ACS USNCO
U.S. National Chemistry Olympiad

2026 U.S. NATIONAL CHEMISTRY OLYMPIAD

NATIONAL EXAM PART III

Prepared by the American Chemical Society Chemistry Olympiad Examinations Task Force

OLYMPIAD LABORATORY PRACTICAL TASK FORCE

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DIRECTIONS TO THE EXAMINER

The laboratory practical part of the National Olympiad Examination is designed to test skills related to the laboratory. Because the format of this part of the test is quite different from the first two parts, there is a separate, detailed set of instructions for the examiner. This gives explicit directions for setting up and administering the laboratory practical.

There are three parts to the National Olympiad Examination. You have the option of administering the three parts in any order, and you are free to schedule rest breaks between parts.

Part I	**60 questions**	**single-answer multiple-choice**	**1 hour, 30 minutes**
Part II	**8 questions**	**problem-solving, explanations**	**1 hour, 45 minutes**
Part III	**2 lab questions**	**laboratory practical**	**1 hour, 30 minutes**

There are two laboratory tasks to be completed during the 90 minutes allotted to this part of the test. Students may carry out the two tasks in any order they wish and move directly from one to the other within the allotted time. Each procedure must be approved for safety by the examiner before the student begins that procedure.

A periodic table and other useful information are provided on page two for student reference.

Students should be permitted to use non-programmable calculators. The use of a programmable calculator, cell phone, watch, or any other device that can access the internet or make copies or photographs during the exam is grounds for disqualification.

Students are permitted to request one replacement or refill of a chemical during the laboratory period. Please indicate on the exam sheet the item replaced or refilled.

DIRECTIONS TO THE EXAMINEE - DO NOT TURN THE PAGE UNTIL DIRECTED TO DO SO.

WHEN DIRECTED, TURN TO PAGE 2 AND READ THE INTRODUCTION AND SAFETY CONSIDERATIONS CAREFULLY BEFORE YOU PROCEED. There are two laboratory-related tasks for you to complete during the next 90 minutes. There is no need to stop between tasks or to do them in the given order. Simply proceed at your own pace from one to the other, using your time productively. You are required to have a procedure for each problem approved for safety by an examiner before you carry out any experimentation on that problem. You are permitted to use a non-programmable calculator. At the end of the 90 minutes, all answer sheets should be turned in. Be sure that you have filled in USNCO ID number at the top of each page. Carefully follow all directions from your examiner for safety procedures and the proper disposal of chemicals at your examination site.

ABBREVIATIONS AND SYMBOLS					
amount of substance	*n*	Faraday constant	*F*	molar mass	*M*
ampere	A	free energy	*G*	mole	mol
atmosphere	atm	frequency	ν	Planck's constant	*h*
atomic mass unit	u	gas constant	*R*	pressure	*P*
Avogadro constant	N_A	gram	g	rate constant	*k*
Celsius temperature	°C	hour	h	reaction quotient	*Q*
centi– prefix	c	joule	J	second	s
coulomb	C	kelvin	K	speed of light	*c*
density	d	kilo– prefix	k	temperature, K	*T*
electromotive force	*E*	liter	L	time	*t*
energy of activation	E_a	measure of pressure	mm Hg	vapor pressure	VP
enthalpy	*H*	milli– prefix	m	volt	V
entropy	*S*	molal	*m*	volume	*V*
equilibrium constant	*K*	molar	M	year	y

CONSTANTS

$R = 8.314\ \text{J mol}^{-1}\ \text{K}^{-1}$

$R = 0.08314\ \text{L bar mol}^{-1}\ \text{K}^{-1}$

$F = 96{,}500\ \text{C mol}^{-1}$

$F = 96{,}500\ \text{J V}^{-1}\ \text{mol}^{-1}$

$N_A = 6.022 \times 10^{23}\ \text{mol}^{-1}$

$h = 6.626 \times 10^{-34}\ \text{J s}$

$c = 2.998 \times 10^{8}\ \text{m s}^{-1}$

0 °C = 273.15 K

1 atm = 1.013 bar = 760 mm Hg

Specific heat capacity of H_2O = $4.184\ \text{J g}^{-1}\ \text{K}^{-1}$

EQUATIONS

$$E = E^\circ - \frac{RT}{nF}\ln Q$$

$$\ln K = \left(\frac{-\Delta H^\circ}{R}\right)\left(\frac{1}{T}\right) + \text{constant}$$

$$\ln\left(\frac{k_2}{k_1}\right) = \frac{E_a}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

PERIODIC TABLE OF THE ELEMENTS

1 1A	2 2A	3 3B	4 4B	5 5B	6 6B	7 7B	8 8B	9 8B	10 8B	11 1B	12 2B	13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
1 **H** 1.008																	2 **He** 4.003
3 **Li** 6.941	4 **Be** 9.012											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
11 **Na** 22.99	12 **Mg** 24.31											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.07	17 **Cl** 35.45	18 **Ar** 39.95
19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.88	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.69	29 **Cu** 63.55	30 **Zn** 65.39	31 **Ga** 69.72	32 **Ge** 72.61	33 **As** 74.92	34 **Se** 78.97	35 **Br** 79.90	36 **Kr** 83.80
37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.95	43 **Tc** (98)	44 **Ru** 101.1	45 **Rh** 102.9	46 **Pd** 106.4	47 **Ag** 107.9	48 **Cd** 112.4	49 **In** 114.8	50 **Sn** 118.7	51 **Sb** 121.8	52 **Te** 127.6	53 **I** 126.9	54 **Xe** 131.3
55 **Cs** 132.9	56 **Ba** 137.3	57 **La** 138.9	72 **Hf** 178.5	73 **Ta** 180.9	74 **W** 183.8	75 **Re** 186.2	76 **Os** 190.2	77 **Ir** 192.2	78 **Pt** 195.1	79 **Au** 197.0	80 **Hg** 200.6	81 **Tl** 204.4	82 **Pb** 207.2	83 **Bi** 209.0	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
87 **Fr** (223)	88 **Ra** (226)	89 **Ac** (227)	104 **Rf** (261)	105 **Db** (262)	106 **Sg** (263)	107 **Bh** (262)	108 **Hs** (265)	109 **Mt** (266)	110 **Ds** (281)	111 **Rg** (272)	112 **Cn** (285)	113 **Nh** (286)	114 **Fl** (289)	115 **Mc** (289)	116 **Lv** (293)	117 **Ts** (294)	118 **Og** (294)

58 **Ce** 140.1	59 **Pr** 140.9	60 **Nd** 144.2	61 **Pm** (145)	62 **Sm** 150.4	63 **Eu** 152.0	64 **Gd** 157.3	65 **Tb** 158.9	66 **Dy** 162.5	67 **Ho** 164.9	68 **Er** 167.3	69 **Tm** 168.9	70 **Yb** 173.0	71 **Lu** 175.0
90 **Th** 232.0	91 **Pa** 231.0	92 **U** 238.0	93 **Np** (237)	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** **(262)**

Student Instructions

Introduction
These problems test your ability to design and carry out laboratory experiments and to draw conclusions from your experimental work. You will be graded on your experimental design, on your skills in data collection, and on the accuracy and precision of your results. Clarity of thinking and communication are also components of successful solutions to these problems, so make your written responses as clear and concise as possible.

