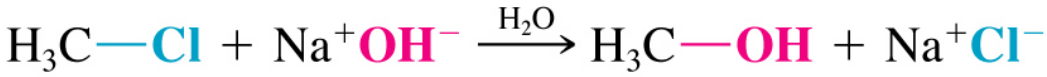
第3章有機化學反應種類及酸鹼有機反應

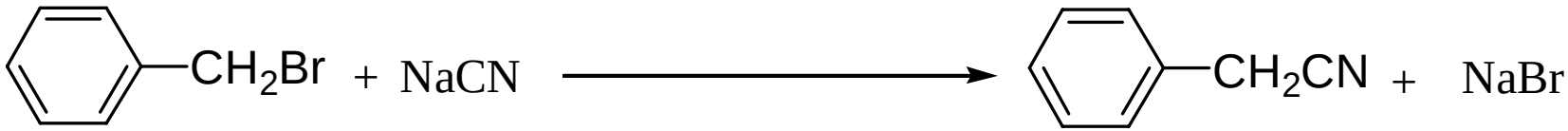
一) 有機化反應的種類及有機反應機制 (organic reactions and their mechanism)

1) a) Substitution reaction: (Saturated compound such as alkanes or alkyl halides, aromatic compounds)



A substitution reaction

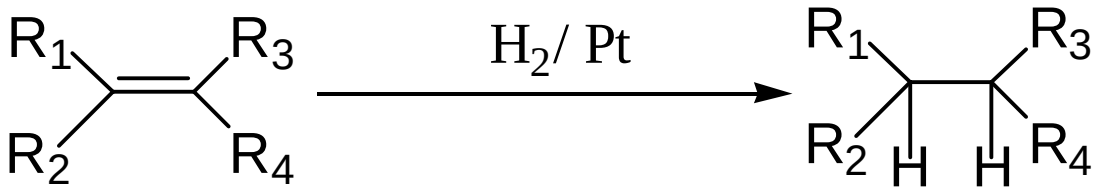
One group replace another



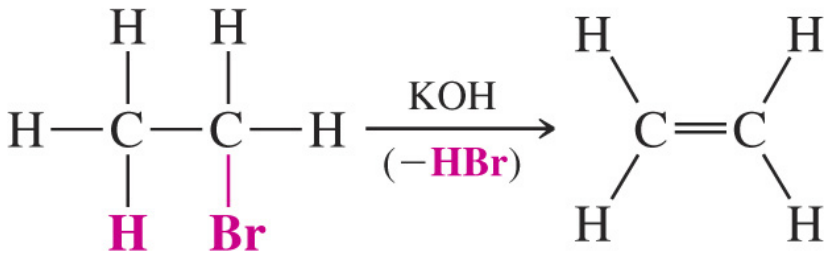
b) Addition reactions: Compounds with multiple bonds

An addition reaction

Two molecules become one, all parts of adding reacts appear in the products



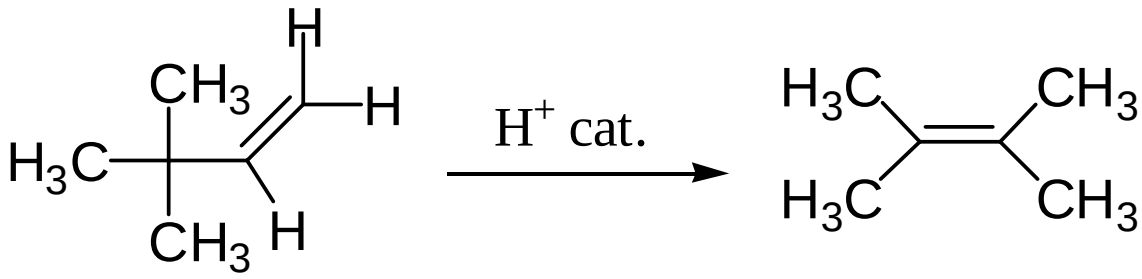
c) Elimination reactions: used in the preparation of double bonds and triple bonds



An elimination reaction

Opposite to addition, a small molecule lost from one molecule

d) Rearrangement reactions:

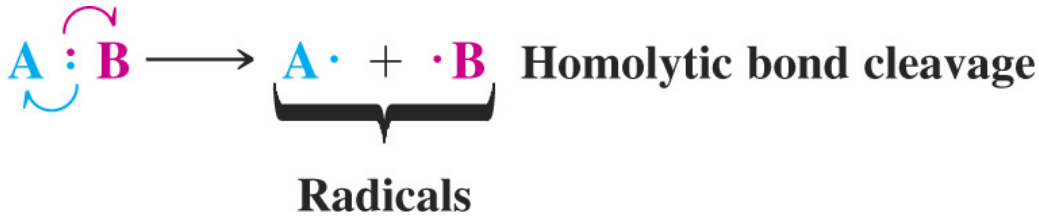


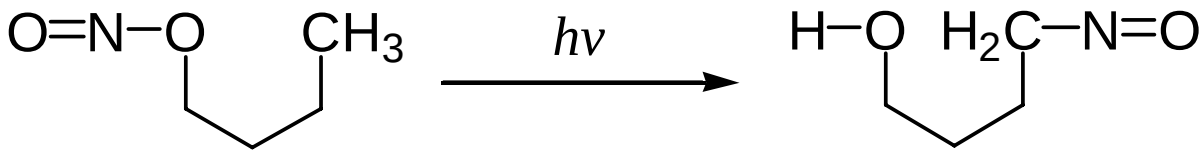
The molecule undergoes a reorganization of it constitutional parts

2) Mechanism of a reaction: 從分子的角度解釋由產物到生成物的過程

Briefly explain the above reactions

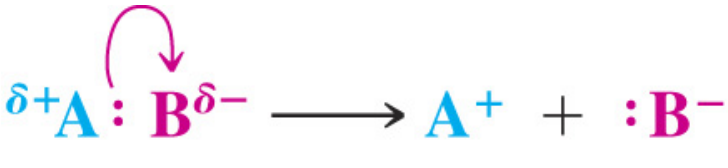
3) Homolysis and heterolysis of covalent bond (共價鍵之均裂和異裂):



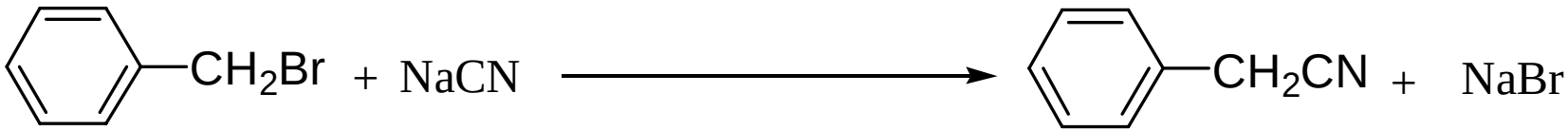


Explain

Curve arrow



Heterolysis normally requires the bonds to be polarized

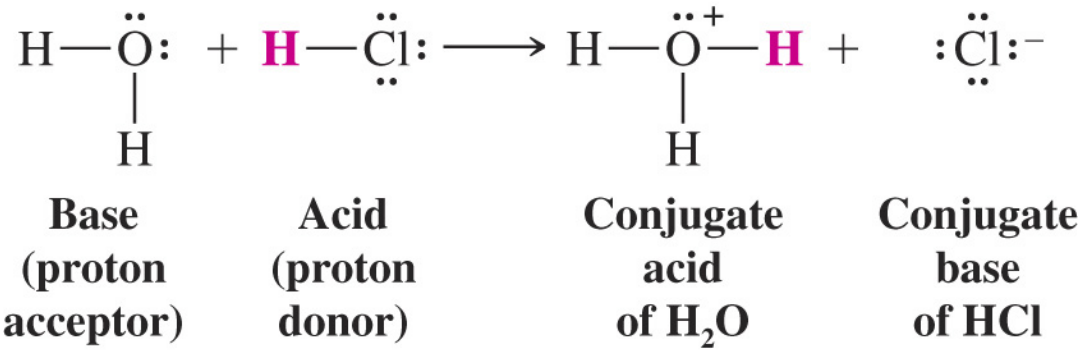


Explain

二)有機酸鹼反應(瞭解用curve arrow表達反應機制；化合物結構與反應性之間的關係； 用熱力學常數預測反應的平衡；溶劑對反應的影響；有機合成的初步概念)

1）Brønsted-Lowry 酸碱理論:

酸：給出質子
鹼：接受質子



***Hydronium* ($H3O^+$): exist in aqueous solution in significant amount**

$$HI + H_2O \longrightarrow H_3O^+ + I^-$$

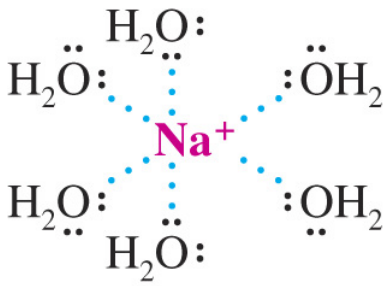
$$HBr + H_2O \longrightarrow H_3O^+ + Br^-$$

H_2SO_4: diprotic acid

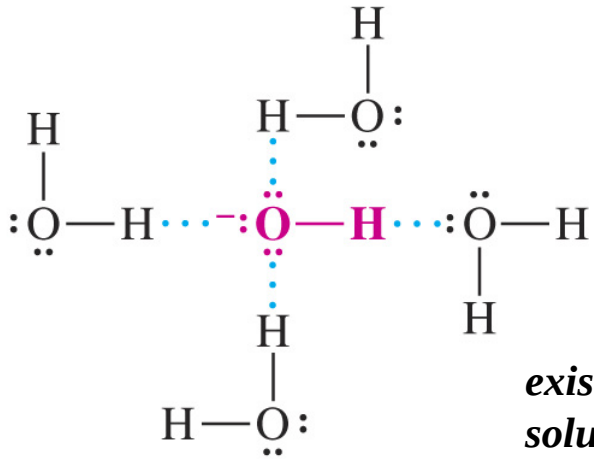
$$H_2SO_4 + H_2O \longrightarrow H_3O^+ + HSO_4^-$$

$$HSO_4^- + H_2O \rightleftharpoons H_3O^+ + SO_4^{2-}$$

$$NaOH \xrightarrow{H_2O} Na_{(aq)}^+ + OH_{(aq)}^-$$



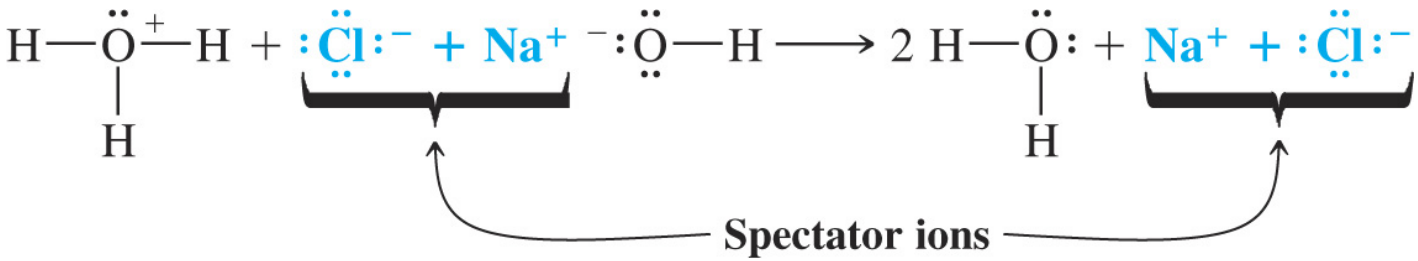
Solvated sodium ion

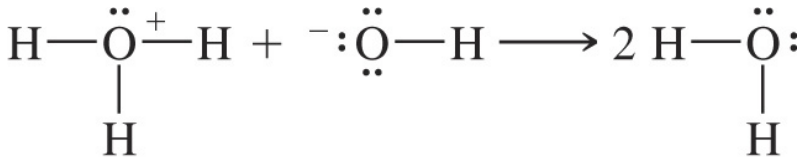


Solvated hydroxide ion

exist in aqueous solution in significant amount

***When Aqueous hydrogen chloride and aqueous sodium hydroxide are mixed, the actual reaction is between hydronium and hydroxide ions*:**



