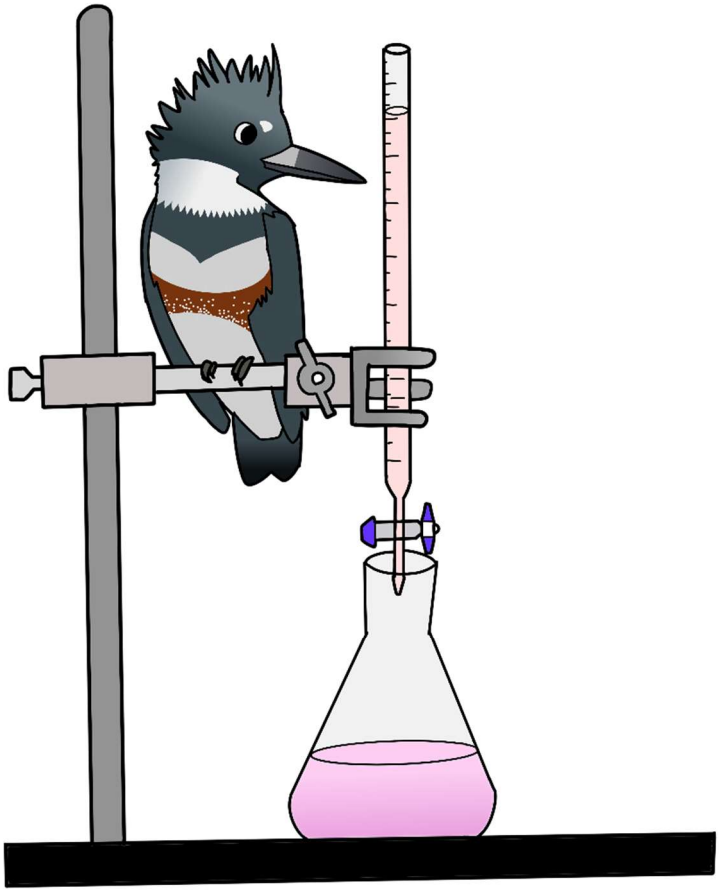
Last Updated: 3/3/2021



BirdSO Chemistry Lab Test

Roland S. Hu

University of Washington Biochemistry 2024

Notes about the test + answer key

This test was originally written in word and then copy and pasted over into scilympiad. Because of this a lot of formatting might be messed up especially with stuff like superscripts, subscripts, certain symbols, colors, etc. Also uploading it to the drive also messes with a lot of the spacing so it might not look super nice. If you have any questions about this feel free to message me and I'll be happy to clear anything up. My contact information is on the next page in the background introduction.

The answers are given in red and as bulleting points along with reasoning for the scoring.

---

[2] Problem 0: Honor Statement + Free Points
[17] Problem 1: Colligative properties question spam
[12] Problem 2: Fuel for Climate Change
[38] Problem 3: All about Chrom(ium)
[13] Problem 4: Generic acid base problem 1
[19] Problem 5: Chemistry Re-Wine
[38] Problem 6: Soda-Licious
[7] Problem 7: Dr. Stone Gun Powder Problem
[10] Problem 8: Generic acid base problem 2
[19] Problem 9: Cya-nara Cadmium

Basic Introduction + Instructions

Hello competitors! My name is Roland Hu (University of Washington Biochem 2024, formerly Palo Alto HS 2020) and I'll be your BirdSO Chemistry Lab Event Supervisor. Before you get started please read the following

1. The test is 45 minutes long and going by BirdSO rules, can be done asynchronously, however I will be on the event supervisor page on scilympiad for any immediate questions. You can also email me or message me on discord if something comes up (contact information is below).
2. The test is a collection of 9 free response questions with **no multiple choice**.
3. Each question will start with a textbox full of background information, constants, conditions, procedures, memes, etc. so do read them carefully.
4. You can assume everything is happening at standard lab pressure and temperature (293 K, 1 atm) unless otherwise specified. Most problems will mention this in the background textbox.
5. Type in your work. You don't have to show every single step but do show the important intermediate steps as it makes it easier to give partial credit especially on the longer calculation problems.
6. For anything involving subscripts, superscripts, or any other weird formatting things, you can ignore them as long as what you are typing isn't too ambiguous. For example, typing in 10^-5 or CO32- is fine.
7. Sig figs don't really matter in anything beyond that first unit test you take in any general chem class. So for this test I won't be taking sig figs into account but you should still try

to use an appropriate number of sig figs. Just don't use too little or too much as certain experimental apparatus are not that accurate or inaccurate.

