

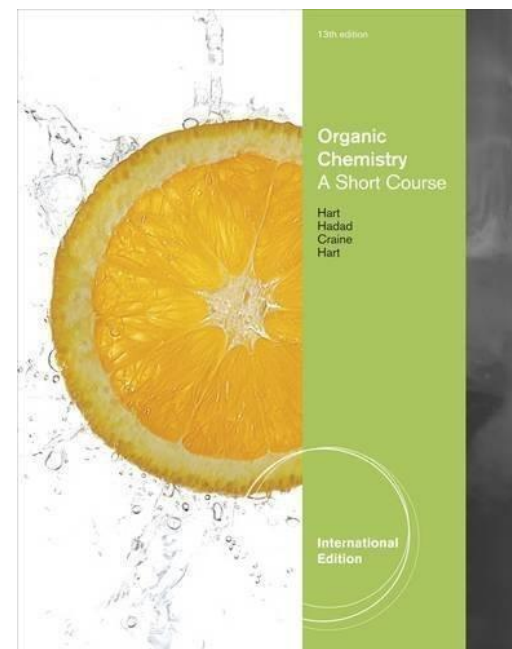
Chem 237 Basics of Organic Medicinal Chemistry

- **Course description**

This is the first year organic chemistry course, introducing basic concepts and principles of organic chemistry (chapters 1 – 11).

- **Texts**

Hart, Craine, Hart and Hadad, Organic Chemistry, A Short Course, 13th Edition (Brooks/Cole, Cengage Learning, CA 94002-3098 USA, 2012).



Periodic Table of the Elements

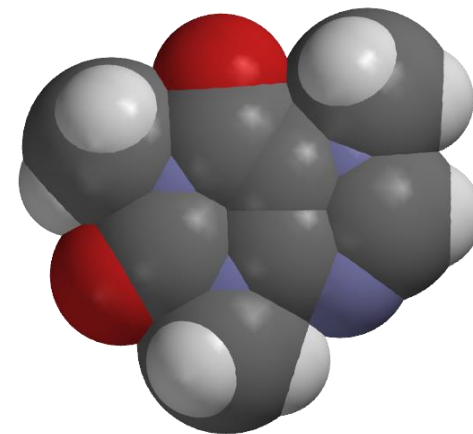
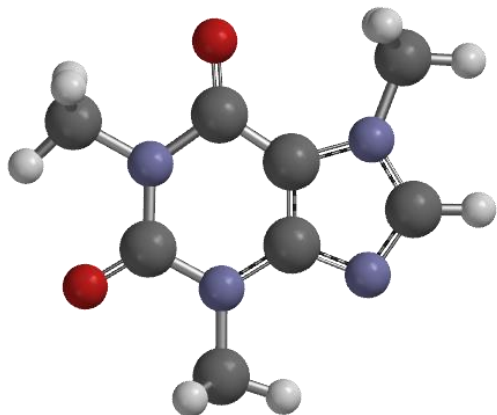
1 IA H Hydrogen 1.008 1	2 IIA He Helium 4.0026 2											13 IIIA B Boron 10.81 2-3	14 IVA C Carbon 12.011 2-4	15 VA N Nitrogen 14.007 2-5	16 VIA O Oxygen 15.999 2-4	17 VIIA F Fluorine 18.998 2-7	18 VIIIA Ne Neon 20.180 2-8
3 Li Lithium 6.94 2-1	4 Be Beryllium 9.0122 2-2											13 Al Aluminium 26.982 3-1	14 Si Silicon 28.085 2-8-4	15 P Phosphorus 30.974 2-8-5	16 S Sulfur 32.06 2-6	17 Cl Chlorine 35.45 2-7	18 Ar Argon 39.948 2-8-8
11 Na Sodium 22.98976928 2-8-1	12 Mg Magnesium 24.305 2-8-2	3 IIIB Sc Scandium 44.955908 2-8-9-2	4 IVB Ti Titanium 47.867 2-8-10-2	5 VB V Vanadium 50.9415 2-8-10-2	6 VIB Cr Chromium 51.9961 2-8-10-1	7 VIIB Mn Manganese 54.938044 2-8-10-2	8 VIIIB Fe Iron 55.845 2-8-10-2	9 VIIIB Co Cobalt 58.933 2-8-10-2	10 VIIIB Ni Nickel 58.693 2-8-10-2	11 IB Cu Copper 63.546 2-8-10-1	12 IIB Zn Zinc 65.38 2-8-10-2	13 Ga Gallium 69.723 2-8-10-3	14 Ge Germanium 72.630 2-8-10-4	15 As Arsenic 74.922 2-8-10-5	16 Se Selenium 78.971 2-8-10-4	17 Br Bromine 79.904 2-8-10-7	18 Kr Krypton 83.798 2-8-10-8
19 K Potassium 39.0983 2-8-9-1	20 Ca Calcium 40.078 2-8-9-2	21 Sc Scandium 44.955908 2-8-9-2	22 Ti Titanium 47.867 2-8-10-2	23 V Vanadium 50.9415 2-8-10-2	24 Cr Chromium 51.9961 2-8-10-1	25 Mn Manganese 54.938044 2-8-10-2	26 Fe Iron 55.845 2-8-10-2	27 Co Cobalt 58.933 2-8-10-2	28 Ni Nickel 58.693 2-8-10-2	29 Cu Copper 63.546 2-8-10-1	30 Zn Zinc 65.38 2-8-10-2	31 Ga Gallium 69.723 2-8-10-3	32 Ge Germanium 72.630 2-8-10-4	33 As Arsenic 74.922 2-8-10-5	34 Se Selenium 78.971 2-8-10-4	35 Br Bromine 79.904 2-8-10-7	36 Kr Krypton 83.798 2-8-10-8
37 Rb Rubidium 85.4678 2-8-18-8-1	38 Sr Strontium 87.62 2-8-18-8-2	39 Y Yttrium 88.90584 2-8-18-9-2	40 Zr Zirconium 91.224 2-8-18-10-2	41 Nb Niobium 92.90637 2-8-18-10-1	42 Mo Molybdenum 95.95 2-8-18-10-2	43 Tc Technetium 98 2-8-18-10-1	44 Ru Ruthenium 101.07 2-8-18-10-1	45 Rh Rhodium 102.91 2-8-18-10-1	46 Pd Palladium 106.42 2-8-18-10-1	47 Ag Silver 107.87 2-8-18-10-1	48 Cd Cadmium 112.41 2-8-18-10-2	49 In Indium 114.82 2-8-18-10-3	50 Sn Tin 118.71 2-8-18-10-4	51 Sb Antimony 121.76 2-8-18-10-5	52 Te Tellurium 127.60 2-8-18-10-6	53 I Iodine 126.90 2-8-18-10-7	54 Xe Xenon 131.29 2-8-18-10-8
55 Cs Caesium 132.90545196 2-8-18-18-8-1	56 Ba Barium 137.327 2-8-18-18-8-2	57-71 Lanthanides	72 Hf Hafnium 178.49 2-8-18-32-10-2	73 Ta Tantalum 180.94788 2-8-18-32-11-2	74 W Tungsten 183.84 2-8-18-32-12-2	75 Re Rhenium 186.21 2-8-18-32-13-2	76 Os Osmium 190.23 2-8-18-32-14-2	77 Ir Iridium 192.22 2-8-18-32-15-2	78 Pt Platinum 195.08 2-8-18-32-17-1	79 Au Gold 196.97 2-8-18-32-18-1	80 Hg Mercury 200.59 2-8-18-32-18-2	81 Tl Thallium 204.38 2-8-18-32-18-3	82 Pb Lead 207.2 2-8-18-32-18-4	83 Bi Bismuth 208.98 2-8-18-32-18-5	84 Po Polonium 209 2-8-18-32-18-6	85 At Astatine (210) 2-8-18-32-18-7	86 Rn Radon (222) 2-8-18-32-18-8
87 Fr Francium (223) 2-8-18-32-18-8-1	88 Ra Radium (226) 2-8-18-32-18-8-2	89-103 Actinides	104 Rf Rutherfordium (261) 2-8-18-32-10-2	105 Db Dubnium (268) 2-8-18-32-11-2	106 Sg Seaborgium (269) 2-8-18-32-12-2	107 Bh Bohrium (270) 2-8-18-32-13-2	108 Hs Hassium (277) 2-8-18-32-14-2	109 Mt Meitnerium (278) 2-8-18-32-15-2	110 Ds Darmstadtium (281) 2-8-18-32-17-1	111 Rg Roentgenium (282) 2-8-18-32-17-2	112 Cn Copernicium (285) 2-8-18-32-18-2	113 Nh Nihonium (286) 2-8-18-32-18-3	114 Fl Flerovium (289) 2-8-18-32-18-4	115 Mc Moscovium (290) 2-8-18-32-18-5	116 Lv Livermorium (293) 2-8-18-32-18-6	117 Ts Tennessine (294) 2-8-18-32-18-7	118 Og Oganesson (294) 2-8-18-32-18-8

