Chem101

General Chemistry

Lecture 10

Organic Compounds:

Alkanes

Organic Compounds

- Carbon containing molecules are organic molecules.
  - Exceptions include:
    - √ CO_2
    - √ CO
    - √ CN^-
    - √ CO_3^{2-}
  - Though containing carbon, these molecules are considered inorganic.

Organic Compounds

- Organic compounds are derived from living systems.
- Most of the matter we interact with is organic.

Exercise

Look around the room you are now sitting in and identify 3 items made of organic compounds and 3 items made of inorganic compounds

Organic *versus* Inorganic

- Numbers know molecules:
  - Organic ≈ 6,000,000
  - Inorganic ≈250,000
- Typical bonding:
  - Organic: covalent bonds
  - Inorganic: ionic bonds
- Size
  - Organic, carbon can form very long straight and branched chains

Organic *versus* Inorganic

- Forces between molecules
  - Organic: weak
  - Inorganic: strong
- Physical states
  - Organic: gases, liquids and low melting point solids
  - Inorganic: high melting point solids
- Flammability
  - Organic: usually flammable
  - Inorganic: usually not flammable

Exercise 11.5

Classify each of the following compounds as organic or inorganic:

a. KBr
b. H_2O
c. H-C≡C-H
d. Li
e. CH_3-NH_3

Exercise 11.9

Devise a test, based on the general properties in Table 11.1, that you could use to quickly distinguish between the substances in each of the following pairs:

a. Gasoline (liquid, organic) and water (liquid, inorganic)
b. Naphthalene (solid, organic) and sodium chloride (solid, inorganic)
c. Methane (gaseous, organic) and hydrogen chloride (gaseous, inorganic)

Bonding Characteristics

- Carbon has 4 electrons in its valence shell
- Carbon needs 4 electrons to fill its valence shell
  - The “octet” rule
- The electronic configuration for carbon is $1s^2,2s^2,2p^2$

Bonding Characteristics

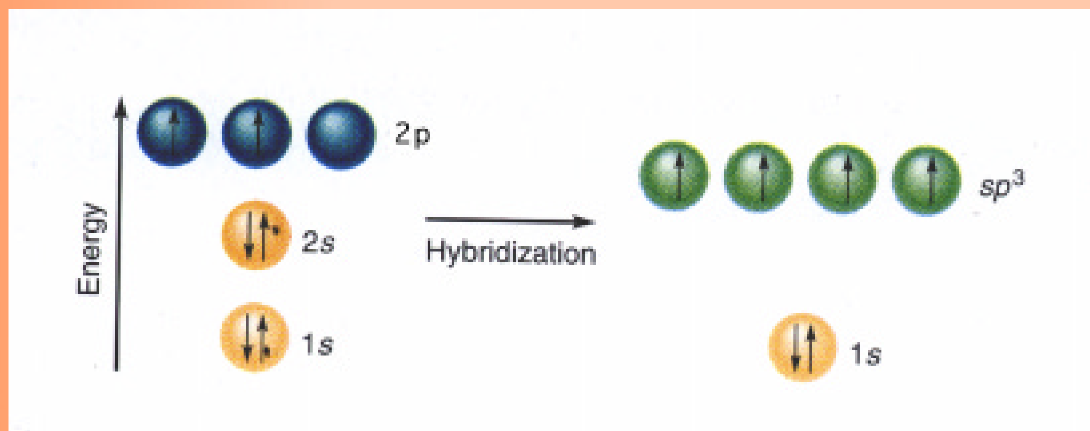
- The two electrons in the *2p* orbitals are in half-filled orbitals and therefore available to form covalent bonds.
  - However, this only allows carbon to form two covalent bonds and carbon needs four to satisfy the octet rule

Bonding Characteristics

- Linus Pauling proposed a solution to this problem:
  - The *2s* orbital mixes with the three *2p* orbitals to form four hybrid orbitals having equal energies.
  - The hybrid orbitals are called sp^3 orbitals.
  - Each of the four sp^3 orbitals one valence electron and each can form a covalent bond.

Bonding Characteristics

- The *2s* orbital mixes with the three *2p* orbitals to form four hybrid orbitals having equal energies.