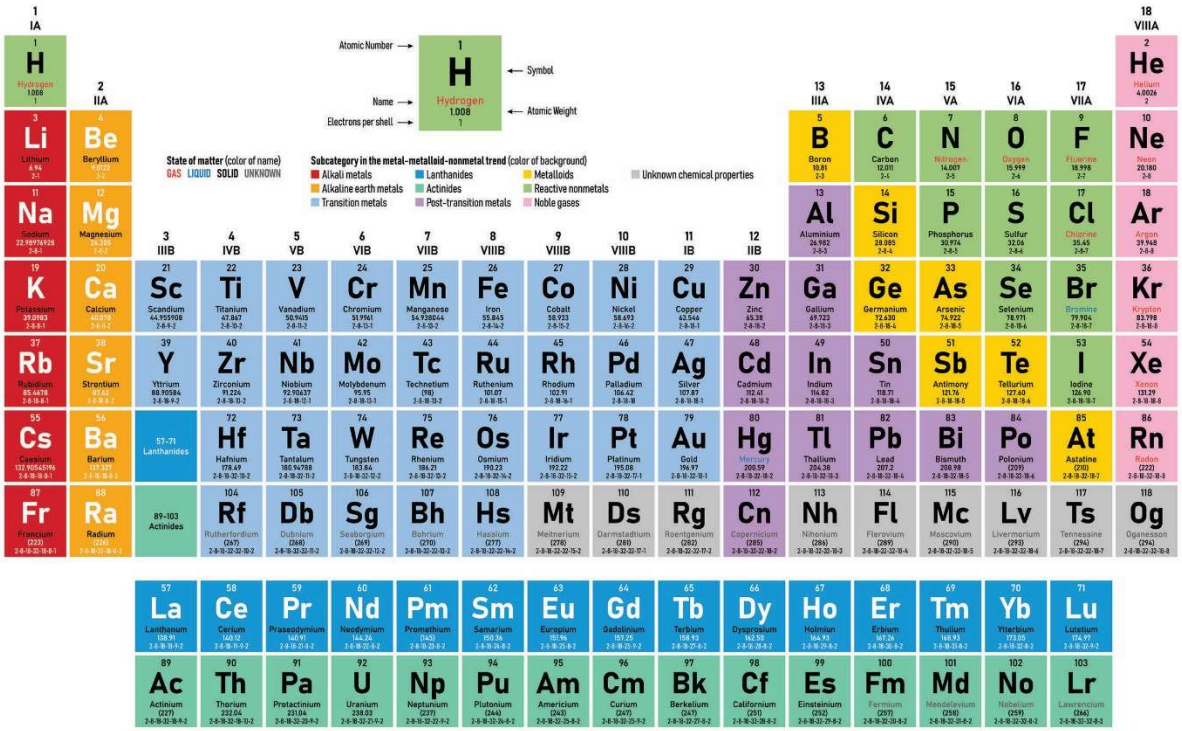
8. There is a periodic table on the following page, as required by the rules. Any other necessary information will be contained in the problems background box.
9. Another general test taking tip is the principle of Occam's razor. "Sometimes the simpler explanations are more correct".
10. Good luck and have fun! (:

.

If you have any questions about the exam after it has concluded whether you are a BirdSO competitor, another competitor taking this test for practice, reviewing the solutions and notice a mistake, or have any questions on the exam, please email me at rolandhu123@gmail.com or message me on discord at r hudini#8811.