Safety Considerations
You are required to wear approved eye protection at all times during this laboratory practical. You also must follow all directions given by your examiner for dealing with spills and with disposal of wastes.

Lab Problem 1

Question: *You are given three mixtures that include compounds containing various forms of the carbonate ion. Using the materials provided, devise a method to rank the mixtures from lowest to highest percent of carbonates. Safety: Do not use more than 2.0 grams of solid mixture for any experiment.*

Lab Problem 2

Question*: Unknown solutions A and B contain a measurable concentration of copper (II) ions along with other inert dyes. Using the provided materials, construct an electrochemical set-up (or device) to determine the concentration of the two unknown copper (II) solutions.*

Answer Sheet for Laboratory Practical **Problem 1**

Examiner's Name: ____

ACS Local Section Name: ____

1. Give a brief description of your experimental plan.

2. Provide any balanced chemical reaction equation(s) and theoretical calculation(s) that support your experimental plan.

For safety reasons, before beginning your experiment you must get approval from the examiner.
Examiner's Initials: ________

3.Record your data/observations.

4. Using the results from parts 2 and 3, rank the provided mixtures in terms of mass percent of carbonate (from lowest to highest).

Unknown Mixture _______ $<$ Unknown Mixture _______ $<$ Unknown Mixture _______

Proctor, please provide items replaced or refilled, if any:

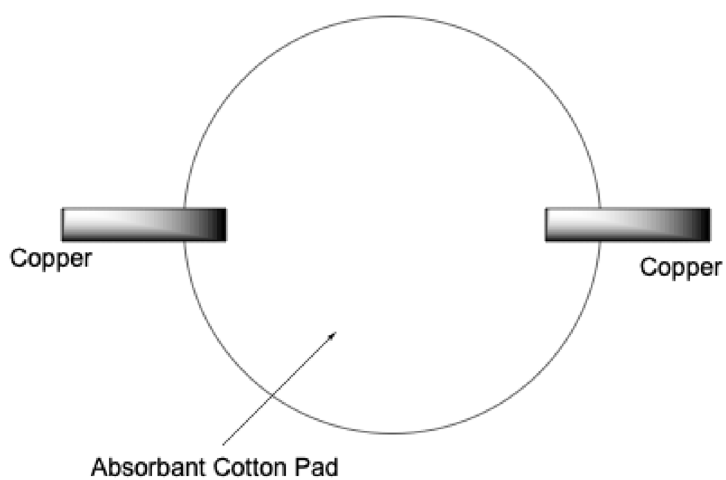
Answer Sheet for Laboratory Practical **Problem 2**

Examiner's Name: ____

ACS Local Section Name: ____

1. Give a brief description of your experimental plan.

2. Using the provided template, complete a detailed illustration of your electrochemical setup that includes all relevant components properly labeled.



For safety reasons, before beginning your experiment you must get approval from the examiner.
Examiner's Initials: ________

3. Record your data/observations.

4. Using your data, show the calculations to give the concentrations for copper (II) ions in solutions A and B.

Solution A copper (II) concentration: ______________________________

Solution B copper (II) concentration: ______________________________

Proctor, please provide items replaced or refilled, if any:

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EXAMINER'S INSTRUCTIONS

Prepared by the American Chemical Society Chemistry Olympiad Examinations Task Force

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Brent Shenton, *Valencia High School, CA (retired)*

Thank you for administering the 2026 USNCO laboratory practical on behalf of your Local Section. It is essential that you follow the instructions provided in order to ensure consistency of results nationwide. There may be considerable temptation to assist the students after they begin the lab exercise. It is extremely important that you do not lend any assistance or hints whatsoever to the students once they begin work. As in international competition, the students are not allowed to speak to anyone until the activity is complete.

The equipment needed for each student for both lab exercises should be available at their lab station or table when the students enter the room. While the students may use any of the provided materials for the two problems, the equipment should be initially separated for Lab Problem #1 and for Lab Problem #2. There are also materials that are to be used for both problems.

Students are permitted to request one replacement or refill of a chemical during the laboratory period. Please indicate on the exam sheet the item replaced or refilled.

It is your responsibility to ensure that all students wear approved eye protection at all times, tie back long hair into a ponytail, and wear close-toed shoes during this laboratory practical. A lab coat or apron for each student is desirable but not mandatory. Disposable gloves should be made available. You will also need to give students explicit directions for handling spills and for disposing of waste materials, following approved safety practices for your examination site. Please check and follow procedures appropriate for your site.

After the students have settled, read the following *instructions* to the students.

> *Hello, my name is ________. Welcome to the lab practical portion of the U.S. National Chemistry Olympiad Examination. In this part of the exam, we will be assessing your lab skills and your ability to reason through a laboratory problem and communicate its results. Do not touch any of the equipment in front of you until you are instructed to do so.*
>
> *You will be asked to complete two laboratory problems. All the materials and equipment you may want to use to solve each problem has been set out for you and is grouped by the number of the problem. You may use any of the supplied general equipment or chemicals to work on either other problem, but specific chemicals have been supplied and labeled for each of the two problems. You will have* ***one hour and thirty minutes*** *to complete the* ***two problems****. You may choose to start with either problem. You are required to have a procedure for each problem approved for safety by an examiner. (Remember that approval does not mean that your procedure will be successful – it is a safety approval.) When you are ready for an examiner to come to your station for each safety approval, please raise your hand.* *(Continued on the next page)*

Safety is an important consideration during the lab practical. ***You must wear safety goggles at all times.*** *Please wash off any chemicals spilled on your skin or clothing with large amounts of tap water. Some solutions may produce "common household odors", these are considered mild and not a general safety concern. If you have any known chemical allergies, please alert your exam proctor before starting.*

The appropriate procedures for disposing of solutions at the end of this lab practical are:

Leave all unused solutions and solids in their container or return to the examiner. The laboratory coordinator will provide any necessary waste disposal instructions at the conclusion of Part III.

Coordinator notes on waste:

Any reaction mixtures from question 1 can be poured down the drain plastic bags can be disposed of in the trash. Solid carbonate mixtures can be thrown in the trash or rinsed down the drain with excess water. Absorbent cotton pads from question 2 that contain very small amounts of copper (II) can be thrown in the trash or taken to your local household hazardous waste (HHW) collection centers. For remaining copper (II) solutions:

- Can be stored and reused for other experiments.
- You can reach out to your local university to see if they are willing to include it with their waste disposal.
- Can be combined in one large beaker or vessel then add a piece of steel wool and let set for several days. At this point the steel wool can be disposed of in the trash and the remaining clear solution can be safely poured down the drain; please note that your solutions may not lose their blue color if they contain blue food coloring.

