

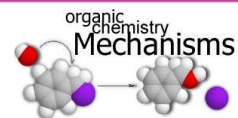
CHEM 344

ORGANIC REACTION MECHANISM

FOR CHEMISTRY' STUDENTS, COLLEGE OF SCIENCE

PRE-REQUISITES COURSE; CHEM 241

CREDIT HOURS; 2 (2+0+0)



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INTRODUCTION

ACIDS AND BASES

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ACID-BASE REACTIONS

- o Many of the reactions that occur in organic chemistry are either acid-base reactions themselves or they involve an acid-base reaction at some stage
- o Arrhenius regarded acid-base reactions as occurring only in water,
 - An **Arrhenius acid** is a source of H^+ ion.
 - An **Arrhenius base** is a source of OH^- ion.

The Arrhenius acid-base theory provided a good start toward understanding acid-base chemistry, but it proved much too limited in its scope.

- o Two classes of acid-base reactions are fundamental in organic chemistry:
 - Brønsted-Lowry
 - Lewis acid-base reactions

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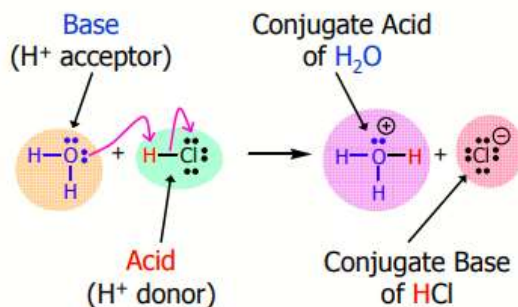
ACID-BASE REACTIONS

BRØNSTED-LOWRY DEFINITION

- o Brønsted-Lowry acid-base reactions involve the transfer of protons
 - A Brønsted-Lowry acid is a proton (H^+) donor.

A Brønsted-Lowry acid is a substance that can donate (or lose) a proton
 - A Brønsted-Lowry base is a proton (H^+) acceptor.

A Brønsted-Lowry base is a substance that can accept (or remove) a proton

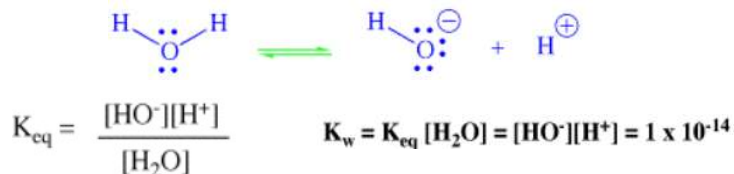


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ACID-BASE REACTIONS

BRØNSTED-LOWRY DEFINITION

- Liquid water is in equilibrium with solvated hydroxide and solvated protons.
- We typically use a value related to the equilibrium constant to define the concentration of these solvated ions in water.
- The water dissociation constant, $K_w = 1 \times 10^{-14}$.



- pH** and **pOH** are important values for acidic and basic solutions.
- These are the log base 10 of the hydrogen ion concentration or of the hydroxide ion concentration, respectively.

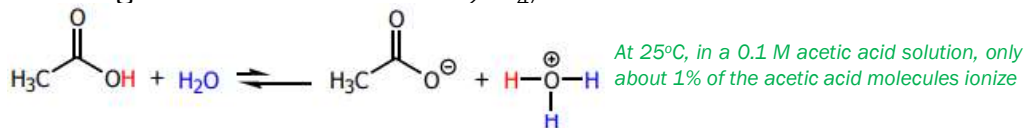
$$pH = -\log[H^+] \quad pOH = -\log[HO^-] \quad 14 = pH + pOH$$

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THE STRENGTH OF BRØNSTED-LOWRY ACIDS AND BASES

THE ACIDITY CONSTANT, K_a

- In contrast to strong acids such as HCl and H_2SO_4 , acetic acid is a much weaker acid



