Lecture Note 2 – Summary of Chemical Reactions

Oct 2023

[Learning Objectives]

1. Type of Reactions

Reactions can be classified into different categories based on different criteria.

Based on if there is oxidation number change (electron transfer), reactions can be classified into ____________ reactions and _____________ reactions.

Based on the characters and number of the reactants/products, reactions can be classified into four fundamental types: ______________ (1), _______________ (2), ___________________ (3), and _________________ (4).

Reaction 1: AB → A + B

Reaction 2: A + B → AB

Reaction 3: A + BC → B + AC

Reaction 4: AB + CD → AD + CB

Provide at least ONE example of each the above reaction type. Use Venn diagram to show the relationship between the four fundamental types of reactions with redox/nonredox.

Types of Double Displacement Reactions

For the following reactions, please write the *net-ionic equation* if applicable by removing the **spectators**.

- Neutralization

  Hydrochloric acid reacting with sodium hydroxide:

  Hydrochloric acid reacting with sodium acetate:

  Glycine (aminoacetic acid) reacting with hydrochloric acid:

  Sodium bicarbonate reacting with hydrochloric acid:

- Precipitations (recall the *solubility rules*)

  Hydrochloric acid reacting with silver nitrate:

  Sulfuric acid reacting with barium hydroxide:

  Calcium chloride reaction with sodium fluoride:

Sodium chloride mixing with potassium nitrate:

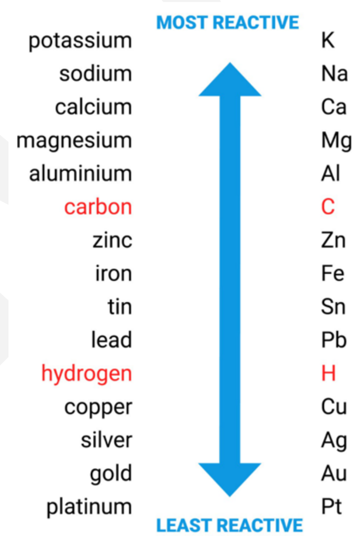
Carbon dioxide bubbled into lime water (calcium hydroxides):

Summary of the driving forces of double displacement reactions:

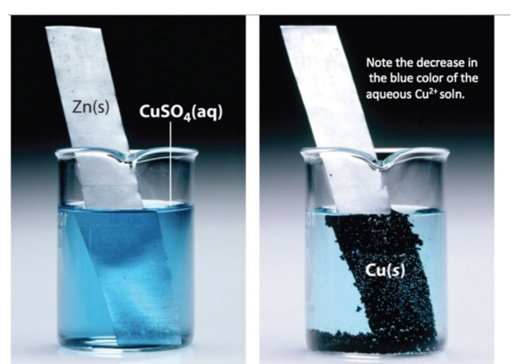
2. Properties of Representative Metals/Nonmetals

2.1 General Properties of Metals

- Metals conduct heat and electricity, tend to _____ electrons (lose or gain).
- _______ metals and most __________ metals are highly reactive, which *violently* react with water to produce $M^{I}OH$) or $M^{II}(OH)_2$ and _______.
  $Na + H_2O \rightarrow Na^+ + OH^- +$ ___
- Metals with a standard reduction potential ____ 0 V (> or <) (**pre-H** metals) react with acid to produce the corresponding salts and ______, such as Mg, Al, and several 4th period transition mentals: _____ and _____.
  $Fe + H^+ \rightarrow$ ___ $+ H_2(g)$
- Some metals such as <u>Cu</u>, <u>Ag</u>, <u>Pt</u>, <u>Au</u> (metallic money) are unreactive, and ___ is commonly used as inert electrodes.



- Most metal oxides are __________ (acidic or basic), reacting with acids to form metal cations and _______: $Fe_2O_3(s) + H^+ \rightarrow Fe^{3+} +$ _____
- More reactive metals can displace the less reactive metals from their cation solutions:
  $Cu(s) + AgNO_3(aq) \rightarrow$ _________ + _________ What is the driving force?



$Zn(s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s)$

[USNCO Example – *L2017-Q8*]

8. An element is a solid at room temperature but soft enough to be cut with an ordinary knife. When placed in water, the element reacts violently. What element is it?