57 La Lanthanum 138.905 2-8-18-18-9-2	58 Ce Cerium 140.12 2-8-18-18-9-2	59 Pr Praseodymium 140.91 2-8-18-18-9-2	60 Nd Neodymium 144.24 2-8-18-22-8-2	61 Pm Promethium (145) 2-8-18-22-8-2	62 Sm Samarium 150.36 2-8-18-26-8-2	63 Eu Europium 151.96 2-8-18-25-8-2	64 Gd Gadolinium 157.25 2-8-18-25-8-2	65 Tb Terbium 158.93 2-8-18-27-8-2	66 Dy Dysprosium 162.50 2-8-18-29-8-2	67 Ho Holmium 164.93 2-8-18-29-8-2	68 Er Erbium 167.26 2-8-18-29-8-2	69 Tm Thulium 168.93 2-8-18-31-8-2	70 Yb Ytterbium 173.05 2-8-18-31-8-2	71 Lu Lutetium 174.97 2-8-18-32-8-2
89 Ac Actinium (227) 2-8-18-32-18-9-2	90 Th Thorium 232.04 2-8-18-32-18-10-2	91 Pa Protactinium 231.04 2-8-18-32-20-9-2	92 U Uranium 238.03 2-8-18-32-21-9-2	93 Np Neptunium (237) 2-8-18-32-22-9-2	94 Pu Plutonium (244) 2-8-18-32-24-8-2	95 Am Americium (243) 2-8-18-32-25-8-2	96 Cm Curium (247) 2-8-18-32-25-9-2	97 Bk Berkelium (247) 2-8-18-32-27-8-2	98 Cf Californium (251) 2-8-18-32-28-8-2	99 Es Einsteinium (252) 2-8-18-32-29-8-2	100 Fm Fermium (257) 2-8-18-32-30-8-2	101 Md Mendelevium (258) 2-8-18-32-31-8-2	102 No Nobelium (259) 2-8-18-32-32-8-2	103 Lr Lawrencium (260) 2-8-18-32-32-8-2

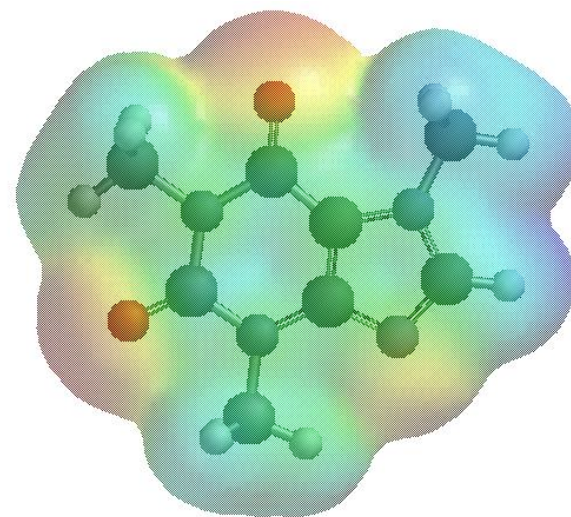
Atomic Number → 1
 Symbol → **H**
 Name → Hydrogen
 Atomic Weight → 1.008
 Electrons per shell → 1

State of matter (color of name)
 GAS LIQUID SOLID UNKNOWN

Subcategory in the metal-metalloid-nonmetal trend (color of background)
 ■ Alkali metals ■ Lanthanides ■ Metalloids ■ Unknown chemical properties
 ■ Alkaline earth metals ■ Actinides ■ Reactive nonmetals
 ■ Transition metals ■ Post-transition metals ■ Noble gases



Chapter 1: Bonding and Isomerism



Organic Chemistry

- Organic compounds are compounds containing carbon

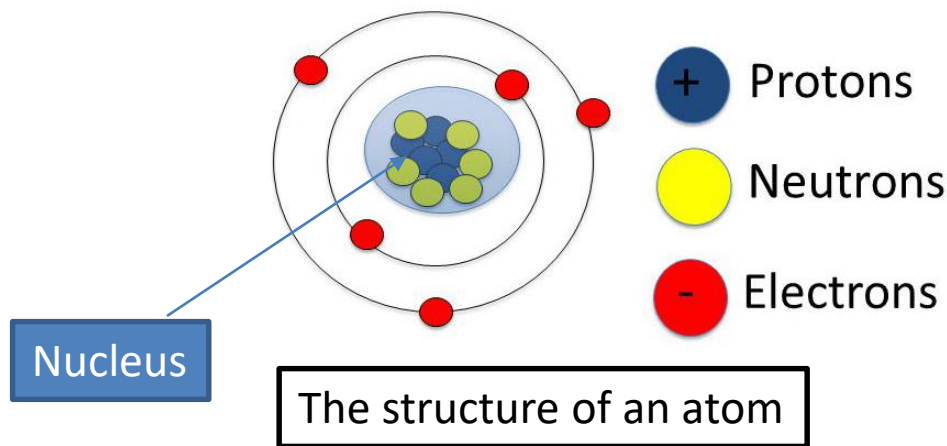


- Atoms to the left of carbon give up electrons.
- Atoms to the right of carbon accept electrons.
- Carbon shares electrons.

Bonding and Isomerism

1.1 How Electrons Are Arranged in Atoms

- An atom is: the *smallest particle* of an element that retains all of the chemical properties of that element.
- An atom consists of negatively charged electrons, positively charged protons, and neutral neutrons



- **Atomic number:** numbers of protons in its nucleus and it's the number of electrons in the neutral atom.
- **Mass number:** the sum of the protons and neutrons of an atom.
(Protons and neutrons are ~ 1837 times the mass of an e^-)
- Isotopes have the same atomic number but different mass numbers (^{12}C and ^{13}C)

- Electrons are located in atomic orbitals (S, P, d, f).
- Orbitals tell us the energy of the electron and the volume of space around the nucleus where an electron is most likely to be found.
- Orbitals are grouped in shells .

Each orbital can hold a maximum of $2e^-$ and the two electrons have opposite spin

Table 1.1 Distribution of Electrons in the First Four Shells That Surround the Nucleus

	First shell	Second shell	Third shell	Fourth shell
Atomic orbitals	<i>s</i>	<i>s, p</i>	<i>s, p, d</i>	<i>s, p, d, f</i>
Number of atomic orbitals	1	1, 3	1, 3, 5	1, 3, 5, 7
Maximum number of electrons	2	8	18	32

Example :

^1H :

^6C

Valence electrons (VE) are located in the outermost shell. They are involved in chemical reactions.

VE = Group number

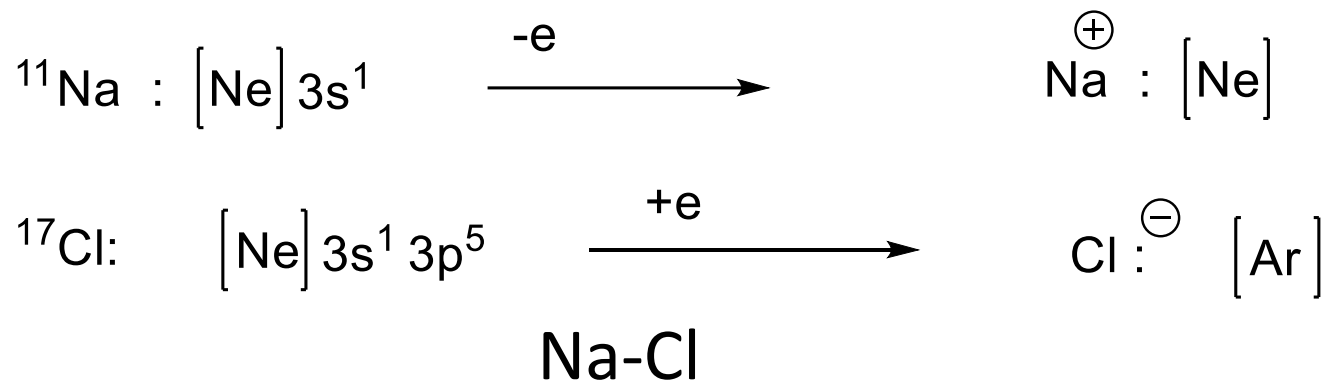
	VE	Lewis symbol of atom
Examples: ${}^1\text{H}: 1s^1$	1	$\text{H}\cdot$
${}^8\text{O}: 1s^2 2s^2 2p^4$	6	$\ddot{\text{O}}\cdot$
${}^6\text{C}: \underline{\hspace{15em}}$		

Table 1.3 Valence Electrons of the First 18 Elements								
Group	I	II	III	IV	V	VI	VII	VIII
	$\text{H}\cdot$							$\text{He}:$
	$\text{Li}\cdot$	$\cdot\text{Be}\cdot$	$\cdot\text{B}\cdot$	$\cdot\overset{\cdot}{\underset{\cdot}{\text{C}}}\cdot$	$\cdot\overset{\cdot}{\underset{\cdot}{\text{N}}}\cdot$	$\cdot\overset{\cdot}{\underset{\cdot}{\text{O}}}\cdot$	$\cdot\overset{\cdot}{\underset{\cdot}{\text{F}}}\cdot$	$\cdot\overset{\cdot}{\underset{\cdot}{\text{Ne}}}\cdot$
	$\text{Na}\cdot$	$\cdot\text{Mg}\cdot$	$\cdot\text{Al}\cdot$	$\cdot\overset{\cdot}{\underset{\cdot}{\text{Si}}}\cdot$	$\cdot\overset{\cdot}{\underset{\cdot}{\text{P}}}\cdot$	$\cdot\overset{\cdot}{\underset{\cdot}{\text{S}}}\cdot$	$\cdot\overset{\cdot}{\underset{\cdot}{\text{Cl}}}\cdot$	$\cdot\overset{\cdot}{\underset{\cdot}{\text{Ar}}}\cdot$

- **Chemical Bonds**

1. Ionic Bonding

An ionic bond is an electrostatic attraction between positive & negative ions resulting from e⁻ transfer.