Bonding Characteristics

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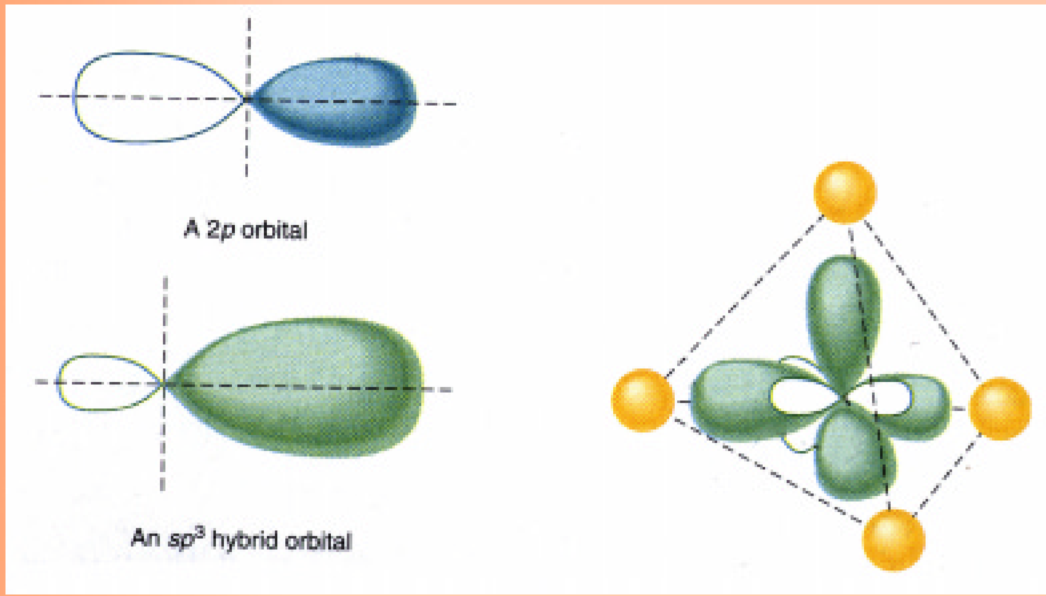
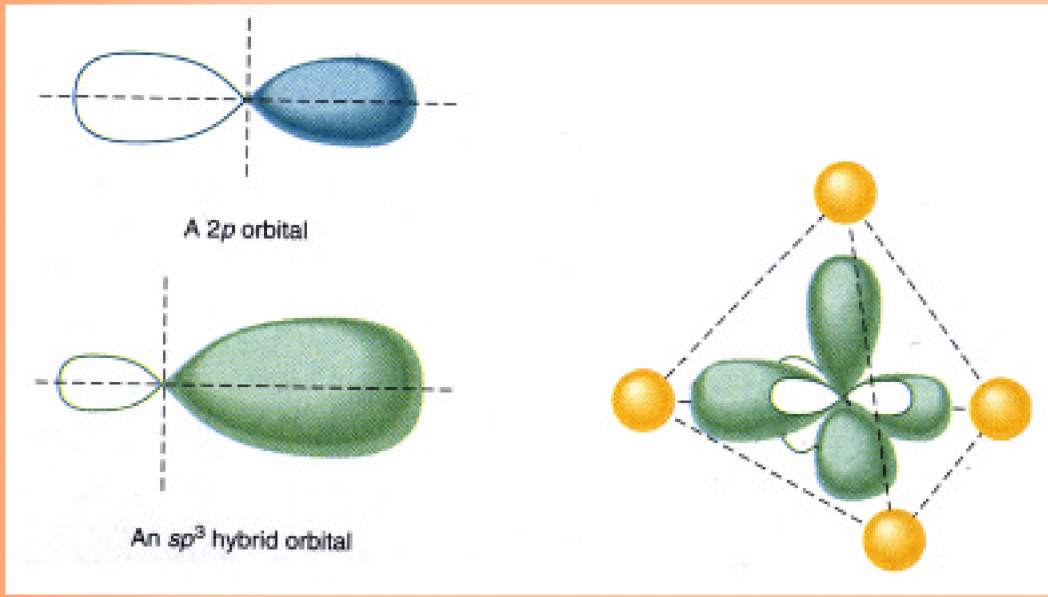


Bonding Characteristics

- The four *sp*^{3} orbitals point away from each other to form a tetrahedral geometry



Bonding Characteristics

- In methane (CH_4), each of the four *sp*^{3} orbitals forms a single σ (sigma) bond with a hydrogen atom

