

Mutual influence of atoms in organic molecules

Lecture 9

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Aim

Based on the structure of atoms and chemical bonds, form knowledge about their mutual influence and consider the factors that determine the reactivity.

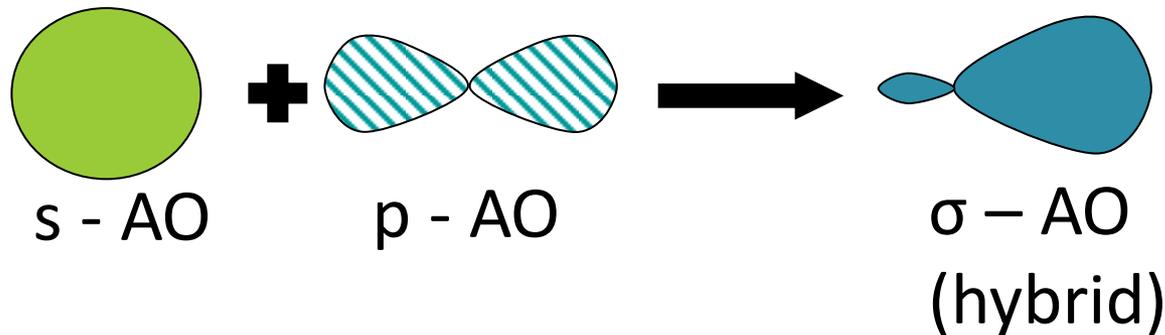
Plan

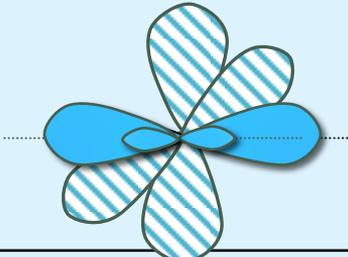
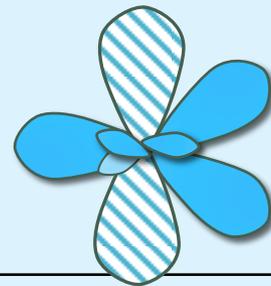
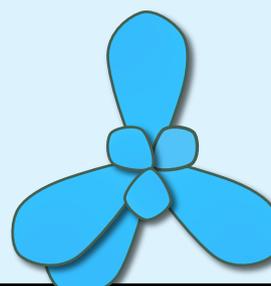
- 1) Hybridization
- 2) Conjugated systems with open and closed chain
- 3) Inductive and mesomeric effects
- 4) Electron-donating and electron-accepting atoms groups
- 5) Types of organic reactions and reagents
- 6) Factors Determining the Reactivity of Organic Compounds

Hybridization

- **HYBRIDIZATION** is the mixing of atomic orbitals of different shapes and energies (within the valence level) with the formation of atomic orbitals of the same shape and energy.

When s-AO and p-AO are mixed, hybrid atomic orbitals (σ - AO) are formed:



Type of Hybridization	Formula	Carbon skeleton structure	view
sp	$1s + 1p = 2sp$	<p>Линейная (180°)</p> $\equiv C -$	
sp^2	$1s + 2p = 3sp^2$	<p>Плоская (120°)</p> $= C \begin{matrix} / \\ \backslash \end{matrix}$	
sp^3	$1s + 3p = 4sp^3$	<p>Тетраэдр (109°)</p> $- C -$	

TYPES OF HYBRIDIZATION OF ATOMIC ORBITALS

How to determine the type of hybridization?

Atom hybridization is determined by the Terney's rule:
count the **number of objects** around the atom.

4 objects - sp^3 hybridization.

3 objects - sp^2 hybridization.

2 objects - sp -hybridization.

OBJECTS OF THE ATOM:

1) Neighboring atoms (partners)

2) Free electronic pairs

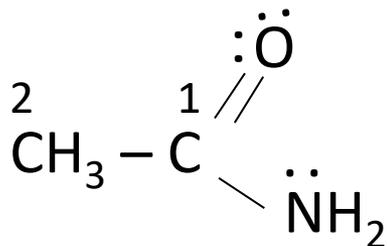
An electronic pair is free if:

1/ Its atom has a multiple connection with the "partner"

2/ Neither its atom nor its "partner" have multiple connections.



Estimation of the hybridization type according to Terney's rule

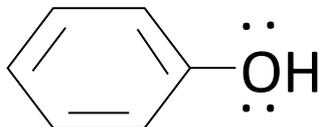


$\text{C}_1 - (3 \text{ partners} + 0 \text{ free electronic pairs} = 3 \text{ objects}) \text{ } sp^2$

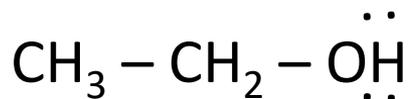
$\text{C}_2 - (4 \text{ partners} + 0 \text{ free electronic pairs} = 4 \text{ objects}) \text{ } sp^3$

$\text{N} - (3 \text{ partners} + 0 \text{ free electronic pairs} = 3 \text{ objects}) \text{ } sp^2$

$\text{O} - (1 \text{ partner} + 2 \text{ free electronic pairs} = 3 \text{ objects}) \text{ } sp^2$



