Student Name: [redacted]

Student Number: [redacted]

Partner's Name and Student #: [redacted]

Demonstrator's Name: [redacted]

PLEASE NOTE: **If ANY of the above information is UNCLEAR or not provided, your grade will NOT be recorded!!**

Lab Day (circle): [redacted]

Lab Week (circle): [redacted] [redacted]

Laboratory Report Form

Experiment 4.

Equilibria

Checklist:

- ○ **Raw Data Sheet written in pen, signed by TA and attached**
- ○ **Completed Report Form attached**

Student's Initials: [redacted]

Table 1. Observations and Discussion

$[Cu(H_2O)_4]^{2+}$ (aq) + 4 NH_3 (aq) ≈ $[Cu(NH_3)_4]^{2+}$ (aq) + 4 H_2O (l) • $CuSO_4$ is a clear solution with a blue tint and a slight odour • Concentrated NH_3 is a clear solution with a very strong chemical, corrosive smell • Upon mixing the solution turned dark blue-purple in colour with a very strong smell • The $[Cu(NH_3)_4]^{2+}$ (aq) complex is a dark blue-purple substance because after reaction the remaining substances must combine to make the dark blue colour • The solution would contain a light blue substance, a clear substance, another clear substance and the $[Cu(NH_3)_4]^{2+}$ substance, therefore its colour must be dark blue • After the previous reaction had been completed, HCl (a clear, colourless, corrosive, 1mol/Litre, slightly smelling, substance) was added to solution • When adding HCl the solution turned from dark blue to a light opaque blue, and then to a clear solution with a blue tint with the addition of extra HCl • This process took approximately 30 drops of HCl and created a solution much like the $CuSO_4$ with a slight smell • With the addition of the HCl the $[Cu(NH_3)_4]^{2+}$ complex was altered into a new complex which would create the light opaque blue colour, and then again into the original clear light blue substance • In other words, the reverse reaction had taken place by the addition of HCl • HCl being added to the solution is an acid, which neutralized some of the base (NH_3) in solution and caused the reaction to happen in the opposite direction • When more HCl was added it caused the reaction to favour the reactants, and produce more $CuSO_4$ giving the solution the clear blue colour observed • At an intermediate stage, there is a salt being produced from the neutralization of NH_3 and HCl (NH_4Cl) • The salt dissolved with the addition of extra HCl however at the intermediate stage the salt is what gave the substance the milky white colour
2$AgNO_3$ (aq) + Na_2CO_3 (aq) ≈ Ag_2CO_3 (s) + 2 $NaNO_3$ (aq) • 0.1 mol/Litre Na_2CO_3 is a clear, colourless solution with no smell • 0.01 mol/Litre $AgNO_3$ is clear with a slight dark tinge and a slight smell • Upon mixing turned light opaque brown, with visible precipitate floating on top,

and no smell

- The mixing of the two substances created $NaNO_3$ which must be what gave the solution a brown colour because the only other product in the reaction was the Ag_2CO_3 which is a solid and therefore must be the precipitate observed in the reaction

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$$2\ H^+\ (aq)\ +\ CO_3^{2-}\ (aq)\ \approx\ H_2CO_3\ (aq)\ \approx\ H_2O\ (l)\ +\ CO_2\ (g)$$

- 6 mol/Litre HNO_3 is very corrosive, clear, colourless, and has a very strong stinky smell
- Upon mixing solution turned clear, slightly translucent, and colourless
- The final products in the reaction include H_2O, CO_2 gas, and H_2CO_3
- Since water is a clear and colourless solution, and carbon dioxide is a gas, the H_2CO_3 must have been what gave the solution a murky translucent appearance
- The reason H_2CO_3 is still found in solution is due to a very large rate constant of 21 s^{-1} causing the equilibrium to be reached very slowly and have the H_2CO_3 still visible (Wikipedia, *Carbonic Acid*)

$$Ag^+\ (aq)\ +\ Cl^-\ (aq)\ \approx\ AgCl\ (s)$$

- 0.1 mol/Litre HCl is a clear colourless solution with a slightly corrosive smell
- 3 drops of HCl were added and upon mixing, solution turned opaque white with no smell
- The HCl dissociated in solution and the resulting Cl^- ion paired up with the pre-existing Ag^+ ion creating thee AgCl solid which gave the solution the opaque white colour observed

