

Please follow the instructions for each section of the exam. Show your work on all mathematical problems. Provide answers with the correct units and significant figures. Be concise in your answers to discussion questions. Point values are in parentheses by each problem.

**Part 0: Warmup. 4 points each**

1. Choose the INCORRECT statement:

- a. Most molecular compounds are either non-electrolytes or weak electrolytes.
- b. An acid produces hydride ions in solution.
- c. Net ionic equations include only the actual participants in the reaction.
- d. Most ionic compounds are strong electrolytes.

Answer     b    

2. If someone were to light a cigar at one end of a closed room, persons on the other end of the room might soon perceive an odor due to gaseous emissions from the cigar. Such a phenomenon is an example of:

- a. ideality
- b. effusion
- c. dissolution
- d. diffusion

Answer     d    

**Part I: Complete all of problems 3-8**

3. Compare the following using a maximum of three sentences for each pair of terms.

- a. **strong electrolyte** versus **weak electrolyte**. (5)

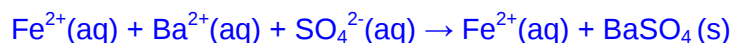
Strong electrolytes are ionic compounds that dissociate completely into their component ions in solution. In a solution of a weak electrolyte, not all of the electrolyte compound dissociates.

- b. **ideal gas** versus **non-ideal (or real) gas**: (5)

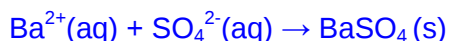
Ideal gases do not interact with one another, are small in volume compared to the total volume the gas occupies, and undergo elastic collisions. Real gases do undergo interactions, inelastic collisions, and have finite volume.

4. It is possible to use precipitation reactions to separate ions in solution by removing target ions as insoluble salts. Propose an approach to separate  $\text{Fe}^{2+}$  from  $\text{Ca}^{2+}$  using precipitation reactions. Include balanced reactions (indicating states of products and reactants). (10)

One possibility is to take advantage of the fact that barium forms an insoluble salt with sulfate, but iron does not. Therefore, if a solution containing sulfate ion is added to a solution containing  $\text{Fe}^{2+}$  and  $\text{Ba}^{2+}$ , we would expect the formation of insoluble barium sulfate, as shown below:



or

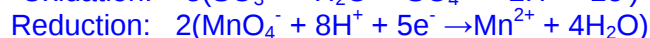
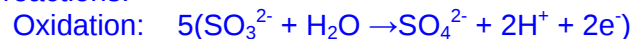


### FORM B

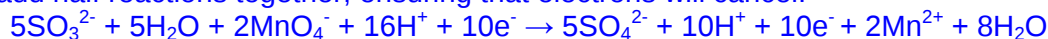
5. Answer the following based on the reaction:  $\text{SO}_3^{2-} + \text{MnO}_4^- \rightarrow \text{SO}_4^{2-} + \text{Mn}^{2+}$

- What is the oxidation state of manganese in the permanganate ion? +7 (2)
- What is the oxidation state of sulfur in the sulfate ion? +6 (2)
- Balance the reaction in acidic aqueous solution. (8)

First balance the half reactions:



Now add half reactions together, ensuring that electrons will cancel.



Finally, cancel redundant terms to get the final balanced reaction.



6. A 1.27 g sample of an oxide of nitrogen, believed to be either NO or N<sub>2</sub>O, occupies a volume of 0.728 L at 25°C and 737 mm Hg. Which oxide is it? (10)

If we can determine the molar mass, we can identify the oxide. How many moles is 1.27g?

Use the ideal gas law:  $n = PV/RT$

$$P = 737 \text{ mm Hg} \times \frac{1 \text{ atm}}{760 \text{ mm Hg}} = 0.969_7 \text{ atm}$$

So,

$$n = \frac{0.969_7 \text{ atm} \times 0.728 \text{ L}}{0.08206 \text{ L atm/mol K} \times 298 \text{ K}} = 0.0288_7 \text{ moles}$$

And,

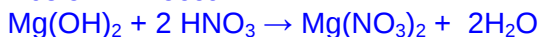
$$\text{molar mass} = \frac{1.27 \text{ g}}{0.0288_7 \text{ moles}} = 43.9_9 \text{ g mol}^{-1}$$

Looking at our two oxides, NO has a molar mass of 29.9 g mol<sup>-1</sup> and N<sub>2</sub>O has a molar mass of 44.0 g mol<sup>-1</sup>. Therefore, the oxide must be N<sub>2</sub>O.