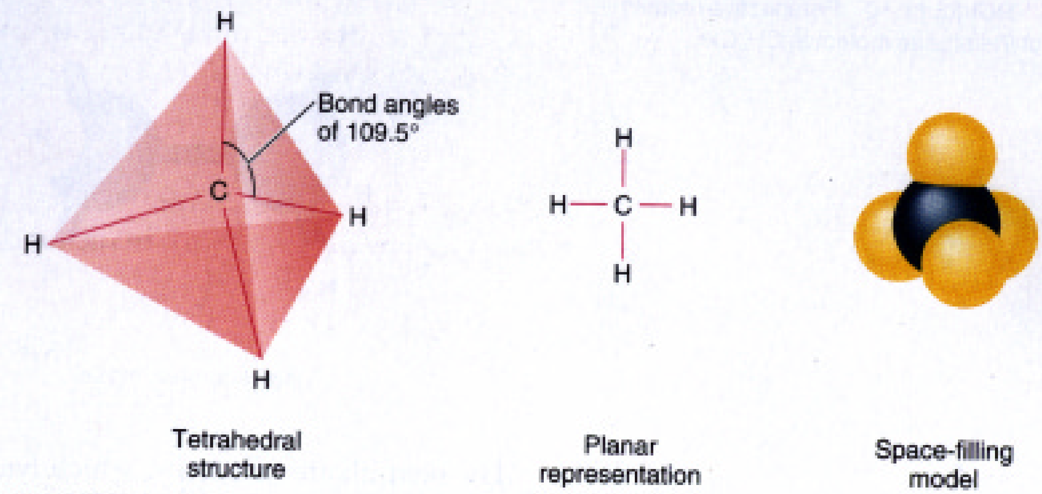


FIGURE 11.9 Structural representations of methane, CH_4.

Bonding Characteristics

- Carbon can also form single bonds with itself.
  - This allows it to form long straight and branched chains of carbon.
- Carbon can also from double and triple bonds with itself
  - This will be discussed in Chapter 12.

Structural Isomers

- The large variety in the arrangement of carbons in organic molecules is what leads to an incredibly large number of possible molecules.
  - The different arrangements produce different molecules with distinguishing physical and chemical properties.

Structural Isomers

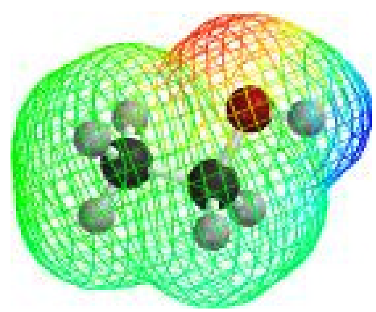
- When different molecules share the same chemical formula, they are called isomers of one another.
  - If the difference is due to the arrangement of the atoms, the isomers are called structural isomers.
  - For example, tThere are 366,319 different structural isomers for the chemical formula $C_{20}H_{42}$.

Structural Isomers

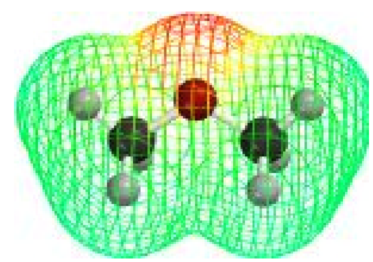
- Both *ethanol* and *dimethylether* have the same chemical formula (C_2H_6O).
- Each has a different arrangement of its atoms (CH_3CH_2OH *versus* CH_3-O-CH_3).
- They also have different physical properties:
  - ethanol is a liquid at room temperature, while dimethylether is a gas

Structural Isomers

- Both *ethanol* and *dimethylether* have the same chemical formula (C_2H_6O).



Ethanol (CH_3CH_2OH)
Liquid at room temperature



Dimethylether (CH_3-O-CH
Gas at room temperature

Oxygen, Nitrogen & Halogens

- The number bonds that other non-metals form can also be determined by applying the “octet” rule.
  - Each is attempting to fill its valence shell.

Exercise 11.15

Use Example 11.1 and Tables 11.6 and 11.2 to determine the number of covalent bonds formed by atoms of the following elements: carbon, hydrogen, oxygen, nitrogen and bromine

Oxygen, Nitrogen & Halogens

Element	Symbol	Group	Number of bonds formed
Carbon	**C**	IV	4
Nitrogen	**N**	V	3
Oxygen	**O**	VI	2
Halogens	**F**, **Cl**, **Br** & **I**	VII	1
Hydrogen	**H**	I or VII	1

Functional Groups

- Organic chemistry is usually organized according to functional group.
  - A function group is a group of covalently bonded group of atoms, often containing elements other than carbon and hydrogen, which have distinctive chemical and physical properties.

Functional Groups

- Classes of organic compounds:

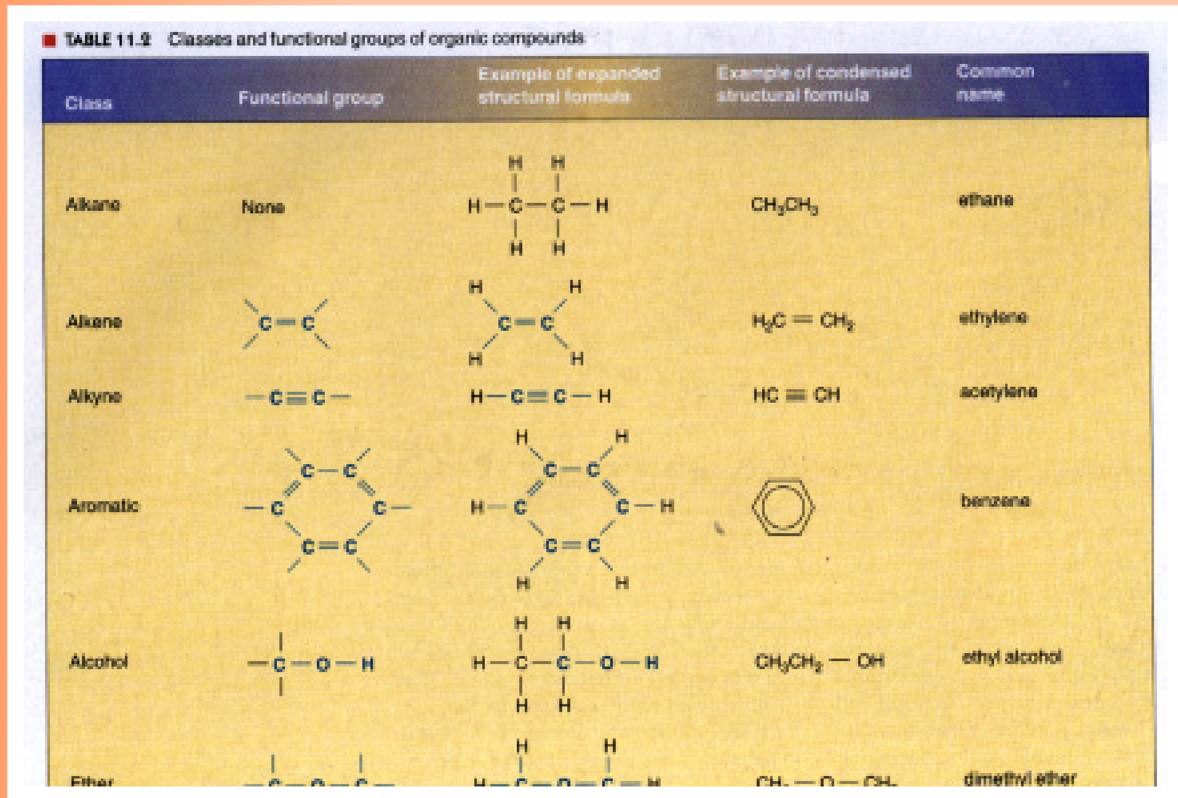


TABLE 11.2 Classes and functional groups of organic compounds

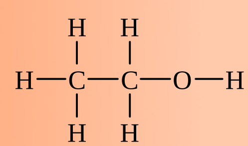
Class	Functional group	Example of expanded structural formula	Example of condensed structural formula	Common name
Alkane	None	H—C—C—H	CH_3CH_3	ethane
Alkene	C=C	H—C=C—H	$H_2C=CH_2$	ethylene
Alkyne	—C≡C—	H—C≡C—H	HC≡CH	acetylene
Aromatic	—C ring C—	H—C ring C—H		benzene
Alcohol	—C—O—H	H—C—C—O—H	CH_3CH_2-OH	ethyl alcohol
Ether	—C—O—C—	H—C—O—C—H	CH_3-O-CH_3	dimethyl ether

Structural Formulas

- Structural formulas show how the atoms in a molecule are arranged
  - Unlike chemical formulas, which give only the types and numbers of each atom in a molecule.
  - Expanded structural formulas explicitly show all the bonds in a molecule.
  - Condensed structural formulas show only some of the the bonds
    - √ The remaining bonds are implied.

Structural Formulas

- Structural formulas show how the atoms in a molecule are arranged.



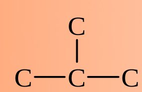
ethanol
expanded structural formula

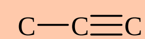
CH_3–CH_2–OH

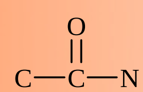
ethanol
condensed structural formula

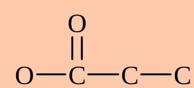
Exercise 11.17

Complete the following structures by adding hydrogen atoms where needed:

a. 

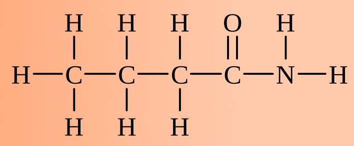
b. 

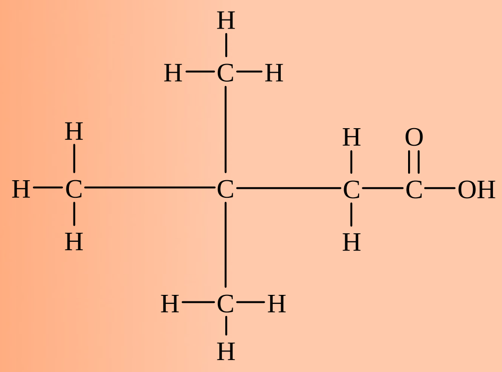
c. 

d. 

