Objective 6. Double replacement reactions 2: balancing acid-base and gas forming reactions, identifying strong and weak acids, write net ionic equations to predict whether a reaction occurs, perform C-V-mole and mole ratio calculations (volumetric)

Quiz Practice problems:

Key ideas: In a double replacement reaction, Compound AB reacts with Compound CD to form Compound AD and Compound CB.

AB + CD ---> AD + CB

Another type of double replacement reaction is an acid-base reaction. An acid donates H^+ and a base accepts H^+ so a transfer of H^+ occurs in an acid-base reaction.

A gas forming reaction is a type of acid-base reaction. If H_2CO_3 is produced as a product, replace the H_2CO_3 with H_2O and CO_2 gas.

Acids are classified by strength (strong or weak).

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 an acid-base reaction.

Identify an acid as strong or weak.

Write a net ionic equation. Identify spectator ions.

Predict whether a reaction occurs from a net ionic equation.

Perform chemical calculations involving an acid-base reaction.

For solutions, use concentration in Molarity = moles/volume. Use algebra to solve for one of these variables.

1. a. Life consists of give and take. Does an acid give or take H^+? Does a base give or take H^+?

b. (i) Name an experiment that you can do to identify an acid.

(ii) Name an experiment that you can do to identify a base.

c. Fill in the blanks in the table: (brackets [ ] mean concentration in M)

$pH = - \log [H^+]$

$[H^+] = 10^{-pH}$

$pOH = - \log [OH^-]$

$[OH^-] = 10^{-pOH}$

$pH + pOH = 14$

Substance	pH	pOH	$[H^+]$, M	$[OH^-]$, M
Lemon juice	2.4			
Stomach acid = HCl	2.5			
Milk		7.5		
blood				$2.51x10^{-7}$
Household ammonia			$3.16x10^{-12}$	
0.15 M NaOH				

Answers:

a. An acid gives H^+. A base take H^+.

b. (i) acid experiment: blue litmus turns red, phenolphthalein is colorless, pH < 7

(ii) base experiment: red litmus turns blue, phenolphthalein is pink, pH > 7

c.

Substance	pH	pOH	$[H^+]$, M	$[OH^-]$, M
Lemon juice	2.4	11.6	$10^{-2.4} = 4.0x10^{-3}$	$10^{-11.6} = 2.5x10^{-12}$
Stomach acid = HCl	2.5	11.5	$10^{-2.5} = 3.2x10^{-3}$	$10^{-11.6} = 3.2x10^{-12}$
Milk	6.5	7.5	$10^{-6.5} = 3.2x10^{-7}$	$10^{-7.5} = 3.2x10^{-8}$
blood	7.4	6.6	$4.0x10^{-8}$	$2.51x10^{-7}$
Household ammonia	11.5	2.5	$3.16x10^{-12}$	$3.2x10^{-3}$
0.15 M NaOH	13.18	0.82	$6.6x10^{-14}$	0.15

2. What ions are in the following acids and bases?

a. muriatic acid = HCl

b. lye = NaOH

c. acetic acid = $HC_2H_3O_2$

d. washing soda = sodium carbonate

Answers:

a. acid

b. base

c. acid
d. base

You can predict whether an acid-base reaction occurs if you can write a net ionic equation.
3. For each reaction,
Predict the products. If H_2CO_3 is produced as a product, replace the H_2CO_3 with H_2O and CO_2 gas.
Balance the equation.
Write a net ionic equation. Strong acids dissociate into ions, e.g., HCl breaks up into H^+ and Cl^-.
Weak acids do not dissociate (actually, only one in a few thousand or million weak acid molecules break up), e.g., $HC_2H_3O_2$ stays as $HC_2H_3O_2$ in an ionic equation.
ID the spectator ions.

a. HCl + NaOH --->
b. baking soda + $HC_2H_3O_2$ --->
(This is a gas forming reaction.)
c. KOH + $HC_2H_3O_2$ --->
d. H_2SO_4 + Na_2CO_3 --->
Answers: remember AB + CD ---> AD + CB
a. HCl + NaOH ---> H_2O + NaCl
HCl = hydrochloric acid is a strong acid.
$H^+ + Cl^- + Na^+ + OH^-$ --> $H_2O + Na^+ + Cl^-$
$H^+ + OH^-$ --> H_2O
Specator ions: $Na^+ + Cl^-$
Note: the basic part of NaOH is OH^-.