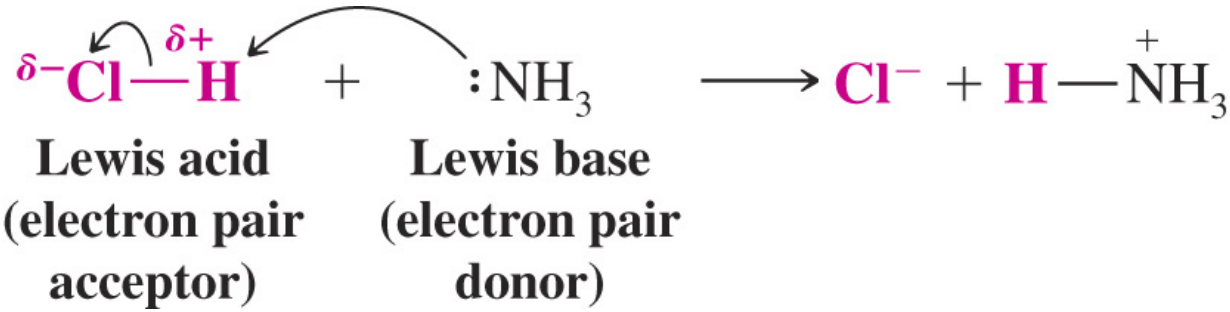


Net reaction

2) Lewis 酸鹼理論(比Brønsted-Lowry 酸鹼理論定義更為廣泛):

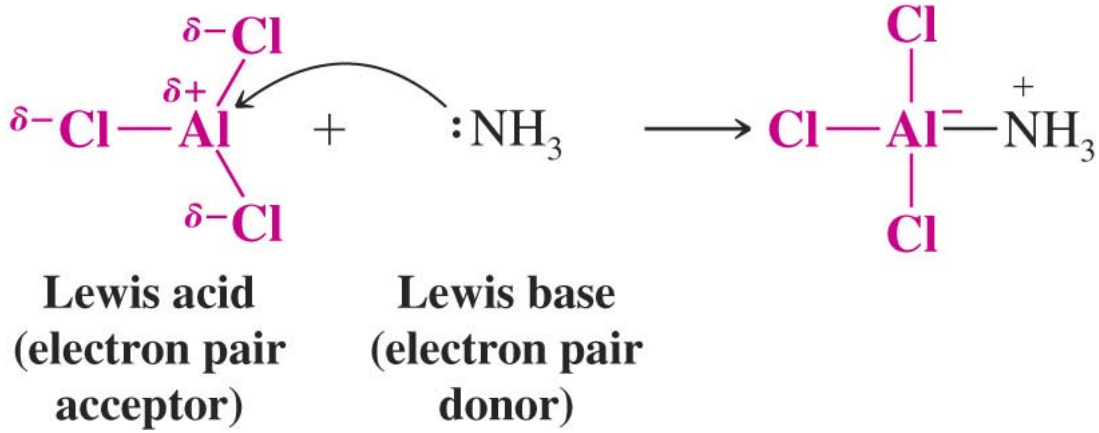
酸：接受電子對

鹼：給出電子對

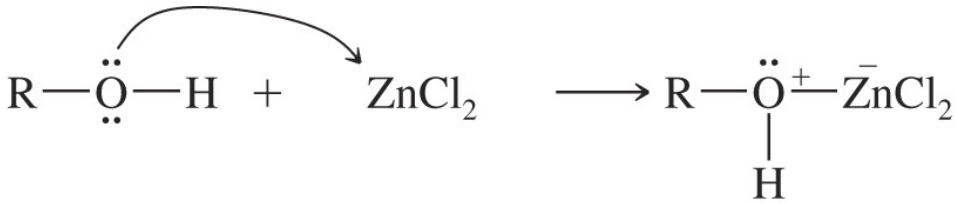


Note that the proton also lose an electron pair as new bond is formed with nitrogen.

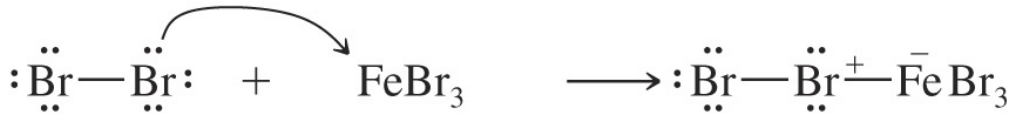
Accept an electron pair without breaking any bond



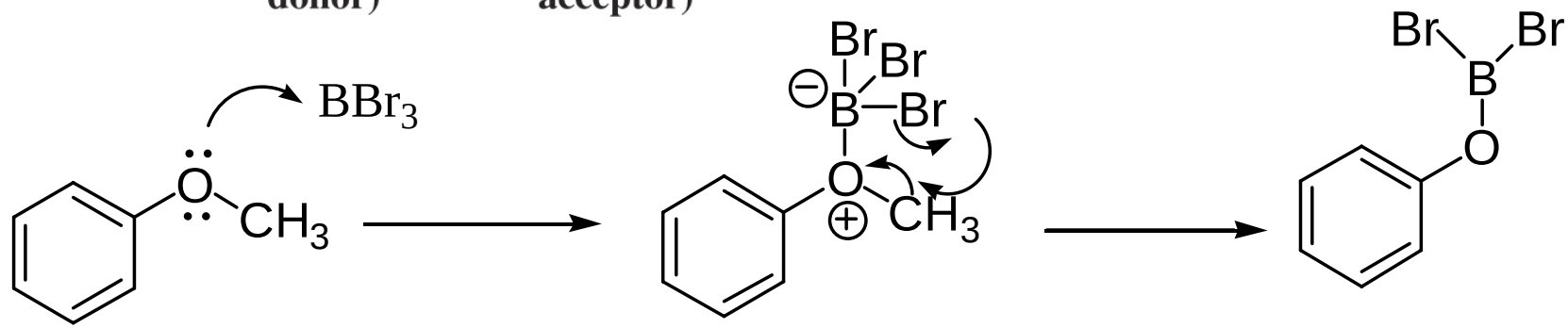
在有機化學中普遍應用的Lewis 酸: Zn^{2+}, Fe^{3+}, BF_3..... etc.

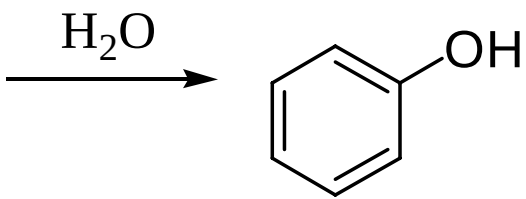


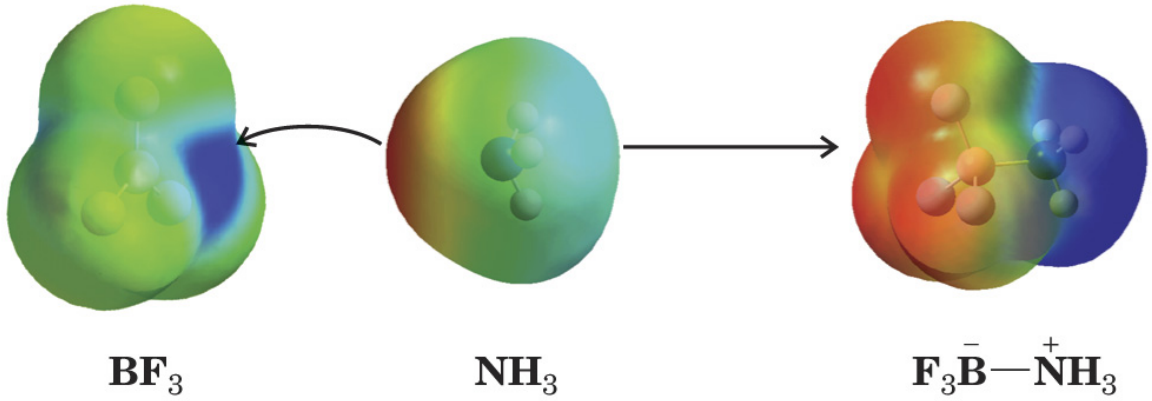
Lewis base (electron pair donor) **Lewis acid (electron pair acceptor)**



Lewis base (electron pair donor) **Lewis acid (electron pair acceptor)**







Opposite Charges Attract and React

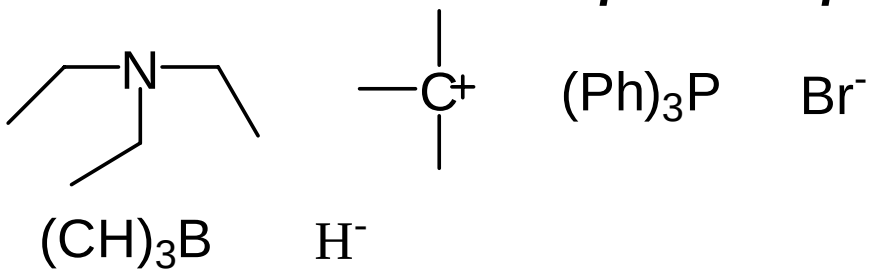
Exercise (page 100): $CH_3OH + BF_3 \longrightarrow$

1) Write the equations:

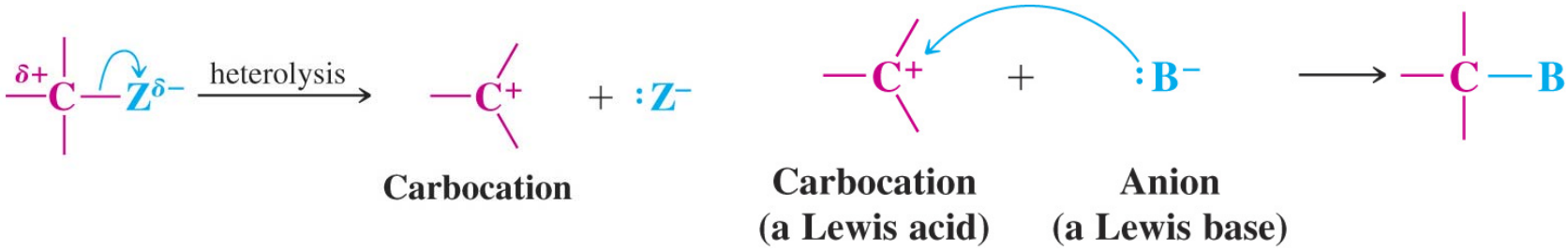
$CH_3Cl + AlCl_3 \longrightarrow$

$CH_3OCH_3 + BF_3 \longrightarrow$

2) Define the Lewis acids and bases for each of the following:

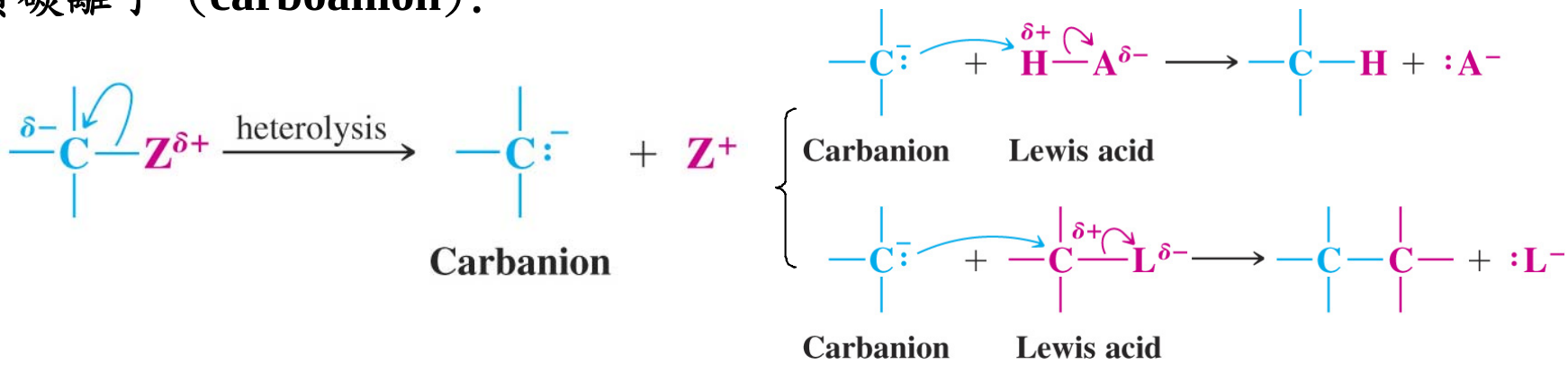


正碳離子(carbocation):