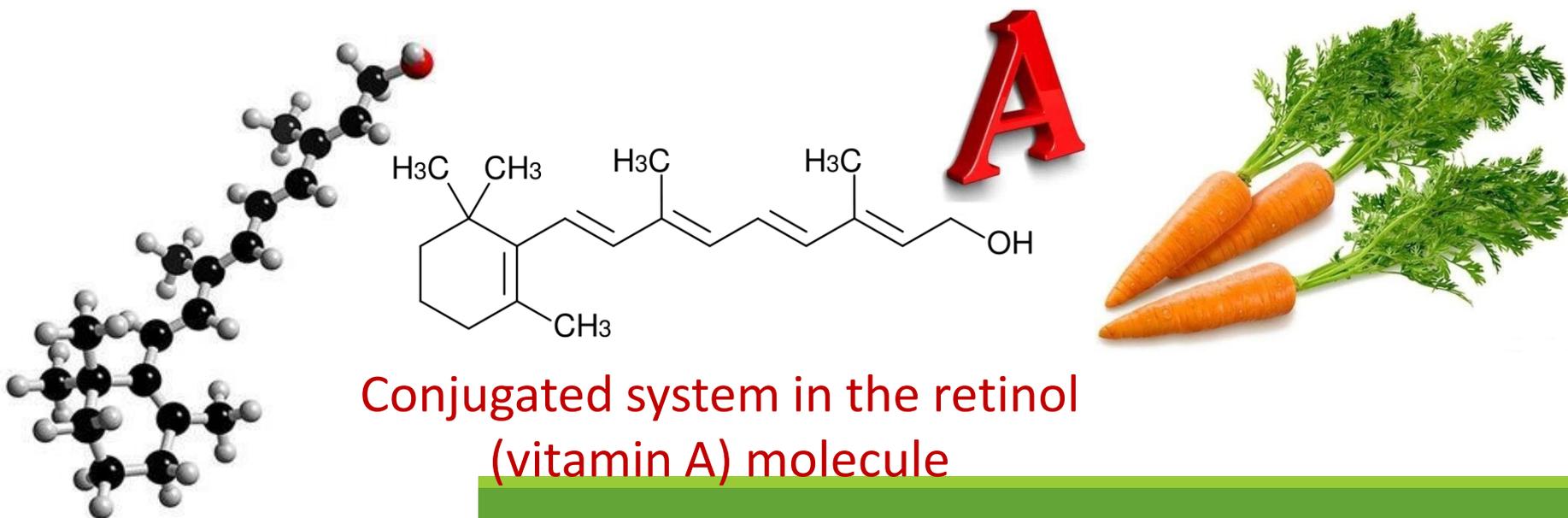
$\text{O} - (2 \text{ partners} + 1 \text{ free electronic pair} = 3 \text{ objects}) \text{ } sp^2$



$\text{O} - (2 \text{ partners} + 2 \text{ free electronic pairs} = 4 \text{ objects}) \text{ } sp^3$

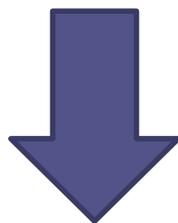
Mutual influence of atoms in organic molecules

- The mutual influence of atoms in molecules is expressed in conjugation effects and electronic effects. Conjugated systems with an open and closed conjugation chain are widespread in nature and among pharmacologically active substances (they have increased stability).



Relevance of the topic

- Biologically active substances perform their functions through the reaction centers of the substituents, or under their influence.



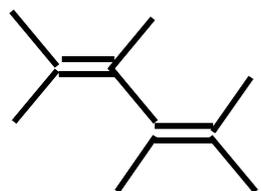
- Knowledge of the concepts of "conjugation", "aromaticity", "electronic effects of substituents" will be used to find the reaction centers of molecules and predict their chemical behavior.



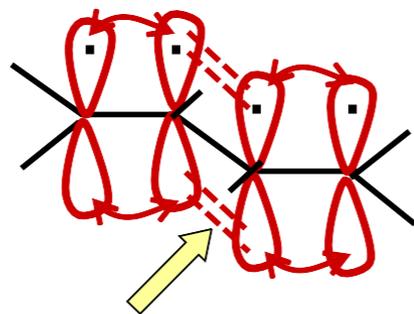
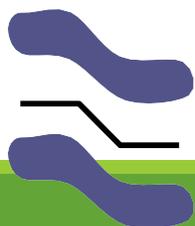
The principle of formation of a Conjugated system

π - π - conjugated

A single four-center π -molecular orbital (MO) with a delocalized electron density is formed, the energy of the system decreases.



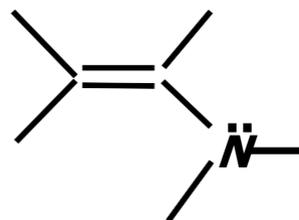
butadiene



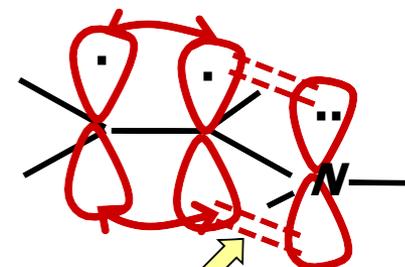
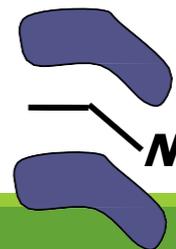
π - π -conjugated

p - π - conjugated

A single 3-center π -MO with a delocalized electron density is formed. 4π electrons belong to 3 atoms. On carbon atoms the electron density increases, and on the nitrogen atom it decreases.