- Equilibrium constant (K_{eq})

$$K_{eq} = \frac{[CH_3CO_2^-][H_3O^+]}{[CH_3CO_2H][H_2O]}$$

- For dilute aqueous solutions, the concentration of water is essentially constant and the K_{eq} expression can be written in terms of the acidity constant (K_a)

$$K_a = K_{eq} [H_2O] = \frac{[CH_3CO_2^-][H_3O^+]}{[CH_3CO_2H]}$$

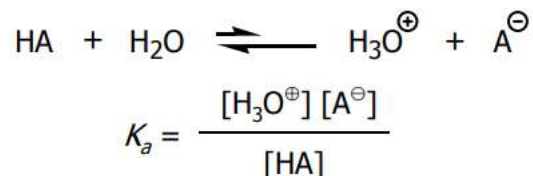
- At 25°C, the acidity constant (K_a) for acetic acid is 1.76×10^{-5}

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THE STRENGTH OF BRØNSTED-LOWRY ACIDS AND BASES

THE ACIDITY CONSTANT, K_a

- For any weak acid dissolved in water



- An acid with a large value of K_a
 - a strong acid
- An acid with a small value of K_a
 - a weak acid

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THE STRENGTH OF BRØNSTED-LOWRY ACIDS AND BASES

ACIDITY AND pK_a

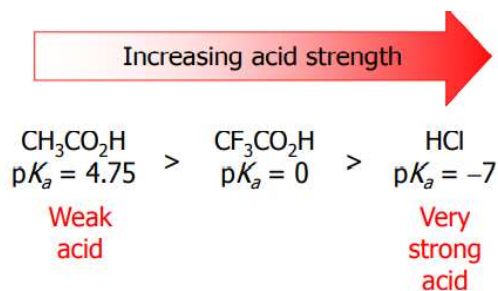
$$pK_a = -\log K_a$$

$$\text{pH} = -\log [\text{H}_3\text{O}^{\oplus}]$$

- For acetic acid, the pK_a is 4.75

$$\begin{aligned} pK_a &= -\log [1.76 \times 10^{-5}] \\ &= -[-4.75] \\ &= 4.75 \end{aligned}$$

- The larger the value of the pK_a , the weaker the acid



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THE STRENGTH OF BRØNSTED-LOWRY ACIDS AND BASES

ACIDITY AND pK_a

- Relative Strength of Selected Acids & Their Conjugate Bases

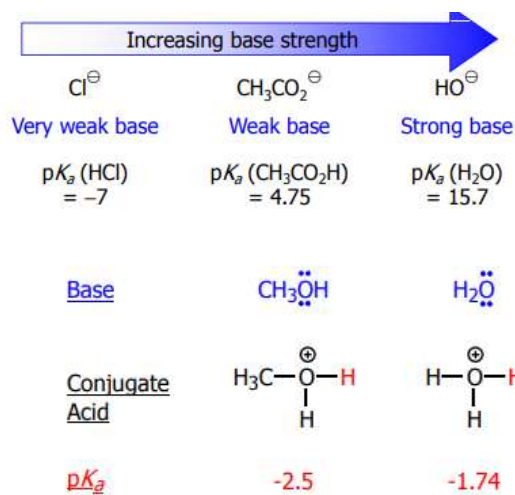
	Acid	pK_a	Conjugate base
↑ Increasing acidity of the acid	H-Cl	-7	Cl ⁻
	CH ₃ COO-H	4.8	CH ₃ COO ⁻
	HO-H	15.7	HO ⁻
	CH ₃ CH ₂ O-H	16	CH ₃ CH ₂ O ⁻
	HC≡CH	25	HC≡C ⁻
	H-H	35	H ⁻
	H ₂ N-H	38	H ₂ N ⁻
	CH ₂ =CH ₂	44	CH ₂ =C ⁻ H
	CH ₃ -H	50	CH ₃ ⁻
			↓ Increasing basicity of the conjugate base

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THE STRENGTH OF BRØNSTED-LOWRY ACIDS AND BASES

PREDICTING THE STRENGTH OF BASES

- The stronger the acid, the weaker its conjugate base
- The larger the pK_a of the conjugate acid, the stronger the base
- Since CH₃O⁺H₂ is a stronger acid than H₃O⁺, H₂O is a stronger base than CH₃OH



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FACTORS AFFECTING ACID STRENGTH RELATIONSHIPS BETWEEN STRUCTURE AND ACIDITY

- The stronger the H-X bond, the weaker the acid.