(A) Na **(B)** Mg **(C)** Cu **(D)** Hg

2.2 General Properties of Nonmetals

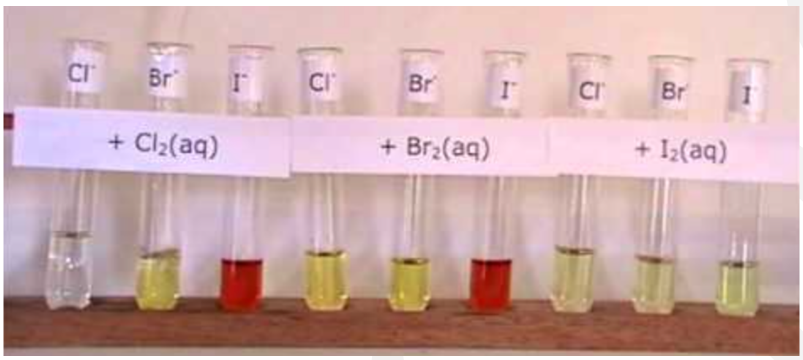
- Electronegative nonmentals tend to ______ electrons, typical examples are halogens, dioxygen.
- Most nonmentals react with hydrogen gas to produce their covalent hydrides.
- Typical nonmetal oxides are __________, reacting with _______ to produce the corresponding acids.

  $N_2O_5 + H_2O \rightarrow$ ______
- The more reactive halogens (X_2) can displace the less reactive halogens from their halide solutions:

  $Cl_2(aq) + KBr(aq) \rightarrow$ _________ + _________ (color change: _____________)

  What is the driving force? How about $Br_2(aq) + NaCl(aq)$?

Justify the following color changes and write the net-ionic equation of the reactions.



2.3 Amphoteric Metals

Several metals close to the metal/nonmental boundary are amphoteric, meaning that they can react with both ______ and ______. Their oxides and hydroxides are also _____________. The most typical example is _____.

Reaction example: $Al + OH^{-}(aq) +$ _______ $\rightarrow$ $Al(OH)_4^{-}$ + _____

[USNCO Example - *N2015-P1-Q12*]

12. A metal dissolves in 3.0 M NaOH solution with evolution of gas to form a clear, colorless solution. Upon neutralization, the solution forms a gelatinous precipitate. What is the metal?

(A) Al **(B)** Ag **(C)** Cu **(D)** Mg

How about if *excess* strong acid is added in the second step?

3. Gas Evolution and Redox Reactions

3.1 Common Gas Evolution Reactions

gas evolved	reaction	net ionic equation
$H_2(g)$	Pre-H metals reacting with ______	
$CO_2(g)$	carbonates or bicarbonates reacting with ______	
$SO_2(g)$	sulfites or bisulfites reacting with _____	
$NH_3(aq)$	ammonium reacting with strong _____	
$NO_x(g)$	metals including **post-H** metals reacting with ___ acids	*why no $H_2(g)$ produced?

[USNCO Example - *L2017-Q10*]

10. Addition of small amounts of which solids to 4 M HCl will result in gas evolution?

I. Zn II. Na_2SO_3

(A) I only **(B)** II only

(C) Both I and II **(D)** Neither I nor II

3.2 Common Redox Reactions

redox reaction	characters	net ionic equation
metals reacting with water/acid/base	H^+ or H_2O is reduced into _____	
decomposition of $H_2O_2(aq)$	____thermic, catalyzed by a variety of catalysts, such as $MnO_2(s)$, Br^-, I^-, Fe^{3+}, etc.	
standardization of $MnO_4^-(aq)$ by $C_2O_4^{2-}$ or $Fe^{2+}(aq)$	MnO_4^- is _____ (color), used as oxidant and indicator (turns pink when last drop of MnO_4^- is added), solution is acidified	$C_2O_4^{2-} + MnO_4^- +$ ____ $\rightarrow$
titration of $H_2O_2(aq)$ using **standardized** $MnO_4^-(aq)$	H_2O_2 is oxidized into ____, solution is acidified, MnO_4^- is reduced to ___ (color___)	
*titration of $I_2(aq)$ using **standardized** $S_2O_3^{2-}(aq)$	starch as indicator, forms ___ (color) complex with I_2/I_3^-, $S_2O_3^{2-}$ is oxidized into ______	

[Extension] What is the color change in iodometry? Why KI(s) is commonly added to $I_2(aq)$?

[USNCO Example - *N2015-P1-Q9*]

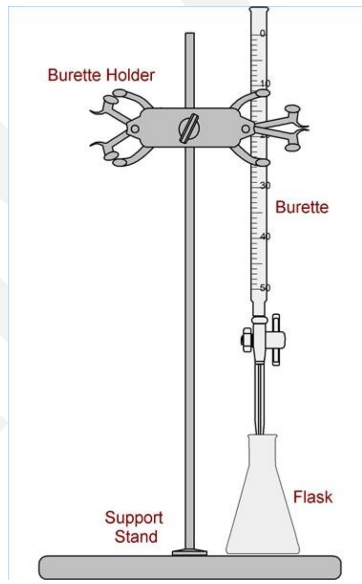
9. A student standardizes a solution of $Na_2S_2O_3$ by titrating it against a solution containing a known mass of $NaIO_3$ that has been dissolved in an excess of a freshly prepared solution of KI in dilute HCl. Which of the following errors will lead to a value of the molarity of the thiosulfate solution that is higher than the true value?

(A) The student overshoots the endpoint of the titration.

(B) The $NaIO_3$ is contaminated with NaCl.

(C) The KI/HCl solution is allowed to stand overnight before it is used in the titration.

(D) The sample of sodium thiosulfate pentahydrate used to make the $Na_2S_2O_3$ solution had partially dehydrated on standing.



4. Titrations and Error Analysis

4.1 Important Concepts in Titrations

- titrant (typical put in the burette), _________ molarity
- analyte (typically put in the titration flask), ____________ molarity
- indicator (phenolphthalein, pH range 8~10, change from ____ to ____)
- **standardization** ($KMnO_4$, I_2, HCl, NaOH, etc.)

  What is the purpose of standardization?

- *primary standard (KIO_3, Na_2CO_3, potassium hydrogen phthalate (KHP), $Na_2C_2O_4$)

  What is the application of each?

  For standardization, the primary standard with a specific measured mass should be put in _______ [buret or flask], why?

- equivalence point vs end point
- half equivalence point

4.2 Error Analysis

[USNCO Example - *N2019-P1-Q12* (acid-base titration)]

12. The ammonia concentration of a solution is determined by titrating with aqueous HCl (previously standardized against Na_2CO_3) using a pH meter. Which of the following errors will lead to a measured concentration of NH_3 that is higher than the actual concentration?

(A) Some of the Na_2CO_3 used in the standardization is spilled before being transferred to the titration flask.

(B) The glass stirring rod used to stir the ammonia solution is wiped with a paper towel after each aliquot of HCl is added.

(C) The ammonia solution is allowed to stand in an open beaker for an hour before being titrated.

(D) The pH meter has been miscalibrated so that all readings are 2.00 pH units higher than the actual pH.

5. Complexation Reactions

A complexation reaction can be described as a reaction that forms a "complex". For instance, in adding a cobalt salt, such as $CoCl_2(s)$, to water, we form $[Co(H_2O)_6]^{2+}(aq)$.

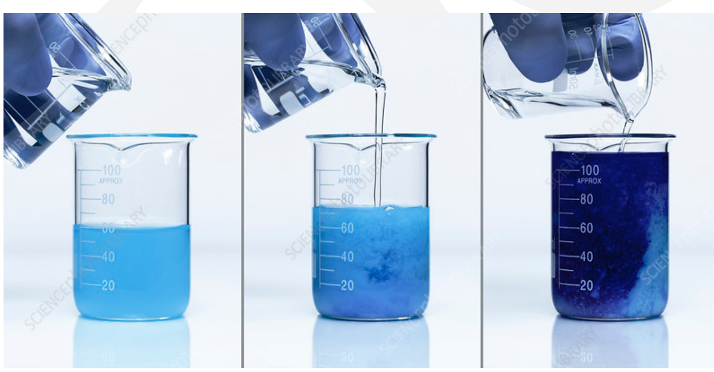
The general equation of a complexation reaction equilibrium is represented as:

$$M + L \rightleftharpoons ML$$

Where M is a metal, and L is a **ligand**.

Examples of Complexation Reaction

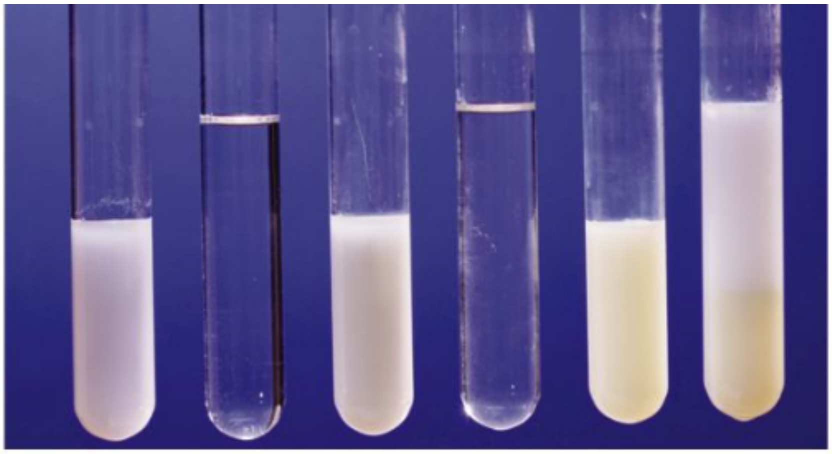
- $Cu(NH_3)_4^{2+}$



When concentrated ammonia is added to copper sulfate solution, initially a blue precipitate is formed (*reaction 1*); as more ammonia is added, a deep blue solution is formed with the dissolution the precipitate (*reaction 2*).

Write down the net ionic equation of 1 and 2:

- $Ag(NH_3)_2^+$ - ammonia test of silver halides

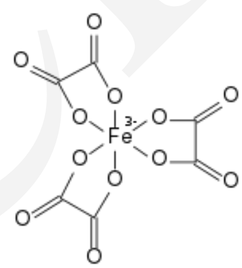


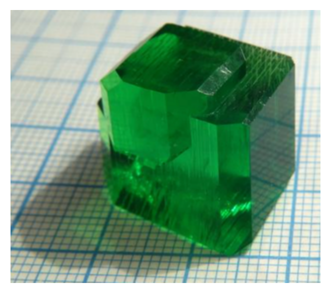
▲ **Figure 3** *From left to right, the test tubes contain – a precipitate of silver chloride, silver chloride after addition of dilute aqueous ammonia, a precipitate of silver bromide, silver bromide after addition of concentrated aqueous ammonia, a precipitate of silver iodide, and silver iodide after addition of concentrated aqueous ammonia, which fails to dissolve the silver iodide precipitate*

Write down the net ionic equation of AgBr(s) reacting with ammonia.

- $Fe(C_2O_4)_3^{3-}$

Excess aqueous sodium oxalate is added to an aqueous solution of iron(III) nitrate:

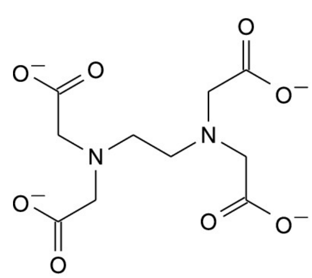




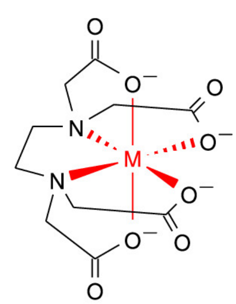
crystals of $Na_3[Fe(C_2O_4)_3]\cdot 3H_2O$

- $Ca(EDTA)^{2-}$

$EDTA^{4-}$, a *hexadentate* ligand, forms very stable complexes (usually octahedral structures) with most of the transition metals in a 1:1 ratio. The donor atoms in $EDTA^{4-}$ are the two ___ atoms, and the four, negatively charged ___ atoms.

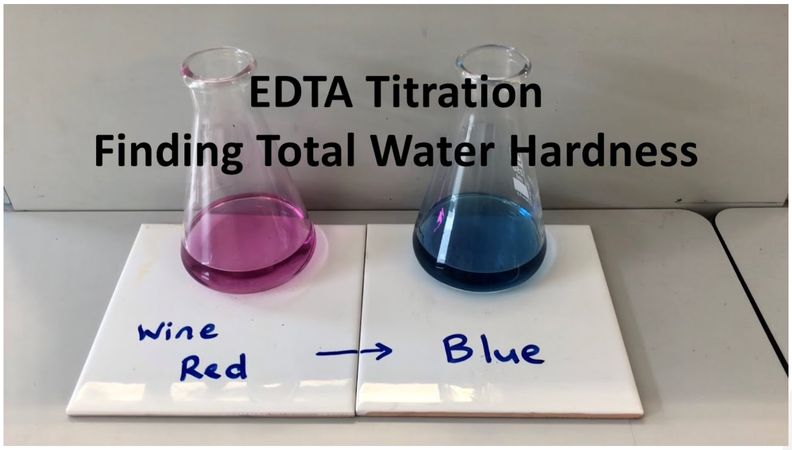


$EDTA^{4-}$



mEDTA-complex

Total Water Hardness using EDTA Titration [EBT as indicator under pH=10]



When the last drop of EDTA solution is added, the color of the solution suddenly change from wine red to blue. Figure out the color of the indicator itself and the indicator-metal complex at pH=10.
Justify your answer.

[Lab Practical – *USNCON2010-P3-Q1*]
You have been given a well plate, several test tubes and pipets, a concentrated ammonia solution, access to distilled water, and four numbered vials containing iron (III) chloride hexahydrate, cobalt (II) sulfate heptahydrate, copper (II) chloride dihydrate, and potassium oxalate monohydrate, though not necessarily in this order. Devise and carry out an experiment to produce at least FIVE new different **complex compounds**, using your understanding of coordination compound geometry and qualitative evidence in your results.