

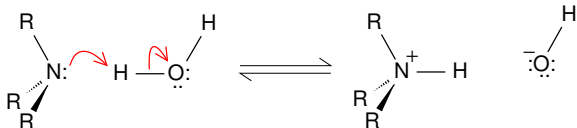
Chemistry 2000 Slide Set 20: Organic bases

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Organic bases

- Other than the conjugate bases of organic acids, the only significant group of organic bases are compounds containing nitrogen atoms, mainly amines, although some others (e.g. imines, compounds that contain a carbon-nitrogen double bond) can also be reasonably strong bases.
- Amines are analogs of ammonia, i.e. they are Lewis bases due to the lone pair on the nitrogen atom:



Strength of bases

- As with acids, it's convenient to have a quantitative measure of the strength of a base.
- Two measures are commonly used:

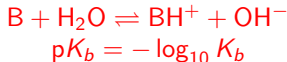
- 1 The pK_a of the conjugate acid
Weaker conjugate acid \Rightarrow stronger base

Example:

Acid	NH_4^+	CH_3NH_3^+
pK_a	9.3	10.6

CH_3NH_3^+ is a weaker acid than ammonium, so
 CH_3NH_2 is a stronger base than ammonia.

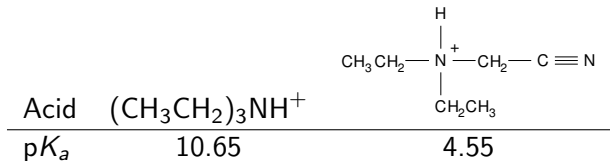
- 2 K_b , the base ionization constant, is the equilibrium constant for the reaction of the base with water:



Larger $K_b \Rightarrow$ smaller $pK_b \Rightarrow$ stronger base

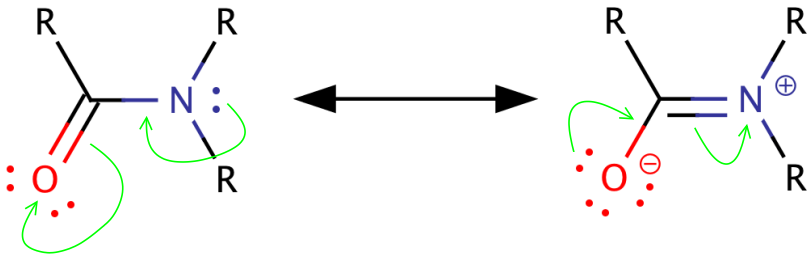
Inductive effects

- Now consider the following pair of compounds:



- This large difference in $\text{p}K_a$ of the conjugate acids of these amines arises because of an inductive effect.
- The highly electronegative nitrogen in the nitrile group withdraws electrons from its carbon atom, leaving the latter with a partial positive charge.
- The proximity of this positive charge to the dissociable proton of the amine destabilizes this proton (by simple repulsion), making it more acidic.

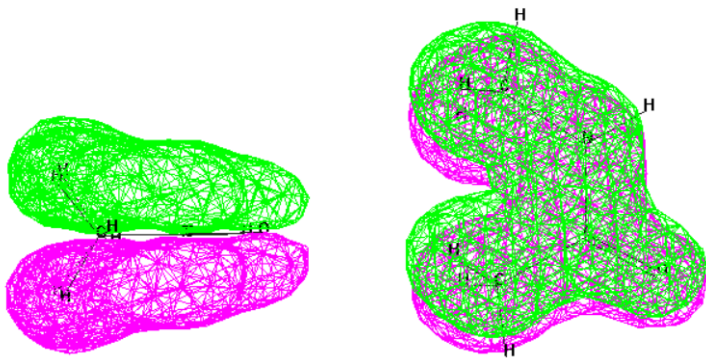
Amides



- Delocalization of the lone pair makes amides extremely poor bases.
- It also makes the amide flat at the N atom.

Amides

Bonding " π " orbital responsible for planarity:

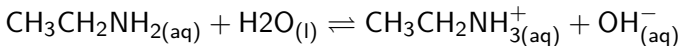


Bases and pH

- Given $(p)K_b$, we can calculate the pH of a solution containing the base.
- One catch: We need a_{H^+} to calculate pH, which we don't get directly from a calculation involving K_b .
- Use $K_w = (a_{H^+})(a_{OH^-})$.