- The strength of H-X bond



	H-F	H-Cl	H-Br	H-I
Bond Length (Å)	0.92	1.28	1.41	1.60
pK_a	3.2	-7	-9	-10

Increasing acidity

- The stronger the acid, the weaker the conjugate base.

- Thus acidity increases as we descend a vertical column in a group in the Periodic Table

Increasing acidity 	<table style="border-collapse: collapse; margin: auto;"> <tr><td>HF</td><td>F⁻</td></tr> <tr><td>HCl</td><td>Cl⁻</td></tr> <tr><td>HBr</td><td>Br⁻</td></tr> <tr><td>HI</td><td>I⁻</td></tr> </table>	HF	F ⁻	HCl	Cl ⁻	HBr	Br ⁻	HI	I ⁻	Increasing basicity
HF	F ⁻									
HCl	Cl ⁻									
HBr	Br ⁻									
HI	I ⁻									

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FACTORS AFFECTING ACID STRENGTH RELATIONSHIPS BETWEEN STRUCTURE AND ACIDITY

- The higher the electronegativity of an atom, the easier it will acquire a negative charge.

- Thus acidity increases from left to right when we compare compounds in the same row of the Periodic Table

Increasing acidity											
<table style="border-collapse: collapse; margin: auto;"> <tr> <td>H₃C-H</td> <td>H₂N-H</td> <td>HO-H</td> <td>F-H</td> </tr> <tr> <td>⊖CH₃</td> <td>⊖NH₂</td> <td>⊖OH</td> <td>⊖F</td> </tr> </table>	H ₃ C-H	H ₂ N-H	HO-H	F-H	⊖CH ₃	⊖NH ₂	⊖OH	⊖F			
H ₃ C-H	H ₂ N-H	HO-H	F-H								
⊖CH ₃	⊖NH ₂	⊖OH	⊖F								
Increasing basicity											

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FACTORS AFFECTING ACID STRENGTH

RELATIONSHIPS BETWEEN STRUCTURE AND ACIDITY

Acidity increases within a given row
(electronegativity effect)

	C	N	O	F
Hydride	(H ₃ C-H)	(H ₂ N-H)	(HO-H)	(F-H)
pK _a	48	38	15.7	3.2
			S	Cl
			(HS-H)	(Cl-H)
			7.0	-7
			Se	Br
			(HSe-H)	(Br-H)
			3.9	-9
				I
				(I-H)
				-10

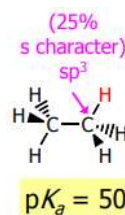
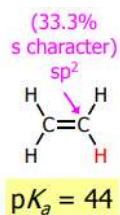
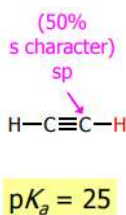
Acidity increases within a
given column
(bond strength effect)

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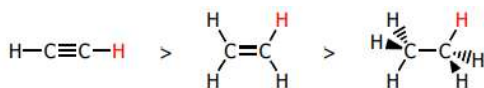
FACTORS AFFECTING ACID STRENGTH

THE EFFECT OF HYBRIDIZATION

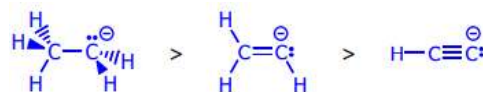
- The higher the percent of **s-character** of the hybrid orbital, the closer the lone pair is held to the nucleus, and the more stable the conjugate base.



