

1982

a) 2 points

$$95 \text{ g F} \times (1 \text{ mole F} / 19.0 \text{ g F}) = 5 \text{ mole F atoms}$$

$$5 \text{ g H} \times (1 \text{ mole H} / 1.00 \text{ g H}) = 5 \text{ mole H atoms}$$

Therefore HF

One point was awarded if  $\text{H}_5\text{F}_5$  or other 1:1 ratios were given.

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b) 2 points

$$\text{Amount of F in UF}_6 = (4.267 \text{ g}) \left( \frac{6 \times 19.0}{238 + 6 \times 19.0} \right) = 1.38 \text{ g F}$$

$$\text{Fraction of F in HF} = (0.970 \text{ g} \times 0.95) / 1.38 \text{ g}$$

$$\text{Fraction of F in solid} = 1 - 0.67 = 0.33$$

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c) 4 points

$$\text{Mass of U} = 4.267 \text{ g} - 1.38 \text{ g} = 2.89 \text{ g U}$$

$$\text{Mass of F} = 1.38 \text{ g} \times 0.333 = 0.46 \text{ g F}$$

$$\text{Mass of O} = 3.730 \text{ g} - (2.89 + 0.46) = 0.38 \text{ g O}$$

$$2.89 \text{ g U} \times (1 \text{ mole U} / 238 \text{ g U}) = 0.012 \text{ mole U atoms}$$

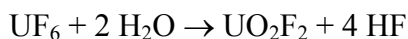
$$0.460 \text{ g F} \times (1 \text{ mole F} / 19.0 \text{ gF}) = 0.024 \text{ mole F atoms}$$

$$0.38 \text{ g O} \times (1 \text{ mole O} / 16.0 \text{ g O}) = 0.024 \text{ mole O atoms}$$

Therefore solid product is  $\text{UO}_2\text{F}_2$

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d) 1 point



1986

3) Average score = 5.18

a) three points

$$PV = (\text{grams} / \text{MM}) RT$$

$$\text{MM} = (3.53 \text{ grams} / \text{liter}) (0.0821 \text{ liter atm/mole K}) \times (300 \text{ K}) (1/[750/760]) = 88.1 \text{ grams/mole}$$

OR

$$(3.53 \text{ grams} / \text{liter}) (760/750) (300/273) \times (22.4 \text{ L/mol}) = 88.1 \text{ g/mol}$$

b) one correct = 1 point; all correct = one additional point

$$\text{gram Q/mole X} = 0.648 \times 88.1 = 57.1$$

$$\text{gram Q/mole Y} = 0.730 \times 104 = 75.9$$

$$\text{gram Q/mole Z} = 0.593 \times 64.0 = 38.0$$

c) one point

Masses in (b) must be integral multiples of atomic weight. Largest common denominator is 19.

Note: credit given for incorrect at. wt. if consistent with values in (b).

d) three points

$$1.37 \text{ grams CO}_2 (1 \text{ mole}/44.0 \text{ grams CO}_2) = 0.0311 \text{ mole CO}_2 = 0.0311 \text{ mole C}$$

$$0.281 \text{ grams H}_2\text{O} (1 \text{ mole}/18.0 \text{ grams H}_2\text{O}) = 0.0156 \text{ mole H}_2\text{O} = 0.0312 \text{ mole H}$$

$$1.00 \text{ gram Z} = (1 \text{ mole}/64 \text{ grams}) = 0.0156 \text{ mole Z}$$

Each mole Z contains 2 moles of CH, or 26 grams, which leaves  $(64 - 26) = 38$  grams, corresponding to 2 moles of Element Q.

Mol. formula is  $\text{C}_2\text{H}_2\text{Q}_2$

1991

2)

a) three points

$$7.2 \text{ g H}_2\text{O} \div 18.0 \text{ g/mol} = 0.40 \text{ mol H}_2\text{O}$$

$$0.40 \text{ mol H}_2\text{O} \times (2 \text{ mol H} / 1 \text{ mol H}_2\text{O}) = 0.80 \text{ mol H}$$

$$7.2 \text{ L CO}_2 \div 22.4 \text{ L/mol} = 0.32 \text{ mol CO}_2$$

$$0.32 \text{ mol CO}_2 \times (1 \text{ mol C} / 1 \text{ mol CO}_2) = 0.32 \text{ mol C}$$

