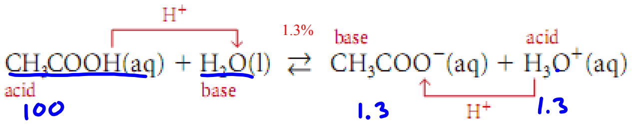
Part 2: Predicting Bronsted - Lowry Reactions

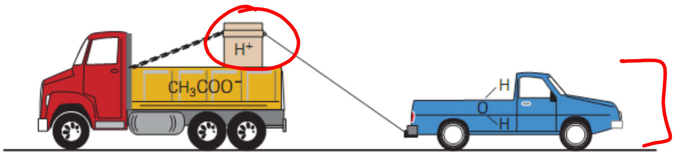
Strength of Acids and Bases



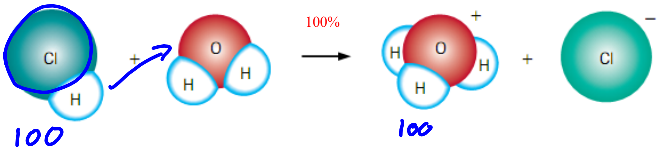
$$CH_3COOH(aq) + H_2O(l) \rightleftarrows CH_3COO^-(aq) + H_3O^+(aq)$$

- At equilibrium, only 1.3% of the CH_3COOH molecules have reacted with water

- This implies that the ability of the CH_3COO-$^-$ part of the acetic acid molecule to keep its proton (H^+) is much greater than the ability of H_2O to attract the proton away



- This means that CH_3COO^- is a stronger base (it has a greater attraction for protons) than H_2O.



- When HCl molecules react with water, the Cl^- of each HCl molecule has a much weaker attraction for its proton (H^+) than any colliding water molecule has

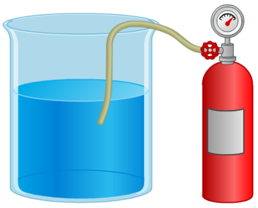
- The water molecules “win” this “competition” for protons overwhelmingly

- At equilibrium, essentially all of the HCl molecules have lost protons to water molecules

Remember:
- The stronger the base, the more it attracts another proton.

- The stronger an acid, the less it attracts its own proton.

http://www.mhhe.com/physsci/chemistry/essentialchemistry/flash/acid13.swf

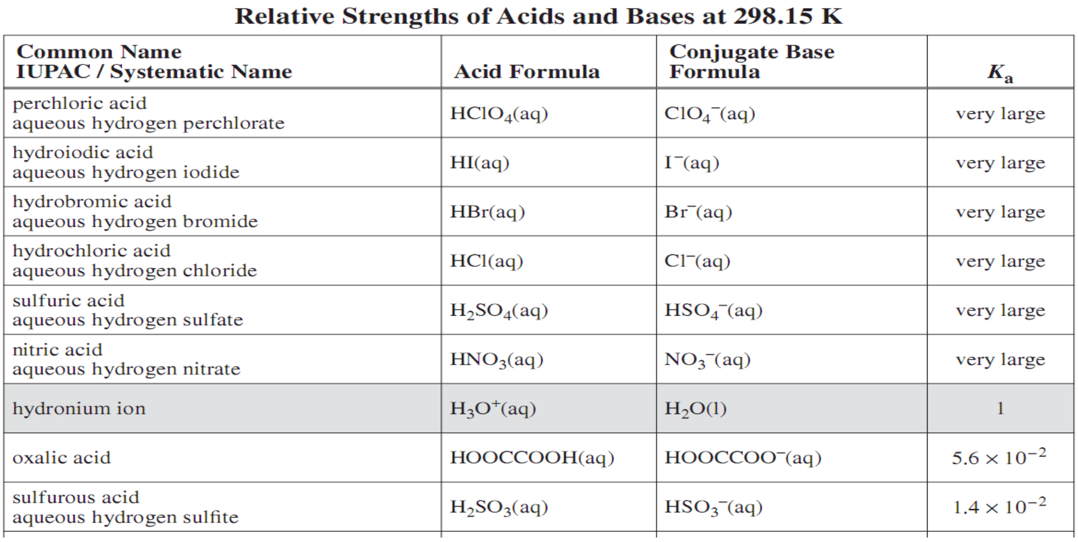


Hydrochloric Acid Hydrofluoric Acid

Table of Relative Strengths of Acids and Bases

- Different Acids and Bases have been compared to each other and ranked.

- The table on pg 8-9 of your data booklet ranks acids from strongest to weakest and bases from weakest to strongest



Relative Strengths of Acids and Bases at 298.15 K

Common Name IUPAC / Systematic Name	Acid Formula	Conjugate Base Formula	K_a
perchloric acid aqueous hydrogen perchlorate	$HClO_4(aq)$	$ClO_4^-(aq)$	very large
hydroiodic acid aqueous hydrogen iodide	$HI(aq)$	$I^-(aq)$	very large
hydrobromic acid aqueous hydrogen bromide	$HBr(aq)$	$Br^-(aq)$	very large
hydrochloric acid aqueous hydrogen chloride	$HCl(aq)$	$Cl^-(aq)$	very large
sulfuric acid aqueous hydrogen sulfate	$H_2SO_4(aq)$	$HSO_4^-(aq)$	very large
nitric acid aqueous hydrogen nitrate	$HNO_3(aq)$	$NO_3^-(aq)$	very large
hydronium ion	$H_3O^+(aq)$	$H_2O(l)$	1
oxalic acid	HOOCCOOH(aq)	HOOCCOO⁻(aq)	5.6×10^{-2}
sulfurous acid aqueous hydrogen sulfite	$H_2SO_3(aq)$	$HSO_3^-(aq)$	1.4×10^{-2}

- This table is built based on empirical evidence

- This table allows us to predict the position of an equilibrium in a reaction between an acid and a base

$$H_3PO_4(aq) + NH_3(aq) \overset{>50\%}{\rightleftarrows} H_2PO_4^-(aq) + NH_4^+(aq) \qquad K_c: >1$$

Does this equilibrium favor the reactants or the products??

