

université
PARIS-SACLAY

FACULTÉ DE
PHARMACIE

TU07 – Refresher training in organic chemistry

Year 2024-2025

Course outline

- Atoms and chemical bonds
 - Number of bonds around an atom
 - Types of chemical bonds
 - Covalent vs ionic
 - Single vs multiple
 - Impact of chemical bonds on structure
 - Functional groups
- Chemical reactivity
 - Nucleophile and electrophile
 - Bond polarisation
 - Inductive and mesomeric effects
 - Principal mechanisms



Atoms and chemical bonds

Organic chemistry is...

Carbon Chemistry!

Atomic number

6

C

Carbon

12.011

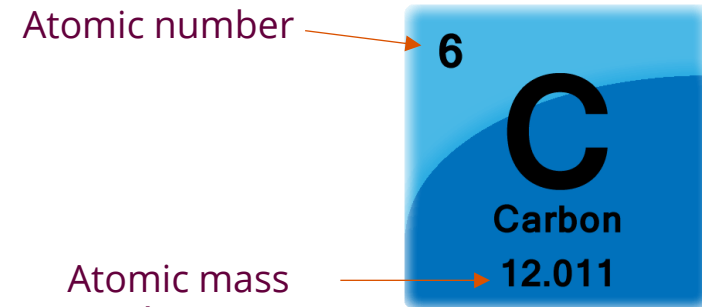
Atomic mass

PERIODIC TABLE OF THE ELEMENTS

1 H Hydrogen 1.008																	2 He Helium 4.003
3 Li Lithium 6.941	4 Be Beryllium 9.012											5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180
11 Na Sodium 22.990	12 Mg Magnesium 24.305											13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.066	17 Cl Chlorine 35.453	18 Ar Argon 39.948
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.88	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.631	33 As Arsenic 74.922	34 Se Selenium 78.971	35 Br Bromine 79.904	36 Kr Krypton 83.798
37 Rb Rubidium 85.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.95	43 Tc Technetium 98.907	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.414	49 In Indium 114.818	50 Sn Tin 118.711	51 Sb Antimony 121.760	52 Te Tellurium 127.6	53 I Iodine 126.904	54 Xe Xenon 131.294
55 Cs Cesium 132.905	56 Ba Barium 137.328	57-71 Lanthanides	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.85	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.967	80 Hg Mercury 200.59	81 Tl Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium [208.982]	85 At Astatine 209.987	86 Rn Radon 222.018
87 Fr Francium 223.020	88 Ra Radium 226.025	89-103 Actinides	104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [269]	109 Mt Meitnerium [278]	110 Ds Darmstadtium [281]	111 Rg Roentgenium [280]	112 Cn Copernicium [285]	113 Nh Nihonium [286]	114 Fl Flerovium [289]	115 Mc Moscovium [289]	116 Lv Livermorium [293]	117 Ts Tennessine [294]	118 Og Oganesson [294]
57 La Lanthanum 138.905	58 Ce Cerium 140.116	59 Pr Praseodymium 140.908	60 Nd Neodymium 144.243	61 Pm Promethium 144.913	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.925	66 Dy Dysprosium 162.500	67 Ho Holmium 164.930	68 Er Erbium 167.259	69 Tm Thulium 168.934	70 Yb Ytterbium 173.055	71 Lu Lutetium 174.967			
89 Ac Actinium 227.028	90 Th Thorium 232.038	91 Pa Protactinium 231.036	92 U Uranium 238.029	93 Np Neptunium 237.048	94 Pu Plutonium 244.064	95 Am Americium 243.061	96 Cm Curium 247.070	97 Bk Berkelium 247.070	98 Cf Californium 251.080	99 Es Einsteinium [254]	100 Fm Fermium 257.095	101 Md Mendelevium 258.1	102 No Nobelium 259.101	103 Lr Lawrencium [262]			

- Alkali Metal
- Alkaline Earth
- Transition Metal
- Basic Metal
- Metalloid
- Nonmetal
- Halogen
- Noble Gas
- Lanthanide
- Actinide

Identity card of atoms



- Atomic number:

positive charges (protons) = negative charges (electrons)
in the nucleus

- Atomic mass:

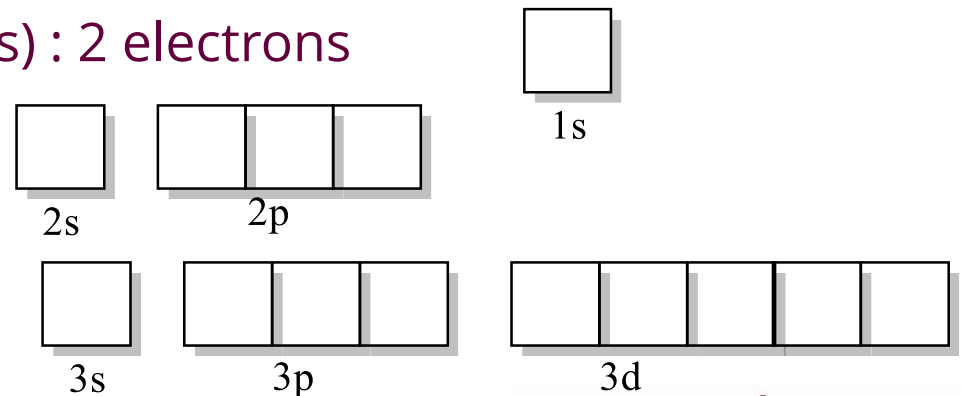
positive (protons) and neutral (neutrons) charges in the nucleus