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$$Ag^+\ (aq) +\ 2NH_3\ (aq)\ \approx\ [Ag(NH_3)_2]^+\ (aq)$$

- After the completion of the previous reaction, 7 drops of concentrated NH_3 were added, turning the solution clear and colourless with a strong chemical smell
- Adding 30 drops of 6 mol/Litre HNO_3 turned the solution to an opaque white colour once again
- By adding the NH_3 we are using up more of the available Ag^+ ions to create a new substance $[Ag(NH_3)_2]^+$ which must be a clear and colourless solution due to the colour changes observed
- Due to the multiple equilibrium reactions occurring the solution should contain

the AgCl solid from the previous reaction, therefore since no solid was observed in the solution the AgCl must have dissolved in the NH_3 added

- By adding HNO_3 (acid), we are neutralizing the base NH_3 and reversing the previous reaction
- Since the NH_3 is being used by the neutralization reaction occurring, the AgCl solid can no longer be dissolved in NH_3 and we therefore see the white milky (opaque) colour again

$$H^{+}\,(aq) + NH_3\,(aq) \approx NH_4^{+}\,(aq)$$

- The addition of 4 more drops of concentrated NH_3 turned the solution back to a clear, colourless solution with a strong chemical smell
- By adding the NH_3 once again, the AgCl solid can dissolve in the NH_3 causing the appearance of the solution to return to a clear colourless state

$$Ag^{+}\,(aq) + I^{-}\,(aq) \approx AgI\,(s)$$

- 0.1 mol/Litre KI is a clear, colourless solution with a chemical smell
- When mixing into the solution, after 5-10 drops the solution turned translucent white with a yellow tint
- When KI was added to the solution it dissociated into its ions due to its very high Ksp value of 59 and allowed the above reaction to occur
- When mixing, the Ag^{+} ions and I^{-} ions paired to form the AgI solid with a Ksp value of 8.5×10^{-17}
- Since the Ksp value of the AgI solid is very low, it can be seen as the yellow colour observed in the solution

$$2Ag^{+}\,(aq) + S^{2-}\,(aq) \approx Ag_2S\,(s)$$

- Na_2S is a clear, colourless solution with a strong smell of rotten eggs
- Upon mixing about 10 drops, the solution turned grey-brown with the smell of rotten eggs and containing a dark precipitate
- After reacting, a new complex, Ag_2S, was formed, with a very low Ksp value of 8.0×10^{-51}
- This explains why the solution was observed to be brown in colour due to the previous yellow solid, and the newly formed black solid in solution combining to make the brown colour with a dark precipitate floating in it
- Sulphur in the Ag_2S and the free sulphur ions in solution are giving the solution

the characteristic rotten egg smell

$$CH_3COOH\ (aq)\ +\ H_2O\ (l)\ \approx\ H_3O^+\ (aq)\ +\ CH_3COO^-\ (aq)$$

- CH_3COOH is a clear, colourless solution with a vinegar smell
- Universal indicator is a clear red solution with the smell of a red frozen treat
- pH paper started yellow
- pH in well 1 (CH_3COOH and indicator): 3
- pH in well 2 (CH_3COOH and indicator): 3
- 0.1 mol/Litre $NaCH_3COO$ is a clear, colourless solution with no smell
- Upon addition solutions turned orange, with the smell of an orange frozen treat
- pH in well 1; 4
- pH in well 2: 4
- Creating 2 distilled water wells, pH in wells 3 and 4 was 6
- Adding 0.1 mol/Litre HCL to wells 1 and 3, well 1 turned slightly more pink, and well 3 turned slightly more red in colour
- pH in well 1: 4
- pH in well 3: 3
- Adding 0.1 mol/Litre NaOH to wells 2 and 4, well 2 turned a clear orange peach colour, while well 4 turned purple in colour
- Well 2 had the smell of a peach flavour frozen treat, and well 4 had the smell of a grape flavour frozen treat
- pH of well 2 was 5
- pH of well 4 was 13

$$4Cl^-\ (aq)\ +\ [Co(H_2O)_6]^{2+}\ (aq)\ \approx\ [CoCl_4]^{2-}\ (aq)\ +\ 6\ H_2O\ (l)$$