We are about to begin the lab practical. Please do not turn the page until directed to do so. Read the directions on the front page. Please write your USNCO Id on the cover and pages 4-7 of the booklet. Are there any questions before we begin?

Distribute **Part III** booklets and again remind students not to turn the page until the instruction is given. Part III contains student instructions and answer sheets for both laboratory problems. There is a periodic table on page two of the booklet. Allow students enough time to read the brief cover directions.

Do not turn to page three until directed to do so. When you start to work, be sure to fill out all of the information at the top of the answer sheets. Are they any additional questions?

If there are no further questions, the students should be ready to start **Part III**.

You may begin.

After **one hour and thirty minutes**, give the following directions.

This is the end of the lab practical. Please stop and bring me your answer sheets. Thank you for your cooperation during this portion of the exam.

Collect all the lab materials. Make sure that the student has filled in their ID number on each page and other required information on the answer sheets. At this point, you might wish to take a few minutes to discuss the lab practical with the students. They can learn about possible observations and interpretations, and you can acquire feedback as to what they actually did and how they reacted to the problems.

Please remember to return the answer sheets from Part III, the Gradescope answer sheets from Part I, and the Part II booklets in the UPS Next Day return envelope you were provided to this address:

American Chemical Society
U.S. National Chemistry Olympiad
1155 16th Street, NW – Room 834
Washington, DC 20036

The label on the UPS Express Pak envelope should have this address and your return address already. The cost of the shipping is billed to ACS USNCO. You can keep a copy of the tracking number to allow you to track your shipment.

Tuesday, April 21, 2026 is the ***absolute*** deadline for receipt of the exam material. **Materials received after this deadline CANNOT be graded**. Be sure to have your envelope sent no later than **Monday, April 20, 2026** for it to arrive on time.

THERE WIL BE NO EXCEPTIONS TO THIS DEADLINE DUE TO THE TIGHT SCHEDULE FOR GRADING THIS EXAMINATION.

NOTE THAT THE EXAMINER WILL NEED TO INITIAL EACH STUDENT'S EXPERIMENTAL PLAN. PLEASE DO NOT COMMENT ON THE PLAN OTHER THAN LOOKING FOR ANY POTENTIAL UNSAFE PRACTICES.

Each student should have available the following:

Materials needed:

List of supplies and reagents:

*Disclaimer: *Links to examples of supplies do not indicate a preference or requirement of supplier, they are merely a reference point to the items necessary for testing. Feel free to order any necessary items from the supplier of your choice.*

- Each student should have:
  - Access to an electronic balance to the 0.01 or 0.001 g. Ideally you will have one balance available for every 3-4 students to avoid students spending time waiting on balances.
  - Wash bottle with deionized water. Access to more if needed.
  - Access to a sink.
  - A 100 mL graduated cylinder.
  - A long-stemmed funnel.
  - Spatula, scoopula, or plastic spoon appropriate for weighing solid samples.
  - 6 quart sized slider storage bags with stand/fill bottoms. Link 1, Link 2 (see pic/link)
  - 3 binder clips or clothes pins. (see picture)
  - 6 Plastic weigh boats and/or weighing paper. Have plenty of extra on hand if students need more.
  - 300 mL white vinegar or 0.8 M acetic acid (approx. 5%) with additional 150 mL upon request. To be labeled as 0.8 M acetic acid.
  - 5 grams of unknown solid A with another 3 that can be requested.
  - 5 grams of unknown solid B with another 3 that can be requested.
  - 5 grams of unknown solid C with another 3 that can be requested.
  - One square, roughly 2 cm x 2 cm, of fine to medium grit sandpaper.
  - One watch glass large enough to hold the cotton pad with electrodes; as seen in pictures.
  - 6 Disposable plastic pipets with extra available. Available from multiple sources; here is an example. These do not need to be graduated as they are in the link, any available long-stemmed Beral or transfer pipet will work.

- Test tube rack to hold the four samples below.
- 10 mL of 1.00 M $Cu(NO_3)_2$. Extra 5 mL available upon request.
- 10 mL of 1.00 M KNO_3. Extra 5 mL available upon request.
- 5 mL of Unknown Cu^{2+} solution A. Extra 5 mL available upon request.
- 5 mL of Unknown Cu^{2+} solution B. Extra 5 mL available upon request.
- A voltmeter/multimeter that can measure in dc voltage (represented on the device as ⎓) and measures to the 0.001 V. The multimeter should have a red (positive) and black (negative) test probe with a pointed metal pin. Alligator clips are not recommended as they will move the electrodes and disrupt the makeshift electrochemical cell. **Check with your physics/electronics colleagues or local college/university for borrowing**. There are many options available for purchase from multiple vendors; example from Amazon. Similar item from Jameco.
  - Have extra batteries on hand. Or, an extra multimeter or two.
  - Lab coordinators should tape the multimeter in the appropriate measurement setting as seen in the pictures. Tape should say "do not remove".
  - Lab coordinators should include a note on the multimeter warning students that multimeters may auto shutoff and if this happens to simply turn the power back on. *Ironically, you may need to move the multimeter dial to turn it back on, make sure to check with your specific model and give your students instructions accordingly. You may assist any student with getting the multimeter turned back on.*
- 8-10 100% cotton pads (pre-cut with the slits) with extra available Any pure cotton pad approximately 5.5 cm in diameter (see pictures) will work. These are an inexpensive purchase from many retailers (Target/Walmart/dollar stores) or Amazon; here is an amazon search for "100% cotton round".
- 2 copper strips that have been polished with sandpaper; do not use copper wire. The size is flexible but should be of appropriate size for the apparatus; we recommend the rough dimensions of 4-8 mm x 25-30 mm with a thickness no greater than 1.1 mm. Copper strips can be purchased through a variety of vendors; here is an example through Amazon.
- *Each student will be given the watch glass with one cotton pad that has 2 slits cut on opposite sides with the two copper electrodes inserted between the two slits of the cotton pad; as seen in pictures. Addition cotton pads should have the slits pre-cut for students.*

Chemistry Olympiad Lab Coordinator Instructions

Thank you for coordinating the lab portion of the 2026 National Chemistry Olympiad. There are two separate parts to this portion of the exam. Listed below are the chemicals and suggested equipment needed for each.

- Feel free to substitute items that are not exact matches for what you have available **if it does not affect your students' chances to successfully perform the labs**. This would include such things as containers and bottles.
- Do not substitute any chemicals or quantitative equipment. **It is important that all students competing across the U.S. have an equal chance at successfully completing the problems.**
- It is recommended that you use reagent grade chemicals throughout.
- If you are having trouble obtaining any of the items needed, we recommend that you reach out to the chemistry department of an area college or university; they are generally very willing to help with equipment and chemicals.
- You should also reach out to your local ACS section president or board as many sections carry a budget line for their educational programs.
- All specific materials for problem one should be identified and grouped together separately from all specific materials for part two. However, students are free to use all materials and chemicals recommended for problem one in problem two and vice versa if they choose to do so.
- Be aware that students may request one refill, for each solution/mixture, during Part III so be prepared for this. We suspect that the most requested will be the acetic acid, but any of the chemicals used may be requested. Please make a note on the test page of what refills you have given a student.
- There are procedures for solution and sample preparation. If you use a different hydrate form that is shown, please double-check your calculations.
- If you have any questions or concerns, please feel free to reach out to Margaret Thatcher (USNCO Program Manager, M_Thatcher@acs.org) or Chris Fowler (USNCO Lab Task Force Chair, cfowler@highpoint.edu).

