Chem Lab

Division C

Georgia Tech Event Workshop Series 2024-25

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Science Olympiad at Georgia Tech®

01 RULES SHEET

02 NEED TO KNOW

03 DIFFICULT TOPICS

04 COMMON QUESTIONS

05 OTHER FREE RESOURCES and Q&A

The Rules Sheet

CHEMISTRY LAB C

See General Rules, Eye Protection & other Policies on www.soinc.org as they apply to every event.

1. **DESCRIPTION:** Teams will complete one or more tasks and answer a series of questions involving the scientific processes of chemistry focused in the areas of equilibrium and **chemical reactions/stoichiometry**.

   A TEAM OF UP TO: 2   **EYE PROTECTION:** C

   CALCULATOR: Class III   **APPROXIMATE TIME:** 50 minutes

2. **EVENT PARAMETERS:**
   a. Each participant must bring safety equipment (e.g., goggles, lab coat, apron), a writing implement, and may bring a stand-alone calculator (Class III).
   b. Each participant may bring one unique 8.5" x 11" sheet of paper, which may be in a sheet protector sealed by tape or laminated, with information on both sides in any form and from any source.
   c. Teams should bring any or all of the items listed on the Division C Chemistry Events Lab Equipment List, posted on soinc.org. Teams not bringing these items will be at a disadvantage, as they are not provided.
   d. Participants must wear goggles, an apron or a lab coat and have skin covered from the neck down to the wrist and toes. Gloves are optional, but if the host requires a specific type, they will notify teams. Pants should be loose fitting; if the host has more specific guidelines, they will notify teams in advance of the tournament. Shoulder-length or longer hair must be tied back. Participants removing safety clothing/goggles or unsafely handling materials, or equipment will be penalized or disqualified.
   e. Supervisors will provide any required reagents, additional glassware, and/or references that are needed for the tasks (e.g., Periodic Table, table of standard reduction potentials, any constants needed).

3. **THE COMPETITION:**
   a. The competition will consist of a series of tasks focused in the areas of equilibrium and **chemical reactions/stoichiometry**. These tasks could include hands-on activities, questions on listed topics, interpretation of data (e.g., graphs, diagrams, tables), or observation of an established and running experiment.
   b. Teams may be asked to collect data using a probeware set-up demonstrated by the Supervisor(s). Following a demonstration of the sensors/probes, participants may be given data sets to interpret.
   c. Nomenclature, formula writing, & stoichiometry (mole conversions & percentage yield) are essential tools of chemistry & may be included in the event. Participants are expected to know the symbols & charges for: nitrate, carbonate, phosphate, acetate, sulfate, ammonium, bicarbonate, & hydroxide. Participants should know how to use the "ite" form of anion (one less oxygen than the "ate" form). With a periodic table, participants should be able to obtain charges for monatomic ions (e.g., Na^+, S^{2-}).
   d. Equilibrium: Students must be able to write equilibrium reactions, predict the direction of a reaction using Le Châtelier's Principle, calculate an equilibrium constant, & use equilibrium constant to determine concentrations. Tasks will be chosen from the following:
      i. Use a titration or data of a weak acid/base with a strong acid/base to calculate an equilibrium constant.
      ii. Investigate an equilibrium reaction and determine what happens when it is stressed.
      iii. Stoichiometry of equilibrium reactions.
      iv. Construct/use a standard absorption curve to determine an equilibrium constant.
      v. Use a colorimeter to predict a curve.
      vi. State & Nationals: knowledge/application of equilibrium to separate chemicals may be included.
   e. Participants should understand the following about **Chemical Reactions/Stoichiometry**:
      i. Classification of reaction type.
      ii. Balancing reactions.
      iii. Reaction prediction (including predicting products of metathesis reactions, solubility, oxidation-reduction, total ionic and net ionic equations).

4. **SCORING:**
   a. High score wins. Points will be divided evenly between equilibrium and **chemical reactions/stoichiometry**.
   b. Time may be limited at each task but will not be used as a tiebreaker or for scoring.
   c. Ties will be broken by pre-selected questions.
   d. A penalty of up to 10% may be given if the area is not cleaned up as instructed.
   e. A penalty of up to 10% may be given if a team brings prohibited lab equipment to the event.

Recommended Resources: The Science Olympiad Store (store.soinc.org) carries a variety of resources to purchase; other resources are on the Event Pages at soinc.org.