### FORM B

7. A 0.755 gram sample of solid magnesium hydroxide is added to 125 mL of a 0.555 M solution of nitric acid. Will the resulting solution be acidic, basic, or neutral? Justify your answer. (10)

The neutralization reaction below will occur:



One approach is to calculate how much nitric acid will be required to neutralize all of the magnesium hydroxide.

$$0.755 \text{ g Mg(OH)}_2 \times \frac{1 \text{ mol Mg(OH)}_2}{58.320 \text{ g}} \times \frac{2 \text{ mol HNO}_3}{1 \text{ mol Mg(OH)}_2} \times \frac{1 \text{ L HNO}_3}{0.555 \text{ mol HNO}_3} = 0.0467 \text{ L}$$

So, we would need 46.7 mL nitric acid to consume all of the magnesium hydroxide. Since we have 125 mL, there is an excess of nitric acid, meaning there will be nitric acid left after the reaction is complete, causing the resulting solution to be **acidic**.

8. How does the kinetic-molecular theory of gases help explain why a helium-filled balloon shrinks if it is taken outside on a cold winter day? (10)

As the temperature decreases, the velocity of gas particles decreases as well. This leads to a decrease in both the frequency and intensity of collisions of gas particles with the walls of the balloon. Since it is these collisions that result in pressure, this leads to a decrease in pressure as well. As the pressure decreases, so does the volume of the balloon.

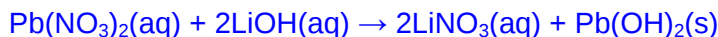
## FORM B

**Part II. Answer two (2) of problems 9-12. Clearly mark the problems you do not want graded. 15 points each.**

9. Write balanced overall reactions and net ionic equations for each of the following: Indicate the state (s, l, g, aq) of each of the reactants and products.

a. Aqueous lead (II) nitrate is mixed with aqueous lithium hydroxide

Balanced Reaction: (5)



Net Ionic Equation: (2)

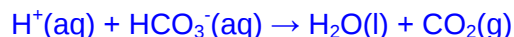


b. Aqueous sulfuric acid is mixed with aqueous sodium bicarbonate

Balanced Reaction: (5)



Net Ionic Equation: (2)



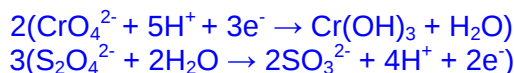
10. Sodium dithionite,  $\text{Na}_2\text{S}_2\text{O}_4$ , is an important reducing agent. One interesting use is in the purification of wastewater by the reduction of chromate ion with  $\text{S}_2\text{O}_4^{2-}$  in basic solution to form insoluble chromium (III) hydroxide, with sulfite ion produced as another product.

a. Write the balanced reaction for the process occurring in basic solution. (10)

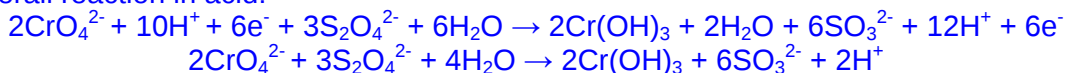
Unbalanced Reaction:



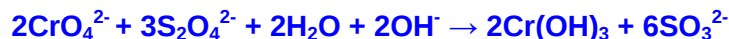
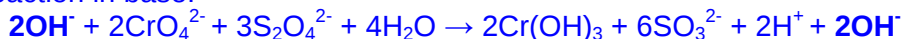
Half Reactions:



Overall reaction in acid:



Overall reaction in base:



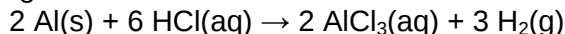
- a. What mass of  $\text{Na}_2\text{S}_2\text{O}_4$  is consumed in a reaction with 100.0 L of wastewater having  $[\text{CrO}_4^{2-}] = 0.0166 \text{ M}$ ? (5)

$$100.0 \text{ L} \times \frac{0.0166 \text{ mol CrO}_4^{2-}}{1\text{L}} \times \frac{3 \text{ mol S}_2\text{O}_4^{2-}}{2 \text{ mol CrO}_4^{2-}} \times \frac{1 \text{ mol Na}_2\text{S}_2\text{O}_4}{1 \text{ mol S}_2\text{O}_4^{2-}} = 2.49 \text{ mol Na}_2\text{S}_2\text{O}_4$$

$$2.49 \text{ mol Na}_2\text{S}_2\text{O}_4 \times \frac{174.109 \text{ g Na}_2\text{S}_2\text{O}_4}{\text{mol Na}_2\text{S}_2\text{O}_4} = 433.53 \text{ g} = 434 \text{ g Na}_2\text{S}_2\text{O}_4$$

## FORM B

11. Birmabright is a metal alloy consisting of aluminum, magnesium, and manganese. A 0.273 g sample of Birmabright is dissolved in an excess of hydrochloric acid, producing hydrogen gas as shown in the balanced reaction below. If 355 mL of hydrogen is collected over water at a temperature of 25°C and pressure of 755 mm Hg, what is the mass percent of aluminum in Birmabright?