<u>Preparation of reagents for both problems:</u>

<u>Problem One</u> (adjust amounts proportionately based on the number of students competing)

1. Acetic Acid solution.
   - Distilled white vinegar (approx. 0.8 M acetic acid) can be purchased from a variety of sources. It is recommended to purchase fresh vinegar.
   - Alternatively, prepare a 0.8 M acetic acid solution. Add 48 mL of glacial acetic acid (17.4 M, 1.049 g/mL) to a 1.000 L volumetric flask half filled with deionized water, cap and mix, dilute with deionized water to the 1L graduation mark, cap and mix. As the concentration does not need to be exact, the dilution can be done using graduated cylinders; erroring on the side of slightly greater than 0.8 M.
   - Each student will receive 300 mL of the vinegar/solution in a bottle or beaker labeled as vinegar.
   - Will be labeled as 0.8 M acetic acid.

2. Preparation of unknown solid A.
   - Pure baking soda, sodium bicarbonate ($NaHCO_3$, 84.007 g/mol). Can be purchased from any source.
   - Each student receives 5.0 g and can request an additional 3.0 g. The solid can be distributed in a weigh boat, beaker, or other easy to use container.
   - It is best to keep solid unknowns sealed to prevent contamination or moisture absorption. If you are not providing students with containers that are capped or covered with parafilm, keep the stock mixtures sealed until just before administering the lab exercise.

3. Preparation of unknown solid B.
    - For the preparation of 100.0 g of mixture place 63.0 g of sodium carbonate (Na_2CO_3 105.99 g/mol) and 37.0 g of powdered sugar in a mortar, beaker, or other container to mix. Mix thoroughly, breaking up all chunks until you obtain a uniform consistency.
        - Sodium carbonate should be anhydrous and 98%+ purity. Available from multiple sources.
        - Powdered sugar can be purchased from any source.
    - Each student receives 5.0 g and can request an additional 3.0 g. The solid can be distributed in a weigh boat, beaker, or other easy to use container.
    - It is best to keep solid unknowns sealed to prevent contamination or moisture absorption. If you are not providing students with containers that are capped or covered with parafilm, keep the stock mixtures sealed until just before administering the lab exercise.

4. Preparation of unknown solid C.
    - For the preparation of 100.0 g of mixture place 33.3 g of sodium bicarbonate ($NaHCO_3$, 84.007 g/mol), 42.0 g of sodium carbonate (Na_2CO_3, 105.99 g/mol) and 24.7 g of powdered sugar in a mortar, beaker, or other container to mix. Mix thoroughly, breaking up all chunks until you obtain a uniform consistency.
    - Each student receives 5.0 g and can request an additional 3.0 g. The solid can be distributed in a weigh boat, beaker, or other easy to use container.
    - It is best to keep solid unknowns sealed to prevent contamination or moisture absorption. If you are not providing students with containers that are capped or covered with parafilm, keep the stock mixtures sealed until just before administering the lab exercise.

Problem Two (adjust amounts proportionately based on the number competing)

5. Preparation of 1.00 M $Cu(NO_3)_2$
    - Materials needed: for 100 mL of solution you will use a 100 mL volumetric flask, a balance with a precision of .01 g, deionized water.
        - To scale up to larger volumes of solutions as necessary for your number of students you can use 250 or 500 mL flasks.
    - Copper(II) nitrate hemi(pentahydrate), $CuN_2O_6 \cdot 2.5H_2O$, 98% (232.59 g/mol)
    - It is ok to substitute with other hydrate forms that are at least 95% purity. You may need to recalculate the mass you will need for solution prep.
    - Do not substitute with sulfate or chloride salts.
    - The total volume of solution needed should be based on at least 15 mL per student, this will allow for the 10 mL initially provided and having at least an additional 5 mL per student on hand to cover unforeseen events or extra sample requests. You will also use the 1.00 M copper (II) nitrate solution to make the dilutions, so you should account for this in your preparations.
    - Using a tared balance, weigh out copper (II) nitrate 23.26 g (100 mL volumetric)
        - 58.15 g (if using a 250 mL volumetric flask), or 116.30 g (if using a 500 mL volumetric flask)
    - Half-fill the volumetric flask with DI water, add the copper (II) nitrate, rinse the remaining solid into the flask with DI water, dissolve the solute, dilute with DI water to the graduation mark, and mix the solution thoroughly.
    - 10 mL of the solution can be delivered to each student in a labeled test tube with a pipet. An extra 5 mL may be requested. An appropriately sized beaker, vial, or container can be used for the solution if a test tube and rack are not available.

6. Preparation of Unknown copper(II) solution A, 0.100 M $Cu(NO_3)_2$
   - Materials needed: for 100 mL of solution you will use a 100 mL volumetric flask, volumetric pipet (5 or 10 mL), any variety of blue food coloring, and deionized water.
     - To scale up to larger volumes of solutions as necessary for your number of students you can use 250 or 500 mL flasks and 10 or 25 mL volumetric pipets.
   - Using a volumetric pipet (or appropriately sized graduated cylinder if necessary), transfer 10.0 mL of the 1.00 M copper (II) nitrate solution to the volumetric flask.
     - 25.00 mL to a 250 mL flask, or 50 mL to a 500 mL flask.
   - Fill about halfway with DI water and add 1 drop of blue food coloring for every 100 mL of solution.
   - Dilute with DI water to the graduation mark and mix the solution thoroughly.
   - The total volume of solution needed should be based on at least 10 mL per student (5 mL given initially and the potential they ask for 5 mL refill), however we recommend having some additional on hand to cover unforeseen events. You will also use the 0.10 M copper (II) nitrate solution to make the following dilution, so you should account for this in your preparations.

7. Preparation of Unknown copper (II) solution B 0.0100 M $Cu(NO_3)_2$
   - Materials needed: for 100 mL of solution you will use a 100 mL volumetric flask, volumetric pipet (5 or 10 mL), any variety of blue food coloring, and deionized water.
     - To scale up to larger volumes of solutions as necessary for your number of students you can use 250 or 500 mL flasks and 10 or 25 mL volumetric pipets.
   - Using a volumetric pipet, transfer 10 mL of the 0.1000 M copper (II) nitrate solution to the volumetric flask.
     - 25.00 mL to a 250 mL flask or 50 mL to a 500 mL flask.
   - Fill about halfway with DI water and add 1 drop of blue food coloring for every 100 mL of solution.
   - Dilute with DI water to the graduation mark and mix the solution thoroughly.
   - The total volume of solution needed should be based on at least 10 mL per student (5 mL given initially and the potential they ask for 5 mL refill), however we recommend having an additional 5 mL per student on hand to cover unforeseen events.

