

PRECIPITATION REACTIONS (section 4.2)

- 4.19 Using solubility guidelines, predict whether each of the following compounds is soluble or insoluble in water: (a) MgBr_2 , (b) PbI_2 , (c) $(\text{NH}_4)_2\text{CO}_3$, (d) $\text{Sr}(\text{OH})_2$, (e) ZnSO_4 .
- 4.20 Predict whether each of the following compounds is soluble in water: (a) AgI , (b) Na_2CO_3 , (c) BaCl_2 , (d) $\text{Al}(\text{OH})_3$, (e) $\text{Zn}(\text{CH}_3\text{COO})_2$.
- 4.21 Will precipitation occur when the following solutions are mixed? If so, write a balanced chemical equation for the reaction. (a) Na_2CO_3 and AgNO_3 , (b) NaNO_3 and NiSO_4 , (c) FeSO_4 and $\text{Pb}(\text{NO}_3)_2$.
- 4.22 Identify the precipitate (if any) that forms when the following solutions are mixed, and write a balanced equation for each reaction. (a) NaCH_3COO and HCl , (b) KOH and $\text{Cu}(\text{NO}_3)_2$, (c) Na_2S and CdSO_4 .
- 4.23 Name the spectator ions in any reactions that may be involved when each of the following pairs of solutions are mixed.
 (a) $\text{Na}_2\text{CO}_3(\text{aq})$ and $\text{MgSO}_4(\text{aq})$
 (b) $\text{Pb}(\text{NO}_3)_2(\text{aq})$ and $\text{Na}_2\text{S}(\text{aq})$
 (c) $(\text{NH}_4)_3\text{PO}_4(\text{aq})$ and $\text{CaCl}_2(\text{aq})$
- 4.24 Write balanced net ionic equations for the reactions that occur in each of the following cases. Identify the spectator ion or ions in each reaction.
- (a) $\text{Cr}_2(\text{SO}_4)_3(\text{aq}) + (\text{NH}_4)_2\text{CO}_3(\text{aq}) \longrightarrow$
 (b) $\text{Ba}(\text{NO}_3)_2(\text{aq}) + \text{K}_2\text{SO}_4(\text{aq}) \longrightarrow$
 (c) $\text{Fe}(\text{NO}_3)_2(\text{aq}) + \text{KOH}(\text{aq}) \longrightarrow$
- 4.25 Separate samples of a solution of an unknown salt are treated with dilute solutions of HBr , H_2SO_4 , and NaOH . A precipitate forms in all three cases. Which of the following cations could the solution contain: K^+ , Pb^{2+} , Ba^{2+} ?
- 4.26 Separate samples of a solution of an unknown ionic compound are treated with dilute AgNO_3 , $\text{Pb}(\text{NO}_3)_2$, and BaCl_2 . Precipitates form in all three cases. Which of the following could be the anion of the unknown salt: Br^- , CO_3^{2-} , NO_3^- ?
- 4.27 You know that an unlabeled bottle contains a solution of one of the following: AgNO_3 , CaCl_2 , or $\text{Al}_2(\text{SO}_4)_3$. A friend suggests that you test a portion of the solution with $\text{Ba}(\text{NO}_3)_2$ and then with NaCl solutions. Explain how these two tests together would be sufficient to determine which salt is present in the solution.
- 4.28 Three solutions are mixed together to form a single solution. One contains 0.2 mol $\text{Pb}(\text{CH}_3\text{COO})_2$, the second contains 0.1 mol Na_2S , and the third contains 0.1 mol CaCl_2 . (a) Write the net ionic equations for the precipitation reaction or reactions that occur. (b) What are the spectator ions in the solution?

