Objective 5. Double replacement reactions 1: balancing precipitation reactions, applying solubility table, write net ionic equations to predict whether a reaction occurs, perform mole-mass and mole ratio calculations (gravimetric)

Quiz Practice problems:

Key ideas: In a double replacement reaction, an ionic compound reacts with another ionic compound to form two new ionic compounds. The ions in the reactant ionic compounds replace or exchange with each other.

AB + CD ---> AD + CB

One type of double replacement reaction is a precipitation reaction.
A net ionic equation is used to predict whether a reaction occurs.

Skills: Given reactants of a double replacement reaction, predict the products (write chemical formulas) of the reaction.
Balance a double replacement reaction.
Use Table of solubility rules of ionic compounds.
Identify the precipitate in a double replacement reaction.
Write a net ionic equation. Identify spectator ions.
Predict whether a reaction occurs from a net ionic equation.
Perform chemical calculations involving a double replacement reaction.

1. Determine if the compound is soluble in water. If so, what ions form when the compound dissolves in water?
Example: NaCl is soluble in water (see rule for sodium compounds or halide compounds).
NaCl forms Na^+ ion and Cl^- ion.
a. sodium phosphate
b. $CaCO_3$
c. KOH
d. AgCl
e. NH_4NO_3
f. barium sulfate

Answers:
a. sodium phosphate is soluble in water and forms 3 Na^+ ions and 1 PO_4^{3-} ion for every Na_3PO_4 that dissolves.
b. $CaCO_3$ is insoluble in water.
c. KOH is soluble in water and forms 3 K^+ ions and 1 OH^- ion for every KOH that dissolves.
d. AgCl is insoluble in water.
e. NH_4NO_3 is soluble in water and forms 1 NH_4^+ ion and 1 NO_3^- ion for every NH_4NO_3 that dissolves.
f. barium sulfate is insoluble in water.

2. Two ions are in solution. Will these two ions combine to form a precipitate?
a. calcium and chloride
b. Na^+ and SO_4^{2-}
c. potassium and carbonate
d. Mg^{2+} and NO_3^-
e. Mg^{2+} and carbonate

Answers:
a. calcium and chloride will not form a precipitate because $CaCl_2$ is soluble in water.
b. Na^+ and SO_4^{2-} will not form a precipitate because Na_2SO_4 is soluble in water.
c. potassium and carbonate will not form a precipitate because $CaCO_3$ is soluble in water.
d. Mg^{2+} and NO_3^- will not form a precipitate because $Mg(NO_3)_2$ is soluble in water.
e. Mg^{2+} and carbonate will form a precipitate because $MgCO_3$ is soluble in water.

3. The following precipitation reactions occur. Which product is the precipitate? Write a net ionic equation. Identify the spectator ions.
a. NaCl + $AgNO_3$ ---> $NaNO_3$ + AgCl
Precipitate = AgCl (see Table of solubility of ionic compounds)
Ionic equation: Na^+ + Cl^- + Ag^+ + NO_3^- ---> Na^+ + NO_3^- + AgCl (s)
Net ionic equation: Cl^- + Ag^+ ---> AgCl (s)
Spectator ions: Na^+ + NO_3^-

b. $CaCl_2$ + K_2CO_3 ---> $CaCO_3$ + 2 KCl

c. barium chloride + sodium sulfate --->

Answers:
b. Precipitate = $CaCO_3$ (see Table of solubility of ionic compounds)
Ionic equation: Ca^{+2} + 2 Cl^- + 2 K^+ + CO_3^{-2} ---> 2 Cl^- + 2 K^+ + $CaCO_3$ (s)
Net ionic equation: Ca^{+2} + CO_3^{-2} ---> $CaCO_3$ (s)