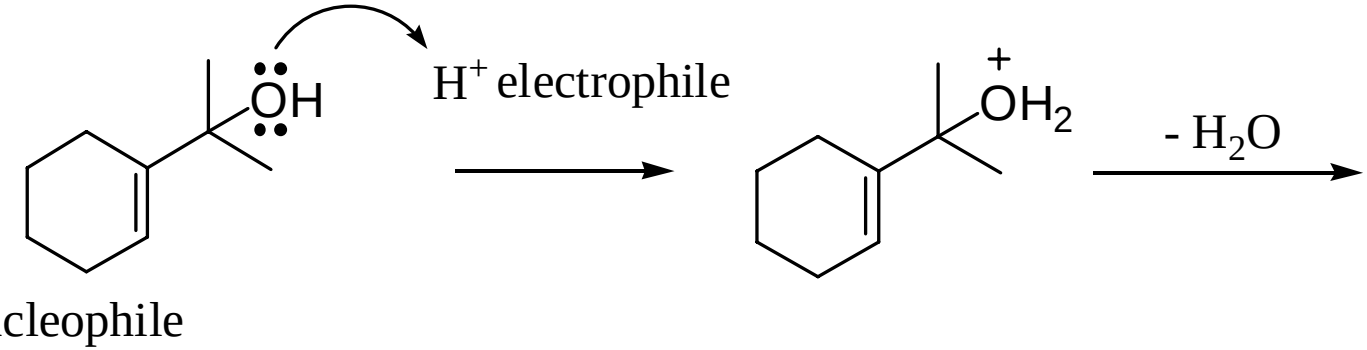


親電試劑 (electrophiles): reagents which in their reactions seek extra electrons that will give them a stable valence shell of electrons.

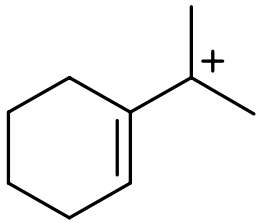
負碳離子 (carboanion):



親核試劑 (nucleophiles): reagents which in their reactions seek a proton or some other positive centers



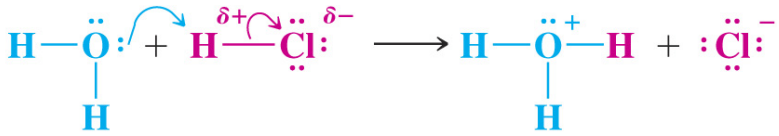
nucleophile



carbocation

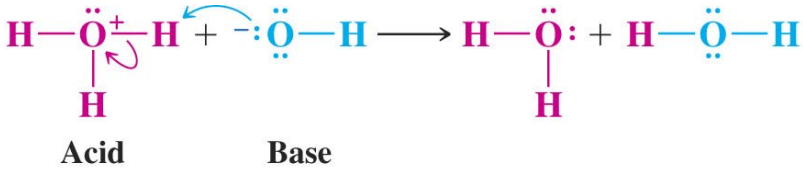
***The curved arrow begins with a covalent bond or unshared electron pair (site of higher electron density) and points toward a site of electron deficiency.**

***It shows the movement of electron flow <u>but not</u> the movement of atoms**

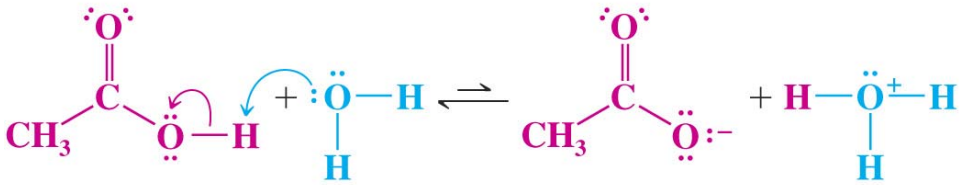


A water molecule uses one of the nonbonding electron pairs to form a bond to a proton of HCl. The bond between the hydrogen and chlorine breaks with the electron pair going to the chlorine atom.

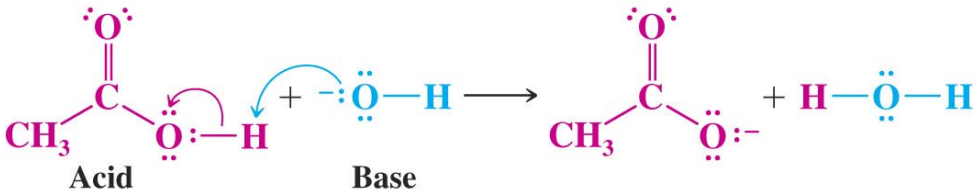
This leads to the formation of a hydronium ion and a chloride ion.



Acid Base



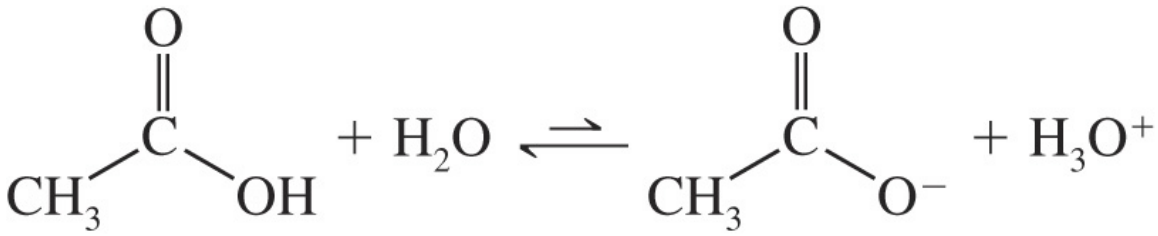
Acid Base



Acid Base

Exercise (page 103):Use the curved-arrow notation to write the reaction between (CH3)2NH and BF3.

3) 酸鹼強度



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

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

Acidic constant

$$K_a = \frac{[H_3O^+][A^-]}{[HA]} \qquad pK_a = -\log K_a$$

$$CH_3CO_2H < CF_3CO_2H < HCl$$

$pK_a = 4.75$ $pK_a = 0$ $pK_a = -7$

Weak acid **Very strong acid**

Increasing acid strength

	Acid	Approximate pK_a	Conjugate Base	
Strongest acid	$HSbF_6$	< -12	SbF_6^-	Weakest base
	HI	-10	I^-	
	H_2SO_4	-9	HSO_4^-	
	HBr	-9	Br^-	
	HCl	-7	Cl^-	
	$C_6H_5SO_3H$	-6.5	$C_6H_5SO_3^-$	
	$(CH_3)_2\overset{+}{O}H$	-3.8	$(CH_3)_2O$	
	$(CH_3)_2C{=}\overset{+}{O}H$	-2.9	$(CH_3)_2C{=}O$	
	$CH_3\overset{+}{O}H_2$	-2.5	CH_3OH	
	H_3O^+	-1.74	H_2O	
	HNO_3	-1.4	NO_3^-	
	CF_3CO_2H	0.18	$CF_3CO_2^-$	
	HF	3.2	F^-	
	CH_3CO_2H	4.75	$CH_3CO_2^-$	
	H_2CO_3	6.35	HCO_3^-	
	$CH_3COCH_2COCH_3$	9.0	$CH_3CO\bar{C}HCOCH_3$	
	NH_4^+	9.2	NH_3	
	C_6H_5OH	9.9	C_6H_5O-	
	HCO_3^-	10.2	CO_3^{2-}	
	$CH_3NH_3^+$	10.6	CH_3NH_2	
	H_2O	15.7	OH^-	
	CH_3CH_2OH	16	$CH_3CH_2O^-$	
	$(CH_3)_3COH$	18	$(CH_3)_3CO^-$	
	CH_3COCH_3	19.2	$^-CH_2COCH_3$	
	$HC{\equiv}CH$	25	$HC{\equiv}C^-$	
	H_2	35	H^-	
	NH_3	38	NH_2^-	
	$CH_2{=}CH_2$	44	$CH_2{=}CH^-$	
Weakest acid	CH_3CH_3	50	$CH_3CH_2^-$	Strongest base

Increasing acid strength

Increasing base strength

Carboxylic acid: 3∼5; alcohol 15 ∼ 18; ketones ∼ 20….

Exercise (page 104-107)*: 1) *HCO2H has Ka = 1.77 ×10^{-4}, in a 0.1 M solution, what is the concentration of hydronium ions?

$$1.77 \times 10^{-4} = \frac{[H_3O^+]\,[HCOO^-]}{0.1}$$

2) *Rationalize the Pka for H2O is 15.7*:

$$Ka = \frac{[10^{-7}][10^{-7}]}{55.5\ M} = 1.8 \times 10^{-16}$$

$$PKa = 15.7$$

***3) The Pk$_a$ of anilinium ion ($C_6H_5N^+H_3$) is 4.6. On this basis, decide aniline is stronger or weaker base than methylamine*:**

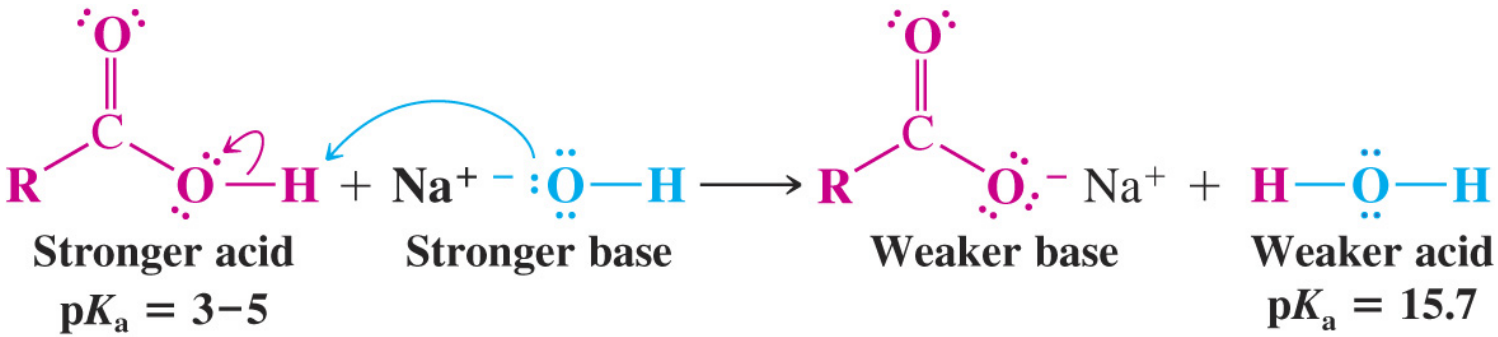
$CH_3N^+H_3$: 10.6, thus it is a weaker base than methylamine

3)利用酸鹼強度判斷酸碱反應的 equilibrium: <u>Acid base reaction favor the formation of the weaker acid and base.</u>

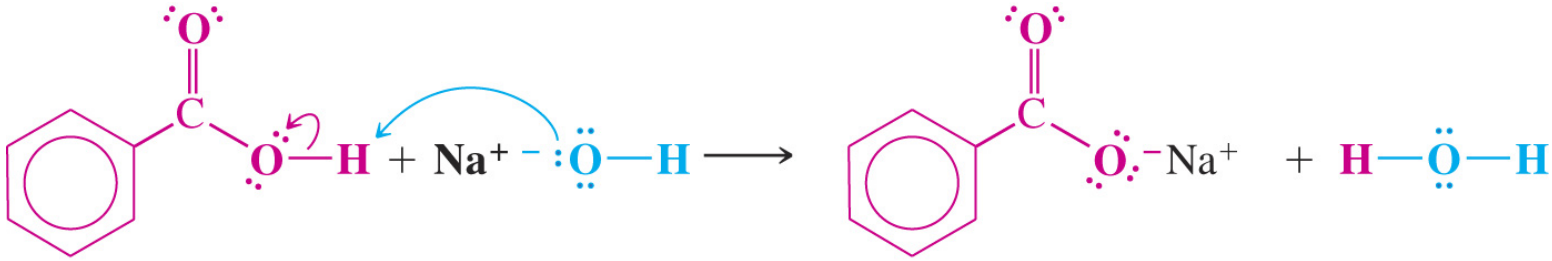
Equilibrium-controlled reactions: favoring the formation of more stable species.

