Pearson

16.5: Acid Strength and the Acid Ionization Constant (K_a)

We have seen that, depending on the structure of an acid, it can be either strong (in which case it completely ionizes in solution) or weak (in which case it only partially ionizes in solution). We can think of acid strength in terms of the equilibrium concepts we discussed in Chapter 15. For the generic acid HA, we can write the following ionization equation:

$$HA\,(aq) + H_2O\,(l) \rightleftharpoons H_3O^+\,(aq) + A^-\,(aq)$$

If the equilibrium lies far to the right, the acid is strong. If the equilibrium lies to the left, the acid is weak. The range of acid strength is continuous, but for most purposes, the categories of strong and weak are useful.

Strong Acids

Hydrochloric acd (HCl) is an example of a strong acid. An HCl solution contains virtually no intact HCl; the HCl has essentially all ionized to form $H_3O^+\,(aq)$ and $Cl^-\,(aq)$ (Figure 16.5). If we have a HCl solution with an H_3O^+ concentration of 1.0 M, abbreviating the concentration of H_3O^+ as $[H_3O^+]$, we say that the 1.0 M HCl solution has $[H_3O^+] = 1.0$ M.

Figure 16.5 Ionization of a Strong Acid

When HCl dissolves in water, it completely ionizes to form H_3O^+ and Cl^-. The solution contains virtually no intact HCl.

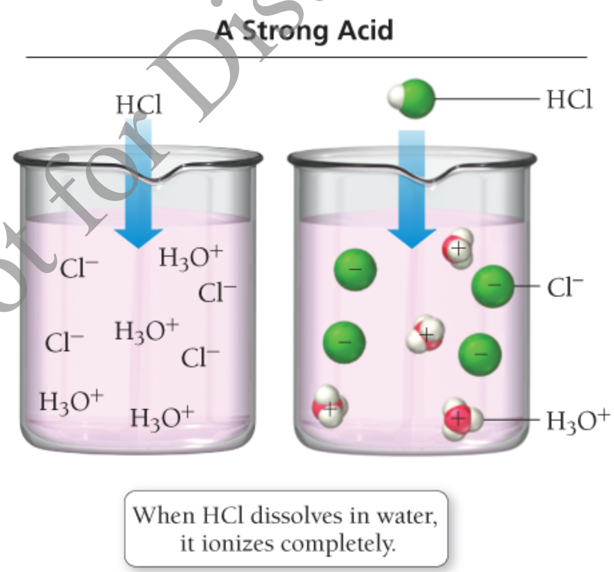


Table 16.3 lists the six important strong acids. The first five acids in the table are **monoprotic acids**, acids containing only one ionizable proton. Sulfuric acid is an example of a **diprotic acid**, an acid containing two ionizable protons.

Table 16.3 Strong Acids

Hydrochloric acid (HCl)	Nitric acid (HNO_3)

Hydrobromic acid (HBr)	Perchloric acid ($HClO_4$)
Hydriodic acid (HI)	Sulfuric acid (H_2SO_4) (*diprotic*)

> An ionizable proton is one that ionizes in solution. We discuss polyprotic acids in more detail in Section 16.10.

Weak Acids

In contrast to HCl, HF is a weak acid, one that does not completely ionize in solution. As we saw in Section 16.4, the strength of the HF bond relative to the HCl bond makes HF less likely to ionize in solution than HCl. Therefore, an HF solution contains a large number of intact (or un-ionized) HF molecules; it also contains some $H_3O^+ (aq)$ and $F^- (aq)$ (Figure 16.6). In other words, a 1.0 M HF solution has $[H_3O^+]$ that is much lower than 1.0 M because only some of the HF molecules ionize to form H_3O^+. Table 16.4 lists some other common weak acids.

Figure 16.6 Ionization of a Weak Acid

When HF dissolves in water, only a fraction of the dissolved molecules ionize to form H_3O^+ and F^-. The solution contains many intact HF molecules.

