Objective 4

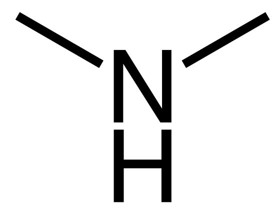
Intro to Reactivity 1: identify acids and bases using Lewis definition.
Use curved arrows to show how base reacts with acid.
Relate strength to pK_a.
Determine direction of equilibrium.
Use pK_a table to estimate pK_a of acid based on structure.

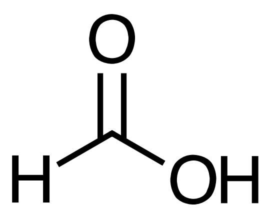
Many Organic compounds are acids or bases (or both)

Many Organic compounds undergo acid-base reactions

Acid-base (proton transfer) reactions are very fast

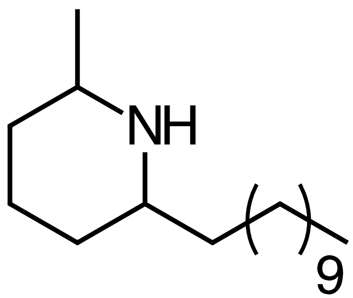
Dimethyl amine is a base and smells like dirty socks.
Neutralize with acid to get rid of smell.





Formic acid is in ant venom and stings when you are bitten by an ant. Use a base, e.g., baking soda, for relief.

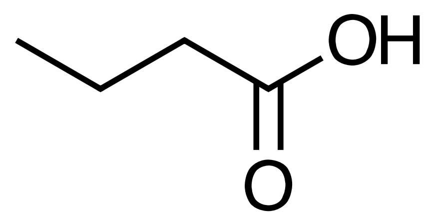
Many Organic compounds are acids or bases (or both)
Many Organic compounds undergo acid-base reactions

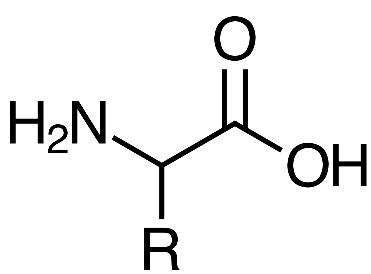


isosolenopsin A
fire ant venom

Tawny crazy ant uses formic acid as fire ant venom antidote
CEN, 3/3/14, p. 44

Butyric acid smells terrible.
Use a base to get rid of smell.

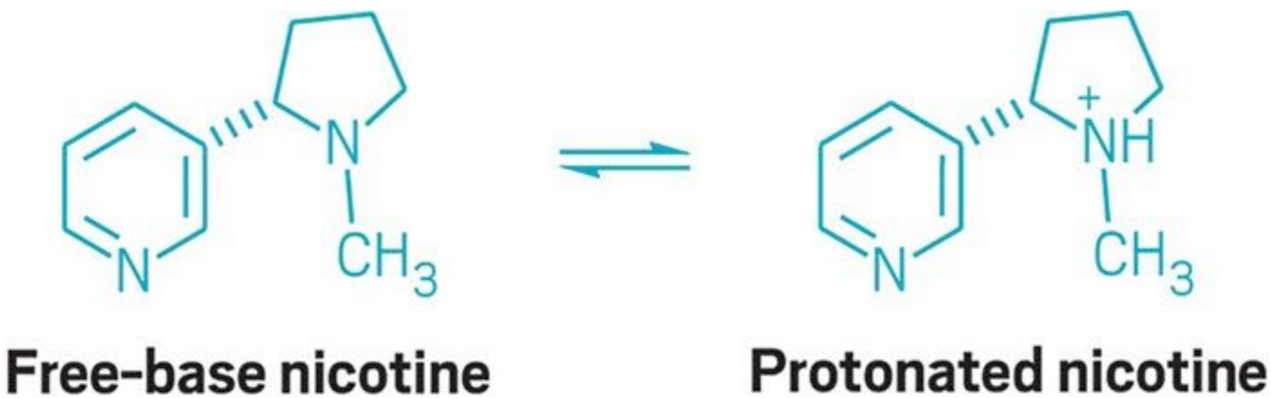




Amino acids change charge (and properties) depending on pH.

https://cen.acs.org/analytical-chemistry/spectroscopy/E-cigaretteschemistry-explain-popularity-among/96/i22

E-cigarettes, e.g., Juul – protonated nicotine is less harsh (more pleasant) than free-base nicotine (“scratchy, back-of-the-throat feeling”).



Many Organic compounds are acids or bases (or both)
Many Organic compounds undergo acid-base reactions
Acid-base (proton transfer) reactions are very fast

Application

Lab 2:

Do an acid-base extraction to separate a mixture:
You have a mixture of a weak acid and weaker acid.
Add a base that reacts with one acid but not the other
➔ Separate weak acid from weaker acid.

