## CHEM1002 Worksheet 9: Weak Acids and Buffers

## Model 1: A Solution Containing a Weak Acid

A strong acid is one that is $100 \%$ ionised in water:

$$
\mathrm{HA}(\mathrm{aq})+\mathrm{H}_{2} \mathrm{O}(\mathrm{l}) \rightarrow \mathrm{H}_{3} \mathrm{O}^{+}(\mathrm{aq})+\mathrm{A}(\mathrm{aq}) \quad\left[\mathrm{H}_{3} \mathrm{O}^{+}(\mathrm{aq})\right]=[\mathrm{HA}]_{\text {initial }} \text { and } \mathrm{pH}=-\log [\mathrm{HA}]_{\text {initial }}
$$

A weak acid is one that is less than $100 \%$ ionised in water and an equilibrium must be considered:

$$
\mathrm{HA}(\mathrm{aq})+\mathrm{H}_{2} \mathrm{O}(\mathrm{l}) \rightleftharpoons \mathrm{H}_{3} \mathrm{O}^{+}(\mathrm{aq})+\mathrm{A}(\mathrm{aq}) \quad K_{\mathrm{a}}=\frac{\left[\mathrm{H}_{3} \mathrm{O}^{+}(\mathrm{aq})\right]\left[\mathrm{A}^{-}(\mathrm{aq})\right]}{[\mathrm{HA}(\mathrm{aq})]}
$$

From the chemical equation, at equilibrium:

$$
\left[\mathrm{H}_{3} \mathrm{O}^{+}(\mathrm{aq})\right]=[\mathrm{A}(\mathrm{aq})] \text { and }[\mathrm{HA}(\mathrm{aq})]=[\mathrm{HA}]_{\text {initial }}-\left[\mathrm{A}^{-}(\mathrm{aq})\right]
$$

As hardly any weak acid ionises, $[\mathrm{HA}]_{\text {initial }}-\left[\mathrm{A}^{-}(\mathrm{aq})\right] \approx[\mathrm{HA}]_{\text {initial }}$ and so:

$$
K_{\mathrm{a}}=\frac{\left[\mathrm{H}_{3} \mathrm{O}^{+}(\mathrm{aq})\right]^{2}}{[\mathrm{HA}]_{\text {initial }}} \quad \text { and } \quad\left[\mathrm{H}_{3} \mathrm{O}^{+}(\mathrm{aq})\right]=\sqrt{K_{\mathrm{a}} \times[\mathrm{HA}]_{\text {initial }}}
$$

After working out $\left[\mathrm{H}_{3} \mathrm{O}^{+}(\mathrm{aq})\right]$, the pH of the weak acid can be calculated:

$$
\mathrm{pH}=-\log \left[\mathrm{H}_{3} \mathrm{O}^{+}(\mathrm{aq})\right]
$$

## Critical thinking questions

1. Calculate the pH of the acetic acid as it is diluted $\left(K_{\mathrm{a}}=10^{-4.76}\right)$.
(a) $2.00 \mathrm{M} \quad \mathrm{pH}=$
(c) $0.500 \mathrm{M} \quad \mathrm{pH}=$
(b) $1.00 \mathrm{M} \quad \mathrm{pH}=$
(d) $0.250 \mathrm{M} \quad \mathrm{pH}=$
2. What are the major species present in a 1.00 M solution of acetic acid?

## Model 2: Buffer solutions

Model 1 describes the pH of a solution of a weak acid. If the conjugate base of the weak acid is added to that solution the pH will increase, as the added weak acid will drive the equilibrium given below towards the left hand side.

$$
\mathrm{HA}(\mathrm{aq})+\mathrm{H}_{2} \mathrm{O}(\mathrm{l}) \rightleftharpoons \mathrm{H}_{3} \mathrm{O}^{+}(\mathrm{aq})+\mathrm{A}(\mathrm{aq})
$$

In the case of acetic acid the solution will contain appreciable amounts of both $\mathrm{CH}_{3} \mathrm{COO}^{-}(\mathrm{aq})$ and $\mathrm{CH}_{3} \mathrm{COOH}(\mathrm{aq})$. A solution like this containing both a weak acid and its conjugate base will have a pH given by the Henderson-Hasselbalch equation:

$$
\mathrm{pH}=\mathrm{p} K_{\mathrm{a}}+\log \frac{[\text { base }]}{[\text { acid }]}=\mathrm{p} K_{\mathrm{a}}+\log \frac{\left[\mathrm{A}^{-}(\mathrm{aq})\right]}{[\mathrm{HA}(\mathrm{aq})]}
$$

## Critical thinking questions

3. Calculate the pH of a 1.00 L solution that is 0.100 M in $\mathrm{CH}_{3} \mathrm{COO}^{-}(\mathrm{aq})$ and $0.400 \mathrm{M} \mathrm{CH}_{3} \mathrm{COOH}(\mathrm{aq})$. $\left(\mathrm{p} K_{\mathrm{a}}\left(\mathrm{CH}_{3} \mathrm{COOH}\right)=4.76\right)$.
4. Calculate the change in pH and final pH if $0.150 \mathrm{~mol} \mathrm{NaOH}(\mathrm{s})$ is added to that solution (Hint: Which of the two species will the NaOH react with?).
5. You require a stable $\mathrm{pH}=5.00$ for an experiment. How would you prepare a buffer for that pH from 1.0 M solutions of $\mathrm{CH}_{3} \mathrm{COO}^{-}(\mathrm{aq})$ and $\mathrm{CH}_{3} \mathrm{COOH}(\mathrm{aq})$ ?
