



AP Chemistry 2000 Scoring Guidelines

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AP[®] Chemistry 2000 — Scoring Standards

Question 1

(10 points)

(a) $K_c = \frac{[\text{H}_2]^2[\text{S}_2]}{[\text{H}_2\text{S}]^2}$ or $K_c = \frac{(\text{H}_2)^2(\text{S}_2)}{(\text{H}_2\text{S})^2}$ **1 pt.**

- No point earned for a K_p expression or if an exponent is incorrectly used

(b) (i) $[\text{H}_2] = 2[\text{S}_2] = \frac{(2.0)(3.72 \times 10^{-2} \text{ mol})}{1.25 \text{ L}} = 5.95 \times 10^{-2} \text{ M}$ **1 pt.**

(ii) $[\text{H}_2\text{S}] = \frac{0.10 \text{ mol} - (2.0)(3.72 \times 10^{-2} \text{ mol})}{1.25 \text{ L}} = 2.05 \times 10^{-2} \text{ M}$ **2 pts.**

or

$$[\text{H}_2\text{S}] = 0.0800 \text{ M} - 0.0595 \text{ M} = 0.0205 \text{ M}$$

Notes: One point is earned for getting the correct number of moles of H_2S ; second point is earned for dividing by 1.25 L and getting a consistent answer. Although not correct, one point may be earned for calculating the initial $[\text{H}_2\text{S}]$ (see below) and using that value as the equilibrium H_2S concentration.

$$[\text{H}_2\text{S}] = \frac{\frac{3.40 \text{ g}}{34.1 \text{ g mol}^{-1}}}{1.25 \text{ L}} = 0.0798 \text{ M}$$

(c) $K_c = \frac{(5.95 \times 10^{-2})^2 \left(\frac{3.72 \times 10^{-2}}{1.25} \right)}{(2.05 \times 10^{-2})^2} = \frac{(5.95 \times 10^{-2})^2 (0.0298)}{(2.05 \times 10^{-2})^2} = 0.250$ **2 pts.**

Notes: One point is earned for correctly using the molarity of the S_2 (dividing the number of moles by the volume). The second point is earned by correctly using the numbers generated in (b) in the expression shown in (a) and getting the appropriate answer.

AP[®] Chemistry 2000 — Scoring Standards

Question 1

(continued)

(d)
$$P = \frac{nRT}{V} = \frac{(3.72 \times 10^{-2} \text{ mol})(0.0821 \text{ L atm mol}^{-1} \text{ K}^{-1})(483 \text{ K})}{1.25 \text{ L}} = 1.18 \text{ atm}$$

or

2 pts.

$$P = [S_2]RT = (0.02976 \text{ mol L}^{-1})(0.0821 \text{ L atm mol}^{-1} \text{ K}^{-1})(483 \text{ K}) = 1.18 \text{ atm}$$

Note: The first point is earned for correctly setting up either of these expressions.

The second point is earned for the correct answer (or an answer consistent with the numbers used). Also, combining $P_{total}V = n_{total}RT$ with $P_{S_2} = X_{S_2}P_{total}$, where X_{S_2} is the mole fraction of S_2 , can earn the points.

(e)
$$K_c' = \frac{1}{\sqrt{K_c}} = \frac{1}{\sqrt{0.250}} = 2.00$$

2 pts.

Notes: One point is earned for recognizing that K_c' must be an inverse related to K_c . A second point is earned for recognizing that the square root of K_c is involved. Only one point can be earned for the expression below, or for correctly calculating just the inverse of K_c or just $\sqrt{K_c}$.

$$K_c = \frac{[H_2S]}{[H_2][S_2]^{1/2}}$$

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Question 2 (10 points)

- (a) (i) $\text{Zn}(s) \rightarrow \text{Zn}^{2+}(aq) + 2 e^{-}$ *1 pt.*
- (ii) $\text{Co}^{2+}(aq) + \text{Zn}(s) \rightarrow \text{Co}(s) + \text{Zn}^{2+}(aq)$ *1 pt.*
- (iii) $0.76 \text{ V} + (-0.28 \text{ V}) = 0.48 \text{ V}$ *1 pt.*