OR

$$n = PV \div RT = [(1 \text{ atm}) (7.2 \text{ L})] \div [(0.0821 \text{ L atm mol}^{-1} \text{ K}^1) (273 \text{ K})] = 0.32 \text{ mol CO}_2$$

$$0.80 \text{ mol H} \div 0.32 = 2.5$$

$$0.32 \text{ mol C} \div 0.32 = 1$$

$$2.5 \times 2 = 5 \text{ mol H}$$

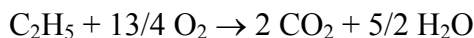
$$1 \times 2 = 2 \text{ mol C}$$

empirical formula = C<sub>2</sub>H<sub>5</sub>

b) two points

$$\text{mol O}_2 \text{ for combustion} = \text{mol CO}_2 + 1/2 \text{ mol H}_2\text{O} = 0.32 + 0.20 = 0.52 \text{ mol O}_2$$

$$0.52 \text{ mol O}_2 \times 32 \text{ g/mol} = 17 \text{ g O}_2$$

alternate approach for mol O<sub>2</sub> from balanced equation

other ratio examples:

$$1, 6.5 \rightarrow 4, 5$$

$$0.25, 1.625 \rightarrow 1, 1.25$$

$$\text{mol O}_2 = 0.40 \text{ mol H}_2\text{O} \times (13/4 \text{ mol O}_2 / (5/2) \text{ mol H}_2\text{O}) = 0.52 \text{ mol O}_2$$

Note: starting moles of C<sub>2</sub>H<sub>5</sub> = 0.16 mol C<sub>2</sub>H<sub>5</sub>

c) three points

MM stands for molar mass.

$$\Delta T = (K_f (\text{g/MM})) / \text{kg of solvent}$$

$$0.5 \text{ }^\circ\text{C} = ((4.68 \text{ }^\circ\text{C kg mol}^{-1}) \times (0.60 \text{ g} / \text{MM})) / 0.1 \text{ kg}$$

$$MM = (4.68 \times 0.60) / (0.5 \times 0.1) = 56 \text{ or } 6 \times 10^1$$

an alternate solution for (c)

$$\text{molality} = 0.5 \text{ } ^\circ\text{C} / (4.68 \text{ } 0.5 \text{ } ^\circ\text{C}/m) = 0.107 \text{ } m$$

$$\text{mol solute} = (0.107 \text{ mol} / \text{kg solvent}) \times 0.100 \text{ kg solvent} = 0.0107 \text{ mol}$$

$$MM = 0.60 \text{ g} / 0.0107 \text{ mol} = 56 \text{ or } 6 \times 10^1$$

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d) one point

$$(56 \text{ g/mol of cmpd}) / (29 \text{ g/mol of empirical formula}) = 1.9 \text{ empirical formula per mol}$$

OR

$$6 \times 10^1 / 29 = 2.1$$

$$\text{Empirical formula times 2 equals molecular formula} = \text{C}_4\text{H}_{10}$$

### 1993 LAB: Redox Titration

3) average = three points

a) one point

$$(1.00 \text{ mol O}_2) (2 \text{ mol MnO}_2 / 1 \text{ mol O}_2) (1 \text{ mol I}_2 / 1 \text{ mol MnO}_2) (2 \text{ mol S}_2\text{O}_3^{2-} / 1 \text{ mol I}_2) = 4 \text{ mol S}_2\text{O}_3^{2-}$$

Note: answer only is sufficient.

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b) two points

$$\text{mol S}_2\text{O}_3^{2-} = (0.00486) (0.0112) = 5.44 \times 10^{-5} \text{ mol S}_2\text{O}_3^{2-}$$

$$\text{mol O}_2 = 5.44 \times 10^{-5} / 4 = 1.36 \times 10^{-5} \text{ mol}$$

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c) one point

less I<sub>2</sub> therefore less S<sub>2</sub>O<sub>3</sub><sup>2-</sup> required therefore lower amount of O<sub>2</sub> (both direction and reason required)

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d) three points (one for M; one for correct use of R; one for correct T)

$$M_{\text{soln}} \text{ in (b)} = 1.36 \times 10^{-5} \text{ mol} / 0.050 \text{ L} = 2.72 \times 10^{-4} \text{ M}$$

$$V = (nRT) / P = [(2.72 \times 10^{-4}) (0.0821) (298)] / 1$$

$$= 6.65 \times 10^{-3} \text{ L or } 6.65 \text{ mL}$$

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e) two points

starch indicator

color disappears or blue disappears (violet or purple OK)

color change alone is not sufficient for 2nd pt

any other color with starch is not sufficient for 2nd pt

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Question 2  
(9 points)