$NH_3 + H_2O$ (?)

$CH_3OH + H_2O$ (?)

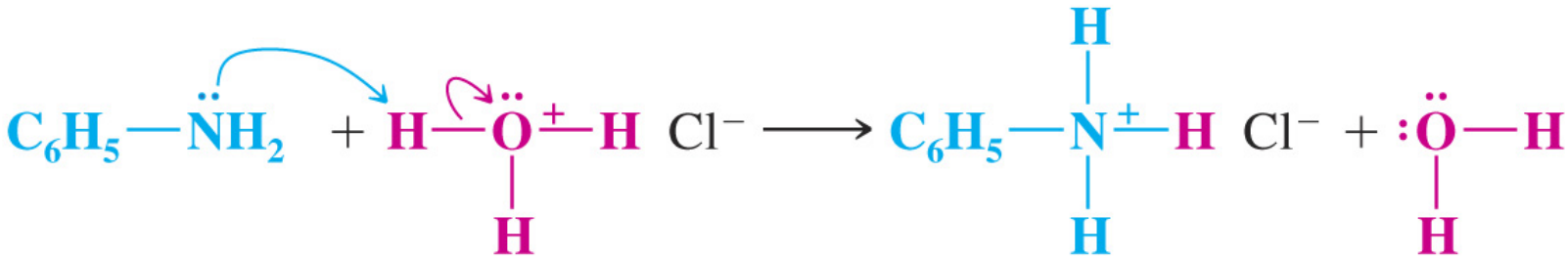


Water insoluble carboxylic acids or bases can become soluble in aqueous sodium hydroxide:



Insoluble in water

Soluble in water (due to its polarity as a salt)



Water insoluble

Water-soluble salt

4）决定化合物酸鹼性強弱的因素

a) Bond strength:

Bond strength decrease

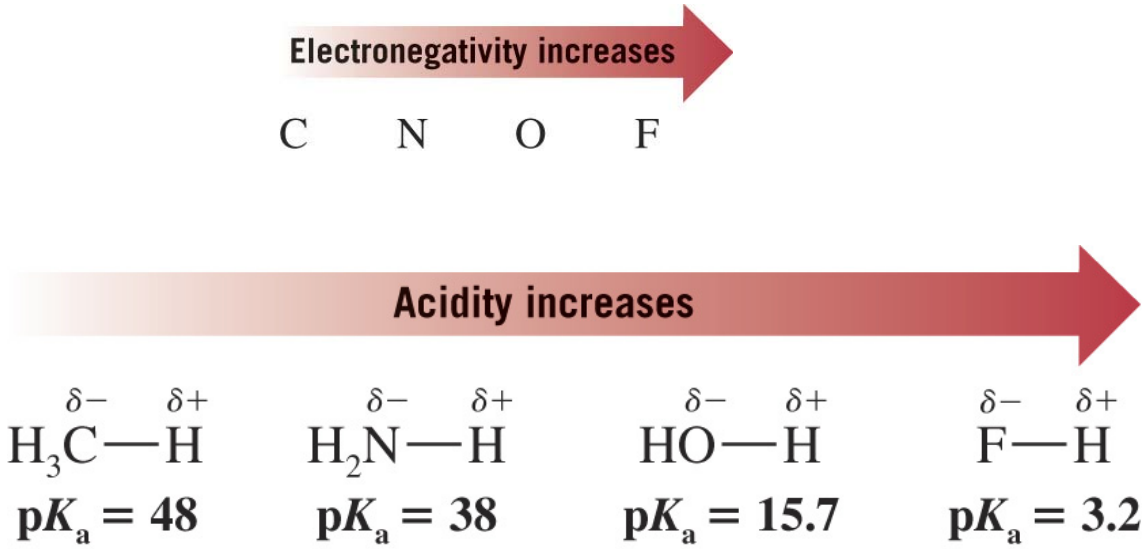
	pK_a
H—F	3.2
H—Cl	−7
H—Br	−9
H—I	−10

Acidity increases

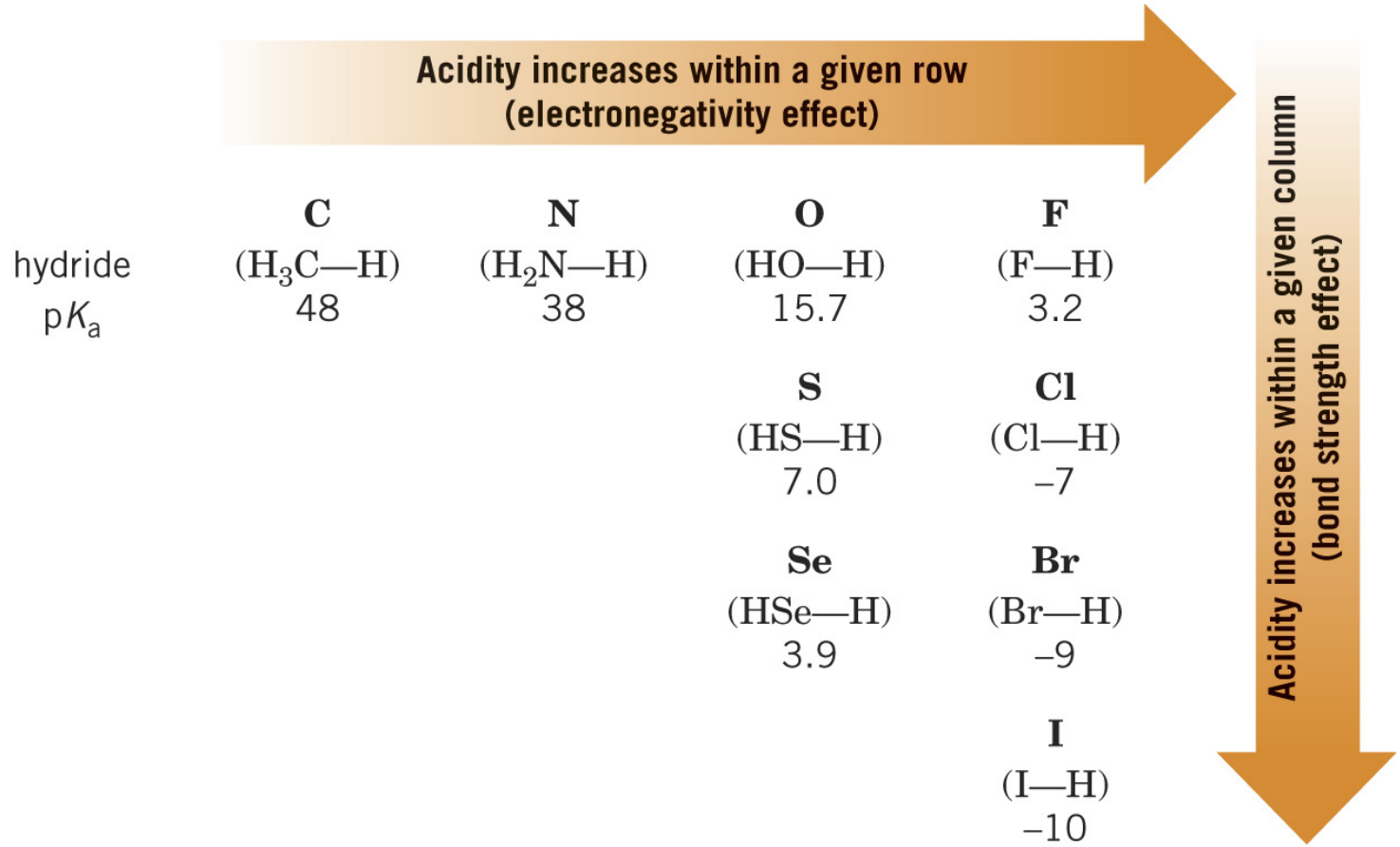
	pK_a
H_2O	15.7
H_2S	7.0
H_2Se	3.9

Acidity increases

b) Electronegativity



Increasingly electronegative atoms polarize the bond and also stabilize the conjugate base better



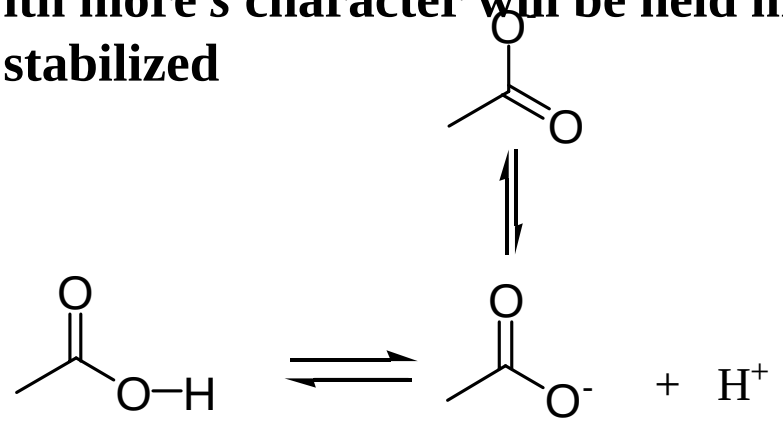
Overview of Acidity Trends

c) Hybridization:

$$HC{\equiv}CH > H_2C{=}CH_2 > H_3C{-}CH_3$$

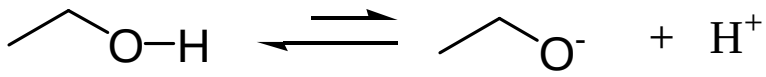
***s* orbitals are smaller and closer to the nucleus than *p* orbitals**
Anions in hybrid orbitals with more *s* character will be held more closely to the nucleus and be more stabilized