- Electrons occupy various core layers from K layer to M layer

- K layer (closest to the nucleus) : 2 electrons

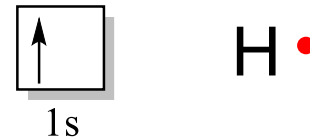
- L Layer : 8 electrons

- M layer : 18 electrons



Atoms and chemical bonds

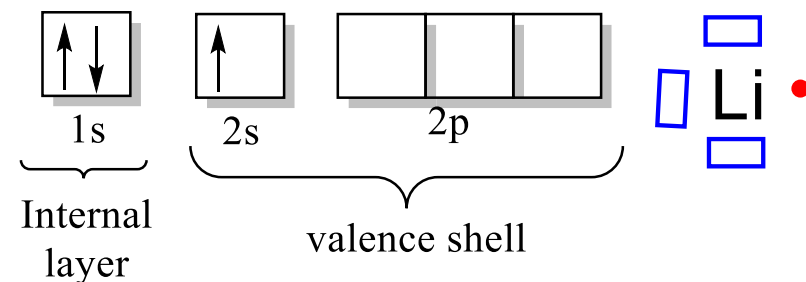
- Hydrogen (H): 1 electron
1 chemical bond is allowed



- Helium (He): 2 electrons
Layer K is full ➤ noble gas
No chemical bond allowed

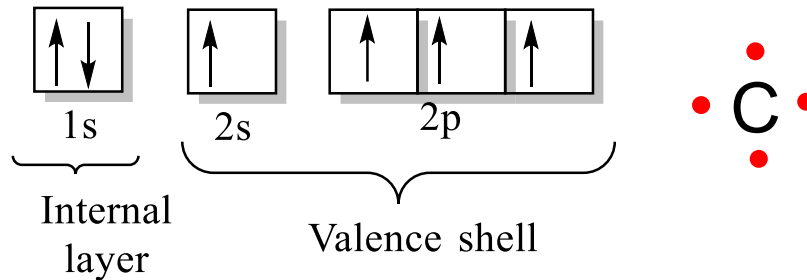


- Lithium (Li): 3 electrons
1 chemical bond is allowed
3 electron holes are present

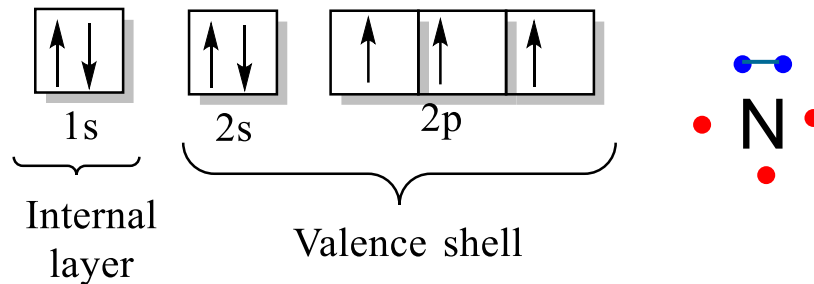


Atoms and chemical bonds

- Carbone (C): 6 electrons
4 chemical bonds are allowed

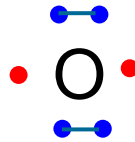
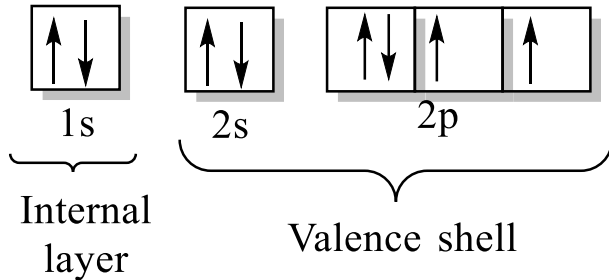


- Nitrogen (N): 7 electrons
3 chemical bonds are allowed
1 lone pair is present

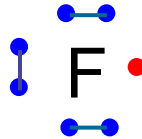
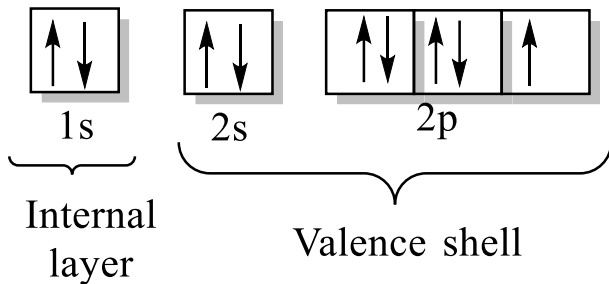