Exercise 11.23

Write a condensed structural formula for the following compounds:

a. 

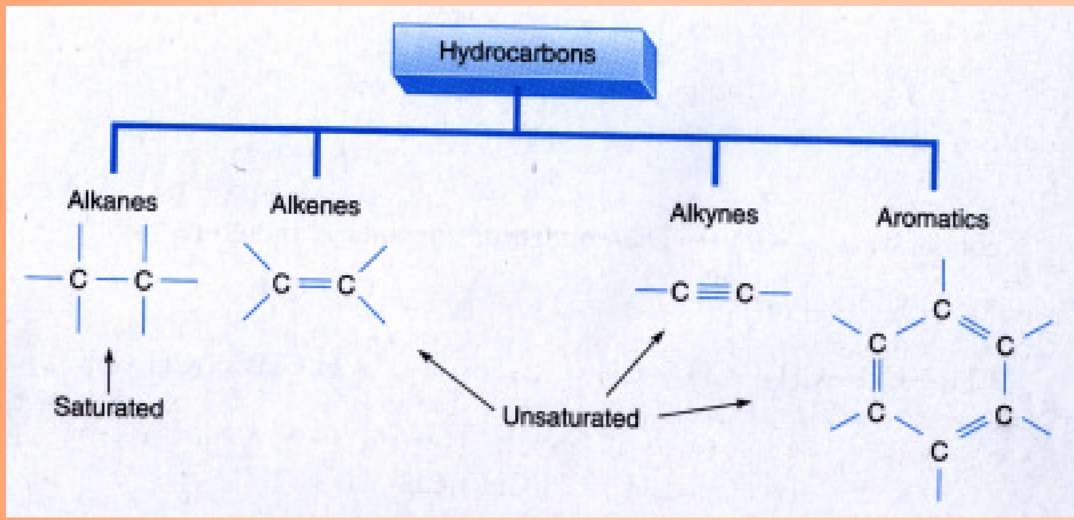
b. 

Alkane Structures

- Hydrocarbons are the simplest of organic compounds.
  - They contain only the elements of hydrogen and carbon.
- Saturated hydrocarbons, or alkanes, contain only single bonds between carbon atoms.

Alkane Structures

- Unsaturated hydrocarbons, which includes alkenes, alkynes and aromatics, contain at least one double or triple carbon-carbon bond.



Alkane Structures

- Most biochemical reactions involve functional groups.
  - Alkanes have no functional groups.
- Hydrocarbons form the core of most organic molecules.
  - The functional groups hang off of this core

Alkane Structures

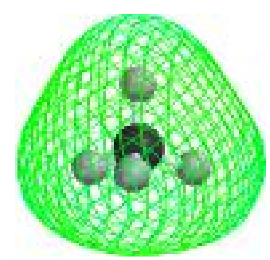
- The chemical formula for alkanes has the form C_nH_{2n+2}.
  - where *n* gives the number of carbon atoms

Alkane Structures

- Methane
  - $n = 1$
  - Primary component of natural gas
  - Carbon is sp^3 hybridized and has tetrahedral geometry.
  - The angle between C–H bonds is 109.5°

Alkane Structures

- Methane



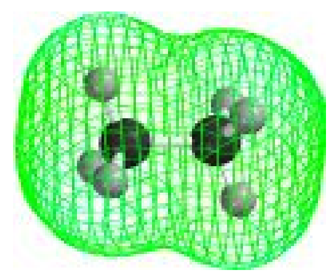
Methane (CH_4)

Alkane Structures

- Ethane
  - $n = 2$
  - Each carbon is sp^3 hybridized and has tetrahedral geometry.

Alkane Structures

- Ethane



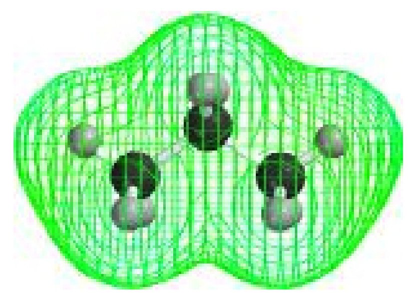
Ethane (C_2H_6)

Alkane Structures

- Propane
  - *n* = 3
  - Each carbon is sp^3 hybridized and has tetrahedral geometry.