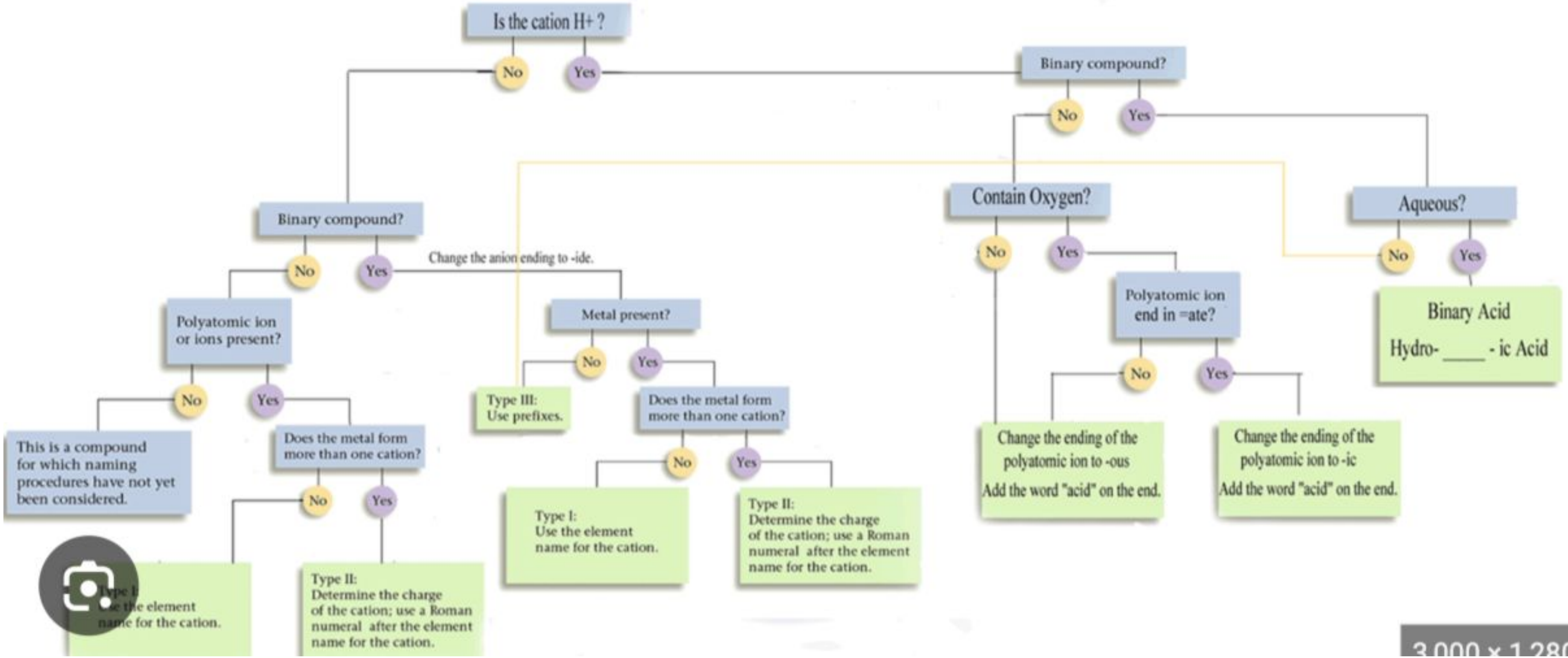
NEED TO KNOW

Topic 1: [Chemistry Basics]

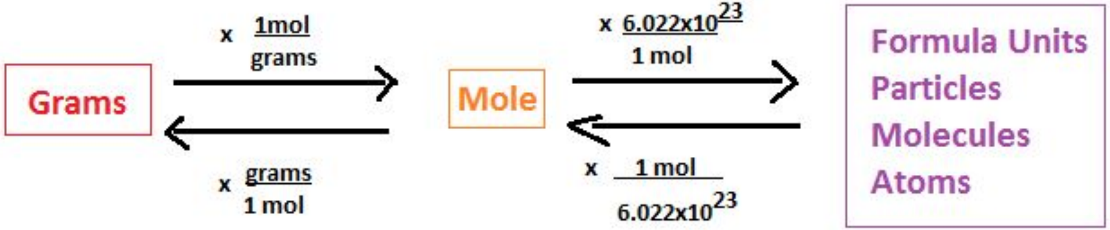
- Naming for Compounds, Acids, Bases, including with Polyatomics
- Perform calculations about mole conversions (Avogadro's rule) and stoichiometry (with gases, acid/base, thermochemistry, etc)
- Determine the charges and valence electrons of ions

- Expect that regional and state competitions include extensions of topics, such as properties of compounds, periodic trends, VSEPR/molecular structure, and bonding theory.

Nomenclature, formula writing, & stoichiometry (mole conversions & percentage yield) are essential tools of chemistry & may be included in the event. Participants are expected to know the symbols & charges for: nitrate, carbonate, phosphate, acetate, sulfate, ammonium, bicarbonate, & hydroxide. Participants should know how to use the "ite" form of anion (one less oxygen than the "ate" form). With a periodic table, participants should be able to obtain charges for monatomic ions (e.g., Na^+, S^{2-}).

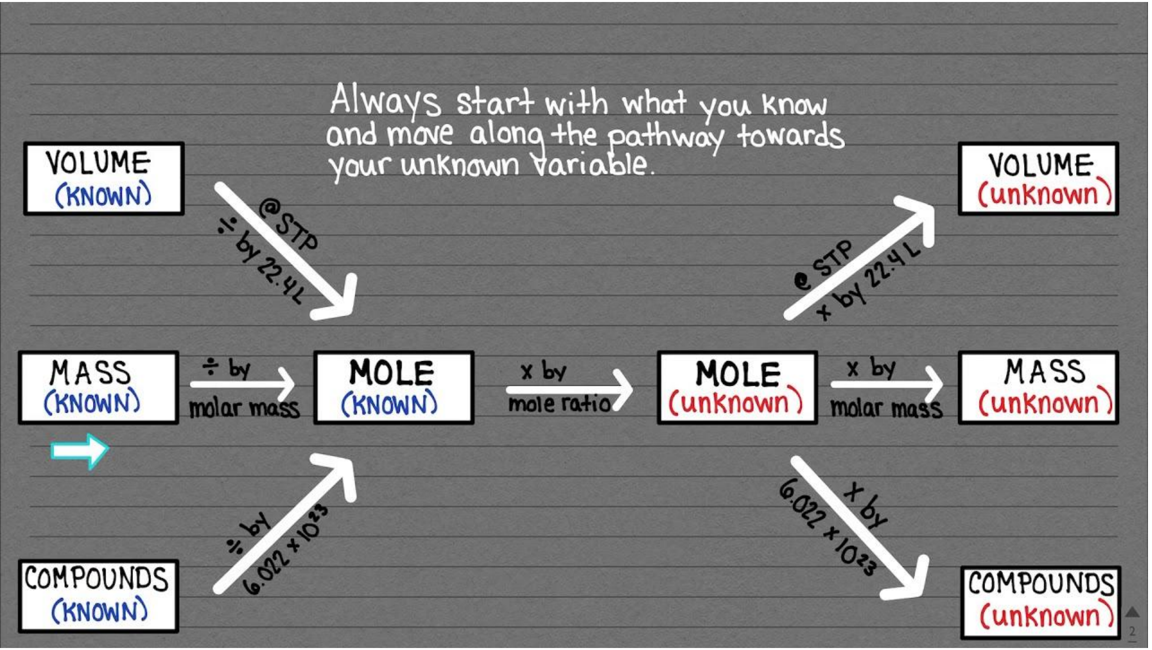

Is the cation H+ ?
No
Yes
Binary compound?
No
Yes
Change the anion ending to -ide.
Polyatomic ion or ions present?
No
Yes
This is a compound for which naming procedures have not yet been considered.
Does the metal form more than one cation?
No
Yes
name for the cation.
Type II: Determine the charge of the cation; use a Roman numeral after the element name for the cation.
Metal present?
No
Yes
Type III: Use prefixes.
Does the metal form more than one cation?
No
Yes
Type I: Use the element name for the cation.
Type II: Determine the charge of the cation; use a Roman numeral after the element name for the cation.
Binary compound?
No
Yes
Contain Oxygen?
No
Yes
Polyatomic ion end in =ate?
No
Yes
Change the ending of the polyatomic ion to -ous
Add the word "acid" on the end.
Change the ending of the polyatomic ion to -ic
Add the word "acid" on the end.
Aqueous?
No
Yes
Binary Acid
Hydro- ____ - ic Acid

