Answer all questions. Be careful to give your final answer to the correct sig. figs.

1. a) ***(3 points)*** The acetate ion (CH_3COO^-) is a weak base. Write down the base-ionization equation for CH_3COO^- in water.

$$CH_3COO^- (aq) + H_2O (l) \rightleftharpoons CH_3COOH (aq) + OH^- (aq)$$

b) ***(2 points)*** Complete the expression for the base-ionization constant (K_b) for CH_3COO^-.

$$K_b = \frac{[CH_3COOH][OH^-]}{[CH_3COO^-]}$$

c) ***(5 points)*** Calculate the pH of a 0.40 M solution of CH_3COO^- (K_a for $CH_3COOH = 1.8 \times 10^{-5}$).

$$CH_3COO^- (aq) + H_2O (l) \rightleftharpoons CH_3COOH (aq) + OH^- (aq)$$

	CH_3COO^-	H_2O	CH_3COOH	OH^-
I	0.40	-	0	0
C	-x		+x	+x
E	(0.40-x)	-	x	x

K_b for $CH_3COO^- = K_w/K_a (CH_3COOH) = (1.0 \times 10^{-14})(1.8 \times 10^{-5}) = 5.6 \times 10^{-10}$

$K_b = x^2/(0.40-x) \approx x^2/0.40$ ∴ $x = [OH^-] = 1.50 \times 10^{-5}$

∴ pOH = 4.82 ∴ **pH = 9.18**

2. a) ***(3 points)*** Calculate the pH when 100 mL of 0.100 M $Ca(OH)_2$ solution is added to 50 mL of 0.400 M HCl solution.

$$Ca(OH)_2 (s) + H_2O (l) \rightarrow Ca^{2+} (aq) + 2\ OH^- (aq)$$

$$HCl (g) + H_2O (l) \rightarrow H_3O^+ (aq) + Cl^- (aq)$$

$n(OH^-) = MV = (2)(0.100\ M)(100 \times 10^{-3}\ L) = 0.200$ moles

$n(H_3O^+) = MV = (0.400\ M)(50 \times 10^{-3}\ L) = 0.20$ moles

∴ OH^- and H_3O^+ neutralize exactly ∴ **pH = 7.00**

b) ***(2 points)*** Which one of the following salts will give a basic solution when dissolved in water? Circle your choice.

$CaCl_2$, NH_4Cl, $NaClO_4$, **[Na_2CO_3]**, KI, none of these

(2 points) Write an equation for the reaction that occurs when the salt dissolves in water and makes the solution basic, or state why none do.

$$CO_3^{2-} (aq) + H_2O (l) \rightleftharpoons HCO_3^- (aq) + OH^- (aq)$$

c) ***(2 points)*** Which one of the following salts will give an acidic solution when dissolved in water? Circle your choice.

$Ca_3(PO_4)_2$, NaBr, **[$FeCl_3$]**, NaF, KNO_2, none of these

(2 points) Write an equation for the reaction that occurs when the salt dissolves in water and makes the solution acidic, or state why none do.

$$FeCl_3 (s) + 6\ H_2O (l) \rightarrow [Fe(H_2O)_6]^{3+} (aq)$$

Then, $[Fe(H_2O)_6]^{3+} + H_2O (l) \rightleftharpoons [Fe(H_2O)_5(OH)]^{2+} + H_3O^+ (aq)$

3. (a) (8 points) What is the pH of a buffer solution prepared from adding 60.0 mL of 0.36 M ammonium chloride (NH_4Cl) solution to 50.0 mL of 0.54 M ammonia (NH_3) solution? (K_b for NH_3 is 1.8×10^{-5}).

new volume (V_f) = (60.0 + 50.0) mL = 110.0 mL

$$\text{new } [NH_4^+] = \frac{M_iV_i}{V_f} = \frac{(0.36\text{ M})(60.0\text{ mL})}{110.0\text{ mL}} = 0.196\text{ M}$$

$$\text{new } [NH_3] = \frac{M_iV_i}{V_f} = \frac{(0.54\text{ M})(50.0\text{ mL})}{110.0\text{ mL}} = 0.245\text{ M}$$

$K_a(NH_4^+) = K_w/K_b(NH_3) = (1.0 \times 10^{-14})/(1.8 \times 10^{-5}) = 5.6 \times 10^{-10}$

$$pH = pK_a + \log\frac{[\text{base}]}{[\text{acid}]} = 9.25 + \log\frac{[0.245]}{[0.196]} = 9.25 + 0.097 = \boxed{9.35}$$

OR

$n(NH_4^+) = MV = (60.0\text{ mL})(10^{-3}\text{L/mL})(0.36\text{ M}) = 2.16 \times 10^{-2}$ mol

$n(NH_3) = (50.0\text{ mL})(10^{-3}\text{L/mL})(0.54\text{ M}) = 2.70 \times 10^{-2}$ mol

$K_a(NH_4^+) = K_w/K_b(NH_3) = (1.0 \times 10^{-14})/(1.8 \times 10^{-5}) = 5.6 \times 10^{-10}$

$$pH = pK_a + \log\frac{n(\text{base})}{n(\text{acid})} = 9.25 + \log\frac{2.70\times10^{-2}}{2.16\times10^{-2}} = \boxed{9.35}$$

OR after calculating new [ ]'s in the first part:

NH_3 (aq) + H_2O(l) ⇌	NH_4^+ (aq) +	OH^- (aq)
0.245 M	0.196 M	0
-x	+x	+x
(0.245-x)	(0.196+x)	x

$$K_b = 1.8 \times 10^{-5} = \frac{x(0.196+x)}{(0.245-x)} \approx \frac{0.196x}{0.245} \therefore x = 2.25 \times 10^{-5}\text{ M} = [OH^-]$$

$\therefore pOH = -\log 2.25 \times 10^{-5} = 4.65$

$\therefore \boxed{pH = 9.35}$

(b) (13 points) What is the final pH after 10.0 mL of 0.200 M NaOH solution is added to a 50.0 mL solution of 0.400 M acetic acid (CH_3COOH)? K_a for acetic acid is 1.8×10^{-5}.

new volume (V_f) = (10.0 + 50.0) mL = 60.0 mL

$n(CH_3COOH) = MV = (0.400\text{ M})(50.0\text{ mL}(10^{-3}\text{ L/mL}) = 20.0 \times 10^{-3}$ mol

$n(OH^-\text{ added}) = MV = (0.200\text{ M})(10.0\text{ mL})(10^{-3}\text{ L/mL}) = 2.00 \times 10^{-3}$ mol

On mixing, 2.00×10^{-3} mol of OH^- will convert 2.00×10^{-3} mol of CH_3COOH to CH_3COO^-.

	CH_3COOH (aq)	+ OH^- (l)	⇌ CH_3COO^- (aq) + H_2O(l)
initial	20.0×10^{-3} mol	0	0
addition	-	2.00×10^{-3} mol	
final	18.0×10^{-3} mol	0	2.00×10^{-3} mol

new $[CH_3COOH] = n/V_f = (18.0 \times 10^{-3}\text{ mol})/(60.0\text{ mL})(10^{-3}\text{ L/mL}) = 0.300$ M

new $[CH_3COO^-] = n/V_f = (2.00 \times 10^{-3}\text{ mol})/(60.0\text{ mL})(10^{-3}\text{ L/mL}) = 0.033$ M

$$pH = pK_a + \log\frac{[\text{base}]}{[\text{acid}]} = 4.74 + \log\frac{[0.033]}{[0.300]} = 4.74 - 0.357 = \boxed{3.78}$$

OR CH_3COOH (aq) + H_2O(l) ⇌ CH_3COO^- (aq) + H_3O^+ (aq)

[I]	0.300 M		0.033 M	0
[C]	- x		+ x	+ x
[E]	(0.300 -x)		(0.033 + x)	x

$K_a = (0.033 + x)x/(0.300 - x) \approx 0.033x/0.300$ ∴ $x = [H_3O^+] = 1.636 \times 10^{-4}$

∴ **pH = 3.79** (same within rounding errors)

(c) (3 points) You don't have to add acid or base to a solution to change the pH, you can instead dilute the solution. What is the new pH if 100 mL of a solution of HCl with pH = 0.52 is diluted by addition of 200 mL of pure water?

original $[H_3O^+]$ = antilog(-pH) = 0.30 M

Use $M_iV_i = M_fV_f$ where V_f = 100 mL + 200 mL = 300 mL

∴ M_f = (0.30 M)(100 mL)/(300 mL) = 0.10 M

∴ new pH = -log(0.10) ∴ **pH = 1.00**

4. (5 points) Calculate the solubility of the salt M_3X_4 (containing M^{4+} and X^{3-} ions) if the $K_{sp} = 4.2 \times 10^{-8}$

M_3X_4 (s) ⇌ 3 M^{4+} (aq) + 4 X^{3-} (aq)

I	(solid)	0	0
C	-x	+3x	+4x
E	(solid)	3x	4x

$K_{sp} = 4.2 \times 10^{-8} = [M^{4+}]^3[X^{3-}]^4$

∴ $K_{sp} = (3x)^3(4x)^4$

∴ $4.2 \times 10^{-8} = 6912\ x^7$

$x^7 = 6.076 \times 10^{-12}$

∴ x = 0.025 M

solubility of M_3X_4 = 0.025 M