b. $NaHCO_3$ + $HC_2H_3O_2$ ---> $NaC_2H_3O_2$ + H_2O + CO_2 (g)
$HC_2H_3O_2$ is a weak acid.
$Na^+ + HCO_3^- + HC_2H_3O_2$ ---> $Na^+ + C_2H_3O_2^- + H_2O + CO_2$ (g)
$HCO_3^- + HC_2H_3O_2$ ---> $C_2H_3O_2^- + H_2O + CO_2$ (g)
Specator ion: Na^+
Note: the basic part of $NaHCO_3$ is HCO_3^-.

c. KOH + $HC_2H_3O_2$ ---> $KC_2H_3O_2$ + H_2O
$HC_2H_3O_2$ is a weak acid.
$K^+ + OH^- + HC_2H_3O_2$ ---> $K^+ + C_2H_3O_2^- + H_2O$
$OH^- + HC_2H_3O_2$ ---> $C_2H_3O_2^- + H_2O$
Specator ion: K^+
Note: the basic part of KOH is OH^-.

d. H_2SO_4 + Na_2CO_3 ---> H_2O + CO_2 (g) + Na_2SO_4
H_2SO_4 = sulfuric acid is a strong acid.
2 $H^+ + SO_4^{2-}$ + $Na^+ + CO_3^{2-}$ ---> $H_2O + CO_2$ (g) + 2 $Na^+ + SO_4^{2-}$
2 $H^+ + CO_3^{2-}$ ---> $H_2O + CO_2$ (g)
Specator ions: SO_4^{2-} + Na^+
Note: the basic part of Na_2CO_3 is CO_3^{2-}.

4. Our stomach contains acid, which helps digest food.
a. What happens to this pH when a person gets heartburn? You calculated the pOH, $[H^+]$, and $[OH^-]$ of stomach acid in Question 1.
b. Milk of Magnesia (magnesium hydroxide ($Mg(OH)_2$)) is used in antacids. Describe how an antacid works. Write a balanced molecular equation and net ionic equation that shows how this antacid works. How many moles of antacid reacts with 1 mole of stomach acid?
c. Calculate the mass of HCl that reacts with 500 mg of Milk of Magnesia.
Step 1: write a balanced chemical equation
Step 2: Given the mass of one substance, calculate moles:
500 mg $Mg(OH)_2$ ---> ____ moles of $Mg(OH)_2$
Step 3: Use coefficients to determine mole ratio:
1 moles $Mg(OH)_2$ to 2 moles HCl so
______ moles of $Mg(OH)_2$ ---> ____ moles of HCl
Step 4: What conversion to do next?
Answers: remember AB + CD ---> AD + CB
a. pH drops due to excess stomach acid.

b. An antacid is a base that reacts with and neutralizes the excess stomach acid.
$Mg(OH)_2$ + 2 HCl --> $MgCl_2$ + 2 H_2O
Ionic equation: $Mg(OH)_2$ + 2 H^+ + 2 Cl^- --> Mg^{2+} + 2 Cl^- + 2 H_2O
$Mg(OH)_2$ is insoluble in water. HCl is a strong acid. $MgCl_2$ is soluble in water.
Net Ionic equation: $Mg(OH)_2$ + 2 H^+ --> Mg^{2+} + 2 H_2O
H^+ is the acid part of HCl.
1 mole of stomach acid (HCl) reacts with 0.5 moles of $Mg(OH)_2$. 1 mole HCl (1 mole $Mg(OH)_2$/2 moles HCl) = 0.5 moles $Mg(OH)_2$.
c. 500 mg $Mg(OH)_2$ (1 g/1000 mg)(1 mole $Mg(OH)_2$/58.3 g $Mg(OH)_2$)(2 moles HCl/1 mole $Mg(OH)_2$)(36.5 g HCl/1 mole HCl) = 0.626 g HCl
Round to 1 significant figure based on 500 mg $Mg(OH)_2$, which has 1 significant figure ==> 0.6 g HCl.

5. a. Alka-Selzer (Baking soda, $NaHCO_3$) and Tums (calcium carbonate ($CaCO_3$) are used in antacids. For each antacid, write a balanced molecular equation and net ionic equation that shows how each antacid works. For each antacid, how many moles of antacid reacts with 1 mole of stomach acid?
(Answer: $CaCO_3$ + 2 HCl → $CaCl_2$ + H_2O + CO_2 for Tums)
b. Antacid commercial: "How many times its weight in excess stomach acid does (antacid) neutralize?"
(i) Calculate the moles of HCl that reacts with 0.50 moles of baking soda.
(ii) Calculate the mass of HCl that reacts with 500 mg of baking soda.
(iii) How many g of HCl reacts with 500 mg of $CaCO_3$?
(iv) Based on your answers from parts (ii) and (iii), which antacid is more effective? Give reasons.
c. Which antacid, Milk of Magnesia or Alka-Selzer or Tums, will make you burp?
d. 550 mg of $CaCO_3$ is added to 100 ml of pH 1.5 HCl.
(i) How many moles of HCl are present?
a. 0.15 b. 0.032 c. 0.0032
(ii) The limiting reactant is:
a. $CaCO_3$ b. HCl c. H_2O
(iii) How many g of CO_2 are produced?
a. 0.070 b. 1.4 c. 0.48
Answers: remember AB + CD ---> AD + CB
a. for Tums: $CaCO_3$ + 2 HCl → $CaCl_2$ + H_2O + CO_2 (g)
Ionic equation: $CaCO_3$ + 2 H^+ + 2 Cl^- --> Ca^{2+} + 2 Cl^- + H_2O + CO_2 (g)
$CaCO_3$ is insoluble in water. HCl is a strong acid. $CaCl_2$ is soluble in water.
Net Ionic equation: $CaCl_2$ + 2 H^+ --> Ca^{2+} + 2 H_2O

For Alka-Selzer: $NaHCO_3$ + HCl → NaCl + H_2O + CO_2 (g)
Ionic equation: Na^+ + HCO_3^- + H^+ + Cl^- --> Na^+ + Cl^- + H_2O + CO_2 (g)
$NaHCO_3$ is soluble in water. HCl is a strong acid. NaCl is soluble in water.
Net Ionic equation: HCO_3^- + H^+ --> H_2O + CO_2 (g)
HCO_3^- is the basic part of Alka-Selzer/baking soda.

b. Antacid commercial: "How many times its weight in excess stomach acid does (antacid) neutralize?"
(i) Calculate the moles of HCl that reacts with 0.50 moles of baking soda.
Balanced chemical equation: $NaHCO_3$ + HCl → NaCl + H_2O + CO_2 (g)
0.50 moles $NaHCO_3$ (1 mole HCl/1 mole $NaHCO_3$) = 0.50 moles HCl
(ii) Calculate the mass of HCl that reacts with 500 mg of baking soda.
500 mg $NaHCO_3$ (1 g/1000 mg)(1 mole $NaHCO_3$ /84 g $NaHCO_3$)(1 mole HCl/1 mole $NaHCO_3$)(36.5 g HCl/1 mole HCl) = 0.217 g HCl
Round to 1 significant figure based on 500 mg $NaHCO_3$, which has 1 significant figure ==> 0.2 g HCl.
(iii) How many g of HCl reacts with 500 mg of $CaCO_3$?
Balanced chemical equation: $CaCO_3$ + 2 HCl → $CaCl_2$ + H_2O + CO_2 (g)
500 mg $CaCO_3$ (1 g/1000 mg)(1 mole $CaCO_3$ /100 g $CaCO_3$)(2 moles HCl/1 mole $CaCO_3$)(36.5 g HCl/1 mole HCl) = 0.365 g HCl
Round to 1 significant figure based on 500 mg $CaCO_3$, which has 1 significant figure ==> 0.4 g HCl.
(iv) Based on your answers from parts (ii) and (iii), which antacid is more effective? Give reasons.
$CaCO_3$ is more effective than $NaHCO_3$ because it neutralizes more HCl (0.4 g HCl per 500 mg compared to 0.2 g HCl per 500 mg).
c. Which antacid, Milk of Magnesia or Alka-Selzer or Tums, will make you burp?
Alka-Selzer and Tums will make you burp. Both antacids produce CO_2 gas.
d. 550 mg of $CaCO_3$ is added to 100 ml of pH 1.5 HCl.
Convert pH 1.5 to [H^+]. [H^+] = 10^{-pH} = $10^{-1.5}$ = 0.032 M
(i) How many moles of HCl are present?

a. 0.15 b. 0.032 c. 0.0032

Molarity = moles/Volume.

Rearrange and solve for moles = Molarity x Volume = 0.032 M x 0.100 l = 0.0032 moles

(ii) The limiting reactant is:

a. $CaCO_3$ b. HCl c. H_2O

$CaCO_3 + 2\ HCl \rightarrow CaCl_2 + H_2O + CO_2\ (g)$

500 mg $CaCO_3$ (1 g/1000 mg)(1 mole $CaCO_3$ /100 g $CaCO_3$)(1 mole CO_2 /1 mole $CaCO_3$) = 0.005 moles CO_2.

0.032 M HCl x 0.100 l x (1 mole CO_2 /2 mole HCl) = 0.0016 moles CO_2.

So HCl is the limiting reactant.

OR

	$CaCO_3$ +	2 HCl → $CaCl_2 + H_2O + CO_2\ (g)$
Initial moles	0.005	0.0032
Moles that react	0.0016	0.0032
Moles leftover	0.0034	0
	Excess	limiting

(iii) How many g of CO_2 are produced?

a. 0.070 b. 1.4 c. 0.48

Use limiting reactant to calculate amount of CO_2 produced.

0.032 M HCl x 0.100 l x (1 mole CO_2 /2 moles HCl) (44 g CO_2/1 mole CO_2)= 0.070 g CO_2.

A titration is performed to accurately determine the concentration of an acid or base. Usually, the base is in the buret and is added (titrated) to an acid.

6. You prepare a solution of NaOH from NaOH solid. You transfer this solution to a buret. You will titrate a known volume and concentration of HCl to determine the concentration of NaOH.

You pipet 10.00 ml of 0.923 M HCl into a flask. You add one drop of phenolphthalein. 12.76 ml of NaOH is needed to turn this solution pink for 15 to 30 seconds.

a. Write a chemical equation that represents the HCl-NaOH reaction.

b. for solutions: Molar concentration = moles/volume in liters.

Calculate the moles of HCl in 10.00 ml of 0.923 M HCl. (What is the conversion factor?)

c. Calculate the moles of NaOH that reacts with HCl. (What is the conversion factor?)

d. Calculate the concentration of the NaOH solution. (Answer: between 0.7 and 0.75 M)

Answers: remember AB + CD ---> AD + CB

a. HCl + NaOH ---> H_2O + NaCl

b. Molarity = moles/Volume.

Rearrange and solve for moles = Molarity x Volume = 0.923 M x 0.01000 l = 0.00923 moles HCl

c. 0.00923 moles HCl (1 mole NaOH /1 mole HCl) = 0.00923 moles NaOH

d. Molarity = moles/Volume.

Molarity of NaOH = moles NaOH /Volume NaOH = 0.00923 moles NaOH/0.01276 l = 0.723 M NaOH

Limiting and excess reactants:

7. You pipet 10.00 ml of 0.923 M HCl into a flask. You add one drop of phenolphthalein. You titrate this solution with 0.73 M NaOH (the NaOH is in a buret).

a. You add 1.00 ml of the 0.73 M NaOH. (The solution is not going to be pink.) The NaOH is the limiting reactant. Calculate the volume of 0.923 M HCl that is leftover.

(i) Calculate the moles of NaOH. (What equation do you want to use?)

(ii) Calculate the moles of HCl that reacts with the NaOH. (What is the conversion factor?)

