Set 14: Water Equilibrium

1. $H_2O(\ell) + H_2O(\ell) \leftrightarrows OH^-(aq) + H_3O^+(aq)$

2. (a) $k_W = [H^+][OH^-] = 1.00 \times 10^{-14}$
$1.48 \times 10^{-7} \times [OH^-] = 1.00 \times 10^{-14}$
$[OH^-] = 6.67 \times 10^{-8}$ mol L^{-1}

   (b) The swimming pool water is **acidic**

3. $k_W = [H^+][OH^-] = 1.00 \times 10^{-14}$
$[H^+] \times 1.58 \times 10^{-6} = 1.00 \times 10^{-14}$
$[H^+] = 6.33 \times 10^{-9}$ mol L^{-1}

4. (a) $[OH^-] = [NaOH] = 1.55 \times 10^{-4}$ mol L^{-1}
$k_W = [H^+][OH^-] = 1.00 \times 10^{-14}$
$[H^+] \times 1.55 \times 10^{-4} = 1.00 \times 10^{-14}$
$[H^+] = 6.45 \times 10^{-11}$ mol L^{-1}

   (b) $[OH^-] = 2 \times [Ba(OH)_2] = 2 \times 3.90 \times 10^{-2} = 0.0780$ mol L^{-1}
$k_W = [H^+][OH^-] = 1.00 \times 10^{-14}$
$[H^+] \times 0.0780 = 1.00 \times 10^{-14}$
$[H^+] = 1.28 \times 10^{-13}$ mol L^{-1}

5. (a) $[H^+] = [HC\ell] = 0.104$ mol L^{-1}
$k_W = [H^+][OH^-] = 1.00 \times 10^{-14}$
$0.104 \times [OH^-] = 1.00 \times 10^{-14}$
$[OH^-] = 9.62 \times 10^{-14}$ mol L^{-1}

   (b) $H_2SO_4(\ell) \rightarrow H^+(aq) + HSO_4^-(aq)$
and $HSO_4^-(aq) \rightarrow 0.9HSO_4^-(aq) + 0.1H^+(aq) + 0.1SO_4^{2-}(aq)$
Overall $H_2SO_4(\ell) \rightarrow 0.9HSO_4^-(aq) + 1.1H^+(aq) + 0.1SO_4^{2-}(aq)$

$[H^+] = 1.1[H_2SO_4] = 1.1 \times 0.125 = 0.1375$ mol L^{-1}
$k_W = [H^+][OH^-] = 1.00 \times 10^{-14}$
$0.1375 \times [OH^-] = 1.00 \times 10^{-14}$
$[OH^-] = 7.27 \times 10^{-14}$ mol L^{-1}

6. (a) The ionisation of water is endothermic: heat + $H_2O(\ell) \leftrightarrows H^+(aq) + OH^-(aq)$
The reverse reaction, neutralisation is therefore exothermic. A change in temperature will change the proportion of reactants and products and so change the equilibrium constant. So when giving the ionisation constant a temperature needs to be stated.

   (b) If the temperature of water is decreased the equilibrium position will move to restore some of the heat removed. To do this hydrogen and hydroxide ions must combine to produce water and heat, hence their concentration will become smaller.

6. (c) If temperature is increased a greater concentration of hydrogen ions will result.

(d) As the temperature is increased the rate of both the forward and reverse reactions will increase, but the endothermic forward reaction will increase more than the reverse reaction leading to an increase in the hydrogen ion concentration.

7. (a) $k_W = [H^+]\,[OH^-] = 1.00 \times 10^{-14}$
$1.55 \times 10^{-5} \times [OH^-] = 1.00 \times 10^{-14}$
$[OH^-] = 6.45 \times 10^{-10}$ mol L^{-1}

(b) Most probably some release of SO_2 from the smelter dissolving in the rain water combined with elevated levels of CO_2 again dissolved in the rain water.

(c) $SO_{2(aq)} + H_2O_{(\ell)} \leftrightarrows HSO_3^-{}_{(aq)} + H^+_{(aq)}$
And $CO_{2(aq)} + H_2O_{(\ell)} \leftrightarrows HCO_3^-{}_{(aq)} + H^+_{(aq)}$

8. $n(H^+)_{\text{in lemon juice}} = cV = 1.60 \times 10^{-4} \times V$ mol
$n(H^+)_{\text{in orange juice}} = cV = 1.30 \times 10^{-6} \times V$ mol
$n(H^+)_{\text{total}} = n(H^+)_{\text{in lemon juice}} + n(H^+)_{\text{in orange juice}}$
$= 1.60 \times 10^{-4} \times V + 1.30 \times 10^{-6} \times V = 1.613 \times 10^{-4} \times V$ mol

$$[H^+] = \frac{n}{V} = \frac{1.613 \times 10^{-4} \times V}{2V} = 8.07 \times 10^{-5} \text{ mol L}^{-1}$$

