Kw and pH CALCULATIONS

Define 'pH' as – $\log_{10}[H^+_{(aq)}]$ and calculate the pH of strong acid solutions and strong base solutions.

Since the Kw for water = $[H^+_{(aq)}] \times [OH^-_{(aq)}] = 10^{-14}$ at 298 K (25⁰ C) it follows that

$[H^+_{(aq)}] = 10^{-14} \div [OH^-_{(aq)}]$ **or** $[OH^-_{(aq)}] = 10^{-14} \div [H^+_{(aq)}]$

alternatively

pH + pOH = 14

pH = 14 – pOH **or** pOH = 14 – pH

Remember that an equilibrium constant is temperature dependant, therefore K_W will have a different value at temperatures other than 298 K (25⁰ C). Water will however be neutral as the $[H^+_{(aq)}] = [OH^-_{(aq)}]$ even if they are $\neq 10^{-7}$ mol L^{-1}.

$$K_W = [H^+][OH^-] = 10^{-14} \text{ or } pH + pOH = 14$$

Set 1.

Unless stated otherwise the, the temperature is 298 K (25⁰ C)

Q1. Calculate the concentration of OH^- ions in 0.10 mol L^{-1} HCl.

Q2. Show that the concentration of H^+ (H_3O^+) ions in pure water is 1×10^{-7} mol L^{-1}.

Q3. Calculate the $[H^+]$ in a 0.25 mol L^{-1} sodium hydroxide.

Q4. 3.65 grams of HCl gas are dissolved in enough water to make 1.5 L of solution. Calculate for this solution

A. the concentration of the solution
B. $[H^+]$
C. $[OH^-]$

Q5. A solution contains 11.22 grams of potassium hydroxide in 250 mL of solution. Calculate for this solution

A. the concentration of the solution
B. $[H^+]$
C. $[OH^-]$

Q6. For a 0.02 mol L^{-1} of nitric acid, calculate the $[OH^-]$ at

A. 25 ⁰C
B. 0 ⁰C ($K_W = 1.1 \times 10^{-15}$)

Q7. Explain why for pure water, acidic, basic and salt solutions the K_W for water at 25 ⁰C is always 1.0×10^{-14}.

Q8. Concentrated hydrochloric acid has a concentration of 11.7 mol L^{-1}. Calculate the pH and the $[OH^-]$ in this solution in mol L^{-1}.

Set 2.

Q1. Calculate the pH of each of the following solutions:

A.	0.1 mol L^{-1} HCl	B.	0.25 mol L^{-1} HNO_3
C.	0.002 mol L^{-1} $Ba(OH_2)$	D.	7.3 g L^{-1} HCl
E.	6.3 g / 250 mL HNO_3	F.	0.55 mol L^{-1} HCl
G.	11.7 mol L^{-1} HCl	H.	1.25×10^{-5} mol L^{-1} H^+

Q2. For a 0.10 mol L^{-1} solution of NaOH at 25 ^{0}C calculate the:

A. $[OH^-]$
B. $[H^+]$
C. pH

Q3. 8.0 grams of NaOH is dissolved 5.0 L of solution at 25 ^{0}C. Calculate the pH of this solution.

Q4. 0.561 grams of KOH is dissolved in 200 mL of solution. Calculate the pH

Q5. Calculate the pH of a 6.5×10^{-4} mol L^{-1} $Ca(OH_2)$ at 25 ^{0}C.

Q6. The pH of vinegar is about 2.8 at 25 ^{0}C. Calculate $[H^+]$.

Q7. The pH of human blood is about 7.4. Calculate $[H^+]$ and $[OH^-]$ (assume 25 ^{0}C).

Q8. Calculate the $[H^+]$ and the $[OH^-]$ in a 0.3 mol L^{-1} HCl at 25 ^{0}C.

Q9. A solution of KOH is made by dissolving 1.06×10^{-5} grams in 300 mL of solution. Calculate the pH of this solution at 25 ^{0}C and state whether the solution is slightly acidic or slightly basic (alkaline).