Atoms and chemical bonds

- Oxygen (O): 8 electrons



- Fluorine (F): 9 electrons



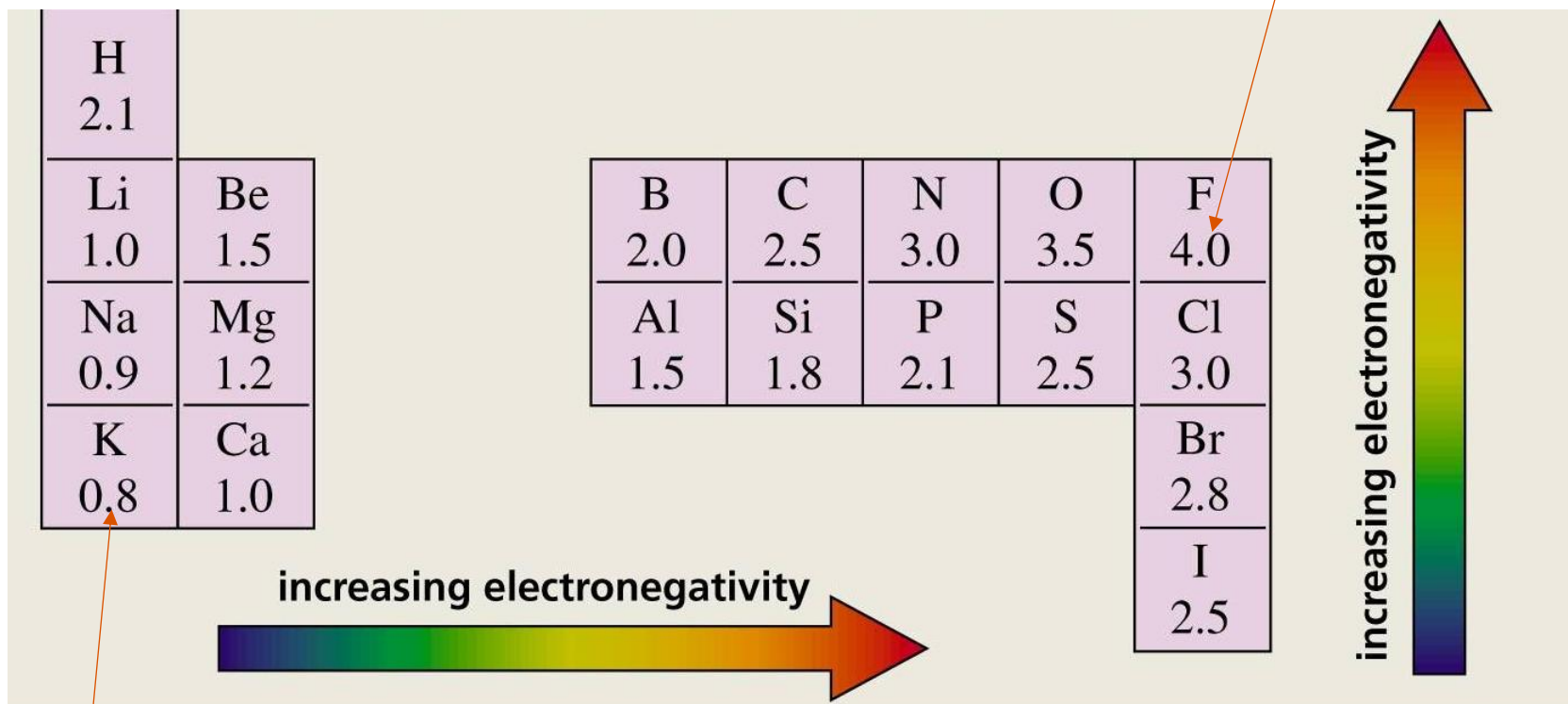
Types of chemical bonds

- Chemical bond = lasting attraction between two atoms by means of two electrons
- The type of chemical bonds is dependent of the electronegativities of the two atoms (ability of an atom to attract electrons)

Types of chemical bonds

Electronegativity based on the Pauling scale

The most electronegative



The less electronegative

Tricks for the two lines: Happy Hector Likes Beer But Could Not Obtain Food, Never!

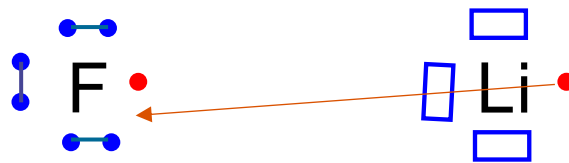
Types of chemical bonds

- Chemical bond = lasting attraction between two atoms by means of two electrons

Ionic bond: chemical bond involving the transfer of one electron from one atom to the other. Concerns atoms possessing very different electronegativities

Fluorine electronegativity : 4,0 \Rightarrow strong attraction of electrons

Lithium electronegativity : 1,0



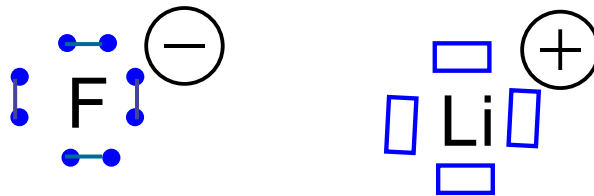
Types of chemical bonds

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Fluorine electronegativity : 4,0 \Rightarrow strong attraction of electrons

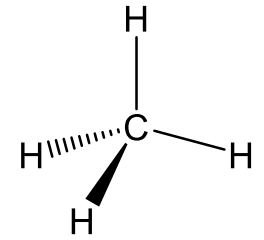
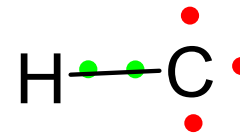
Lithium electronegativity : 1,0



Types of chemical bonds

Pure covalent bond: sharing of two electrons from two atoms possessing similar electronegativities

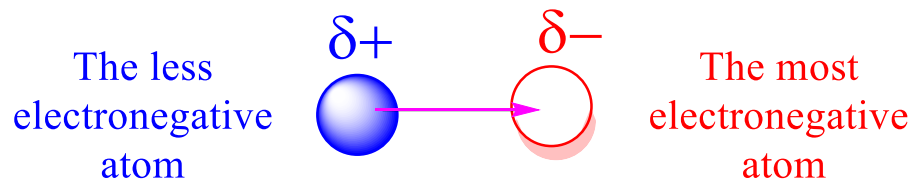
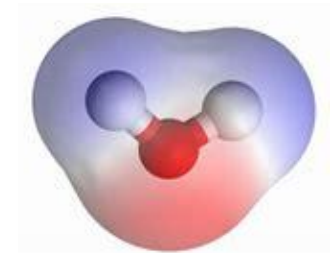
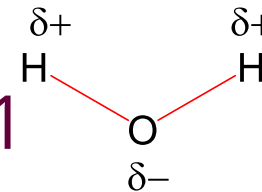
- Carbon electronegativity : 2,5
- Hydrogen electronegativity : 2,1



Polar covalent bond: covalent bond with a partial ionic character => Polarized bond

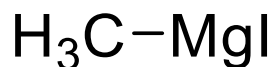
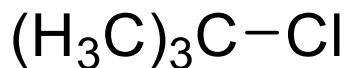
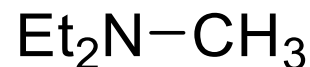
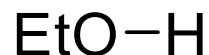
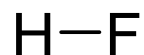
Oxygen electronegativity : 3,5

Hydrogen electronegativity : 2,1



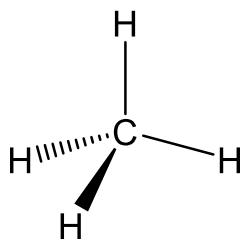
Type of chemical bonds - Exercise

- By considering the atom electronegativity, indicate the bond polarisation. Represent also the lone pairs and electron holes present on the atoms. Is the bond a covalent or a ionic one?

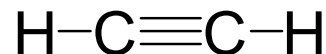
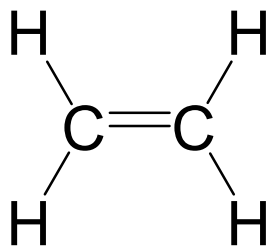


Single and multiple bonds

- When the two atoms share two electrons (one on each atom), you have a single bond.