(iii) Calculate the moles of HCl in 10.00 ml of 0.923 M HCl. This is the original amount of HCl in the flask. (What equation do you want to use?)

(iv) Subtract the moles of HCl that reacts from the original moles of HCl.

(v) Convert moles of HCl to volume of HCl. (What is the conversion factor?)

b. You add 11.00 ml of the 0.73 M NaOH. The NaOH is the limiting reactant. Calculate the volume of 0.923 M HCl that is leftover. What color is the solution?

c. You add 15.00 ml of the 0.73 M NaOH. The NaOH is the excess reactant. Calculate the volume of 0.73 M NaOH that is leftover. What color is the solution?

Answers: remember AB + CD ---> AD + CB

a.	HCl +	NaOH ---> H_2O + NaCl
Initial moles	(iii) 0.00923	(i) 0.73 M x 0.00100 l = 0.00073
Moles that react	(ii) 0.00073	0.00073 (1:1 mole ratio of HCl to NaOH)
Moles leftover	(iv) 0.0085	0
	Excess	limiting

(v) Molarity = moles/Volume.
Rearrange and solve for Volume = moles/Molarity = 0.0085 moles HCl/0.923 M = 0.0092 l = 9.2 ml of 0.923 M HCl.

b.	HCl +	NaOH ---> H_2O + NaCl
Initial moles	0.00923	0.73 M x 0.01100 l = 0.000803
Moles that react	0.00803	0.00803 (1:1 mole ratio of HCl to NaOH)
Moles leftover	0.00120	0
	Excess	limiting

Volume = moles/Molarity = 0.0012 moles HCl/0.923 M = 0.0013 l = 1.3 ml of 0.923 M HCl.
Solution is colorless. Phenolphthalein is colorless in acid solution.

c.	HCl +	NaOH ---> H_2O + NaCl
Initial moles	0.00923	0.73 M x 0.01500 l = 0.01095
Moles that react	0.00923	0.00923 (1:1 mole ratio of HCl to NaOH)
Moles leftover	0	0.00172
	Limiting	Excess

Volume = moles/Molarity = 0.00172 moles NaOH/0.73 M = 0.00236 l = 2.36 ml of 0.73 M NaOH.
Solution is pink. Phenolphthalein is pink in basic solution.

8. You titrate 15.00 ml of HCl solution with 19.32 ml of 0.157 M KOH. Calculate the concentration of the HCl.
Answers: remember AB + CD ---> AD + CB

	HCl +	KOH ---> H_2O + KCl
Initial moles	15 ml, ? M	0.157 M x 0.01932 l = 0.00303 moles KOH
Moles that react	0.00303	0.00303 (1:1 mole ratio of HCl to KOH)
Moles leftover	0	0

In a titration, all of the acid is neutralized by the base.
Molarity = moles/Volume.
Molarity HCl = moles HCl /Volume HCl = 0.00303/0.01500 l = 0.202 M HCl
OR
All in 1 step: 0.157 M KOH x 0.01932 l KOH x (1 mole HCl /1 mole KOH) (1/0.015 l HCl) = 0.202 M HCl

9. You want to determine the concentration of battery acid. 2.00 ml of battery acid is titrated with 31.74 ml of 2.241 M NaOH. What is the concentration of battery acid?
Answers: remember AB + CD ---> AD + CB
Battery acid is sulfuric acid (H_2SO_4).
H_2SO_4 + 2 NaOH ---> 2 H_2O + Na_2SO_4
All in 1 step: 2.241 M NaOH x 0.03174 l NaOH x (1 mole H_2SO_4 /2 moles NaOH) (1/0.00200 l H_2SO_4) = 17.8 M H_2SO_4