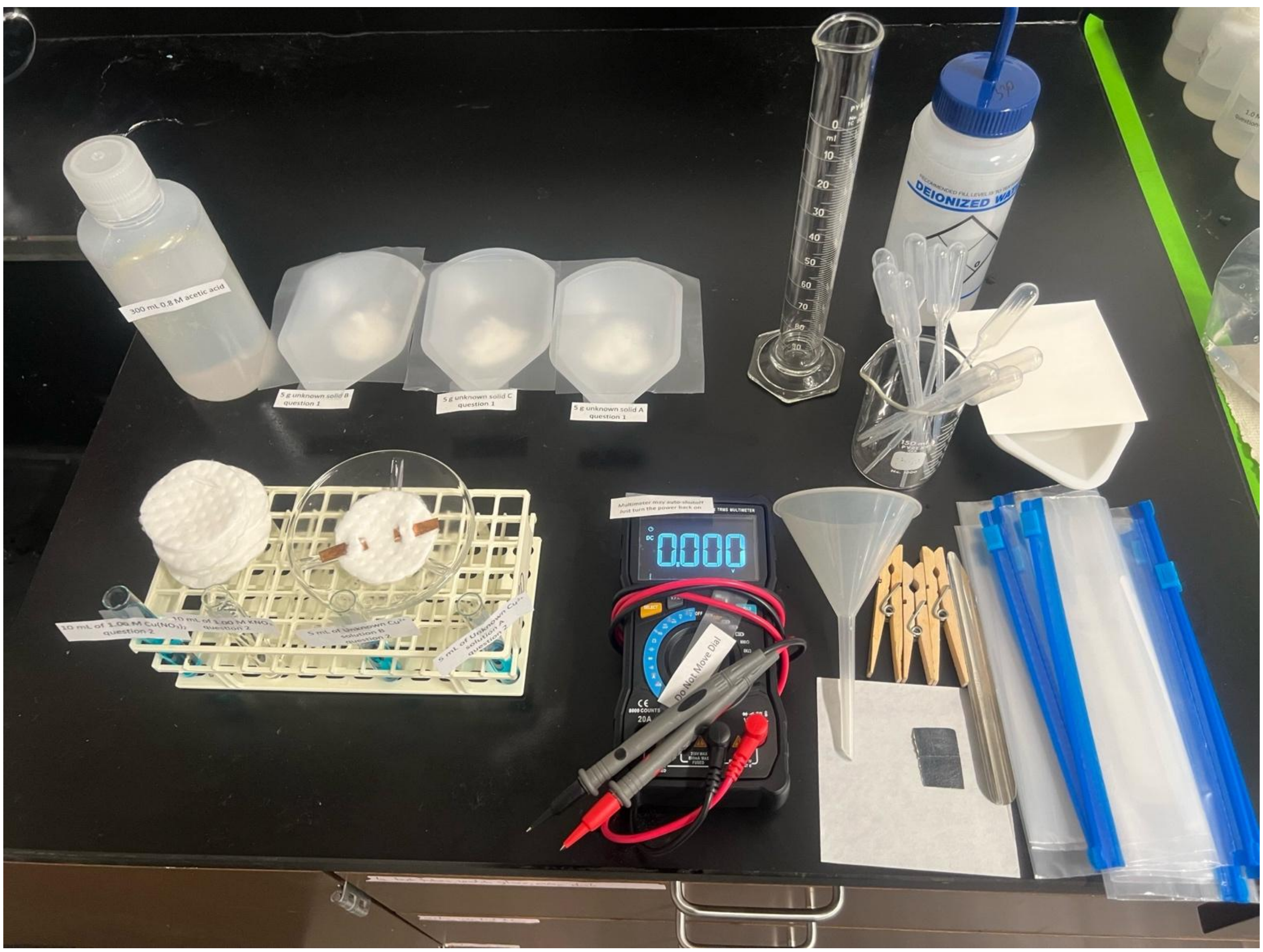
8. Preparation of 1.00 M KNO_3
   - Materials needed: for 100 mL of solution you will use a 100 mL volumetric flask, electronic balance with a precision of .01 g, and deionized water.
     - To scale up to larger volumes of solutions as necessary for your number of students you can use 250 or 500 mL flasks.
   - Potassium nitrate, KNO_3, ACS Reagent Grade (101.10 g/mol)
   - It is ok to substitute with other hydrate forms that are at least 95% purity. You may need to recalculate the mass you will need for solution prep.
   - OK, but not preferred, to substitute KCl.
   - The total volume of solution needed should be based on at least 15 mL per student (10 mL given initially and the potential they ask for 5 mL refill), however we recommend having some additional on hand to cover unforeseen events.
   - Using a tared balance, weigh out copper (II) nitrate 23.26 g.
     - 58.15 g for 250 mL or 116.30 g for 500 mL.
   - Half-fill the volumetric flask with DI water, add the copper (II) nitrate, rinse the remaining solid into the flask with DI water, dissolve the solute, dilute with DI water to the graduation mark, and mix the solution thoroughly.
   - The total volume of solution needed should be based on at least 10 mL per student, however we recommend having an additional 5-10 mL per student on hand to cover unforeseen events.

Setup on Test Day

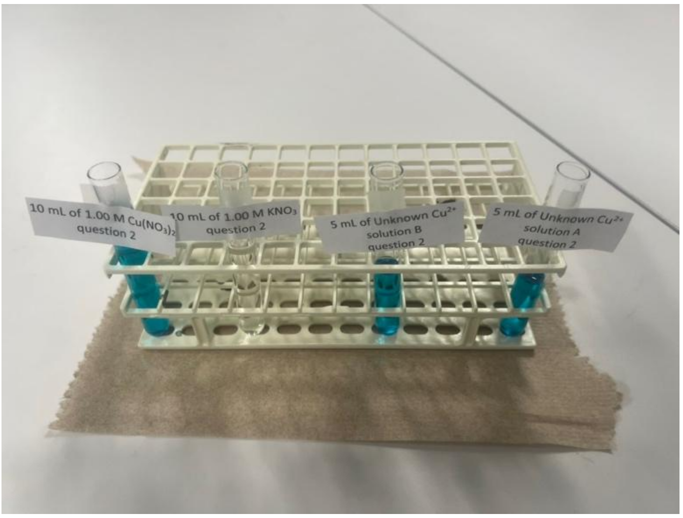
1. Group the following materials together for problem one
   - Labeled container with acetic acid
   - Labeled containers of the unknown solid mixtures

2. Group the following materials together for problem two
   - Watch glass with cotton round and copper electrodes
   - Extra cotton rounds
   - Vials/test tubes with the 3 copper solutions and potassium nitrate solution; test tube rack if needed.