Acid-Base (H^+ Transfer) Reactions Are Very Common In Organic Chemistry

Bronsted-Lowry definition:

Acids are proton (H^+) donors ("*Givers*")
Bases are H^+ acceptors ("*Takers*")

Every acid has a partner (conjugate) base. (Remove acidic H)

HCl	+	H_2O	-->	H_3O^+	+	Cl^-
acid		base		conjugate acid of _____		conjugate base of _____

Lewis definition:

Acids are electron pair acceptors (electrophile)
Bases are electron pair donors (nucleophile)
Electron pairs ===> curved arrows

HCl is a **strong** acid

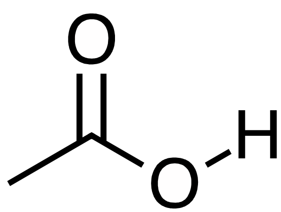
Organic acids are **weak** acids

Use K_a and pK_a to determine acid strength

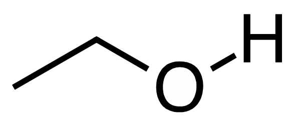
Generic Acid: HA <==> H^+ + A^-

$pK_a = - \log K_a$

$$K_a = \frac{[H^+][A^-]}{[HA]}$$



$pK_a = 4.8$



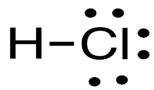
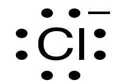
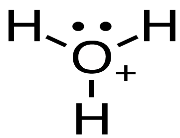
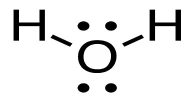
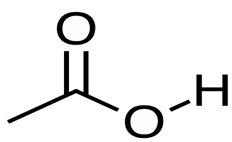
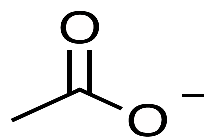
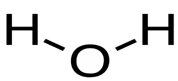
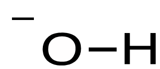
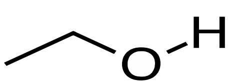
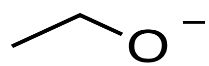
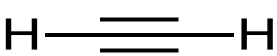
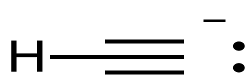
$pK_a = 16$

Which organic compound is the stronger acid? Give reasons.

Draw the conjugate base of each compound.

Which conjugate base is stronger? Give reasons.

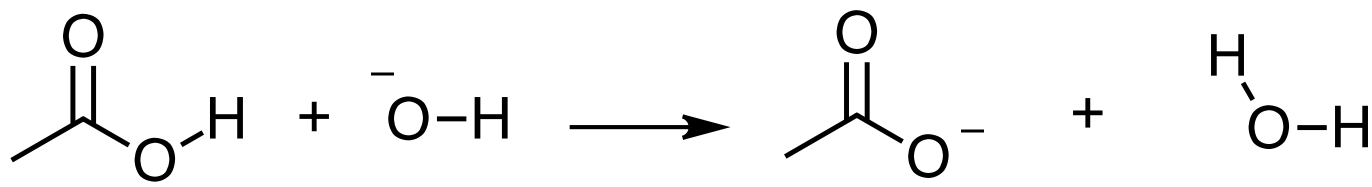
Table 3.1 pK_a of common compounds (Klein, p. 100)

acid	pK_a	base
	-7	
	-1.7	
	4.8	
	15.7	
	16	
	25	

1. Large pK_a ==> weak acid
2. Every acid has a partner (conjugate) base
3. Acids are listed from strongest to weakest
4. Bases are listed from weakest to strongest
5. Conjugate base of a weak acid is strong
6. Conjugate acid of weak base is strong
7. **PREDICT**: An acid reacts with any base <u>below</u> it ==> Need a ***Strong Base to react with a Weak Acid***

What Base Should I Use to React with an Acid?
(Or How to Determine the Position of Equilibrium)

Will CH_3COOH react with OH^-? YES



Acetic Acid $pK_a = 4.8$	hydroxide base	conjugate base of acetic acid	Conjugate Acid of hydroxide $pK_a = 15.7$

OH^- (base) is below CH_3COOH (acid) on the pK_a table.
OH^- is a strong enough base to react with CH_3COOH.
Reaction occurs:

Stronger acid (CH_3COOH) → weaker acid (H_2O)
Stronger base(OH^-) → weaker base (CH_3COO^-)

Position of the equilibrium? *More products*/less reactants

What Base Should I Use to React with an Acid?

(Or How to Determine the Position of Equilibrium)

Will CH_3OH (acid) react with CH_3COO^- (base)?

$$CH_3OH + CH_3COO^- \rightarrow CH_3O^- + CH_3COOH$$

pK_a of CH_3OH = ? pK_a of CH_3COOH = ?

CH_3OH is _(above/below)_ CH_3COO^- on the pK_a table.

Will there be more products or more reactants?