2.

a) Assume a 100 g sample of unknown (*not necessary for credit*)

$$1 \quad \begin{aligned} 65.60 \text{ g C}/12.01 \frac{\text{g}}{\text{mole}} &= 5.462 \text{ mole C} \\ 9.44 \text{ g H}/1.0079 \frac{\text{g}}{\text{mole}} &= 9.366 \text{ mole H} \end{aligned}$$

$$\text{g of O} = 100 \text{ g} - (65.60 + 9.44)\text{g} = 24.96 \text{ g of O}$$

$$1 \quad 24.96 \text{ g O} \left( \frac{1 \text{ mol}}{15.9994 \text{ g}} \right) = 1.560 \text{ mol O}$$

$$1 \quad \text{C}_{5.462} \text{H}_{9.366} \text{O}_{1.560} \Rightarrow \text{C}_{5.462/1.560} \text{H}_{9.366/1.560} \text{O}_{1.560/1.560} \Rightarrow \text{C}_{3.5} \text{H}_{6.0} \text{O}_{1.0} \\ \Rightarrow \text{C}_7\text{H}_{12}\text{O}_2$$

*1 point for getting moles of C and moles of H*

*1 point for getting moles of O*

*1 point for correct empirical formula (Overzealous rounding to C<sub>3</sub>H<sub>6</sub>O, or C<sub>4</sub>H<sub>6</sub>O) loses this last point)*

*1 point for correct empirical formula calculation, but omitting oxygen. This leads to variations of CH<sub>1.7</sub>; such as, C<sub>10</sub>H<sub>17</sub>, C<sub>3</sub>H<sub>5</sub>, C<sub>4</sub>H<sub>7</sub>).*

*1 point converting gram ratio to C<sub>21</sub>H<sub>30</sub>O<sub>8</sub>*

b)  $\Delta T = iK_f m$

Method 1

$$1 \quad m = \frac{\Delta T}{K_f} = \frac{15.2^\circ \text{C}}{\left(40.0 \frac{\text{K} \cdot \text{kg}}{\text{mol}}\right)} = 0.380 \frac{\text{mol}}{\text{kg}}$$

$$0.01608 \text{ kg} \left( \frac{0.380 \text{ mol}}{\text{kg}} \right) = 0.00611 \text{ mol}$$

$$1 \quad MM = \frac{1.570 \text{ g}}{0.00611 \text{ mol}} = 257 \frac{\text{g}}{\text{mol}}$$

*1 point for correct molality*

*1 point for converting molality to MM*

Method 2

$$1 \quad \text{mol}_{\text{solute}} = \frac{\Delta T \cdot \text{kg}_{\text{solvent}}}{K_f} = 0.00611 \text{ mol}$$

$$1 \quad MM = \frac{1.570 \text{ g}}{0.00611 \text{ mol}} = 257 \frac{\text{g}}{\text{mol}}$$

*1 point for correct mole determination*

*1 point for converting to MM*

Method 3

$$2 \quad MM = \frac{K_f \cdot \text{g}}{\Delta T \cdot \text{kg}_{\text{solvent}}} = 257 \text{ g/mol}$$

*1 point for equation/substitution*

*1 point for MM calculation*

$$\text{Empirical mass} \Rightarrow [7(12 \frac{\text{g}}{\text{mole}}) + 12(1 \frac{\text{g}}{\text{mole}}) + 2(16 \frac{\text{g}}{\text{mole}})] = 128 \frac{\text{g}}{\text{mole}}$$

Mass of empirical formula (128 g/mole) is ~ 1/2 the molecular mass

$$1 \quad \text{Molecular formula is double the empirical formula} \Rightarrow \text{C}_{14}\text{H}_{24}\text{O}_4$$

*1 point for molecular formula consistent with EF and MM.*

*No penalty for simply ignoring the van't Hoff factor, "i".*

*Only 1 point awarded for this section if  $\Delta T = (15.2\text{K} + 273\text{K}) = 288\text{K}$  and  $MM = 13.6 \text{ g/mol} \Rightarrow$  no possible molecular formula*

Question 2 (continued)

c) 1 
$$n = \frac{g}{MM} = \frac{PV}{RT} = \frac{(1\text{atm})(0.577\text{L})}{(0.0821 \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}})(573\text{K})} = 0.0123 \text{ mol}$$