ACIDS, BASES, AND NEUTRALIZATION REACTIONS (section 4.3)

- 4.29 Which of the following solutions has the largest concentration of solvated protons: (a) 0.2 M LiOH , (b) 0.2 M HI , (c) 1.0 M methyl alcohol (CH_3OH)? Explain
- 4.30 Which of the following solutions is the most basic? (a) 0.6 M NH_3 , (b) 0.150 M KOH , (c) 0.100 M $\text{Ba}(\text{OH})_2$. Explain.
- 4.31 What is the difference between (a) a monoprotic acid and a diprotic acid, (b) a weak acid and a strong acid, (c) an acid and a base?
- 4.32 Explain the following observations: (a) NH_3 contains no OH^- ions, and yet its aqueous solutions are basic; (b) HF is called a weak acid, and yet it is very reactive; (c) although sulfuric acid is a strong electrolyte, an aqueous solution of H_2SO_4 contains more HSO_4^- ions than SO_4^{2-} ions.
- 4.33 Is there any correlation between the anions that form when each of the strong acids in Table 4.2 dissociates and the anions that normally form soluble ionic compounds (Table 4.1)? Which anions if any are exceptions to the general trend?
- 4.34 What is the relationship between the solubility rules in Table 4.1 and the list of strong bases in Table 4.2? Another way of asking this question is, why is $\text{Cd}(\text{OH})_2$, for example, not listed as a strong base in Table 4.2?
- 4.35 Label each of the following substances as an acid, base, salt, or none of the above. Indicate whether the substance exists in aqueous solution entirely in molecular form, entirely as ions, or as a mixture of molecules and ions. (a) HF , (b) acetonitrile, CH_3CN , (c) NaClO_4 , (d) $\text{Ba}(\text{OH})_2$.
- 4.36 An aqueous solution of an unknown solute is tested with litmus paper and found to be acidic. The solution is weakly conducting compared with a solution of NaCl of the same concentration.
- Which of the following substances could the unknown be: KOH , NH_3 , HNO_3 , KClO_2 , H_3PO_3 , CH_3COCH_3 (acetone)?
- 4.37 Classify each of the following substances as a nonelectrolyte, weak electrolyte, or strong electrolyte in water: (a) H_2SO_3 , (b) $\text{C}_2\text{H}_5\text{OH}$ (ethanol), (c) NH_3 , (d) KClO_3 , (e) $\text{Cu}(\text{NO}_3)_2$.
- 4.38 Classify each of the following aqueous solutions as a nonelectrolyte, weak electrolyte, or strong electrolyte: (a) LiClO_4 , (b) HClO , (c) $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$ (propanol), (d) HClO_3 , (e) CuSO_4 , (f) $\text{C}_{12}\text{H}_{22}\text{O}_{11}$ (sucrose).
- 4.39 Complete and balance the following molecular equations, and then write the net ionic equation for each:
 (a) $\text{HBr}(\text{aq}) + \text{Ca}(\text{OH})_2(\text{aq}) \longrightarrow$
 (b) $\text{Cu}(\text{OH})_2(\text{s}) + \text{HClO}_4(\text{aq}) \longrightarrow$
 (c) $\text{Al}(\text{OH})_3(\text{s}) + \text{HNO}_3(\text{aq}) \longrightarrow$
- 4.40 Write the balanced molecular and net ionic equations for each of the following neutralization reactions:
 (a) Aqueous acetic acid is neutralized by aqueous barium hydroxide.
 (b) Solid chromium(III) hydroxide reacts with nitrous acid.
 (c) Aqueous nitric acid and aqueous ammonia react.
- 4.41 Write balanced molecular and net ionic equations for the following reactions, and identify the gas formed in each: (a) solid cadmium sulfide reacts with an aqueous solution of sulfuric acid; (b) solid magnesium carbonate reacts with an aqueous solution of perchloric acid.
- 4.42 Because the oxide ion is basic, metal oxides react readily with acids. (a) Write the net ionic equation for the following reaction:
 $\text{FeO}(\text{s}) + 2 \text{HClO}_4(\text{aq}) \longrightarrow \text{Fe}(\text{ClO}_4)_2(\text{aq}) + \text{H}_2\text{O}(\text{l})$

(b) Based on the equation in part (a), write the net ionic equation for the reaction that occurs between NiO(s) and an aqueous solution of nitric acid.

- 4.43 Magnesium carbonate, magnesium oxide, and magnesium hydroxide are all white solids that react with acidic solutions. (a) Write a balanced molecular equation and a net ionic equation for the reaction that occurs when each substance reacts with a hydrochloric acid solution. (b) By observing the reactions in part (a) could you distinguish any of the three

magnesium substances from the other two? If so how? (c) If excess HCl(aq) is added, would the clear solutions left behind after the reaction is complete contain the same or different ions in each case?