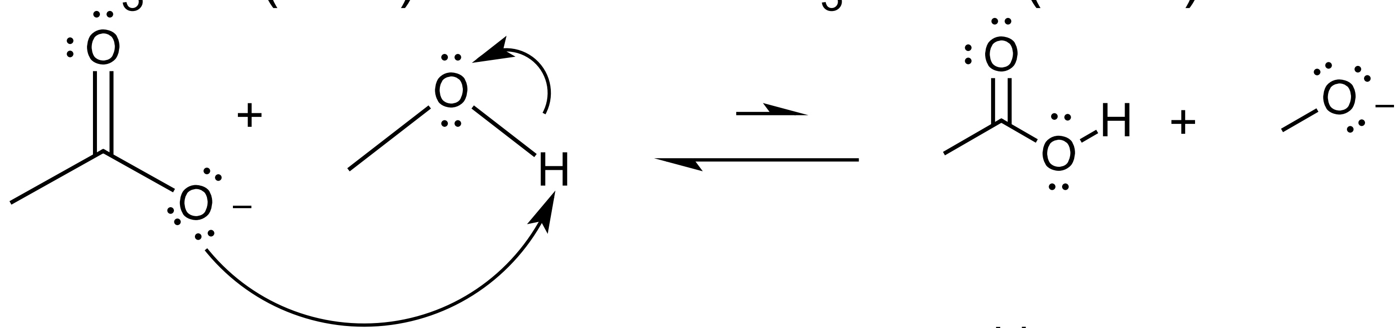
More products   More reactants

What is the position of the equilibrium?

More products   More reactants

What Base Should I Use to React with an Acid?
(Or How to Determine the Position of Equilibrium)

Will CH_3OH (acid) react with CH_3COO^- (base)?



base

acid
pK_a = 16
weaker acid

acid
pK_a = 4.8
stronger acid

base

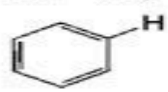
CH_3OH is *below* CH_3COO^- on the pK_a table.
CH_3COO^- is NOT a strong enough base to react with CH_3OH.

Will there be more products or more reactants?

What is the position of the equilibrium? More reactants

More practice: Klein, Problem 3.52

Table 6.3
Acidities of molecules and ions commonly encountered in organic chemistry.[a]

Acid	*Conjugate base*	pK_a
$HClO_4$	ClO_4^-	−10
HI	I^-	−10
$R-C(=\overset{+}{O}H)-H$	$R-C(=O)-H$	−10
H_2SO_4	HSO_4^-	−10
HBr	Br^-	−9
HCl	Cl^-	−7
$R-C(=\overset{+}{O}H)-R$	$R-C(=O)-R$	−7
$ArSO_3H$	$ArSO_3^-$	−6.5
$R-C(=\overset{+}{O}H)-OR'$	$R-C(=O)-OR'$	−6
$R-\overset{+}{O}(H)-R'$	$R-O-R'$	−3.5
$R-\overset{+}{O}(H)-H$	$R-O-H$	−2
H_3O^+	H_2O	−1.7
HNO_3	NO_3^-	−1.4
HSO_4^-	SO_4^{2-}	2
HF	F^-	3.1
$ArNH_3^+$	$ArNH_2$	4
RCOOH	$RCOO^-$	5
H_2CO_3	HCO_3^-	6.4
H_2S	HS^-	7
ArSH	ArS^-	7
$CH_3-C(=O)-CH(H)-C(=O)-CH_3$	$CH_3-C(=O)-\overset{-}{C}(H)-C(=O)-CH_3$	9
HCN	CN^-	9.2
NH_4^+	NH_3	9.2
ArOH	ArO^-	10
$R-CH_2NO_2$	$R-\overset{-}{C}H-NO_2$	10
RNH_3^+	RNH_2	11
RSH	RS^-	11
$CH_3-C(=O)-CH(H)-C(=O)-OR$	$CH_3-C(=O)-\overset{-}{C}(H)-C(=O)-OR$	11
CH_3OH	CH_3O^-	15.2
H_2O	HO^-	15.7
RCH_2OH	RCH_2O^-	16
R_2CH-OH	R_2CH-O^-	17
R_3C-OH	R_3C-O^-	17
$R-C(=O)-NH_2$	$R-C(=O)-NH^-$	17
$R-C(=O)-CH_3$	$R-C(=O)-CH_2^-$	20
$RO-C(=O)-CH_3$	$RO-C(=O)-CH_2^-$	24
$R-CH_2CN$	$R-\overset{-}{C}H-CN$	25
$H-C\equiv C-H$	$H-C\equiv C^-$	25
H_2	H^-	35
NH_3	NH_2^-	38
$Ph-CH_3$	$Ph-CH_2^-$	40
		43
$CH_2=CH_2$	$CH_2=CH^-$	44
CH_4	CH_3^-	48

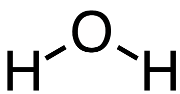
[a] pK_a values from J. March, *Advanced Organic Chemistry*, 4th ed., John Wiley & Sons, New York, 1992, pp. 250–252.
Abbreviations: Ar = aryl; Ph = phenyl; R = alkyl.

http://classes.uleth.ca/200603/chem2500a/sorrtd.pka.jpg

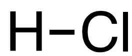
Acids and Bases

Objective: determine relative acid strength

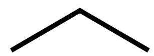
a. Rank the following compounds in order of acid strength.