Since the gas was collected over water,  $P_{\text{total}} = P_{\text{H}_2} + P_{\text{H}_2\text{O}}$ . The vapor pressure of water at 25°C is 23.75 mm Hg. Therefore,  $P_{\text{H}_2} = (755 - 23.75) \text{ mm Hg} = 731 \text{ mm Hg}$ .

Now we can find the number of moles of  $\text{H}_2$  produced ( $n = PV/RT$ )

$$P = 731 \text{ mm Hg} \times \frac{1 \text{ atm}}{760 \text{ mm Hg}} = 0.961_8 \text{ atm}$$

So,

$$n = \frac{0.961_8 \text{ atm} \times 0.355 \text{ L}}{0.08206 \text{ L atm/mol K} \times 298 \text{ K}} = 0.0139_6 \text{ moles H}_2$$

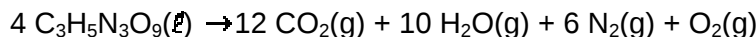
So, the mass of aluminum consumed must have been:

$$0.0139_6 \text{ moles H}_2 \times \frac{2 \text{ mol Al}}{3 \text{ mol H}_2} \times \frac{26.9815 \text{ g Al}}{1 \text{ mol Al}} = 0.251_1 \text{ g Al}$$

And the percent aluminum must be:

$$\frac{0.251_1 \text{ g Al}}{0.273 \text{ g sample}} \times 100\% = \mathbf{92.0\% \text{ Aluminum}}$$

12. Nitroglycerine ( $\text{C}_3\text{H}_5\text{N}_3\text{O}_9$ , molar mass = 227.088 g/mol) is a contact explosive that rapidly decomposes via the reaction below and releases a large quantity of heat and gas. Assume 10.0 grams of nitroglycerine decomposes in a 2.0 L soda bottle and instantaneously generates a temperature of 5230K.



- a. What will the pressure be inside the bottle once the reaction is complete? (5)

First find the total number of moles of gas produced:

$$10.0 \text{ g C}_3\text{H}_5\text{N}_3\text{O}_9 \times \frac{1 \text{ mol C}_3\text{H}_5\text{N}_3\text{O}_9}{227.088 \text{ g}} \times \frac{29 \text{ mol gas}}{4 \text{ mol C}_3\text{H}_5\text{N}_3\text{O}_9} = 0.319_3 \text{ mol gas}$$

Now find the pressure

$$P = \frac{nRT}{V} = \frac{(0.319_3 \text{ mol})(0.08206 \text{ L atm/mol K})(5230 \text{ K})}{2.0 \text{ L}} = 68.5_1 \text{ atm} = \mathbf{69 \text{ atm}}$$

- b. What is the partial pressure of water when the reaction is complete? (5)

$$P_{\text{H}_2\text{O}} = \frac{n_{\text{H}_2\text{O}} (P_{\text{total}})}{n_{\text{total}}} = \frac{10 \text{ mol H}_2\text{O}}{29 \text{ mol total}} \times 69 \text{ atm} = 23.8 \text{ atm} = \mathbf{24 \text{ atm}}$$

- c. What volume would the gas mixture produced occupy at STP? (5)

Use the combined gas law to find:

$$V_2 = \frac{P_1 V_1 T_2}{P_2 T_1} = \frac{(69 \text{ atm})(2.0 \text{ L})(273 \text{ K})}{(1 \text{ atm})(5230 \text{ K})} = \mathbf{7.2 \text{ L}}$$

**FORM B**  
**Possibly Useful Information**

|                                                     |                                                   |
|-----------------------------------------------------|---------------------------------------------------|
| $R = 0.08206 \text{ L atm mol}^{-1} \text{ K}^{-1}$ | STP = 1 atm, 0°C<br>$K = 273.15 + ^\circ\text{C}$ |
| 1 atmosphere = 760 Torr = 760 mm Hg                 | $\left(P + \frac{n^2a}{V^2}\right)(V - bn) = nRT$ |
| $P_{\text{total}} = n_{\text{total}}RT/V$           | $P_A = X_A P_{\text{total}}$                      |
| $N_A = 6.02214 \times 10^{23} \text{ mol}^{-1}$     | $\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$       |

| Molar Masses             |                    |
|--------------------------|--------------------|
| Compound                 | Molar Mass (g/mol) |
| aluminum chloride        | 133.340            |
| carbon dioxide           | 44.010             |
| chromium (III) hydroxide | 103.018            |
| hydrochloric acid        | 36.461             |
| hydrogen gas             | 2.016              |
| magnesium hydroxide      | 58.320             |
| nitric acid              | 63.013             |
| nitrogen gas             | 28.0135            |
| nitrogen monoxide        | 30.006             |
| nitroglycerine           | 227.088            |
| oxygen gas               | 31.999             |
| sodium carbonate         | 105.989            |
| sodium dithionite        | 174.109            |
| sodium nitrite           | 68.995             |
| water                    | 18.015             |