1 
$$0.0123 \text{ moles} = \frac{1.570 \text{ g}}{MM} \Rightarrow \frac{128 \text{ g}}{\text{mol}}$$

*1 point for correct number of moles*

*Alternate solution = 1 point*

$$n_2 = n_1 \frac{V_2 T_1}{V_1 T_2} = 1\text{mol} \left( \frac{0.577\text{L}}{22.4\text{L}} \right) \left( \frac{273\text{K}}{573\text{K}} \right) = 0.0123\text{mol}$$

*1 point for correct substitution into the "moles = g/MM" equation (and answer)*

*1 point deduction for using wrong value of R (e.g., 8.314 J/K-mole) and/or using T in deg C (300°C)*

- .....
- d) 1 Compound must dimerize in solution, since the MM in solution is double that in the gas phase, or  
Compound must dissociate ( $A_{(g)} \rightarrow 2B_{(g)}$ ) in the gas phase, since MM in gas is ½ that in the solution.

*1 point for a reference to either (or both) of the above ideas. The terms "dimerize" or "dissociate" are, of course, not required, but some expression of that idea is needed to get this last point.*

*Do not accept "non-ideal behavior" or "the material dissociates in solution" as acceptable explanations.*

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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<sup>-1</sup> **1 pt.**  
=  $(97.034 + 54.0474)$  g mol<sup>-1</sup> = 151.0814 g mol<sup>-1</sup>

% 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 BeC<sub>2</sub>O<sub>4</sub> = 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 H<sub>2</sub>O(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:  $\text{C}_2\text{O}_4^-$ ,  $\text{BeC}_2\text{O}_4$ ,  $\text{C}_2\text{O}_4$ , 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)  $\text{mol BeC}_2\text{O}_4 = \text{mol C}_2\text{O}_4^{2-} = 3.34 \times 10^{-3} \text{ mol C}_2\text{O}_4^{2-}$

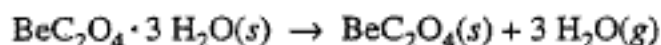
$\text{mass BeC}_2\text{O}_4 = (3.34 \times 10^{-3} \text{ mol BeC}_2\text{O}_4)(97.034 \text{ g mol}^{-1}) = 0.32385 \text{ g}$

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

Note: The point is earned if an incorrect value for moles of  $\text{BeC}_2\text{O}_4$  is used correctly in the calculation.

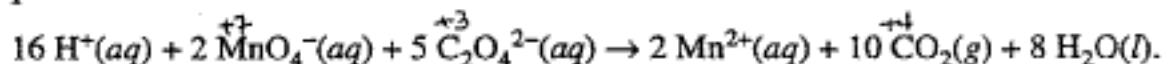
3. Answer the following questions about  $\text{BeC}_2\text{O}_4(s)$  and its hydrate.

- (a) Calculate the mass percent of carbon in the hydrated form of the solid that has the formula  $\text{BeC}_2\text{O}_4 \cdot 3 \text{H}_2\text{O}$
- (b) When heated to  $220.^\circ\text{C}$ ,  $\text{BeC}_2\text{O}_4 \cdot 3 \text{H}_2\text{O}(s)$  dehydrates completely as represented below.



If 3.21 g of  $\text{BeC}_2\text{O}_4 \cdot 3 \text{H}_2\text{O}(s)$  is heated to  $220.^\circ\text{C}$ , calculate

- (i) the mass of  $\text{BeC}_2\text{O}_4(s)$  formed, and,
- (ii) the volume of the  $\text{H}_2\text{O}(g)$  released, measured at  $220.^\circ\text{C}$  and 735 mm Hg.
- (c) A 0.345 g sample of anhydrous  $\text{BeC}_2\text{O}_4$ , which contains an inert impurity, was dissolved in sufficient water to produce 100. mL of solution. A 20.0 mL portion of the solution was titrated with  $\text{KMnO}_4(aq)$ . The balanced equation for the reaction that occurred is as follows.



The volume of 0.0150 M  $\text{KMnO}_4(aq)$  required to reach the equivalence point was 17.80 mL.