Note: phase designations not required in part (i) or part (ii)

- (b) (i) $\Delta G^{\circ} = -nFE^{\circ} = -2(96,500)(0.55\text{V})$ *2 pts.*
 $= -1.1 \times 10^5 \text{ J}$ or $-1.1 \times 10^2 \text{ kJ}$

- First point earned for $n = 2$ (consistent use of $n = 4$ also accepted)
- Second point earned for negative sign, correct number (2 ± 1 sig. figs.), and appropriate units (kJ or J or kJ/mole or J/mole)

- (ii) $\Delta G^{\circ} = -RT \ln(K)$ *1 pt.*

$$-1.1 \times 10^5 \text{ J} = -[8.31 \text{ J mol}^{-1} \text{ K}^{-1}][298 \text{ K}][\ln(K)]$$

$$K = 2.0 \times 10^{19} \quad (\text{full credit also for correct use of } \log K = \frac{nE^{\circ}}{0.0592})$$

- (iii) $\text{O}_2 + 2 \text{H}_2\text{O} \rightarrow 2 \text{H}_2\text{O}_2$ -0.55 V
- $\text{O}_2 + 4 \text{H}^+ + 4 e^{-} \rightarrow 2 \text{H}_2\text{O}$ 1.23 V
-
- $2 \text{O}_2 + 4 \text{H}^+ + 4 e^{-} \rightarrow 2 \text{H}_2\text{O}_2$ 0.68 V *2 pts.*
- $\Rightarrow \text{O}_2 + 2 \text{H}^+ + 2 e^{-} \rightarrow \text{H}_2\text{O}_2$ 0.68 V (not required)

- Two points earned for correct voltage with supporting numbers (chemical equations not necessary)
- One point earned for correct chemical equations with incorrect voltage

- (c) $3,600 \text{ sec} \times \frac{100 \text{ C}}{1 \text{ sec}} \times \frac{1 \text{ mol } e^{-}}{96,500 \text{ C}} \times \frac{1 \text{ mol Cu}}{2 \text{ mol } e^{-}} \times \frac{63.55 \text{ g Cu}}{1 \text{ mol Cu}} = 119 \text{ g Cu}$ *2 pts.*

- Two points earned for correct answer (3 ± 1 sig. figs.)
- One point earned for any two of these steps:
 - (amp)(sec) \Rightarrow coulombs
 - coulombs \Rightarrow mol e^{-}
 - mol e^{-} \Rightarrow mol Cu
 - mol Cu \Rightarrow g Cu

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Question 3
(10 points)

(a) Molar Mass = $[9.012 + 2(12.011) + 4(16.00) + 3(16.00 + 2(1.0079))]$ g mol⁻¹ **1 pt.**
= $(97.034 + 54.0474)$ g mol⁻¹ = 151.0814 g mol⁻¹

% Carbon = $\frac{2(12.011)}{151.0814} \times 100 = 15.90\%$ **1 pt.**

- No point earned for 0.1590.

(b) (i) $\frac{3.21 \text{ g BeC}_2\text{O}_4 \cdot 3 \text{ H}_2\text{O}}{151.0814 \text{ g mol}^{-1}} = 0.02124 \text{ mol BeC}_2\text{O}_4 \cdot 3 \text{ H}_2\text{O}$

$$0.02124 \text{ mol BeC}_2\text{O}_4 \cdot 3 \text{ H}_2\text{O} \times \frac{1 \text{ mol BeC}_2\text{O}_4}{1 \text{ mol BeC}_2\text{O}_4 \cdot 3 \text{ H}_2\text{O}} = 0.02124 \text{ mol BeC}_2\text{O}_4$$

$0.02124 \text{ mol BeC}_2\text{O}_4 \times 97.034 \text{ g mol}^{-1} = 2.06 \text{ g BeC}_2\text{O}_4$ **1 pt.**

or

$$\% \text{ BeC}_2\text{O}_4 = \frac{97.034 \text{ g mol}^{-1}}{151.0814 \text{ g mol}^{-1}} \times 100\% = 64.23\%$$