- Relative acidity of the hydrocarbons



- Relative basicity of the carbanions

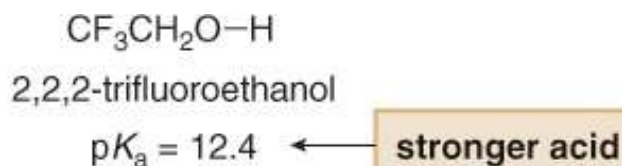
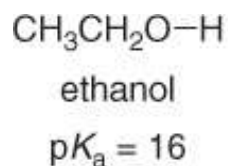


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FACTORS AFFECTING ACID STRENGTH

INDUCTIVE EFFECTS

- The **inductive effect** of a group can be *electron donating* or *electron withdrawing*
- When electron density is pulled away from the negative charge through σ bonds by very electronegative atoms, it is referred to an **electron withdrawing inductive** effect.

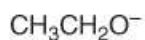


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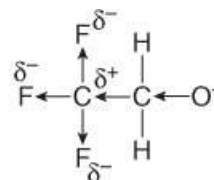
FACTORS AFFECTING ACID STRENGTH

INDUCTIVE EFFECTS

- More electronegative atoms stabilize regions of high electron density by an electron withdrawing inductive effect.
- The more electronegative the atom and the closer it is to the site of the negative charge, the greater the effect.
- The acidity of $\text{H}-\text{A}$ increases with the presence of electron withdrawing groups in A.



No additional electronegative atoms stabilize the conjugate base.



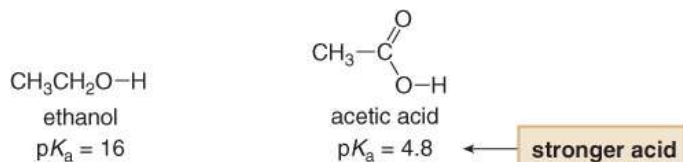
CF_3 withdraws electron density, stabilizing the conjugate base.

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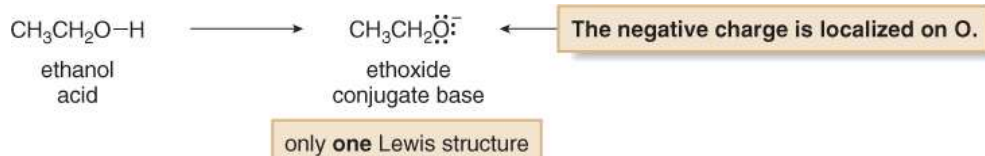
FACTORS AFFECTING ACID STRENGTH

RESONANCE EFFECTS

- when we compare the acidities of ethanol and acetic acid, we note that the latter is more acidic than the former.



- When the conjugate bases of the two species are compared, it is evident that the conjugate base of acetic acid enjoys resonance stabilization, whereas that of ethanol does not.

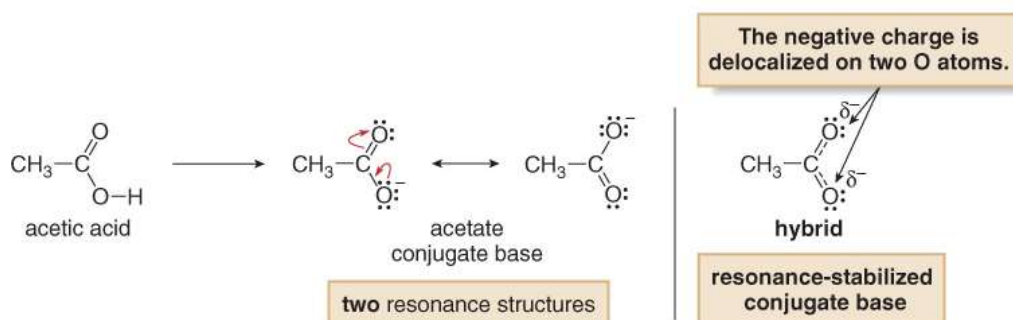


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FACTORS AFFECTING ACID STRENGTH

RESONANCE EFFECTS

- Resonance delocalization makes CH_3COO^- more stable than $\text{CH}_3\text{CH}_2\text{O}^-$, so CH_3COOH is a stronger acid than $\text{CH}_3\text{CH}_2\text{OH}$.