- (i) Identify the reducing agent in the titration reaction.
- (ii) For the titration at the equivalence point, calculate the number of moles of each of the following that reacted.
- $\text{MnO}_4^-(aq)$
  - $\text{C}_2\text{O}_4^{2-}(aq)$
- (iii) Calculate the total number of moles of  $\text{C}_2\text{O}_4^{2-}(aq)$  that were present in the 100. mL of prepared solution.
- (iv) Calculate the mass percent of  $\text{BeC}_2\text{O}_4(s)$  in the impure 0.345 g sample.

$$a) \text{MM}_{\text{hydrate}} = 4.01 \frac{\text{g}}{\text{mol}} + 2(12.01 \frac{\text{g}}{\text{mol}}) + 4(16.00 \frac{\text{g}}{\text{mol}}) + 3(2(1.01 \frac{\text{g}}{\text{mol}}) + 16.00 \frac{\text{g}}{\text{mol}})$$

$$= 151.09 \frac{\text{g}}{\text{mol}}$$

$$\% \text{ carbon} = 100 * \frac{2(12.01 \frac{\text{g}}{\text{mol}})}{151.09 \frac{\text{g}}{\text{mol}}} = 15.90 \%$$

$$b) 3.21 \text{ g BeC}_2\text{O}_4 \cdot 3\text{H}_2\text{O} \quad \text{MM}_{\text{BeC}_2\text{O}_4} = 97.03 \frac{\text{g}}{\text{mol}}$$

$$i) 3.21 \text{ g BeC}_2\text{O}_4 \cdot 3\text{H}_2\text{O} * \frac{\text{mol BeC}_2\text{O}_4 \cdot 3\text{H}_2\text{O}}{151.09 \text{ g BeC}_2\text{O}_4 \cdot 3\text{H}_2\text{O}} * \frac{\text{mol BeC}_2\text{O}_4}{\text{mol BeC}_2\text{O}_4 \cdot 3\text{H}_2\text{O}} * \frac{97.03 \text{ g BeC}_2\text{O}_4}{\text{mol BeC}_2\text{O}_4}$$

$$= 2.06 \text{ g BeC}_2\text{O}_4$$

$$ii) 2.06 \text{ g BeC}_2\text{O}_4 * \frac{3 \text{ mol H}_2\text{O}}{\text{mol BeC}_2\text{O}_4} * \frac{\text{mol BeC}_2\text{O}_4}{97.03 \text{ g BeC}_2\text{O}_4} = 0.0637 \text{ mol H}_2\text{O}$$

$$PV = nRT \quad T = 220.^\circ\text{C} = 493 \text{ K} \quad P = 735 \text{ mm Hg} * \frac{\text{atm}}{760 \text{ mmHg}} = 0.967 \text{ atm}$$

$$(0.967 \text{ atm})V = (0.0637 \text{ mol})(0.08206 \frac{\text{L atm}}{\text{mol K}})(493 \text{ K})$$

$$V = 2.66 \text{ L H}_2\text{O}$$

GO ON TO THE NEXT PAGE.

ADDITIONAL PAGE FOR ANSWERING QUESTION 3.

c) 0.345 g BeC<sub>2</sub>O<sub>4</sub> w/ impurity  
100. mL soln.

20.0 mL soln. = 17.80 mL 0.0150 M KMnO<sub>4</sub>

i) C<sub>2</sub>O<sub>4</sub><sup>2-</sup> is the reducing agent.

ii) 17.80 mL \* 0.0150 M = 0.267 mmol MnO<sub>4</sub><sup>-</sup> =  $2.67 \times 10^{-4}$  mol MnO<sub>4</sub><sup>-</sup>

$2.67 \times 10^{-4}$  mol MnO<sub>4</sub><sup>-</sup> \*  $\frac{5 \text{ mol C}_2\text{O}_4^{2-}}{2 \text{ mol MnO}_4^-}$  =  $6.68 \times 10^{-4}$  mol C<sub>2</sub>O<sub>4</sub><sup>2-</sup>

iii)  $\frac{6.68 \text{ mol C}_2\text{O}_4^{2-}}{20.0 \text{ mL soln}}$  \*  $\frac{n}{100. \text{ mL soln}}$  =  $3.34 \times 10^{-3}$  mol C<sub>2</sub>O<sub>4</sub><sup>2-</sup>

iv) m<sub>BeC<sub>2</sub>O<sub>4</sub></sub> =  $3.34 \times 10^{-3}$  mol C<sub>2</sub>O<sub>4</sub><sup>2-</sup> \*  $\frac{\text{mol BeC}_2\text{O}_4}{\text{mol C}_2\text{O}_4^{2-}}$  \*  $\frac{97.03 \text{ g BeC}_2\text{O}_4}{\text{mol BeC}_2\text{O}_4}$

= 0.324 g BeC<sub>2</sub>O<sub>4</sub>

% BeC<sub>2</sub>O<sub>4</sub> =  $100 * \frac{0.324 \text{ g}}{0.345 \text{ g}}$  = 93.9 %

**STOP**

If you finish before time is called, you may check your work on this part only.  
Do not turn to the other part of the test until you are told to do so.

