

The Strong Acid/Strong Base Equilibrium Calculation

After an entire lecture on water with nothing added, you must be pumped to know that in this lecture something will actually be added to water—a strong acid or a strong base. By the end of lecture you will be able to calculate the pH of such a solution.

But first, some review and overview and a few time outs for background:

- We were able to use the RICE expression to determine the pH for the autodissociation of water



- We are about to learn that a couple of equally simple equations will provide estimates of pH or pOH for two categories of compounds—and derivations for these equations will follow easily from the RICE equation as will be shown

Strong acids or bases in water: $[\text{H}^+] = C_a$ for strong acids and $[\text{OH}^-] = C_b$ for strong bases

Weak acids or bases in water: $[\text{H}^+] = (K_a C_a)^{0.5}$ for weak acids and $[\text{OH}^-] = C_b$ for strong bases

Time out 1. Memorizing the strong acids and bases.

Like it or not, sometimes it is just easier to commit really important stuff to memory. Like the seven strong acids and the strong bases. Knowing these makes so many things better, like being able to know what stuff is a strong or weak acid or base, or being able to identify spectator ions. So like or not, learn the following at once or prepare to fail the course:

1. Strong acids : HCl, HBr, HI, HClO₄, HClO₃, H₂SO₄ and HNO₃ all dissociate completely
2. Strong bases : OH⁻ of alkali and earth metals LiOH, NaOH, CsOH, KOH, Ba(OH)₂, Ca(OH)₂ all dissociate completely

Timeout 2. Electrolytes in solution

Notice that we paid a great deal of attention to the concentration of two charged ions, H^+ and OH^- , when looking at water. In fact, we will be looking almost exclusively at charged ions in water during this section. Charged ions typically come from salts:

- Salt into water $\rightarrow$ cation (positively charged species) and anion (negatively charged species) with the most common examples coming from inorganic materials like NaCl or $Ca_3(PO_4)_2$
- But acids and bases, which form protons and hydroxides, also produce electrolytes with common examples being HCl, NaOH, $NaC_2H_3O_2$ and $HC_2H_3O_2$

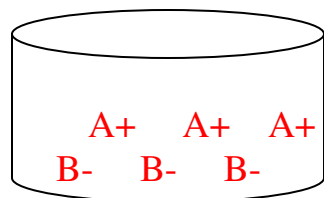
One of the easiest ways to classify electrolytes is by the extent to which they dissociate in water to make ions. There are three general categories

“strong” electrolytes dissociate completely

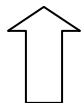
“weak” electrolytes dissociate a little

“non” electrolytes don’t dissociate at all

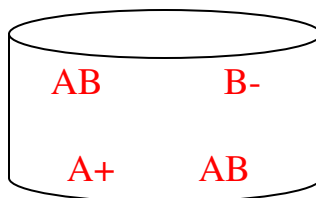
By the way, I love to make simple pictures to show off the important chemical features of a system. Prepare yourself to see how I show these different categories of electrolytes generally.

Examples of Strong

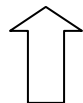
Strong acids: HCl
Strong bases: NaOH
Soluble salts: NaCl



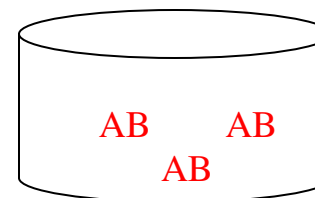
We look at these today

Weak

Weak acids: acetic
Weak bases: ammonium
Sparingly soluble salts



We look at these next time

Non

insoluble salts like sulfides
molecules like CO₂
or alcohols or sugars



We never look at these

Timeout 2: spectator ions.