Mass BeC₂O₄ = 3.21g × 0.6423 = 2.06 g

- No point earned for an answer larger than original mass (3.21g)

(ii) $0.02124 \text{ mol BeC}_2\text{O}_4 \cdot 3 \text{ H}_2\text{O} \times \frac{3 \text{ mol H}_2\text{O}}{1 \text{ mol BeC}_2\text{O}_4 \cdot 3 \text{ H}_2\text{O}} = 0.0637 \text{ mol H}_2\text{O}$

$$V = \frac{nRT}{P} = \frac{(0.063 \text{ mol})(0.0821 \text{ L atm mol}^{-1} \text{ K}^{-1})(220 + 273) \text{ K}}{(735/760) \text{ atm}} = 2.67 \text{ L H}_2\text{O} \quad \textbf{2 pts.}$$

or

$3.21 \text{ g BeC}_2\text{O}_4 \cdot 3 \text{ H}_2\text{O} - 2.06 \text{ g BeC}_2\text{O}_4 = 1.15 \text{ g H}_2\text{O}$

$$\frac{1.15 \text{ g H}_2\text{O}}{18.02 \text{ g mol}^{-1} \text{ H}_2\text{O}} = 0.0639 \text{ mol H}_2\text{O} \Rightarrow \text{use ideal gas law as above}$$

Note: One point is earned for determining the amount of H₂O(g) formed and one point is earned for the proper use of the ideal gas law with a consistent answer.

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Question 3
(continued)

(c) (i) The reducing agent is $\text{C}_2\text{O}_4^{2-}$ **1 pt.**

• Also accepted: C_2O_4^- , BeC_2O_4 , C_2O_4 , or $5 \text{C}_2\text{O}_4^{2-}$

(ii) $n_{\text{MnO}_4^-} = (0.0150 \text{ mol L}^{-1}) \times (0.01780 \text{ L}) = 2.67 \times 10^{-4} \text{ mol MnO}_4^-$ **1 pt.**

$n_{\text{C}_2\text{O}_4^{2-}} = \frac{5}{2} n_{\text{MnO}_4^-} = \frac{5}{2} (2.67 \times 10^{-4}) = 6.68 \times 10^{-4} \text{ mol C}_2\text{O}_4^{2-}$ **1 pt.**

Notes: One point is earned for determining $n_{\text{MnO}_4^-}$ and one point is earned for determining $n_{\text{C}_2\text{O}_4^{2-}}$. An incorrect value of $n_{\text{MnO}_4^-}$ can lead to an incorrect, but internally consistent, value for $n_{\text{C}_2\text{O}_4^{2-}}$. A point may be earned if $n_{\text{MnO}_4^-}$ is correctly calculated (i.e., reflects correct stoichiometry of the balanced equation) from an incorrect value of $n_{\text{C}_2\text{O}_4^{2-}}$.

(iii) Total $n_{\text{C}_2\text{O}_4^{2-}} = \frac{100. \text{ mL}}{20.0 \text{ mL}} \times n_{\text{MnO}_4^-} = 5 (6.68 \times 10^{-4} \text{ mol C}_2\text{O}_4^{2-})$ **1 pt.**

$= 3.34 \times 10^{-3} \text{ mol C}_2\text{O}_4^{2-}$

(iv) $\text{mol BeC}_2\text{O}_4 = \text{mol C}_2\text{O}_4^{2-} = 3.34 \times 10^{-3} \text{ mol C}_2\text{O}_4^{2-}$

$\text{mass BeC}_2\text{O}_4 = (3.34 \times 10^{-3} \text{ mol BeC}_2\text{O}_4)(97.034 \text{ g mol}^{-1}) = 0.32385 \text{ g}$

$\% \text{ BeC}_2\text{O}_4 = \frac{0.32385 \text{ g BeC}_2\text{O}_4}{0.345 \text{ g sample}} \times 100\% = 93.9\%$ **1 pt.**

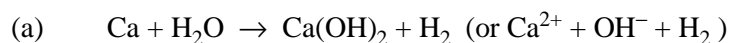
Note: The point is earned if an incorrect value for moles of BeC_2O_4 is used correctly in the calculation.