d) Resonance effect

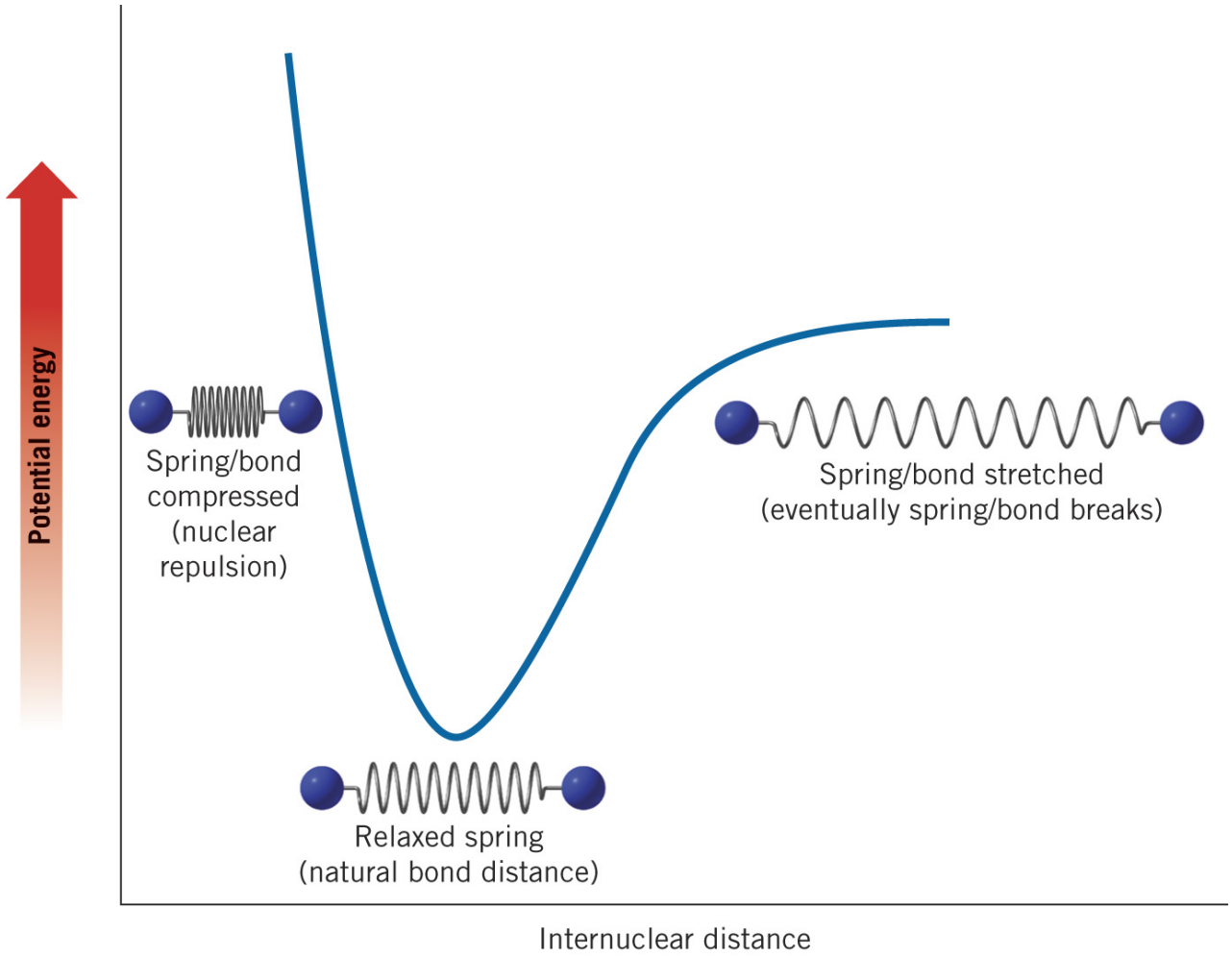


pKa = 4.75

stabilized by the resonance;
Less potential energy than CH3CH2O-



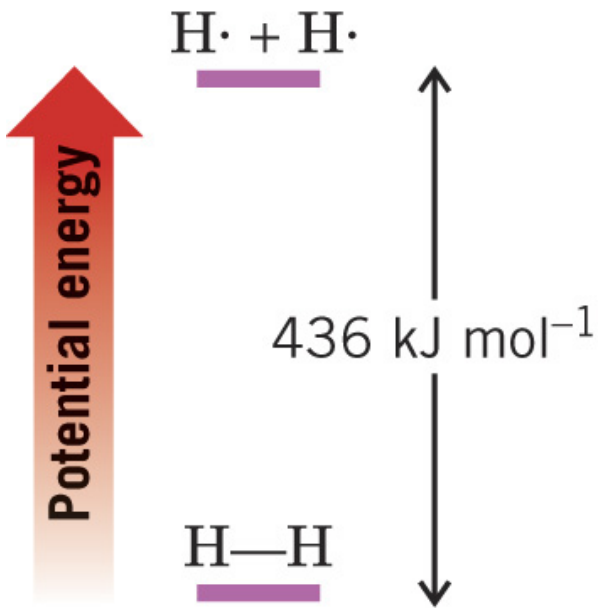
pKa = 16



The higher the potential energy of an object the less stable it is

Enthalpy ΔHo is a measure of the change in bond energies in a reaction:

- **Exothermic reactions:**
  - **ΔHo is negative and heat is evolved.**
  - **Potential energy in the bonds of reactants is more than that of products**
- **Endothermic reactions**
  - **ΔHo is positive and heat is absorbed**
  - **Potential energy in the bonds of reactants is less than that of products**



$$H_2 \longrightarrow 2H^{\bullet}$$

ΔGo: the standard free energy change:

$$\Delta G^\circ = -RT \ln K_{eq}$$

If ΔGo is negative, products are favored at equilibrium (Keq >1)
If ΔGo is positive, reactants are favored at equilibrium (Keq<1)
If ΔGo is zero, products and reactants are equally favored (Keq = 1)

$$\Delta G^\circ = \Delta H^\circ - T\,\Delta S^\circ$$

Entropy change ΔS° is related to the changes in relative order of the system

A + B ⟶ C ***ΔS°: negative***

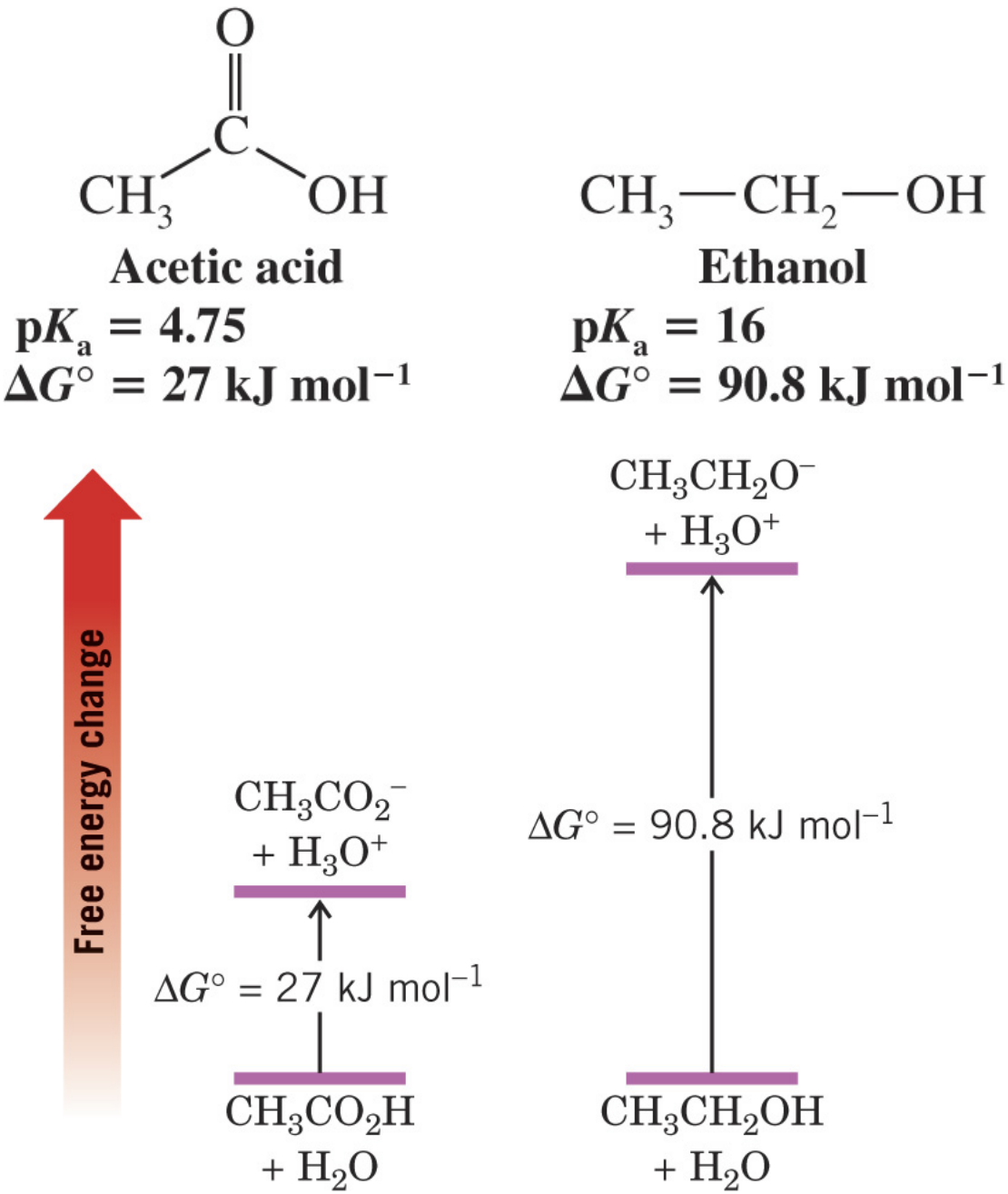
A + B ⟶ C + D ***ΔS° ~ 0***

A ⟶ C + D ***ΔS°: positive***

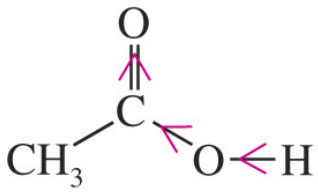
The more random a system is, the greater is its entropy

A positive ΔS° means a system which is going from <u>more ordered to less ordered</u>

A negative ΔS° :products unfavored


Acetic acid
$pK_a = 4.75$
$\Delta G° = 27$ kJ mol^{-1}
Ethanol
$pK_a = 16$
$\Delta G° = 90.8$ kJ mol^{-1}
Free energy change
$CH_3CO_2^-$ + H_3O^+
$\Delta G° = 27$ kJ mol^{-1}
CH_3CO_2H + H_2O
$CH_3CH_2O^-$ + H_3O^+
$\Delta G° = 90.8$ kJ mol^{-1}
CH_3CH_2OH + H_2O

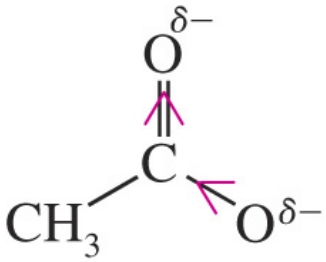
e) Inductive effect



Acetic acid
(stronger acid)

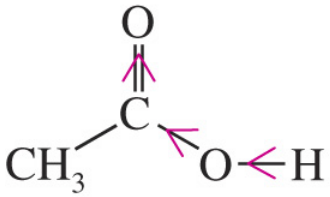
Ethanol
(weaker acid)

The proton is more positive

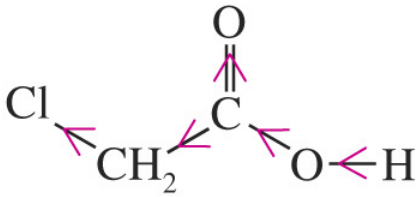


Acetate anion
Weaker base

Ethoxide anion
Stronger base



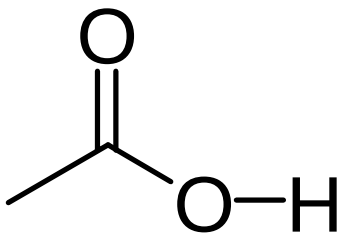
pK_a = 4.75



pK_a = 2.86

***Indicating the stronger acid (page 120): a) CHCl2CO2H > CH2ClCO2H b) CH2FCO2H* > CH2BrCO2H; c) CCl3CO2H > CHCl2CO2H; d) CH2FCO2H > CH2FCH2CO2H**

f) Solvent effect (protic solvent: is one has hydrogen attached to a strongly electronegtive element such as oxygen or nitrogen)



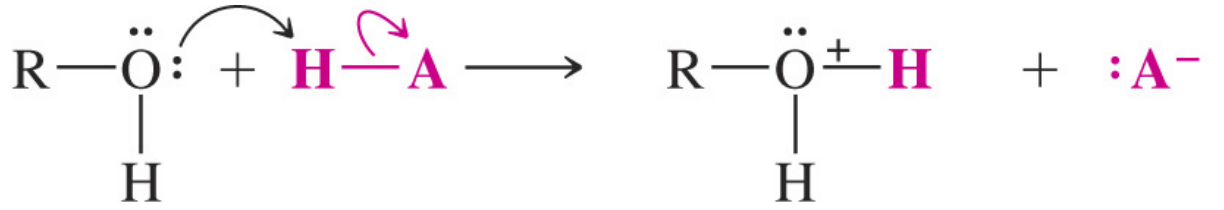
pKa = 4.75 in H_2O

Pka = 130 in gas phase

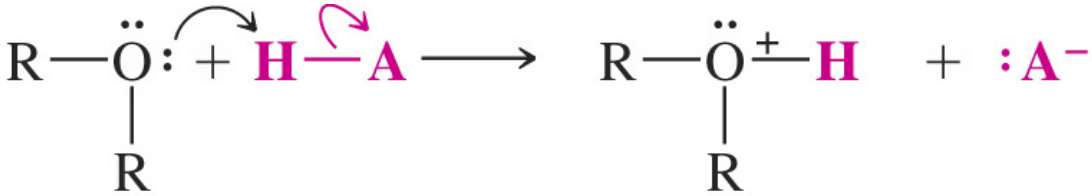
Explain the table in page 121.

