CHEMISTRY 225: ACIDS AND BASES

In order to do some of the following questions you will need to look up values in your text book - such as relative atomic masses and the K_a and K_b values for various substances.

1) Define the terms ***acid*** and ***base*** according to the Brønsted-Lowry theory. Write equations which show the behaviour of each of the following acids or bases in water, or the specified solvent. In each case identify the acid or base and its conjugate acid or base.
   a) hydrochloric acid
   b) nitric acid
   c) ammonia
   d) hydroxide ion
   e) ethanoic acid
   f) ethanoate ion
   g) benzoate ion ($C_6H_5CO_2^-$), a weak base.
   i) sulphide ion
   k) hydrogensulfide ion (acting as a weak acid)
   l) hydrogensulfide ion (acting as a weak base)
   m) as for (k) and (l) with the hydrogencarbonate ion.
   n) ethanoic acid in liquid ammonia (in which it is a strong acid)
   o) nitric "acid" in hydrogen fluoride (in which it is a ***base***)
   p) hydrogen chloride in ethanoic "acid" (the ethanoic acid actually functions here as a base)

2) A solid pellet containing 2·00 g of sodium hydroxide is dissolved in water and made up to 500 cm^3 with water. State or calculate:
   a) what four species are present in the solution.
   b) the $[OH^-]$ (Ans. 0·1M)
   c) the $[H_3O^+]$ (Ans. 10^{-13}M)
   d) the pH of the solution. (Ans. 13)

3) 2·0 cm^3 of 14·0 M HNO_3 (the normal concentrated acid) are made up to 400 cm^3 with water. Calculate
   a) the analytical concentration of the resulting solution. (Ans. 0·0700 mol dm^{-3})
   b) the $[H_3O^+]$ of the solution.
   c) the pH of the solution. (Ans. 1·15)
   d) the mass of solid KOH which would have to be added to the 400 cm^3 of this solution to increase the pH to 7·0. (Ans. 1·57 g)
   e) If 1·57 g of potassium hydroxide from a bottle on the shelf were actually weighed out and added to 400 cm^3 of acid solution as described, the pH would almost certainly be a long way from 7. Why is this? (Hint: calculate the pH using 1.570 g of potassium hydroxide.)

4) a) Calculate the pH of a solution whose $[H_3O^+]$ is 10^{-4} M. (Ans. 4)
   b) Calculate the pK_a of an acid whose K_a is 0·03. (Ans. 1.52)
   c) Calculate the pOH value of a solution whose $[OH^-]$ is $5{\cdot}3\times10^{-5}$ M. (Ans. 4·3)
   d) Calculate the pK_b value for a base whose K_b value is 1×10^{-7}. (Ans. 7)
   e) Calculate the pK_w of water at 0°C when the K_W value is $1{\cdot}14\times10^{-15}$. (Ans. 14·9)

5) Calculate $[H_3O^+]$ and $[OH^-]$ in solutions with the following pH values:
   a) 8·0 (Ans. 10^{-8}, 10^{-6})
   b) 0·2 (Ans. 0·63, $1{\cdot}58 \times 10^{-14}$)
   c) 12·3 (Ans. $5{\cdot}01 \times 10^{-13}$, 0·02)
   d) -1·2 (Ans. 15·8, $6{\cdot}31 \times 10^{-16}$)
   e) 15 (Ans. 10^{-15}, 10)

   (Above answers all in mol dm^{-3})

Classify the above solutions as strongly basic, weakly acidic, etc. (Ans. weakly basic, strongly acidic, strongly basic, very strongly acidic, very strongly basic)

6) If the values given in question (5) were the pK_a values of acids, what would be their K_a values? Which would be weak and which strong? (Ans. 10^{-8}, 0·63, $5{\cdot}01 \times 10^{-13}$, 15·8, 10^{-15}, weak, strong, very weak, strong, very weak)

7) Calculate the approximate pH values of each of the following solutions of hydrochloric acid: 10^{-1}, 10^{-2}, 10^{-3}, 10^{-4}, 10^{-5}, 10^{-8} M. (Ans. 1,2,3,4,5,7)

8) Given $K_a(HCO_3^-) = 6\times10^{-11}$ and $K_b(HCO_3^-) = 3{\cdot}33\times10^{-8}$, calculate the equilibrium constants for the reactions:
   a) $2HCO_3^- \rightleftharpoons H_2CO_3 + CO_3^{2-}$ (Ans. $2{\cdot}0\times10^{-4}$)
   b) $H_2CO_3 + 2H_2O \rightleftharpoons 2H_3O^+ + CO_3^{2-}$ (Ans. $1{\cdot}8\times10^{-17}$)

9) Hydrazoic acid (HN_3) is a weak monoprotic acid whose pK_a is 4·72. Calculate:
   a) the approximate concentrations of hydronium, hydroxide and azide (N_3^-) ions in a 0·1 M solution of the acid. (Ans.0·0014M, 7.2×10^{-12}M, 0·0014M)
   b) the degree of dissociation of the acid. (Ans. 0·014)
   c) the pH of the solution. (Ans. 2·86)

