STUDENT USNCO ID:

ACS USNCO
U.S. National Chemistry Olympiad

2025 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.

Only non-programmable calculators that do not have any on-board memory space (accessed through a mini-USB or other linkage) are to be used on the ACS Local Section Exam and on the National Exam, if used. The use of an unacceptable calculator, cell phone, or any other device that can access the internet, make copies or photographs, or has access to stored information 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 all the required information at the top of each answer sheet. 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

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

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

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

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: *Using the provided materials, determine the buffer capacity, concentrations of the conjugate acid and base, and the Ka of the conjugate acid for the unknown buffer solution.*

Lab Problem 2

Question*: You have been given four unknown solutions, each containing one salt. These salts may contain ions of sodium, calcium, magnesium, ammonium, acetate, carbonate, chloride, and nitrate. Using the provided materials, determine the chemical formula for the salt contained in each unknown solution. Each unknown solution only contains one salt, and of the possible ions listed, each cation and anion are used only once in the four unknown solutions.*

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.

2. Record your data/observations.

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

3. Show all calculations for:

a) buffer capacity

b) concentrations of the conjugate acid and base

c) K_a of the conjugate acid

4. The buffer capacity is ____

   The concentration of the conjugate acid is ________________

   The concentration of the conjugate base is ________________

   The K_a of the conjugate acid is ________________

Proctor, please indicate the item replaced or refilled provided (if any):

STUDENT USNCO ID:

Answer Sheet for Laboratory Practical **Problem 2**

Examinor's Name:____

ACS Local Section Name:____

1. Give a brief description of your experimental plan.

2. Record your data/observations.

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

STUDENT USNCO ID:

Continue: Record your data/observations.

3. Identify the salt in each unknown solution, giving a brief justification for your choices.

Unknown #	Contains	Justification
1		
2		
3		
4		

Proctor, please indicate the item replaced or refilled provided (if any):

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2025 U.S. NATIONAL CHEMISTRY OLYMPIAD

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EXAMINER'S INSTRUCTIONS

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Edward Tisko, *University of Nebraska at Omaha, NE*

Thank you for administering the 2025 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 equipment or chemicals from one problem to work on the other problem, but the suggested ideal equipment and chemicals to be used for each problem has been grouped for you. Additionally, there is equipment that you will use for both lab 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 in their container or return to the examiner. Silver solids and solutions should be collected by your examiner for repurposing or appropriate disposal. Ammonium nitrate solutions can be diluted to under 0.4 M and washed with excess water down the drain. All other solutions can be washed down the drain with excess water and any solids disposed of in the trash.

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 USNCO 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.

Wednesday, April 16, 2025 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 14, 2025** 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:

Each student should have available the following equipment and materials:

- Per student: one Universal Test Paper or 4-panel test strips
- Per student: one Clear, 15-well spot plate.
- Per student: one 500 mL Wash Bottle filled with deionized or distilled water; unlimited refills.
- Per student: one 10 mL graduated cylinder
- Per student: two 50 mL beakers
- Per student: one 100-250 mL beaker for waste
- Per Student: 10-20, with extras available, disposable plastic pipets, graduated
- Per student: 100 mL polypropylene reagent bottle for the 100 mL of unknown buffer
- Per student: 50-100 mL polypropylene reagent bottle for the 30 mL of 1.0M HCl.
- Per student: 50-100 mL polypropylene reagent bottle for the 30 mL of 1.0M NaOH.

Option 1:

- Per student: seven test tubes with disposable plastic pipets for qualitative analysis solutions.
- Per student: test tube rack
- Attach appropriate labels.

Option 2:

- Per student: six or seven polypropylene dropper bottles for qualitative analysis solutions.; glass droppers are ok.
- Per student: optional, one amber dropping bottle for silver nitrate
- Attach appropriate labels.

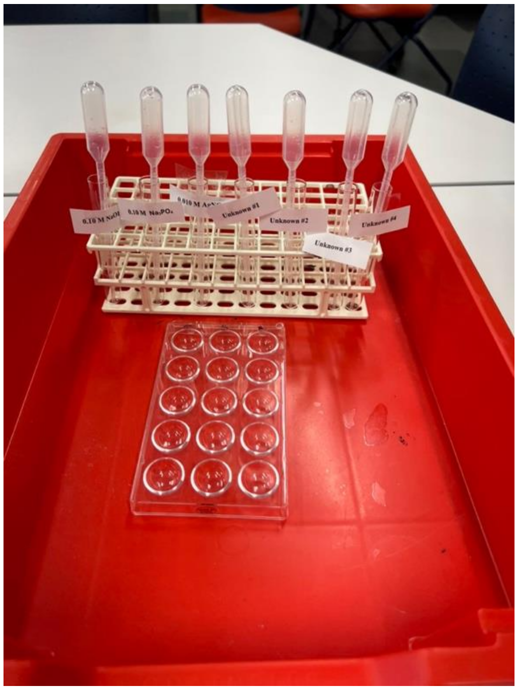
Chemicals needed:

- sodium tetraborate decahydrate (381.37 g/mol)
- magnesium chloride hexahydrate (anhydrous or another hydrate is acceptable)
- anhydrous calcium acetate (hydrate is acceptable)
- ammonium nitrate
- anhydrous sodium carbonate (hydrate is acceptable)
- trisodium phosphate dodecahydrate (other hydrated forms are acceptable if it is trisodium)
- solid sodium hydroxide
- 11.6 M HCl (also known as 36% by weight HCl)
- silver nitrate

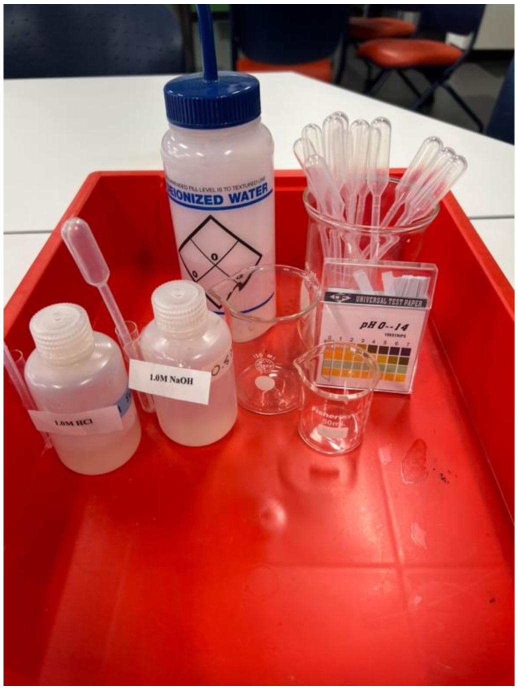
(Continued on the next page)

Suggested Set-up Photos

Equipment for problem 1



Equipment for problem 2



Equipment for both problems

Chemistry Olympiad Lab Coordinator Instructions

Thank you for coordinating the lab portion of the 2025 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 materials recommended for problem one should be identified and grouped together separately from all the materials recommended 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, during Part III so be prepared for this. We suspect that the most requested will be the buffer, but any of the solutions used may be requested.
- Feel free to use test tubes (disposable is fine) with stoppers and pipets instead of using the dropper bottles if that works better for your section. A couple of test tube racks per student may be needed in this case, depending on the typed you have available.
- There are procedures for solution 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).

Materials needed for the preparation of reagents for both problems:

- 1.000 L volumetric flask
- 100.0 mL volumetric flask
- 10.00 mL graduated pipet with pipet pump
- 100 mL graduated cylinder
- sodium tetraborate decahydrate (381.37 g/mol)
- magnesium chloride hexahydrate (anhydrous or another hydrate is acceptable)
- anhydrous calcium acetate (hydrate is acceptable)
- ammonium nitrate
- anhydrous sodium carbonate (hydrate is acceptable)
- trisodium phosphate dodecahydrate (other hydrated forms are acceptable if it is trisodium)
- solid sodium hydroxide
- silver nitrate
- 11.6 M HCl
- Electronic balance with precision of .01 g
- pH meter and necessary buffer solutions for calibration as needed
- fume hood

Per Student:

- Per student: one Universal Test Paper or 4-panel test strips SEE HERE or HERE
  - Per student: one vial pH test strips (use this option only if you cannot obtain the 4-panel test strips)
- Per student: one Clear, 15 well spot plate. It is not recommended to substitute white or porcelain spot plates.
- Per student: one 500 mL Wash Bottle filled with deionized or distilled water
- Per student: one 10 mL graduated cylinder
- Per student: two 50 mL beakers
- Per student: one 100-250 mL beaker for waste
- Per Student: 10-20+ disposable plastic pipettes, graduated SEE HERE or HERE or HERE
- Per student: 100 mL polypropylene reagent bottle for the 100 mL of unknown buffer
- Per student: 50-100 mL polypropylene reagent bottle for the 30 mL of 1.0M HCl.
- Per student: 50-100 mL polypropylene reagent bottle for the 30 mL of 1.0M NaOH.

Section coordinators will have some flexibility on how to provide the solutions specific to prompt 2:

Option 1:

- Per student: seven test tubes with disposable plastic pipets for qualitative analysis solutions.
- Per student: test tube rack
- Attach appropriate labels.

Option 2:

- Per student: six or seven polypropylene dropper bottles; glass droppers are ok.
- Per student: optional, one amber dropping bottle for silver nitrate.
- Attach appropriate labels.