4) Organic compounds as bases:

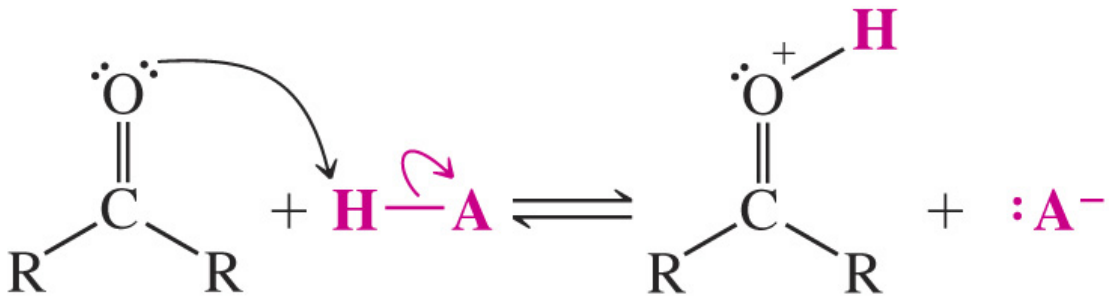
a) organic compound containing an atom with a lone pair (O,S,N) can act as a base



Alcohol **Strong acid** **Alkyloxonium ion** **Weak base**

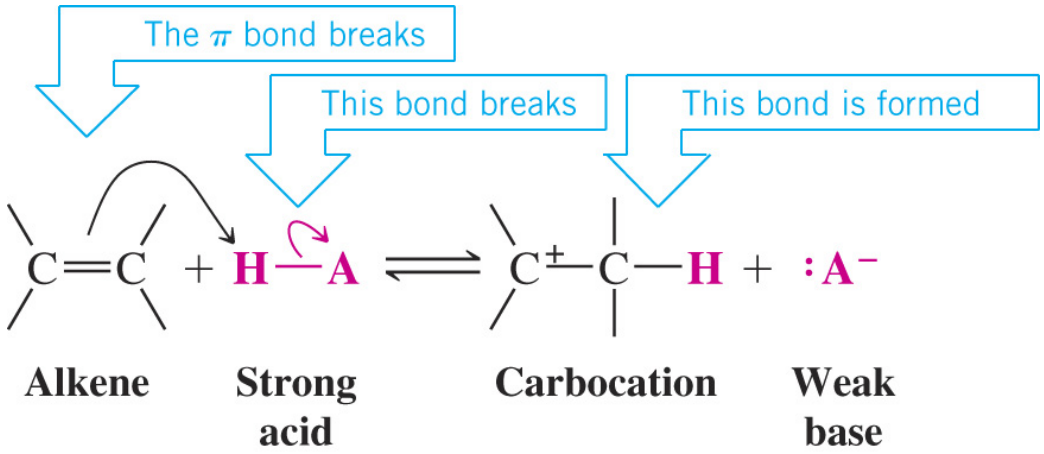


Ether **Strong acid** **Dialkyloxonium ion** **Weak base**

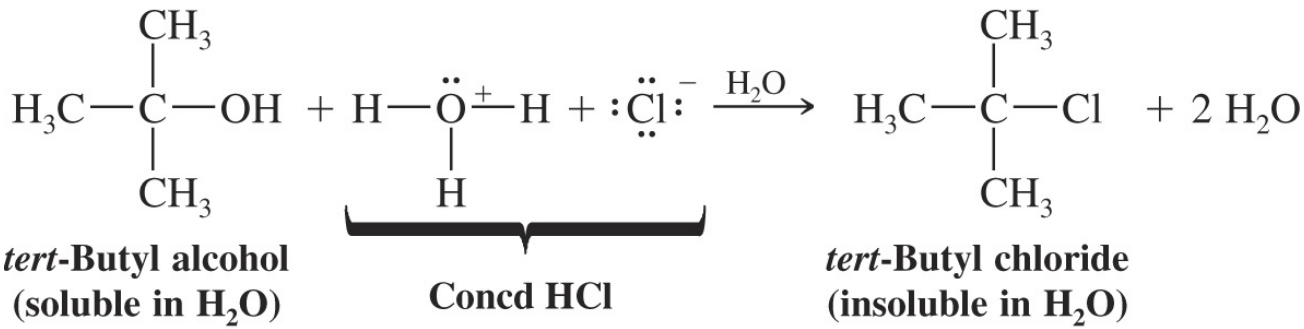


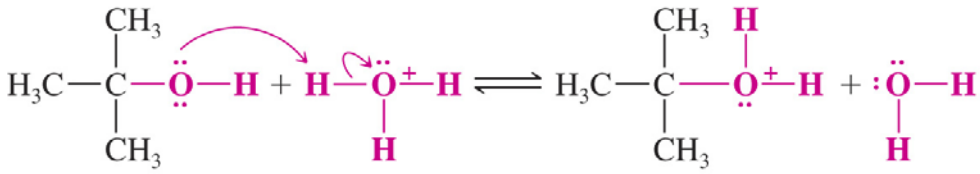
Ketone **Strong acid** **Protonated ketone** **Weak base**

b) π Electrons can also act as bases



5) A step-wise mechanism of a organic reaction:

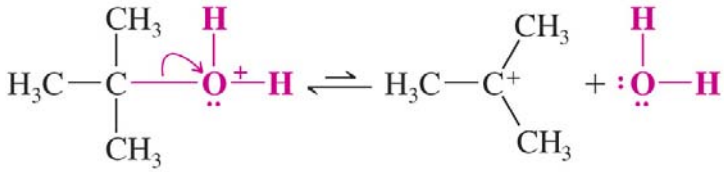




tert-Butyloxonium ion

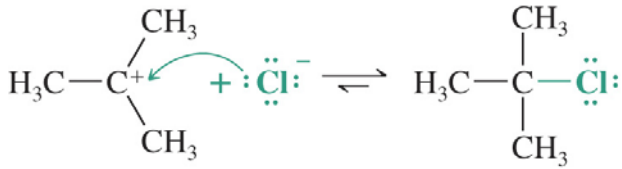
tert-Butyl alcohol acts as a base and accepts a proton from the hydronium ion. (Chloride anions are spectators in this step of the reaction.)

The products are a protonated alcohol and water (the conjugate acid and base).



Carbocation

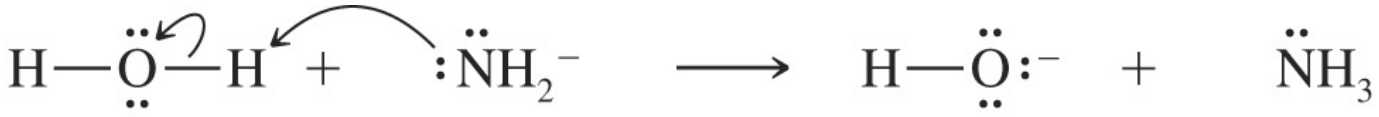
The bond between the carbon and oxygen of the *tert*-butyloxonium ion breaks heterolytically, leading to the formation of a carbocation and a molecule of water.



tert-Butyl chloride

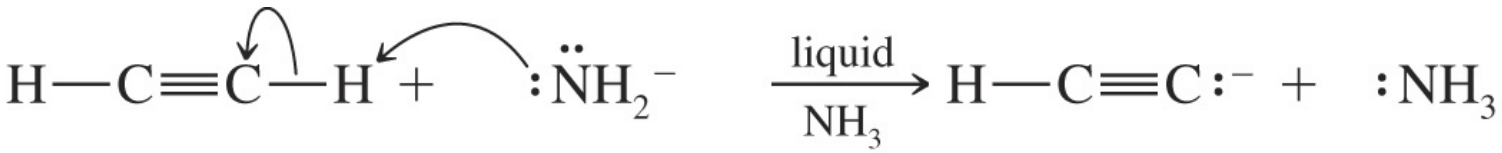
The carbocation, acting as a Lewis acid, accepts an electron pair from a chloride ion to become the product.

6) Acid-base reaction in non-aqueous solution:



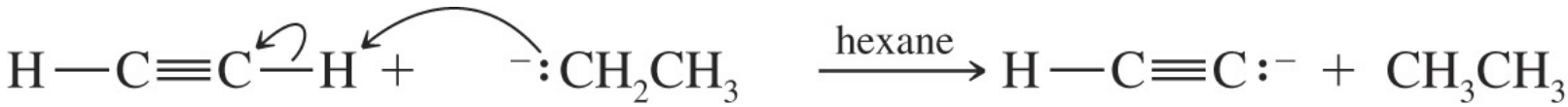
Stronger acid $pK_a = 15.7$ **Stronger base** **Weaker base** **Weaker acid** $pK_a = 38$

Any base stronger than hydroxide will be converted to hydroxide in water



Stronger acid $pK_a = 25$ **Stronger base (from $NaNH_2$)** **Weaker base** **Weaker acid** $pK_a = 38$

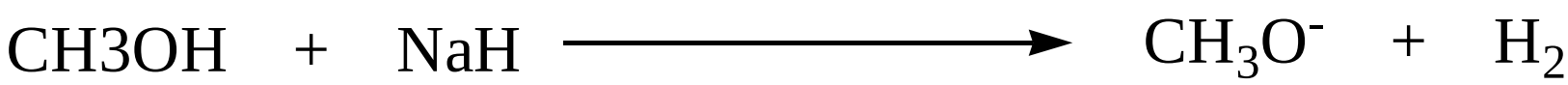
Sodium amide can be used as a strong base in solvents such as liquid NH3



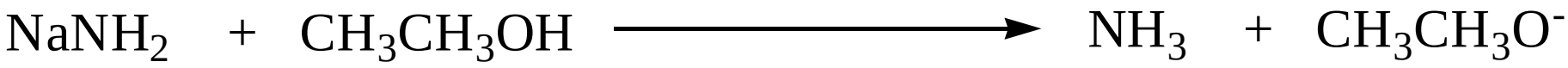
Stronger acid $pK_a = 25$ **Stronger base (from CH_3CH_2Li)** **Weaker base** **Weaker acid** $pK_a = 50$

Write the acid-base reactions (page 126):

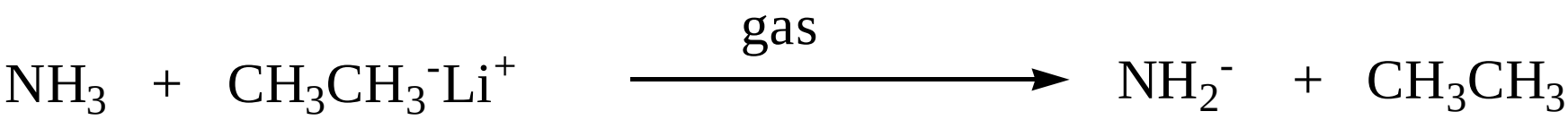
a)



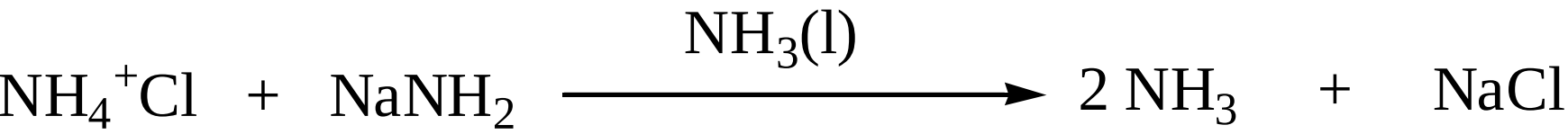
b)



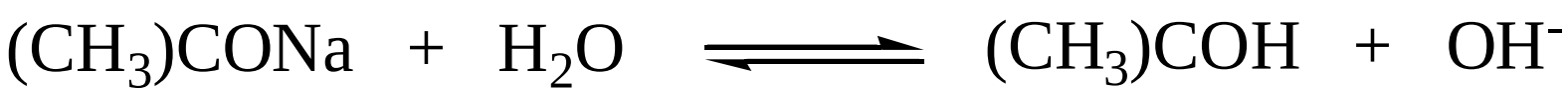
c)