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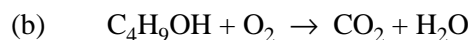
Question 4

(15 points)

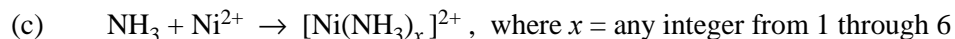
Students choose five of the eight reactions. Only the answers in the boxes are graded (unless clearly marked otherwise). Each correct answer earns 3 points; 1 point for reactants and 2 points for products. Reactants must be completely correct to earn the reactant point. All products must be correct to earn both product points; one of the two products correct earns 1 product point. Equations need not be balanced nor phases indicated (and no penalty if present but incorrect). Any spectator ions on the reactant side nullify the 1 possible reactant point, but if they appear again on the product side, there is no product-point penalty. Ion charges must be correct.



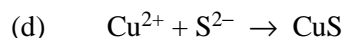
- 1 product point for “ $\text{Ca}^{2+} + \text{H}_2$ ”, “ $\text{Ca}^{2+} + \text{OH}^-$ ” or “ $\text{CaO} + \text{H}_2$ ”



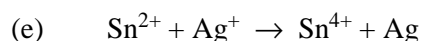
- “ $\text{C}_4\text{H}_{10}\text{O}$ ” or structural formula also accepted for butanol
- No penalty for “ $\text{CO}_2 + \text{CO} + \text{H}_2\text{O}$ ” as products
- 1 product point for “ $\text{CO} + \text{H}_2\text{O}$ ”



- For full credit, charges must be correct (square brackets not required)
- 1 product point earned if only product error is charge



- 1 product point earned if reactants correct but response shows incorrect stoichiometry for a copper sulfide product (e.g., Cu_2S , CuS_2 , Cu_5S_9)
- 2 product points earned if reactant charges incorrect but the product is consistent

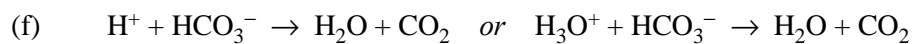


- To earn product point, Sn must be in 4+ state

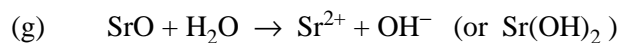
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Question 4

(continued)



- If the only product is H_2CO_3 , one product point is earned
- HBr written as undissociated and Br^- included as a product loses the reactant point only, but if HBr as a reactant produces Br_2 as a product, a product point is lost



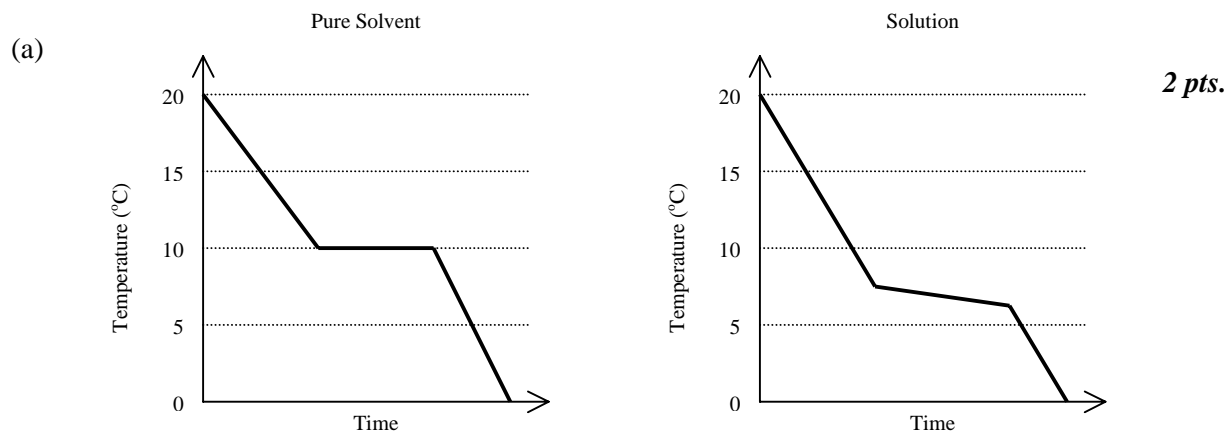
- Only 1 product point for “ $\text{Sr}(\text{OH})_2 + \text{H}_2$ ” (extra product)