The resulting e⁻ configuration of both ions are those of the nearest noble gas, Ne and Ar respectively, both satisfy the octet rule.

2. Covalent Bonding

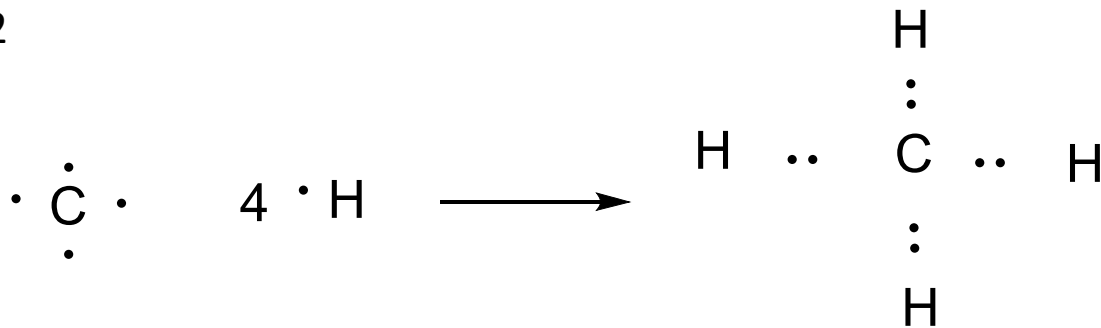
- Ionic bonds occur when an e^- is transferred between a metal and nonmetal.
- Covalent bonds are resulting from **sharing** e^-



The result is both atoms have a [He] e^- configuration, *i.e.*

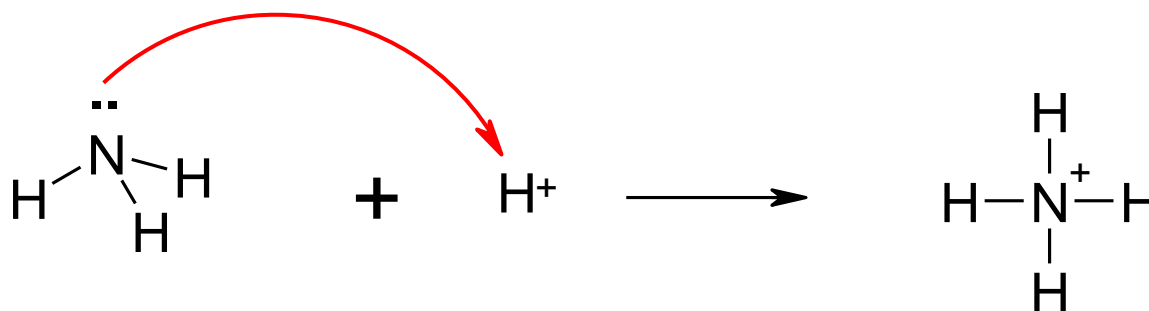
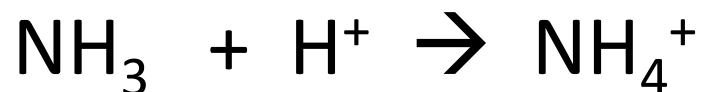
The bond is commonly display as a line rather than a pair of e^- (:), *i.e.* H - H rather than H : H

Example 2



A second general version of a covalent bond is possible. This occurs when BOTH e⁻ come from one atom: a **coordinate covalent bond**

i.e.



Electronegativity (EN) : measures the tendency of an atom to attract a shared pair of electrons (or electron density).

TABLE 1.3 The Electronegativities of Selected Elements^a

IA	IIA	IB	IIB	IIIA	IVA	VA	VIA	VIIA
H 2.1								
Li 1.0	Be 1.5			B 2.0	C 2.5	N 3.0	O 3.5	F 4.0
Na 0.9	Mg 1.2			Al 1.5	Si 1.8	P 2.1	S 2.5	Cl 3.0
K 0.8	Ca 1.0							Br 2.8
								I 2.5

increasing electronegativity

increasing electronegativity

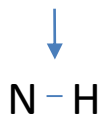
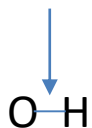
^aElectronegativity values are relative, not absolute. As a result, there are several scales of electronegativities. The electronegativities listed here are from the scale devised by Linus Pauling.

Covalent bonds can be classified as

A. Nonpolar covalent bond ($\Delta EN = 0-0.5$)

Examples C-C C-H

B. Polar covalent bond ($\Delta \text{EN} = 0.5 \text{ } 1.9$)



A polar bond has a negative end and a positive end

$$\text{dipole moment (D)} = \mu = e \times d$$

(e) : magnitude of the charge on the atom

(d) : distance between the two charges

Table 1.4 The Dipole Moments of Some Commonly Encountered Bonds

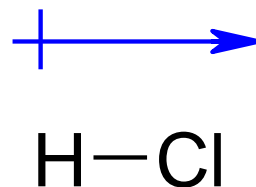
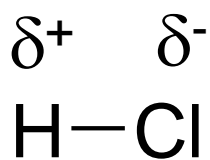
Bond	Dipole moment (D)	Bond	Dipole moment (D)
H—C	0.4	C—C	0
H—N	1.3	C—N	0.2
H—O	1.5	C—O	0.7
H—F	1.7	C—F	1.6
H—Cl	1.1	C—Cl	1.5
H—Br	0.8	C—Br	1.4
H—I	0.4	C—I	1.2

if The ΔEN increases the polarity increases

Note : If ΔEN is more than 1.9 then the bond is ionic Ex: Li-F

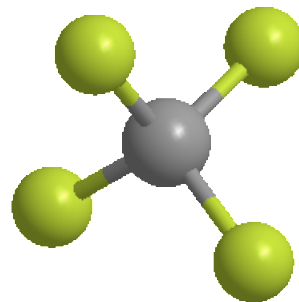
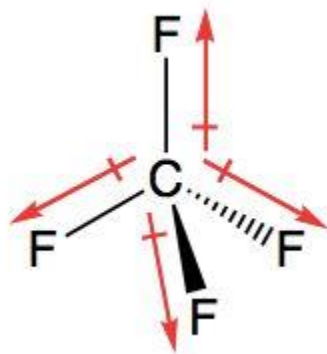
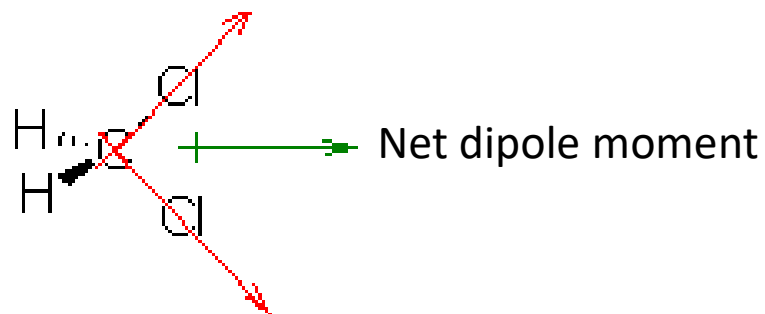
Bond Polarity & Electronegativity (cont'd)

The result of polar covalent bonding is that the e^- pair spend more time near the more EN atom. This means it will acquire a permanent excess negative charge. The other atom acquires a permanent excess positive charge. This is indicated by a δ^+ or δ^- (where δ means a “partial charge”) or a dipole arrow which points from the positive end of the bond to the negative end.



Bond Polarity & Electronegativity (cont'd)

The more polar the molecule the stronger the dipole moment. The molecular dipole moment is the vector sum of the bond moments, *i.e.*



Net dipole moment = 0

Lewis Structures

It only deals with VE

Procedure for obtaining good Lewis structures: eg. CO₂

- 1) determine total number of valence shell e⁻ (including ionic charge if present).

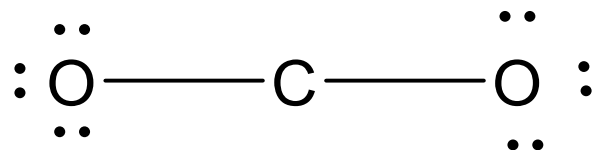
$$\text{CO}_2 = 4 + 2(6) = 16.$$

- 2) Chose a central atom and draw a skeleton of the molecule connected with single bonds. (the central **atom** is usually the **least electronegative element** in the **molecule** or **ion**; hydrogen and the halogens are usually terminal).