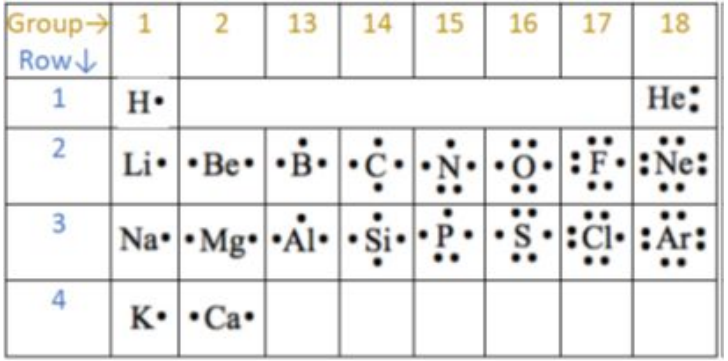
MOLE MAP



Formula for Percent Yield

$$\text{Percent yield} = \frac{\text{Actual Yield}}{\text{Theoretical Yield}} \times 100\%$$





Topic 2: [Equilibrium]

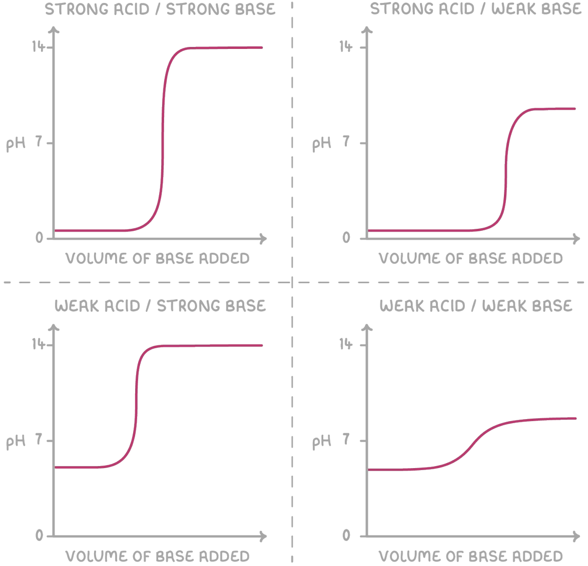
- Understand Le Chatelier's Principle and predict reactions
- Be familiar with Ka, Kb, pKa, and pKb
- Prepare to perform a titration with weak/strong acids and bases
- Analyze titration curves and perform calculations based on data gathered
- Understand standard absorption curves and colorimeters

- Expect that regional and state competitions include extensions of topics, such as buffers, Gibbs free energy constant, and equilibrium concepts of organic compounds.

Equilibrium: Students must be able to write equilibrium reactions, predict the direction of a reaction using Le Châtelier's Principle, calculate an equilibrium constant, & use equilibrium constant to determine concentrations. Tasks will be chosen from the following:

i. Use a titration or data of a weak acid/base with a strong acid/base to calculate an equilibrium constant.
ii. Investigate an equilibrium reaction and determine what happens when it is stressed.
iii. Stoichiometry of equilibrium reactions.
iv. Construct/use a standard absorption curve to determine an equilibrium constant.
v. Use a colorimeter to predict a curve.
vi. State & Nationals: knowledge/application of equilibrium to separate chemicals may be included.

Change	Direction System Shifts to Reestablish Equilibrium
Adding a reactant	Shifts towards products
Adding a product	Shifts towards reactants
Removing a reactant	Shifts towards reactants
Removing a product	Shifts towards products
Increasing pressure (decreasing volume)	Shifts toward less gas molecules
Decreasing pressure (increasing volume)	Shifts towards more gas molecules
Adding an inert gas	No effect
Increasing the temperature	Endothermic: shifts towards products Exothermic: shifts towards products
Decreasing the temperature	Endothermic: shifts towards reactants Exothermic: shifts towards products



EQUILIBRIUM

$$K_c = \frac{[C]^c[D]^d}{[A]^a[B]^b}, \text{ where } a\,A + b\,B \rightleftarrows c\,C + d\,D$$