Q10. The average pH of sea-water at 25 ^{0}C is 8.5. Calculate the $[H^+]$ and the $[OH^-]$.

Q11. The pH of stomach acid is 1.7. Calculate the $[H^+]$ and the $[OH^-]$ in the stomach.

Set 1

so $k_w = 10^{-14} = [OH^-][H^+]$

Q1

$10^{-14} = [OH^-][0.1]$

$= 10^{-13}$ mol L^{-1}.

Q2

$10^{-14} = [OH^-][H^+]$ pure water neutral

so $10^{-14} = [10^{-7}][10^{-7}]$

Q3

$10^{-14} = [0.25][H^+]$

$= 4 \times 10^{-14}$.

Q4

a) $n(HCl) = \frac{m}{mr}$ $\frac{3.65}{36.45} = 0.1$ mol

$n(HCl) = CV$

$0.1 = C \times 1.5$ $C_{(HCl)} = 0.067$ mol L^{-1}

b) $C(HCl) = C(H^+) = 0.067$ mol L^{-1}

c) $10^{-14} = [H^+][OH^-]$

$10^{-14} = [0.067][OH^-]$

$[OH^-] = 1.5 \times 10^{-13}$ mol L^{-1}

Q5

a) $n(KOH) = \frac{m}{Mr}$ $\frac{11.22}{56.1} = 0.2$ mol.

$n(KOH) = CV$ $0.2 = C \times 0.25 = 0.8$ mol L^{-1}

c) $C(KOH) = C(OH^-) = 0.8$ mol L^{-1}

b) $10^{-14} = [H^+][OH^-]$

$10^{-14} = [H^+][0.8]$

$[H^+] = 1.25 \times 10^{-14}$ mol L^{-1}

Q6

a) $C_{(HNO_3)} = C_{(H^+)}$

$10^{-14} = [H^+][OH^-]$

$10^{-14} = [0.02][OH^-]$

$[OH^-] = 5 \times 10^{-13}$ mol L^{-1}

b) $1.1 \times 10^{-15} = [H^+][OH^-]$

$= [0.02][OH^-]$

$[OH^-] = 5.5 \times 10^{-14}$ mol L^{-1}

Q8

$pH = -\log_{10}[11.7]$

$= -1.07$

$10^{-14} = [H^+][OH^-]$

$= [11.7][OH^-]$

$= 8.55 \times 10^{-16}$ mol L^{-1}

Set 2

Q1 a) $pH = -\log [H^+] = -\log_{10} [0.1] = 1$

b) $-\log [0.25] = 0.6$

c) 0.002 mol of $Ba(OH)_2$ = 0.004 mol of OH^-

so $10^{-14} = [H^+][OH^-]$
$= [H^+][0.004]$
$= 2.5 \times 10^{-12}$ $-\log_{10}$ = 11.6

d) $7.3\,g\,L^{-1}$ of HCl

$g\,L^{-1} \div M \rightarrow mol\,L^{-1}$

$7.3 \div 36.45 = 0.2\,mol\,L^{-1}$

$pH = -\log [0.2]$

$pH = 0.7$

e) 6.3g / 250ml so ×4 = $25.2\,g\,L^{-1}$

Mr · HNO_3 = 63

$\frac{25.2}{Mr\ (63)} = mol\,L^{-1}$ so $= 0.4\,mol\,L^{-1}$

$pH = -\log [0.4]$
$= 0.4$

f) $pH = -\log [0.55]$ $pH = 0.26$

g) $pH = -\log [11.7]$ $pH = -1.07$

h) $pH = -\log [1.25 \times 10^{-5}]$ $pH = 4.9$

Q2 b) $10^{-14} = [OH][H^+] = [0.1][H^+] = 1 \times 10^{-13}\,mol\,L^{-1}$

a) 0.1

c) pH = 13.

Q3

$n(NaOH) = 8g$ per 5L so $1.6 g L^{-1}$

$g L^{-1} \div m = 1.6 \div 40 = 0.04 mol L^{-1}$.