- 4.44 As K₂O dissolves in water, the oxide ion reacts with water molecules to form hydroxide ions. Write the molecular and net ionic equations for this reaction. Based on the definitions of acid and base, what ion is the base in this reaction? What is the acid? What is the spectator ion in the reaction?

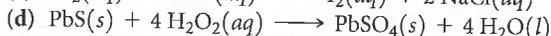
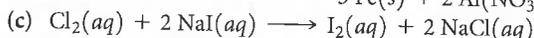
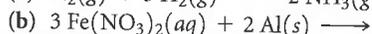
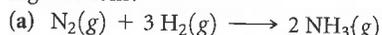
OXIDATION-REDUCTION REACTIONS (section 4.4)

- 4.45 Define oxidation and reduction in terms of (a) electron transfer and (b) oxidation numbers.
- 4.46 Can oxidation occur without oxygen? Can oxidation occur without reduction?
- 4.47 Which region of the periodic table shown here contains the most readily oxidized elements? Which region contains the least readily oxidized?

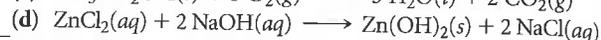
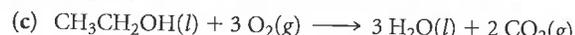
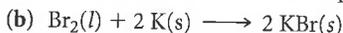
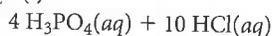
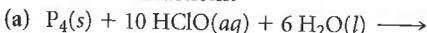
- 4.48 Determine the oxidation number of sulfur in each of the following substances: (a) barium sulfate, BaSO₄, (b) sulfurous acid, H₂SO₃, (c) strontium sulfide, SrS, (d) hydrogen sulfide, H₂S. (e) Based on these compounds what is the range of oxidation numbers seen for sulfur? Is there any relationship between the range of accessible oxidation states and sulfur's position on the periodic table?

- 4.49 Determine the oxidation number for the indicated element in each of the following substances: (a) S in SO₂, (b) C in COCl₂, (c) Mn in KMnO₄, (d) Br in HBrO, (e) As in As₄, (f) O in K₂O₂.
- 4.50 Determine the oxidation number for the indicated element in each of the following compounds: (a) Co in LiCoO₂, (b) Al in NaAlH₄, (c) C in CH₃OH (methanol), (d) N in GaN, (e) Cl in HClO₂, (f) Cr in BaCrO₄.

- 4.51 Which element is oxidized and which is reduced in the following reactions?



- 4.52 Which of the following are redox reactions? For those that are, indicate which element is oxidized and which is reduced. For those that are not, indicate whether they are precipitation or neutralization reactions.



- 4.53 Write balanced molecular and net ionic equations for the reactions of (a) manganese with dilute sulfuric acid, (b) chromium with hydrobromic acid, (c) tin with hydrochloric acid, (d) aluminum with formic acid, HCOOH.

- 4.54 Write balanced molecular and net ionic equations for the reactions of (a) hydrochloric acid with nickel, (b) dilute sulfuric acid with iron, (c) hydrobromic acid with magnesium, (d) acetic acid, CH₃COOH, with zinc.

- 4.55 Using the activity series (Table 4.5), write balanced chemical equations for the following reactions. If no reaction occurs, simply write NR. (a) Iron metal is added to a solution of copper(II) nitrate; (b) zinc metal is added to a solution of magnesium sulfate; (c) hydrobromic acid is added to tin metal; (d) hydrogen gas is bubbled through an aqueous solution of nickel(II) chloride; (e) aluminum metal is added to a solution of cobalt(II) sulfate.

- 4.56 Using the activity series (Table 4.5), write balanced chemical equations for the following reactions. If no reaction occurs, simply write NR. (a) Nickel metal is added to a solution of copper(II) nitrate; (b) a solution of zinc nitrate is added to a solution of magnesium sulfate; (c) hydrochloric acid is added to gold metal; (d) chromium metal is immersed in an aqueous solution of cobalt(II) chloride; (e) hydrogen gas is bubbled through a solution of silver nitrate.

- 4.57 The metal cadmium tends to form Cd²⁺ ions. The following observations are made: (i) When a strip of zinc metal is placed in CdCl₂(aq), cadmium metal is deposited on the strip. (ii) When a strip of cadmium metal is placed in Ni(NO₃)₂(aq), nickel metal is deposited on the strip. (a) Write net ionic equations to explain each of the preceding observations. (b) What can you conclude about the position of cadmium in the activity series? (c) What experiments would you need to perform to locate more precisely the position of cadmium in the activity series?