$k_W = [H^+]\,[OH^-] = 1.00 \times 10^{-14}$
$8.07 \times 10^{-5} \times [OH^-] = 1.00 \times 10^{-14}$
$[OH^-] = 1.24 \times 10^{-10}$ mol L^{-1}

9. (a)

$$n(A\ell(OH)_3) = \frac{m}{M} = \frac{5.00 \times 10^{-3}}{78.004} = 6.41 \times 10^{-5} \text{ mol} \qquad \left[M(A\ell(OH)_3) = 78.004 \text{ g mol}^{-1}\right]$$

$n(OH^-) = 3n(A\ell(OH)_3) = 3(6.41 \times 10^{-5}) = 1.923 \times 10^{-4}$ mol

$$n(Mg(OH)_2) = \frac{m}{M} = \frac{5.00 \times 10^{-3}}{58.326} = 8.57 \times 10^{-5} \text{ mol} \qquad \left[M(Mg(OH)_2) = 58.326 \text{ g mol}^{-1}\right]$$

$n(OH^-) = 2n(Mg(OH)_2) = 2(8.57 \times 10^{-5}) = 1.71 \times 10^{-4}$ mol
$n(OH^-)_{\text{total}} = 1.923 \times 10^{-4} + 1.71 \times 10^{-4} = 3.64 \times 10^{-4}$ mol

$n(H^+)_{\text{in stomach}} = cV = 2.50 \times 10^{-4} \times 1.5 = 3.75 \times 10^{-4}$ mol
$OH^-{}_{(aq)} + H^+_{(aq)} \leftrightarrows H_2O_{(\ell)}$
$n(H^+)_{\text{left}} = n(H^+)_{\text{in stomach}} - n(OH^-)_{\text{total}} = 3.75 \times 10^{-4} - 3.64 \times 10^{-4} = 1.10 \times 10^{-5}$ mol

$$[H^+] = \frac{n}{V} = \frac{1.10 \times 10^{-5}}{1.5} = 7.33 \times 10^{-6} \text{ mol L}^{-1}$$

$k_W = [H^+]\,[OH^-] = 1.00 \times 10^{-14}$
$7.33 \times 10^{-6} \times [OH^-] = 1.00 \times 10^{-14}$
$[OH^-] = 1.36 \times 10^{-9}$ mol L^{-1}

9. (b) If another tablet was taken this would represent another 3.64×10^{-4} moles of hydroxide ions available to react with hydrogen ions. This is more than is required to react with all the hydrogen ions present. When all the hydrogen ions are used up the reaction with $A\ell(OH)_3$ and $Mg(OH)_2$ would stop and since both these hydroxides are insoluble in water they would remain undissolved. The concentration of both hydrogen and hydroxide ions would therefore be 1.00×10^{-7} mol L^{-1}.

10. (a) $n(H^+)_{\text{after medication}} = \frac{1}{3}\, n(H^+)_{\text{original}} = \frac{1}{3}(2.00 \times 10^{-2}) = 6.67 \times 10^{-3}$ mol

$n(Mg(OH)_2)_{\text{Required}} = \frac{1}{2} n(OH^-)_{\text{Required}} = \frac{1}{2} n(H^+)_{\text{reacted}} = \frac{1}{2}(n(H^+)_{\text{original}} - n(H^+)_{\text{after medication}})$

$= \frac{1}{2}(2.00 \times 10^{-2} - 6.67 \times 10^{-3})$

$= 6.67 \times 10^{-3}$ mol

$M(Mg(OH)_2) = 58.326$ g mol^{-1}

$m(Mg(OH)_2) = nM = 6.67 \times 10^{-3} \times 58.326 = 0.3887$ g

Since concentration is in g L^{-1} then $V = \frac{m}{c} = \frac{0.3887}{80} = 4.86 \times 10^{-3}$ L = 4.86 mL

(b) $[H^+] = \frac{n}{V} = \frac{6.67 \times 10^{-3}}{0.800} = 8.34 \times 10^{-3}$ mol L^{-1}

$k_W = [H^+]\,[OH^-] = 1.00 \times 10^{-14}$

$8.34 \times 10^{-3} \times [OH^-] = 1.00 \times 10^{-14}$

$[OH^-] = 1.20 \times 10^{-12}$ mol L^{-1}