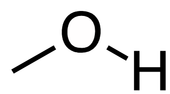
1



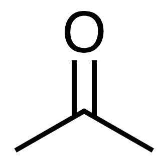
2



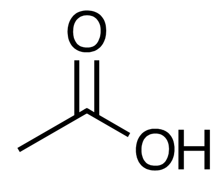
3



4



5

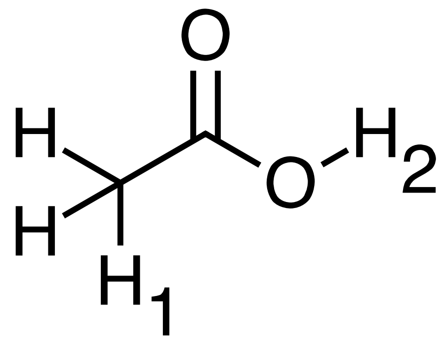


6

Rank each number in sequence from strongest to weakest.

b. Which of the above compound(s) behave like a base?

Acetic acid is an acid with 4 H's. Which H is acidic?
See pK_a table.



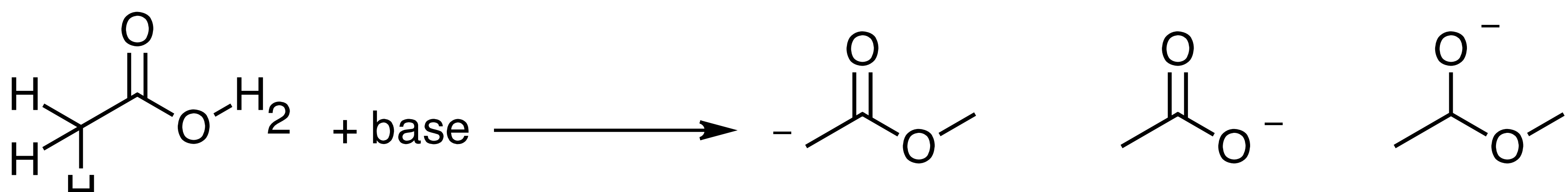
pK_a of H_1 ≈

pK_a of H_2 ≈

Acids and Bases

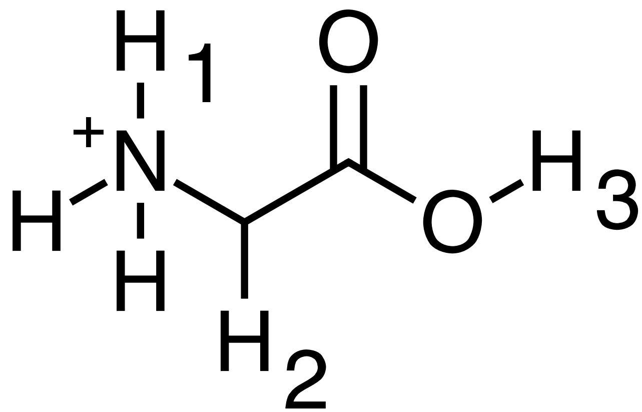
Objective: determine the conjugate base of an acid.

What is the conjugate base of CH_3COOH?



A B C

Amino acids have at least 2 acidic H's.
Which H is the most acidic, H_1 or H_2 or H_3?
Use pK_a table to estimate acid strength.

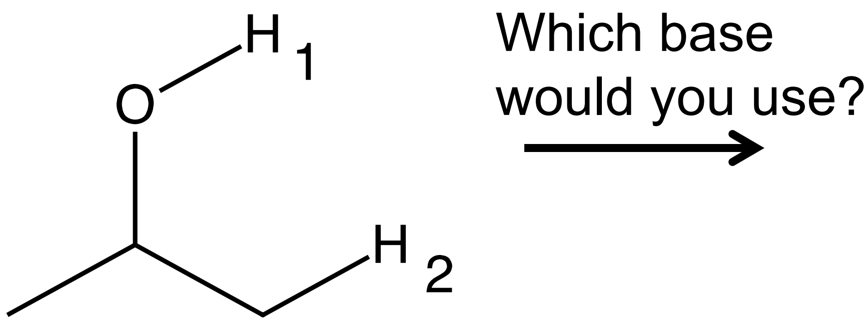


pK_a of $H_1 \approx$

pK_a of $H_2 \approx$

pK_a of $H_3 \approx$

Rubbing alcohol reacts with a base. Which H reacts?
In other words, which H is more acidic, H_1 or H_2?
Use pK_a table to estimate acid strength.