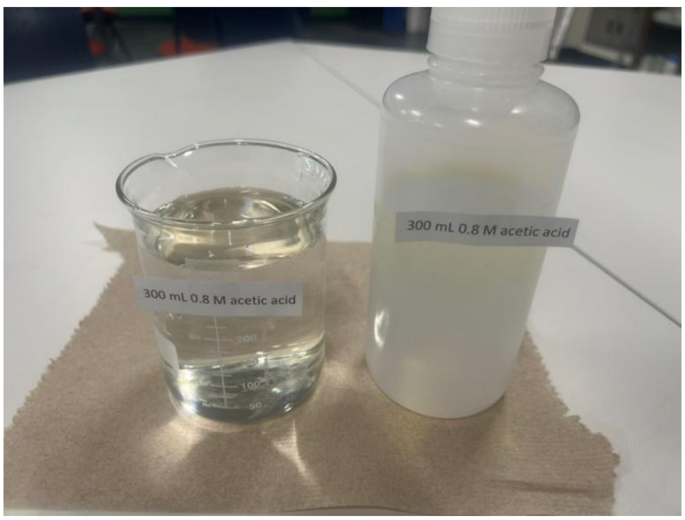
3. Group the following materials together that might be used for both problems
   - Wash bottle with DI water
   - Disposable pipets
   - Quart sized slider bags
   - 100 mL graduated cylinder
   - Long-stemmed funnel
   - Multimeter
   - Piece of sandpaper
   - Spatula, scoopula, or plastic spoon



Suggested Set-up Photos

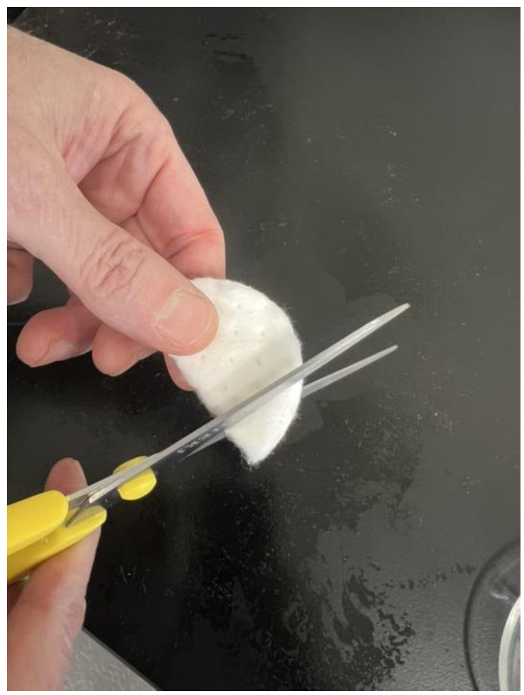


Question 2 solutions. Test tubes and a rack work well but you can use any appropriately sized containers.

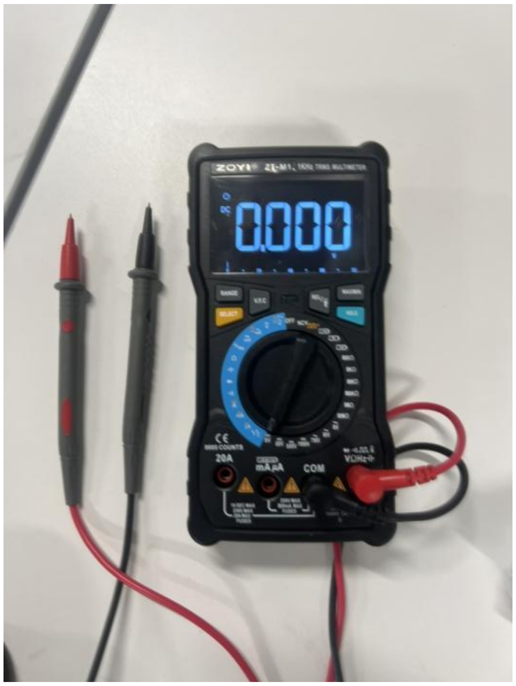


Question 2 acetic acid. Use the best container option you have available.

Absorbent cotton pads.

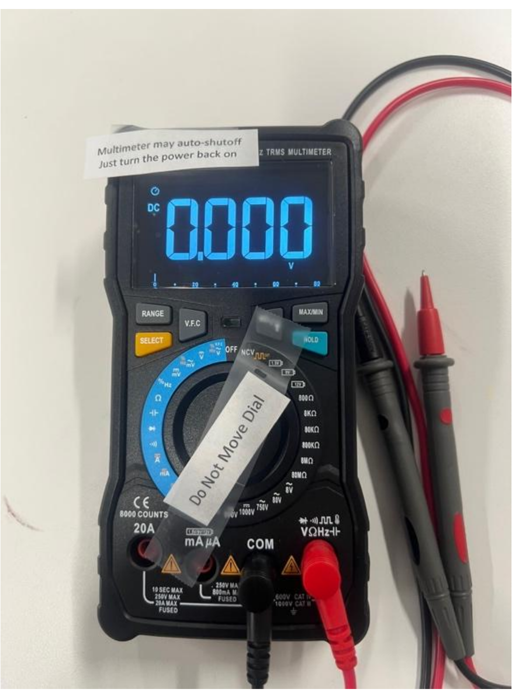


Cutting slits into the cotton pad. Fold in half, cut two slits on each end of the semi-circle.

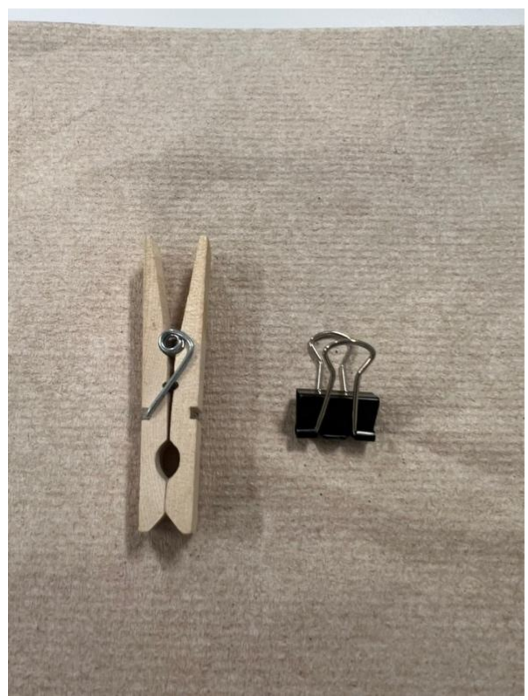


A voltmeter/multimeter that can measure in dc voltage (represented on the device as ⎓) and measures to the 0.001 V

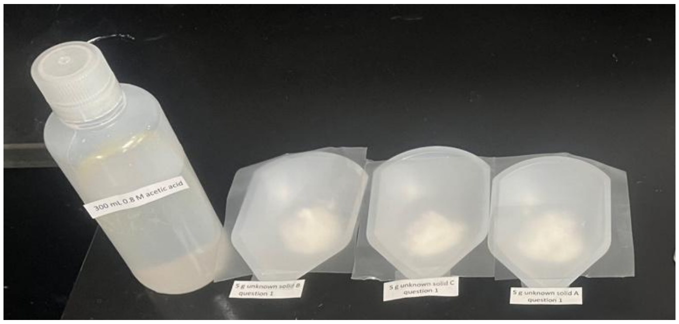
Watch glass has the cotton pad with copper strips placed through the slits. Extra pre-slit cotton pads are provided.