vinylamine

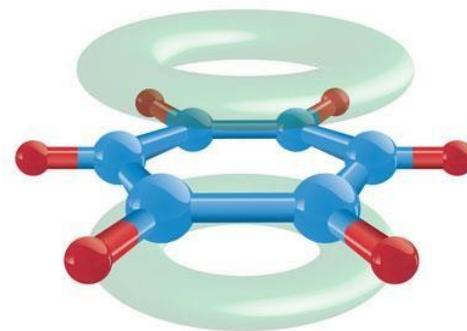


p - π - conjugated

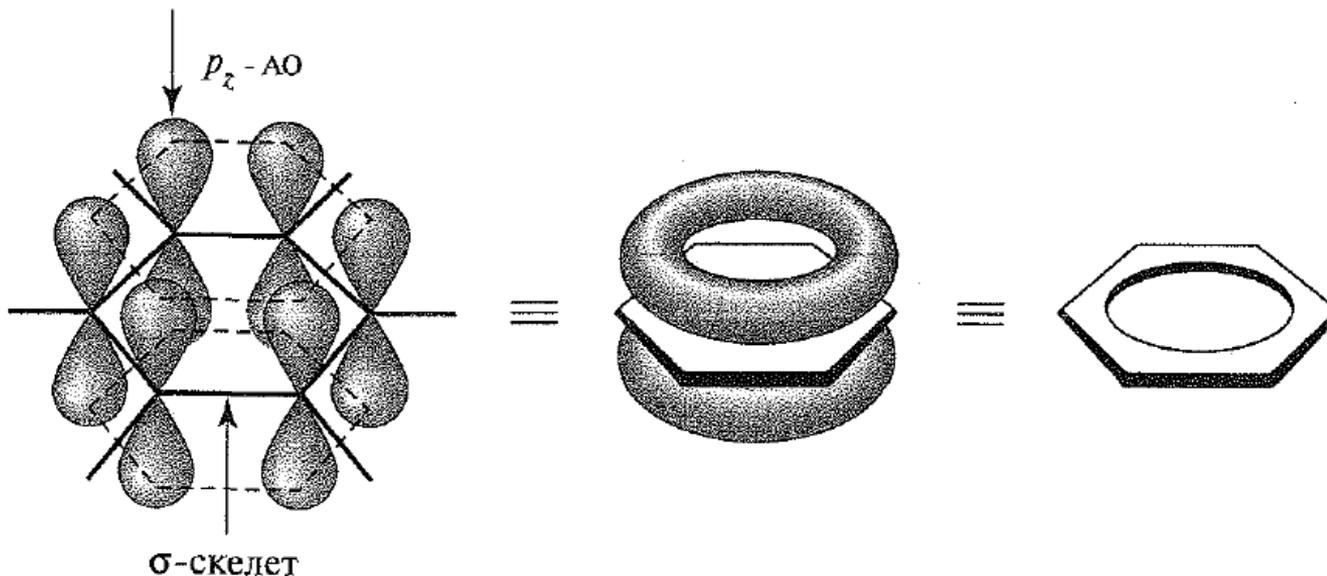
Conjugated systems with closed chain

- Among such systems, aromatic systems are the most important.
- Aromaticity is a special case of Conjugated.

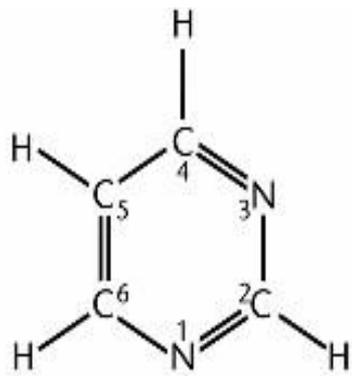
- Aromaticity criteria:
- the Conjugated chain is closed;
- the number of electrons participating in conjugation obeys the **Hückel's rule**: it is equal to $4n + 2$, where n is any integer, including zero.



Atomic-orbital model of benzene



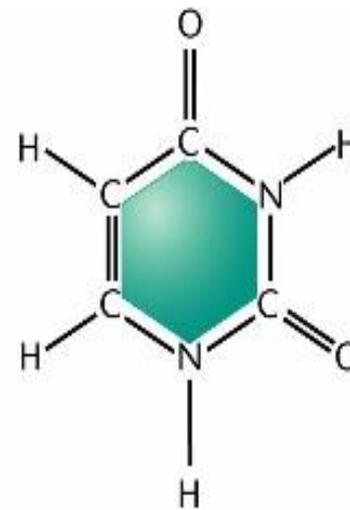
- The benzene framework is formed by six sp^2 -hybridized carbon atoms;
- All σ -bonds (C-C and C-H) lie in the same plane;
- Six unhybridized p-AOs are located perpendicular to the plane of the molecule and parallel to each other;
- Each p-AO overlaps with two neighboring p-AOs;
- A single delocalized π -system is formed;
- All C-C bonds in benzene have the same length of 0.139 nm (intermediate between single and double).