Draw the product.

pK_a of $H_1 \approx$

pK_a of $H_2 \approx$

1. For a strong acid, K_a is big and pK_a is ____.

For a weak acid, K_a is ________ and pK_a is big.

2. a. Rank the following acids in order of strength:

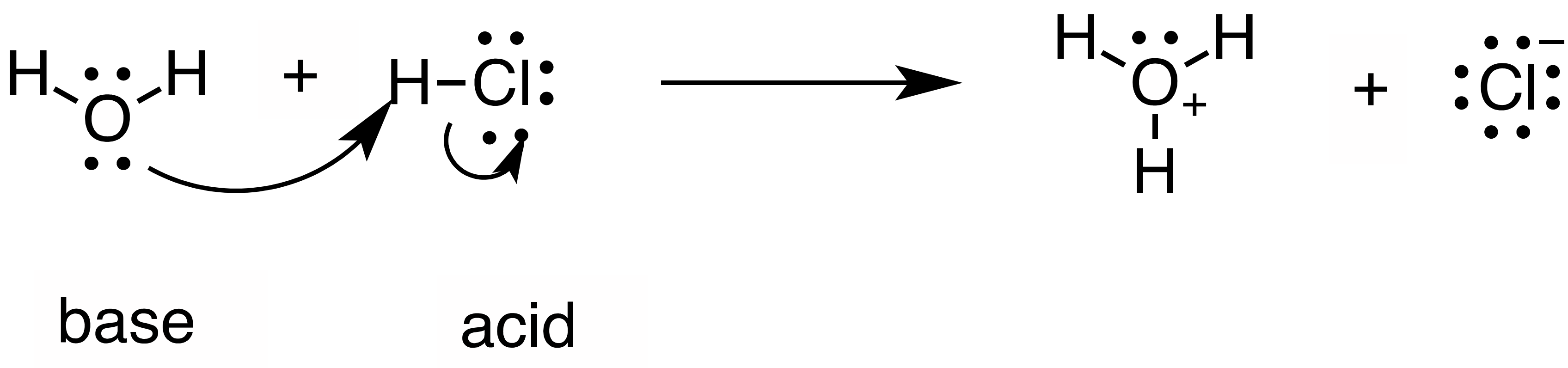
HCl, H_2O, acetic acid, ethanol, ethane, ethylene.

b. Which acid in part a reacts with ammonia (pK_a of NH_4^+ = 9.3)?

c. Is the conjugate base of a strong acid strong or weak?

Curved Arrows show Bonds Breaking and Forming

Start (arrow tail) at electron pair donor/Lewis base/
NUCLEOPHILE
and
End (arrow head) at electron pair acceptor/Lewis acid/
ELECTROPHILE



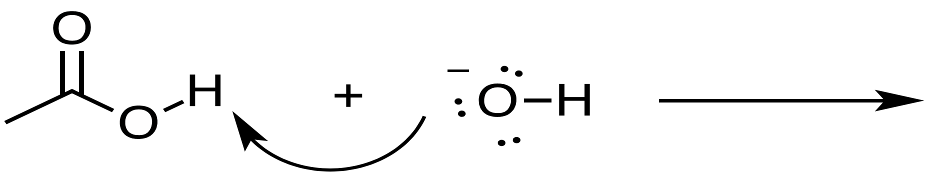
1. Lone pair on O forms σ bond to H
2. Too many bonds on H so H-Cl σ bond breaks to form lone pair on Cl

Acids and Bases

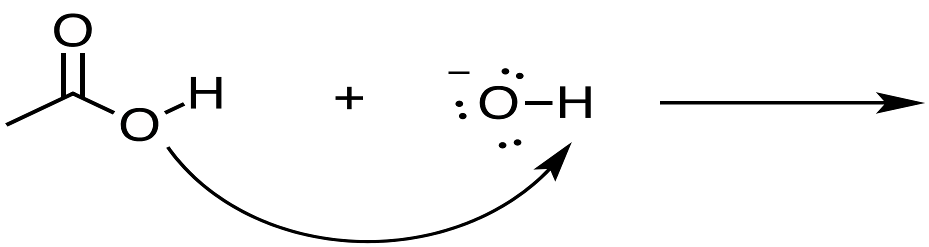
Objective: use curved arrows to show bonds breaking and forming in a reaction.

CH_3COOH reacts with OH^- to form CH_3COO^- and H_2O. Which curved arrow shows this reaction? Then, draw the products of the reaction.