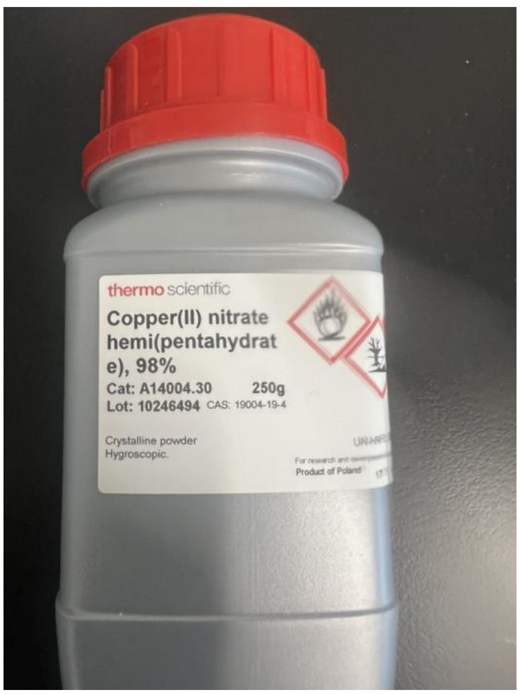
If multimeter has an auto-shutoff the voltage measurement setting may need to be moved to turn it back on. Please help your students if this happens to ensure that they get back to the proper setting.



Examples of clothes pin or binder clips options.



Question 1 chemicals. Acetic acid (0.8 M) in a Nalgene, beaker, or other appropriate container. Solids can be distributed in a covered weigh boat or other container that allows for the solid to be easily scooped out and weighed.



Copper(II) nitrate

Potassium nitrate

STUDENT USNCO ID:

Answer Sheet for Laboratory Practical **Problem 1**

Examiner's Name: ____

ACS Local Section Name: ____

1. Give a brief description of your experimental plan.

   Sample plan, **up to 5 pts**

   1. Label slider plastic bag to identify sample
   2. Measure "mass" 1.0 g of sample, carefully transfer to the bag. Preferably in a corner opposite to the closing end of the slider. Push out as much air as possible and insert the funnel into the corner near where the slide fully closes.
   3. Measure enough 0.8M acetic acid solution to ensure complete reaction of the carbonate sample.
   4. Support volume choice with reaction equations and theoretic calculations in Q2
   5. Pour the acetic acid solution into the plastic bag using the funnel, immediately slide it close.
   6. Make sure the carbonate sample has completely reacted, and none of the gases produced leak out of the bag.
   7. Set aside to compare with next sample.
   8. Compare the relative sizes of the inflated bags.

** Titration methods **will not** differentiate carbonate content.

** While it was not intended that students use electronic balances to weigh zipper bags of solutions, there were no instructions indicating that they could not do this. This was method that yielded accurate results.

2. Provide any balanced chemical reaction equation(s) and theoretical calculation(s) that support your experimental plan.

4 total pts or 2 pts each for showing or indicating stoichiometry difference with carbonate and bicarbonate

(carbonate) X_2CO_3 (s) + 2 CH_3CO_2H (aq) → 2 CH_3CO_2X (aq) + H_2O (l) + CO_2 (g)

(bicarbonate) $XHCO_3$ (s) + CH_3CO_2H (aq) → CH_3CO_2X (aq)+ H_2O (l) + CO_2 (g)

If using 1.00 g of solid that contains the carbonate ion, the amount of vinegar needed and CO_2 produced can be shown using common carbonates. Showing variations, **up to 6 pts.**

$$1.00\ g\ NaHCO_3 * \frac{1\ mol}{84.007\ g} * \frac{1\ mol\ H^+}{1\ mol\ HCO_3^-} * \frac{1\ L}{0.83\ mol\ H^+} = 0.014\ L, 14\ mL\ acid$$

$$1.0\ \ g\ NaHCO_3 * \frac{1\ mol}{84.007\ g} * \frac{1\ mol\ CO_2}{1\ mol\ HCO_3^-} * \frac{RT}{P}\left(\frac{0.08206\frac{L*atm}{mol*K}*298K}{1\ atm}\right) = 0.291\ L\ CO_2(\text{g})$$

(students may have asked for Temp and Pressure of the room, or assumed 273K and 1.00 atm.)

$$1.00\ g\ Na_2CO_3 * \frac{1\ mol}{105.99\ g} * \frac{2\ mol\ H^+}{1\ mol\ HCO_3^-} * \frac{1\ L}{0.83\ mol\ H^+} = 0.023\ L, 23\ mL\ acid$$

$$1.00\ g\ Na_2CO_3 * \frac{1\ mol}{105.99\ g} * \frac{1\ mol\ CO_2}{1\ mol\ CO_3^{2-}} * \frac{RT}{P}\left(\frac{0.08206\frac{L*atm}{mol*K}*298K}{1\ atm}\right) = 0.231\ L\ CO_2(\text{g})$$

$$1.00\ g\ Li_2CO_3 * \frac{1\ mol}{73.89\ g} * \frac{2\ mol\ H^+}{1\ mol\ HCO_3^-} * \frac{1\ L}{0.83\ mol\ H^+} = 0.033\ L, 33\ mL\ acid$$

Probably unlikely that salt is pure lithium carbonate, should use excess acid to completely react all carbonates, therefor should use at least 35 mL vinegar per gram of solid unknown.

3.Record your data/observations.

Sample data table. Masses of unknowns should be consistent within a set. Volume of vinegar should be consistent and in excess. More than one data set preferred. **6 total pts**

Sample Data for qualitative observations of gas filling bags

Unknown Solid	Mass of Unknown Solid	Volume of Vinegar	Bag Inflation Volume
A	1.009 g	40 mL	Mostly full
A	1.011 g	40 mL	Mostly full
B	0.995 g	40 mL	Minimally full
B	1.004 g	40 mL	Minimally full
C	1.011 g	40 mL	Moderately full
C	0.998 g	40 mL	Moderately full

Sample Data for quantitative observations of mass lost

Unknown Solid	Mass of Unknown Solid	Mass Vinegar	Final Mass	Mass CO_2 (mass $CO_3^{2-} \propto$ mass CO_2)
A	1.009 g	40.012 g	40.493 g	0.528 g
A	1.011 g	41.234 g	41.715 g	0.530 g
B	0.995 g	40.349 g	41.084	0.260 g
B	1.004 g	40.253 g	40.994	0.263 g
C	1.011 g	41.045 g	41.703	0.353 g
C	0.998 g	40.874 g	41.524	0.348 g

Might show a drawing or give a description of the inflated bag being rolled and clipped. This allows for better visualization of the differences in the inflation volumes

If attempting to titrate, data for similar mass samples of A-C should give similar volume of vinegar. Not able to differentiate.