10) Find the $[H_3O^+]$, $[OH^-]$, and pH in:
   a) a solution of 0·200 M NaOH.
   b) a solution of 0·500 M HCl
   c) a mixture of 40 cm^3 of (a) and 25 cm^3 of (b).
   d) the solution formed when 0·500 g of solid NaOH is added to solution (c). (Ans. pH11.9)

11) Find the pH of
   a) a solution of 0·500 M NH_4Cl given $pK_a(NH_4^+) = 9{\cdot}24$
   b) a mixture of 20·0 cm^3 of 1·00 M NH_3 and 20·0 cm^3 of 1·00 M HCl.
   c) a mixture of 40·0 cm^3 2·00 M HCl, 20·0 cm^3 2 M NH_3 and 20·0 cm^3 2·00 M NaOH.

12) Discuss qualitatively the nature of the species present in 0·1 M solutions of each of:
   a) NH_4NO_3, b) $(NH_4)_2CO_3$, c) NaHS, d) $Al_2(SO_4)_3$
   State explicitly what numerical constants you would need to consider in order to predict whether the solutions of (b) and (c) are acidic, basic, or neutral.

13) a) How many moles of solid NaOH must be added to 200 cm^3 of 0·100 M HCl in order that the resulting solution has a pH of 7?
   b) How many moles of solid NH_4Cl must be added to 200 cm^3 of 0·100 M NH_3 in order that the resulting solution has a pH of 9·0? ($pK_a(NH_4^+)$=9.2)

14) a) 250 cm^3 of a solution containing 2·34 g of NH_4Cl is found to have a pH of 5·0. Use this information to calculate $K_a(NH_4^+)$ and hence $K_b(NH_3)$.
   b) A solution containing 0·49 g NaCN in 1000 cm^3 of solution has a pH of 10·7. Use this information to calculate K_a(HCN).

15) For the weak diprotic acid hydrogen selenide, H_2Se, $K_{a1} = 1{\cdot}7\times10^{-4}$, and $K_{a2} = 1\times10^{-10}$.
   a) Calculate the equilibrium constant for the reaction:
   $H_2Se(aq) + 2H_2O(l) \rightleftharpoons 2H_3O^+ + Se^{2-}$
   b) Name the entities present in a 0·05 M solution of H_2Se and indicate their approximate concentrations qualitatively, eg. "moderately high", "low", or "very low".

16) What mass of solid ammonium bromide must be added to 1000 cm^3 of 0·1 M

ammonia solution to obtain a solution of pH 9·00? ($pK_b(NH_3)$=4.8)

17) What masses of ethanoic acid and sodium ethanoate would you need to dissolve to make up 500 cm^3 of a buffer solution of pH 5·00. The solution must be 0·100 mol dm^{-3} in ethanoic acid. (pK_a of ethanoic acid is 4·76).

18) Calculate the pH of a 0·0500 M solution of sodium benzoate (often used as a food preservative) given that the pK_a of benzoic acid is 4.21.

19) Calculate the pH of a 0·00100 M solution of cocaine hydrochloride given that the pK_b of cocaine is 5·59. (Cocaine hydrochloride is composed of the conjugate acid of cocaine and the chloride ion.)

20) Sketch a graph of pH against cm^3 of titrant added in each of the cases below. Indicate on each graph (i) the volume of titrant added at the equivalence point(s) and (ii) the pH at the equivalence point(s).
   a) the titration of 25 cm^3 0·1 M potassium hydroxide with 0·2 M nitric acid.
   b) the titration of 25 cm^3 of 0·1 M ethanoic acid with 0·1 M sodium hydroxide.
   c) the titration of 25 cm^3 of 0·2 M ethanoic acid with 0·1 M sodium hydroxide.
   d) the titration of 0·1 M triethylamine (a weak monoprotic base) with 0·1 M hydrochloric acid.
   e) the titration of 25 cm^3 0·1 M phosphoric acid with 0·1 M sodium hydroxide solution.

Further Answers

10) a) $5\times10^{-}$M, 0.2M, 13.3
    b) 0.5M, 2.0×10^{-14}M, 0.3
    c) 0.069M, 1.44×10^{-13}, 1.16
    d) 8.1×10^{-14}M, 0.123M, 13.09
11) a) 4.77
    b) 4.77
    c) 4.77
13) a) 0.02 mol
    b) 0.032 mol
14) a) $K_a=5.7\times10^{-10}$, $K_b=1.75\times10^{-5}$
    b) $K_a=3.98\times10^{-10}$
15) a) 1.7×10^{-14}
16) 15.5g
17) 3.0g ethanoic acid, 7.1g sodium ethanoate.
18) 8.45
19) 5.71