$10^{-14} = [OH^-][H^+] = 10^{-14} = [0.04][H^+]$

$H^+ = 2.5 \times 10^{-13} mol L^{-1}$ $pH = 12.6$

Q4

$n(KOH) = 0.561 g$ per 200ml, so $0.561 \times 5 = 2.805 g L^{-1}$

$2.805 g L^{-1} \div 56.1 = 0.05 mol L^{-1}$.

$10^{-14} = [0.05][H^+]$ $H^+ = 2 \times 10^{-13}$ $pH = 12.70$

Q5

$n(Ca(OH)_2) \times 2 = n(OH^-)$ $6.5 \times 10^{-4} \times 2 = 0.0013 mol L^{-1}$

$10^{-14} = [OH^-][H^+] = 0.0013 [H^+]$ $H^+ = 7.69 \times 10^{-12} mol L^{-1}$

$pH = 11.11$.

Q6

$pH = 2.8$ so $2.8 = -\log[H^+]$

$10^{-2.8} = 1.58 \times 10^{-3} mol L^{-1}$

Q7

$pH = 7.4$ so $10^{-7.4} = 3.98 \times 10^{-8} mol L^{-1} = [H^+]$

so $10^{-14} = 3.98 \times 10^{-8} [OH^-] = 2.51 \times 10^{-7} mol L^{-1}$

Q8

$10^{-14} = [0.3][OH^-] = 3.33 \times 10^{-14} mol L^{-1}$

Q9 $[OH^-]$ $1.06 \times 10^{-5} \times \frac{1000}{300} = 3.53 \times 10^{-5} g L^{-1} \div 56.1 = 6.30 \times 10^{-7} mol L^{-1}$

$10^{-14} = 6.3 \times 10^{-7} [H^+] = 1.587 \times 10^{-8} = pH\ 7.8$ basic

Q10 $8.5 = -\log[H^+] = 3.16 \times 10^{-9} mol L^{-1}$, so $10^{-14} = [OH^-] 3.16 \times 10^{-9} = 3.16 \times 10^{-6} mol L^{-1}$

Q11 $1.7 = -\log[H^+] = 0.02 mol L^{-1}$, so $10^{-14} = [OH^-] 0.02 = 5 \times 10^{-13} mol L^{-1}$

Set 3.

Q1. What is the pH of each of the following solutions?

A. 0.01 mol L^{-1} HCl
B. 0.1 mol L^{-1} solution of a monoprotic acid which is 20% ionised.
C. A solution of HCl containing 2 g of HCl per litre.
D. A solution containing 2 g NaOH per litre.
E. A solution containing 0.63 g of HNO_3 in 500 mLs of solution.
F. A 0.01 mol L^{-1} solution of ethanoic acid (CH_3COOH) given that it is 4.2% ionised at this concentration.

Q2. Calculate the hydrogen ion concentration of solutions whose pH values are

A. 4.3 B. 10.7 C. 7 D. 0

Q3. A. Calculate the pH of a solution obtained by adding 49 mLs of 0.15 mol L^{-1} NaOH to 50 mLs of 0.12 mol L^{-1} HCl.

B. Calculate the pH of a solution obtained by adding 19.4 mLs of 0.072 mol L^{-1} $Ba(OH)_2$ to 27.8 mLs of 0.058 mol L^{-1} HCl.

Q4. Arrange the following 0.1 M solutions in order of increasing pH

$NaCl$ NH_4Cl NaOH HCl NH_3 CH_3COOH

Q5. A. Explain why the pH of 0.1 mol L^{-1} HCl is 1.0 while that of 0.1 mol L^{-1} CH_3COOH is 2.87.

B. Why is a solution of iron(III) chloride acidic?

Q6. Calculate the pH of the solutions formed when 50 mLs of 0.1 mol L^{-1} HCl is added to each of the following

A. 49.5 mls 0.23 mol L^{-1} NaOH
B. 25.0 mls 0.15 mol L^{-1} $Ba(OH)_2$
C. 13.6 mls 0.042 mol L^{-1} KOH
D. 24.7 mLs 0.059 mol L^{-1} HNO_3
E. 14.8 mLs 0.037 mol L^{-1} NaOH and 15.0 mls 0.14 mol L^{-1} $Ca(OH)_2$

EXTENSION – [note i) and ii) contain information you need to calculate both questions.]