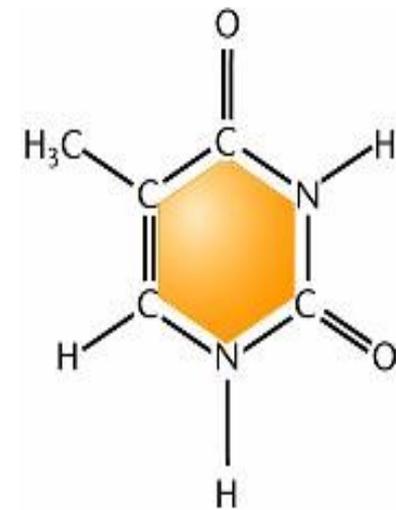
Pyrimidine ring



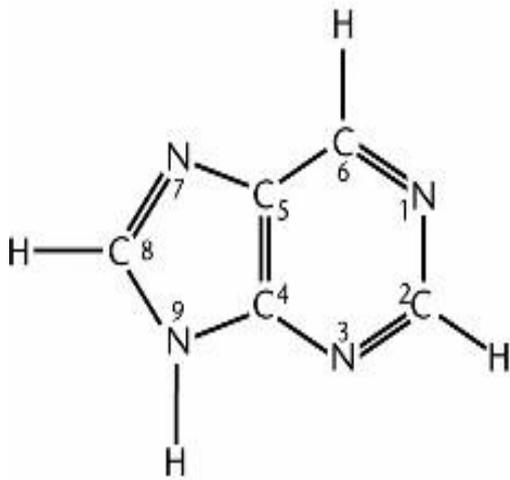
Cytosine



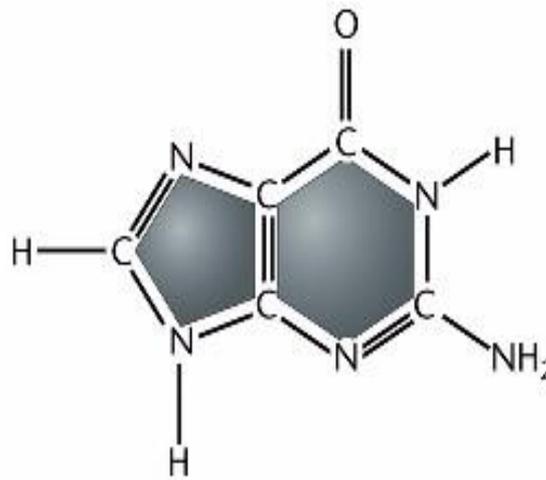
Uracil



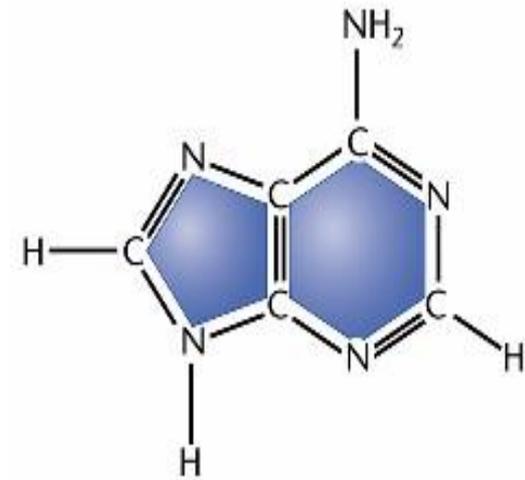
Thymine



Purine ring

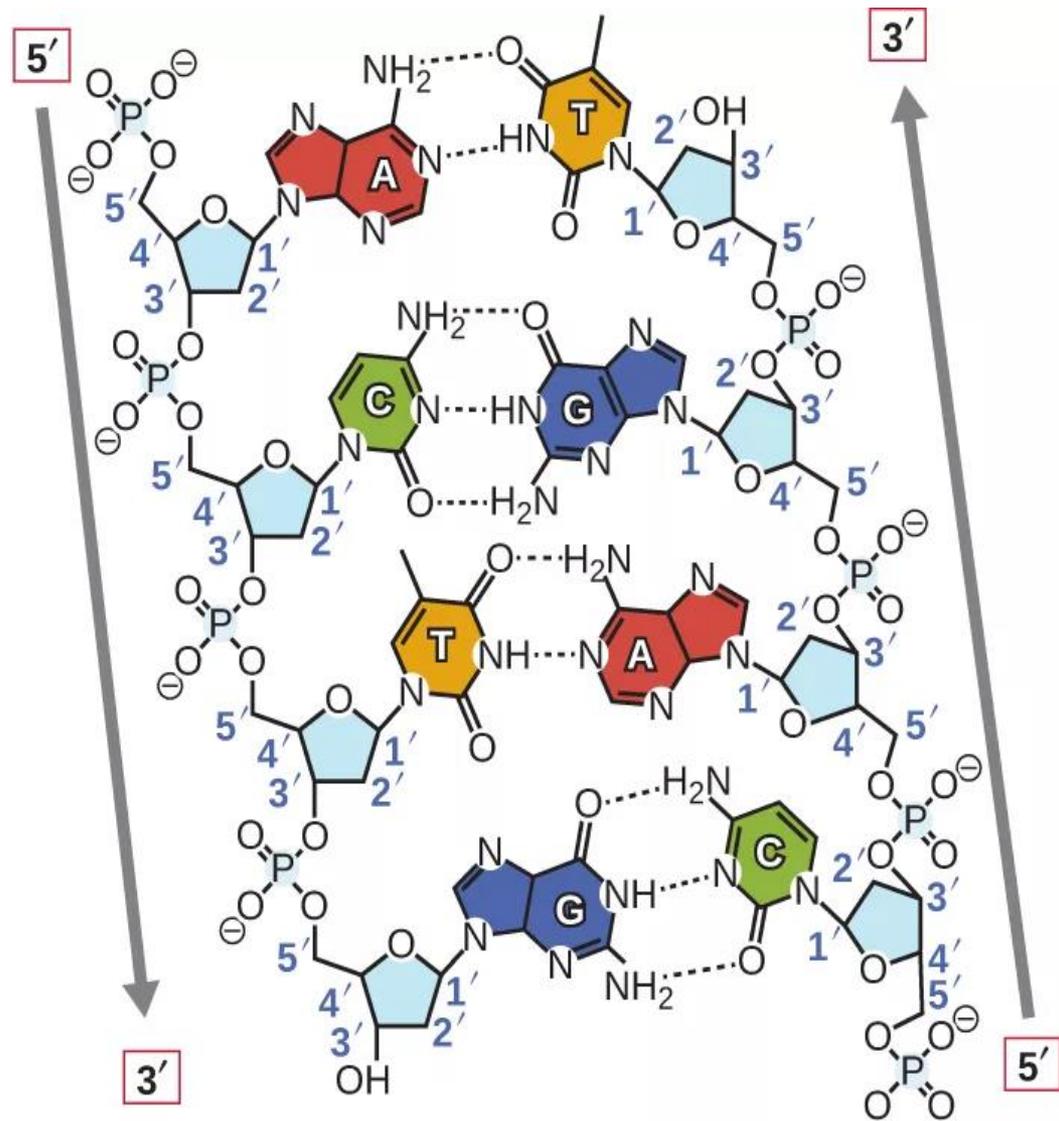
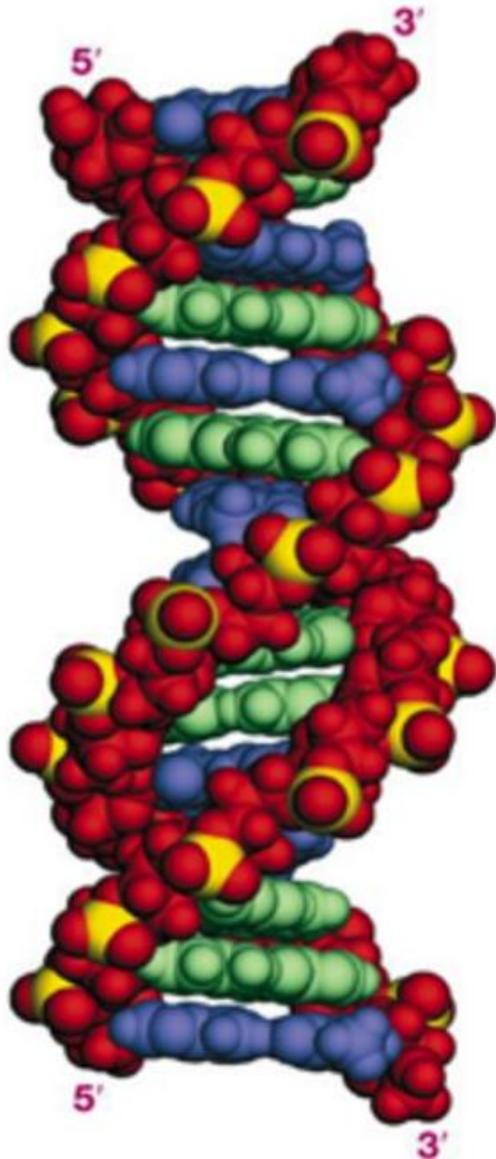


Guanine



Adenine

DNA Structure



Stability of Conjugated systems

The formation of a conjugated system is an energetically favorable process, because this increases the degree of overlapping of orbitals and delocalization of p-electrons.