$$K_p = \frac{(P_C)^c(P_D)^d}{(P_A)^a(P_B)^b}$$

$$K_a = \frac{[H^+][A^-]}{[HA]}$$

$$K_b = \frac{[OH^-][HB^+]}{[B]}$$

$$K_w = [H^+][OH^-] = 1.0 \times 10^{-14} \text{ at } 25°C$$

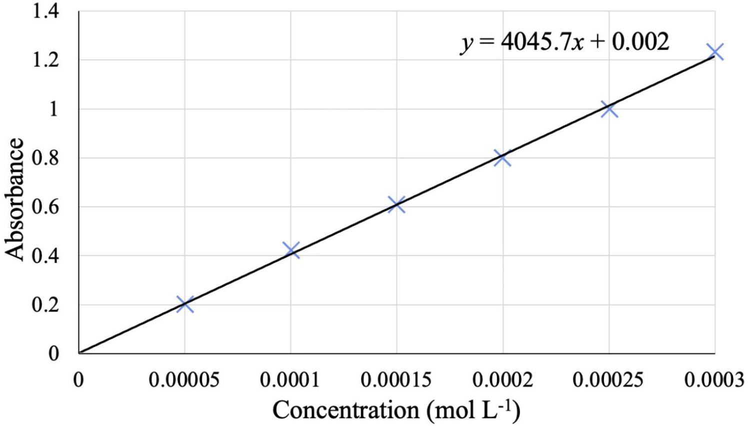
$$= K_a \times K_b$$

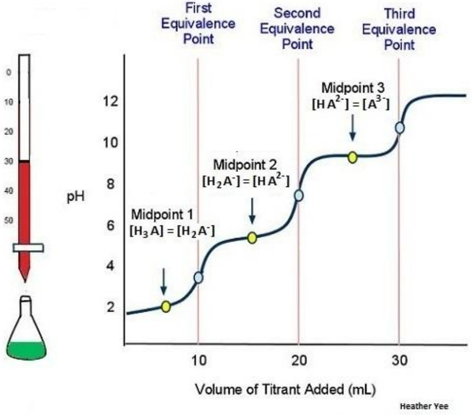
$$pH = -\log[H^+],\ pOH = -\log[OH^-]$$

$$14 = pH + pOH$$

$$pH = pK_a + \log\frac{[A^-]}{[HA]}$$

$$pK_a = -\log K_a,\ pK_b = -\log K_b$$





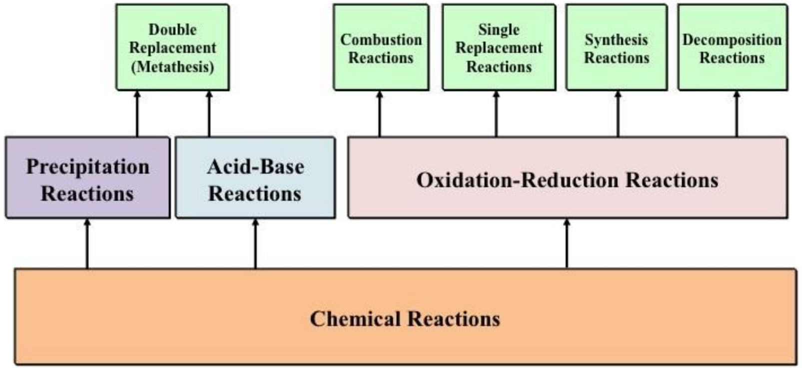
Topic 3: [Reactions]

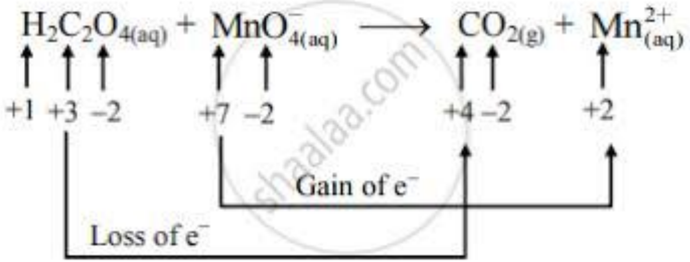
- Understand synthesis, decomposition, single replacement, double replacement, combustion, oxidation-reduction, metathesis, and acid and base reactions
- Know how to balance reactions
- Be familiar with writing out equations!
  - For example, write out the net ionic equation for oxidation and reduction reactions (half-reactions for redox)
  - Know your solubility rules!

Participants should understand the following about **Chemical Reactions/Stoichiometry**:

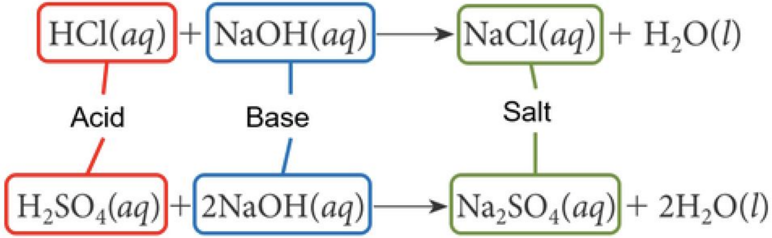
i. Classification of reaction type.
ii. Balancing reactions.
iii. Reaction prediction (including predicting products of metathesis reactions, solubility, oxidation-reduction, total ionic and net ionic equations).

Summary of Classes of Reactions





Need to know how to balance in acidic and basic solutions!



Weak Acid-Strong Base Neutralization: pH>7

$HC_2H_3O_2 + NaOH \rightarrow NaC_2H_3O_2 + H_2O$

Ionic Equation: $HC_2H_3O_2$ + ~~Na^+~~ + $OH^- \rightarrow$ ~~Na^+~~ + $C_2H_3O_2^- + H_2O$

Net Ionic Equation: $HC_2H_3O_2 + OH^- \rightarrow C_2H_3O_2^- + H_2O$

Strong Acid-Weak Base Neutralization: pH<7

$HCl + NH_3 \rightarrow NH_4^+ + Cl^-$

Ionic Equation: H^+ + ~~Cl^-~~ + $NH_3 \rightarrow NH_4^+$ + ~~Cl^-~~

Net Ionic Equation: $H^+ + NH_3 \rightarrow NH_4^+$

Compound of	Rule
Li^+, Na^+, K^+, or NH_4^+	Always soluble
NO_3^- or $C_2H_3O_2^-$	Always soluble
Cl^-, Br^-, or I^-	Insoluble with Ag^+, Hg_2^{2+}, or Pb^{2+}. Soluble with any other ion.
SO_4^{2-}	Soluble with all the ions except Sr^{2+}, Ba^{2+}, Ag^+, Hg_2^{2+}, or Pb^{2+}
CO_3^{2-} or PO_4^{3-}	Soluble with Li^+, Na^+, K^+, or NH_4^+. Insoluble with any other ion.
OH^- or S^{2-}	Soluble with Ca^{2+}, Sr^{2+}, Ba^{2+}, Li^+, Na^+, K^+, or NH_4^+. Insoluble with any other ion.

Precipitation Reactions

- **Metathesis Reactions**
  - reactions in which the positive ions and negative ions present in the reactants appear to exchange partners
  - also called **exchange reactions**

AX + BY → AY + BX

$AgNO_3 + NaCl \rightarrow AgCl + NaNO_3$

Lab Materials Check!