*The first question is just an acknowledgment

Periodic Table of the Elements



[2] Problem 0: Honor Statement + Free Points

(glorified free points)

[1pt] Please type the following text exactly as written:

The work on this test is solely our own. I accept the consequences of academic dishonesty.

[1pt] What is your favorite branch of chemistry?

[17] Problem 1: Colligative properties question spam

These questions all deal with colligative properties! Some things to keep in mind: Kf is freezing point depression and KB is boiling point elevation.

a) [3 pts] What are colligative properties and how do they work. Why do they not depend on the chemical identity of the solute?

b) [2] Estimate the vapor pressure of seawater at 20 °C given that the vapor pressure of pure water is 2.338 kPa at that temperature and the solute is largely Na+ and Cl- ions, each present at about 0.5 mol/dm3

c) [2] Calculate the mole fraction of carbon dioxide in fat given that the Henry's law constant is 8.6x104 Torr and the partial pressure of carbon dioxide is 55 kPa.

d) [2] Estimate the freezing point of 150 mL of water (KF=1.86K kg mol-1) containing 7.5 g of sucrose.

e) [2] Water has KB=0.51 K kg mol-1 . What is the boiling temperature of a 1 M solution of NaCl?

f) [6] 4.5 g of a non-dissociating substance when dissolved in 125 g CCl4 leads to an elevation of the boiling point of 0.65 K. Calculate the freezing point depression, the molecular mass of the substance, and the factor by which the vapor pressure of CCl4 is lowered. Note, for CCl4, the equilibrium freezing temperature is 250.3 K, the freezing point depression constant KF is 30 K kg/mol, the boiling temperature is 349.8 K, and the boiling point elevation constant KB is 4.95 K kg/mol.

[12] Problem 2: Fuel for Climate Change

The majority of the world's power comes from fossil fuels. Fossil fuels are nice since they are convenient to burn, energy dense, "widely" available, and make good subject for comics. What is not so nice about fossil fuels is the carbon emissions they produce. Carbon dioxide emissions from fossil fuels are one of the major contributors to climate change. It is clear that within the next couple decades' humanity has to come up with an alternative to solve this energy crisis. The government has recruited BirdSO test takers to handle this crisis by letting you take command of their fuel research department (lucky you!).

You can assume everything takes place at 298 K and 1 atm.

a) [2] You have looked into hydrogen gas as a possible alternative to fossil fuels. However, you are stumped on how to get hydrogen. You figure out one way you can form hydrogen is by reacting methane with water to get CO2 and Hydrogen gas. Write out this equation and balance it.

b) [2] When your supervisors see your expression they get super paranoid. Your reaction produces CO2 which as stated in the background is a nu Bueno. You assure them that this CO2 can be easily capture and will not be released into the atmosphere. Suggest 2 ways of capturing CO2.

c) [2] After getting the approval of your superiors you then set out to calculate the enthalpy for your reaction. Here are some helpful values.

   Enthalpy of formation of $CH_4(g) = -74.8$ kJ/mol

   Enthalpy of formation of $CO_2(g) = -393.5$ kJ/mol

   Enthalpy of formation of $H_2O(l) = -285.8$ kJ/mol

d) [1] Another way of producing hydrogen gas is through the electrolysis of water. You are given the 2 following half reactions and overall cell reaction.

$2H_2O\ (l) \rightarrow O_2(g) + 4H^+\ (aq) + 4e^-$

$2H^+\ (aq) + 2e^- \rightarrow H_2(g)$

$2H_2O\ (l) \rightarrow 2H_2\ (g) + O_2\ (g)$

Which half reaction occurs at the cathode?

e) [2] What is the enthalpy change for the overall cell reaction?

f) [3] What is the cell potential? (hint you might want to use this value below)

Entropy of formation of $H_2O(l) = -163.0$ J/K/mol

[38] Problem 3: All about Chrom(ium)