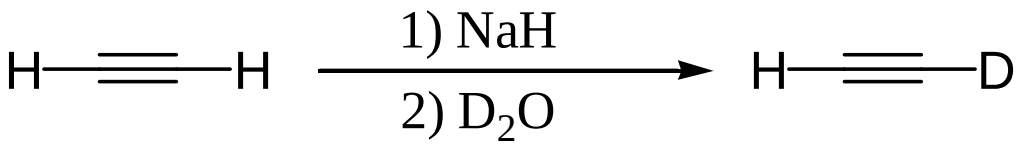
d)

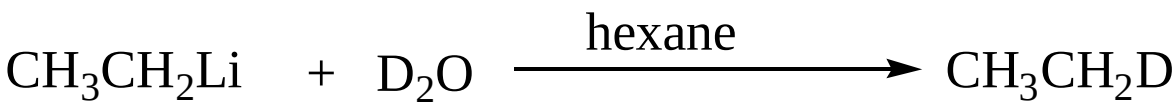


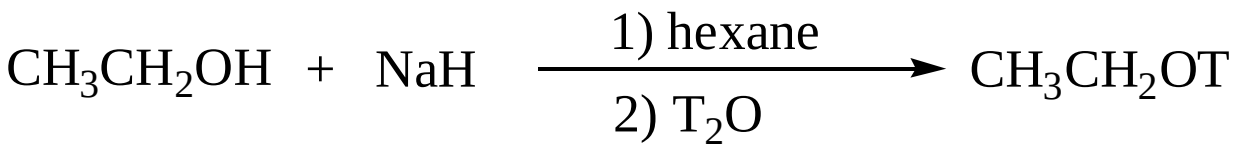
e)



f)







***Exercise (page 129)*:**

3.15: what is the conjugate base of each of the following acid?

(a) NH_3: NH_2^- (c) H_2: H^- (e) CH_3OH: CH_3O^-

(b) H_2O: OH^- (d) $HC\equiv CH$: $^-C\equiv CH$ (f) H_3O^+: H_2O

3.16: List the bases you gave as answers to Problem 3.15 in order of decreasing basicity:

Acidity: $H_3O^+ > H_2O > CH_3OH > HC\equiv CH > H_2 > NH_3$

Basicity: $NH_2^- > H^- > {}^-C\equiv CH > CH_3O^- > OH^- > H_2O$

3.17: what is the conjugate acid of each of the following bases:

(a) HSO_4^-: H_2SO_4 (c) CH_3NH_2: $CH_3NH_3^+$ (e) $CH_3CH_2^-$: CH_3CH_3

(b) H_2O: H_3O^+ (d) NH_2^-:NH_3 (f) $CH_3CO_2^-$: CH_3CO_2H

3.18 List the acids you gave as answers to Problem 3.15 in order of decreasing acidity:

Acidity: $H_2SO_4 > H_3O^+ > CH_3CO_2H > CH_3NH_3^+ > NH_3 > CH_3CH_3$

3.19 Designate the LA and LB in each of the following reactions:

a) $H_3CH_2C{-}Cl$ + $AlCl_3$ ⟶ $H_3CH_2C{-}\overset{+}{Cl}{-}\overset{-}{Al}(Cl)_2{-}Cl$

LB LA

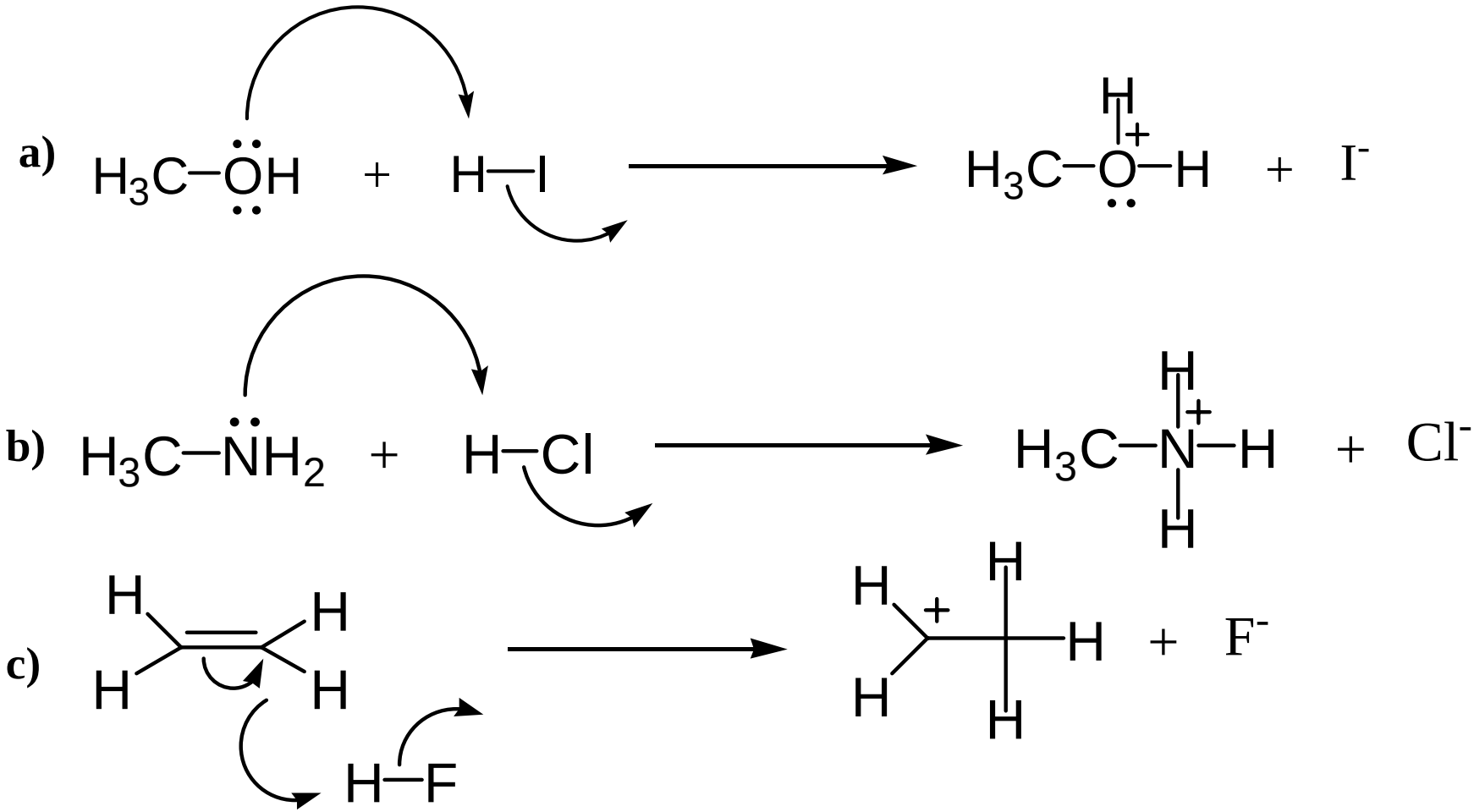
b) $H_3C{-}OH$ + BF_3 ⟶ $H_3C{-}\overset{+}{O}(H){-}\overset{-}{B}(F)_2{-}F$

LB LA

c) $(H_3C)_3\overset{+}{C}$ + H_2O ⟶ $(H_3C)_3C{-}\overset{+}{O}H_2$

LA LB

3.20 Rewrite each of the following reactions using curved arrows and show all non-bonding electron pairs:



3.21 When CH3OH is treated with NaH, the product is $CH3O^-Na^+$ and H_2 and not Na^+CH_2OH and H_2, explain:

$$Pk_{aCH3} > Pk_{aOH}$$

$$Pk_aCH_3OH \sim 15;\ \ Pk_aH_2 \sim 35;$$

3.22 What reaction will take place if EtOH is added to a solution of $HC\equiv C^-Na^+$ in liquid ammonia:

3.22 omitted

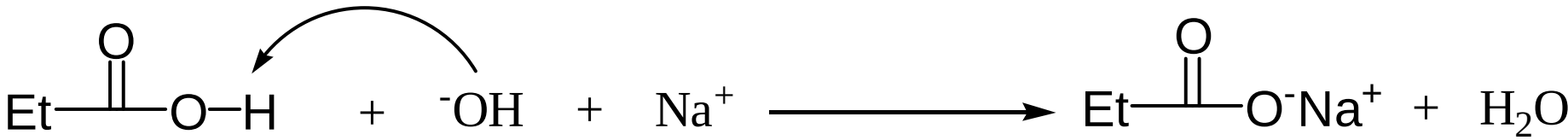
3.33 Acid HA has a PKa = 20; acid HB has a PKa = 10:

a) Which is the stronger acid: HB

b)

3.25 Write the equation, using curved-arrow notation:

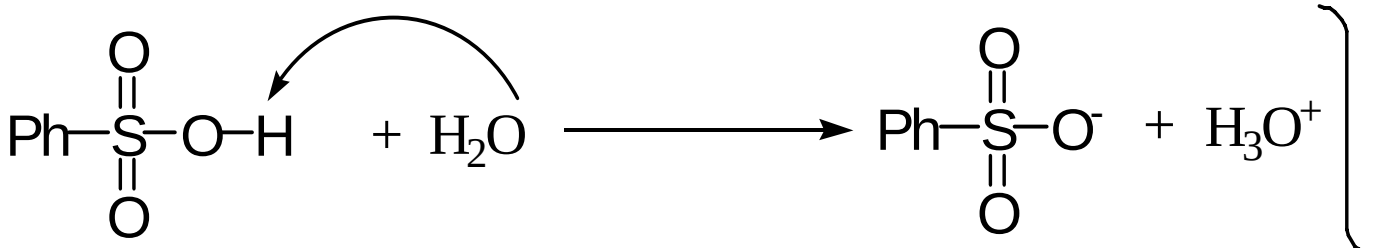
a)



PKa ~5

H_2O PKa ~15.7

b)



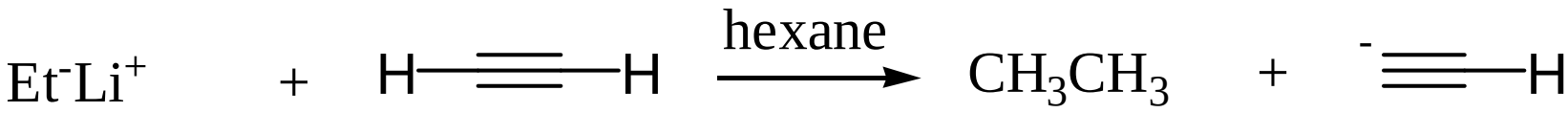
PKa ~-6.5

$H_3O^+ + Na^+ + OH^- \longrightarrow 2H_2O + Na^+$

c)

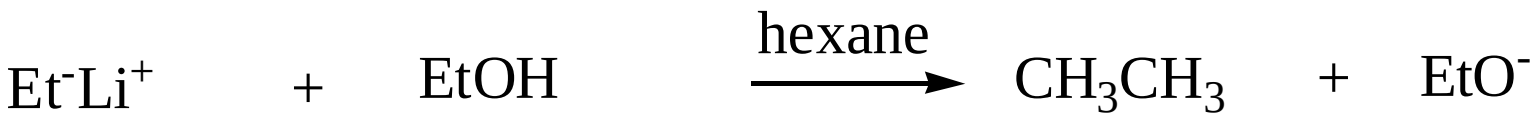
PK_{aEtOH} ~16 $PK_{a\ ethyne}$ ~25

d)