The material for the next month or so is almost exclusively concerned with compounds that impact the proton or hydroxide concentration. Obviously H⁺ and OH⁻ impact the amount of H⁺ or OH⁻. And we will learn about various kinds of compounds that produce amounts of H⁺ and OH⁻ by ways not immediately obvious (like Fe⁺⁺⁺ or NH₃.) But there are also compounds that when thrown into water, have little or no impact on the pH. These compounds are referred to as spectator ions. And as a general rule, among ions, spectators include:

The alkali metals and earth cations like Na⁺ or Ca⁺⁺ or Rb⁺ or Mg⁺⁺

The anions of strong acids: Cl⁻, Br⁻, I⁻, NO₃⁻, SO₄⁼, ClO₃⁻ and ClO₄⁻ (see memorizing strong acids is already paying off.)

Here is the rule for spectators: if you see one, toss it. It has no effect on pH.

Enough time outs. On to the main point of the lecture.

How to calculate the pH of a strong acid or base.

Consider the acid/base nature of strong electrolytes. By definition strong electrolytes “dissociate completely” which means that in setting up the RICE expression, there is a very simple general result that every bit of the initial concentration of electrolyte turns into ions at equilibrium:

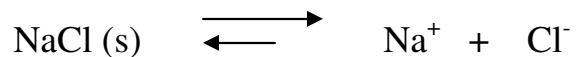
$AB \xrightleftharpoons{\hspace{1cm}} A^+ + B^-$			
100%	0%	0%	initial
0%	100%	100%	equil.

$$K = \frac{[A^+][B^-]}{[AB]}$$

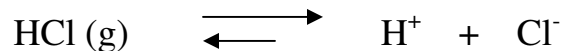
$$= \frac{(100)(100)}{0} = \infty$$

That is why we approximate that strong electrolytes have a $K \approx \infty$ and don't need to provide a K value when solving problems.

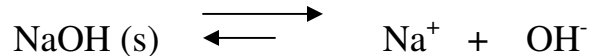
Examples:



$$K_{sp} = [Na^+][Cl^-] = \infty$$

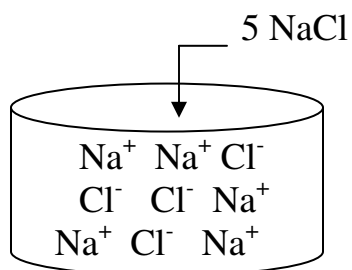


$$K_a = \frac{[H^+][Cl^-]}{[HCl]} = \infty$$

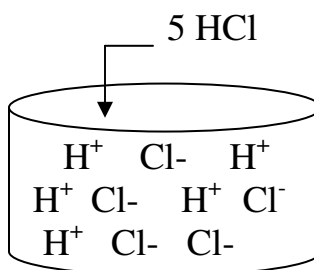


$$K_b = \frac{[Na^+][OH^-]}{[NaOH]} = \infty$$

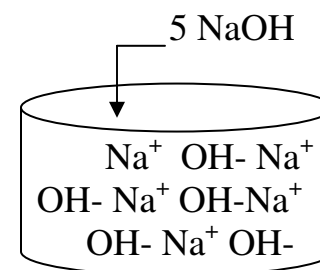
But what does this mean for acid base equilibria? Look at each example and find the protons or hydroxides:



Soluble Salt



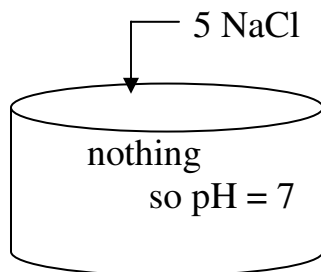
Strong acid



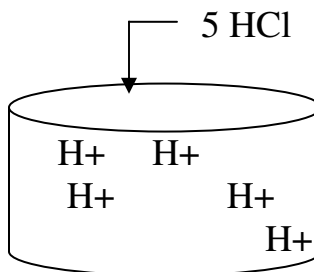
Strong Base

- In each case, 100% ionization

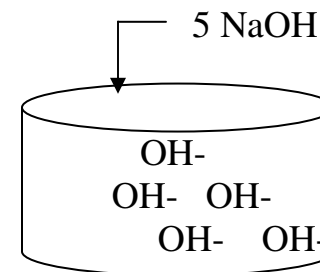
But what is present that matters for acid/base? Toss the spectators!!