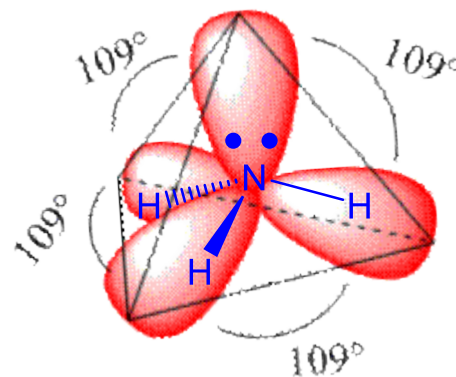
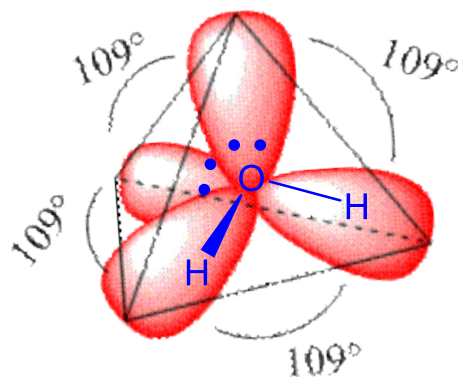
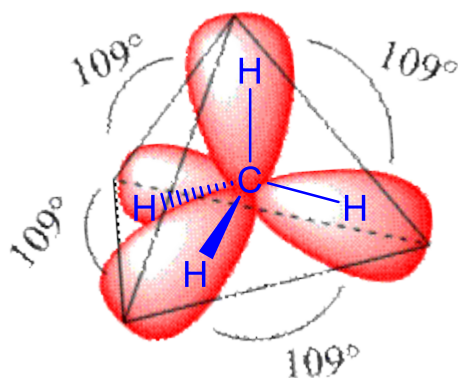


- When the two atoms share four/six electrons (two/three on each atom), you have a double/triple bond.



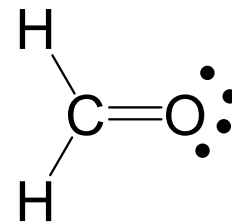
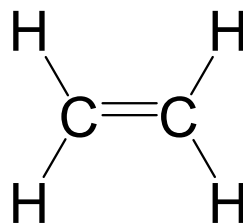
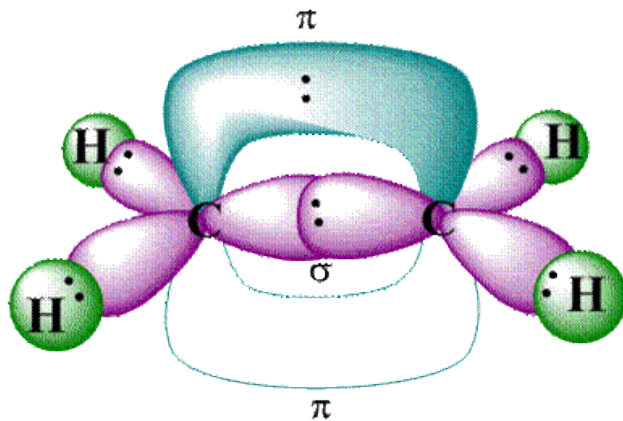
Impact of bonds on chemical structures

- An atom possesses a tetrahedral structure if he has around it 4 atoms and/or lone pairs
 - Only single bonds and lone pairs
 - Free rotation about single bonds



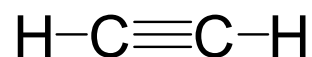
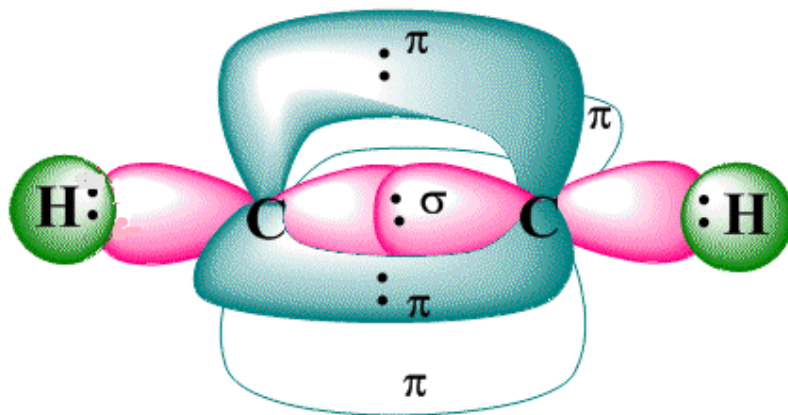
Impact of bonds on chemical structures

- An atom possesses a trigonal (plane) structure if he has around it 3 atoms and/or lone pairs
 - One double bond must be present
 - No free rotation about double bonds (rigid structure)



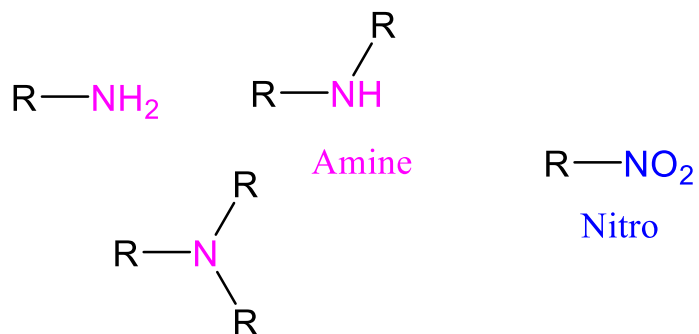
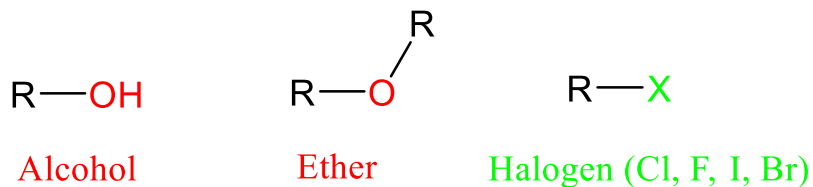
Impact of bonds on chemical structures