Property of Conjugated systems:

They have increased thermodynamic stability

Properties of aromatic systems:

- Resistance to oxidants and t° , despite a high degree of unsaturation;
- The tendency to enter into substitution reactions rather than addition;
- Increased thermodynamic stability compared to open circuit coupled systems.

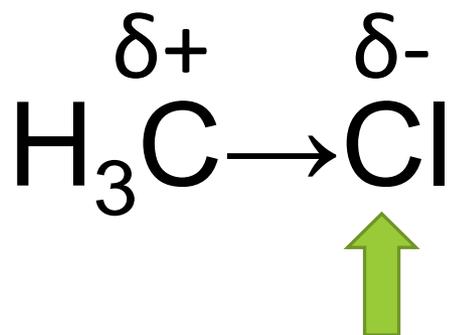
Electronic effects

The mutual influence of atoms in a molecule is transmitted using electronic effects:

- Inductive effect (I)
- Mesomeric effect (M)

Inductive effect (I)

Inductive effect (I) is the transfer of the electronic influence of substituents along the chain of σ - bonds.



$-\text{I}$ (Cl)

δ - partial charge

« δ^- » - excess electron density

« δ^+ » - electron density deficit

A more electronegative element pulls σ -bond electrons onto itself

Negative inductive effect (-I)

-I the effect is caused by any substituents containing atoms with more electronegativity than that of a carbon atom:

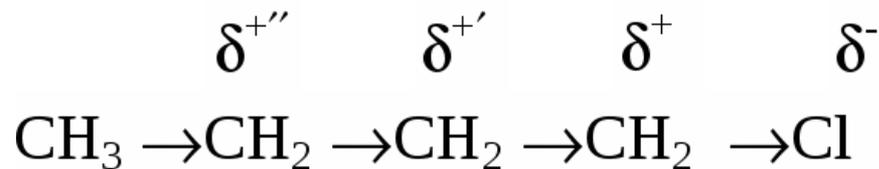
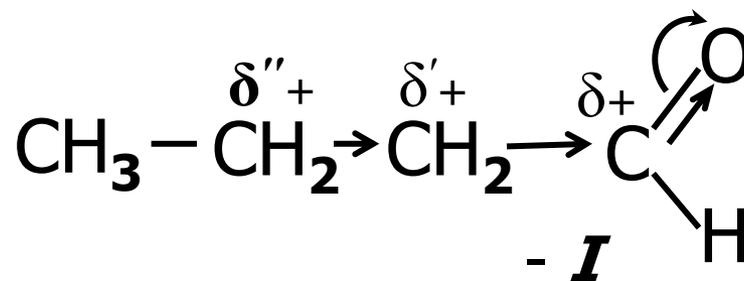
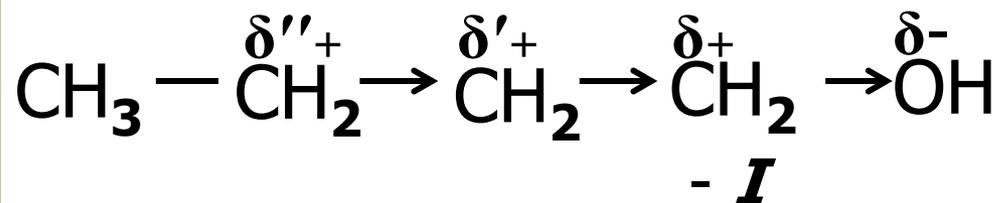
1) -F, -Cl, -Br, -I

2) -OH, -OR

3) -NH₂, -NHR -NR₂

4) -COH, -COOH, -COR, -COOR, -NO₂, -SO₃H
and etc.

Examples of $-I$ effect



1-хлорбутан

$- I_{\text{Cl}}$

$$\delta^+ > \delta'^+ > \delta''^+$$

The inductive effect is weakened after 3-4 bonds!

Positive inductive effect (+I)

+I the effect is possessed by substituents that shift the electron density towards the carbon atom:

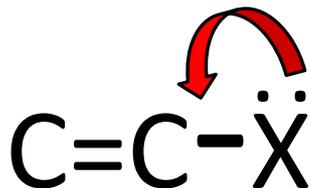
Group	Example
1) - R (-CH ₃ , -C ₂ H ₅ ...) alkyl radicals	$\delta^- \text{CH}_2 = \text{CH} \leftarrow \delta^+ \text{CH}_3$ <p style="text-align: right;">+I</p>
2) - O ⁻ Negatively charged oxygen	$\text{CH}_3 - \overset{\delta''-}{\text{CH}_2} \leftarrow \overset{\delta'-}{\text{CH}_2} \leftarrow \overset{\delta-}{\text{CH}_2} \leftarrow \overset{-}{\text{O}}$ <p style="text-align: right;">+I</p>
3) - Me ⁺ Metal cation	$\text{CH}_3 - \overset{\delta''-}{\text{CH}_2} \leftarrow \overset{\delta'-}{\text{CH}_2} \leftarrow \overset{\delta-}{\text{CH}_2} \leftarrow \overset{\delta+}{\text{MgBr}}$ <p style="text-align: right;">+I</p>

The mesomeric effect (M) is the transfer of the electronic influence of substituents on π -bonds in a conjugated system. In this case, the deputy himself is a member of the coupled system.