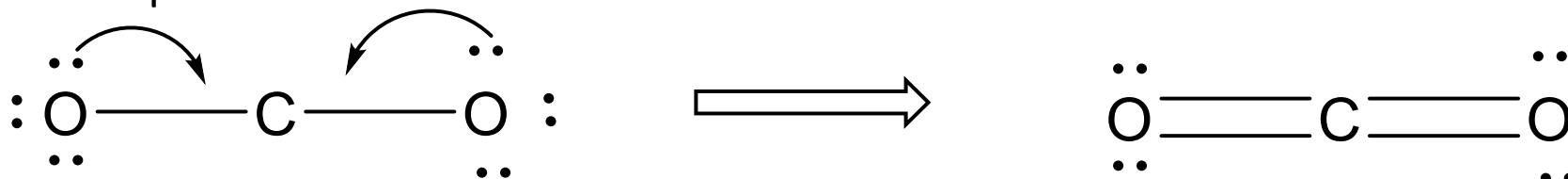


- 3) determine number of remaining e⁻. complete the octet of the terminal atoms.

$$16 - 4 = 12$$



4) Complete the octet Use lone pair e⁻ from terminal atoms to create multiple bonds.



5) determine the formal charges of all atoms.

Formal charge =
number of valence electrons – (number of lone pair electrons + 1/2 number of bonding electrons)

For O $6 - 6 = 0$

For C $4 - 4 = 0$

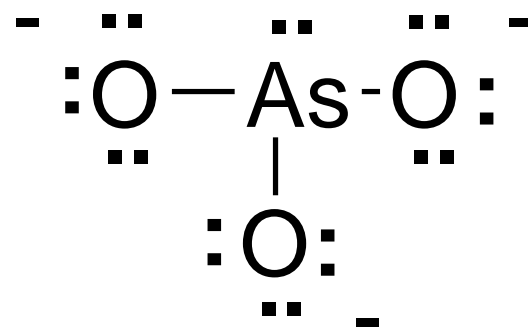
Ex: NO_3^-

1. $\text{VE} = 5 + 6 \cdot 3 + 1 = 24$

Lewis Structures (other examples)

Example 2: AsO_3^{3-}

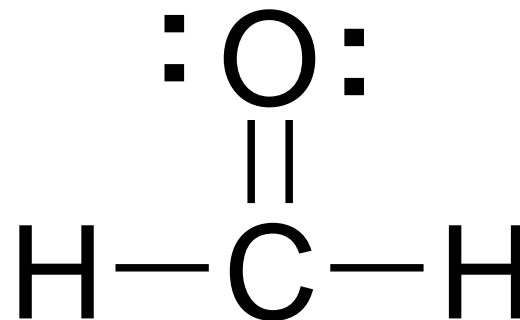
- 1) # e^- : $5 + 3(6) + 3 = 26$
- 2) form 3 single bonds
- 3) 20 e^- remain
- 4) O needs 6, As needs 2
- 5) All octets
- 6) Formal charges



Lewis Structures (cont'd)

Example 3: CH₂O

- 1) # e⁻: 4 + 2(1) + 6 = 12
- 2) try 3 single bonds
- 3) 6 e⁻ remain
- 4) O 6 but C?
- 5) Form a double bond
- 6) Both O & C octets
- 7) Formal charges

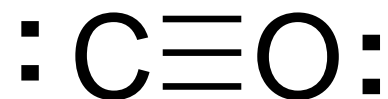


Lewis Structures (cont'd)

Example 4: CO

- 1) # e⁻: 4 + 6 = 10
- 2) try 1 single bond
- 3) 8 e⁻ remain
- 4) C needs 6 as does O short 4 e⁻
- 5) Share 4 more e⁻ - triple bond
- 6) Octets
- 7) Formal charges

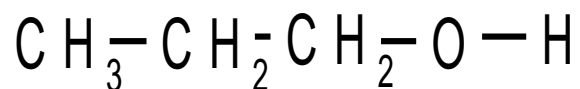
-1 +1



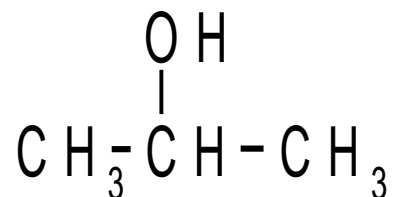
1.8 Isomers

Structural or **constitutional** isomers have same molecular formula but different structural formula.

They have different physical and chemical properties:



1-propanol
(bp 97.4 C)



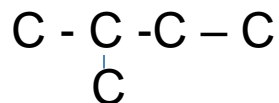
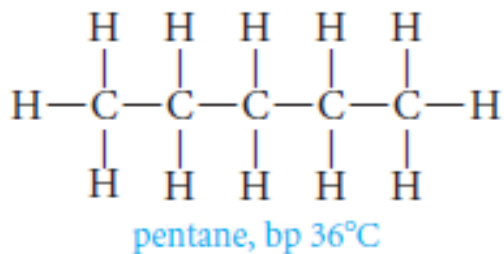
2-propanol
(bp 82.4 C)

1.9 Writing Structural Formulas

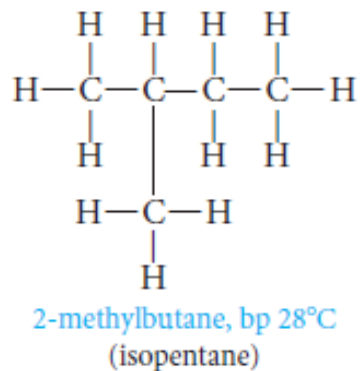
write out all possible structural formulas that correspond to the molecular formula C_5H_{12} .



Continuous chain



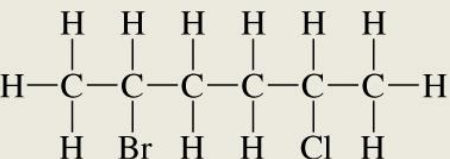
Branched chain



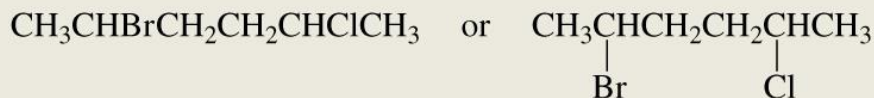
C forms 4 covalent bonds

Dash formula

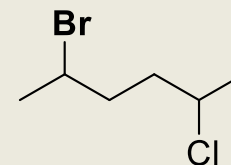
Kekul structure



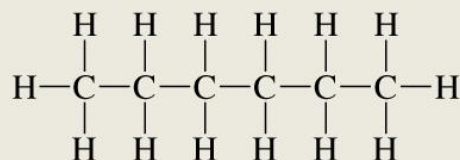
Condensed structures



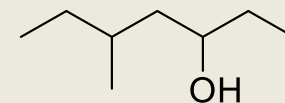
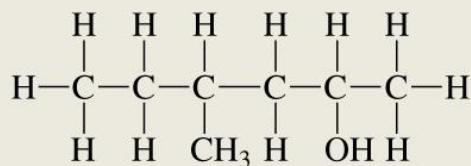
Bond line formula



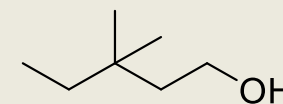
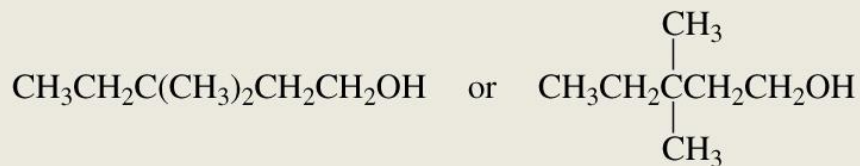
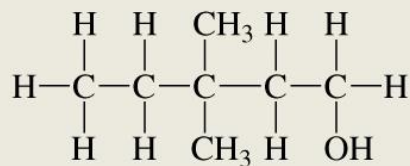
Repeating CH_2 groups can be shown in parentheses.

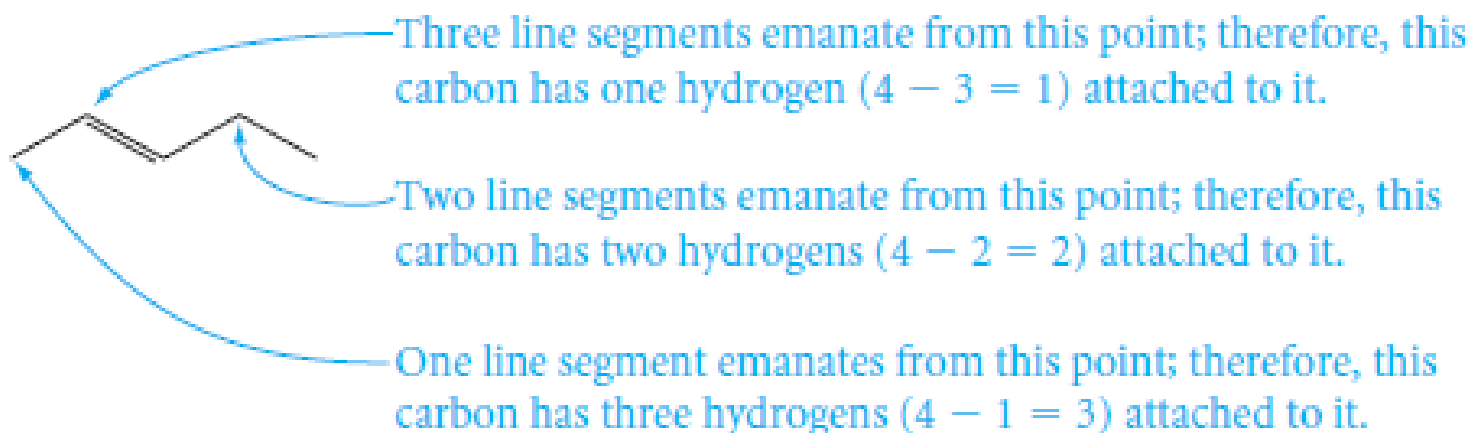


Groups bonded to a carbon can be shown (in parentheses) to the right of the carbon, or hanging from the carbon.