F. i) 150mls Ethanoic acid pH = 2.74 (hint use Ka expression to start you off).

ii) and what is the concentration of ethanoate ions at equilibrium if the number of ethanoic acid molecules increases to = 3.9394×10^{-4} moles?

Remember this is an EXOTHERMIC REACTION and so the temperature of this solution will change and change the Ka value also.

Answers:
Set 1

1. 1×10^{-13} $molL^{-1}$
2. $[H^+] [OH^-] = 10^{-14}$; $[H^+] = [OH^-]$; $[H^+]^2 = 10^{-14}$; $\sqrt{[H^+]^2} = [H^+] = \sqrt{10^{-14}} = 10^{-7}$
3. 4×10^{-14} $molL^{-1}$
4. A. 0.067 $molL^{-1}$ B. 1.5×10^{-13} $molL^{-1}$
5. A. 0.8 $molL^{-1}$ B. 1.25×10^{-14} $molL^{-1}$
6. A. 5×10^{-14} $molL^{-1}$ B. 5.5×10^{-15} $molL^{-1}$
7. $K_w = [H^+] [OH^-] = 10^{-14}$. The value of the equilibrium constant is constant (same) at a specified temperature.
8. pH = – 1.07; $[OH^-] = 8.55 \times 10^{-16}$ $molL^{-1}$

Set 2

1.	A.	1.0	B.	0.60	C.	11.6	D.	1.18		
	E.	0.40	F.	0.26	G.	– 1.07	H.	4.9		
2.	A.	0.1	B.		1×10^{-13}			C.	11.6	
3.	A.	0.04 $molL^{-1}$	B.		2.5×10^{-13} $molL^{-1}$			C.	12.6	

4. 12.7
5. 11.1
6. 1.58×10^{-13} $molL^{-1}$
7. $[H^+] = 3.98 \times 10^{-8}$ $molL^{-1}$; $[OH^-] = 2.51 \times 10^{-7}$ $molL^{-1}$
8. $[H^+] = 0.3$ $molL^{-1}$; $[OH^-] = 3.33 \times 10^{-14}$ $molL^{-1}$
9. 9.8; slightly alkaline
10. $[H^+] = 3.16 \times 10^{-8}$ $molL^{-1}$ $[OH^-] = 3.16 \times 10^{-8}$ $molL^{-1-1}$
11. $[H^+] = 0.02$ $molL^{-1}$; $[OH^-] = 5.0 \times 10^{-13}$ $molL^{-1}$

Set 3

1. A. 2.00 B. 1.70 C. 1.26 D. 12.7 E. 1.70 F. 3.38
2. A. 5.01×10^{-5} B. 2.00×10^{-11}
   C. 10^{-7} D. 10^0 or 1
3. A. 12.1 B. 12.4
4. HCl CH_3COOH NH_4Cl $NaCl$ NH_3 $NaOH$
5. A. The $[H^+]$ in HCl = 0.1 $molL^{-1}$ because it is fully dissociated into ions whereas the $[H^+]$ in CH_3COOH = 0.00132 $molL^{-1}$ because it is only partially dissociated into ions, much of the ethanoic acid remaining as molecular CH_3COOH.
   B. Fe^{3+} ions react with water forming H+ ions according to the following equation
   $Fe^{3+}_{(aq)} + 3H_2O_{(l)} \rightarrow Fe(OH)_{3(s)} + 3H^+_{(aq)}$
6. A. 12.8 B. 12.5 C. 1.16 D. 1.06 E. 2.50

   F. CH_3COOH $Ka = [H^+][CH_3COO^-] / [CH_3COOH]$

pH = $-\log_{10}[H^+] = 2.74$
$[H^+] = 10^{[-2.74]} = 1.8197 \times 10^{-3}$ $molL^{-1}$
$[H^+] = [CH_3COO^-] = [CH_3COOH]$ (due to mole ratio in expression)
$n(H^+) = cV = 0.2 \times 1.8197 = 3.6394 \times 10^{-4}$ moles