- Iron products that contain reduced iron and oxygen are also accepted

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Question 5
(10 points)



Notes: One point is earned for each correct graph. The first graph should show a line that drops to 10°C, holds steady at 10°C, and then falls steadily to 0°C. There must be a discernable plateau at 10°C to earn this point. The second graph should show a line that drops to below 10°C, levels off (or slants down a bit), and then falls more sharply to 0°C.

- (b) (i) Measure mass of solute, mass of solvent, mass of solution
(two of three must be shown) **1 pt.**

Measure the ΔT_{fp} (or the freezing point of the solution) **1 pt.**

- Volume of solution (without density), molality, or number of moles do not earn points

- (ii) Given: $\Delta T = iK_f m$ (or $\Delta T = K_f m$) **2 pts.**
 $m = (\text{mol solute})/(\text{kg solvent})$
 moles = g/(molar mass)

Combine to get: molar mass = $(i)(K_f)(\text{g solute})/(\Delta T)(\text{kg solvent})$

Notes: One point is earned for any two equations, and two points are earned for all three equations. “Solute” and “solvent” must be clearly identified in the equations.

- (iii) the difference in the vertical position of the horizontal portions of the graphs **1 pt.**
 is equal to ΔT_{fp} , the change in freezing point due to the addition of the solute.

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Question 5
(continued)

- (c) The molar mass is too small. **1 pt.**

If some of the solvent evaporates, then the (kg solvent) term used in the equation in (b) (ii) is larger than the actual value. If the (kg solvent) term used is too large, then the value calculated for the molar mass will be too small.

1 pt.

or

If some of the solvent evaporates, then the concentration (molality) of the solute will be greater than we think it is. More moles of solute results in a smaller molar mass (or since $\Delta T = iK_f m$, then the ΔT_{obs} would be greater than it should be). Since the molar mass of the unknown solute is inversely proportional to ΔT , an erroneously high value for ΔT implies an erroneously low value for the molar mass (calculated molar mass would be too small).

- (d) % error = $\frac{(126 \text{ g mol}^{-1} - 120 \text{ g mol}^{-1})}{120 \text{ g mol}^{-1}} \times 100\%$ **1 pt.**

or

$$\% \text{ error} = \frac{6 \text{ g mol}^{-1}}{120 \text{ g mol}^{-1}} \times 100\%$$

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Question 6
(10 points)

- (a) $\Delta H^\circ = 33 - (90. + 143) \text{ kJ} = -200 \text{ kJ}$ *1 pt.*
- Correct set up (work), a numerical result, and a “-” sign, earn this point
 - No “math error” point deducted for computational mistakes

- (b) ΔS° for this reaction should be small or negligible (near zero or zero) *1 pt.*
- No point earned for statements that ΔS° is constant or the same

because

the number of moles (of gas) is the same on each side of the equation. *1 pt.*

- Point may be earned even if first point not earned

- (c) ΔG° is negative (-) at 298 K *1 pt.*
- Point earned only if consistent with answers given in parts (a) and (b)

because

$\Delta G^\circ = \Delta H^\circ - T(\Delta S^\circ)$, ΔH° is negative, and ΔS° is near zero, thus it follows that ΔG° will be negative. *1 pt.*

- Equation need not be written explicitly to earn point

Notes: Responses that ΔG° is positive (+), or not able to be determined, are accepted together with appropriate explanations IF they are fully consistent with incorrect responses given in part (a) and/or part (b). Since question concerns the reaction at 298 K, discussion of what might happen at high or low temperatures does not earn any explanation point.