Spectator ions: $2\ Cl^- + 2\ K^+$

c. barium chloride = $BaCl_2$ = soluble in water
sodium sulfate = Na_2SO_4 = soluble in water
$BaCl_2 + Na_2SO_4$ -->
Remember AB + CD --> AD + CB
A = Ba^{+2}, B = Cl^-, C = Na^+, D = SO_4^{-2}
So $BaCl_2 + Na_2SO_4$ --> $BaSO_4$ (s) + 2 NaCl
Precipitate = $BaSO_4$ (see Table of solubility of ionic compounds)
Ionic equation: $Ba^{+2} + 2\ Cl^- + 2\ Na^+ + SO_4^{-2}$ ---> $BaSO_4$ (s) + $2\ Cl^- + 2\ Na^+$
Net ionic equation: $Ba^{+2} + SO_4^{-2}$ ---> $BaSO_4$ (s)
Spectator ions: $2\ Cl^- + 2\ Na^+$

You can predict whether a precipitation reaction occurs if you can write a net ionic equation.
4. Predict whether the reaction occurs. If so, write a net ionic equation.
Example: KCl + Na_3PO_4 --->
AB + CD ----> AD + CB
Products: KCl + Na_3PO_4 ---> K_3PO_4 + NaCl
Balance the equation: 3 KCl + Na_3PO_4 ---> K_3PO_4 + 3 NaCl
See Table of solubility of ionic compounds: KCl, Na_3PO_4, K_3PO_4, and NaCl are soluble.
Ionic equation: $3\ K^+ + 3\ Cl^- + 3\ Na^+ + PO_4^{-3}$ ---> $3\ K^+ + PO_4^{-3} + 3\ Na^+ + 3\ Cl^-$
Every ion cancels out so each ion is a spectator ion. Therefore, this reaction does not occur.

a. KOH + $MgCl_2$ --->
(Answer: this reaction occurs so you should be able to write a net ionic equation. One product is solid $Mg(OH)_2$.)

b. sodium carbonate + calcium chloride --->
(Answer: this reaction occurs.)

In many reactions, all of one reactant reacts (this reactant is called the limiting reactant) and not all of other reactant reactants (this reactant is called the excess reactant).
c. 10 g of $CaCl_2$ is mixed with 10 g of K_2CO_3. A reaction occurs (see Question 3b). The limiting reactant is K_2CO_3. Calculate the moles of excess $CaCl_2$ leftover.
(Answer: original moles of $CaCl_2$ = 0.090 moles, moles of $CaCl_2$ that reacts with 10 g of K_2CO_3 = 0.072 moles, moles of $CaCl_2$ leftover = 0.018 moles)

d. 50 g of $CaCl_2$ is mixed with 200 g of $AgNO_3$. A reaction occurs. All of the $CaCl_2$ reacts.
$CaCl_2 + AgNO_3$ --->
(i) You have 50 g of $CaCl_2$. Moles of $CaCl_2$ = _______.
If all of the $CaCl_2$ reacts, how many moles of $AgNO_3$ reacts with it? (What is the conversion factor?)
(ii) You have 200 g of $AgNO_3$. Moles of $AgNO_3$ = _______.
If all of the $AgNO_3$ reacts, how many moles of $CaCl_2$ reacts with it?
(iii) The limiting reactant is ______. (Compare your answers to (i) and (ii).)
(iv) The mass of $AgNO_3$ that is leftover (excess) = _______ g. (Answer: between 45 and 50 g)