Google chrome is one of the most popular web browsers used in the world. Noted for it's speed, sleek design, and ability to eat of your computers ram in a flash. Being a nerdy chemist you must've realized that the origin of its name is from the element chromium, because chromium is often used to plate cars and other fancy objects. Hence the association of the word chrome with "metallic sleek finish that looks super speedy". However, something not so sleek about chrome is that certain forms of it are quite toxic. This problem deals with both the pretty side and the toxic side of chromium.

a) [4] What are the oxidation states of chromium in each of the following species?
   Cr_2O_3
   CrO_4^{2-}
   $Cr_2O_7^{2-}$
   $FeCrO_4$

b) [2] One of components of stainless steel is chromium and more specifically: chromite. The stainless steel is produced when the iron chromite is reduced in the presence of carbon (typically in a blast furnace). Write out the balanced redox reaction knowing that the products are iron, chromium and carbon dioxide.

c) [6] Since we getting into redox reactions let's talk about chrome-plating. To plate chrome, you typically use chromium III ions in an acidic solution. To get a solution of these ions you typically take chromite and oxidize it in the presence of molten NaOH and air. This will give you sodium chromate which can be leached out and then dissolved in something like sulfuric acid to get your acidic solution.
   Write the half reactions of $FeCr_2O_4$ in basic solution and the balanced full reaction.

d) [6] Another cool thing you can do with chromium ions is titrate them. This is used a lot in mining when prospectors want to determine how much chromium is present in their ores. You have been given a 5 g sample of chromite ore which you have oxidized into chromate dissolved in a 1 L solution of sodium hydroxide. Using an pipette you take 25 m of this solution and transfer it to a beaker with 100 ml of DI water and potassium iodide. The reaction forms triiodide ions and chromium III ions. These triiodide ions where then titrated with .1 M potassium thiosulfate to give iodide ions and tetrathionate ions. A total of 3 titrations were performed which each used about 23 mL of sodium thiosulfate solution.
   Write out the half reactions and the full reaction of the reaction of chromate ions with iodide ions. Note you can do the chromium half reaction in both an acidic and basic solution. You can do either one but your full reaction must be consistent with your half. (triiodide ions are I_3^- and tetrathionate ions are $S_4O_6^{2-}$)

e) [6] Write out the 2 half reactions and the full reaction for the reaction between triiodide ions and thiosulfate ions.

f) [5] What was the concentration of the sodium chromate solution? (hint you can use the redox reactions you created to find the relative stoichiometric ratios of ions).

g) [2] How much chromite was in the ore? (give your answer in mass percent)

h) [2] How much of the ore was chromium?

i) [2] As mentioned in the background chromium and it's derivate can be quite toxic. This is a especially prevalent when mining for certain minerals and ores. Some amount of crocoite, a mineral consisting of lead chromate was accidently leached into a reservoir!

What is the solubility of lead chromate in water? (Ksp for lead chromate is 1.77 * 10^-14)

a. Crocoite is pretty nasty stuff: https://www.quora.com/How-dangerous-is-handling-crocoite-bare-handed though apparently it was used as the coloring on school buses or smth.

j) [3] Because most people don't want lead chromate in their drinking water, it is believed that you at least remove some of it by manipulating solubility. One example involves using potassium chromate to get the lead ions out. What is the solubility of lead chromate in .1 M of potassium chromate? What will happen to the water (hint think about precipitation)?

[13] Problem 4: Generic acid base problem 1

1 g of NH4CL and 1 g of Ba(OH)2 * 8H2O are dissolved in 100 ml of water. The pKa of NH4+ is 9.24

a) [3] What is the pH of the solution?
b) [5] List the concentration of all ions present (hint there are 5 of them)
c) [3] What is the pH after you add 10 ml of 1 M HCl?
d) [2] What is the concentration of NH3 after you add the HCl?

[19] Problem 5: Chemistry Re-Wine

The fermentation of grapes to produce wine is a technique that dates back to the Neolithic period where people basically mashed up a bunch of grapes (or other miscellaneous fruit) and left them in jars only to come back and get wine. This simple process is made possible by the yeast and bacteria that break down the sugars into CO2 and ethanol. In fact, it's not hard to illicitly ferment alcohol, however one should consider drinking mashed up semi spoiled fruits carries a higher risk of botulism than getting a buzz.