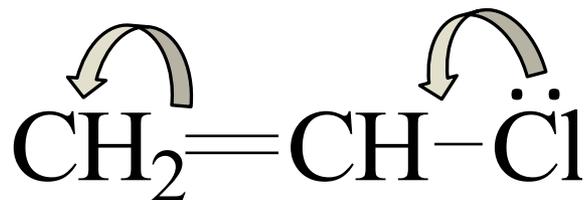
Positive mesomeric effect (+ M)	Negative mesomeric effect (-M)
<ul style="list-style-type: none"> • Has the groups containing the atoms with a lone electron pair or an integer "-" charge, located next to the π-bond. • Increase the electron density in the conjugated system. 	<ul style="list-style-type: none"> • Has the unsaturated groups and "+" charged atoms. • Decrease the electron density in the conjugated system.
-OH -NH ₂ -O ⁻ -F, -Cl, -Br, -I -OR -NHR -NR ₂	-NO ₂ -COH -NH ₃ ⁺ -SO ₃ H -COOH -NR ₃ ⁺ -COOR

МЕЗОМЕРНЫЙ ЭФФЕКТ

+ М - эффект

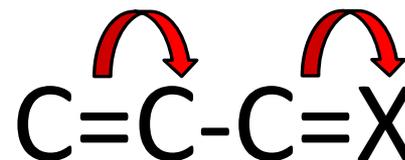


В *p,π*-сопряженных системах

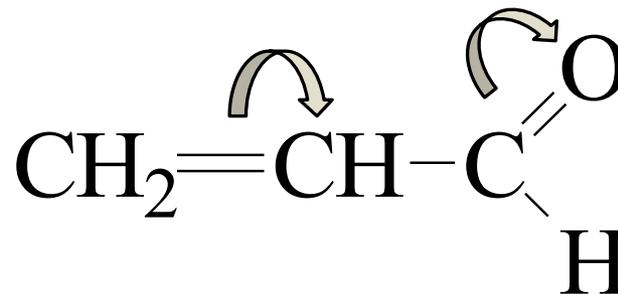


+M_{Cl}

- М - эффект



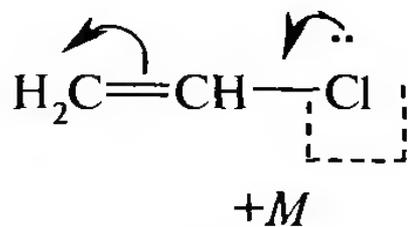
В *π,π*-сопряженных системах



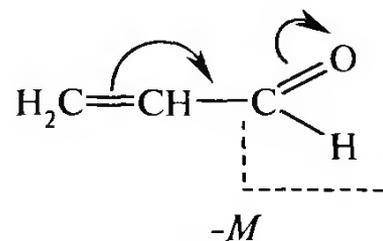
-M_{C=O}

+ M effect

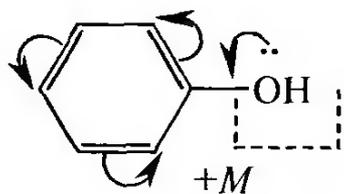
- M effect



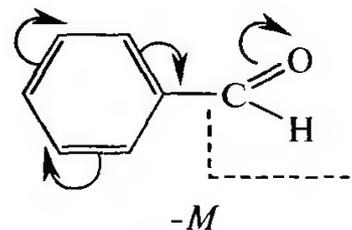
chloroethene



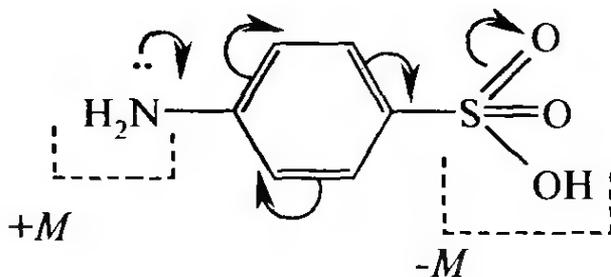
propenal



phenol



benzaldehyde

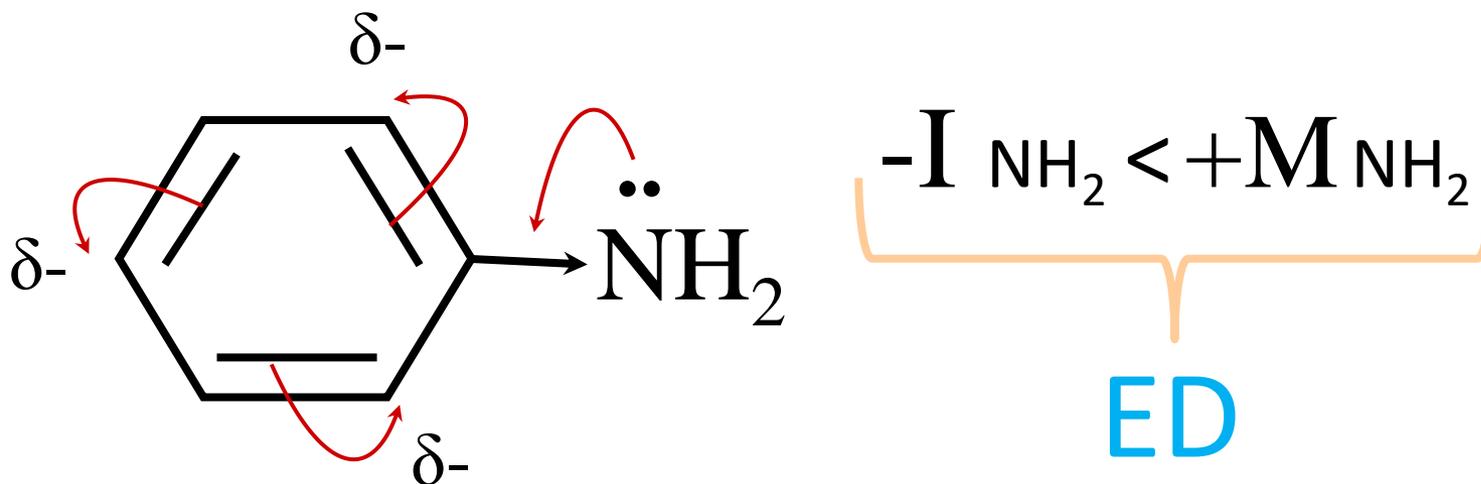


p-aminobenzenesulfonic acid

Electron-donors and electron-acceptors

The substituents with the **-I** and **-M** effects are called **electron-acceptors (EA)**.