- An atom possesses a linear structure if he has around it 2 atoms and/or lone pairs
 - A triple bond must be present
 - No free rotation about double bonds (rigid structure)



Functional groups

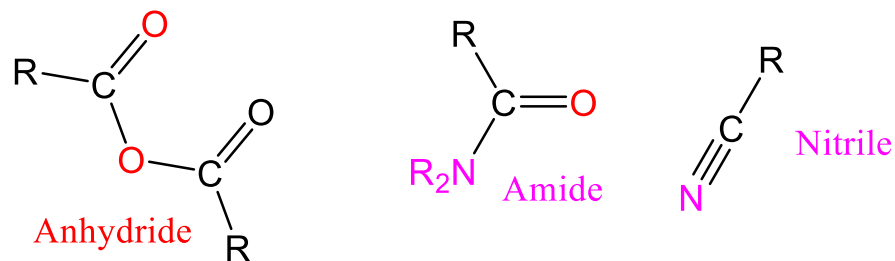
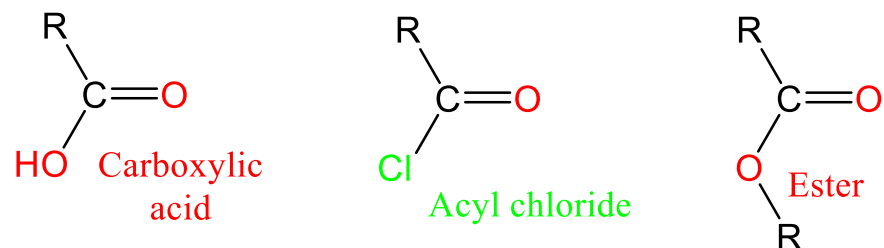
Monovalent functions



Divalent Functions



Trivalent Functions

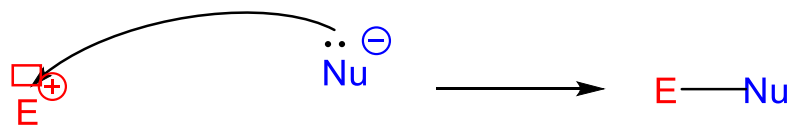




Chemical reactivity

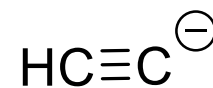
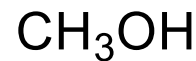
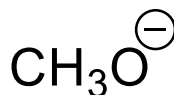
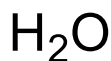
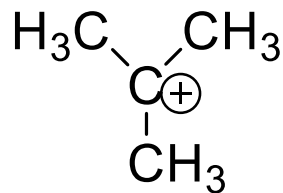
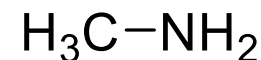
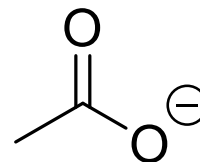
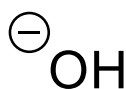
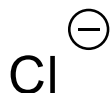
Chemical reactivity

- Nucleophiles and electrophiles
 - A nucleophile is an atom or atoms group possessing a lone pair (eventually with a negative charge). He reacts with electrophiles.
 - An electrophile is an atom or atoms group possessing a hole (eventually with a positive charge or a partial positive charge in the case of carbon). He reacts with nucleophiles.



Chemical reactivity

- Exercice: Represent the lone pairs and electron holes present on the atoms then categorize these compounds as nucleophile or electrophile. Indicate which atom is concerned.

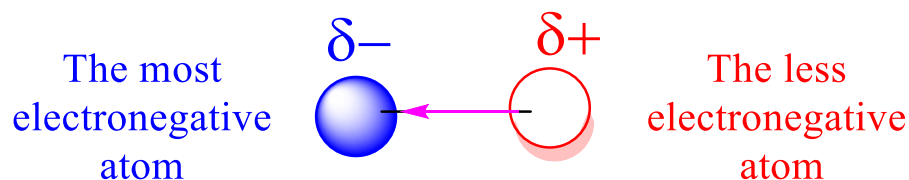


Chemical reactivity

- In complex structures, it depends on the chemical bond polarization and substituents

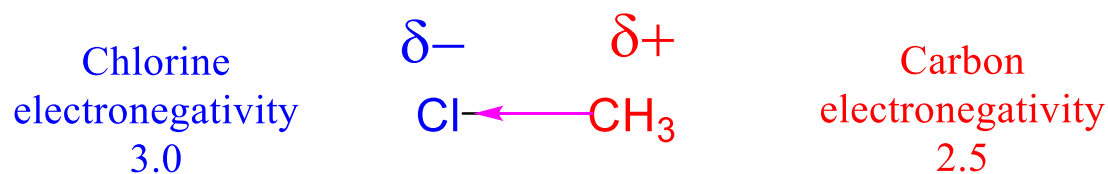
Directions of increasing electronegativity

1A	2A											3A	4A	5A	6A	7A	8												
1 H 1.0202												5 B 10.811	6 C 12.0110	7 N 14.0067	8 O 15.8994	9 F 18.9984	10 Ne 20.179												
3 Li 0.981	4 Be 0.9102											13 Al 20.0810	14 Si 20.000	15 P 20.719	16 S 20.000	17 Cl 20.000	18 Ar 20.000												
11 Na 0.9300	12 Mg 0.9300	3B	4B	5B	6B	7B	8B			1B	2B	19 K 0.8208	20 Ca 0.90	21 Sc 0.89	22 Ti 0.72	23 V 0.82	24 Cr 0.89	25 Mn 0.89	26 Fe 0.82	27 Co 0.89	28 Ni 0.82	29 Cu 0.89	30 Zn 0.89	31 Ga 0.77	32 Ge 0.72	33 As 0.72	34 Se 0.72	35 Br 0.72	36 Kr 0.72
37 Rb 0.82	38 Sr 0.82	39 Y 0.82	40 Zr 0.72	41 Nb 0.82	42 Mo 0.72	43 Tc 0.72	44 Ru 0.72	45 Rh 0.72	46 Pd 0.72	47 Ag 0.72	48 Cd 0.72	49 In 0.72	50 Sn 0.72	51 Sb 0.72	52 Te 0.72	53 I 0.72	54 Xe 0.72												
55 Cs 0.72	56 Ba 0.72	71 Lu 0.72	72 Hf 0.72	73 Ta 0.72	74 W 0.72	75 Re 0.72	76 Os 0.72	77 Ir 0.72	78 Pt 0.72	79 Au 0.72	80 Hg 0.72	81 Tl 0.72	82 Pb 0.72	83 Bi 0.72	84 Po 0.72	85 At 0.72	86 Rn 0.72												
87 Fr 0.72	88 Ra 0.72	103 Ac 0.72	104 Rf 0.72	105 Db 0.72	106 Sg 0.72	107 Bh 0.72	108 Hs 0.72	109 Mt 0.72	110 Ds 0.72	111 Rg 0.72	112 Cn 0.72	113 Uut 0.72	114 Fl 0.72	115 Uup 0.72	116 Lv 0.72	117 Uus 0.72	118 Uuo 0.72												