**Vapor Pressure of Water  
at Various Temperatures**

| Temperature (°C) | Vapor Pressure (mmHg) |
|------------------|-----------------------|
| 15.0             | 12.79                 |
| 17.0             | 14.53                 |
| 19.0             | 16.48                 |
| 21.0             | 18.65                 |
| 23.0             | 21.07                 |
| 25.0             | 23.76                 |
| 30.0             | 31.82                 |
| 50.0             | 92.51                 |

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**TABLE 5.3 Some Common Gas-Forming Reactions**

| Ion                | Reaction                                                                                               |
|--------------------|--------------------------------------------------------------------------------------------------------|
| $\text{HSO}_3^-$   | $\text{HSO}_3^- + \text{H}^+ \longrightarrow \text{SO}_2(\text{g}) + \text{H}_2\text{O}(\text{l})$     |
| $\text{SO}_3^{2-}$ | $\text{SO}_3^{2-} + 2 \text{H}^+ \longrightarrow \text{SO}_2(\text{g}) + \text{H}_2\text{O}(\text{l})$ |
| $\text{HCO}_3^-$   | $\text{HCO}_3^- + \text{H}^+ \longrightarrow \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l})$     |
| $\text{CO}_3^{2-}$ | $\text{CO}_3^{2-} + 2 \text{H}^+ \longrightarrow \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l})$ |
| $\text{S}^{2-}$    | $\text{S}^{2-} + 2 \text{H}^+ \longrightarrow \text{H}_2\text{S}(\text{g})$                            |
| $\text{NH}_4^+$    | $\text{NH}_4^+ + \text{OH}^- \longrightarrow \text{NH}_3(\text{g}) + \text{H}_2\text{O}(\text{l})$     |

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**TABLE 5.1 Solubility Guidelines for Common Ionic Solids**

Follow the lower-numbered guideline when two guidelines are in conflict. This leads to the correct prediction in most cases.

1. Salts of group 1 cations (with some exceptions for  $\text{Li}^+$ ) and the  $\text{NH}_4^+$  cation are soluble.
2. Nitrates, acetates, and perchlorates are soluble.
3. Salts of silver, lead, and mercury(I) are insoluble.
4. Chlorides, bromides, and iodides are soluble.
5. Carbonates, phosphates, sulfides, oxides, and hydroxides are insoluble (sulfides of group 2 cations and hydroxides of  $\text{Ca}^{2+}$ ,  $\text{Sr}^{2+}$ , and  $\text{Ba}^{2+}$  are slightly soluble).
6. Sulfates are soluble except for those of calcium, strontium, and barium.

|                                                                                          |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|------------------------------------------------------------------------------------------|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|
| FORM B                                                                                   |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| <div>11A12A3456789101112131415161718</div>                                               |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| <div>1H2LiBe3B4C5N6O7F8Ne</div>                                                          |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| <div>2He3Li4Be5B6C7N8O9F10Ne</div>                                                       |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| <div>3Na4Mg5Al6Si7P8S9Cl10Ar</div>                                                       |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| <div>4K5Ca6Sc7Ti8V9Cr10Mn11Fe12Co13Ni14Cu15Zn16Ga17Ge18As19Se20Br21Kr</div>              |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| <div>5Rb6Sr7Y8Zr9Nb10Mo11Tc12Ru13Rh14Pd15Ag16Cd17In18Sn19Sb20Te21I22Xe</div>             |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| <div>6Cs7Ba8La9Hf10Ta11W12Re13Os14Ir15Pt16Au17Hg18Tl19Pb20Bi21Po22At23Rn</div>           |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| <div>7Fr8Ra9Ac10Rf11Db12Sg13Bh14Hs15Mt16Ds17Rg18Pt19Au20Hg21Tl22Pb23Bi24Po25At26Rn</div> |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| <div>8La9Ce10Pr11Nd12Pm13Sm14Eu15Gd16Tb17Dy18Ho19Er20Tm21Yb22Lu</div>                    |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| <div>9ThPaU1Np2Pu3Am4Cm5Bk6Cf7Es8Fm9Md10No11Lr</div>                                     |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |