is no free rotation around carbon-carbon bonds in cycloalkanes*.

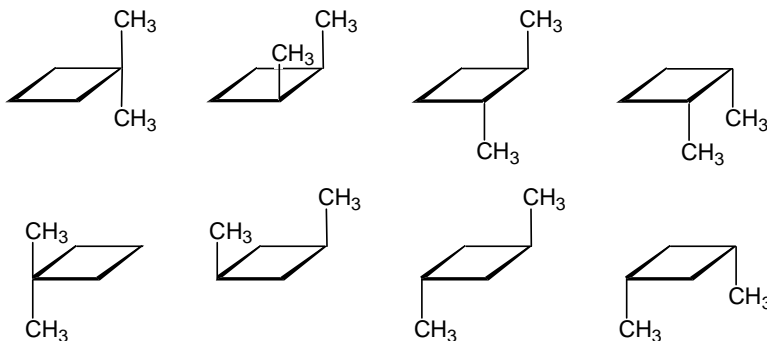


- These molecules are **stereoisomers** — compounds with the same molecular and structural formula but different spatial arrangements of atoms.
- Stereoisomers in which the spatial arrangement is maintained by rings (or double bonds) are called **geometric isomers** or **cis-trans isomers**.

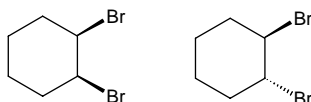
67

Examples: Stereoisomers

- State whether each possible pairing of the molecules below are structural isomers, geometric isomers, or the same molecule.



- Name the following molecules:



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Physical and Chemical Properties of Alkanes

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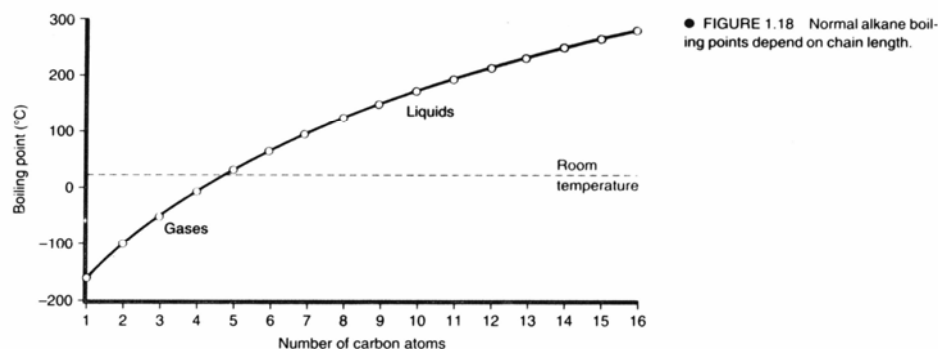
Physical Properties of Alkanes

- Since alkanes are composed of relatively nonpolar C—C bonds and C—H bonds, **alkanes are nonpolar molecules**.
- Because they have only weak attractions for each other, they tend to have lower melting points and boiling points than other organic compounds of comparable molecular weights.
- The straight chain alkanes make up a **homologous series** in which each member differs from a previous member by having one additional CH_2 group. In a homologous series, the physical properties are closely related and vary in a systematic way.

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■ TABLE 1.8 Physical properties of some normal alkanes

Carbon atoms (no.)	IUPAC name	Condensed structural formula	Melting point (°C)	Boiling point (°C)	Density (g/mL)
1	methane	CH ₄	-182.5	-164.0	0.55
2	ethane	CH ₃ CH ₃	-183.2	-88.6	0.57
3	propane	CH ₃ CH ₂ CH ₃	-189.7	-42.1	0.58
4	butane	CH ₃ CH ₂ CH ₂ CH ₃	-138.4	-0.5	0.60
5	pentane	CH ₃ CH ₂ CH ₂ CH ₂ CH ₃	-129.7	36.1	0.63
6	hexane	CH ₃ CH ₂ CH ₂ CH ₂ CH ₂ CH ₃	-95.3	68.9	0.66
7	heptane	CH ₃ CH ₂ CH ₂ CH ₂ CH ₂ CH ₂ CH ₃	-90.6	98.4	0.68
8	octane	CH ₃ CH ₂ CH ₂ CH ₂ CH ₂ CH ₂ CH ₂ CH ₃	-56.8	125.7	0.70
9	nonane	CH ₃ CH ₂ CH ₂ CH ₂ CH ₂ CH ₂ CH ₂ CH ₂ CH ₃	-53.5	150.8	0.72
10	decane	CH ₃ CH ₂ CH ₂ CH ₂ CH ₂ CH ₂ CH ₂ CH ₂ CH ₂ CH ₃	-29.7	174.1	0.73

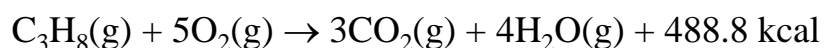
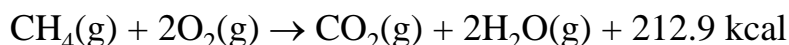


Physical Properties of Alkanes

- The general rule when judging solubility is “like dissolves like” — polar substances mix with polar substances, nonpolar with nonpolar, but not polar with nonpolar.
- Alkanes (nonpolar) are **insoluble in water** (polar), and since they are less dense than water, they **float** (e.g., oil slicks).
- Alkanes and other substances that do not dissolve in water are often referred to as being **hydrophobic** (“water fearing”).
- Liquid alkanes of high molecular weight serve as emollients (skin softeners) to replace oils washed away by bathing or swimming.
 - Vaseline is a semisolid mixture of alkanes.

Alkane Reactions

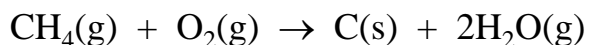
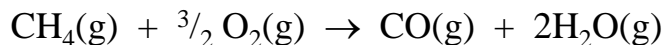
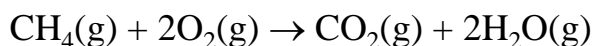
- Alkanes are the least reactive of all organic compounds. They do not usually react with strong acids or bases, or with most oxidizing or reducing agents.
- They do, however, burn very easily in combustion reactions, releasing a great deal of energy:



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Alkane Reactions

- In the absence of enough oxygen for complete conversion to carbon dioxide, some common waste products are generated in the incomplete burning of alkanes:



- CO, carbon monoxide, is poisonous, colorless, and odorless. In the exhaust train of most cars, a *catalytic converter* converts CO to CO₂.
- Solid elemental carbon produces engine deposits; but this reaction is done to produce lampblack, which is used in some ink pigments.

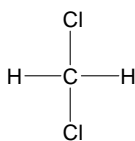
74

Alkyl Halides

- **Alkyl halides**, or **haloalkanes**, are alkanes in which one or more hydrogen atoms are replaced by halogen atoms (F, Cl, Br, or I).
- Most alkyl halides are not very water-soluble. Alkyl fluorides and chlorides have densities that are higher than those of alkanes, but still less than that of water. Alkyl bromides and iodides are generally more dense than water. Compounds containing more than one halogen are often more dense than water.
- Alkyl halides are named as alkanes with *halo-*substituents (*fluoro-*, *bromo-*, *chloro-*, and *iodo-*).
- A number of simple alkyl halides are better known by their common names; for instance, CHCl_3 , trichloromethane, is almost always referred to as “chloroform.”

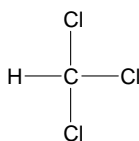
75

Some Common Alkyl Halides



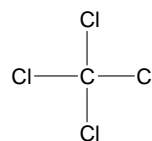
Dichloromethane (methylene chloride)

A colorless, mildly toxic liquid (bp 41°C) more dense than water. It is used as a paint remover and degreaser. It is also used to decaffeinate coffee beans; since it has such a low boiling point, the residual solvent can be removed from the beans at fairly low temperatures.



Trichloromethane (chloroform)

A colorless liquid (bp 60°C); a very commonly used organic solvent. Chloroform vapor is an anesthetic: James Young Simpson was the first to use chloroform as an anesthetic during childbirth in 1846 (presumably, not on himself!), and it was widely used in surgery in the 19th and early 20th centuries. However, since chloroform is carcinogenic, and toxic to the liver, it is not widely used for this purpose anymore.

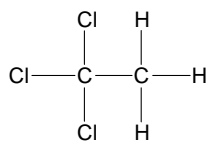


Tetrachloromethane (carbon tetrachloride)

Formerly a common organic solvent, and was widely used for dry cleaning and spot removal; it has been shown to be toxic and carcinogenic, and contributes to ozone depletion, so it has been replaced by other solvents.

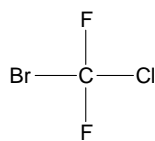
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Some Common Alkyl Halides



1,1,1-Trichloroethane

Formerly a very commonly used organic solvent; heavily used in dry cleaning, but it has been replaced by other solvents (such as tetrachloroethylene).

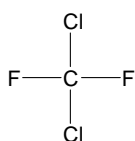


Bromochlorodifluoromethane (Halon 1211)

An example of a **halon**, a haloalkane that has bromine atoms in addition to chlorine and fluorine atoms. Halons are very stable, and are useful in fire extinguishers, since they do not damage electronic equipment. Their use has largely been phased out under the Montreal Protocols, but they are still used in fire suppression systems aboard some aircraft, since no completely satisfactory and safe alternatives have been discovered.

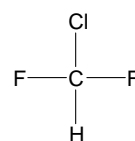
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Chlorofluorocarbons (CFCs)



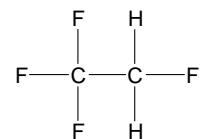
Dichlorodifluoromethane (Freon-12)

An example of the **chlorofluorocarbons** (CFCs, or **freons**), developed in the 1920s; they are relatively nontoxic, very unreactive, and boil at low temperatures, and were thus ideal for use as refrigerants; they were also widely used as aerosol propellants and as foaming agents. Unfortunately, they persist in the environment for a long time (up to a century), and make their way into the upper atmosphere, where they are split by high energy light from the Sun, releasing chlorine atoms. These Cl atoms destroy ozone in the stratospheric ozone layer that shields us from much of the Sun's UV radiation. (F. Sherwood Rowland, Mario J. Molina, Paul Crutzen, Nobel Prize in Chemistry, 1995) In 1987, a treaty called the Montreal Protocol on Substances that Deplete the Ozone Layer was signed, which cut back on the production and use of CFCs; in 1990, in response to the alarming increase in the size of the "ozone hole" over the South Pole, the agreement was extended to become a ban on the use of CFCs starting in 2000.



Chlorodifluoromethane (Freon-22)

An example of a **hydrochlorofluorocarbon** (HCFC), developed as alternatives to the CFCs. The HCFCs are not fully halogenated, and are less stable than the CFCs, and degrade before they reach the upper atmosphere.



1,1,1,2-Tetrafluoroethane (Freon-134a)

A **hydrofluorocarbon** (HFC), another group of CFC-alternatives that are not damaging to the ozone layer. Freon-134a is now widely used in the air conditioning systems of automobiles in place of Freon-12.

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Petroleum

- **Petroleum** is a mixture of hydrocarbons formed over millions of years, primarily from the decay of microscopic ocean-dwelling plants and animals. The resulting crude oil collects in underground pockets in sedimentary rock.
- Petroleum is separated into different fractions by *fractional distillation*.
- Most petroleum products are burned as fuel, but about 2% is used to synthesize other organic compounds. (That's still a lot!)
- Over half of all synthetic industrial organics, including dyes, drugs, plastics, fibers, detergents, insecticides, etc., are made from petroleum sources

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Table 1.9 Petroleum Fractions

Fraction	Boiling Range	Molecular-size range	Typical uses
Gas	-164-30°C	C ₁ -C ₄	Heating, cooking
Gasoline	30-200°C	C ₅ -C ₁₂	Motor fuel
Kerosene	175-275°C	C ₁₂ -C ₁₆	Fuel for stoves; diesel and jet engines
Heating oil	Up to 375°C	C ₁₅ -C ₁₈	Furnace oil
Lubricating oils	350°C-up	C ₁₆ -C ₂₀	Lubrication, mineral oil
Greases	Semisolid	C ₁₈ -up	Lubrication, petroleum jelly
Paraffin (wax)	Melts 52-57°C	C ₂₀ -up	Candles, toiletries
Pitch and tar	Residue in boiler	High	Roofing, asphalt paving

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Carbon, in fact, is a singular element: it is the only element that can bind itself in long stable chains without a great expense of energy, and for life on earth (the only one we know so far) precisely long chains are required. Therefore carbon is the key element of living substance: but its promotion, its entry into the living world, is not easy and must follow an obligatory, intricate path . . . If the elaboration of carbon were not a common daily occurrence, on the scale of billions of tons a week, wherever the green of a leaf appears, it would by full right deserve to be called a miracle.