Groups bonded to the far-right carbon are not put in parentheses.

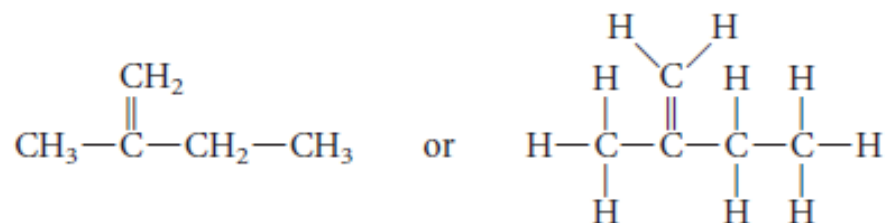


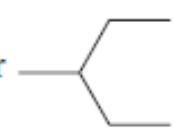


EXAMPLE 1.12

Write a more detailed structural formula for .

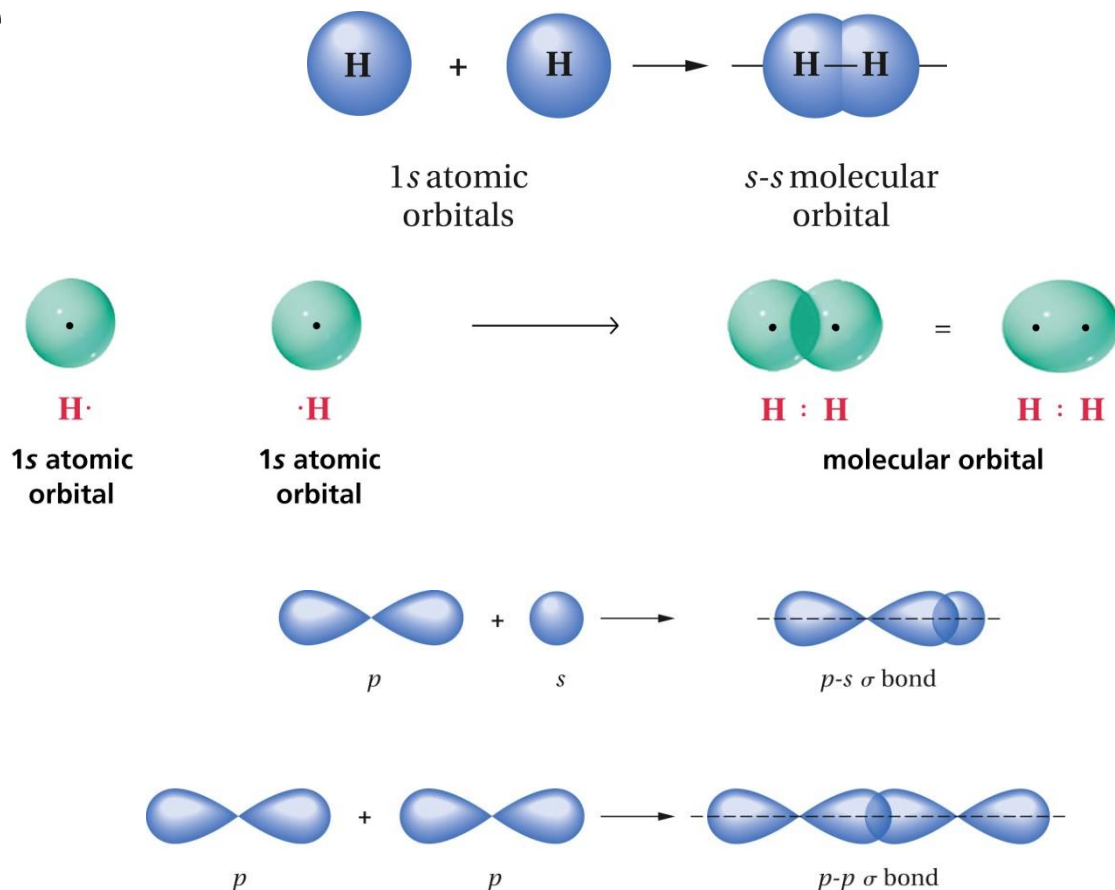
Solution



PROBLEM 1.23 Write a more detailed structural formula for .

1.14 The Orbital View of Bonding; the Sigma Bond

Sigma (σ) bonds: are characterized by a region of high e^- density along the internuclear axis.

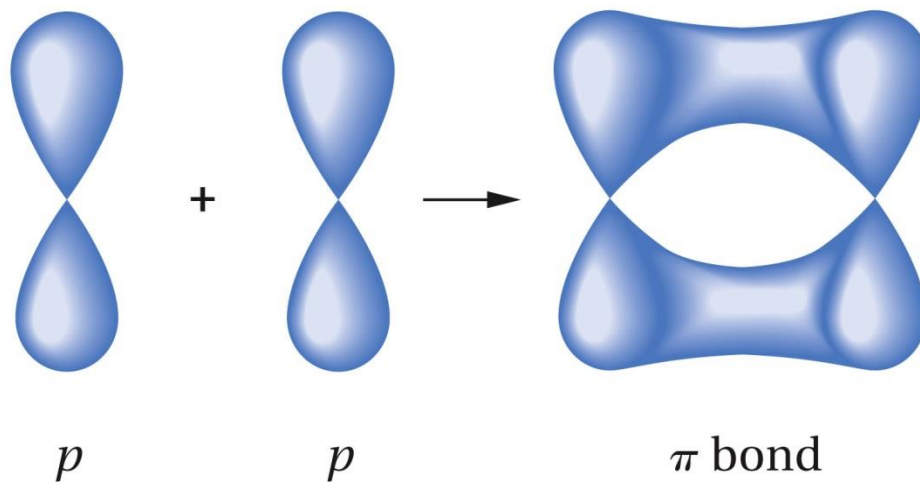


Orbitals approach each other in a **head to head** fashion

1.14 The Orbital View of Bonding; the pi (π) bond

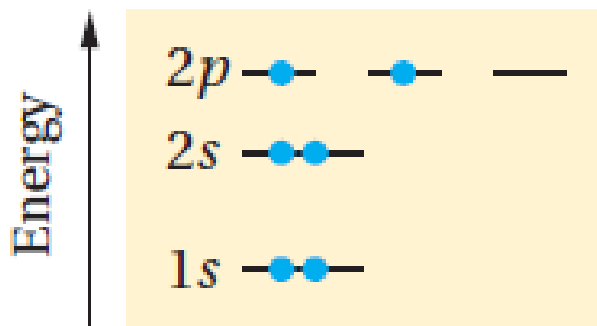
There is one other type of bond, a **pi (π) bond**. In contrast to a sigma bond the e^- density in a pi bond is not located on the internuclear axis, but rather on either “side” of it.

π bonds are formed by the side to side overlap of 2 “p” orbitals



Carbon sp^3 Hybrid Orbitals

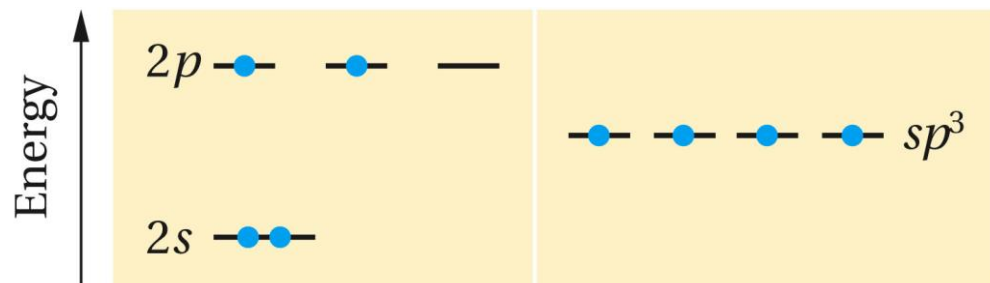
${}^6\text{C}: 1s^2 2s^2 2p^2$



Distribution of the six electrons in a carbon atom. Each dot stands for an electron.

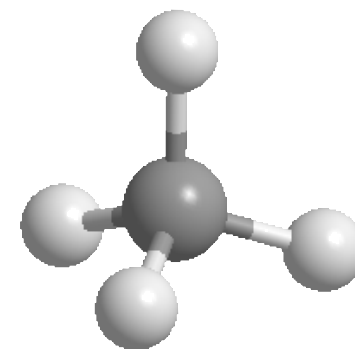
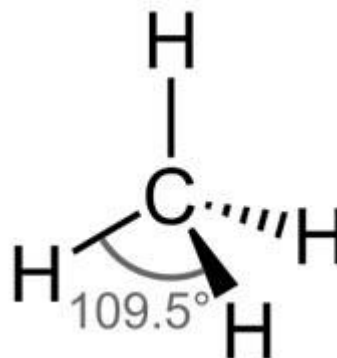
Q: Should the carbon form only two bonds !!!