e. The amount of salt in water is determined by testing for chloride ion. Silver nitrate solution is added to the salt-containing water sample. The precipitate that forms is collected, dried, and weighed. The mass of chloride ion and salt is calculated from the mass of precipitate.
(i) Write a molecular equation and net ionic equation that represents this reaction. What is the precipitate that forms?
(ii) 10.0 ml of a saline sample is analyzed. Silver nitrate solution is added. How can you make sure that all of the chloride precipitates out of solution? In other words, which reactant should be the limiting reactant? Give reasons.
(iii) You want the % yield of this reaction to be 100%. Explain why.
(iv) 0.25 g of precipate is collected, dried, and weighed. What is the chemical formula of the precipitate? Calculate the mass of sodium ion. (Answer: approximately 0.04 g Na^+ in 10.0 ml of water)
(v) The RDA of sodium is 2300 mg per day. Would you drink a cup (240 ml) of this water to get your RDA of sodium?
(vi) 100 g of NaCl is dissolved in water. This solution is mixed with 100 g of silver nitrate dissolved in water. Which reactant is the limiting reactant?
Calculate the mass of AgCl that precipitates out of solution. (Answer: between 80 and 90 g)
Answers: Remember AB + CD --> AD + CB
a. A = K^+, B = OH^-, C = Mg^{+2}, D = Cl^-
So KOH + $MgCl_2$ ---> KCl + $Mg(OH)_2$ (s)
Balance: 2 KOH + $MgCl_2$ ---> 2 KCl + $Mg(OH)_2$ (s)

Precipitate = $Mg(OH)_2$ (see Table of solubility of ionic compounds)
Ionic equation: $2\ K^+ + 2\ OH^- + Mg^{+2} + 2\ Cl^-$ ---> $2\ K^+ + 2\ Cl^- + Mg(OH)_2$ (s)
Net ionic equation: $2\ OH^- + Mg^{+2}$ ---> $Mg(OH)_2$ (s)
Spectator ions: $2\ Cl^- + 2\ K^+$

b. sodium carbonate + calcium chloride --->
$Na_2CO_3 + CaCl_2$ -->
A = Na^+, B = CO_3^{-2}, C = Ca^{+2}, D = Cl^-
So $Na_2CO_3 + CaCl_2$ --> $NaCl + CaCO_3$ (s)
Balance: $Na_2CO_3 + CaCl_2$ --> $2\ NaCl + CaCO_3$ (s)
Precipitate = $CaCO_3$ (see Table of solubility of ionic compounds)
Ionic equation: $2\ Na^+ + CO_3^{-2} + Ca^{+2} + 2\ Cl^-$ ---> $2\ Na^+ + 2\ Cl^- + CaCO_3$ (s)
Net ionic equation: $CO_3^{-2} + Ca^{+2}$ ---> $CaCO_3$ (s)
Spectator ions: $2\ Cl^- + 2\ Na^+$

c. 10 g of $CaCl_2$ is mixed with 10 g of K_2CO_3. The limiting reactant is K_2CO_3. Calculate the moles of excess $CaCl_2$ leftover.

Balance:	$K_2CO_3 + CaCl_2$ --> $2\ KCl + CaCO_3$ (s)	
Mass	10 g	10 g
Molar mass	138	111
Moles start	0.072	0.090
Moles that react	0.072	0.072 (1 mole of K_2CO_3 reacts with 1 mole of $CaCl_2$, so 1:1 mole ratio)
Moles leftover	0	0.018 (moles leftover = moles start – moles that react)
	Limiting	Excess

All of the limiting reactant reacts.

OR
Calculate the amount of one product that is produced from the mass of one reactant.
Calculate the amount of the same product that is produced from the mass of the other reactant.
Compare the amount of product produced.
The reactant that produces the SMALLER amount of product is the LIMITING reactant.
10 g K_2CO_3 (1 mole K_2CO_3 /138 g K_2CO_3)(1 mole $CaCO_3$ /1 mole K_2CO_3) = 0.072 moles $CaCO_3$
10 g $CaCl_2$ (1 mole $CaCl_2$ /111 g $CaCl_2$)(1 mole $CaCO_3$ /1 mole $CaCl_2$) = 0.090 moles $CaCO_3$
0.072 moles is SMALLER than 0.090 moles so K_2CO_3 is the LIMITING reactant.