Example: pH of solution containing a weak base

- Calculate the pH of a 0.045 M solution of ethanamine ($\text{CH}_3\text{CH}_2\text{NH}_2$).
 $\text{p}K_b = 3.37$ at 25°C
- As usual, start with the reaction and equilibrium expression:

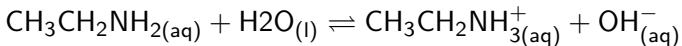


$$K_b = \frac{(a_{\text{BH}^+})(a_{\text{OH}^-})}{a_{\text{B}}}$$

- $K_b = 10^{-\text{p}K_b} = 10^{-3.37} = 4.3 \times 10^{-4}$

Example: pH of solution containing a weak base

(continued)



$$K_b = 4.3 \times 10^{-4}$$

- $[\text{B}] = 0.045 \text{ M} \gg K_b$
- We should be able to treat the base as mostly unreacted, i.e. $a_{\text{B}} \approx 0.045$.
(The same reasoning applies to K_b problems as to K_a problems.)
- As usual, we ignore water autoionization in solving the equilibrium problem, as it is almost always negligible.
- Thus, $a_{\text{BH}^+} = a_{\text{OH}^-}$.

Example: pH of solution containing a weak base

(continued)

- Putting it all together, we have

$$K_b = 4.3 \times 10^{-4} = \frac{(a_{\text{BH}^+})(a_{\text{OH}^-})}{a_{\text{B}}} \approx \frac{(a_{\text{OH}^-})^2}{0.045}$$

$$\therefore a_{\text{OH}^-} = 4.4 \times 10^{-3}$$

- To get a pH, we have to use the water autoionization equilibrium:

$$K_w = (a_{\text{H}^+})(a_{\text{OH}^-})$$

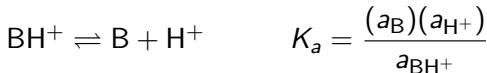
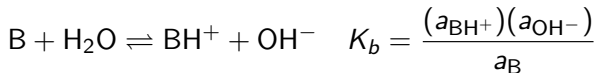
$$\therefore a_{\text{H}^+} = \frac{K_w}{a_{\text{OH}^-}} = \frac{1.0 \times 10^{-14}}{4.4 \times 10^{-3}} = 2.3 \times 10^{-12}$$

$$\therefore \text{pH} = -\log_{10} a_{\text{H}^+} = 11.64$$

- A more precise calculation using an ICE table gives 11.62, a negligible difference.

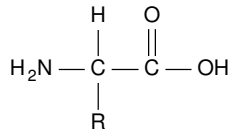
K_b and K_a

- We have already mentioned that weaker bases have stronger conjugate acids and vice versa.
- Consider the base ionization and acid dissociation equilibria for a base and its conjugate acid:



$$\therefore K_a K_b = \frac{\cancel{(a_{\text{B}})}(a_{\text{H}^+})}{\cancel{a_{\text{BH}^+}}} \frac{\cancel{(a_{\text{BH}^+})}(a_{\text{OH}^-})}{\cancel{a_{\text{B}}}} = K_w$$

Amino acids in aqueous solution



- Amino acids include both a carboxylic acid functional group and a basic amine functional group.
- Due to inductive effects, the two functional groups in an amino acid have slightly different pK_a s than is typical for these functional groups.
- Carboxylic acids typically have pK_a s of between 3 and 5. In an amino acid, the pK_a is around 2.
- The pK_a of an alkyl ammonium ion is usually between 10 and 11.
In most amino acids, the pK_a of the conjugate acid of the amine is between 9 and 10.

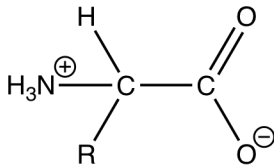
Exercise: Sketch the distribution curves for a typical amino acid.

$$pK_a(-\text{COOH}) \approx 2,$$

$$pK_a(-\text{NH}_3^+) \approx 9.5$$

Hint: Start at low pH. What is protonated at very low pH? Then think about the sequence of deprotonations as we decrease the pH.

Zwitterion

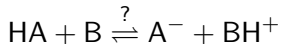


- Zero charge, but ionized groups with opposite charges in different parts of the molecule: **zwitterion**

Reactions between acids and bases

- Suppose that we put an acid HA and a base B in solution together.