Alkane Structures

- Propane



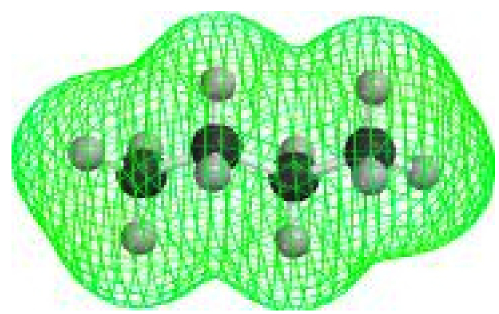
Propane (C_3H_8)

Alkane Structures

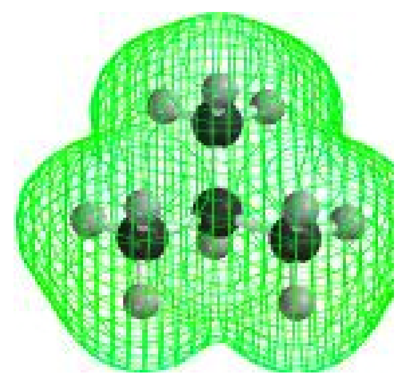
- Butane
  - $n = 4$
  - Each carbon is sp^3 hybridized and has tetrahedral geometry.
  - There are two possible arrangements of the carbon atoms.
  - This results in a pair of structural isomers.

Alkane Structures

- Butane



***n*-Butane (C_4H_{10})**



Isobutane (C_4H_{10})

Conformations of Alkanes

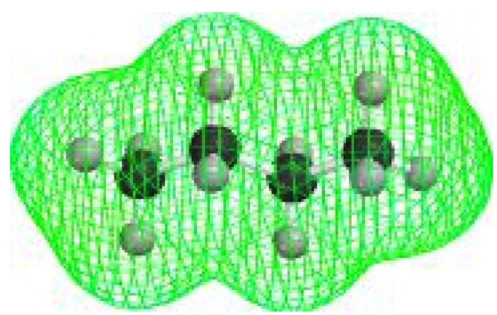
- In alkanes the atoms are constantly rotating about the carbon-carbon single bonds.
  - The different arrangements that result from these rotations are called conformations.
- Alkanes with four or more carbon-carbon bonds have many differenent conformations.

Conformations of Alkanes

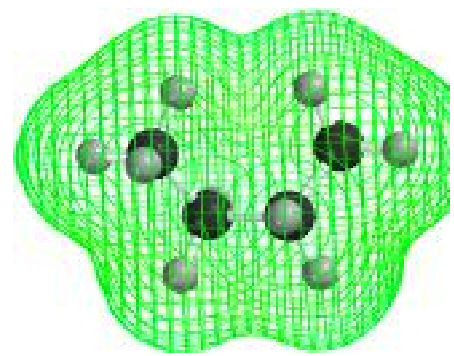
- The different conformations are *not* isomers of one another.
  - They are considered different forms of the same molecule.
- Switching from one isomer to another requires the breaking and making of covalent bonds.
- Switching from one conformer to another involves only rotation about bonds.

Alkane Structures

- Two conformations of *n*-butane:



***n*-Butane (C_4H_{10})**



***n*-Butane (C_4H_{10})**

Naming Alkanes

- At first common names were given to organic compoudS.
  - As more and more organic compounds were discovered, finding unique names for the new molelcules became more difficult.
- A group called the *International Union of Pure and Applied Chemistry* (IUPAC), devised a systematic method to name organic compounds.

IUPAC Names for Alkanes

- Each IUPAC name comprises three components:

Prefix — Root — Ending

IUPAC Names for Alkanes

- Each IUPAC name comprises three components:

Prefix — Root — Ending

  - Root part gives the number of carbon atoms in the longest continuous cahin of carbons in the molecule.

IUPAC Names for Alkanes

- Each IUPAC name comprises three components:

Prefix — Root — Ending

  - Ending part gives the functional class of the primary functional group in the molecule.
  - The ending *-ane* is used to designate alkanes.

IUPAC Names for Alkanes

- IUPAC names for alkanes, n = 1 to 10.

TABLE 11.4 Names of alkanes

Number of carbon atoms	Name	Molecular formula	Structure of the normal isomer
1	methane	CH_4	CH_4
2	ethane	C_2H_6	CH_3CH_3
3	propane	C_3H_8	$CH_3CH_2CH_3$
4	butane	C_4H_{10}	$CH_3CH_2CH_2CH_3$
5	pentane	C_5H_{12}	$CH_3CH_2CH_2CH_2CH_3$
6	hexane	C_6H_{14}	$CH_3CH_2CH_2CH_2CH_2CH_3$
7	heptane	C_7H_{16}	$CH_3CH_2CH_2CH_2CH_2CH_2CH_3$
8	octane	C_8H_{18}	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_3$
9	nonane	C_9H_{20}	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_3$
10	decane	$C_{10}H_{22}$	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_3$

IUPAC Names for Alkanes

- Each IUPAC name comprises three components:

Prefix — Root — Ending

  - Prefix part gives the identity, number, and location of atoms or groups of atoms that are attached to the longest carbon chain.
    - √ If there are no additional groups then no prefix is required.