- (d) When $[\text{O}_3]$ is held constant and $[\text{NO}]$ is doubled (as in Experiments 1 and 2), the rate also doubles \Rightarrow reaction is first-order in $[\text{NO}]$. *1 pt.*

When $[\text{NO}]$ is held constant and $[\text{O}_3]$ is doubled (as in Experiments 1 and 3), the rate also doubles \Rightarrow reaction is first-order in $[\text{O}_3]$. *1 pt.*

Rate = $k [\text{O}_3] [\text{NO}]$ (or Rate = $k [\text{O}_3]^1 [\text{NO}]^1$, or Rate = $10^6 (x) [\text{O}_3] [\text{NO}]$) *1 pt.*

Notes: First point for correctly determining the order with respect to $[\text{NO}]$ and work shown, second point earned for correctly determining the order with respect to $[\text{O}_3]$ and work shown, and third point earned for correctly writing a rate-law expression that is consistent with answers to analysis of experimental results.

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Question 6
(continued)

- (e) Step 1 must be rate-determining, as the rate law for this elementary step is the only one that agrees with the rate law determined experimentally in part (d) above. **2 pts.**

The following arguments are acceptable, but not required:

If Step 2 were the rate-determining step, then the reaction would be second-order with respect to $[O_3]$ – this is inconsistent with the kinetic data.

If Step 3 were the rate-determining step, then the reaction would be second-order with respect to $[NO]$ – this is inconsistent with the kinetic data.

Notes: Two points are earned for identifying Step 1 as the rate-determining step and giving a valid explanation relating the similarity of the rate law of the slow step to that found from the experimental results. Only one point is earned for identifying Step 1 as the rate-determining step but only a minimal or partly incorrect explanation is given (e.g., an explanation based solely on the fact that both reactant molecules are only present in Step 1). Two points may be earned for identifying Step 2 or Step 3 as the rate-determining step IF the rate law determined in part (d) contains $[O_3]^2$ or $[NO]^2$, respectively.

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Question 7
(8 points)

- (a) The isotopes have the same number (34) of protons, but a different number of neutrons. *1 pt.*
1 pt.

- No comment about the number of electrons is necessary

- (b) $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^4$
or
 $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^4$ *1 pt.*

- No point is earned for $[\text{Ar}] 4s^2 3d^{10} 4p^4$, because the question specifically asks for a complete electron configuration.

Since there are three different $4p$ orbitals, there must be two unpaired electrons. *1 pt.*



Notes: The second part should have some explanation of Hund's rule, and may include a diagram. The second point can still be earned even if the first point is not IF the electron configuration is incorrect, but the answer for the second part is consistent with the electron configuration given in the first part.

- (c) (i) The ionized electrons in both Se and Br are in the same energy level, but Br has more protons than Se, so the attraction to the nucleus is greater. *1 pt.*

Note: There should be two arguments in an acceptable answer -- the electrons removed are from the same ($4p$) orbital **and** Br has more protons (a greater nuclear charge) than Se.

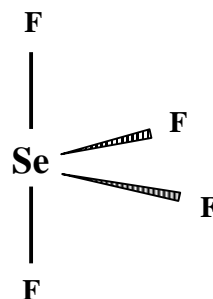
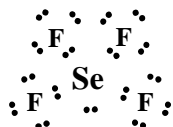
- (ii) The electron removed from a Te atom is in a $5p$ orbital, while the electron removed from an Se atom is in a $4p$ orbital. The $5p$ orbital is at a higher energy than the $4p$ orbital, thus the removal of an electron in a $5p$ orbital requires less energy. *1 pt.*

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Question 7
(continued)

(d)

1 pt.



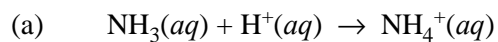
Notes: One point earned for a correct Lewis diagram and a sketch. The Lewis diagram and the molecular structure may be combined into one sketch if both aspects (electron pairs and structure) are correct. Dots, lines, or a mixture of both can be used in the Lewis diagram. The lone pair of electrons need not be shown in the sketch -- just the atomic positions. No credit earned for just a verbal description of molecular geometry (“see-saw”, “saw-horse”, or something “distorted”), because the question clearly asks the student to “sketch the molecular structure”.