Box – To contain the materials	X
10 ml Graduated Cylinder - Measuring volumes	X
25 ml Graduated Cylinder - Measuring volumes	X
100 ml Graduated Cylinder - Measuring volumes	X
50 ml Beakers - Doing reactions, developing chromatograms	X
100 ml Beakers - Doing reactions, developing chromatograms	X
250 ml Beakers - Doing reactions, developing chromatograms	X
400 ml Beakers - Doing reactions, developing chromatograms	X
50 ml Erlenmeyer Flasks - Doing reactions	X
125 ml Erlenmeyer Flasks - Doing reactions	X
250 ml Erlenmeyer Flasks - Doing reactions	X
Test Tubes - Mix Chemicals, heat chemicals	X
Test Tube Brush - Clean Test Tubes	X
Test Tube Holder - Holds test tubes for heating	X
Test Tube Rack - Hold Test Tubes	X
Spot Plates - For semi-micro scale reactions, testing solubility, pH	X
Petri Dishes - Doing reactions, developing chromatograms	X
Slides - To put hairs, crystals, or fibers on for use with a microscope	
Cover Slips - To cover & prevent items from coming off slides	
Droppers - Add small amounts of liquids to reactions	X
Spatulas or spoons - Getting small amounts of solids out of containers	X
Metal Tongs, Forceps, or Tweezers – Holding & retrieving objects	X
Stirring Rods - Stirring mixtures	X
Thermometer - Determining the temperature of a solution	X
pH or Litmus paper - Test acidity or alkalinity of solution	X
Hand Lens - Magnification of small items for identification	
Flame Loop – For identification of ions in a compound	
Cobalt Blue Glass – To filter out any sodium that might contaminate flame test from hands	
Filter Paper - Filter solids from liquids	X
Funnel - Hold Filter Paper	X
9V battery - Electrolysis	X
Alligator Clip Wires - Connecting meters to metals	X
Nail - Electrolysis	X
Piece of Cu metal - Electrolysis	X
Piece of Zn metal - Electrolysis	X
Multimeter - Measuring current, voltage, and resistivity	X
9V or less Battery Conductivity Tester - Determining ionic strength of solution	X
Calipers-mechanical, not digital - Measuring lengths very precisely	X
Paper Towels - Cleaning	X
Pencil - Writing, Marking Chromatogram	
Ruler - Measuring lengths	

DIFFICULT TOPICS

Topic 1: [Redox]

- Acidic Solution

$$MnO_4^-(aq) + Zn(s) \longrightarrow MnO_2(s) + Zn(OH)_4^{2-}(aq)$$

$$MnO_4^- \longrightarrow MnO_2$$

$$Zn \longrightarrow Zn(OH)_4^{2-}$$

$$MnO_4^- \longrightarrow MnO_2 + 2H_2O$$

$$Zn + 4H_2O \longrightarrow Zn(OH)_4^{2-}$$

$$MnO_4^- + 4H^+ \longrightarrow MnO_2 + 2H_2O$$

$$Zn + 4H_2O \longrightarrow Zn(OH)_4^{2-} + 4H^+$$

$$MnO_4^- + 4H^+ + 3e^- \longrightarrow MnO_2 + 2H_2O$$

$$Zn + 4H_2O \longrightarrow Zn(OH)_4^{2-} + 4H^+ + 2e^-$$

$$2(MnO_4^- + 4H^+ + 3e^- \longrightarrow MnO_2 + 2H_2O)$$
$$3(Zn + 4H_2O \longrightarrow Zn(OH)_4^{2-} + 4H^+ + 2e^-)$$

$$2MnO_4^- + \cancel{8H^+} + \cancel{6e^-} \longrightarrow 2MnO_2 + \cancel{4H_2O}$$
$$3Zn + \cancel{12H_2O}\ [8H_2O] \longrightarrow 3Zn(OH)_4^{2-} + \cancel{12H^+}\ [4H^+] + \cancel{6e^-}$$

$$2MnO_4^- + 3Zn + 8H_2O \longrightarrow 2MnO_2 + 3Zn(OH)_4^{2-} + 4H^+$$

Topic 1: [Redox]

- Basic Solution

$$MnO_4^-(aq) + Zn(s) \longrightarrow MnO_2(s) + Zn(OH)_4^{2-}(aq)$$

$$MnO_4^- \longrightarrow MnO_2$$

$$Zn \longrightarrow Zn(OH)_4^{2-}$$

$$MnO_4^- \longrightarrow MnO_2 + 2H_2O$$

$$Zn + 4H_2O \longrightarrow Zn(OH)_4^{2-}$$

$$MnO_4^- + 4H^+ \longrightarrow MnO_2 + 2H_2O$$

$$Zn + 4H_2O \longrightarrow Zn(OH)_4^{2-} + 4H^+$$

$$MnO_4^- + 4H^+ + 4OH^- \longrightarrow MnO_2 + 2H_2O + 4OH^-$$

$$Zn + 4H_2O + 4OH^- \longrightarrow Zn(OH)_4^{2-} + 4H^+ + 4OH^-$$

$$MnO_4^- + \underbrace{4H^+ + 4OH^-}_{4H_2O} \longrightarrow MnO_2 + 2H_2O + 4OH^-$$

$$Zn + 4H_2O + 4OH^- \longrightarrow Zn(OH)_4^{2-} + \underbrace{4H^+ + 4OH^-}_{4H_2O}$$

$$MnO_4^- + \cancel{4H_2O}\ [2H_2O] \longrightarrow MnO_2 + \cancel{2H_2O} + 4OH^-$$

$$Zn + 4OH^- \longrightarrow Zn(OH)_4^{2-}$$

$$MnO_4^- + 4H^+ + 3e^- \longrightarrow MnO_2 + 2H_2O$$

$$Zn + 4H_2O \longrightarrow Zn(OH)_4^{2-} + 4H^+ + 2e^-$$

$$2(MnO_4^- + 4H^+ + 3e^- \longrightarrow MnO_2 + 2H_2O)$$

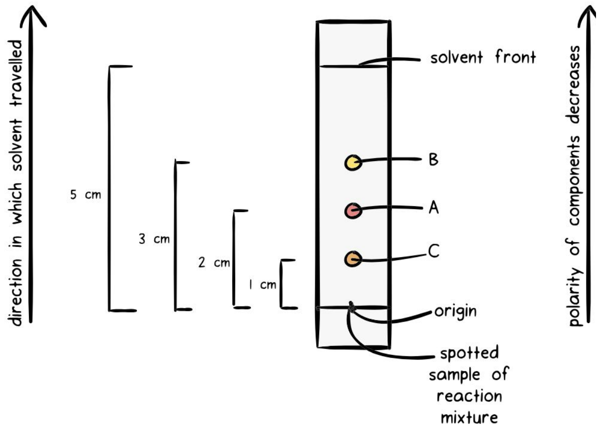
$$3(Zn + 4H_2O \longrightarrow Zn(OH)_4^{2-} + 4H^+ + 2e^-)$$