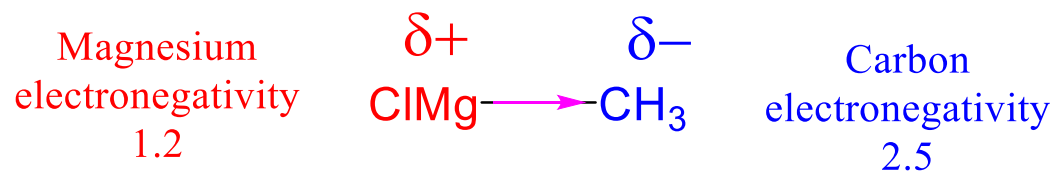


Chemical reactivity

- Electronic effect of substituents – Inductive effect
 - Concerns the bond polarization and the impact on the adjacent bonds. The effect is defined relative to a bond formed with a carbon atom.
 - Electro-withdrawing effect $-I$: When an atom or a group of atoms attracts the electrons of the bond

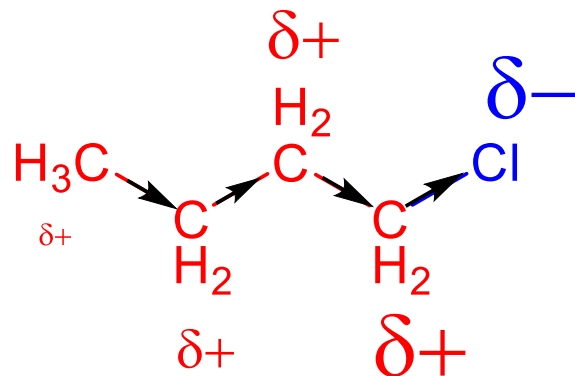


- Electro-donating effect $+I$: When an atom or a group of atoms repels the electrons of the bond



Chemical reactivity

- Electronic effect of substituents – Inductive effect
 - The inductive effect is transferred through the single bonds but declined rapidly with the distance



Chemical reactivity

- Exercise: Determine if these substituents possess a +I or a -I effect???



Chemical reactivity

- Electronic effect of substituents – Inductive effect

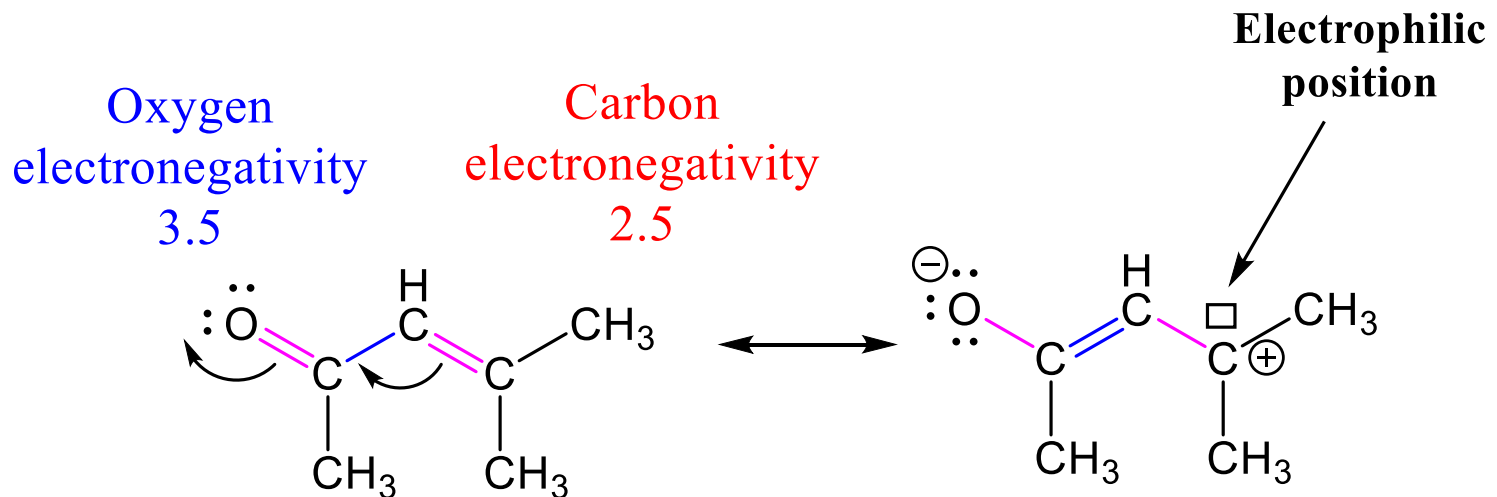
-I			+I	
-NO ₂	-COR			-Alkyl
-CN	-COOR	-CONR ₂		
-NR ₂	-OR		-Na	-MgCl
				-Li
-SR	-Halogènes			

Chemical reactivity

- Electronic effect of substituents – mesomeric effect
 - Concerns the delocalization of the π electrons in a molecule ie the lone pairs, electron holes and π bonds (in multiple bonds)
 - The mesomeric effect can only take place when there is one single bond (and only one) between two π electrons:
 - π bond - σ bond - π bond
 - lone pair - σ bond - π bond
 - Electron hole - σ bond - π bond (or lone pair)
 - Mesomeric effects are superior to inductive effects