Determining the ethanol content of wine is important in the industry and the most popular method is to perform a redox titration with KMnO4. Permanganate ions react with ethanol to form Mn2+ ions and ethanoic acid (CH3COOH).

You are asked with determining the ethanol content of a sample of wine. You take a 10ml sample and dilute it to 500 ml to create a stock solution. From this stock solution you take 20ml and titrate it with 14.4 ml of a .05 M KnMnO4.

a) [6] Write balanced ionic half equations and the full ionic equation for the determination of ethanol in wine with permanganate ions. (hint use an acidic solution)
b) [4] What is the concentration in moles/ L of ethanol in the wine stock solution?
c) [3] What is the % ethanol by volume in the wine sample? The density of water is 1 g/ml and the density of ethanol is .79 g/ml.

Ethanol isn't the only product formed in fermentation, other compounds such as acetic acid are formed which give a slightly sour taste. However too much acetic acid formation is not ideal is typical sign of wine souring and spoilage. (this is how vinegar is made!). Industry standard dictates that the acetic acid (or any volatile acid) should not be higher than 1.2 g / L to be considered "wine".

d) [2] You take 20 ml of the same unknown wine from before and distill it to remove all the ethanol and end up with 100 ml of distillate. Then you want to take 10 ml of the distillate and titrate it with 10 ml of NaOH. What was the concentration of the NaOH used?
e) [2] Suppose that you wish to titrate your solution from the permanganate titration from before instead of wine. Should you use a higher or lower concentration of NaOH and why?
f) [2] Unfortunately the method describe previously is flawed. If you use your permanganate solution you won't be able to determine how much acetic acid is present. Explain why.

[38] Problem 6: Soda-Licious

A soda drink by the name of BirdSO Cola is prepared by dissolving carbon dioxide into water at 15 atm. BirdSO Cola like most sodas has an acidic flavor additive along with sodium benzoate. The flavor additive is there to acidify the soda and the benzoate is a shelf stabilizer. However, the flavor additive is a market secret and BirdSO refuses to share much about it with the public in fear of rival soft drink corporation BearSO Pepsi stealing it. Nonetheless BirdSO cola is still well known for destroying the tooth enamel of scioly test takes around the world. No wonder BirdSO has an annual revenue of about 33 billion USD (scource: CocaCola Gross Margin 2006-2020 | KO | MacroTrends).

After breaking into BirdSO Cola national labs in California, you determine that flavor additive is the "fictional" triprotic acid H4BirdSO with a molar mass of 300 g/mol. It's ka(1-4) are 10^-3, 10^-4, 10^-5 and is added in a concentration of 5g/L. You also use determine from your massive BirdSO Cola addiction that that the ka(1-2) for carbonic acid is 10^-6, 10^-10. Soidum benzoate is added till it's .1% by mass.

Here are those values in a more organized manner (for your convenience):
Acidic additive (H3BirdSO): K1 = 10^-3, K2 =10^-4, K3 = 10^-5
Molar mass H3BirdSO = 300 g/mol
Carbonic acid: K1 = 10^-6, K2 = 10^-10
Benzoic acid (HBenzoate): K = 10^-4
Sodium Benzoic acid .1% by mass

a) [8] Calculate the concentration of CO2 in BirdSO cola in a sealed and unsealed bottle. You can assume the partial pressure of CO2 is 1 atm and the henry's law constant for CO2 is 1.3*10^6 mm Hg.
b) [12] Write out the equilibria expressions and their respective constants for everything present in a bottle of BirdSO Cola. One of them has already been done for you. (Hint there are 6 more for a total of 7)
You can also assume that no cross reactions happen.

H2O + H2O -> H3O+ + OH-
Kw = [H3O+][OH-] = 10^-14

c) [16] What is the pH of an open bottle of BirdSO cola (p(CO2) = 1 atm)?
this problem is very involved, if I have time I might make a hand written version
d) [2] How will the pH change if the Cola was boiled until all the dissolved CO2 was removed?