- 4.58 (a) Use the following reactions to prepare an activity series for the halogens:



- (b) Relate the positions of the halogens in the periodic table with their locations in this activity series. (c) Predict whether a reaction occurs when the following reagents are mixed: Cl₂(aq) and KI(aq); Br₂(aq) and LiCl(aq).

CONCENTRATIONS OF SOLUTIONS (section 4.5)

- 4.59 (a) Is the concentration of a solution an intensive or an extensive property? (b) What is the difference between 0.50 mol HCl and 0.50 M HCl?
- 4.60 (a) Suppose you prepare 500 mL of a 0.10 M solution of some salt and then spill some of it. What happens to the concentration of the solution left in the container? (b) Suppose you prepare 500 mL of a 0.10 M aqueous solution of some salt and let it sit out, uncovered, for a long time, and some water evaporates. What happens to the concentration of the solution left in the container? (c) A certain volume of a 0.50 M solution contains 4.5 g of a salt. What mass of the salt is present in the same volume of a 2.50 M solution?
- 4.61 (a) Calculate the molarity of a solution that contains 0.175 mol ZnCl_2 in exactly 150 mL of solution. (b) How many moles of HCl are present in 35.0 mL of a 4.50 M solution of nitric acid? (c) How many milliliters of 6.00 M NaOH solution are needed to provide 0.325 mol of NaOH?
- 4.62 (a) Calculate the molarity of a solution made by dissolving 12.5 grams of Na_2CrO_4 in enough water to form exactly 550 mL of solution. (b) How many moles of KBr are present in 150 mL of a 0.275 M solution? (c) How many milliliters of 6.1 M HCl solution are needed to obtain 0.100 mol of HCl?
- 4.63 The average adult human male has a total blood volume of 5.0 L. If the concentration of sodium ion in this average individual is 0.135 M, what is the mass of sodium ion circulating in the blood?
- 4.64 A person suffering from hyponatremia has a sodium ion concentration in the blood of 0.118 M and a total blood volume of 4.6 L. What mass of sodium chloride would need to be added to the blood to bring the sodium ion concentration up to 0.138 M, assuming no change in blood volume?
- 4.65 The concentration of alcohol ($\text{C}_2\text{H}_5\text{OH}$) in blood, called the "blood alcohol concentration" or BAC, is given in units of grams of alcohol per 100 mL of blood. The legal definition of intoxication, in many states of the United States, is that the BAC is 0.08 or higher. What is the concentration of alcohol, in terms of molarity, in blood if the BAC is 0.08?
- 4.66 The average adult male has a total blood volume of 5.0 L. After drinking a few beers, he has a BAC of 0.10 (see Exercise 4.65). What mass of alcohol is circulating in his blood?
- 4.67 Calculate (a) the number of grams of solute in 0.250 L of 0.175 M KBr, (b) the molar concentration of a solution containing 14.75 g of $\text{Ca}(\text{NO}_3)_2$ in 1.375 L, (c) the volume of 1.50 M Na_3PO_4 in milliliters that contains 2.50 g of solute.
- 4.68 (a) How many grams of solute are present in 15.0 mL of 0.736 M $\text{K}_2\text{Cr}_2\text{O}_7$? (b) If 14.00 g of $(\text{NH}_4)_2\text{SO}_4$ is dissolved in enough water to form 250 mL of solution, what is the molarity of the solution? (c) How many milliliters of 0.0455 M CuSO_4 contain 3.65 g of solute?