- 1 mol/Litre $CoCL_2$ was a dark purple-red, translucent substance with an earthy smell
- 12 molar HCL was clear in colour, transparent, with a very strong chemical smell
- Upon mixing, solution turned dark purple in colour, clear, with a chemical smell
- Upon adding 10 drops of distilled water, solution turned pink, with a sweet, chemical smell
- The addition of a common Cl ion in the reaction caused a shift towards the products, making more of the $[CoCl_4]^{2-}$ with dark purple characteristics, and more H_2O molecules

• The combination of the dark purple and water made the pink colour observed
$4\ Br^{-}\ (aq)\ +\ [Cu(H_2O)_4]^{2+}\ (aq)\ \approx\ [CuBr_4]^{2-}\ (aq)\ +\ 4\ H_2O\ (l)$ • $CuBr_2$ is a dark grey-blue, shiny, solid substance with no smell • Adding 5 drops of distilled water to the solid turned the solution to a dark rusty colour • Adding 10 more drops of distilled water dissolved the metal, and turned the solution to a clear teal colour • Adding 5 more drops of distilled water turned the solution into a clear, blue colour • KBr is a white crystal structure with a pink colour • Dissolved in distilled water • Solution from step 25 mixed with KBr in a hot water bath turned to a lime green colour • 1 mol/ Litre $CoCl_2$ in a hot water bath turned darker and more purple in colour • The addition of heat in both reactions favoured the forward reaction acting as a catalyst and shifting equilibrium to favour the products

Calculations

1. pH of water = 6.0
2. pH of buffer=

$CH_3COOH + H2O \rightleftharpoons H_3O^+ + CH_3COO^-$
[HA] [H3O+]$^+$ [A-]

$C_i V_i = C_f V_f$
$C_f = (C_i V_i)/V_f$
$= [CH_3COO^-]$
=(0.1M x 10drops)/(20 drops)
= 0.05M

pH = pKa + log([A-]/[HA]) = pKa + log(0.05/0.05)
= pKa + log(1)
= pKa
= -log(Ka)
= $-\log(1.8 \times 10^{-5})$
= 4.75

3. pH of Water + Acid

water = 20 drops
acid (HCl) = 5 drops
HCl = 0.1 mol/Litre

$C_i V_i = C_f V_f$
$[HCl]_f = [HCl]_i \times V_i/V_f$
= 0.01 mol/Litre x (5 drops/25 drops)
= 0.02 mol/Litre

pH = -log[H+] = -log(0.02)
pH = 1.70

4. pH of water + Base

$C_i V_i = C_f V_f$

$[OH^-] = [NaOH] = C_f = (C_i V_i)/V_f$
$= (0.1\ M \times 5\ drops)/25\ drops$
$= 0.02\ M$

$pOH = -\log[OH^-]$
$= -\log(0.02\ M)$
$= 1.70$

$pH = 14 - pOH$
$= 14 - 1.70$
$= 12.3$

5. pH of buffer and acid

	HCl	+ CH_3COO^-	➔ $CH_3COOH + Cl^-$
0.1 M	(5drops/25drops)	0.05(20/25)	0.05(20/25)
I	0.02	0.04	0.04
C	-0.02	-0.02	+0.02
E	0	0.02	0.06

$pH = pKa + \log([A^-]/[HA])$
$= pKa + \log(0.02/0.06)$
$= -0.477121255 + 4.744727495$
$= 4.27$

6. pH of buffer and base

$C_i V_i = C_f V_f$
$[NaOH]_f = [NaOH]_i \times V_i/V_f$
$= 0.02\ mol/Litre \times (25\ drops/35\ drops)$
$= 0.014\ mol/Litre$

$C_i V_i = C_f V_f$
$[CH_3COONa]_f = [CH_3COONa]_i \times V_i/V_f$
$= 0.1\ mol/Litre \times (10\ drops/35\ drops)$
$= 0.029\ mol/Litre$

$C_i V_i = C_f V_f$

$[CH_3COOH]_f = [CH_3COOH]_i \times V_i/V_f$

= 0.1 mol/Litre x (10 drops/35 drops)

= 0.029 mol/Litre

	CH_3COOH	+	NaOH	→	CH_3COONa	+	H_2O
I	0.029		0.014		0.029		
C	-0.014		-0.014		+0.014		
E	0.015		0		0.043		

$pH = pKa + \log([HA/[A^-])$

$= pKa + \log(0.043/0.015)$

$= -\log(1.8 \times 10^{-5}) + \log(0.043/0.015)$

$= 5.20$

7. pH of water + acid – pH of water = -4.3

8. pH of water + base – pH of water = 6.3

9. pH of buffer + acid – pH of buffer = -0.48

10. pH of buffer + base – pH of buffer = 0.45

Conclusion:

To conclude, equilibrium shift will occur if the concentrations of either reactants or products are changed. Multiple equilibria can occur if there are more than one equilibrium reactions proceeding within a solution using the same ion. Adding a strong acid or a base to a buffer solution changes the amount that the acid or base affects the pH of the solution. The addition of a common ion will cause an equilibrium shift in reaction. Increasing the temperature of an equilibrium system will also cause an observable equilibrium shift towards the products.

Raw data:

[redacted]

Observations Raw Data

[redacted]

Equilibrium Shift

- $CuSO_4$ is clear with blue tint slight smell
- concentrated NH_3 is clear, very strong smell chemical corrosive, corrosive
- upon mixing solution turned dark blue - purple - still smells very strong chemi
- 1mol/L HCl is clear, slight smell, corrosive
- upon mixing turned light opaque blue, and then clear with blue tint much like original $CuSO_4$, around 30 drops, slight smell
- repeating steps 2 & 3 - turns dark blue once again very strong smell
  - no definite change upon adding 1mol HCl in color, however smell is almost gone, changed clear in colour after about 60 drops

Multiple Equilibria

- 0.1mol/L Na_2CO_3 - clear, colourless, no smell
- 0.01 mol/L $AgNO_3$ is clear, slight dark tinge, slight smell

upon mixing turned light brown, visible pieces floating on top, no smell, opaque.

- 6 mol/L HNO_3 is very corrosive, ~~clear~~ clear and colorless, smells stinky
- upon mixing, solution turned clear, slightly translucent, and colorless

- 0.1 mol/L HCl, clear, colorless, slight corrosive smell

- 3 drops, upon mixing solution turned opaque white, no smell
- add 7 drops concentrated NH_3 turned clear, colorless, ~~[illegible]~~ chemical smell

repeat 2+3
- add 30 drops 6mol/L HNO_3, turned solution opaque white
- add 4 drops NH_3, turned clear, strong chemical smell, colorless

[redacted]

- 0.1 mol/L KI clear, colorless, chemical smell
- when mixing after 8-10 drops solution turned translucent white with yellow tint.

- Na_2S clear, colorless, smell of rotten eggs
- upon mixing turned grey-brown, after 10 drops, smells of rotten eggs
- dark precipitate in the solution

Buffer Solution Prep

- CH_3COOH, clear, colorless, vinegar smell

Well 1 Well 2

- universal indicator is red, clear, smells like red freeze & vodka
- upon mixing solutions turned pink
- pH paper started yellow
  - pH in well 1: 3
  - pH in well 2: 3

- 0.1 mol/L $NaCH_3COO$ is clear, colorless, no smell
- solutions turned orange, well 1 pH 4, smells like orange freeze
  well 2 pH 4

~~After adding distilled water & indicator pH in each well remained ...~~

creating two distilled water wells, pH in wells 3 & 4 was 6

added 0.1 mol/L HCl to wells 1 & 3, well 1 turned slightly more pink, well 3 turned slightly more red
well 1 - pH 4
well 3 - pH 3

- add NaOH to wells 2 & 4
  0.1 mol

- when adding well 2 turned orange peach color, clear white
  well 4 turned purple.

well 2 - smells like peach freeze — well 2 - pH: 5
well 4 - smells like grape freeze — well 4 - pH: 13

- 1 mol/L $CoCl_2$ dark [purple-] red, translucent, earthy smell

-add 12 Molar HCl clear in color, transparent, very strong chemical smell

- upon mixing solution turned dark purple, clear, chemical smell

-add 10 drops distilled water, solution turned pink, sweet, chemical smell

$CuBr_2$ - dark grey-blue, shiny solid, no smell

-add 5 drops water - solution turned dark rusty color

-add 10 drops distilled water - solution turned clear, teal color, metal dissolved

-add 5 more drops to total 2 mL - solution is clear, blue color.

-KBr - white crystals with slight pink color - dissolved in distilled water

- in hot water, solution turned to lime green

1mol/L $CoCl_2$ in hot water bath turned darker and more purple in color

[redacted]