A: We know from experience that carbon usually forms four single bonds, and often these bonds are all equivalent, as in CH_4



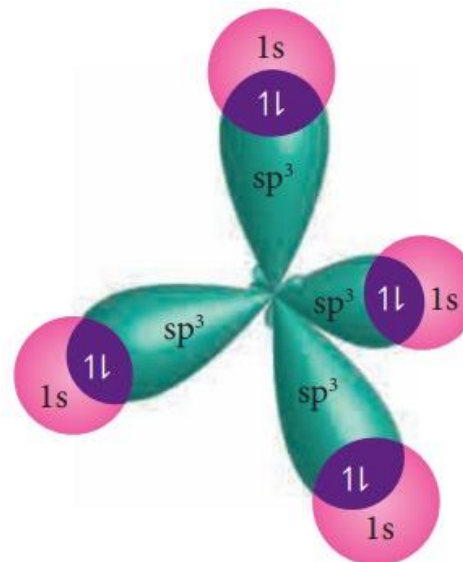
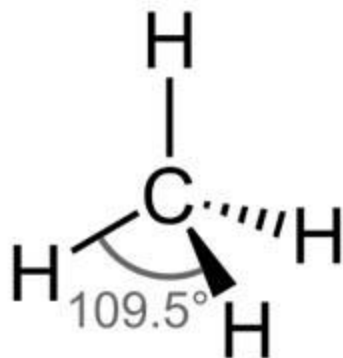
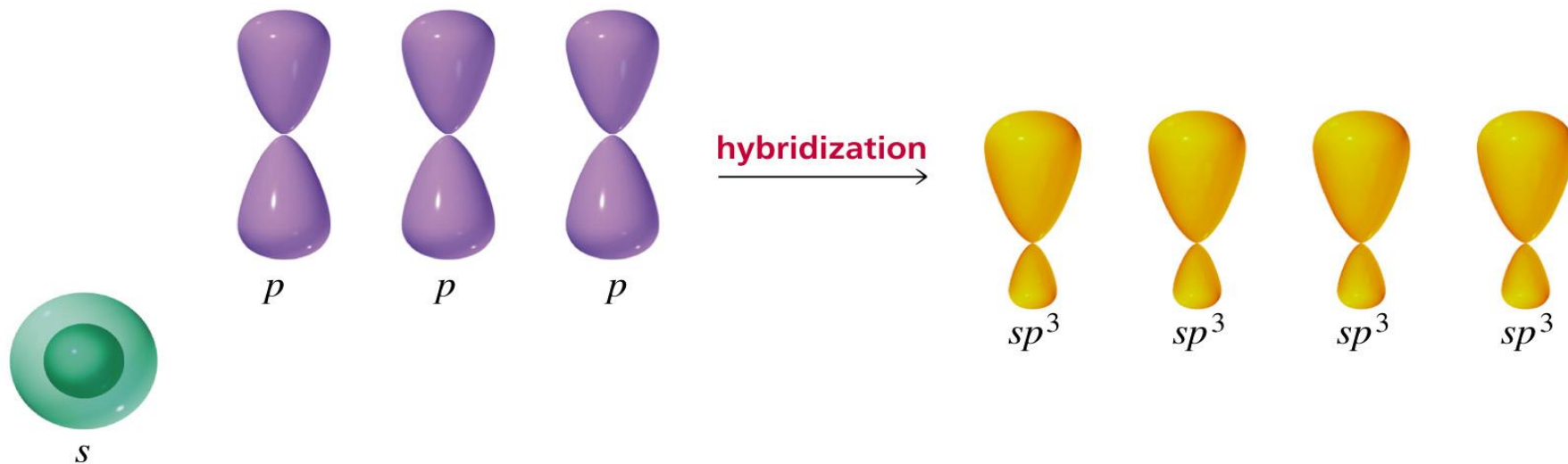
Atomic orbitals of carbon

Four equivalent sp^3 hybrid orbitals



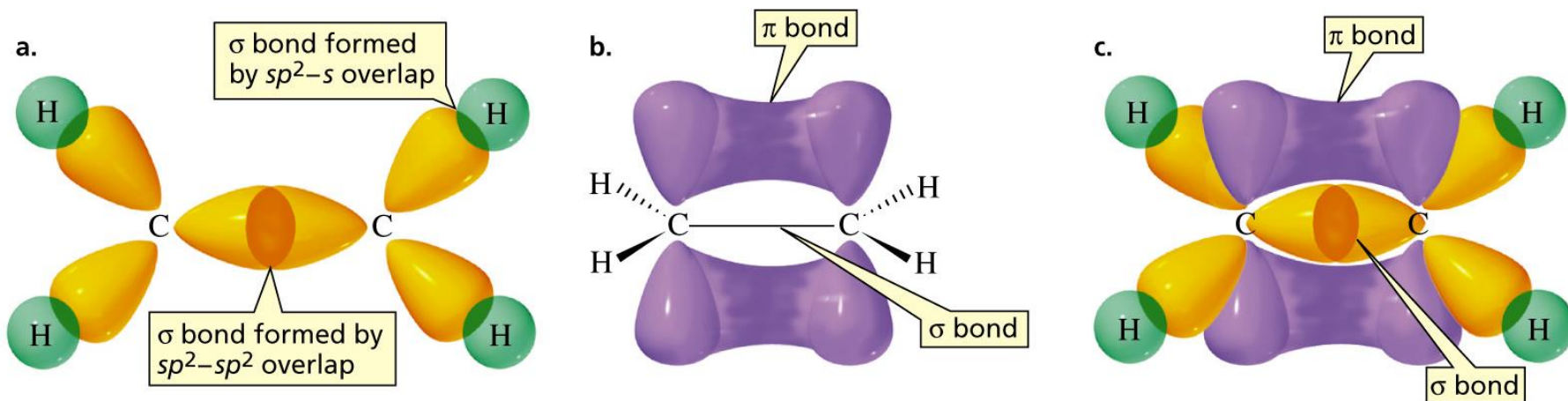
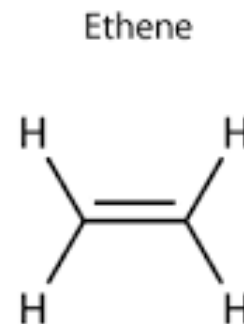
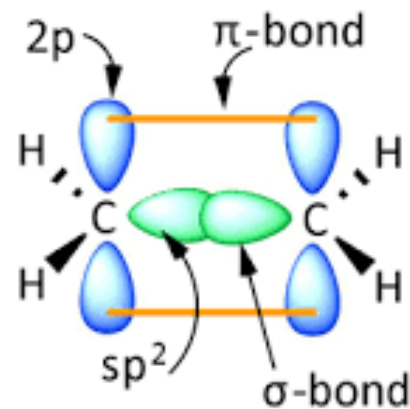
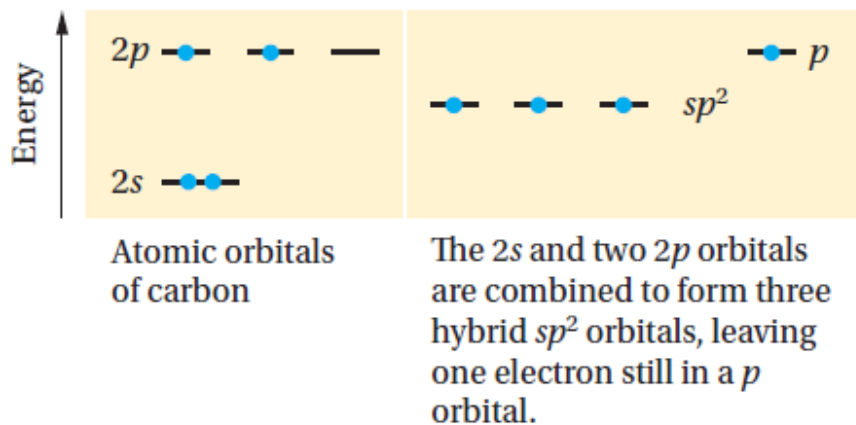
3D Structure of Methane Molecule

Mix or combine the four atomic orbitals of the valence shell to form four identical hybrid orbitals



SP²-Hybridized orbitals

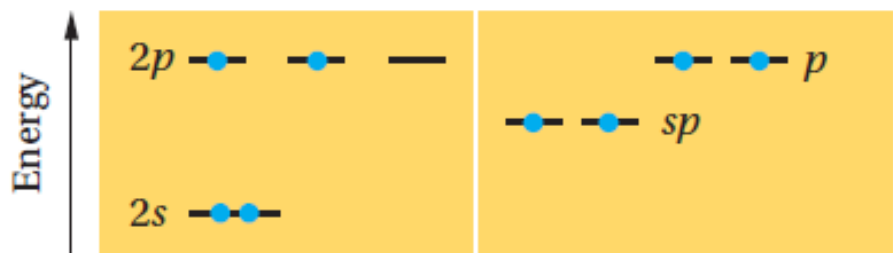
One part *s* and two parts *p* in character and are directed toward the three vertices of an equilateral triangle.