IUPAC Names for Alkanes

- The names used to describe saturated hydrocarbon groups are derived from the corresponding name for the corresponding alkane.
  - The *-ane* ending is changed to *-yl*.
  - These groups are called alkyl groups.

IUPAC Names for Alkanes

- The names of the common alkyl groups:

TABLE 11.5 Common alkyl groups

Parent alkane	Structure of parent alkane	Structure of alkyl group	Name of alkyl group
methane	CH_4	$CH_3—$	methyl
ethane	CH_3CH_3	$CH_3CH_2—$	ethyl
propane	$CH_3CH_2CH_3$	$CH_3CH_2CH_2—$	propyl
		| CH_3CHCH_3	isopropyl
n-butane	$CH_3CH_2CH_2CH_3$	$CH_3CH_2CH_2CH_2—$	butyl
		| $CH_3CH_2CHCH_3$	*sec*-butyl (secondary-butyl)[a]
isobutane	CH_3 | CH_3CHCH_3	CH_3 | $CH_3CHCH_2—$	isobutyl
		CH_3 | CH_3CCH_3 |	*t*-butyl (tertiary-butyl)[a]

[a]For an explanation of *secondary* and *tertiary*, see Section 13.2.

IUPAC Names for Alkanes

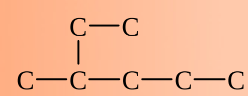
- If more than one of the same kind of group is present, Geek prefixes are used to indicate their numbers:

Number	Greek prefix
2	*Di-*
3	*Tri-*
4	*Tetra-*
5	*Penta-*
6	*Hexa-*
7	*Hepta-*
8	*Octa-*
9	*Nona-*
10	*Deca-*

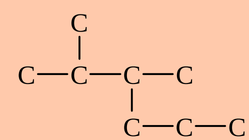
Exercise 11.29

For each of the following carbon skeletons, give the number of carbon atoms in the longest chain:

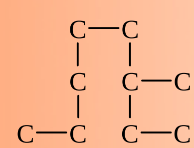
a.



b.

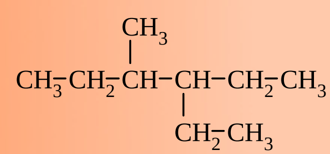


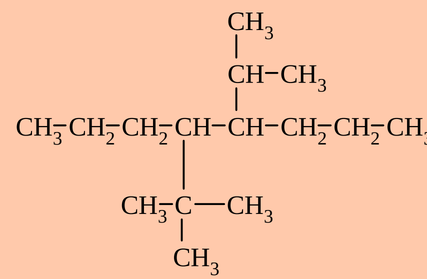
c.

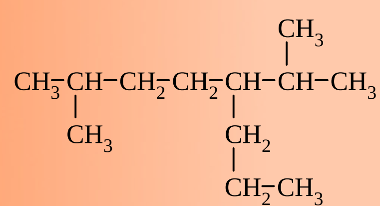


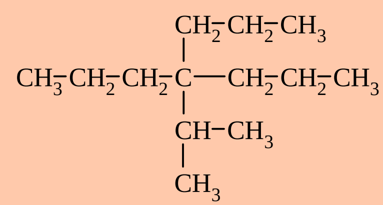
Exercise 11.33

Give the correct IUPAC name for each of the following alkanes:

a. 

b. 

c. 

d. 

Exercise 11.35

Draw a condensed structural formula for each of the following compounds:

a. 2,2,4-trimethylpentane

b. 4-isopropyloctane

c. 3,3-diethylhexane

d. 5-*t*-butyl-2-methyl

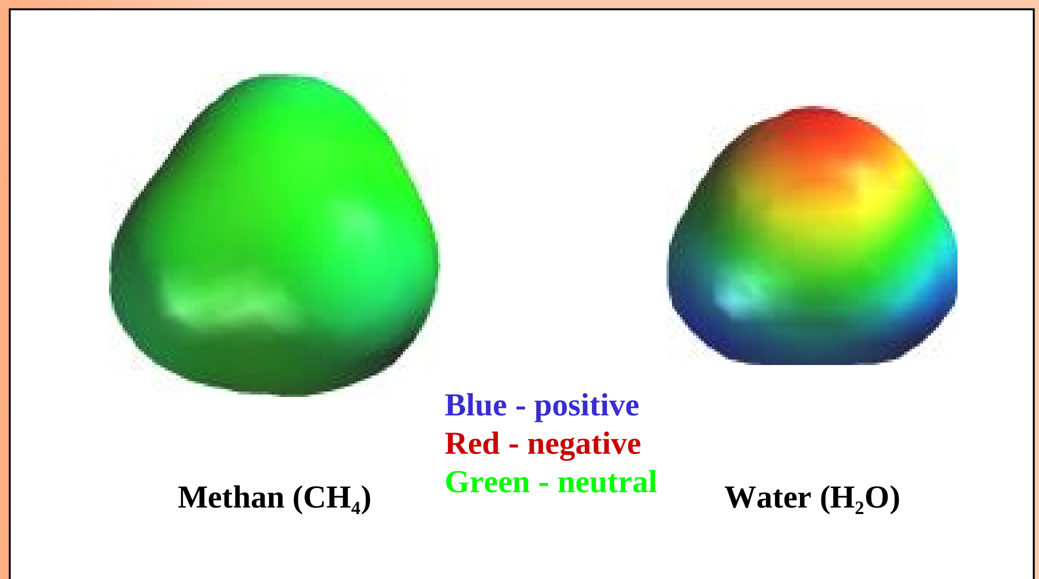
Cycloalkanes

Physical properties of Alkanes

- Melting and boiling points
  - Intermolecular interactions with itself
- Solubility
  - In water (a polar solvent)
  - In non-polar solvents

Physical properties of Alkanes

- Comparing the polarity of methane with water



Physical properties of Alkanes

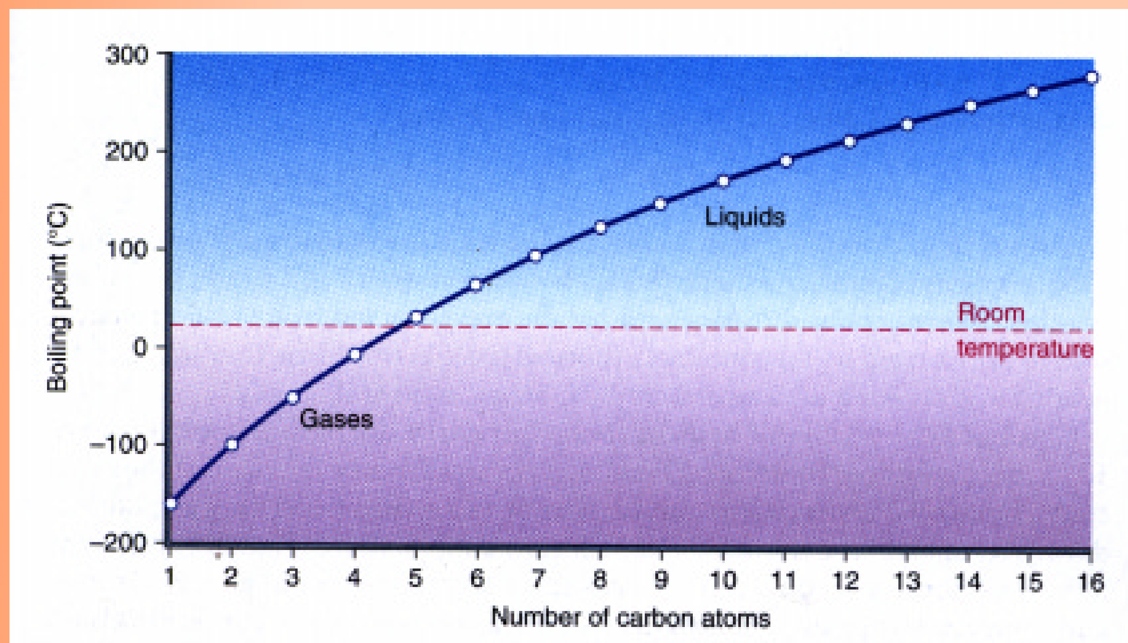
- Melting and boiling points for alkanes

TABLE 11.8 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_3CH_3	−183.2	−88.6	0.57
3	propane	$CH_3CH_2CH_3$	−189.7	−42.1	0.58
4	butane	$CH_3CH_2CH_2CH_3$	−133.4	−0.5	0.60
5	pentane	$CH_3CH_2CH_2CH_2CH_3$	−129.7	36.1	0.63
6	hexane	$CH_3CH_2CH_2CH_2CH_2CH_3$	−95.3	68.9	0.66
7	heptane	$CH_3CH_2CH_2CH_2CH_2CH_2CH_3$	−90.6	98.4	0.68
8	octane	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_3$	−56.8	125.7	0.70
9	nonane	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_3$	−53.5	150.8	0.72
10	decane	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_3$	−29.7	174.1	0.73

Physical properties of Alkanes

- Boiling point chain length dependence



Alkane Reactions

- Combustion with oxygen
  - Complete combustion
  - Incomplete combustion