This problem sheet has calculations that involve the fundamental principles of solution stoichiometry, buffer solutions and pH.

A variety of units are used in the questions and you need to check these carefully. Look out for SI prefixes such as μ (micro), m (milli) and k (kilo).

Your answers should be written out in full with all intermediate steps shown and a clear explanation of your methodology. Ensure that all numerical quantities are shown with units and that your final answer is rounded to an appropriate number of significant figures.

Where appropriate, assume a value of 1×10^{-14} for K_w, the ionic product of water.

As each sheet is different, you MUST hand your sheet in with your answers.

Diluting solutions

1. You are required to make 1150 μL of 3 mM solution of a protein from a stock solution of concentration 15 mM. What volume of stock solution would you need to use? [units μL]

2. You are required to make 1350 mL of a protein solution containing 3 μg mL^{-1} from a stock solution whose containing 15 mg mL^{-1}. What volume of stock solution would you need to use? [units mL]

3. What is the concentration of the final solution when 21 mL of a glucose solution containing 1.8 g L^{-1} of glucose is diluted by adding 100 mL of water? [units mmol L^{-1}]

Hydrogen ions, hydroxide ions and pH

4. What is the hydroxide ion concentration in a solution if the hydronium ion concentration is 3.004×10^{-9} mol L^{-1}?
5. What is the hydronium ion concentration in a solution if the hydroxide ion concentration is 3.858×10^{-3} μmol L^{-1}?
6. What is $[OH^-]$ in a solution where $[H_3O^+]$ is 8.814×10^{-4} mmol L^{-1}?
7. What is $[H_3O^+]$ in a solution where $[OH^-]$ is 6.934×10^{-12} mol L^{-1}?
8. What is the pH of a solution of whose hydronium ion concentration is 1.156×10^{-4} mol L^{-1}?
9. What is the pH of a solution of whose hydroxide ion concentration is 4.542×10^{-5} mmol L^{-1}?
10. What is the pH of a solution of whose hydronium ion concentration is 4.029×10^{-3} μmol L^{-1}?
11. What is the pH of a solution of whose hydroxide ion concentration is 2.556×10^{-5} mmol L^{-1}?
12. Calculate the hydronium ion concentration of a solution of pH 8.03. [units mol L^{-1}]
13. Calculate the hydroxide ion concentration of a solution of pH 10.46. [units mol L^{-1}]
14. Calculate the $[H_3O^+]$ of a solution of pH -0.47. [units mol L^{-1}]
15. Calculate the $[OH^-]$ of a solution of pH 7.34. [units mol L^{-1}]

Problems using pK_a and the Henderson-Hasselbalch Equation

16. A weak acid has a pK_a of 3.705. Calculate the pH of a solution in which the ratio of the concentrations of undissociated acid to acid anion ($[HA]/[A^-]$) equals 9.061.

17. A weak acid has a pK_a of 7.345. Calculate the pH of a solution in which the ratio of the concentrations of acid anion to undissociated anion ($[A^-]/[HA]$) equals 3.099 (note the slight difference from the previous question).

18. A weak acid has a pK_a of 7.739. If the solution pH is 7.545, what percentage of the acid is undissociated?

19. You need to prepare a buffer solution of pH 4.035 from 100 mL of 0.318 M solution of a weak acid whose pK_a is 4.266. What volume of 0.255 M NaOH would you need to add? [units mL]

20. You need to prepare a buffer solution of pH 4.137 from 10 mL of 0.396 M solution of a sodium salt of a weak acid, Na^+A^- where the pK_a of the weak acid HA is 4.256. What volume of 0.448 M HCl would you need to add? [units mL]

1. 1000 µL = 1 mL
   1150 µL = 1.15 mL.
   Volume of stock solution required = (Final volume × Final concentration) / concentration of stock solution
   = (1.15 × 3) /15 = 0.23mL = 230 µL.

2. 3 µg = 0.003 mg.
   Volume of stock solution required = (Final volume × 0.003) / 15
   = (1350 × 0.003) / 15 = 0.27 mL.

3. Gram molecular weight of Glucose ($C_6H_{12}0_6$) = 180
   180 gram of glucose in one Litre = 1 mol / L
   1.80 gram / L = 0.01 mol / L
   Concentration of final solution = (Final volume × 0.01) / 21
   = (121 × 0.01) / 21 = 0.0576 mmol /L

4. $[H_3O^+] \times [OH^-] = 1\times 10^{-14}$
   $(3.004 \times 10^{-9} \times [OH^-] = 1\times 10^{-14}$
   $[OH^-] = (1\times 10^{-14}) / 3.004 \times 10^{-9}$
   $= 3.3288 \times 10^{-6}$ mol/ L

5. $[H_3O^+] \times [OH^-] = 1\times 10^{-14}$ mol/L = $(1\times 10^{-14} \times 10^{-6})$ µ mol/L
   $[H_3O^+] \times (3.858 \times 10^{-3}) = (1\times 10^{-14} \times 10^{-6})$ µ mol/L
   $[H_3O^+] = (1\times 10^{-14} \times 10^{-6}) / (3.858 \times 10^{-3})$
   $= 2.592\times 10^{-18}$ µ mol/L