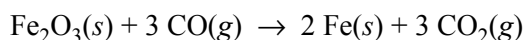
**AP<sup>®</sup> CHEMISTRY**  
**2003 SCORING GUIDELINES (Form B)**

**Question 2**

**Total Score 10 points**

2. Answer the following questions that relate to chemical reactions.

(a) Iron(III) oxide can be reduced with carbon monoxide according to the following equation.



A 16.2 L sample of  $\text{CO}(g)$  at 1.50 atm and  $200.^\circ\text{C}$  is combined with 15.39 g of  $\text{Fe}_2\text{O}_3(s)$ .

(i) How many moles of  $\text{CO}(g)$  are available for the reaction?

$PV = nRT$ $n_{\text{CO}} = \frac{PV}{RT} = \frac{(1.50 \text{ atm})(16.2 \text{ L})}{0.0821 \frac{\text{L}\cdot\text{atm}}{\text{mol}\cdot\text{K}} (473 \text{ K})} = 0.626 \text{ mol CO}$	1 point for correct substitution 1 point for answer
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(ii) What is the limiting reactant for the reaction? Justify your answer with calculations.

$n_{\text{Fe}_2\text{O}_3} = 15.39 \text{ g Fe}_2\text{O}_3 \left( \frac{1 \text{ mol Fe}_2\text{O}_3}{159.7 \text{ g Fe}_2\text{O}_3} \right) = 0.0964 \text{ mol Fe}_2\text{O}_3$ $n_{\text{CO required}} = 0.0964 \text{ mol Fe}_2\text{O}_3 \left( \frac{3 \text{ mol CO}}{1 \text{ mol Fe}_2\text{O}_3} \right) = 0.289 \text{ mol}$ <p>CO required to completely react with 0.0964 mol <math>\text{Fe}_2\text{O}_3</math></p> <p>0.626 mol CO are available, so CO is in excess and <math>\text{Fe}_2\text{O}_3</math> is limiting.</p> <p>OR</p> $n_{\text{Fe}_2\text{O}_3 \text{ required}} = 0.626 \text{ mol CO} \left( \frac{1 \text{ mol Fe}_2\text{O}_3}{3 \text{ mol CO}} \right) = 0.209 \text{ mol}$ <p>0.209 mol <math>\text{Fe}_2\text{O}_3</math> corresponds to 33.4 g <math>\text{Fe}_2\text{O}_3</math> (the amount of <math>\text{Fe}_2\text{O}_3</math> required to completely react with 0.626 mol CO)</p> <p>0.0964 mol of <math>\text{Fe}_2\text{O}_3</math> is available, so there is not enough <math>\text{Fe}_2\text{O}_3</math> to completely react with 0.626 mol CO. Therefore, <math>\text{Fe}_2\text{O}_3</math> is the limiting reactant.</p>	1 point for moles of CO or $\text{Fe}_2\text{O}_3$ required  1 point for correct conclusion  <u>NOTE:</u> Answer must be consistent with moles of CO calculated in part (a)
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**Question 2 (cont'd.)**

(ii) Calculate the pH of the resulting solution.

$n_{\text{HNO}_3} = 0.300 \text{ mol H}_3\text{PO}_4 \left( \frac{6 \text{ mol HNO}_3}{2 \text{ mol H}_3\text{PO}_4} \right) = 0.900 \text{ mol HNO}_3$ $[\text{HNO}_3] = \frac{0.900 \text{ mol HNO}_3}{2.0 \text{ L}} = 0.45 \text{ M}$ <p>Since all the <math>\text{H}_3\text{PO}_4</math> has reacted, the only acid in the solution is <math>\text{HNO}_3</math>. Since <math>\text{HNO}_3</math> is a strong acid it completely dissociates.</p> $\text{pH} = -\log[\text{H}^+] = -\log(0.45) = 0.35$ <p>If <math>\text{Ba}(\text{NO}_3)_2</math> is used as the limiting reactant</p> $n_{\text{HNO}_3} = 0.600 \text{ mol Ba}(\text{NO}_3)_2 \left( \frac{6 \text{ mol HNO}_3}{3 \text{ mol Ba}(\text{NO}_3)_2} \right) = 1.2 \text{ mol HNO}_3$ $[\text{HNO}_3] = \frac{1.2 \text{ mol HNO}_3}{2.0 \text{ L}} = 0.60 \text{ M}$ $\text{pH} = -\log[\text{H}^+] = -\log(0.60) = 0.22$	<p>1 point for number of moles of <math>\text{H}^+</math></p> <p>1 point for calculation of <math>[\text{H}^+]</math> and pH</p> <p>Must be consistent with part (b) (i)</p>
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(iii) What is the concentration, in  $\text{mol L}^{-1}$ , of the nitrate ion,  $\text{NO}_3^-(aq)$ , after the reaction reaches completion?