$PK_{aCH3CH3} \sim 50$ $PK_{aCHCH} \sim 25$

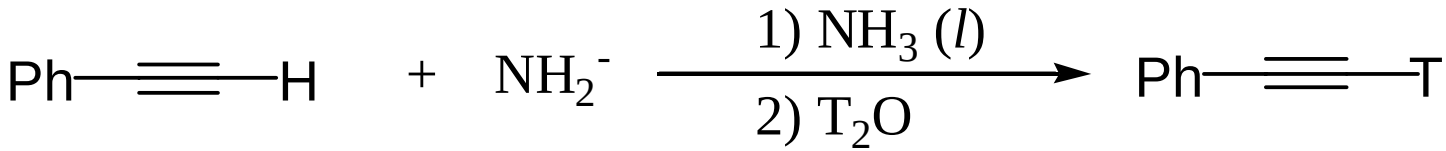
e)



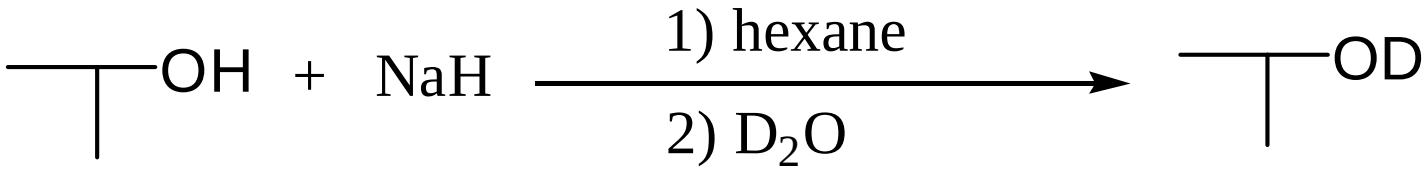
$PK_{aCH3CH3} \sim 50$ $PK_{aEtOH} \sim 16$

3.26 Showing the syntheses of each of the following:

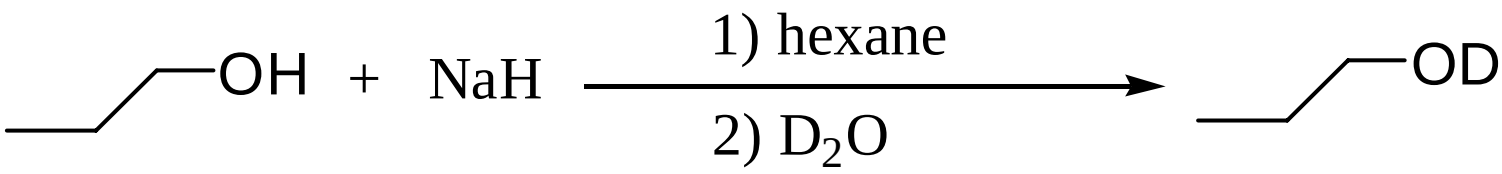
a)



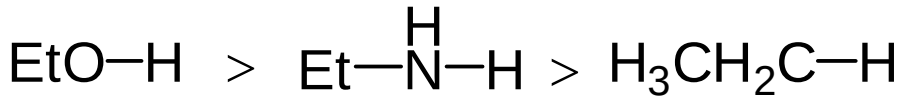
b)



c)

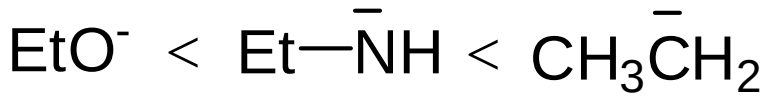


3.27 a) arrange the following compounds in order of decreasing acidity and explain:



electronegtivity decreases

b) Arrange the conjugate bases in order of increasing basicity:



3.28 Arrange the following compounds in order of decreasing acidity :

a)

b) $CH_3CHClCO_2H > CH_3CH_2CO_2H > CH_3CH_2CH_2OH$

c) $CH_3CH_2OH_2^+ > CH_3CH_2OH > CH_3OCH_3$

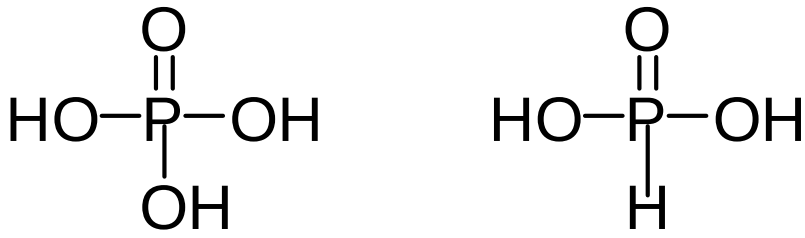
3.29 Arrange the following compounds in order of increasing basicity:

a) $CH_3NH_3^+ < CH_3NH_2 < CH_3NH^-$

b) $CH_3O^- < CH_3NH^- < CH_3CH_2^-$

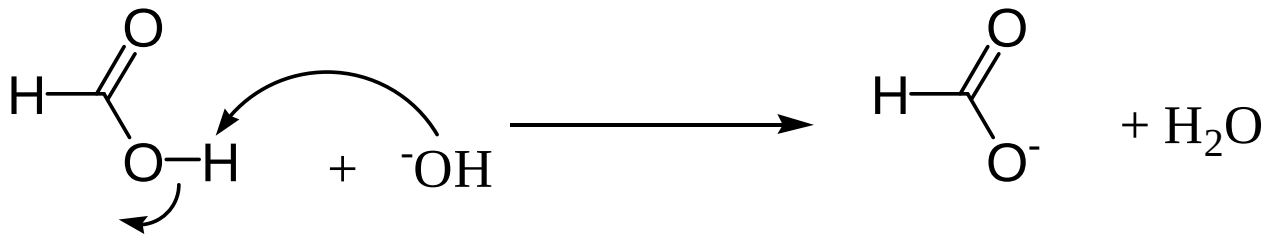
c) $CH_3C{\equiv}C^- < CH_3CH_2{=}CH^- < CH_3CH_2CH_2^-$

3.30 Draw the structures of triprotic acid H3PO4 and diprotic acid H3PO3

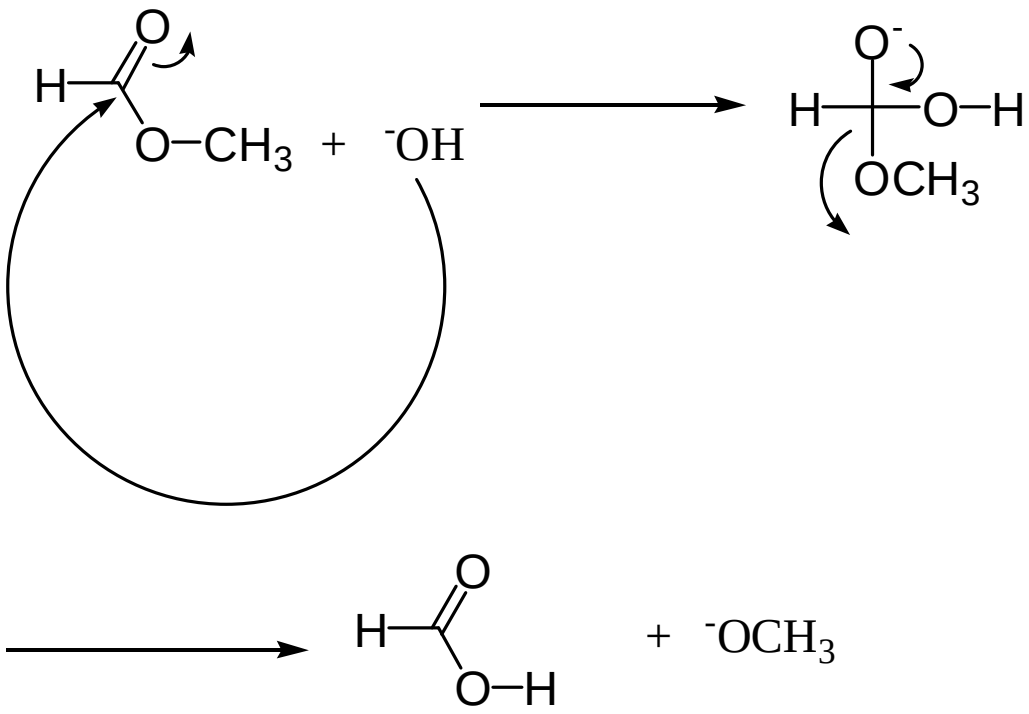


3.31 Supply the curved arrow necessary for the following reactions:

a)

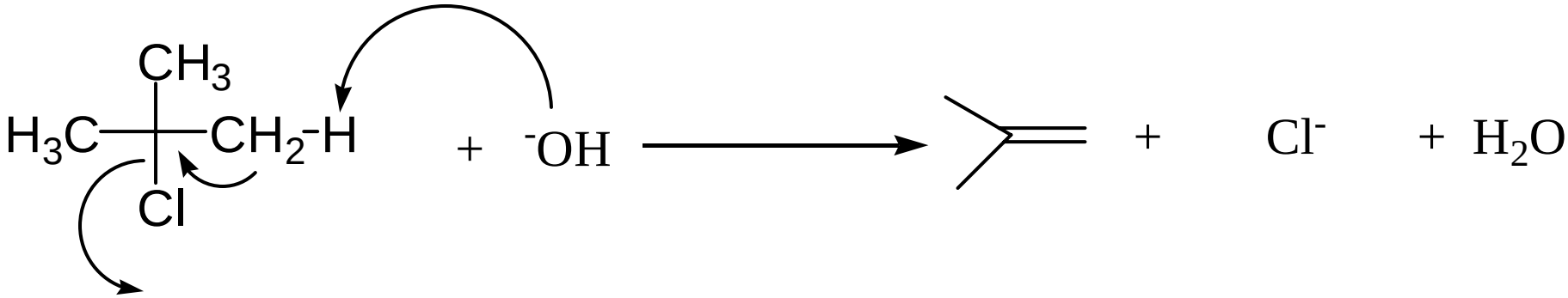


b), c)



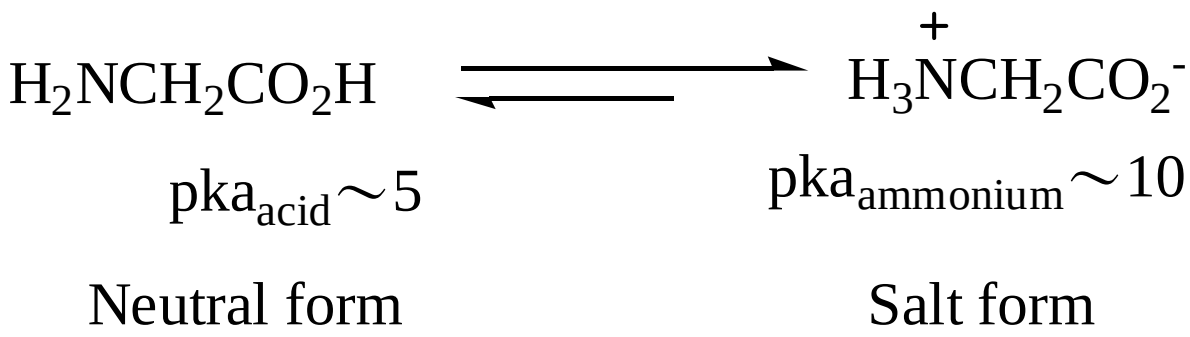
d)

e)



3.32

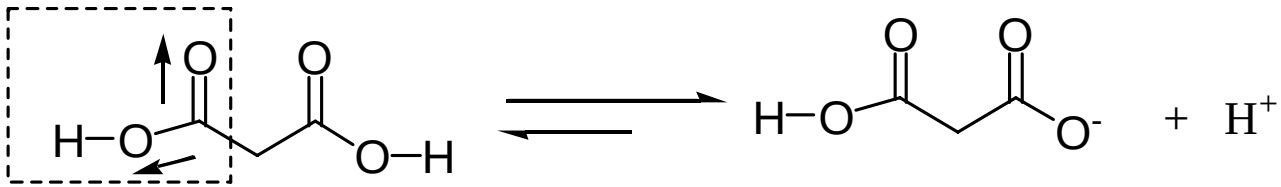
a)



b): salt form is dominating

3.33

a)



electron-attracting inductive effect

b) Two negative centers

3.34: HB 3.35 Omitted

3.36 a) Explain both protons being more acidic than acetic acid

b) Explain all of the C-C bond in dianion are same length as well as all of the C-O bonds