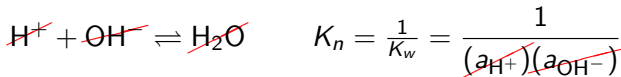
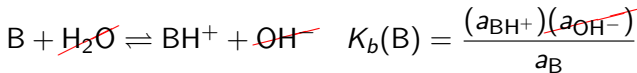
Will a reaction occur?



Approach: Let's look at K for this reaction.

If K is large, then the equilibrium mixture will contain a lot of the products.

If it's small, then the reaction will only occur to a negligible extent.

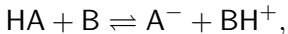


$$\therefore K = K_a(\text{HA}) K_b(\text{B}) / K_w$$

- Recall that $K_a(\text{HA}) = K_w / K_b(\text{A}^-)$.

$$\therefore K = K_b(\text{B}) / K_b(\text{A}^-)$$

Recap: For the reaction



$$K = K_b(\text{B})/K_b(\text{A}^-)$$

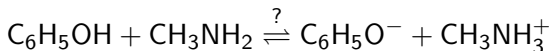
Conclusion: K is large if B is a much stronger base than A^- .

Equivalently: K is large if HA is a much stronger acid than BH^+ .

In yet other words: Equilibrium favors the direction that makes the weaker acid/base pair.

Example: Reaction of phenol with methanamine

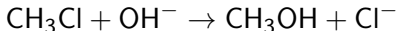
- Is the following reaction product-favored or reactant-favored?



Acid	$\text{C}_6\text{H}_5\text{OH}$	CH_3NH_3^+
$\text{p}K_a$	9.95	10.6

Nucleophilic substitution reactions and strength of bases

- Consider the substitution reaction



- Although it doesn't look like an acid-base reaction, it does involve a nucleophile (or Lewis base), OH^- .
- The principle is the same as for more obvious acid-base reactions: **equilibrium favors** the side with **the weaker base**.

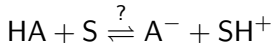
Nucleophilic substitution reactions and strength of bases

Which of the following substitution reactions would you predict to occur?

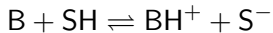
- $\text{CH}_3\text{Cl} + \text{F}^- \rightarrow \text{CH}_3\text{F} + \text{Cl}^-$
- $\text{CH}_3\text{Cl} + \text{Br}^- \rightarrow \text{CH}_3\text{Br} + \text{Cl}^-$
- $\text{CH}_3\text{CN} + \text{F}^- \rightarrow \text{CH}_3\text{F} + \text{CN}^-$
 $\text{p}K_a(\text{HCN}) = 9.4, \text{p}K_a(\text{HF}) = 3.2$

Solvent leveling

- We can apply the principle developed above to talk about what acids and bases can exist in a solvent.
- Consider an acid in a solvent S:



- This reaction will occur (i.e. the acid HA can't exist in its protonated form) if HA is a stronger acid than SH^+ , the conjugate acid of the solvent.
- Similarly, for a base B and a protic solvent SH, the reaction



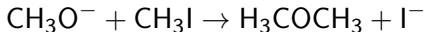
will occur if B is a stronger base than S^- .

Conclusions:

- 1 The strongest acid that can exist in a solvent is the conjugate acid of the solvent.
 - 2 The strongest base that can exist in a solvent is the conjugate base of the solvent.
- These effects are collectively known as **solvent leveling**.

Application: Making methoxymethane

- Methoxide (CH_3O^-) is the conjugate base of methanol.
- If we react sodium methoxide (CH_3ONa) with CH_3I in an appropriate solvent, the following reaction should occur:

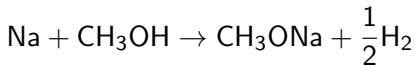


- Why do we expect this reaction to occur?
- Why won't this work in water?
- Which of the following solvents could we use instead of water (assuming that the reactants are soluble)?
 - methanol ($\text{p}K_a = 15.5$)
 - ethanol ($\text{p}K_a = 15.9$)
 - phenol
 - ethoxyethane ($\text{CH}_3\text{CH}_2\text{OCH}_2\text{CH}_3$)

Application: Making sodium methoxide

■ How could we make sodium methoxide?

Option 1: We can make sodium hydroxide by reacting sodium with water. Analogously, we can make sodium methoxide by the reaction of sodium with methanol:



Option 2: Find a base stronger than methoxide, throw it into methanol, and let solvent leveling do the work.
Example: The hydride ion