4. Using the results from parts 2 and 3, rank the provided mixtures in terms of carbonate mass percent (from lowest to highest).

Student answer may not be correct but should be based on their collected data/observations. Students should comment on sources of error **4 total points.**

___ **Mixture B (36%) < Mixture C (48%) < Mixture A (71%)**

For safety reasons, before beginning your experiment you must get approval from the examiner.
Examiner's Initials: ________

Answer Sheet for Laboratory Practical **Problem 2**

Examiner's Name: ____

ACS Local Section Name: ____

1. Give a brief description of your experimental plan.

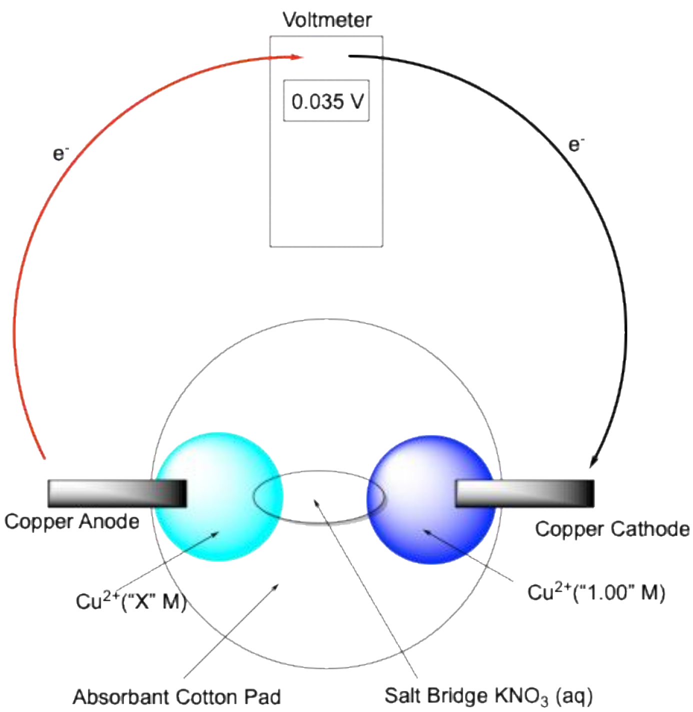
Sample plan, **up to 5 pts**

1) Use provided cotton pad as an electrochemical cell
2) Polish copper strips with sandpaper.
3) Pull cotton pads apart on opposite ends and insert the copper strips on either end so that about half of the strip is between the cotton and the remaining half is sticking out; just like the cotton pad with copper strips that was provided.
4) Place pad with electrodes on watch glass.
5) Carefully saturate the cotton around the copper electrodes. One side with the 1.0M Cu^{2+} solution, the other side with the unknown Cu^{2+} solution.
6) Connect the two solutions using the 1.0 M KNO_3 to serve as the salt bridge.
7) Use the multimeter to record the cell potential. The red (+) lead should go to the cathode and the black (-) lead should go to the anode. (students may reverse this not knowing if the unknown solution is higher or lower than 1.0 M, which will lead to a negative E_{cell})
8) Determine unknown concentration using the Nernst Equation.

2. Using the provided template, complete a detailed illustration of your electrochemical setup that includes all relevant components properly labeled. **8 total points**

Anode/Cathode may be flipped giving a negative voltage

May show half reactions or cell notation



Anode/Oxidation $Cu(s) \rightarrow Cu^{2+}$ (aq, dilute) + 2 e^-

Cathode/Reduction. Cu^{2+} (aq, conc or 1.0M) + 2 $e^- \rightarrow Cu(s)$

$Cu(s) \mid Cu^{2+}$ (aq, dilute) $\parallel$ Cu^{2+} (aq, conc or 1.0M) $\mid Cu(s)$

3. Record your data/observations.

6 total points

Cell by be run in reverse/flipped, giving a negative voltage. Multiple trials in table should be expected. Student may take average for E_{cell}

Anode Cu^{2+} Unknown	Cathode Cu^{2+}	E^o_{cell} (May be measured non-zero value or assumed zero of a 1.0M/1.0M cell)	E_{cell}
A	1.0 M	0.000 V	+0.030 V
A	1.0 M	0.000 V	+0.039 V
A	1.0 M	0.000 V	+0.029 V
B	1.0 M	0.000 V	+0.044 V
B	1.0 M	0.000 V	+0.043 V
B	1.0 M	0.000 V	+0.059 V

4. Show all calculations for: **6 total points**

a) Concentration of Cu^{2+} in unknown solution A: (0.100 M)

$$E = E^o - \frac{RT}{nF}\ln Q \qquad Q = \frac{[Cu^{2+}]_{anode}}{[Cu^{2+}]_{cathode}} \qquad -\frac{RT}{nF} = \frac{-1\left(8.314\frac{J}{mol\ K}\right)(298\ K)}{(2\ mol\ e^-)\left(96500\frac{J}{V\ mol}\right)} = -0.012837\ V$$

For a Concentration Cell, E^o = 0.00 V. $\ln Q = \frac{E - E^o}{-0.012837\ V} = \frac{0.030V - 0.000\ V}{-0.012837\ V} = -2.337$

$Q = e^{-2.337} = 0.0966 \quad Q = \frac{[Cu^{2+}\ anode]}{[Cu^{2+}\ cathode]} \rightarrow \quad 0.0966 = \frac{X}{1.0\ M} \rightarrow \quad X = 0.0966\ M =$

Triall 2: X = 0.0480 M. Trial 3: X = 0.104 M. Unknown A avg = 0.0830 M students may have used avg Ecell

b) Concentration of Cu^{2+} in unknown solution B: (0.0100 M) shown as if +/- voltmeter leads were flipped.

$$E = E^o - \frac{RT}{nF}\ln Q \qquad Q = \frac{[Cu^{2+}]_{anode}}{[Cu^{2+}]_{cathode}} \qquad -\frac{RT}{nF} = \frac{-1\left(8.314\frac{J}{mol\ K}\right)(298\ K)}{(2\ mol\ e^-)\left(96500\frac{J}{V\ mol}\right)} = -0.012837\ V$$

For a Concentration Cell, E^o = 0.00 V. $\ln Q = \frac{E - E^o}{-0.012837\ V} = \frac{-0.044V - 0.000\ V}{-0.012837\ V} = 3.428$

$Q = e^{3.428} = 30.801 \quad Q = \frac{[Cu^{2+}\ anode]}{[Cu^{2+}\ cathode]} \rightarrow \quad 30.801 = \frac{1.0\ M}{X} \rightarrow \quad X = 0.0325\ M =$ students may have used avg Ecell

Trial 2: X = 0.0351 M. Trial 3: X = 0.0101 M Unknown B avg = 0.0259 M. Should show lower concentration than A

For safety reasons, before beginning your experiment you must get approval from the examiner.
Examiner's Initials: ________