[7] Problem 7: Dr. Stone Gun Powder Problem

In the anime and or manga Dr. Stone one of the major plot points in the story is the creation of gun powder (or black powder?) from natural materials, namely nitric acid, sulfur, charcoal, and sugar*. Though the story follows random anime logic, the actual science behind the show is pretty accurate.

note do not actually try to make gunpowder

* https://www.youtube.com/watch?v=yUYxk-y-tU8 *

Gunpowder compositions vary widely depending on its intended purpose (fireworks, flares, rockets, munitions, etc) but is usually a mixture of saltpeter (potassium nitrate), sulfur, and carbon.

You know from watching the show that the gun powder made is 75% saltpeter, 13% carbon, and 12% sulfur by mass.

a) [2] Write out the chemical equation for the combustion of gunpowder. (hint it might be helpful to determine the molar ratios of the ingredients)
b) [2] You know from a testing that 1 g of gun powder releases 2.15 kJ of heat, what is the molar enthalpy change for the combustion of gun powder?
c) [2] How fast will a 5 g bullet go when shot out of a cartridge containing 2 g of gunpowder. You can assume that the cartridge is 35% efficient.
d) [1] Since gun powder compositions can vary a lot, what do you think will happen if there were other additives?

[10] Problem 8: Generic acid base problem 2

A student prepares a saturated solution of magnesium hydroxide in water at 25 C. She determines that the solution has a pH of 10.5.
* when asked for solubility you should give your answer in both mol / L and g / 100 ml.*

a) [3] What is the solubility of magnesium hydroxide in water?
b) [2] What is the solubility product of magnesium hydroxide in water?
c) [2] What is the solubility of magnesium hydroxide in a .01 NaOH solution?
d) [3] You mix 10 g of magnesium hydroxide into a 100 ml of a .1 M HCl solution. What is the pH of this solution?

[19] Problem 9: Cya-nara Cadmium

Last Question and the Tie Breaker

Cadmium is a soft, silvery-white heavy metal that often exists as a minor component in Zinc ore. Because of this, mining and refinement of zinc often leads to the leaching of cadmium ions into sewage or other waterways. It should be noted that Cadmium often gets compared to other heavy metals such as mercury, lead, and chromium due to its highly toxic nature. It is often complex with cyanide to form cadmium cyanide, which unlike most other metal cyanides is water soluble.

Here are some equilibria constants you'll need to solve this problem.

Cd(OH)2 Ksp(in pure water) = 5.9*10^-15

Cd2+ + CN- -> CdCN+	K1 = 10^5.48
CdCN+ + CN- -> Cd(CN)2	K2 = 10^5.12
Cd(CN)2 + CN- -> Cd(CN)3-	K3 = 10^4.63
Cd(CN)3- + CN- -> Cd(CN)32-	K4 = 10^3.65

a) [14] Calculate the solubility of Cd(OH)2 in a solution containing 1*10^-3 M CN- ions and the pH of the solution.

b) [5] Though multiple cadmium cyanide complexes exist suppose that only Cd(CN)32- is formed. What do you think will happen to the solubility (decrease, increase, stay the same)? Justify your answer by calculating the factor by which the solubility changes.

scrapped problem

[7] Problem XX: Quick Titration "lab" problem

Every scioly chem lab test has one of these standard titrations problems. Usually you have a vial or two of an unknown and you want to determine something about it, pka, concentration, solubility, flavor (prob not this one) etc. This would normally be done in a lab on site but since everything is virtual you'll instead get given some data and just crunch some calculations. I would tell you a chem joke about it but it'd be too basic. (:

You start with a 10 g sample of window cleaner solution containing high concentration of ammonia. You dilute it with 90 grams of water to create a stock solution. Then you take 5 grams of that stock solution and titrate it with 42 ml of .05 M HCl to its equivalence point.

Pkb of ammonia is 4.75

a) [5] What was the mass percent of ammonia in your unknown solution?
b) [2] Name 2 indicators that you could use in this experiment (that is not universal indicator).