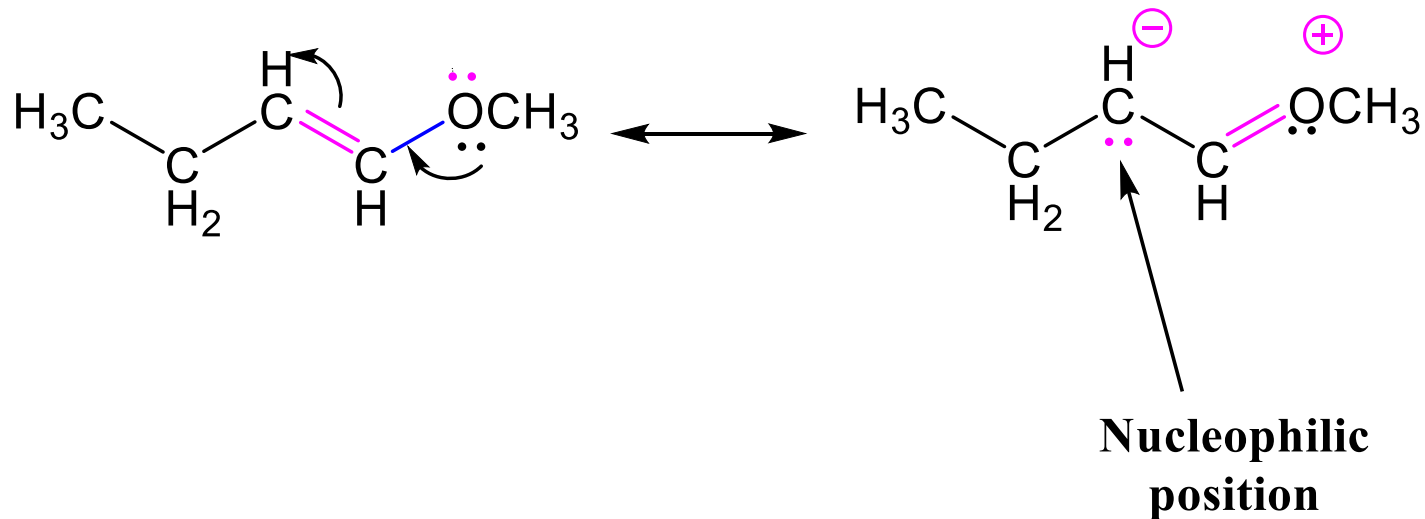
Chemical reactivity

- Electronic effect of substituents – mesomeric effect
 - When you have a π **bond** - σ **bond** - π **bond**, the electrons are displaced from the less electronegative atom to the most negative atom



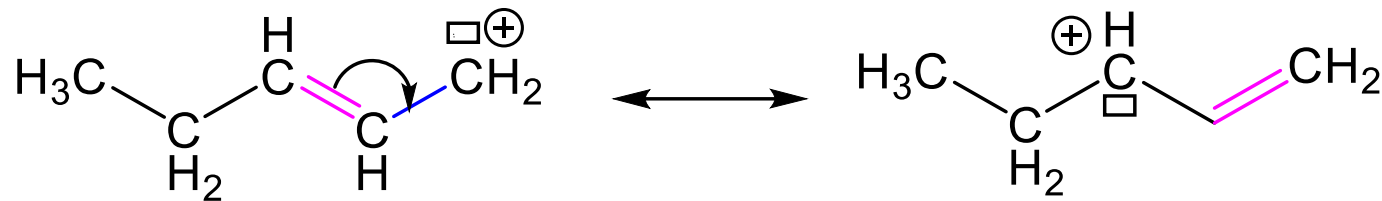
Chemical reactivity

- Electronic effect of substituents – mesomeric effect
 - When you have a **lone pair - σ bond - π bond**, the electrons are displaced from the lone pair in direction to to the π bond



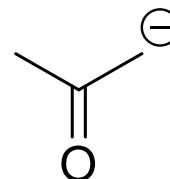
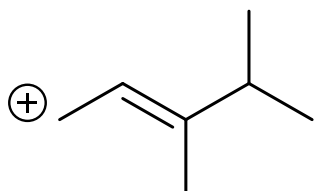
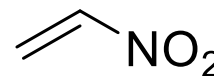
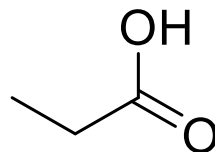
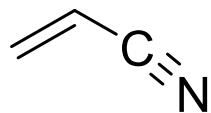
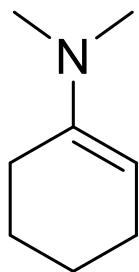
Chemical reactivity

- Electronic effect of substituents – mesomeric effect
 - When you have an electron **hole**- σ **bond** - π **bond** (or **lone pair**), the electrons are displaced from the π bond in direction to to the electron hole



Chemical reactivity

- Exercise: For each compound represent the mesomeric forms. Then identify the electrophilic or nucleophilic atoms of the compounds



Chemical reactivity

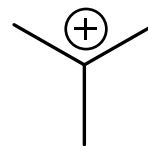
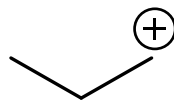
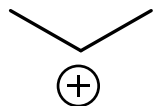
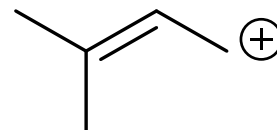
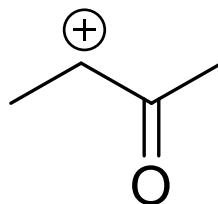
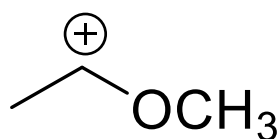
- Electronic effect of substituents – mesomeric effect

-M			+M	
-NO ₂	-COR		-NR ₂	-OR
-CN	-COOR	-CONR ₂	-SR	-Halogènes

The inductive effects and the mesomeric effects explain the stability and the reactivity of organic molecules

Chemical reactivity

- Exercise: Thanks to the inductive and/or mesomeric effects, classify this carbocation from the less stable to the most stable.