- The acidity of $\text{H}-\text{A}$ increases when the conjugate base A^- is resonance stabilized.

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FACTORS AFFECTING ACID STRENGTH

SUMMARY OF THE FACTORS THAT DETERMINE ACIDITY

Factor	Example
1. Element effect: The acidity of H–A increases both left-to-right across a row and down a column of the periodic table.	<div style="text-align: center;"> <p style="text-align: center;">Increasing acidity</p> <p style="text-align: center;"> $\begin{array}{cccc} \text{—C—H} & \text{—N—H} & \text{—O—H} & \text{H—F} \\ & & \text{—S—H} & \text{H—Cl} \\ & & & \text{H—Br} \\ & & & \text{H—I} \end{array}$ </p> <p style="text-align: right; transform: rotate(-90deg);">Increasing acidity</p> </div>
2. Inductive effects: The acidity of H–A increases with the presence of electron-withdrawing groups in A.	$\text{CH}_3\text{CH}_2\text{O—H}$ $\text{CF}_3\text{CH}_2\text{O—H}$ <div style="text-align: right; margin-right: 50px;">more acidic</div>
3. Resonance effects: The acidity of H–A increases when the conjugate base A: [–] is resonance stabilized.	$\text{CH}_3\text{CH}_2\text{O—H}$ $\text{CH}_3\text{COO—H}$ <div style="text-align: right; margin-right: 50px;">more acidic</div>
4. Hybridization effects: The acidity of H–A increases as the percent s-character of A: [–] increases.	CH_3CH_3 $\text{CH}_2=\text{CH}_2$ $\text{H—C}\equiv\text{C—H}$ <div style="text-align: center; margin-top: 10px;"> <p style="text-align: center;">Increasing acidity</p> </div>

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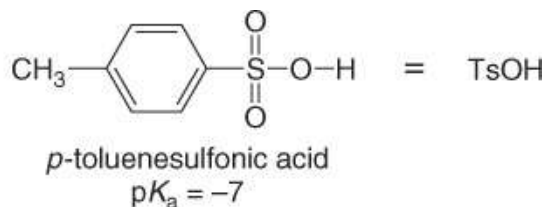
FACTORS AFFECTING ACID STRENGTH

COMMONLY USED ACIDS IN ORGANIC CHEMISTRY

- In addition to the familiar acids HCl, H₂SO₄ and HNO₃, a number of other acids are often used in organic reactions.
- Two examples are acetic acid and *p*-toluene-sulfonic acid (TsOH).



acetic acid
pK_a = 4.8

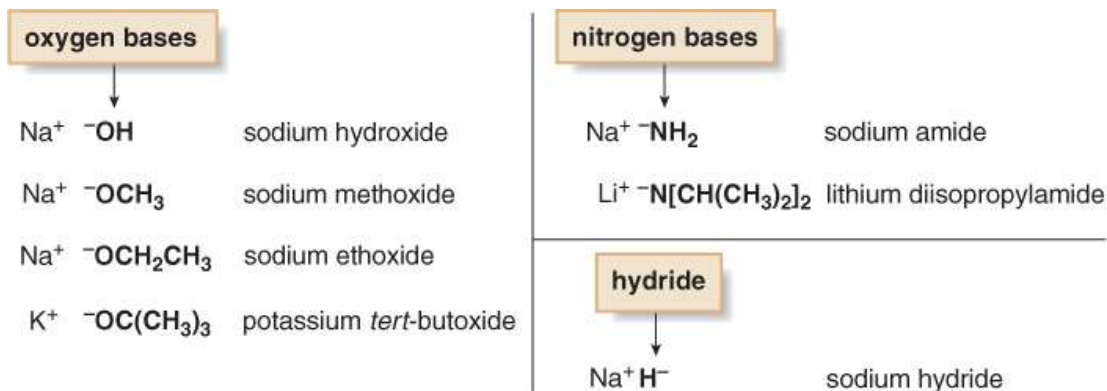


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FACTORS AFFECTING ACID STRENGTH

COMMONLY USED BASES IN ORGANIC CHEMISTRY

- Common strong bases used in organic reactions are more varied in structure.