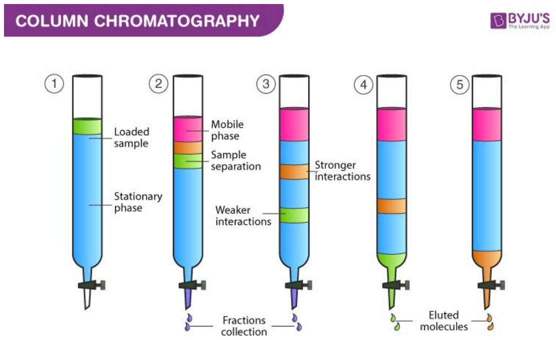
$$2MnO_4^- + \cancel{8H^+} + \cancel{6e^-} \longrightarrow 2MnO_2 + \cancel{4H_2O}$$

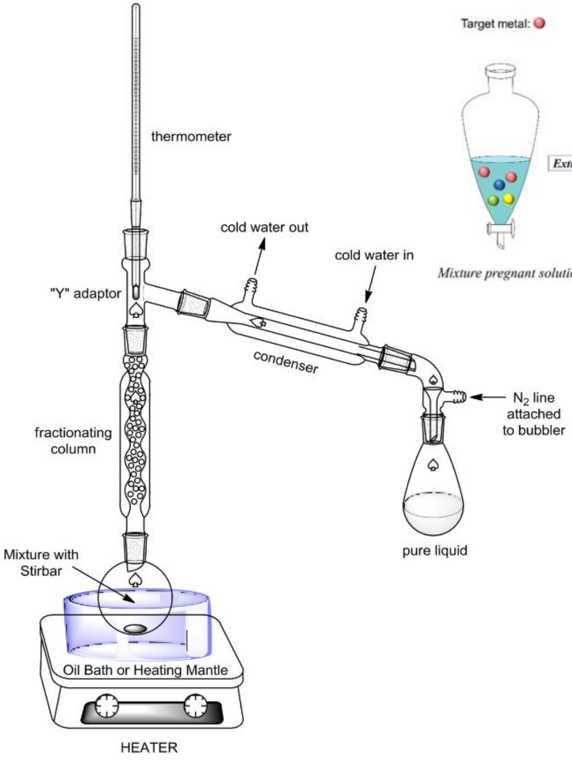
$$3Zn + \cancel{12H_2O}\ [8H_2O] \longrightarrow 3Zn(OH)_4^{2-} + \cancel{12H^+}\ [4H^+] + \cancel{6e^-}$$

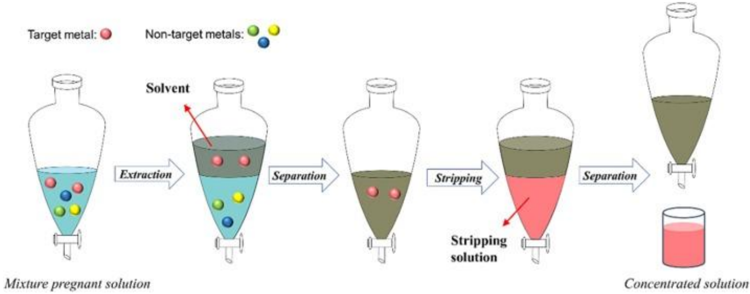
$$2MnO_4^- + 3Zn + 8H_2O \longrightarrow 2MnO_2 + 3Zn(OH)_4^{2-} + 4H^+$$

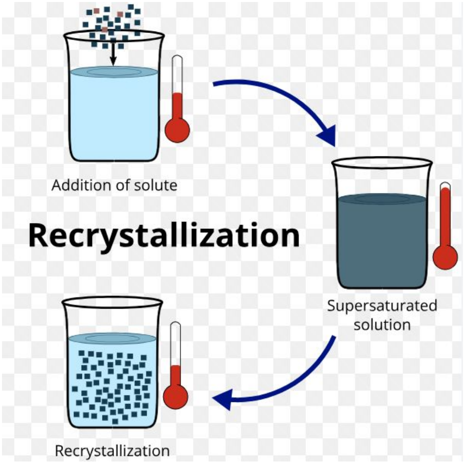
Topic 2: [Compound Sep.]











COMMON QUESTIONS

All of the following questions have been pulled from past YJI exams (which can be found on our website) or the Text Exchange on SciOly Wiki

Question 1: Equilibrium

Part B: Acid Rain (13 points total)

The pH value of pure water is 7.0, whereas natural rainwater is weakly acidic. This is caused by dissolution of atmospheric carbon dioxide. In many areas, however, rainwater is more acidic. This has many causes, some of which are natural and some of which derive from human activity. In the atmosphere, sulfur dioxide and nitrogen monoxide are oxidized to sulfur trioxide and nitrogen dioxide, respectively, which react with water to give sulfuric acid and nitric acid. The resulting so-called "acid rain" has an average pH value of 4.5. Values as low as 1.7 have, however, been reported.

Sulfur dioxide is a diprotic acid in aqueous solution. At 25^{0}C, the acidity constants are

$$SO_2(aq) + H_2O(l) \leftrightarrows HSO_3^-(aq) + H^+(aq) \qquad K_{a1} = 1.20 \times 10^{-2}$$
$$HSO_3^-(aq) \leftrightarrows SO_3^{2-}(aq) + H^+(aq) \qquad K_{a2} = 6.61 \times 10^{-8}$$

The solubility of sulfur dioxide gas at 25^{0}C is 33.9 liters in one liter of water at a sulfur dioxide partial pressure of 0.987 atm. The pH of the saturated solution is 0.91.