$n(H^+)$ in HCl = cV = 0.05 x 0.1 = 0.005 or 5×10^{-3} moles added

	$[H^+]$	$[CH_3COO^-]$	$[CH_3COOH]$
n(Initial)	3.6394×10^{-4}	3.6394×10^{-4}	3.6394×10^{-4}
n(Change)	0.00036394 + 0.005 = 0.00536394	3.6394×10^{-4}	3.6394×10^{-4}
n(Equilibrium)	$5.36394 \times 10^{-3} - 0.0300 \times 10^{-3}$ = 5.06394×10^{-3} (due to mole ratio)	$3.6394 \times 10^{-4} - 0.300 \times 10^{-4}$ = 3.39×10^{-4} moles	(in question ii) 3.9394×10^{-4}

$[H^+] = 5.06394 \times 10^{-3} / 0.2 = 2.532 \times 10^{-3}$ $molL^{-1}$.

pH = $-\log_{10}[H^+] = -\log_{10}[2.532 \times 10^{-3}] = 2.5965$

$[CH_3COO^-] = n/V = 3.39 / 0.2 = 1.695 \times 10^{-3}$ $molL^{-1}$

Set 3

Q1

a) $pH = -\log(0.01) = 2$

b) $0.2 \times 0.1 = 0.02 \text{ mol L}^{-1} = 1.70$

c) $2 \text{ g L}^{-1} \div M_r\ 36.45 = 0.055 \text{ mol L}^{-1} = 1.26 \text{ pH}$.

D) $2 \text{ g L}^{-1} \div 40 = 0.05 \text{ mol L}^{-1}$, $10^{-14} = [H^+][0.05]$

$= 2 \times 10^{-13} = \text{pH } 12.70$.

E) $0.63 \text{ g in } 0.5 \text{ L} = 1.26 \text{ g L}^{-1} \div 63 = 0.02 \text{ mol L}^{-1} = 1.7 \text{ pH}$

F) $0.01 \times 4.2\% = 0.00042 \text{ mol L}^{-1}$ $pH = 3.38$,

Q2

a) $pH = -\log[H^+] = 5 \times 10^{-5} \text{ mol L}^{-1}$

b) $10.7 \times -1 = -10.7 \Rightarrow 10^x = 2 \times 10^{-11} \text{ mol L}^{-1}$

c) $1 \times 10^{-7} \text{ mol L}^{-1}$ d) 1 mol L^{-1}

Q3

a)

NaOH	KCl
$n = cV$	$n = cV$
$= 0.15 \times 0.049$	$= 0.12 \times 0.05$
$= 0.00735$ mols	$= 0.006$ mols

LR KCl, excess OH^- ions $0.00735 - 0.006$
$= 0.00135$ mol

$n(OH^-) = cV$
$0.00135 = c \times 0.099$
$c(OH^-) = 0.0136 \text{ mol L}^{-1}$

$10^{-14} = [H^+]\ 0.0136$
$H^+ = 7.35 \times 10^{-13} \text{ mol L}^{-1}$ pH = 12.1

b)

$Ba(OH)_2$	KCl
$n = cV$	$n = cV$
$n = 0.072 \times (19.4 \times 10^{-3})$	$n = 0.058 \times (27.8 \times 10^{-3})$
$n = 0.0013968$ mols	$n = 0.0016124$

$n(OH) = 2 \times n(Ba(OH)_2)$
$= 0.0027936$ mols

$\therefore$ KCl LR.

excess OH^- ions $0.0027936 - 0.0016124 = 0.0011812$ mols.

$n(OH^-) = c \times 0.0472$
$= 0.025 \text{ mol L}^{-1}$

$\rightarrow 10^{-14} = [H^+]\ 0.025$
$= 4 \times 10^{-13} = 12.4 \text{ pH}$.