Primo Levi, "Carbon" in
The Periodic Table (1975)

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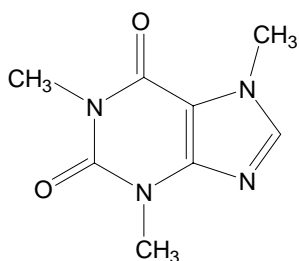
The End

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Complex Organic Names

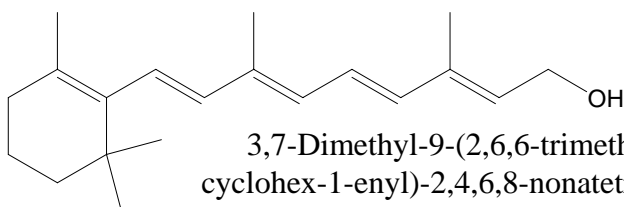
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Complex Organic Names



3,7-Dihydro-1,3,7-trimethyl-1H-purine-2,6-dione

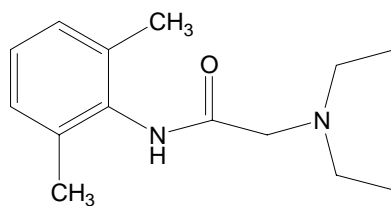
Caffeine



3,7-Dimethyl-9-(2,6,6-trimethyl-1-cyclohex-1-enyl)-2,4,6,8-nonatetraen-1-ol

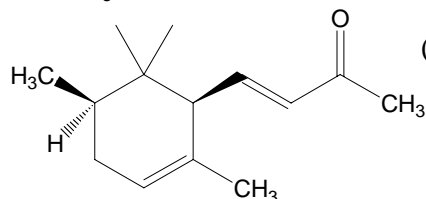
Vitamin A

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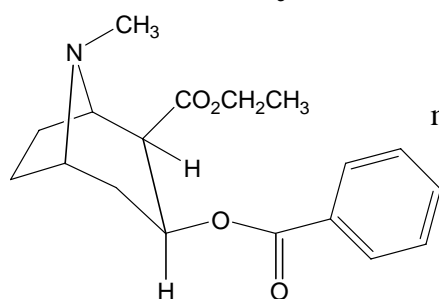
2-Diethylamino-*N*-(2,6-dimethylphenyl)acetamide

Lidocaine



(+)-*cis*- α -4-(2,5,6,6-tetramethyl-2-cyclohexen-1-yl)-3-butene-2-one

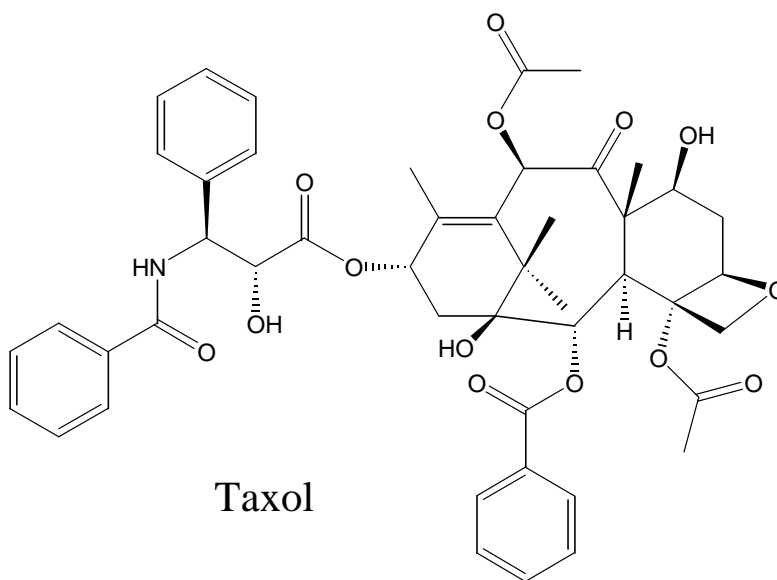
α -Irone



[1*R*-(exo,exo)]-3-benzyloxy-8-methyl-8-azabicyclo[3.2.1]octane-2-carboxylic acid ethyl ester