Substituents with **+I** and **+M** effects are called **electron-donors (ED)**.



Electron-donors and electron-acceptors

Заместитель	Электронные эффекты		Характер совместного действия
	индуктивный	мезомерный	
Алкильные группы (R)	+I	—	Electron-donors
—O ⁻	+I	+M	
—NH ₂ , —NHR, —NR ₂	-I	+M	
—OH, —OR	-I	+M	
—NH ₃ ⁺ , —NR ₃ ⁺	-I	—	Electron-acceptors
Галогены (F, Cl, Br, I)	-I	+M	
>C=O	-I	-M	
—COOH, —COOR	-I	-M	
—NO ₂	-I	-M	
—C≡N	-I	-M	
—SO ₃ H	-I	-M	

Types of reactions and reagents in organic chemistry

- **A chemical reaction** is a process accompanied by a change in the distribution of electrons in the outer shells of the atoms of the reacting substances.

Reactivity is the ability of a substance to react chemically and react at a slower or faster rate.

A reaction center is an atom or group of atoms directly involved in a given chemical reaction.



Substrate
(reactant)



Reagent
(reactive
particle)

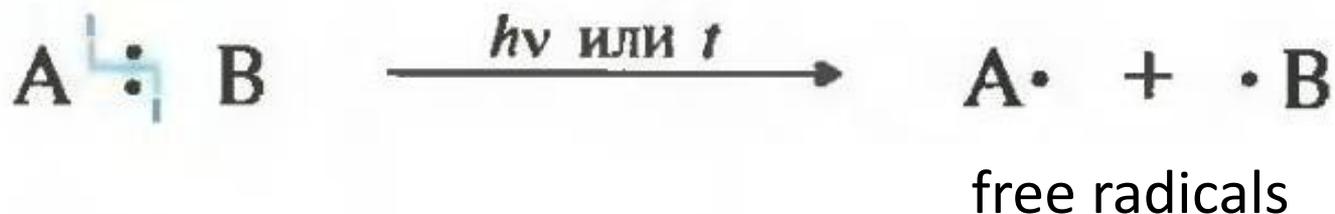


**Reaction
products**

Classification of reactions in organic chemistry

By the mechanism of breaking the covalent bond

1. Radical reactions (bond homolysis)



2. Ionic reactions (bond heterolysis)



Classification of reactions in organic chemistry

1. Substitution reactions (S)

By the direction of reaction

Substitution type	Example in a general form
Radical substitution S_R	$\begin{array}{c} \\ -C-X \\ \end{array} + Y^\bullet \longrightarrow \begin{array}{c} \\ -C-Y \\ \end{array} + X^\bullet$
Electrophilic substitution S_E	$\begin{array}{c} \\ -C-X \\ \end{array} + E^+ \longrightarrow \begin{array}{c} \\ -C-E \\ \end{array} + X^+$ <p style="text-align: center;">Leaving group</p>
Nucleophilic substitution S_N	$\begin{array}{c} \\ -C-X \\ \end{array} + Y^- \longrightarrow \begin{array}{c} \\ -C-Y \\ \end{array} + X^-$

Classification of reactions in organic chemistry

2. Addition reactions (A)

By the direction of reaction

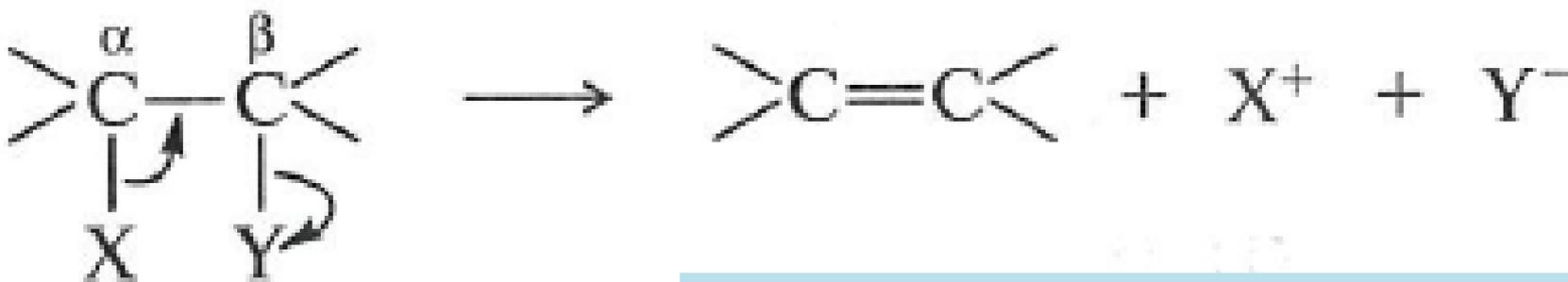
Addition type	Example in a general form
Radical addition A_R	$\text{>C=C<} + \text{X-Y} \longrightarrow \text{>}\overset{\cdot}{\text{C}}-\overset{\text{Y}}{\text{C}}\text{<} \xrightarrow{\text{X}^{\cdot}} \text{>}\overset{\text{X}}{\text{C}}-\overset{\text{Y}}{\text{C}}\text{<}$
Electrophilic addition A_E	$\text{>C=C<} + \overset{\delta^+}{\text{E}}-\overset{\delta^-}{\text{Y}} \longrightarrow \text{>}\overset{+}{\text{C}}-\overset{\text{E}}{\text{C}}\text{<} \xrightarrow{\text{Y}^-} \text{>}\overset{\text{Y}}{\text{C}}-\overset{\text{E}}{\text{C}}\text{<}$
Nucleophilic addition A_N	$\text{>C=C<} + \overset{\delta^+}{\text{E}}-\overset{\delta^-}{\text{Y}} \longrightarrow \text{>}\overset{-}{\text{C}}-\overset{\text{Y}}{\text{C}}\text{<} \xrightarrow{\text{E}^+} \text{>}\overset{\text{E}}{\text{C}}-\overset{\text{Y}}{\text{C}}\text{<}$