Na⁺ Cl⁻
are spectators



Cl⁻ is spectator
only 5H⁺ matters



Na⁺ is spectator
only 5 OH⁻ matters

Do you see the result? The H⁺ or OH⁻ for a strong acid or base is just the amount of acid or base added initially.

So strong acid / strong base calculations are easy. It is just the analytical amount you started with

And the equations for strong acids and bases we talked about at the beginning of the lecture are derived:

Strong acids or bases in water:

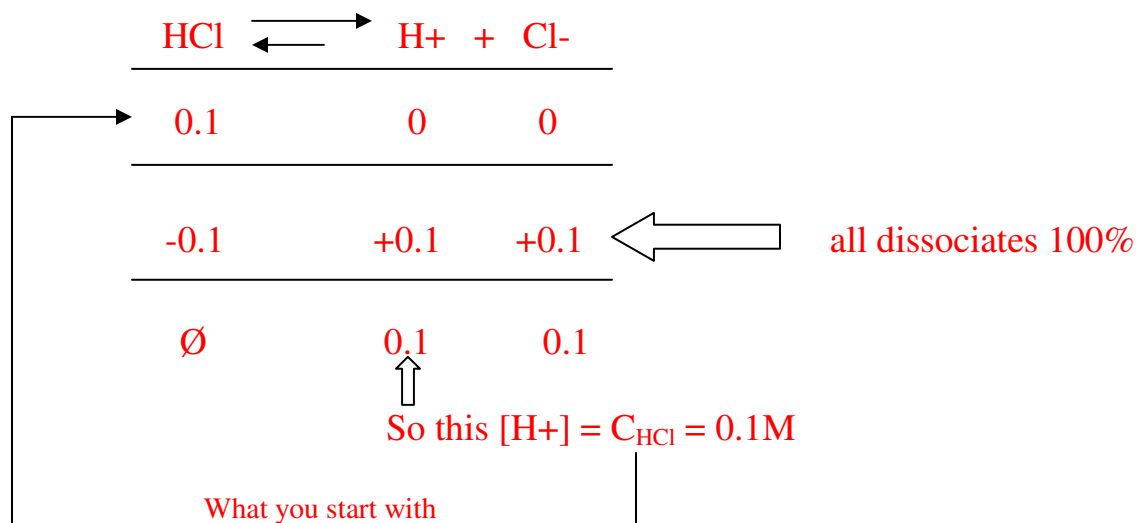
$$[\text{H}^+] = C_a \text{ for strong acids}$$

and

$$[\text{OH}^-] = C_b \text{ for strong bases}$$

Example:

What is pH of 0.1M HCl?



and $\text{pH} = -\log [0.1] = 1$

or don't go through all the hassle. Since $C_a = 0.1\text{ M}$, $\text{H}^+ = 0.1$ and $\text{pH} = 1$

Example:

What is the pOH of 0.01M LiOH?

Remove spectator ion, Li^+ , and all we have left is 0.01M OH^-

So $\text{pOH} = -\log [\text{OH}^-] = -\log [0.01] = 2$

note: I did this problem without setting up equilibria

A final, HUGELY IMPORTANT Timeout: Getting back and forth between pH and pOH.

You may have felt unfulfilled when I asked you for the pOH of LiOH (and the answer was 2.) You probably thought, what the heck is a pOH? I want to know the pH.

And the answer is, you already do know it.

Remember that: $K_w = [\text{H}^+][\text{OH}^-] = 1 \times 10^{-14}$ at 25°C

Then take $-\log$ of the entire equation: $\text{p}K_w = \text{pH} + \text{pOH} = 14$ at 25°C

So to get back and forth between pH and pOH, just note that the two numbers have to equal 14.

- So if the pH of 0.1 M HCl is 1, then the $\text{pOH} = 14 - 1 = 13$
- and if the pOH of 0.01 M LiOH = 2 then the $\text{pH} = 14 - 2 = 12$.

And this last result makes sense—it says that a strong base like LiOH has a high pH.