6. $[H_30^+] \times [OH^-] = 1\times 10^{-14}$ mol/L = $(1\times 10^{-14} \times 10^{-3})$ m mol/L
   $(8.814 \times 10^{-4}) \times [OH^-] = 1\times 10^{-14} \times 10^{-3}$
   $= [OH^-] = (1\times 10^{-14} \times 10^{-3}) / (8.814 \times 10^{-4})$
   $= 1.135 \times 10^{-22}$ m mol/L

7. $[H_3O^+] \times [OH^-] = 1\times 10^{-14}$ mol/L
   $[H_3O^+] \times [6.934 \times 10^{-12}] = 1\times 10^{-14}$
   $[H_3O^+] = (1\times 10^{-14}) / (6.934 \times 10^{-12})$
   $= 1.442 \times 10^{-3}$ mol/L.

8. $[H^+] = [H_30^+] = 1.156 \times 10^{-4}$ mol / L

$pH = - \log [H_30^+]$
$= - \log 1.156 \times 10^{-4}$
$= 4 – \log 1.156$
$= 3.937.$

9. $[H^+] \times [OH^-] = 1\times 10^{-14}$ mol/L = $(1\times 10^{-14} \times 10^{-3})$ m mol/L
$[H^+] \times 4.542 \times 10^{-5} = (1\times 10^{-14} \times 10^{-3})$
$[H^+] = (1\times 10^{-14} \times 10^{-3}) /4.542 \times 10^{-5}$
$= 2.2016 \times 10^{-13}$
$pH = -\log [H^+] = -\log 2.2016 \times 10^{-13} = 13- 0.3427 = 12.657.$

10. $[H_3O^+] = 4.029 \times 10^{-3}$ µmol / L= $4.029 \times 10^{-3} \times 10^{6}$ mol /L
$[H_3O^+] = [H^+]$
$pH = -\log [H_3O^+] = -\log 4029 = 3.605$

11. $[OH^-] = 2.556 \times 10^{-5}$ mmol / L= $2.556 \times 10^{-5} \times 10^{3}$ mol / L
$[OH^-] = 2.556 \times 10^{-2}$ mol / L
$[H^+] \times [OH^-] = 1\times 10^{-14}$ mol/L
$[H^+]\times 2.556 \times 10^{-2} = 1\times 10^{-14}$
$[H^+] = (1\times 10^{-14}) / 2.556 \times 10^{-2} = 3.9123 \times 10^{-13}$
$pH = -\log [H^+] = - \log 3.9123 \times 10^{-13} = 13- \log 3.9123 = 12.40.$

12. $H_2O + H^+$ ---- $[H_3O^+]$
$pH = - \log [H^+]$
$8.03 = - \log [H^+]$
$\log [H^+] = -8.03$
$[H^+]$ = antilog $-8.03 = 9.332 \times 10^{-9}$
Hydronium ions will be same as hydrogen ions
$[H^+] = [H_3O^+]= 9.332 \times 10^{-9}$ mol / L.

13. pH = 10.46, pOH = 14- pH= 14- 10.46 = 3. 54
$pOH = - \log [OH^-]$
$3.54 = - \log [OH^-]$
or $\log [OH^-] = -3.54$
$[OH^-]$ = antilog $-3.54 = 2.884 \times 10^{-4}$ mol / L.

14. $H_2O + H^+$ ---- $[H_3O^+]$
$pH = - \log [H^+]$
$-0.47 = - \log [H^+]$
$\log [H^+] = 0.47$
$[H^+]$ = antilog 0.47 = 2.95
Hydronium ions will be same as hydrogen ions
$[H^+] = [H_3O^+] = 2.95$ mol / L.

15. pH = 7.34, pOH = 14- pH= 14- 7.34 = 6.66
$pOH = - \log [OH^-]$
$6.66 = - \log [OH^-]$
or $\log [OH^-] = -6.66$
$[OH^-]$ = antilog $-6.66 = 2.187 \times 10^{-7}$ mol / L.

16. pH= pKa + log $[A^-]/[HA]$

pH= pKa - log $[HA]/[A^-]$

= 3.705 – log 9.061

= 2.747.

17. pH= pKa + log $[A^-]/[HA]$

= 7.345 + log 3.099

= 7.836

18. pH= pKa + log $[A^-]/[HA]$

or log $[A^-]/[HA]$ = pH-pKa = 7.545 – 7.739 = -0.194

$[A^-]/[HA]$ = antilog 0.194 = 1.56.

19. pH = pKa + log [salt] / [acid]

4.035 = 4.266 + log [salt] / [acid]

log [salt] / [acid] = 4.035 - 4.266 = -0.231

[acid] / [salt] = antilog 0.231= 1.702.

Given [acid] =0.318M

Therefore [salt] = 0.318/ 1.702.= 0.186 M

Mass of NaOH dissolved in 1litre of solution = no. of moles × mol.wt

= 0.186 × 40 = 7.44g

20. pH = pKa + log [salt] / [acid]