8. Calculate the molar concentration of a saturated sulfur dioxide solution. Assume that the change in volume due to the dissolution of SO_2 is negligible.

9. Calculate the percentage of bisulfite ions in a saturated solution of sulfur dioxide.

10. The dominant equilibrium in an aqueous solution of bisulfite ions is shown below:

$$2HSO_3^-(aq) \leftrightarrows SO_3^{2-}(aq) + SO_2(aq) + H_2O(aq)$$

Calculate the equilibrium constant for this equilibrium.

11. Calculate the pH of a 0.0100 M aqueous solution of sodium sulfite.

8. Calculate the molar concentration of a saturated sulfur dioxide solution. Assume that the change in volume due to the dissolution of SO_2 is negligible.

$$PV = nRT$$

$$n = \frac{PV}{RT} = \frac{(0.987\ atm)(33.9\ L)}{(0.08206\ ^{Latm}/_{molK})(298\ K)} = 1.37\ mol\ sulfur\ dioxide$$

$$M = \frac{n}{V} = \frac{3.63\ mol}{1\ L} = 1.37\ M$$

9. Calculate the percentage of bisulfite ions in a saturated solution of sulfur dioxide.

The second dissociation will not occur as readily since K_{a2} is much smaller than K_{a1}.

$SO_2(aq)$ +	$H_2O(l)$ ⇆	$HSO_3^-(aq)$ +	$H^+(aq)$
1.37 M	-----	0	0
-x	-----	+x	X
1.37 – x	-----	x	x

One should not assume that the change in x will be negligible in this equilibrium system, so the quadratic equation is needed, if solved through the equilibrium method.

$$K_{a1} = \frac{x^2}{1.37 - x} = 1.20\ x\ 10^{-2}$$

$$x^2 = 1.20 \times 10^{-2}(1.37 - x)$$
$$x^2 = 0.0164 - 0.0120x$$
$$x^2 + 0.0120x - 0.0164 = 0$$
$$x = 0.122\ M\ HSO_3^-$$

$$\%\ comp = \frac{0.122\ M}{1.37\ M}\ x\ 100 = 8.91\ \%$$

10. The dominant equilibrium in an aqueous solution of bisulfite ions is shown below:

$$2HSO_3^-(aq) \leftrightarrows SO_3^{2-}(aq) + SO_2(aq) + H_2O(aq)$$

Calculate the equilibrium constant for this equilibrium.

$$K = K_{a2} \times 1/K_{a1} = (6.61 \times 10^{-8})(1/1.20 \times 10^{-2})$$
$$K = 5.51 \times 10^{-6}$$

11. Calculate the pH of a 0.0100 M aqueous solution of sodium sulfite.

Sulfite is the conjugate base of the bisulfite ion. $K_b = K_w/K_{a2} = 1.51 \times 10^{-7}$

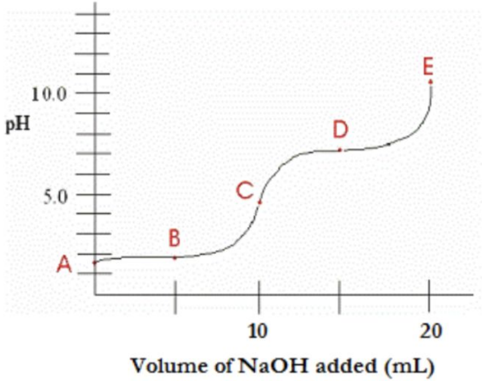
$SO_3^{2-}(aq)$ +	$H_2O(aq)$ ⇆	$HSO_3^-(aq)$ +	$OH^-(aq)$
0.0100 M	----	0	0
-x	----	+x	+x
0.0100 – x ≈ 0.0100	----	x	x

$$K_b = \frac{x^2}{0.0100} = 1.51\ x\ 10^{-7}$$

$$[OH^-] = 3.89 \times 10^{-5}$$
$$pOH = 4.41$$
$$pH = 14 - pOH = 9.59$$

Question 2: Titrations

Part C: Titration (8 points total)
An unknown sample is titrated against a 0.40M NaOH solution. The titration curve is to the right is collected.



12. What type of titration does this curve represent?
    a. A weak monoprotic acid by a strong base.
    b. A weak diprotic acid by a strong base.
    c. A weak triprotic acid by a strong base.
    d. A weak diprotic base by a strong acid.
    e. A strong monoprotic acid by a strong base.

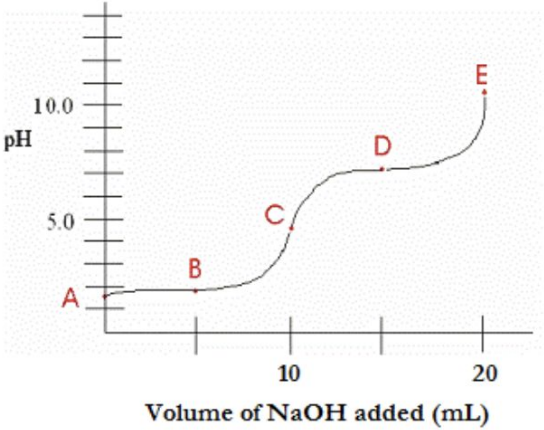
13. If point B has a pH of 1.85 and point D has a pH of 7.19, what is the concentration of the major pH-determining species present at point C?
    a. 1.41×10^{-2} M
    b. 3.02×10^{-5} M
    c. 6.46×10^{-8} M
    d. 6.21×10^{-10} M

14. If 20 mL of the 0.4 M titrant were added to reach point E, and the total volume at point E is 35 mL, what was the initial concentration of the unknown sample at point A?
    a. 0.800 M
    b. 0.533 M
    c. 0.267 M
    d. 0.229 M
    e. 0.114 M

15. A student is given a 0.10 M solution of the unknown sample. She uses 100 mL of the unknown sample and titrates it completely with 0.1 M NaOH. A similar-shaped titration curve, as shown above, is obtained. Calculate the pH at point E of this second titration.
    a. 4.09
    b. 7.50
    c. 8.66
    d. 9.85
    e. 10.1

Part C: Titration

An unknown sample is titrated against a 0.40M NaOH solution. The titration curve is to the right is collected..