d. 50 g of $CaCl_2$ is mixed with 200 g of $AgNO_3$. A reaction occurs. All of the $CaCl_2$ reacts.
$CaCl_2 + AgNO_3$ --->
(i) You have 50 g of $CaCl_2$. Moles of $CaCl_2$ = 50 g (1 mole $CaCl_2$/111 g $CaCl_2$) = 0.45 moles $CaCl_2$
If all of the $CaCl_2$ reacts, how many moles of $AgNO_3$ reacts with it? (What is the conversion factor?)
Balance the chemical equation: $CaCl_2 + 2\ AgNO_3$ ---> $Ca(NO_3)_2 + 2\ AgCl$ (s)
The coefficients tell you the mole ratio of reactants and products.
1 mole of $CaCl_2$ reacts with 2 moles of $AgNO_3$.
0.45 moles $CaCl_2$ (2 moles $AgNO_3$/1 mole $CaCl_2$) = 0.90 moles $AgNO_3$.
(ii) You have 200 g of $AgNO_3$. Moles of $AgNO_3$ = 200 g (1 mole $AgNO_3$/170 g $AgNO_3$) = 1.18 moles $AgNO_3$
If all of the $AgNO_3$ reacts, how many moles of $CaCl_2$ reacts with it?
1 mole of $CaCl_2$ reacts with 2 moles of $AgNO_3$.
1.18 moles $AgNO_3$ (1 mole $CaCl_2$/2 moles $AgNO_3$) = 0.59 moles $CaCl_2$.

(iii) The limiting reactant is $CaCl_2$. (Compare your answers to (i) and (ii).)
50 g of $CaCl_2$ = 0.45 moles $CaCl_2$ (2 moles $AgNO_3$/1 mole $CaCl_2$) reacts with 0.90 moles $AgNO_3$.
200 g of $AgNO_3$ = 1.18 moles $AgNO_3$ reacts with 0.59 moles $CaCl_2$.
(iv) The mass of $AgNO_3$ that is leftover (excess) = 47.6 g. (Answer: between 45 and 50 g)

Balance:	$CaCl_2 + 2\ AgNO_3$ ---> $Ca(NO_3)_2 + 2\ AgCl$ (s)	
Mass	50 g	200 g
Molar mass	111	170
Moles start	0.45	1.18
Moles that react	0.45	0.90 (1 mole of $CaCl_2$ reacts with 2 mole of $AgNO_3$, so 1:2 mole ratio)
Moles leftover	0	0.28 (moles leftover = moles start – moles that react)
Mass leftover	0	0.28 moles $AgNO_3$ (170 g $AgNO_3$/1 mole $AgNO_3$) = 47.6 g
	Limiting	Excess

e. The amount of salt in water is determined by testing for chloride ion. Silver nitrate solution is added to the salt-containing water sample. The precipitate that forms is collected, dried, and weighed. The mass of chloride ion and salt is calculated from the mass of precipitate.