SP-Hybridized orbitals

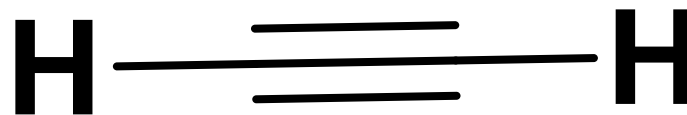
Bonding in Ethyne: A Triple Bond

- A triple bond consists of one σ bond and two π bonds

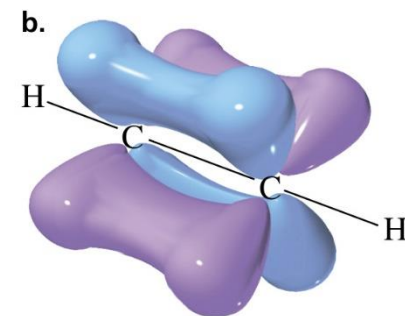
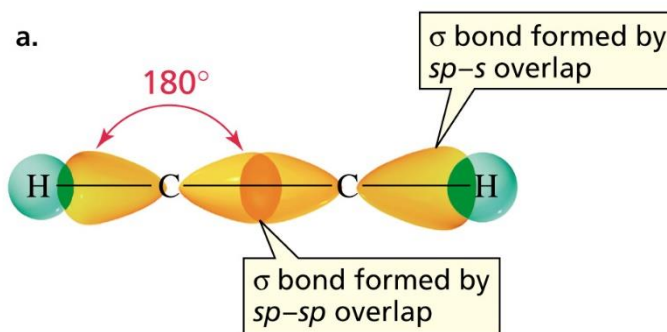


Atomic orbitals of carbon

The 2s and one 2p orbital are combined to form two hybrid sp orbitals, leaving one electron in each of two p orbitals.



sp orbitals forms a sigma bond between the two carbons, and lateral overlap of the properly aligned p orbitals forms two pi bonds



Valence Bond Theory (cont'd)

Orbitals are combined in various portions to make equivalent hybrid orbitals, *i.e.*

AOs(#(s, p))	hybrid	Angle	orientation
1, 1	2 sp	180°	linear
1, 2	3 sp ²	120°	trigonal planar
1, 3	4 sp ³	109°	tetrahedral

1.12 Resonance

There are molecules (or ions) for which more than one correct Lewis structure can be drawn, these equivalent Lewis structures are resonance structures.

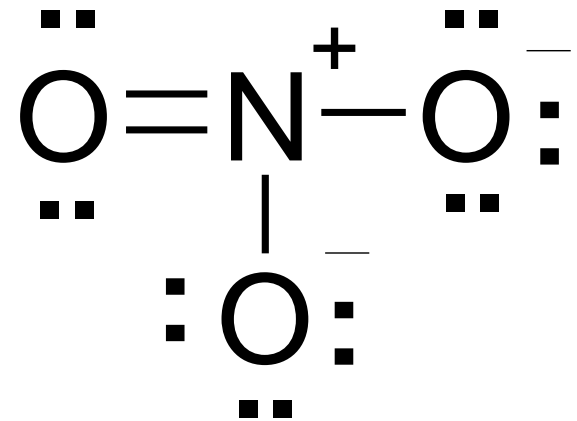
The assumption in these diagrams is that the atom positions do not change, we are only allowed to change the distribution of e^- , *i.e.* the bonds and lone pairs.

Lewis structures do not always explain properties of molecules. Resonance theory is a second layered approach.

Resonance (cont'd)

Example 1: NO_3^-

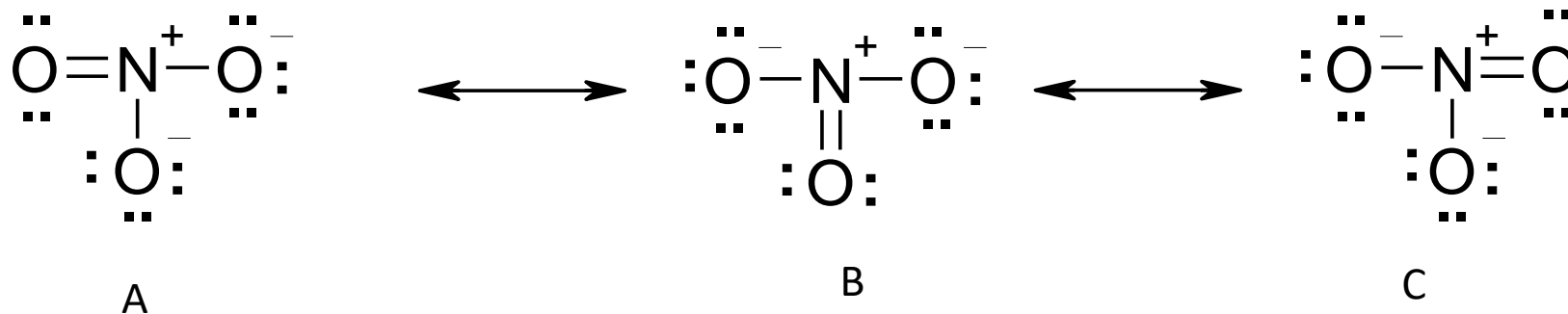
- 1) # e^- : $5 + 3(6) + 1 = 24$
- 2) try 3 single bonds
- 3) 18 e^- remain
- 4) Each O needs 6, leave 2 short
- 5) Share 1 pair but which one?
- 6) Pick one O, octets
- 7) Formal charges



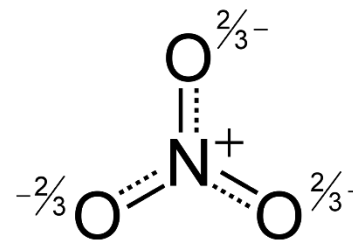
Resonance (cont'd)

Example 1: NO_3^- (cont'd)

Depending on your choice of the double bond to oxygen, there are three possible structures differing in the location of the double bond and charges on the oxygen.



In real the structure is hybrid of all (A, B and C)



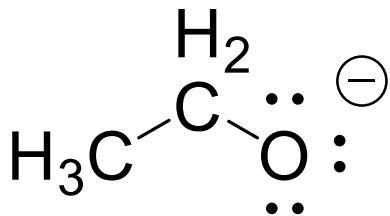
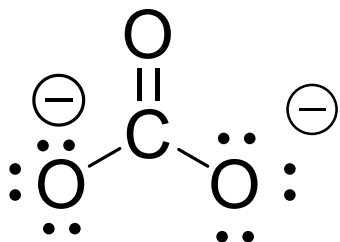
A resonance hybrid

The Lewis structure can be converted to other by changing the position of electrons

Rules for drawing resonance structures :

- 1) Electrons only can be oved (lone pair / π electrons)
- 2) Electrons move toward SP/ SP² hybridized atom only.

Examples: Write a second resonance structure for the following compounds?



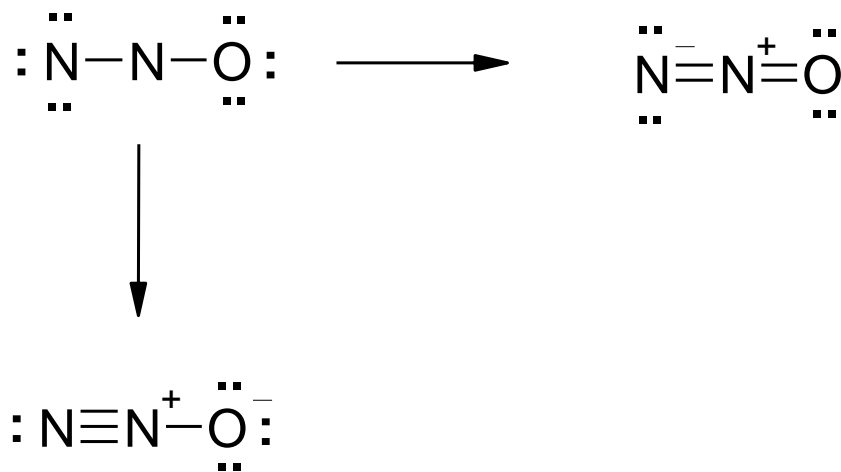
Exercise



Resonance (cont'd)

Example 2: N₂O

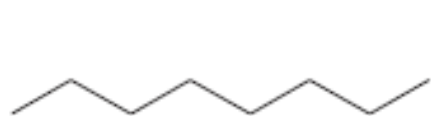
- 1) # e⁻: 2(5) + 6 = 16
- 2) try 2 single bonds
- 3) 12 e⁻ remain
- 4) 16 e⁻ for octets – 4 short
- 5) Options – 2 double bonds, 1 triple & 1 single
- 6) Octets
- 7) Formal charges
- 8) Which is better and why?



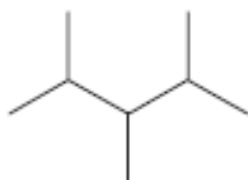
1.17: Classification According to Molecular Framework

- The three main classes of molecular frameworks for organic structures are **acyclic**, **carbocyclic**, and **heterocyclic** compounds.

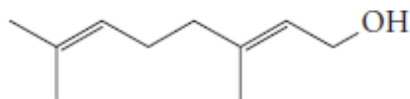
1.17.a Acyclic Compounds (*not cyclic*): contain chains that may be **unbranched** or **branched**.