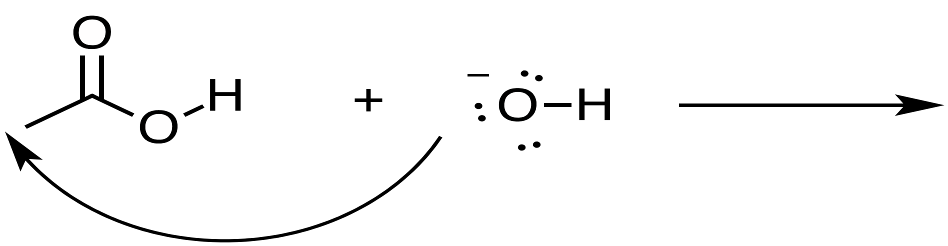
A



B

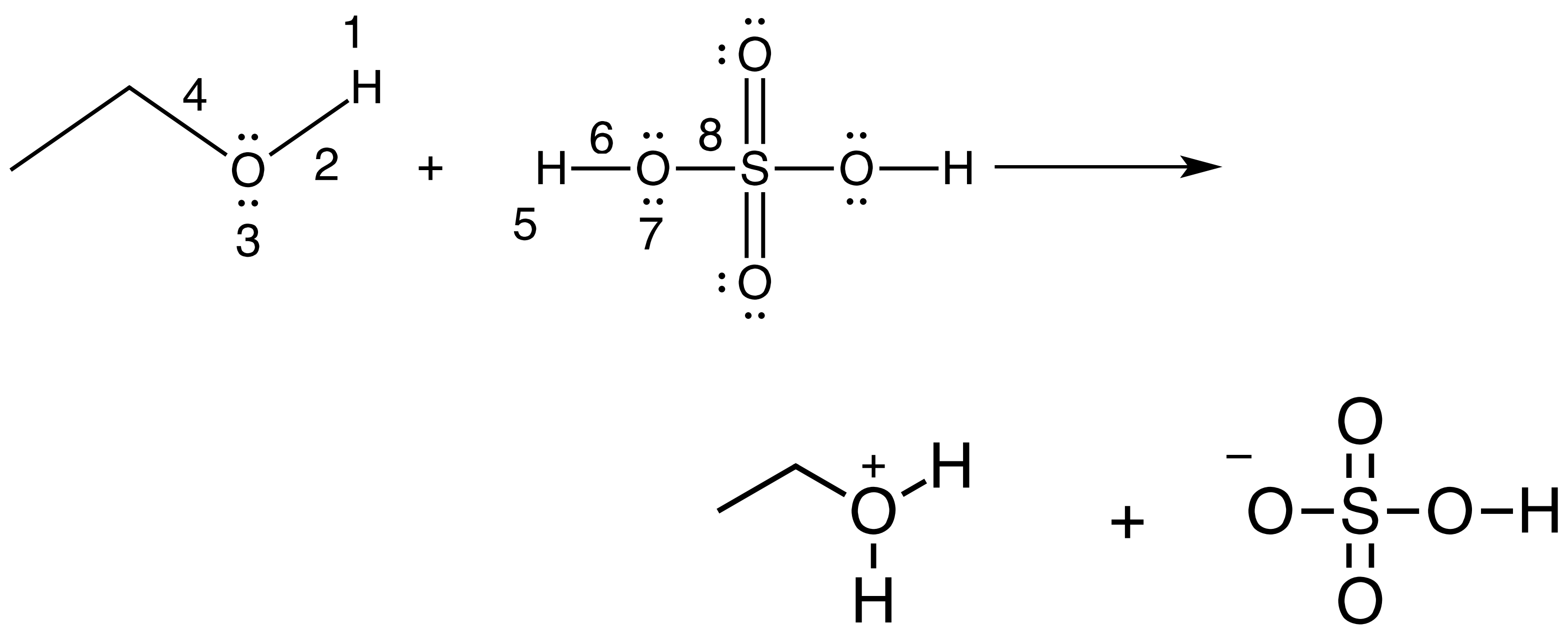


C



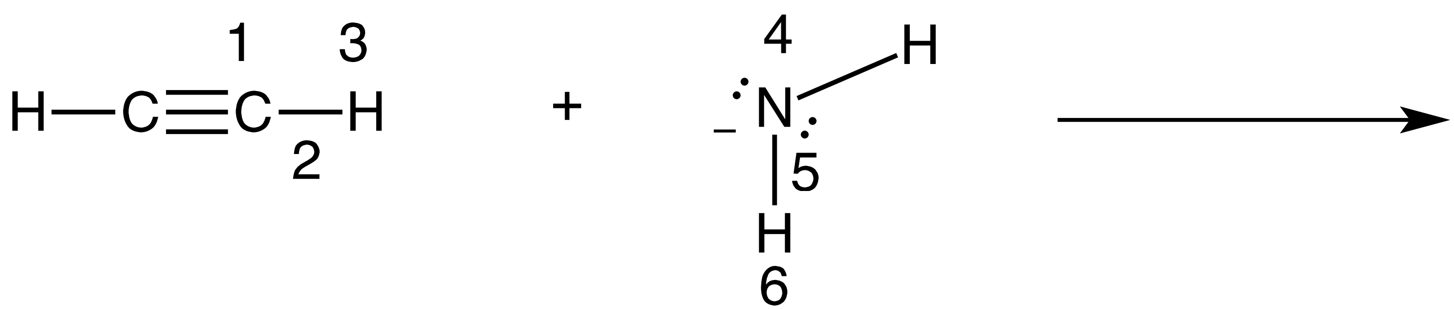
Objective: use curved arrows to show bonds breaking and forming in a reaction
Draw the product(s) of the following reaction.