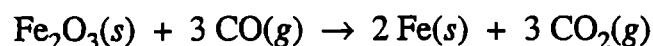
<p>The final concentration of <math>\text{NO}_3^-</math> must be the same as the initial concentration.</p> $n_{\text{NO}_3^-} = 0.600 \text{ mol Ba}(\text{NO}_3)_2 \left( \frac{2 \text{ mol NO}_3^-}{1 \text{ mol Ba}(\text{NO}_3)_2} \right) = 1.2 \text{ mol NO}_3^-$ $[\text{NO}_3^-] = \frac{1.2 \text{ mol NO}_3^-}{2.0 \text{ L}} = 0.60 \text{ M NO}_3^-$	<p>1 point for concentration of <math>\text{NO}_3^-</math></p>
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2A<sub>1</sub>

Answer EITHER Question 2 below OR Question 3 printed on page 14. Only one of these two questions will be graded. If you start both questions, be sure to cross out the question you do not want graded. The Section II score weighting for the question you choose is 20 percent.

2. Answer the following questions that relate to chemical reactions.

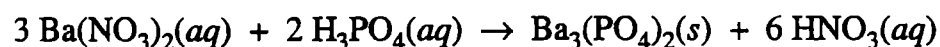
(a) Iron(III) oxide can be reduced with carbon monoxide according to the following equation.



A 16.2 L sample of  $\text{CO}(g)$  at 1.50 atm and  $200.^\circ\text{C}$  is combined with 15.39 g of  $\text{Fe}_2\text{O}_3(s)$ .

- How many moles of  $\text{CO}(g)$  are available for the reaction?
- What is the limiting reactant for the reaction? Justify your answer with calculations.
- How many moles of  $\text{Fe}(s)$  are formed in the reaction?

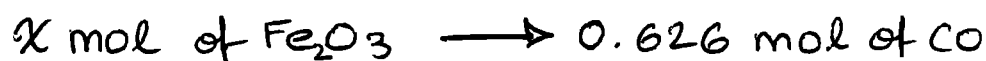
(b) In a reaction vessel, 0.600 mol of  $\text{Ba}(\text{NO}_3)_2(s)$  and 0.300 mol of  $\text{H}_3\text{PO}_4(aq)$  are combined with deionized water to a final volume of 2.00 L. The reaction represented below occurs.



- Calculate the mass of  $\text{Ba}_3(\text{PO}_4)_2(s)$  formed.
- Calculate the pH of the resulting solution.
- What is the concentration, in  $\text{mol L}^{-1}$ , of the nitrate ion,  $\text{NO}_3^-(aq)$ , after the reaction reaches completion?

$$d) \text{ i) } PV = nRT \Rightarrow n = \frac{PV}{RT} = \frac{1.5(16.2)}{(0.0821)(473)} = 6.26 \times 10^{-1} \text{ mol}$$

$$\text{ii) Number of moles of } \text{Fe}_2\text{O}_3 = n_{\text{Fe}_2\text{O}_3} = \frac{15.39}{(159.7)} = 9.637 \times 10^{-2} \text{ mol}$$



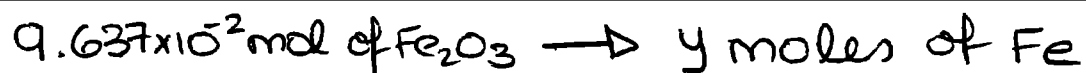
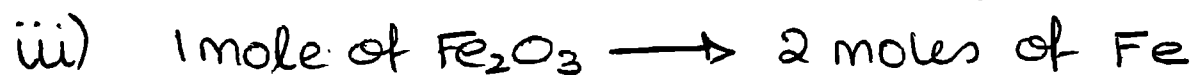
$\Rightarrow x = 0.209 \text{ mol}$  ; but we have only  $9.637 \times 10^{-2} \text{ mol}$  of  $\text{Fe}_2\text{O}_3$ , which means that  $\text{Fe}_2\text{O}_3$  is the limiting reagent.