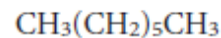
unbranched chain of
eight carbon atoms



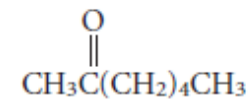
branched chain of
eight carbon atoms



geraniol
(oil of roses)
bp 229–230°C

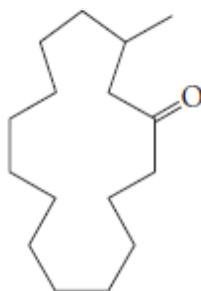


heptane
(petroleum)
bp 98.4°C

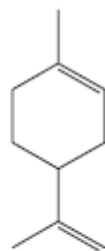


2-heptanone
(oil of cloves)
bp 151.5°C

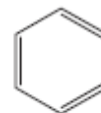
1.17b: Carbocyclic Compounds: contain rings of carbon atoms



muscone
(musk deer)
bp 327–330°C

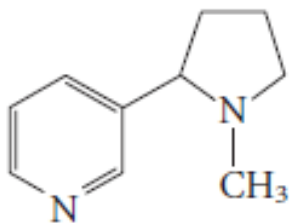


limonene
(citrus fruit oils)
bp 178°C

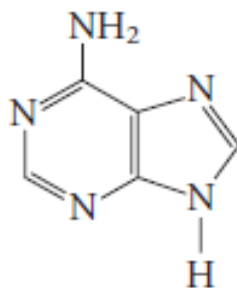


benzene
(petroleum)
mp 5.5°C, bp 80.1°C

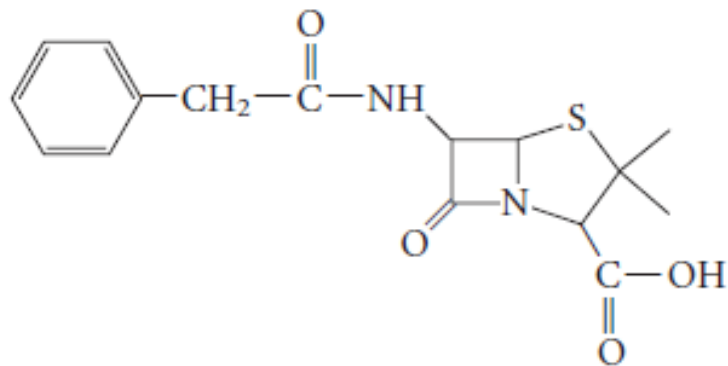
1.17.c Heterocyclic Compounds (In heterocyclic compounds, at least one atom in the ring must be a heteroatom, an atom that is *not* carbon: *eg.* N, O,S...)



nicotine
bp 246°C



adenine
mp 360–365°C
(decomposes)



penicillin-G
(amorphous solid)

Classification According to Functional Group

A functional group is an arrangement of atoms with distinctive **physical** and **chemical** properties.

Table 1.6 The Main Functional Groups

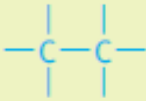
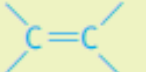
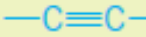


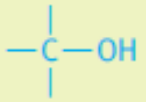
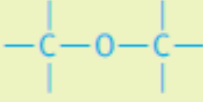
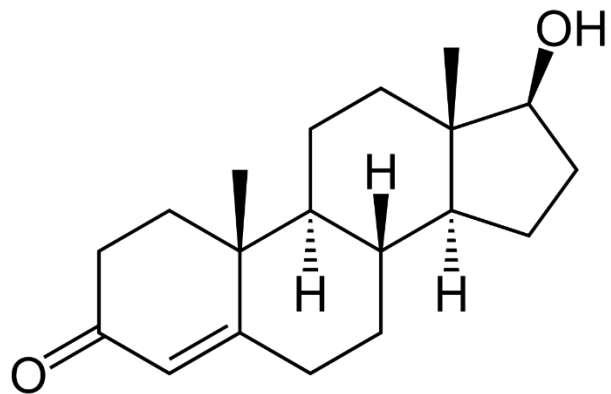
	Structure	Class of compound	Specific example	Common name of the specific example
<i>A. Functional groups that are a part of the molecular framework</i>				
		alkane	CH ₃ —CH ₃	ethane, a component of natural gas
		alkene	CH ₂ =CH ₂	ethylene, used to make polyethylene
		alkyne	HC≡CH	acetylene, used in welding
		arene		benzene, raw material for polystyrene and phenol
<i>B. Functional groups containing oxygen</i>				
<i>1. With carbon–oxygen single bonds</i>				
		alcohol	CH ₃ CH ₂ OH	ethyl alcohol, found in beer, wines, and liquors
		ether	CH ₃ CH ₂ OCH ₂ CH ₃	diethyl ether, once a common anesthetic

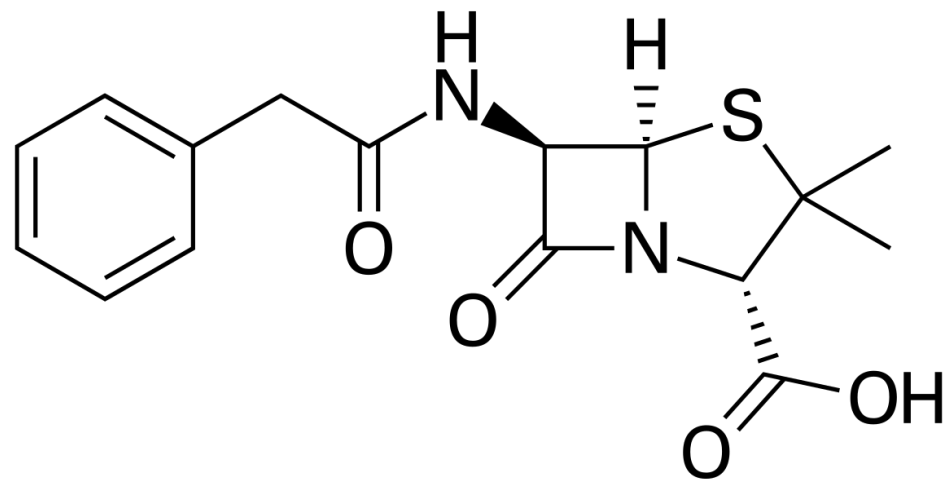
Table 1.6 continued

	Structure	Class of compound	Specific example	Common name of the specific example
2. With carbon–oxygen double bonds*	$\begin{array}{c} \text{O} \\ \parallel \\ -\text{C}-\text{H} \end{array}$	aldehyde	$\text{CH}_2=\text{O}$	formaldehyde, used to preserve biological specimens
	$\begin{array}{c} \text{O} \\ \parallel \\ -\text{C}-\text{C}-\text{C}- \\ \quad \quad \end{array}$	ketone	$\begin{array}{c} \text{O} \\ \parallel \\ \text{CH}_3\text{CCH}_3 \end{array}$	acetone, a solvent for varnish and rubber cement
3. With single and double carbon–oxygen bonds	$\begin{array}{c} \text{O} \\ \parallel \\ -\text{C}-\text{OH} \end{array}$	carboxylic acid	$\begin{array}{c} \text{O} \\ \parallel \\ \text{CH}_3\text{C}-\text{OH} \end{array}$	acetic acid, a component of vinegar
	$\begin{array}{c} \text{O} \\ \parallel \\ -\text{C}-\text{O}-\text{C}- \\ \quad \end{array}$	ester	$\begin{array}{c} \text{O} \\ \parallel \\ \text{CH}_3\text{C}-\text{OCH}_2\text{CH}_3 \end{array}$	ethyl acetate, a solvent for nail polish and model airplane glue
C. Functional groups containing nitrogen**	$\begin{array}{c} \\ -\text{C}-\text{NH}_2 \\ \end{array}$	primary amine	$\text{CH}_3\text{CH}_2\text{NH}_2$	ethylamine, smells like ammonia
	$-\text{C}\equiv\text{N}$	nitrile	$\text{CH}_2=\text{CH}-\text{C}\equiv\text{N}$	acrylonitrile, raw material for making Orlon
D. Functional group with oxygen and nitrogen	$\begin{array}{c} \text{O} \\ \parallel \\ -\text{C}-\text{NH}_2 \end{array}$	primary amide	$\begin{array}{c} \text{O} \\ \parallel \\ \text{H}-\text{C}-\text{NH}_2 \end{array}$	formamide, a softener for paper
E. Functional group with halogen	$-\text{X}$	alkyl or aryl halide	CH_3Cl	methyl chloride, refrigerant and local anesthetic
F. Functional groups containing sulfur†	$\begin{array}{c} \\ -\text{C}-\text{SH} \\ \end{array}$	thiol (also called mercaptan)	CH_3SH	methanethiol, has the odor of rotten cabbage
	$\begin{array}{c} \quad \quad \\ -\text{C}-\text{S}-\text{C}- \\ \quad \quad \end{array}$	thioether (also called sulfide)	$(\text{CH}_2=\text{CHCH}_2)_2\text{S}$	diallyl sulfide, has the odor of garlic

Ex. What functional groups can you find in the following natural products?



testosterone



penicillin-G