Classification of reactions in organic chemistry

By the direction of reaction

3. Elimination reactions (E)

Example in a general form

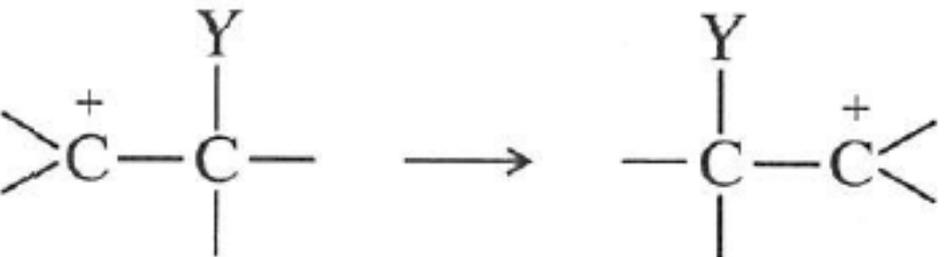


- Groups X and Y can leave sequentially or simultaneously, unite or not unite

Classification of reactions in organic chemistry

4. Regrouping

By the direction of reaction

Regrouping type	Example in a general form
Radical regrouping	 $\begin{array}{c} & \text{Y} & \\ & & \\ > \dot{\text{C}} - & \text{C} - & \\ & & \\ & & \end{array} \longrightarrow \begin{array}{c} \text{Y} & \\ & \\ - \text{C} - & \dot{\text{C}} < \\ & \end{array}$
Nucleophilic regrouping	 $\begin{array}{c} & \text{Y} & \\ & & \\ > \text{C}^+ - & \text{C} - & \\ & & \\ & & \end{array} \longrightarrow \begin{array}{c} \text{Y} & \\ & \\ - \text{C} - & \text{C}^+ < \\ & \end{array}$

Classification of reactions in organic chemistry

By the direction of reaction

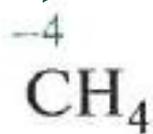
5. Redox reactions

In the course of these reactions, the oxidation state of the carbon atom, which acts as a reaction center, changes.

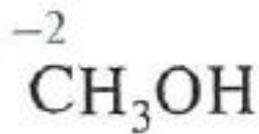
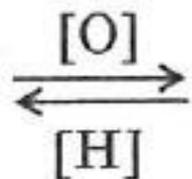
Oxidation of organic compounds is the process of removing hydrogen to form a multiple bond or a new bond between a carbon atom and a heteroatom. Reduction is the reverse process of oxidation.

Redox series

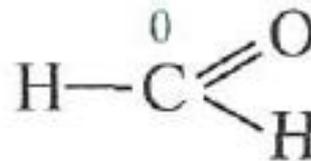
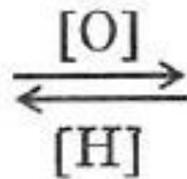
Minimum carbon oxidation state



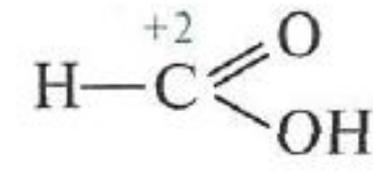
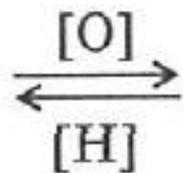
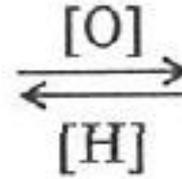
methane



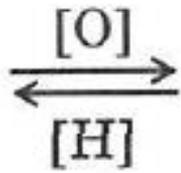
methanol



formaldehyde



methanoic acid



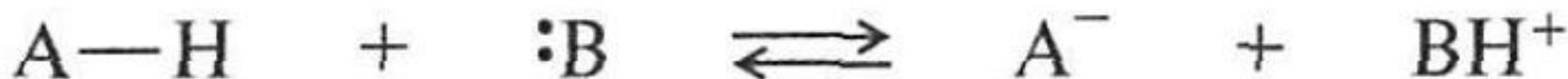
carbon dioxide

Maximum carbon oxidation state

Classification of reactions in organic chemistry

By the direction of reaction

6. Acid-base interactions



кислота

основание

сопряженное
основание

сопряженная
кислота

The acid (кислота) is the hydrogen proton donor H^+ .

The base (основание) is the acceptor of the hydrogen proton H^+ .

Reagents types

Reagent	Definition	Examples
Electrophile E ⁺ , E	A particle that forms a new covalent bond due to the partner's electronic pair.	H ⁺ , Br ⁺ , R ₃ C ⁺ , SO ₃ , AlCl ₃
Nucleophile Nu, Nu ⁻	Particles forming a new covalent bond with a partner carrying a partial or full positive charge, providing their electron pair.	H ⁻ , Cl ⁻ , OH ⁻ , RO ⁻ NH ₃ , H ₂ O, CH ₂ =CH ₂ (alkenes), C ₆ H ₆ (arenes)

Reagents types

Reagent	Definition	Examples
Acid HA (BH ⁺)	Neutral molecules or ions capable of donating a hydrogen proton H ⁺ .	HCl, HC≡CH, CH ₃ COOH, NH ₄ ⁺ , H ₃ O ⁺
Base B, B ⁻	Neutral molecules or "-" charged particles capable of tearing a proton away from an acid site.	OH ⁻ , RO ⁻ NH ₃ , H ₂ O, R-OH, R-NH ₂ , CH ₂ =CH ₂ (alkenes)

Reagents types

Reagent	Definition	Examples
Radical ·R	Free atom or particle with unpaired \bar{e}	·Cl, ·Br, ·OH, ·CH ₃
Oxidizer [O]	Neutral molecule or ion that accepts \bar{e}	O ₂ Fe ³⁺
Reducing agent [H]	Neutral molecule or ion that gives off \bar{e}	H ₂ , Fe ²⁺ , H ⁻

Conclusions

- 1) Atoms in molecules are linked by not only localized but also delocalized covalent bonds
- 2) Conjugation is a delocalized π -bond that occurs with a certain interaction between atoms
- 3) Substituents in the hydrocarbon chain and heteroatoms in the cycles are electro donors or electro acceptors
- 4) The type of substitute is determined using the concept of electronic effects
- 5) The presence of a substituent leads to a redistribution of the electron density and the appearance of reaction centers.
- 6) The type of reaction center determines the type of attacking reagent and the way of breaking the bond.