12. What type of titration does this curve represent?
    a. A weak monoprotic acid by a strong base.
    b. A weak diprotic acid by a strong base.
    c. A weak triprotic acid by a strong base.
    d. A weak diprotic base by a strong acid.
    e. A strong monoprotic acid by a strong base.

13. If point B has a pH of 1.85 and point D has a pH of 7.19, what is the concentration of the major pH-determining species present at point C? **Species = H^+ from first dissociation**
    a. 1.41×10^{-2} M
    b. 3.02×10^{-5} M pH at C = $(pK_{a1} + pK_{a2})/2$ which is (pt B + pt D)/2
    c. 6.46×10^{-8} M
    d. 6.21×10^{-10} M

14. If 20 mL of the 0.4 M titrant were added to reach point E, and the total volume at point E is 35 mL, what was the initial concentration of the unknown sample at point A?
    a. 0.800 M
    b. 0.533 M
    c. 0.267 M Requires 0.008 mol OH^- so 0.004 mol H_2A must be present in 15 mL
    d. 0.229 M
    e. 0.114 M

15. A student is given a 0.10 M solution of the unknown sample. She uses 100 mL of the unknown sample and titrates it completely with 0.1 M NaOH. A similar-shaped titration curve, as shown above, is obtained. Calculate the pH at point E of this second titration.
    a. 4.09
    b. 7.50
    c. 8.66
    d. 9.85 Will need 200 mL equimolar base and the pK_{b2} (from question 13)
    e. 10.1

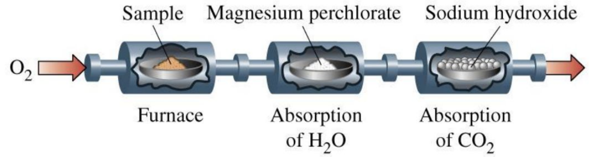
Question 3: Stoichiometry

Part E: Unknown Ester

A student prepares a fragrant ester in lab which presents a pineapple-like odor. In order to confirm the molecular formula of her ester, she performs the following two experiments.

Experiment #1: Combustion Analysis

The student places a 100.0-mg sample of the ester in a combustion chamber, as shown below.

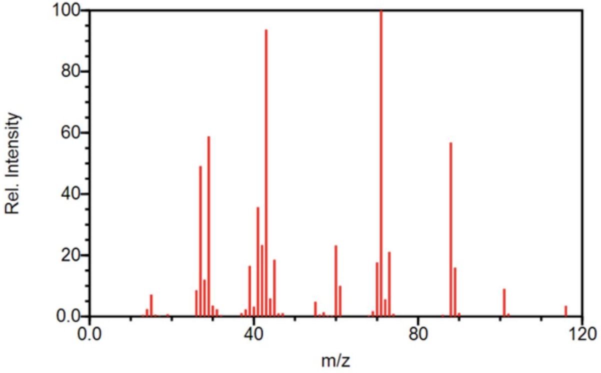


In excess oxygen, the sample is combusted completely. The masses of the magnesium perchlorate and sodium hydroxide sinks are given in the data table below.

Initial Mass of Magnesium Perchlorate Chamber	34.321 grams
Final Mass of Magnesium Perchlorate Chamber	34.414 grams
Initial Mass of Sodium Hydroxide Chamber	37.237 grams
Final Mass of Sodium Hydroxide Chamber	37.464 grams

Experiment #2: Mass Spectroscopy

The student obtained the following mass spectrum of her unknown ester sample.



NIST Chemistry WebBook (http://webbook.nist.gov/chemistry)

16. Calculate the number of moles of water absorbed by the magnesium chlorate.

17. Calculate the number of moles of carbon dioxide absorbed by the sodium hydroxide.

18. Write a balanced chemical equation representing the reaction between the sodium hydroxide pellets and the carbon dioxide gas. **NET IONIC NOT NEEDED, BUT ACCEPTED**

19. Determine the empirical formula of the student's ester. Recall that esters contain carbon, hydrogen, and oxygen atoms.

16. Calculate the number of moles of water absorbed by the magnesium chlorate.

34.414 g – 34.321 g = 0.093 grams of water
moles of H_2O = (0.093 g)/(18.02 g/mol) = 0.00517 mol H_2O

17. Calculate the number of moles of carbon dioxide absorbed by the sodium hydroxide.

37.464 g – 37.237g = 0.227 grams of carbon dioxide
moles of CO_2 = (0.227 g)/(44.01 g/mol) = 0.00516 mol CO_2

18. Write a balanced chemical equation representing the reaction between the sodium hydroxide pellets and the carbon dioxide gas. **NET IONIC NOT NEEDED, BUT ACCEPTED**

$2NaOH + CO_2 \rightarrow Na_2CO_3 + H_2O$ OR $NaOH + CO_2 \rightarrow NaHCO_3$

19. Determine the empirical formula of the student's ester. Recall that esters contain carbon, hydrogen, and oxygen atoms.

$$(0.00517 \text{ mol } H_2O)\left(\frac{2\ mol\ H}{1\ mol\ water}\right)\left(\frac{1.008\ g\ H}{1\ mol\ H}\right) = 0.0104 \text{ grams H}$$

$$(0.00516 \text{ mol } CO_2)\left(\frac{1\ mol\ C}{1\ mol\ CO_2}\right)\left(\frac{12.01\ g\ C}{1\ mol\ C}\right) = 0.0620 \text{ grams C}$$

mass of oxygen = 0.1000 g – (0.0104 g + 0.0620 g) = 0.0276 grams O

moles of O = (0.0276 g)/(16.00 g/mol) = 0.00173 mol O

C: (0.00516 mol C)/0.00173 = 3 mol C

H: (0.01034 mol H)/0.00173 = 6 mol H

O: 0.00173/0.00173 = 1 mol C

empirical formula: C_3H_6O

Additional Resources

Scioly Test Bank

Practice Exam + Key

Resource 3: Youtube Videos

Resource 4: (AP) Chemistry Prep Books

THANKS!