iii)

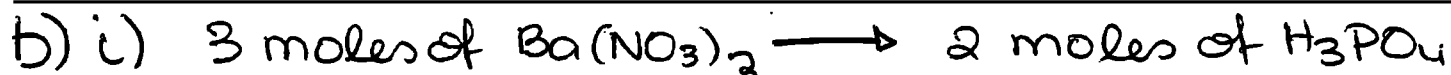
GO ON TO THE NEXT PAGE.

2A<sub>2</sub>

## ADDITIONAL PAGE FOR ANSWERING QUESTION 2.

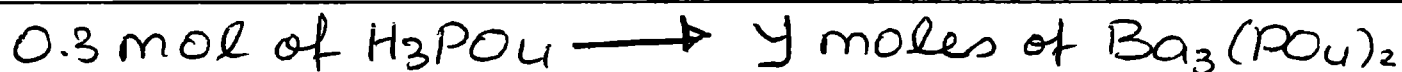


$$\Rightarrow y = \frac{2(9.637 \times 10^{-2})}{1} = 19.27 \times 10^{-2} \text{ mol}$$



$$\Rightarrow x = \frac{2(0.6)}{3} = 0.4 \text{ moles of } \text{H}_3\text{PO}_4 \text{ needed}$$

but we have only 0.3 mol of  $\text{H}_3\text{PO}_4 \Rightarrow \text{H}_3\text{PO}_4$  is the limiting reagent:

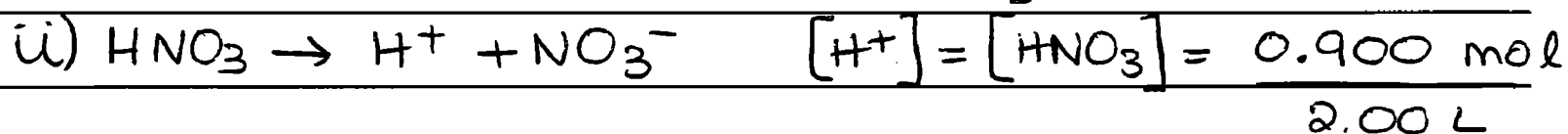


$$\Rightarrow y = \frac{0.3}{2} = 0.150 \text{ mol of } \text{Ba}_3(\text{PO}_4)_2 \text{ formed}$$

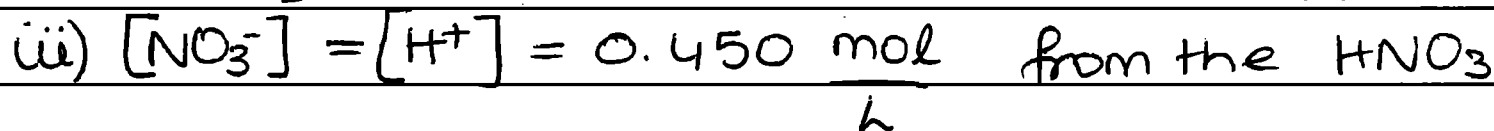
$$= \text{mass of } \text{Ba}_3(\text{PO}_4)_2 \text{ formed} = n_{\text{Ba}_3(\text{PO}_4)_2} \times M_{\text{Ba}_3(\text{PO}_4)_2}$$

$$= 0.150 \times 601$$

$$= 90.2 \text{ g}$$



$$\Rightarrow [\text{H}^+] = 0.450 \text{ M} ; \text{pH} = -\log[\text{H}^+] = -\log(0.450) = 0.347$$



but since  $\text{Ba}(\text{NO}_3)_2$  is in excess:

$$[\text{Ba}(\text{NO}_3)_2] = \frac{0.15}{2} = 0.0750 \text{ M} \Rightarrow [\text{NO}_3^-] = 0.150$$

$$\Rightarrow \text{Total } [\text{NO}_3^-] = 0.600 \text{ M}$$

GO ON TO THE NEXT PAGE.



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**Question 2**

Sample 2A (Score 10)

This response earned a perfect score. A summary of the earned points for the response is as follows: 2 points for part (a)(i), part (a)(ii), part (b)(i) and part (b)(ii), and 1 point each for part (a)(iii) and part (b)(iii) .