

1. An acid-base buffer consists of _____. (Pick the one answer that always is true.)

- (a) a weak acid.
- (b) a conjugate acid base pair. *← only correct if conj. acid/base pair of weak acid + weak base*
- (c) mixture of a weak acid and a weak base. *←*
- (d) a weak base.
- (e) a mixture of a strong acid and a strong base. *For example, HCl/Cl⁻ are conj. acid base pair, but they do not make a buffer*

2. What buffer component ratio, base/acid, is needed to make a pH 10.00 buffer solution using a mixture of [CH₃NH₃]Cl and CH₃NH₂?

- (a) 0.21
- (b) 3.7
- (c) 4.8
- (d) 0.27
- (e) 0.56

$$K_b \text{ of } \text{CH}_3\text{NH}_2 = 3.7 \times 10^{-4}$$

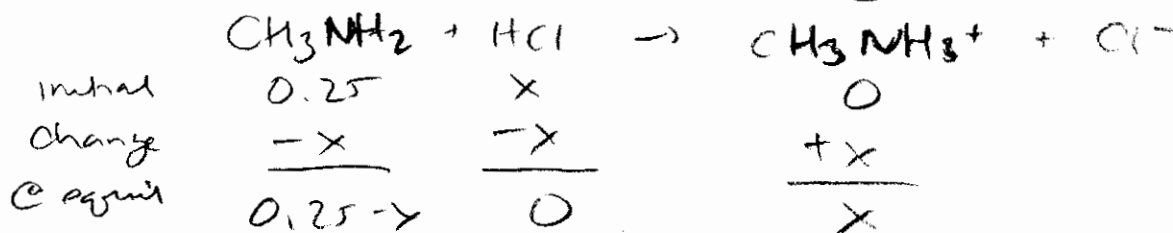
$$K_a \text{ of } \text{CH}_3\text{NH}_3^+ = \frac{K_w}{K_b} = \frac{1.008 \times 10^{-14}}{3.7 \times 10^{-4}} = 2.72 \times 10^{-11}$$

$$pK_a = -\log K_a = -\log (2.72 \times 10^{-11}) = 10.565$$

$$10^{(pH - pK_a)} = 10^{(10.00 - 10.565)} = 0.27$$

3. How many grams of HCl would need to be added to 250. mL of a 0.10 M aqueous solution of CH₃NH₂ to make a pH 10.00 buffer? [A longer question. You may want to come back to it.]

- (a) 5.7 g
- (b) 0.16 g
- (c) 37 g
- (d) 1.2 g
- (e) 0.72 g



$$250. \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}} \times \frac{0.10 \text{ mol CH}_3\text{NH}_2}{\text{L}} = 0.025 \text{ mol}$$

From previous question $\frac{\text{CH}_3\text{NH}_2}{\text{CH}_3\text{NH}_3^+} = 0.27 = \frac{0.025 - x}{x}$

$$0.27x = 0.025 - x$$

$$1.27x = 0.025$$

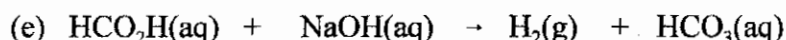
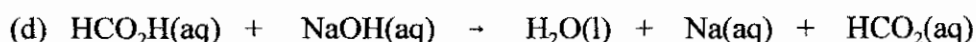
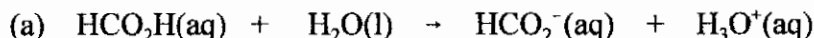
$$x = \frac{0.025}{1.27} = 0.0197 \text{ moles} \times \frac{36.461 \text{ g}}{\text{mol}} = \boxed{0.72 \text{ g}}$$

$$\text{mw HCl} = 1.008 + 35.453 = 36.461 \text{ g/mol}$$

Consider the following titration for the next 5 questions.

30.0 mL of 0.030 M formic acid, HCO_2H (in the flask), is titrated with 0.045 M NaOH (in buret).

4. What is the overall reaction occurring in the titration?



5. How many mL of the NaOH solution need to be added to reach the equivalence point of the titration?

- (a) 5.0 mL (b) 10.0 mL (c) 15.0 mL (d) 20.0 mL (e) 30. mL

See Form B # 2

6. Which of the following is present in the flask after 5.0 mL of the NaOH solution has been added? Mark all correct answers.

BEFORE EQUIV PT

- (a) $\text{HCO}_2\text{H}(\text{aq})$ (b) $\text{NaOH}(\text{aq})$ (c) $\text{HCO}_2(\text{aq})$
(d) $\text{Na}[\text{HCO}_2](\text{aq})$ (e) $\text{HCO}_3(\text{aq})$

same as $\text{Na}^+(\text{aq}) + \text{HCO}_2^-(\text{aq})$

7. How is the solution best characterized after 5.0 mL of the NaOH solution has been added?

- (a) solution of a strong acid (b) solution of a strong base
(c) solution of a weak acid (d) solution of a weak base
(e) buffer solution (ab) neutral solution

Mix of weak acid HCO_2H and its conj. acid HCO_2^- - makes buffer

Continuation of the titration question from the previous page:

30.0 mL of 0.030 M formic acid, HCO_2H (in the flask), is titrated with 0.045 M NaOH (in buret).

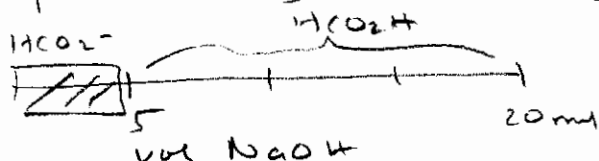
8. What is the pH of the solution in the flask after 5.0 mL of the NaOH solution has been added?