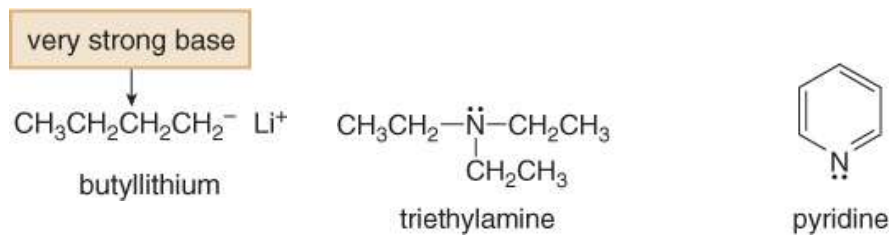


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FACTORS AFFECTING ACID STRENGTH

IT SHOULD BE NOTED THAT:

- Strong bases have weak conjugate acids with high pK_a values, usually > 12 .
- Strong bases have a net negative charge, but not all negatively charged species are strong bases. For example, none of the halides F^- , Cl^- , Br^- , or I^- , is a strong base.
- Carbanions, negatively charged carbon atoms, are especially strong bases. A common example is butyllithium.
- Two other weaker organic bases are triethylamine and pyridine.

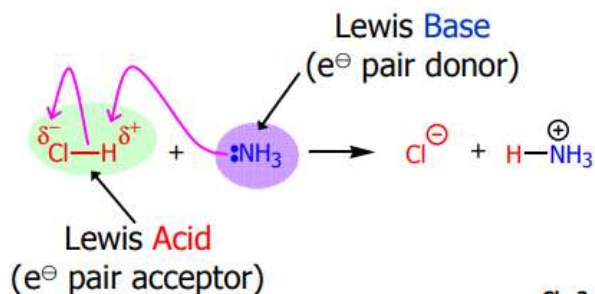


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ACID-BASE REACTIONS

LEWIS ACIDS AND BASES

- **G. N. Lewis** defined acids and bases in a broader scheme
 - An acid as a molecule that forms a covalent bond by accepting a pair of electrons
Lewis Acids are electron pair acceptors
 - A base as a molecule that forms a covalent bond by donating a pair of electrons.
Lewis Bases are electron pair donors

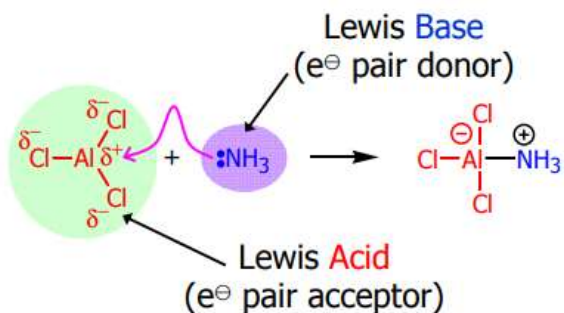


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ACID-BASE REACTIONS

LEWIS ACIDS AND BASES

- In **Lewis acid-base theory**, the attraction of oppositely charged species is fundamental to reactivity