Use numbers to represent curved arrows to show bonds breaking and forming.



Objective: use curved arrows to show bonds breaking and forming in a reaction
Draw the product(s) of the following reaction.

Use numbers to represent curved arrows to show bonds breaking and forming.

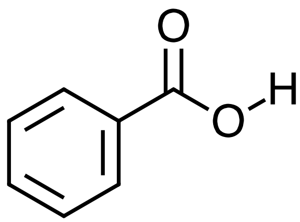


More practice: Klein, Problem 3.44

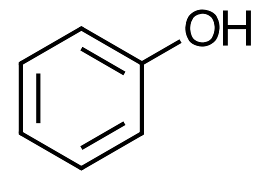
Application of Acids, Bases, pK_a

Lab 2: Use Acid-base Reaction to Separate an Acid-Base Mixture

Flow Chart



"acid"
benzoic acid
pK_a = 4.2



"base"
phenol
pK_a = 10

Acid-base mixture in ether

↓ Add $NaHCO_3$ (aq)
Conj. Acid = H_2CO_3
pK_a = 6

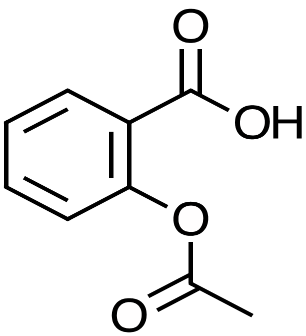
Benzoic acid reacts with $NaHCO_3$ but phenol does not.

↓

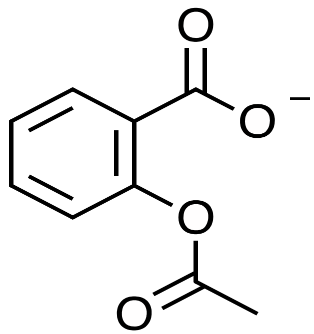
Benzoate ion (aq) ← → Phenol in ether

Ether and water are immiscible.
How do you convert benzoate back to benzoic acid?

<u>Application</u>: Use pK_a To Predict Charge at a Specific pH (see Lab 2)



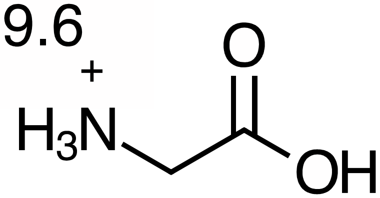
aspirin (acid)
$pK_a = 3$
charge = 0



conjugate base
of aspirin
charge = -1

In stomach (pH 2), aspirin charge = ________
In blood (pH 7.4), aspirin charge = ________

$pK_a = 9.6$



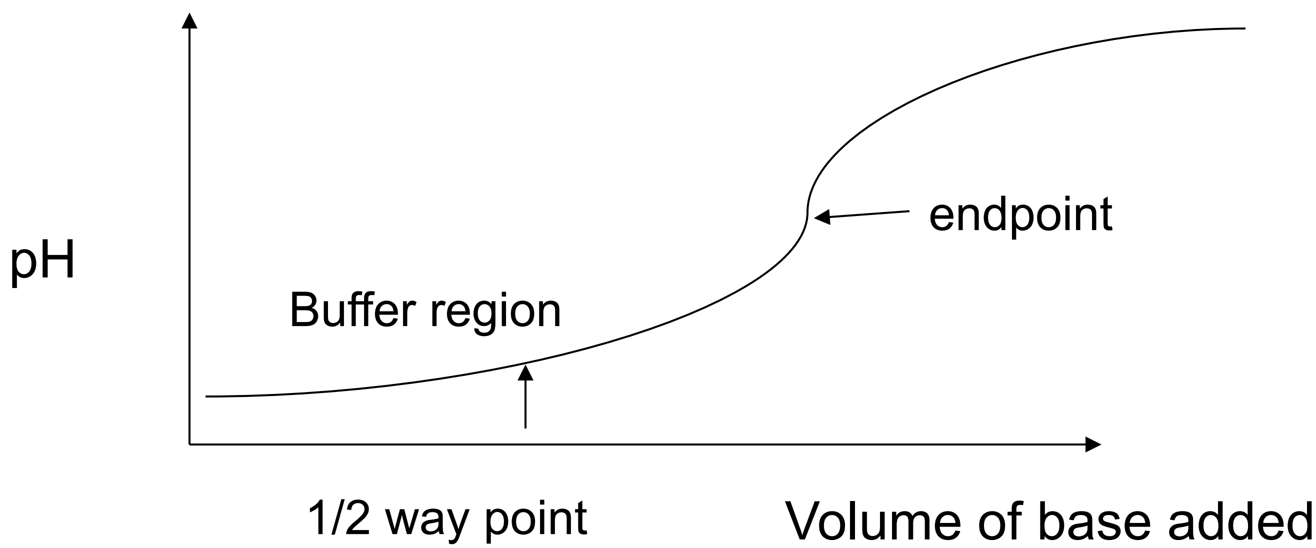
$pK_a = 2.3$

glycine charges = +1, 0, -1 depending on pH

In stomach (pH 2), glycine charge = ________
In blood (pH 7.4), glycine charge = ________