Cocaine

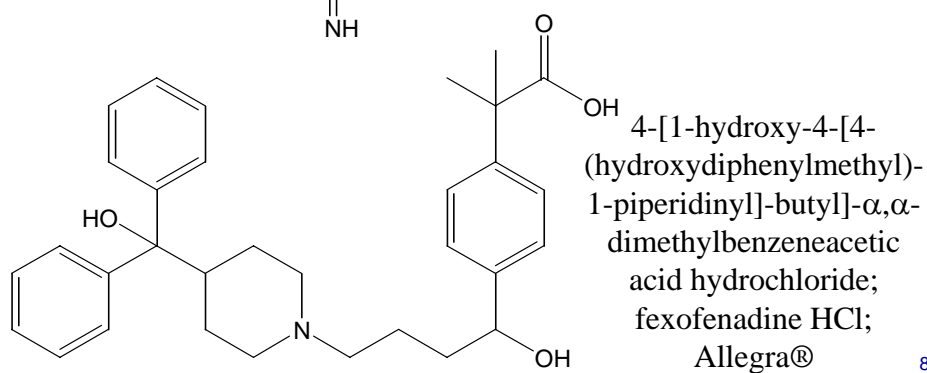
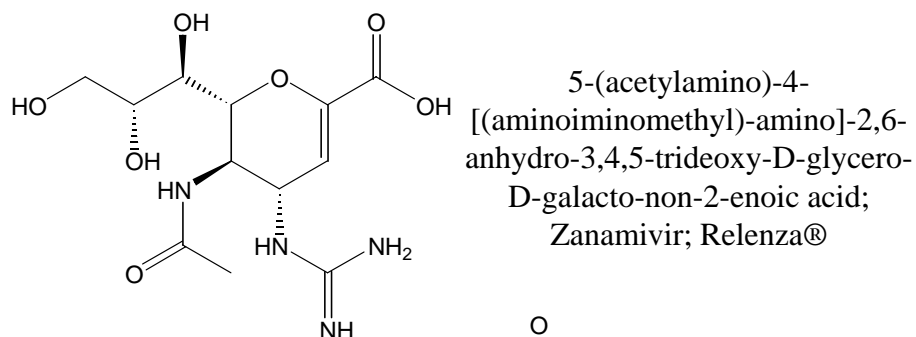
85



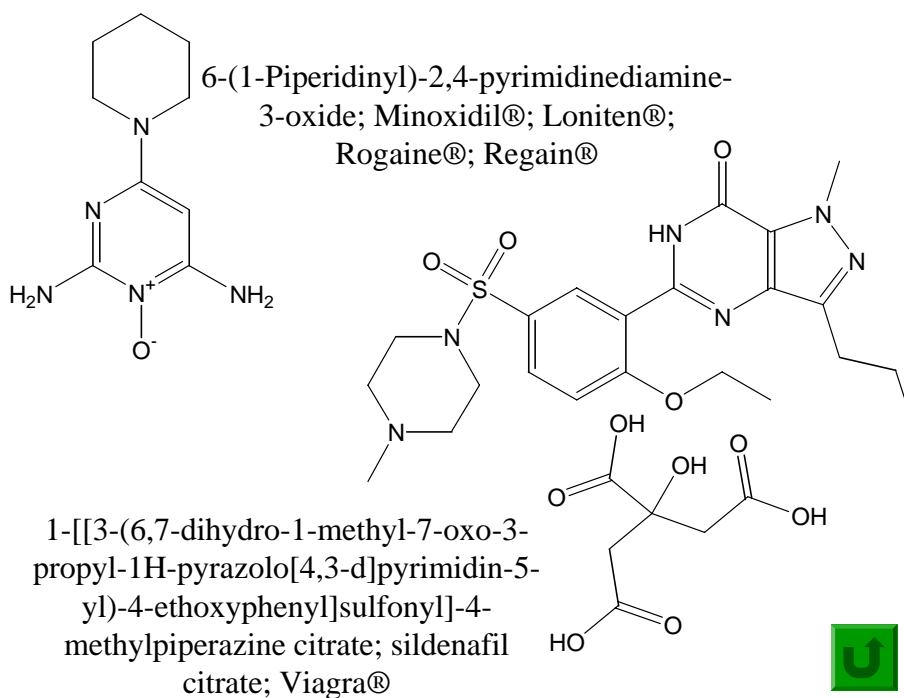
Taxol

5- β , 20-epoxy-1,2- α -4,7- β , 10- β , 13- α -hexahydroxytax-11-en-9-one 4,10-diacetate 2-benzoate 13-ester with (2*R*,3*S*)-*N*-benzoyl-3-phenylisoserine

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