10. a. Phosphoric acid (H_3PO_4), which is an acid is soda, removes rust (Fe_2O_3). This means you can use soda to remove rust from a rusty part. Write a balanced chemical equation and net ionic equation.
b. You add 1 can (355 ml) of soda (assume 0.05 M H_3PO_4) to 1.0 g of rust (from a rusty nail). Is this enough soda to remove the rust? In other words, the limiting reactant is ____. Calculate the amount of excess reactant leftover.
c. The reaction of rust with sulfuric acid is faster than the reaction of rust with acetic acid. Write balanced chemical equations and net ionic equations to explain why one reaction is faster than the other.
Answers: remember AB + CD ---> AD + CB
a. 2 H_3PO_4 + Fe_2O_3 --> 3 H_2O + 2 $FePO_4$
H_3PO_4 is a weak acid. Fe_2O_3 is insoluble in water. $FePO_4$ is insoluble in water.
Ionic and net ionic equation: 2 H_3PO_4 + Fe_2O_3 --> 3 H_2O + 2 $FePO_4$

b.	2 H_3PO_4 +	Fe_2O_3	--> 3 H_2O + 2 $FePO_4$
Initial moles	0.05 M x 0.355 l = 0.01775 moles	1.0 g (1 mole Fe_2O_3 /160 g Fe_2O_3) = 0.00625 moles Fe_2O_3	
Moles that react	0.0125	0.00625 (2:1 mole ratio of H_3PO_4 to Fe_2O_3)	
Moles leftover	0.00525	0	
	Excess	limiting	

1 can of soda will remove 1.0 g of rust.
c. 3 H_2SO_4 + Fe_2O_3 --> 3 H_2O + $Fe_2(SO_4)_3$
Sulfuric acid is a strong acid. $Fe_2(SO_4)_3$ is soluble in water.
Ionic equation: 6 H^+ + 3 SO_4^{2-} + Fe_2O_3 --> 3 H_2O + 2 Fe^{3+} + 3 SO_4^{2-}
Net ionic equation: 6 H^+ + Fe_2O_3 --> 3 H_2O + 2 Fe^{3+}
H^+ is the acid part of Sulfuric acid.
Sulfuric acid is a strong acid (high $[H^+]$) and will react with rust faster than H_3PO_4, which is a weak acid (low $[H^+]$).

11. You can buy hydrochloric acid at a hardware store as muriatic acid. Hydrochloric acid is used commercially in the "pickling" of steel. Pickling consists of dipping steel into an acid bath to remove rust (Fe_2O_3) from its surface before processing the steel into finished goods.

Fe_2O_3 (s) + HCl (aq) ---> $FeCl_3$ (aq) + H_2O (l)

a. Balance the chemical equation. Write a net ionic equation.

b. If 0.5 moles of rust are present, calculate the moles of acid that reacts.

c. You have 10.0 g of rust. Calculate the mass of acid that reacts with all of the rust and the mass of each product (theoretical yield) that is produced when 10.0 g of rust reacts.

d. The % yield of $FeCl_3$ is 75%. Calculate the actual yield of $FeCl_3$.

Answers: remember AB + CD ---> AD + CB

a. Fe_2O_3 (s) + 6 HCl (aq) ---> 2 $FeCl_3$ (aq) + 3 H_2O (l)

HCl is a strong acid. $FeCl_3$ is soluble in water.

Ionic equation: Fe_2O_3 + 6 H^+ + 6 Cl^- + --> 2 Fe^{3+} + 6 Cl^- + 3 H_2O

Net ionic equation: Fe_2O_3 + 6 H^+ --> 2 Fe^{3+} + 3 H_2O

b. 0.5 moles Fe_2O_3 (6 moles HCl /1 mole Fe_2O_3) = 3 moles HCl

c. 10.0 g Fe_2O_3 (1 mole Fe_2O_3 /160 g Fe_2O_3)(6 moles HCl /1 mole Fe_2O_3) (36.5 g HCl/1 mole HCl) = 13.7 g HCl

d. 10.0 g Fe_2O_3 (1 mole Fe_2O_3 /160 g Fe_2O_3)(2 moles $FeCl_3$ /1 mole $FeCl_3$) (162.5 g $FeCl_3$ /1 mole HCl) = 20.3 g $FeCl_3$.

This mass is the theoretical yield of $FeCl_3$.

% yield = (actual yield/ theoretical yield) x 100

Rearrange and solve for actual yield = % yield x theoretical yield/ 100 = 75% x 20.3 g/100 = 15.2 g $FeCl_3$.