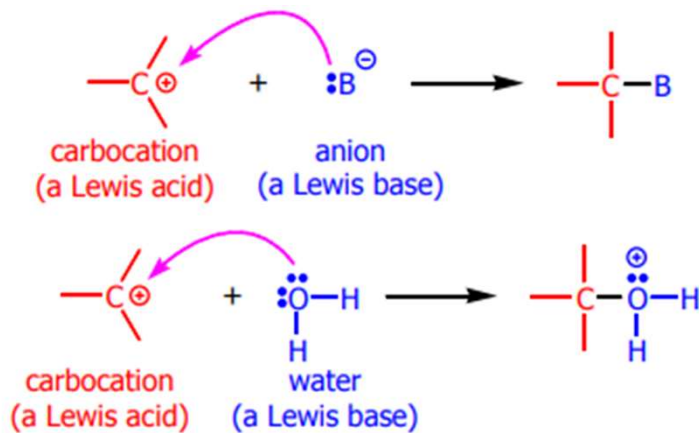


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ACID-BASE REACTIONS

LEWIS ACIDS AND BASES

- Carbocations are electron deficient; they have only six electrons in their valence shell.
- Carbocations are Lewis acids

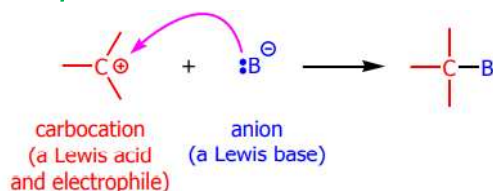


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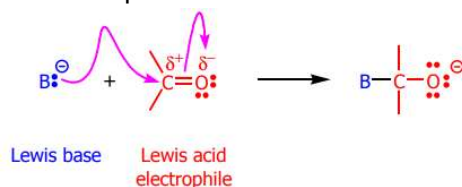
ACID-BASE REACTIONS

LEWIS ACIDS AND BASES

- By accepting an electron pair from a Lewis base, a carbocation fills its valence shell
- All Lewis acids are electrophiles.



- Carbon atoms that are electron poor because of bond polarity, but are not carbocations, can also be electrophiles

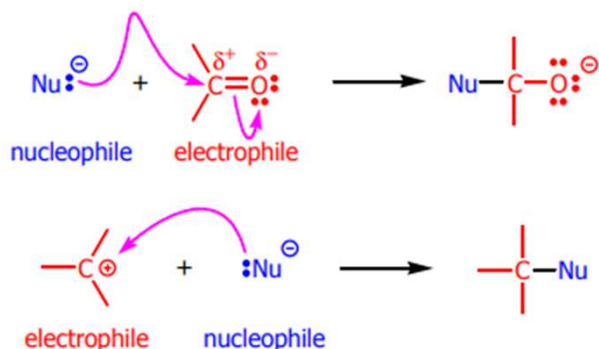


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ACID-BASE REACTIONS

LEWIS ACIDS AND BASES

- Carbanions are Lewis bases
- A carbanion as nucleophile is a Lewis base that seeks a positive center such as a positively charged carbon atom

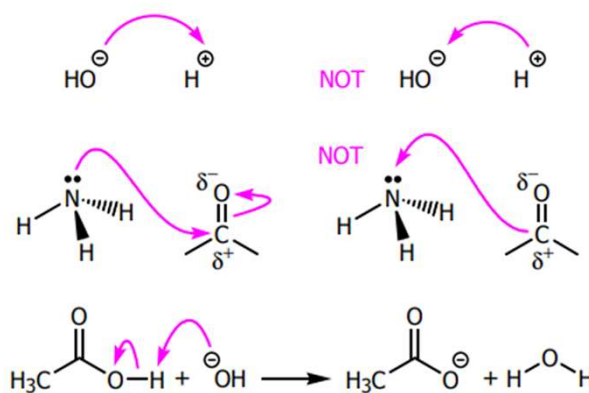


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ACID-BASE REACTIONS

HOW TO USE CURVED ARROWS IN ILLUSTRATING REACTIONS

- show the direction of electron flow in a reaction mechanism
- point from the source of an electron pair to the atom receiving the pair
- always show the flow of electrons from a site of higher electron density to a site of lower electron density
- never show the movement of atoms. Atoms are assumed to follow the flow of the electron



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