- (a) 3.26 (b) 9.78 (c) 1.71 (d) 4.22 (e) 10.74

buffer solution use Henderson Hasselbalch

$$\text{pH} = \text{pK}_a + \log \frac{\text{base}}{\text{acid}}$$

$$\text{pK}_a = -\log K_a = -\log (1.8 \times 10^{-4}) = 3.744$$

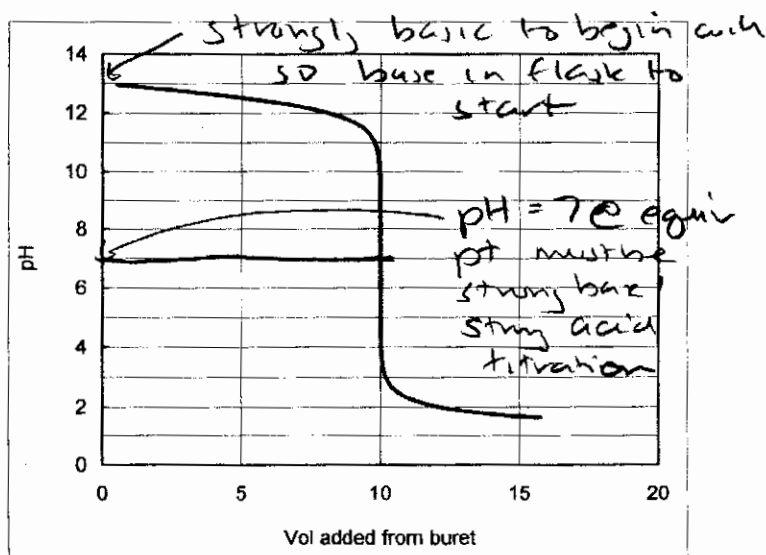


$$\frac{\text{mol base}}{\text{mol acid}} = \frac{1/4 \text{ orig mol HCO}_2\text{H}}{3/4 \text{ " " " "}} = \frac{1}{3} = 0.333$$

$$\text{pH} = 3.744 + \log(0.333) = \boxed{3.26}$$

9. Consider the adjacent titration curve. Which one of the following statement is true? The titration curve corresponds to the titration of a

- (a) weak acid (flask) with a strong base (buret).
 (b) weak base (flask) with a strong acid (buret).
 (c) strong acid (flask) with a strong base (buret).
 (d) strong base (flask) with a strong acid (buret).



10. What is the K_{sp} expression for chromium(III) fluoride?

(a) $[Cr^{3+}][F^-]$

(b) $[Cr^{3+}][F^-]^3$

(c) $[Cr^+]^3[F^{3-}]$

(d) $\frac{[Cr]^3[F]}{[Cr_3F]}$

(e) $\frac{[Cr_2F_3]}{[Cr^{3+}]^2[F^{2-}]^3}$



11. The solubility of chromium(III) fluoride in water at 25 °C is 1.25×10^{-3} M. What is the K_{sp} value for chromium(III) fluoride at this temperature?

(a) 6.6×10^{-11}

(b) 7.8×10^{-9}

(c) 1.6×10^{-6}

(d) 8.2×10^{-2}

(e) 5.6×10^{-7}

See Form B, # 16

12. What will happen if HCl is added to a saturated aqueous solution of chromium(III) fluoride in water? ("Saturated solution" means that there is solid chromium(III) fluoride present and the system is at equilibrium.) *See Form B, # 17*

(a) Nothing happens.

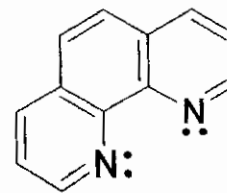
(b) The chromium(III) fluoride solubility equilibrium shifts to the RIGHT and more chromium(III) fluoride precipitates out of solution.

(c) The chromium(III) fluoride solubility equilibrium shifts to the LEFT and more chromium(III) fluoride precipitates out of solution.

(d) The chromium(III) fluoride solubility equilibrium shifts to the RIGHT and more solid chromium(III) fluoride dissolves.

(e) The chromium(III) fluoride solubility equilibrium shifts to the LEFT and more solid chromium(III) fluoride dissolves.

Consider the following for the next two questions. Iron (II) forms an orange-red complex ion with three phenanthrolines, abbreviated "phen". (Structure shown to the right.)



phen

13. What is the K_f expression for formation of the complex ion?
Careful. Some answers are very similar.

- (a) $\frac{[\text{Fe}(\text{phen})_3]}{[\text{Fe}][\text{phen}]^3}$ (b) $\frac{[\text{Fe}^{2+}]^3[\text{phen}]}{[\text{Fe}(\text{phen})_3^{2+}]}$
 (c) $\frac{[\text{Fe}(\text{phen})_3^{2+}]}{[\text{Fe}^{2+}][\text{phen}]^3}$ (d) $[\text{Fe}^{2+}][\text{phen}]^3$ (e) $\frac{[\text{Fe}(\text{phen})_3^{2+}]^3}{[\text{Fe}^{2+}][\text{phen}]}$

See Form B, # 10

14. The concentration of iron(II) can be determined by adding excess "phen" to an aqueous solution to form the colored complex ion. To do this analysis, a standard solution containing $4.46 \times 10^{-5} \text{ M Fe}^{2+}$ was prepared. After addition of excess phen, the absorption of the standard solution = 0.682 at 508 nm.