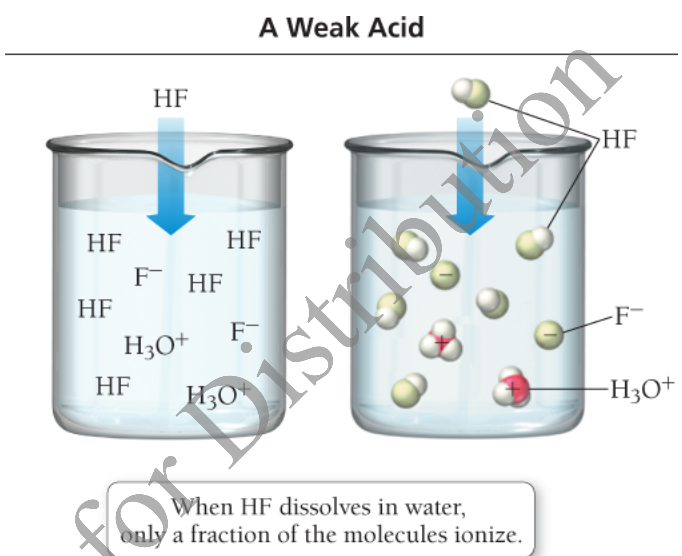


Table 16.4 Common Weak Acids

Hydrofluoric acid (HF)	Sulfurous acid (H_2SO_3) (*diprotic*)
Acetic acid ($HC_2H_3O_2$)	Carbonic acid (H_2CO_3) (*diprotic*)
Formic acid ($HCHO_2$)	Phosphoric acid (H_3PO_4) (*triprotic*)

> We can also write the formulas for acetic acid and formic acid as CH_3COOH and HCOOH, respectively, to indicate that in these compounds the only H that ionizes is the one attached to an oxygen atom.

Notice that two of the weak acids in Table 16.4 are diprotic, meaning that they have two ionizable protons, and one is **triprotic** (three ionizable protons). We discuss polyprotic acids in more detail in Section 16.10.

The Acid Ionization Constant (K_a)

We quantify the relative strength of a weak acid with the **acid ionization constant** (K_a), which is the equilibrium constant for the ionization reaction of the weak acid in water. Based on the law of mass action (see Section 15.3) for the two equivalent reactions:

$$\begin{aligned} \mathrm{HA}\,(aq) + \mathrm{H_2O}\,(l) &\rightleftharpoons \mathrm{H_3O^+}\,(aq) + \mathrm{A^-}\,(aq) \\ \mathrm{HA}\,(aq) &\rightleftharpoons \mathrm{H^+}\,(aq) + \mathrm{A^-}\,(aq) \end{aligned}$$

> The terms *strong* and *weak* acids are often confused with the terms *concentrated* and *dilute* acids. Can you articulate the difference between these terms?

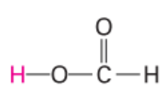
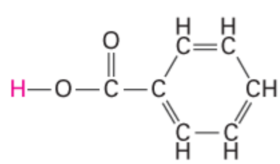
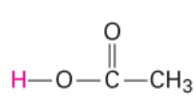
The equilibrium constant is:

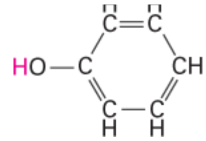
$$K_a = \frac{[\mathrm{H_3O^+}][\mathrm{A^-}]}{[\mathrm{HA}]} = \frac{[\mathrm{H^+}][\mathrm{A^-}]}{[\mathrm{HA}]}$$

Since $[\mathrm{H_3O^+}]$ is equivalent to $[\mathrm{H^+}]$, both forms of the above expression are equal. Although the ionization constants for all weak acids are relatively small (otherwise the acid would not be a weak acid), they do vary in magnitude. The smaller the constant, the less the acid ionizes, and the weaker the acid. Table 16.5 lists the acid ionization constants for a number of common weak acids in order of decreasing acid strength.

> Recall from Chapter 15 that the concentrations of pure solids or pure liquids are not included in the expression for K_c Therefore, $\mathrm{H_2O}\,(l)$ is not included in the expression for K_a

Table 16.5 Acid Ionization Constants (K_a) for Some Monoprotic Weak Acids at 25 °C

Acid	Formula	Structural Formula	Ionization Reaction
Chlorous acid	$HClO_2$	H—O—Cl=O	$HClO_2(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + ClO_2^-(aq)$
Nitrous acid	HNO_2	H—O—N=O	$HNO_2(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + NO_2^-(aq)$
Hydrofluoric acid	HF	H—F	$HF(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + F^-(aq)$
Formic acid	$HCHO_2$		$HCHO_2(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + CHO_2^-(aq)$
Benzoic acid	$HC_7H_5O_2$		$HC_7H_5O_2(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + C_7H_5O_2^-(aq)$
Acetic acid	$HC_2H_3O_2$		$HC_2H_3O_2(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + C_2H_3O_2^-(aq)$
Hypochlorous acid	HClO	H—O—Cl	$HClO(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + ClO^-(aq)$
Hydrocyanic acid	HCN	H—C≡N	$HCN(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + CN^-(aq)$

Phenol	HC_6H_5O		$HC_6H_5O(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + C_6H_5O^-(aq)$

Conceptual Connection 16.3 **The Magnitude of the Acid Ionization Constant**

Conceptual Connection 16.4 **Relative Strengths of Weak Acids**

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