- 4.69 (a) Which will have the highest concentration of potassium ion: 0.20 M KCl, 0.15 M K_2CrO_4 , or 0.080 M K_3PO_4 ? (b) Which will contain the greater number of moles of potassium ion: 30.0 mL of 0.15 M K_2CrO_4 or 25.0 mL of 0.080 M K_3PO_4 ?
- 4.70 In each of the following pairs, indicate which has the higher concentration of I^- ion: (a) 0.10 M BaI_2 or 0.25 M KI solution, (b) 100 mL of 0.10 M KI solution or 200 mL of 0.040 M ZnI_2 solution, (c) 3.2 M HI solution or a solution made by dissolving 145 g of NaI in water to make 150 mL of solution.
- 4.71 Indicate the concentration of each ion or molecule present in the following solutions: (a) 0.25 M NaNO_3 , (b) 1.3×10^{-2} M MgSO_4 , (c) 0.0150 M $\text{C}_6\text{H}_{12}\text{O}_6$, (d) a mixture of 45.0 mL of 0.272 M NaCl and 65.0 mL of 0.0247 M $(\text{NH}_4)_2\text{CO}_3$. Assume that the volumes are additive. *110 mL*
- 4.72 Indicate the concentration of each ion present in the solution formed by mixing (a) 42.0 mL of 0.170 M NaOH and 37.6 mL of 0.400 M NaOH, (b) 44.0 mL of 0.100 M and Na_2SO_4 and 25.0 mL of 0.150 M KCl, (c) 3.60 g KCl in 75.0 mL of 0.250 M CaCl_2 solution. Assume that the volumes are additive.
- 4.73 (a) You have a stock solution of 14.8 M NH_3 . How many milliliters of this solution should you dilute to make 1000.0 mL of 0.250 M NH_3 ? (b) If you take a 10.0-mL portion of the stock solution and dilute it to a total volume of 0.500 L, what will be the concentration of the final solution?
- 4.74 (a) How many milliliters of a stock solution of 6.0 M HNO_3 would you have to use to prepare 1.10 mL of 0.500 M HNO_3 ? (b) If you dilute 10.0 mL of the stock solution to a final volume of 0.250 L, what will be the concentration of the diluted solution?
- 4.75 (a) Starting with solid sucrose, $\text{C}_{12}\text{H}_{22}\text{O}_{11}$, describe how you would prepare 250 mL of a 0.250 M sucrose solution. (b) Describe how you would prepare 350.0 mL of 0.100 M $\text{C}_{12}\text{H}_{22}\text{O}_{11}$ starting with 3.00 L of 1.50 M $\text{C}_{12}\text{H}_{22}\text{O}_{11}$.
- 4.76 (a) How would you prepare 175.0 mL of 0.150 M AgNO_3 solution starting with pure AgNO_3 ? (b) An experiment calls for you to use 100 mL of 0.50 M HNO_3 solution. All you have available is a bottle of 3.6 M HNO_3 . How would you prepare the desired solution?
- 4.77 Pure acetic acid, known as glacial acetic acid, is a liquid with a density of 1.049 g/mL at 25 °C. Calculate the molarity of a solution of acetic acid made by dissolving 20.00 mL of glacial acetic acid at 25 °C in enough water to make 250.0 mL of solution.
- 4.78 Glycerol, $\text{C}_3\text{H}_8\text{O}_3$, is a substance used extensively in the manufacture of cosmetics, foodstuffs; antifreeze, and plastics. Glycerol is a water-soluble liquid with a density of 1.2656 g/mL at 15 °C. Calculate the molarity of a solution of glycerol made by dissolving 50.000 mL glycerol at 15 °C in enough water to make 250.00 mL of solution.