Application: Use pK_a To Predict Charge at a Specific pH

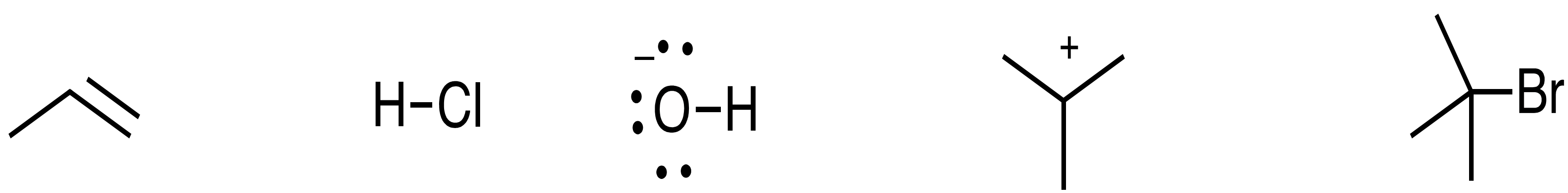
At pH = pK_a ====> equal [ ] of acid and conjugate base
At pH > pK_a ====> more conjugate base than acid
At pH < pK_a ====> more acid than conjugate base



Lewis base	***Lewis acid***
Electron pair donor	Electron pair acceptor, e.g., H^+
(-) charge	(+) charge
(-) pole (δ-)	(+) pole (δ+)
Nucleophile ($Nu:^-$)	**Electrophile** (E^+)
Electron Source	Electron Sink
Lone pair, e.g., OH^-	Electron deficient species
π bond	Less EN atom in polar bond

"Curved arrow" starts at e^- pair donor and ends at e^- pair acceptor.

Identify each compound as a Lewis acid or Lewis base.



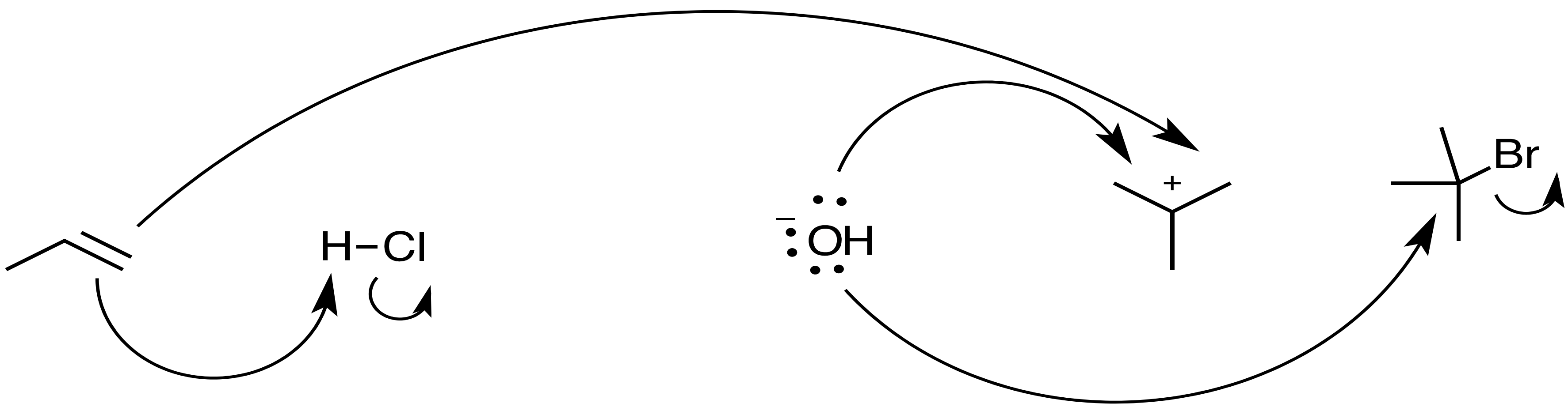
A B C D E

Lewis acids (*Electrophiles*): HCl, $(CH_3)_3C^+$, C bonded to Br
Lewis bases (*Nucleophiles*): pi bond, OH^- lone pair

Use curved arrows to show bonds breaking and forming ==> show how reactants form products. Follow Bonding and Structure Rules.

Curved arrow starts at Nucleophile and ends at Electrophile.

Draw the product of each reaction (4 total).



More practice: Klein, Problem 3.39