To determine $[\text{Fe}^{2+}]$ in an unknown solution, 5.00 mL of the solution was diluted to 25.0 mL. After addition of excess phen, the absorption of the standard solution = 0.264 at 508 nm. What is the $[\text{Fe}^{2+}]$ in the original (undiluted) solution?

- (a) $9.65 \times 10^{-4} \text{ M}$ (b) $4.83 \times 10^{-5} \text{ M}$ (c) $2.41 \times 10^{-6} \text{ M}$
 (d) $1.73 \times 10^{-5} \text{ M}$ (e) $8.63 \times 10^{-5} \text{ M}$

$$\rightarrow A = \epsilon l c \rightarrow \epsilon l = \frac{A}{c} = \frac{0.682}{4.46 \times 10^{-5}} = 1.529 \times 10^4$$

diluted sample

$$c = \frac{A}{\epsilon l} = \frac{0.264}{1.529 \times 10^4} = 1.727 \times 10^{-5} \text{ M} = c_{\text{dil}}$$

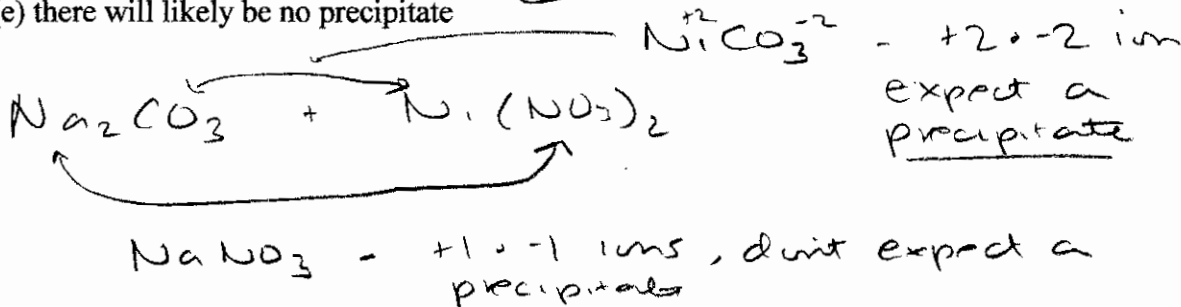
orig sample

$$c_{\text{conc}} V_{\text{conc}} = c_{\text{dil}} V_{\text{dil}}$$

$$c_{\text{conc}} = \frac{c_{\text{dil}} V_{\text{dil}}}{V_{\text{conc}}} = \frac{1.727 \times 10^{-5} \text{ M} (25.0 \text{ mL})}{(5.0 \text{ mL})} = \boxed{8.63 \times 10^{-5} \text{ M}}$$

15. Will mixing an aqueous solution of sodium carbonate and nickel(II) nitrate likely result in a precipitate? If so, what will precipitate?

- (a) Na_2NO_3 (b) $\text{Ni}(\text{CO}_3)_2$ (c) NiCO_3 (d) NaNO_3
 (e) there will likely be no precipitate



16. 5.00 mL of a 2.0×10^{-2} M sodium chloride solution is mixed with 5.00 mL of a solution containing 2.0×10^{-3} M copper(I) and 0.10 M lead(II). What happens?

K_{sp} of copper(I) chloride = 1.9×10^{-7} M and K_{sp} of lead(II) chloride = 1.7×10^{-5} M

- (a) nothing
 (b) only copper(I) chloride precipitates
 (c) only lead(II) chloride precipitates
 (d) both lead(II) chloride and copper(I) chloride precipitate

$[\text{Cl}^-] = \frac{\text{mol Cl}^-}{\text{tot V}} = \frac{(5.00 \text{ mL})(2.0 \times 10^{-2} \text{ M})}{10.0 \text{ mL}} = 1.0 \times 10^{-2} \text{ M}$

$[\text{Cu}^+] = \frac{\text{mol Cu}^+}{\text{tot V}} = \frac{(5.00 \text{ mL})(2.0 \times 10^{-3} \text{ M})}{10.0 \text{ mL}} = 1.0 \times 10^{-3} \text{ M}$

$[\text{Pb}^{2+}] = \frac{\text{mol Pb}^{2+}}{\text{tot V}} = \frac{(5.0 \text{ mL})(0.10 \text{ M})}{10.0 \text{ mL}} = 0.050 \text{ M}$

$\text{CuCl ion product} = [\text{Cu}^+][\text{Cl}^-] = (1.0 \times 10^{-3})(1.0 \times 10^{-2}) = 1.0 \times 10^{-5} > K_{sp}$

so CuCl precipitates

$\text{PbCl}_2 \text{ ion product} = [\text{Pb}^{2+}][\text{Cl}^-]^2 = (0.050)(1.0 \times 10^{-2})^2 = 5.0 \times 10^{-6} < K_{sp}$

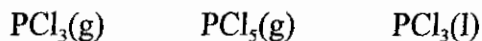
so PbCl_2 does NOT

17. All physical processes tend to towards higher entropy and lower energy. precipitates

The answers in order are

- (a) higher, lower (b) lower, higher (c) higher, higher (d) lower, lower

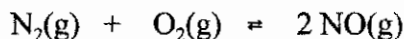
18. Place the following in order of increasing S°



- (a) $\text{PCl}_3(\text{g}) < \text{PCl}_5(\text{g}) < \text{PCl}_3(\text{l})$ (b) $\text{PCl}_5(\text{g}) < \text{PCl}_3(\text{g}) < \text{PCl}_3(\text{l})$
 (c) $\text{PCl}_3(\text{l}) < \text{PCl}_5(\text{g}) < \text{PCl}_3(\text{g})$ (d) $\text{PCl}_3(\text{l}) < \text{PCl}_3(\text{g}) < \text{PCl}_5(\text{g})$
 (e) $\text{PCl}_5(\text{g}) < \text{PCl}_3(\text{l}) < \text{PCl}_3(\text{g})$

See Form B, #18

Consider the following reaction for the next 2 questions.



19. What is ΔS° for the above reaction?

- (a) 185.8 J/K (b) 24.9 J/K (c) -185.8 J/K (d) -24.9 J/K
 (e) 421.4 J/K

$$\begin{aligned} \Delta S^\circ &= 2S^\circ_{\text{NO}(\text{g})} - S^\circ_{\text{N}_2(\text{g})} - S^\circ_{\text{O}_2(\text{g})} \\ &= 2(210.7 \text{ J/K}) - 191.5 \text{ J/K} - 205 \text{ J/K} \\ &= \boxed{24.9 \text{ J/K}} \end{aligned}$$

20. What is ΔG° for the above reaction at 500 K?

- (a) 180.4 kJ (b) -168 kJ (c) 168 kJ (d) -127 kJ
 (e) 127 kJ

$$\begin{aligned} \Delta G^\circ &= \Delta H^\circ - T\Delta S^\circ \\ \text{need to know } \Delta H^\circ \text{ too} \\ \Delta H^\circ &= 2\Delta H_f^\circ \text{NO}(\text{g}) - \Delta H_f^\circ \text{N}_2(\text{g}) - \Delta H_f^\circ \text{O}_2(\text{g}) \\ &= 2(90.2 \text{ kJ}) - 0 - 0 = 180.4 \text{ kJ} \\ \Delta G^\circ &= 180.4 \text{ kJ} - (500 \text{ K})(24.9 \text{ J/K})\left(\frac{1 \text{ kJ}}{1000 \text{ J}}\right) \\ &= \boxed{168 \text{ kJ}} \end{aligned}$$

Consider the following titration for the next 5 questions.

30.0 mL of 0.030 M formic acid, HCO_2H (in the flask), is titrated with 0.045 M NaOH (in buret).
weak acid *strong base*

1. What is the overall reaction occurring in the titration?

- (a) $\text{HCO}_2\text{H}(\text{aq}) + \text{NaOH}(\text{aq}) \rightarrow \text{H}_2(\text{g}) + \text{HCO}_3(\text{aq})$
- (b) $\text{HCO}_2\text{H}(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{HCO}_2^-(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$
- (c) $\text{H}_3\text{O}^+(\text{aq}) + \text{OH}^-(\text{aq}) \rightarrow 2 \text{H}_2\text{O}(\text{l})$
- (d) $\text{HCO}_2\text{H}(\text{aq}) + \text{NaOH}(\text{aq}) \rightarrow \text{H}_2\text{O}(\text{l}) + \text{Na}^+(\text{aq}) + \text{HCO}_2^-(\text{aq})$
- (e) $\text{HCO}_2\text{H}(\text{aq}) + \text{NaOH}(\text{aq}) \rightarrow \text{H}_2\text{O}(\text{l}) + \text{Na}(\text{aq}) + \text{HCO}_2(\text{aq})$ *← need charges*

2. How many mL of the NaOH solution need to be added to reach the equivalence point of the titration?

- (a) 30. mL (b) 20.0 mL (c) 15.0 mL (d) 10.0 mL (e) 5.0 mL
- @ equiv mol NaOH = mol HCO₂H*
- $$C_{\text{NaOH}} V_{\text{NaOH}} = C_{\text{HCO}_2\text{H}} V_{\text{HCO}_2\text{H}}$$
- $$V_{\text{NaOH}} = \frac{C_{\text{HCO}_2\text{H}} V_{\text{HCO}_2\text{H}}}{C_{\text{NaOH}}} = \frac{(0.030\text{M})(30.0\text{mL})}{(0.045\text{M})}$$
- $$= \boxed{20.0\text{mL}}$$

3. Which of the following is present in the flask after 15 mL of the NaOH solution has been added? Mark all correct answers.

- (a) $\text{HCO}_3(\text{aq})$
 - (b) $\text{NaOH}(\text{aq})$
 - (c) $\text{HCO}_2\text{H}(\text{aq})$
 - (d) $\text{HCO}_2(\text{aq})$
 - (e) $\text{Na}[\text{HCO}_2](\text{aq})$
- ← BEFORE EQUIV. PT*
- ← note same as $\text{Na}^+(\text{aq}) + \text{HCO}_2^-(\text{aq})$*

4. How is the solution best characterized after 15.0 ml of the NaOH solution has been added?

- Mix of weak acid HCO_2H + weak base HCO_2^-*
- (a) solution of a strong acid
 - (b) solution of a strong base
 - (c) solution of a weak acid
 - (d) solution of a weak base
 - (ab) buffer solution *← so its a*
 - (e) neutral solution

Continuation of the titration question from the previous page:

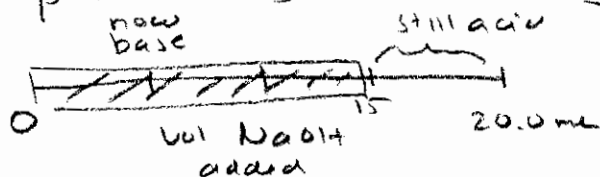
30.0 mL of 0.030 M formic acid, HCO_2H (in the flask), is titrated with 0.045 M NaOH (in buret).

5. What is the pH of the solution in the flask after 15.0 mL of the NaOH solution has been added?

- (a) 3.26 (b) 10.74 (c) 2.30 (d) 4.22 (e) 9.78

buffer solution - use Henderson Hasselbalch
 $\text{pH} = \text{pK}_a + \log \frac{\text{base}}{\text{acid}}$

$\text{pK}_a = -\log K_a = -\log (1.8 \times 10^{-4}) = 3.744$

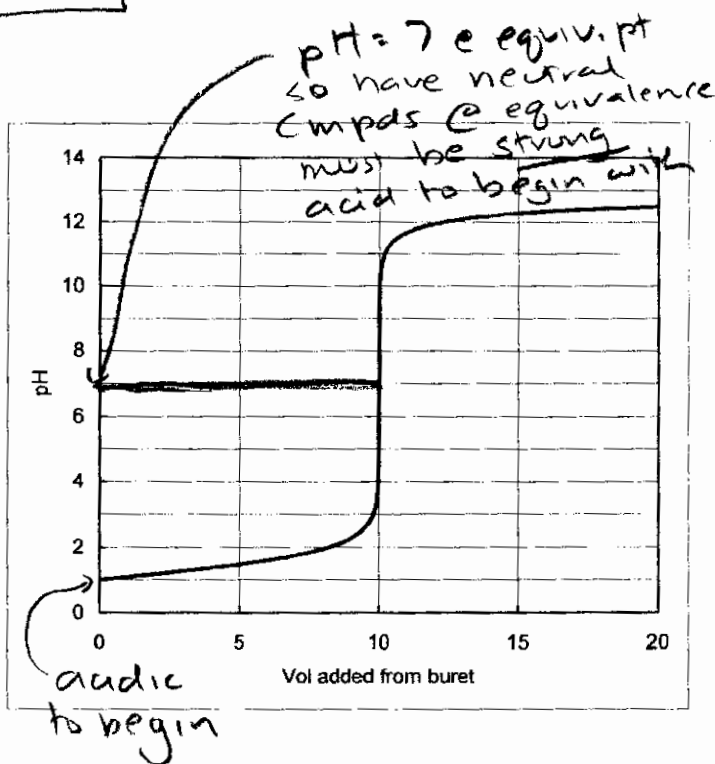


$\frac{\text{mol base}}{\text{mol acid}} = \frac{3/4 \text{ orig mol acid}}{1/4 \text{ orig mol acid}} = 3$

$\text{pH} = 3.744 + \log 3 = \boxed{4.22}$

6. Consider the adjacent titration curve. Which one of the following statement is true? The titration curve corresponds to the titration of a

- (a) weak acid (flask) with a strong base (buret).
 (b) weak base (flask) with a strong acid (buret).
 (c) strong acid (flask) with a strong base (buret).
 (d) strong base (flask) with a strong acid (buret).



7. An acid-base buffer consists of _____. (Pick the one answer that always is true.)

- (a) mixture of a weak acid and a weak base.
- (b) a mixture of a strong acid and a strong base.
- (c) a weak acid.
- (d) a weak base.
- (e) a conjugate acid base pair.

← note this is only correct if its a weak conj. acid-base pair

8. What buffer component ratio, base/acid, is needed to make a pH 11.25 buffer solution using a mixture of $[\text{CH}_3\text{NH}_3^+]\text{Cl}$ and CH_3NH_2 ?

- (a) 0.27 (b) 1.8 (c) 3.7 (d) 0.21 (e) 4.8

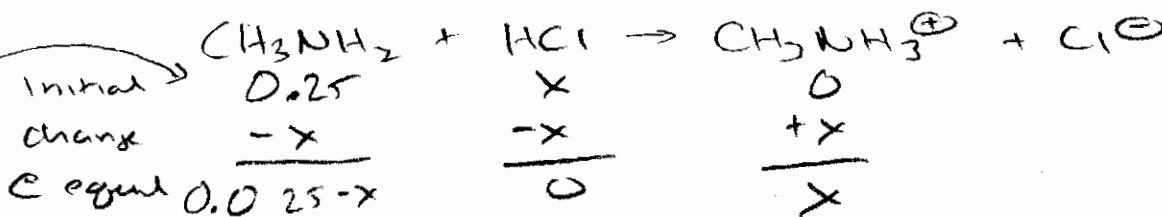
$K_a \cdot K_b = K_w$ } K_b of $\text{CH}_3\text{NH}_2 = 3.7 \times 10^{-4}$
 $\rightarrow K_a$ of $\text{CH}_3\text{NH}_3^+ = \frac{K_w}{K_b} = \frac{1.008 \times 10^{-14}}{3.7 \times 10^{-4}} = 2.72 \times 10^{-11}$

$pK_a = -\log K_a = 10.565$

$10^{\text{pH} - pK_a} = \frac{\text{base}}{\text{acid}} = 10^{(11.25 - 10.565)} = \boxed{4.84}$

9. How many grams of HCl would need to be added to 250. mL of a 0.10 M aqueous solution of CH_3NH_2 to make a pH 11.25 buffer? [A longer question. You may want to come back to it.]

- (a) 37 g (b) 0.16 g (c) 1.2 g (d) 0.72 g (e) 5.7 g



$250. \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}} \times \frac{0.10 \text{ mol } \text{CH}_3\text{NH}_2}{\text{L}} = 0.025 \text{ mol}$

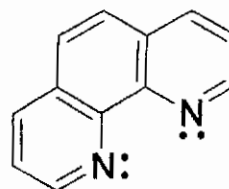
From previous question $\frac{\text{CH}_3\text{NH}_2}{\text{CH}_3\text{NH}_3^+} = 4.8 = \frac{0.025 - x}{x}$

$4.8x = 0.025 - x$
 $5.8x = 0.025$
 $x = \frac{0.025}{5.8} = 4.31 \times 10^{-3} \text{ mol HCl} \times \frac{36.461 \text{ g}}{\text{mol}} = \boxed{0.16 \text{ g}}$

$\text{mwt HCl} = 1.008$
 $+ 35.453$

 36.461 g/mol

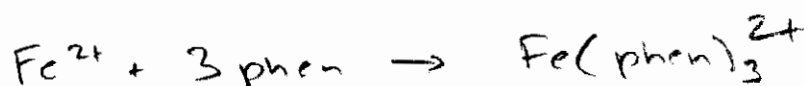
Consider the following for the next two questions. Iron (II) forms an orange-red complex ion with three phenanthrolines, abbreviated "phen". (Structure shown to the right.)



phen

10. What is the K_f expression for formation of the complex ion? Careful. Some answers are very similar.

- (a) $\frac{[\text{Fe}(\text{phen})_3]}{[\text{Fe}][\text{phen}]^3}$ (b) $\frac{[\text{Fe}^{2+}]^3[\text{phen}]}{[\text{Fe}(\text{phen})_3^{2+}]}$
 (c) $\frac{[\text{Fe}(\text{phen})_3^{2+}]^3}{[\text{Fe}^{2+}][\text{phen}]}$ (d) $[\text{Fe}^{2+}][\text{phen}]^3$ (e) $\frac{[\text{Fe}(\text{phen})_3^{2+}]}{[\text{Fe}^{2+}][\text{phen}]^3}$



$$K_f = \frac{[\text{Fe}(\text{phen})_3^{2+}]}{[\text{Fe}^{2+}][\text{phen}]^3}$$

11. The concentration of iron(II) can be determined by adding excess "phen" to an aqueous solution to form the colored complex ion. To do this analysis, a standard solution containing $4.46 \times 10^{-5} \text{ M Fe}^{2+}$ was prepared. After addition of excess phen, the absorption of the standard solution = 0.682 at 508 nm.

To determine $[\text{Fe}^{2+}]$ in an unknown solution, 5.00 mL of the solution was diluted to 100.0 mL. After addition of excess phen, the absorption of the standard solution = 0.738 at 508 nm. What is the $[\text{Fe}^{2+}]$ in the original (undiluted) solution?

- (a) $8.63 \times 10^{-5} \text{ M}$ (b) $3.46 \times 10^{-6} \text{ M}$ (c) $9.65 \times 10^{-4} \text{ M}$
 (d) $4.83 \times 10^{-5} \text{ M}$ (e) $1.73 \times 10^{-5} \text{ M}$

$$A = \epsilon l C \rightarrow \epsilon l = \frac{A}{C} = \frac{0.682}{4.46 \times 10^{-5}} = 1.529 \times 10^4$$

diluted sample

$$C = \frac{A}{\epsilon l} = \frac{0.738}{1.529 \times 10^4} = 4.83 \times 10^{-5} \text{ M}$$

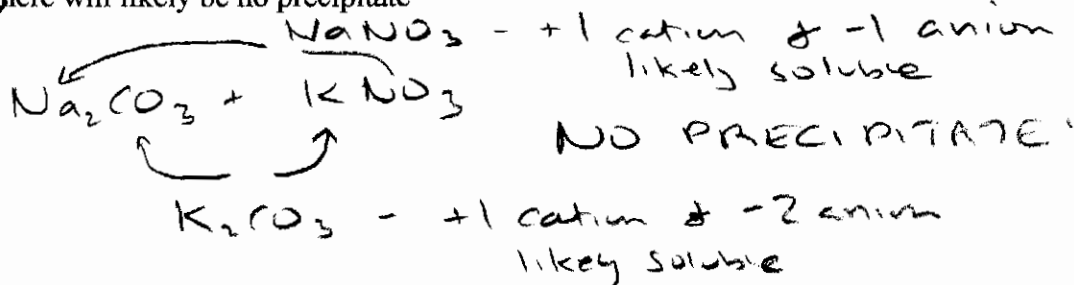
Orig sample $C_{\text{conc}} V_{\text{conc}} = C_{\text{dil}} V_{\text{dil}}$

$$C_{\text{conc}} = C_{\text{dil}} \frac{V_{\text{dil}}}{V_{\text{conc}}} = 4.83 \times 10^{-5} \text{ M} \left(\frac{100. \text{ mL}}{5. \text{ mL}} \right) = 9.65 \times 10^{-4} \text{ M}$$

12. Will mixing an aqueous solution of sodium carbonate and potassium nitrate likely result in a precipitate? If so, what will precipitate?