(i) Write a molecular equation and net ionic equation that represents this reaction. What is the precipitate that forms?
$NaCl + AgNO_3$ ---> $NaNO_3 + AgCl$ (s)
$Na^+ + Cl^- + Ag^+ + NO_3^-$ ---> $Na^+ + NO_3^- + AgCl$ (s)
$Cl^- + Ag^+$ ---> AgCl (s)
AgCl is the precipitate.
(ii) 10.0 ml of a saline sample is analyzed. Silver nitrate solution is added. How can you make sure that all of the chloride precipitates out of solution? In other words, which reactant should be the limiting reactant? Give reasons.
Make sure all of the Cl^- precipitates out of solution by making NaCl the limiting reactant.
(iii) You want the % yield of this reaction to be 100%. Explain why.
You want the % yield to be 100% to make the reaction "quantitative" so all of the reactant (Cl^-) that reacts produces the predicted amount of product (AgCl). The amount of product (AgCl) is used to accurately determine the amount of reactant (salt) in a water sample.
If the % yield is not 100%, then the theoretical yield (remember % yield = (actual yield/theoretical yield) x 100) of product has higher error (uncertainty) and amount of product to determine the amount of reactant in a sample will not be as accurately.
(iv) 0.25 g of precipate is collected, dried, and weighed. What is the chemical formula of the precipitate? Calculate the mass of sodium ion. (Answer: approximately 0.04 g Na^+ in 10.0 ml of water)
$NaCl + AgNO_3$ ---> $NaNO_3 + AgCl$ (s)
The chemical formula of the precipitate is AgCl.
0.25 g AgCl (1 mole AgCl/143.5 g AgCl)(1 mole NaCl/1 mole AgCl)(1 mole Na^+ /1 mole NaCl)(23 g Na^+ /1 mole Na^+)
= 0.040 g Na^+ in 10.0 ml of water
(v) The RDA of sodium is 2300 mg per day. Would you drink a cup (240 ml) of this water to get your RDA of sodium?
(0.040 g Na^+ / 10.0 ml of water) 240 ml = 0.96 g = 960 mg Na^+ in 1 cup of water.
No. You would not get your RDA of sodium from 1 cup of this water. You would get (960/2300)x100 = 42% of the RDA.
(vi) 100 g of NaCl is dissolved in water. This solution is mixed with 100 g of silver nitrate dissolved in water. Which reactant is the limiting reactant?
Calculate the mass of AgCl that precipitates out of solution. (Answer: between 80 and 90 g)
Calculate the amount of one product that is produced from the mass of one reactant.
Calculate the amount of the same product that is produced from the mass of the other reactant.
Compare the amount of product produced.
The reactant that produces the SMALLER amount of product is the LIMITING reactant.
100 g NaCl (1 mole NaCl /58.5 g NaCl)(1 mole AgCl /1 mole NaCl) = 1.71 moles AgCl
100 g $AgNO_3$ (1 mole $AgNO_3$ /170 g $AgNO_3$)(1 mole AgCl /1 mole $AgNO_3$) = 0.59 moles AgCl
0.59 moles is SMALLER than 1.71 moles so NaCl is the LIMITING reactant.
0.59 moles AgCl (143.5 g AgCl/1 mole AgCl = 84.4 g AgCl precipitates out of solution.

5. The quality of drinking water depends on the impurities and their concentrations in a water sample. Drinking water that contains sulfate in excess of 500 mg SO_4^{2-}/liter may cause laxative effects. You are given 25.00 ml of a water sample. 32.95 ml of 0.257 M barium chloride solution is added to this 25.00 ml water sample. 1.26 g of barium sulfate is collected, dried, and weighed.
a. Describe how to prepare 250 ml of 0.25 M barium chloride solution from solid barium chloride.
b. Write a molecular equation and net ionic equation that represents the reaction that occurs.
c. Calculate the moles of barium chloride. (Hint: Molarity = moles/volume. Solve for moles.)
d. Which reactant should be the limiting reactant?
e. Calculate the mass of sulfate in mg SO_4^{2-}/liter in this water sample.
f. Would you drink this water? Give reasons.
Answers:
a. Molarity x volume of solution you want to make = moles of solute. Then, convert moles to mass.
0.25 M = 0.25 moles $BaCl_2$/l of solution
0.25 moles $BaCl_2$/l of solution (0.25 l) (208 g $BaCl_2$/1 mole $BaCl_2$) = 13 g $BaCl_2$.
Measure 13 g of solid $BaCl_2$. Place in appropriate volume measuring device, e.g., volumetric flask. Then, add sufficient water to the flask to make 250 ml of solution. Make sure all of the $BaCl_2$ dissolves.
b. $SO_4^{2-} + BaCl_2$ --> $BaSO_4$ (s) + 2 Cl^-
$SO_4^{2-} + Ba^{+2} + 2\ Cl^-$ --> $BaSO_4$ (s) + 2 Cl^-
$SO_4^{2-} + Ba^{+2}$ --> $BaSO_4$ (s)
c. 32.95 ml of 0.257 M $BaCl_2$ ==> 0.257 M x 0.03295 l = 0.00847 moles $BaCl_2$.
d. Sulfate should be the limiting reactant.
e. 1.26 g $BaSO_4$ (s) (1 mole $BaSO_4$ /233 g $BaSO_4$)(1 mole SO_4^{2-}/1 mole $BaSO_4$) (96 g SO_4^{2-}/1 mole SO_4^{2-}) (1000 mg/1 g)
= 519 mg SO_4^{2-}.
This is the mass of in the 25.0 ml water sample.
The concentration of SO_4^{2-} in 1 liter of water = 519 mg / 0.025 l = 20,800 mg SO_4^{2-}/l.