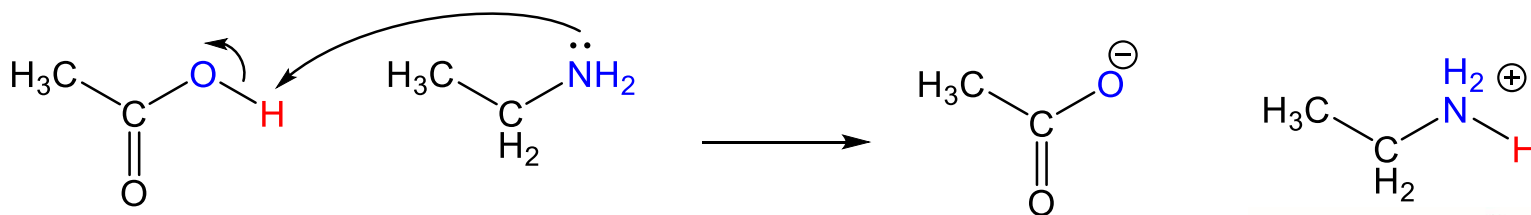


Chemical reactivity

- Acids and bases

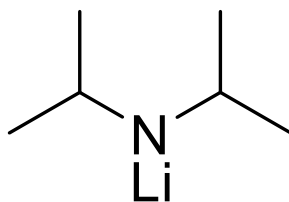
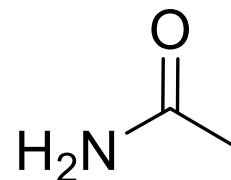
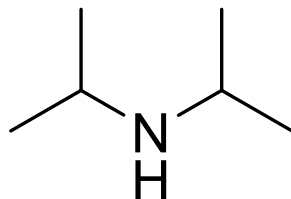
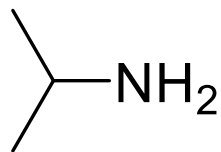
- Acid: molecule able to give a proton (H^+)
- Base: molecule able to catch a proton
- An acid/base pair is defined by its pKa.
 - When $pH < pK_a$ the acid form is predominant
 - When $pH > pK_a$ the basic form is predominant

- Acid-base reaction: displacement of the proton from the acid function to the basic one



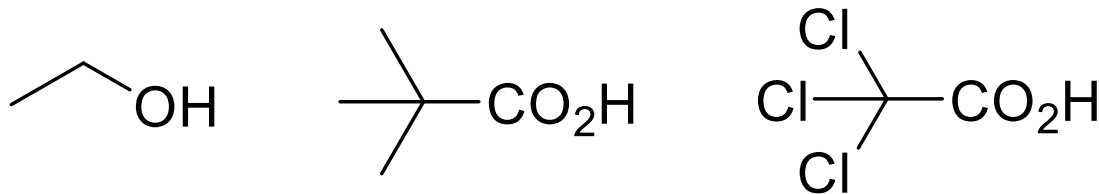
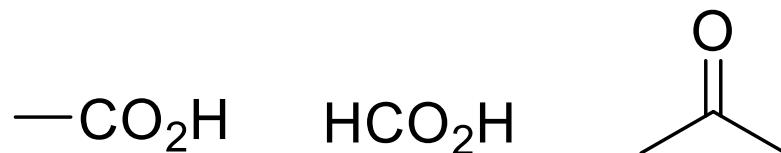
Chemical reactivity

- Exercise: Thanks to the inductive and/or mesomeric effects, classify these nitrogen functions from the less basic to the most basic.



Chemical reactivity

- Exercise: Thanks to the inductive and/or mesomeric effects, classify these molecules from the less acid to the most acid.



Principal mechanisms

- Nucleophilic substitution

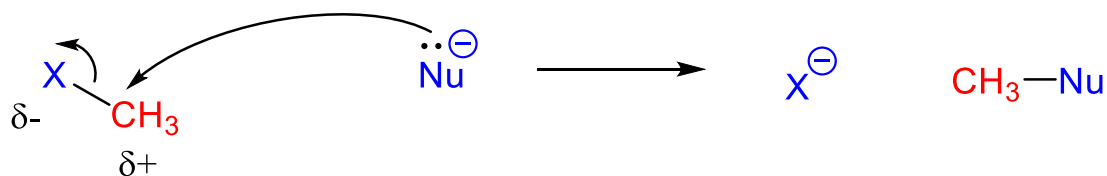
- When the carbon has only single bonds
- A nucleophile (Nu) attacks the electrophilic carbon ($\delta+$)
And causes the departure of the leaving group X^-

The nucleophile can be for example:

- an amine
- an alcohol

The leaving group is in general:

- water
- an halide (Cl^- , Br^- , I^-)



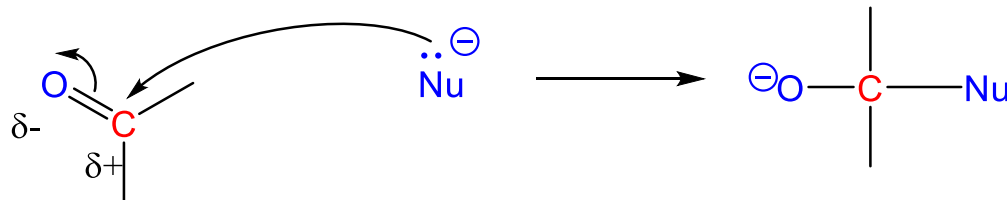
Principal mechanisms

- Nucleophilic Addition

- When the carbon possesses a double bond.
- A nucleophile (Nu) attacks the electrophilic carbon (δ^+) and the two electrons of the π bond are sent as a supplementary lone pair on the oxygen (δ^-) for example (π bond is more fragile than σ bond)

The nucleophile can be for example:

- an amine
- an alcohol (or water)



Principal mechanisms

- Nucleophilic addition/leaving group departure
 - When the carbon possesses a double bond and a leaving group.
 - A nucleophile (Nu) attacks the electrophilic carbon (δ^+) and the two electrons of the π bond are sent as a supplementary lone pair on the oxygen (δ^-)
 - In a second step the lone pair of the oxygen creates a new double bond and causes the departure of the leaving group.