(a) K_2CO_3 (b) $K(CO_3)_2$ (c) K_2NO_3 (d) KNO_3

(e) there will likely be no precipitate



13. 5.00 mL of a 0.20 M sodium chloride solution is mixed with 5.00 mL of a solution containing $2.0 \times 10^{-3} M$ copper(I) and 0.10 M lead(II). What happens?
 K_{sp} of copper(I) chloride = $1.9 \times 10^{-7} M$ and K_{sp} of lead(II) chloride = $1.7 \times 10^{-5} M$

(a) nothing
 (b) only copper(I) chloride precipitates
 (c) only lead(II) chloride precipitates
 (d) both lead(II) chloride and copper(I) chloride precipitate

$[Cl^-] = \frac{\text{mole } Cl^-}{\text{tot } V} = \frac{(5.00 \text{ mL})(0.20 \text{ M})}{10.0 \text{ mL}} = 0.10 \text{ M}$ from NaCl

$[Cu^+] = \frac{\text{mole } Cu^+}{\text{tot } V} = \frac{(5.00 \text{ mL})(2.0 \times 10^{-3} \text{ M})}{10.0 \text{ mL}} = 1.0 \times 10^{-3} \text{ M}$

$[Pb^{2+}] = \frac{\text{mole } Pb^{2+}}{\text{tot } V} = \frac{(5.00 \text{ mL})(0.10 \text{ M } Pb^{2+})}{10.0 \text{ mL}} = 0.05 \text{ M}$

$CuCl$ ion prod = $[Cu^+][Cl^-] = (1.0 \times 10^{-3})(0.10) = 1.0 \times 10^{-4} > K_{sp}$

so CuCl precipitates

$PbCl_2$ ion prod = $[Pb^{2+}][Cl^-]^2 = (0.05)(0.1)^2 = 5.0 \times 10^{-4} > K_{sp}$

so $PbCl_2$ precipitates

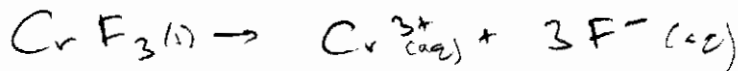
14. All physical processes tend to towards lower energy and higher entropy.

The answers in order are

(a) higher, lower (b) lower, higher (c) higher, higher (d) lower, lower

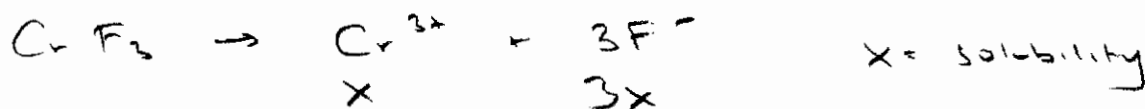
15. What is the K_{sp} expression for chromium(III) fluoride?

- (a) $[Cr^{3+}][F^-]^3$ (b) $[Cr^{+3}][F^{3-}]$ (c) $[Cr^{3+}][F^-]$
 (d) $\frac{[Cr]^{3+}[F]}{[Cr_3F]}$ (e) $\frac{[Cr_2F_3]}{[Cr^{3+}]^2[F^{2-}]^3}$



16. The solubility of chromium(III) fluoride in water at 25 °C is 1.25×10^{-3} M. What is the K_{sp} value for chromium(III) fluoride at this temperature?

- (a) 7.8×10^{-9} (b) 8.2×10^{-2} (c) 6.6×10^{-11} (d) 5.6×10^{-7}
 (e) 1.6×10^{-6}



$$K_{sp} = [Cr^{3+}][F^{-}]^3 = x(3x)^3 = 27x^4$$

$$K_{sp} = 27(1.25 \times 10^{-3})^4 = \boxed{6.6 \times 10^{-11}}$$

17. What will happen if HCl is added to a saturated aqueous solution of chromium(III) fluoride in water? ("Saturated solution" means that there is solid chromium(III) fluoride present and the system is at equilibrium.)

(a) Nothing happens.

(b) The chromium(III) fluoride solubility equilibrium shifts to the RIGHT and more solid chromium(III) fluoride dissolves.

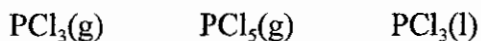
(c) The chromium(III) fluoride solubility equilibrium shifts to the LEFT and more solid chromium(III) fluoride dissolves.

(d) The chromium(III) fluoride solubility equilibrium shifts to the RIGHT and more chromium(III) fluoride precipitates out of solution.

(e) The chromium(III) fluoride solubility equilibrium shifts to the LEFT and more chromium(III) fluoride precipitates out of solution.

← strong acid
 $CrF_3 \rightarrow Cr^{3+} + 3F^{-}$ ← weak base
 $F^{-} + H_3O^{+} \rightarrow HF + H_2O$ (HF is a weak acid)
 rxn ② cause $[F^{-}] \downarrow$, rxn ① shifts RIGHT

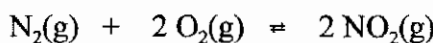
18. Place the following in order of increasing S°



- (a) $\text{PCl}_5(\text{g}) < \text{PCl}_3(\text{g}) < \text{PCl}_3(\text{l})$ (b) $\text{PCl}_5(\text{g}) < \text{PCl}_3(\text{l}) < \text{PCl}_3(\text{g})$
 (c) $\text{PCl}_3(\text{l}) < \text{PCl}_3(\text{g}) < \text{PCl}_5(\text{g})$ (d) $\text{PCl}_3(\text{l}) < \text{PCl}_5(\text{g}) < \text{PCl}_3(\text{g})$
 (e) $\text{PCl}_3(\text{g}) < \text{PCl}_5(\text{g}) < \text{PCl}_3(\text{l})$

logic - liquids have lower entropy than gasses so $\text{PCl}_3(\text{l})$ has the smallest S°