f. You do not want to drink this water because the 20,800 mg SO_4^{2-}/l concentration is much higher than the 500 mg SO_4^{2-}/liter that may cause laxative effects.

6. Predict whether each reaction occurs. (Hint: write a net ionic equation.)
a. Na_2SO_4 (aq) + $Ba(NO_3)_2$ (aq) -->
b. Saline solution (NaCl (aq)) is added to KNO_3 (aq).
c. You mix baking soda with lye (NaOH).
Answers: Remember AB + CD --> AD + CB
a. Na_2SO_4 (aq) + $Ba(NO_3)_2$ (aq) --> 2 $NaNO_3$ + $BaSO_4$ (s)
2 Na^+ + SO_4^{2-} + Ba^{+2} + 2 NO_3^- --> 2 Na^+ + 2 NO_3^- $BaSO_4$ (s)
SO_4^{2-} + Ba^{+2} --> $BaSO_4$ (s)
This reaction occurs because the $BaSO_4$ precipitate forms.
b. Saline solution (NaCl (aq)) is added to KNO_3 (aq).
NaCl + KNO_3 --> $NaNO_3$ + KCl
Na^+ + Cl^- + K^+ + NO_3^- ---> Na^+ + NO_3^- + K^+ + Cl^-
This reaction does not occur. No precipitate forms. All the ions are spectator ions.
c. You mix baking soda with lye (NaOH).
$NaHCO_3$ + NaOH --> NaOH + $NaHCO_3$
Na^+ + HCO^- + Na^+ + OH^- ---> Na^+ + OH^- + Na^+ + HCO^-
This reaction does not occur. No precipitate forms. All the ions are spectator ions.

7. Sodium hydroxide (used to make paper, Al, textiles, soaps) is produced in industry by the following reaction:
$Ca(OH)_2$ + Na_2CO_3 ----->
How much of each reactant is needed to make 1 ton of sodium hydroxide?
Answers:
Balance: $Ca(OH)_2$ + Na_2CO_3 ---> $CaCO_3$ (s)+ 2 NaOH
To make 1 ton of NaOH, convert tons of NaOH --> g NaOH --> moles NaOH --> moles each reactant --> g each reactant
1 ton = 2000 lbs or 1 metric ton = 1000 kg
1 ton NaOH = 2000 lbs NaOH = 908000 g NaOH.
1 ton NaOH (2000 lbs/1 ton)(454 g/1 lb) (1 mole NaOH/40 g NaOH) (1 mole $Ca(OH)_2$ /2 moles NaOH)(74 g $Ca(OH)_2$ /1 mole $Ca(OH)_2$) = 839900 g $Ca(OH)_2$.
1 ton NaOH (2000 lbs/1 ton)(454 g/1 lb) (1 mole NaOH/40 g NaOH) (1 mole Na_2CO_3 /2 moles NaOH)(106 g Na_2CO_3 /1 mole Na_2CO_3) = 1203100 g Na_2CO_3.
Check conservation of mass: mass of reactants = mass of products
839900 g $Ca(OH)_2$ + 1203100 g Na_2CO_3 = 908000 g NaOH + 1135000 g $CaCO_3$
2043000 g = 2043000 g