The SeF₄ molecule is polar, because the polarities induced by the bonds and the lone pair of electrons do not cancel.

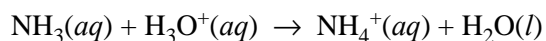
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Question 8
(8 points)



or

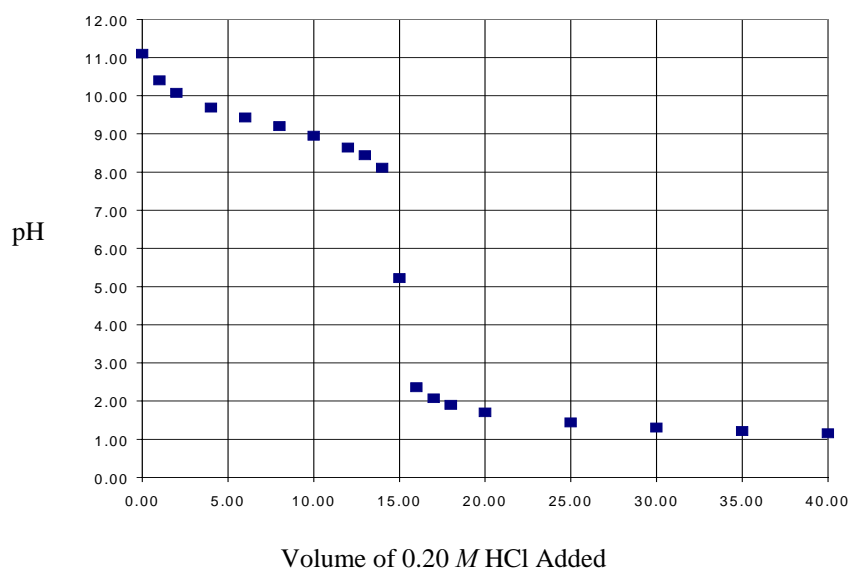


1 pt.

Note: phase designations not required to earn point

(b) Sketch of Titration Curve:

3 pts.



- 1st pt. \Rightarrow initial pH must be > 7 (calculated pH ≈ 11)
- 2nd pt. \Rightarrow equivalence point occurs at $15.0 \text{ mL} \pm 1 \text{ mL}$ of HCl added (equivalence point must be detectable from the shape of the curve or a mark on the curve)
- 3rd pt. \Rightarrow pH at equivalence point must be < 7 (calculated pH ≈ 5).

Note: a maximum of 1 point earned for any of the following:

- a line without an equivalence point
- a random line that goes from high pH to low pH
- an upward line with increasing pH (equivalence point MUST be at 15.0 mL)

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Question 8
(continued)

(c) Methyl Red would be the best choice of indicator, *1 pt.*

because

the pK_a for Methyl Red is closest to the pH at the equivalence point. *1 pt.*

Notes:

- explanation must agree with equivalence point on graph
- alternative explanation that titration involves strong acid and weak base (with product an acidic salt) earns the point

d) The resulting solution is basic. *1 pt.*

K_b for NH_3 (1.8×10^{-5}) and K_a for NH_4^+ (5.6×10^{-10}) indicate that NH_3 is a stronger base than NH_4^+ is an acid

or

1 pt.

$[\text{OH}^-] = K_b = 1.8 \times 10^{-5}$ because of the equimolar and equivolume amounts of ammonium and ammonia \Rightarrow cancellation in the buffer pH calculation. Thus $\text{pOH} \approx 5$ and $\text{pH} \approx 9$ (i.e., recognition of buffer, so that $\log\left(\frac{0.05}{0.05}\right) = 0 \Rightarrow \text{pOH} = \text{p}K_b \approx 5 \Rightarrow \text{pH} = 14 - \text{pOH} \approx 9$)