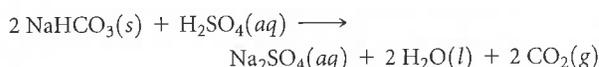
SOLUTION STOICHIOMETRY AND CHEMICAL ANALYSIS (section 4.6)

- 4.79 What mass of KCl is needed to precipitate the silver ions from 15.0 mL of 0.200 M AgNO_3 solution?
- 4.80 What mass of NaOH is needed to precipitate the Cd^{2+} ions from 35.0 mL of 0.500 M $\text{Cd}(\text{NO}_3)_2$ solution?
- 4.81 (a) What volume of 0.115 M HClO_4 solution is needed to neutralize 50.00 mL of 0.0875 M NaOH? (b) What volume of 0.128 M HCl is needed to neutralize 2.87 g of $\text{Mg}(\text{OH})_2$? (c) If 25.8 mL of AgNO_3 is needed to precipitate all the Cl^- ions in a

785-mg sample of KCl (forming AgCl), what is the molarity of the AgNO₃ solution? (d) If 45.3 mL of 0.108 M HCl solution is needed to neutralize a solution of KOH, how many grams of KOH must be present in the solution?

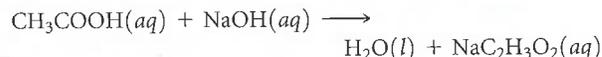
- 4.82 (a) How many milliliters of 0.120 M HCl are needed to completely neutralize 50.0 mL of 0.101 M Ba(OH)₂ solution? (b) How many milliliters of 0.125 M H₂SO₄ are needed to neutralize 0.200 g of NaOH? (c) If 55.8 mL of BaCl₂ solution is needed to precipitate all the sulfate ion in a 752-mg sample of Na₂SO₄, what is the molarity of the solution? (d) If 42.7 mL of 0.208 M HCl solution is needed to neutralize a solution of Ca(OH)₂, how many grams of Ca(OH)₂ must be in the solution?

- 4.83 Some sulfuric acid is spilled on a lab bench. You can neutralize the acid by sprinkling sodium bicarbonate on it and then mopping up the resultant solution. The sodium bicarbonate reacts with sulfuric acid as follows:



Sodium bicarbonate is added until the fizzing due to the formation of CO₂(g) stops. If 27 mL of 6.0 M H₂SO₄ was spilled, what is the minimum mass of NaHCO₃ that must be added to the spill to neutralize the acid?

- 4.84 The distinctive odor of vinegar is due to acetic acid, CH₃COOH, which reacts with sodium hydroxide in the following fashion:



If 3.45 mL of vinegar needs 42.5 mL of 0.115 M NaOH to reach the equivalence point in a titration, how many grams of acetic acid are in a 1.00-qt sample of this vinegar?

- 4.85 A 4.36-g sample of an unknown alkali metal hydroxide is dissolved in 100.0 mL of water. An acid–base indicator is added and the resulting solution is titrated with 2.50 M HCl(aq)

solution. The indicator changes color signaling that the equivalence point has been reached after 17.0 mL of the hydrochloric acid solution has been added. (a) What is the molar mass of the metal hydroxide? (b) What is the identity of the alkali metal cation: Li⁺, Na⁺, K⁺, Rb⁺, or Cs⁺?

- 4.86 An 8.65-g sample of an unknown group 2A metal hydroxide is dissolved in 85.0 mL of water. An acid–base indicator is added and the resulting solution is titrated with 2.50 M HCl(aq) solution. The indicator changes color signaling that the equivalence point has been reached after 56.9 mL of the hydrochloric acid solution has been added. (a) What is the molar mass of the metal hydroxide? (b) What is the identity of the metal cation: Ca²⁺, Sr²⁺, Ba²⁺?

- 4.87 A solution of 100.0 mL of 0.200 M KOH is mixed with a solution of 200.0 mL of 0.150 M NiSO₄. (a) Write the balanced chemical equation for the reaction that occurs. (b) What precipitate forms? (c) What is the limiting reactant? (d) How many grams of this precipitate form? (e) What is the concentration of each ion that remains in solution?

- 4.88 A solution is made by mixing 15.0 g of Sr(OH)₂ and 55.0 mL of 0.200 M HNO₃. (a) Write a balanced equation for the reaction that occurs between the solutes. (b) Calculate the concentration of each ion remaining in solution. (c) Is the resultant solution acidic or basic?

- 4.89 A 0.5895-g sample of impure magnesium hydroxide is dissolved in 100.0 mL of 0.2050 M HCl solution. The excess acid then needs 19.85 mL of 0.1020 M NaOH for neutralization. Calculate the percent by mass of magnesium hydroxide in the sample, assuming that it is the only substance reacting with the HCl solution.

- 4.90 A 1.248-g sample of limestone rock is pulverized and then treated with 30.00 mL of 1.035 M HCl solution. The excess acid then requires 11.56 mL of 1.010 M NaOH for neutralization. Calculate the percent by mass of calcium carbonate in the rock, assuming that it is the only substance reacting with the HCl solution.

ADDITIONAL EXERCISES

- 4.91 Gold is one of the few metals that can be obtained by panning, where a simple pan is used to separate gold from other deposits found in or near a stream bed. What two properties of gold make it possible to find gold, but not metals like copper, silver, lead, and aluminum, by panning?
- 4.92 The accompanying photo shows the reaction between a solution of Cd(NO₃)₂ and one of Na₂S. What is the identity of the precipitate? What ions remain in solution? Write the net ionic equation for the reaction.