A

B

$\overset{>50\%}{\rightleftarrows}$ Favors prod. $k_c > 1$

B

A

$\overset{<50\%}{\rightleftarrows}$ favors react. $k_c < 1$

H_3O^+ or OH^- $\rightarrow$

$\overset{>99.9\%}{\rightleftarrows}$ k_c = huge number

Predicting the position of equilibrium in an acid-base reaction

- According to the Brønsted–Lowry concept, a proton will only transfer if an acid entity collides with a base entity that is a better proton attractor than itself

- The Bronsted-Lowry theory suggests that the predominant acid–base reaction should be the one that involves proton transfer **from the strongest acid to the strongest base present** in the system

Steps to Predicting and Acid-Base reaction

Step 1: List all entities present as they exist in aqueous solution.

- Ionic compounds dissociate
- Weak acids don't ionize
- Strong acids from the hydronium ion and a conjugate base ~~HNO_3~~ H_3O^+ NO_3^-

Step 2: Use the entity lists of the Relative Strengths of Aqueous Acids and Bases table to identify and label each entity present as a Brønsted–Lowry acid or base.

- Amphiprotic entities are labelled for both possibilities.
- ~~Conjugate bases of strong acids are not included or labelled as bases because they cannot act as bases in aqueous solution.~~
- Metal ions are treated as spectators

Step 3: Use the order of the entities in the Relative Strengths of Aqueous Acids and Bases table to identify and label the strongest Brønsted–Lowry acid (the highest one on the table) and the strongest Brønsted–Lowry base (the lowest one on the table) that are present in the solution.

Step 4: Write a balanced equation to show a proton transfer from the strongest acid to the strongest base

Step 5: Predict the position of equilibrium

Products Favoured

$$SA + SB \overset{>50\%}{\rightleftarrows}$$

Reactants Favoured

$$SB + SA \overset{<50\%}{\rightleftarrows}$$

Examples:

1. Ammonium nitrate fertilizer is produced by the quantitative reaction of aqueous ammonia with nitric acid. Write a balanced acid–base equilibrium equation.

$\underset{SB}{NH_{3(aq)}} \quad \overset{SA}{H_3O^+_{(aq)}} \quad \underset{B}{NO^-_{3(aq)}} \quad \underset{B}{\overset{A}{H_2O_{(l)}}}$ ✓

$NH_{3(aq)} + H_3O^+_{(aq)} \rightarrow H_2O_{(l)} + NH^+_{4(aq)}$

2. Hydrofluoric acid and an aqueous solution of sodium sulfate are mixed

$\overset{SA}{HF_{(aq)}} \quad Na^+_{(aq)} \quad \underset{SB}{SO^{2-}_{4(aq)}} \quad \underset{B}{\overset{A}{H_2O_{(l)}}}$

$HF_{(aq)} + SO^{2-}_{4(aq)} \overset{<50\%}{\rightleftharpoons} F^-_{(aq)} + HSO^-_{4(aq)}$

3. Methanoic acid is added to an aqueous solution of sodium hydrogen sulfide

$\overset{SA}{HCOOH_{(aq)}} \quad Na^+_{(aq)} \quad \underset{SB}{\overset{A}{HS^-_{(aq)}}} \quad \underset{B}{\overset{A}{H_2O_{(l)}}}$

$HCOOH_{(aq)} + HS^-_{(aq)} \overset{>50\%}{\rightleftharpoons} HCOO^-_{(aq)} + H_2S_{(aq)}$

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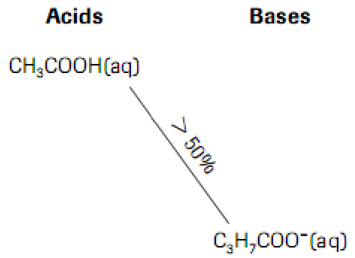
LAB EXERCISE 16.D

Creating an Acid–Base Table

Complete the Analysis of the investigation report, including a short table of the four acids and bases involved. Use entity position generalizations in the acid–base table for reactions that favour products or reactants. The evidence for reaction 1 is interpreted as:



Purpose

The purpose of this investigation is to test an experimental design for using equilibrium position to create a table of relative strengths of acids and bases.

Report Checklist

○ Purpose
○ Problem
○ Hypothesis
○ Prediction
○ Design
○ Materials
○ Procedure
○ Evidence
● Analysis
○ Evaluation

Problem

What is the order of acid strength for the first four members of the carboxylic acid family?

Evidence

$$CH_3COOH(aq) + C_3H_7COO^-(aq) \overset{>50\%}{\rightleftharpoons} CH_3COO^-(aq) + C_3H_7COOH(aq)$$

$$HCOOH(aq) + CH_3COO^-(aq) \overset{>50\%}{\rightleftharpoons} HCOO^-(aq) + CH_3COOH(aq)$$

$$C_2H_5COOH(aq) + C_3H_7COO^-(aq) \overset{<50\%}{\rightleftharpoons} C_2H_5COO^-(aq) + C_3H_7COOH(aq)$$

$$C_2H_5COOH(aq) + HCOO^-(aq) \overset{<50\%}{\rightleftharpoons} C_2H_5COO^-(aq) + HCOOH(aq)$$