Consider the following reaction for the next 2 questions.



more complicated, larger molecules have more entropy than less complicated, small molecules so $\text{PCl}_3(\text{g}) < \text{PCl}_5(\text{g})$

19. What is ΔS° for the above reaction?

- (a) -121.5 J/K (b) 121.5 J/K (c) -156.5 J/K (d) 156.5 J/K
 (e) 480 J/K

$$\begin{aligned} \Delta S^\circ &= 2 S^\circ_{\text{NO}_2(\text{g})} - S^\circ_{\text{N}_2(\text{g})} - 2 S^\circ_{\text{O}_2(\text{g})} \\ &= 2(240) - 191.5 - 2(205.0) \\ &= \boxed{-121.5 \text{ J/K}} \end{aligned}$$

20. What is ΔG° for the above reaction at 500 K?

- (a) 168 kJ (b) -168 kJ (c) -127 kJ (d) 127 kJ
 (e) 66.40

$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$$

Need to know ΔH° as well

$$\begin{aligned} \Delta H^\circ &= 2\Delta H_f^\circ \text{NO}_2(\text{g}) - \Delta H_f^\circ \text{N}_2(\text{g}) - 2\Delta H_f^\circ \text{O}_2(\text{g}) \\ &= 2(33.2 \text{ kJ}) - 0 - 2(0) = 66.4 \text{ kJ} \end{aligned}$$

$$\begin{aligned} \Delta G^\circ &= 66.4 \text{ kJ} - (500 \text{ K}) \left(\frac{-121.5 \text{ J}}{\text{K}} \right) \left(\frac{1 \text{ kJ}}{1000 \text{ J}} \right) \\ &= \boxed{127 \text{ kJ}} \end{aligned}$$

ADDITIONAL INFORMATION

Some K_a Values at 25 °C

	K_{a1}	K_{a2}	K_{a3}
$\text{CH}_3\text{CO}_2\text{H}$	1.8×10^{-5}		
$\text{C}_6\text{H}_5\text{CO}_2\text{H}$	6.3×10^{-5}		
H_3BO_3	5.8×10^{-10}		
H_2CO_3	4.3×10^{-7}	5.6×10^{-11}	
$\text{H}_2\text{C}_2\text{O}_4$	5.6×10^{-2}	5.4×10^{-5}	
HCO_2H	1.8×10^{-4}		
H_3PO_4	7.5×10^{-3}	6.2×10^{-8}	4.8×10^{-13}
H_2SO_4	very large	1.2×10^{-2}	
HF	3.5×10^{-4}		

Some K_b values at 25 °C

	K_b
NH_3	1.8×10^{-5}
CH_3NH_2	3.7×10^{-4}
$(\text{CH}_3)_3\text{N}$	6.4×10^{-5}
$\text{C}_5\text{H}_5\text{N}$	1.7×10^{-9}

Thermodynamic Information at 25 °C (298 K):

Compound	ΔH_f° , kJ	ΔG_f° , kJ	S° , J/K
$\text{H}_2(\text{g})$	0	0	130.6
$\text{HNO}_3(\text{aq})$	-206.6	-110.5	146
$\text{H}_2\text{O}(\text{g})$	-241.83	-228.60	188.72
$\text{H}_2\text{O}(\text{l})$	-285.84	-237.19	69.94
$\text{NH}_3(\text{g})$	-45.9	-16	193
$\text{N}_2(\text{g})$	0	0	191.5
$\text{N}_2\text{O}(\text{g})$	82.05	104.2	219.7
$\text{NO}(\text{g})$	90.2	86.6	210.7
$\text{NO}_2(\text{g})$	33.2	51.3	240.0
$\text{O}_2(\text{g})$	0	0	205.0

EQUATIONS

$$K_a K_b = K_w = 1.008 \times 10^{-14}$$

$$pH = pK_a + \log \frac{[base]}{[acid]}$$

$$pK_a = -\log(K_a)$$

$$\Delta H^\circ = \sum \Delta H_f^\circ \text{ products} - \sum \Delta H_f^\circ \text{ reactants}$$

$$\Delta S_{\text{tot}} = \Delta S + \Delta S_{\text{surr}}$$

$$\Delta S^\circ = \sum S^\circ \text{ products} - \sum S^\circ \text{ reactants}$$

$$\Delta S_{\text{surr}} = -\frac{\Delta H}{T}$$

$$\Delta G^\circ = \sum \Delta G_f^\circ \text{ products} - \sum \Delta G_f^\circ \text{ reactants}$$

$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$$

$$\Delta G = \Delta G^\circ + RT \ln Q \quad \text{or} \quad \Delta G = \Delta G^\circ + 2.303 RT \log Q$$

$$\Delta G^\circ = -RT \ln K \quad \text{or} \quad \Delta G^\circ = -2.303 RT \log K$$

$$K = e^{-\frac{\Delta G^\circ}{RT}} \quad \text{or} \quad K = 10^{-\frac{\Delta G^\circ}{2.303 RT}}$$

$$K_w = 1.008 \times 10^{-14}$$

$$R = 8.314 \times 10^{-3} \text{ kJ/(mol}\cdot\text{K)}$$

$$0^\circ \text{ C} = 273.15 \text{ K}$$