Problem One (adjust amounts proportionately based on the number of students competing)

1. Preparation of .00625 M Borax Buffer
   - Materials needed: 1.000 L volumetric flask, 100.0 mL volumetric flask, electronic balance with a precision of .01 g, two 10.00 mL graduated pipets with pipet pumps, fume hood, calibrated pH meter, 100 mL reagent bottles (one per student) identical or similar to: 100 mL polypropylene reagent bottles, 1.0 M NaOH, 1.0 M HCl (see steps 2 & 3 below), sodium tetraborate decahydrate
   - Fill both a 1.000 L volumetric flask and a 100.0 mL volumetric flask about half-full of deionized or distilled water.
   - Using a fume hood, pipet 10.00 mL of concentrated HCl (36%, 11.6 M, 1.179 g/mL) into the smaller 100.0 mL volumetric flask. Add deionized or distilled water into the 100.0 mL volumetric flask up to the graduation mark and mix well.
   - Pipet 4.10 mL of the solution just created in the 100.0 mL volumetric flask into the ~~1.000 mL~~ 1.000 L volumetric flask that is approximately half full of deionized or distilled water.
   - Add 2.38 g Sodium Tetraborate decahydrate ($Na_2B_4O_7 \cdot 10H_2O$, 381.37 g/mol) to the mixture in the 1.000 L volumetric flask. Stir until the solid is completely dissolved; this can take some time. Borax, 100%, is available at most grocery or box stores.
   - Add deionized or distilled water to the 1.000 L graduation mark and mix well.
   - Test the pH of solution and adjust with HCl or NaOH to obtain a pH of 9.00 (pH range of 8.95-9.05 will work). It is recommended to use a pH meter to calibrate the buffer solution.

- Provide a bottle with 100 mL of buffer for each student workstation. It should be labeled **100 mL Unknown Buffer**. Note: this process will need to be repeated as needed to create enough solution for all the students that will be testing.

2. Dropper bottle similar or identical to: Polypropylene Dropper Bottle filled with 30.0 mL of 1.0 M NaOH (40.00 g of NaOH dissolved in a 1.000 L volumetric flask half-filled with deionized or distilled water and then topped off with enough deionized or distilled water to make 1.000 L of solution). It should be labeled **1.0 M NaOH**.
3. Dropper bottle similar or identical to: Polypropylene Dropper Bottle filled with 30.0 mL of 1.00 M HCl (In a fume hood use a 100 mL graduated cylinder to add 86 mL of 11.6 M HCl dissolved in a 1.000 L volumetric flask half-filled with deionized or distilled water and then topped off with enough deionized or distilled water to make 1.000 L of solution). It should be labeled **1.0 M HCl**.
4. One 10 mL graduated cylinder, two 50 mL beakers, one 400 mL waster beaker

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

1. Prepare the following seven solutions. Note all amounts are based on the preparation of 1.000 L of solution. Adjust amounts appropriately if you need more or less based on the number of students testing in your local section. The 1.0M solutions of HCl and NaOH may be used in problem two.
    - Dissolve 20.33 g of $MgCl_2 \cdot 6H_2O$ (203.3 g/mol) in a 1.000 L volumetric flask that is half-filled with deionized or distilled water. Add deionized or distilled water into the 1.000 L volumetric flask up to the graduation mark and mix well. Dispense into Polypropylene Dropper Bottle or test tube. Label **Unknown Solution One**
    - Repeat above process except use 15.82 g of anhydrous calcium acetate (158.17 g/mol). Dispense into Polypropylene Dropper Bottle or test tube. Label **Unknown Solution Two**
    - Repeat the above process except use 53.00 grams of sodium carbonate (106.01 g/mol). Dispense into Polypropylene Dropper Bottle or test tube. Label **Unknown Solution Four**
    - Repeat the above process except use 4.00 grams of sodium hydroxide (40.01 g/mol). Dispense into Polypropylene Dropper Bottle or test tube. Label **0.10 M NaOH**
    - Repeat the above process except use 38.01 grams of sodium phosphate dodecahydrate (380.14 g/mol). Dispense into Polypropylene Dropper Bottle or test tube. Label **0.10 M sodium phosphate**
    - Repeat the above process except use 1.70 grams of silver nitrate (169.89 g/mol). Label **0.010 M Silver nitrate.** Dispense into Polypropylene Dropper Bottle or test tube. This may be stored in amber dropping bottles due to the light sensitivity of silver nitrate. Alternatively, the silver nitrate solution can be stored in the dark and transferred to a clear bottle or test tube immediately before administering Part III.
    - **Repeat the above process except use approximately 1,900 grams of ammonium nitrate (80.03 g/mol) to prepare a saturated solution; this should be a saturated solution. Dispense into Polypropylene Dropper Bottle or test tube. Label **Unknown Solution Three.** Alternatively, as this solution is saturated, you can start adding solid ammonium nitrate to 100 mL of water until no more solute dissolves. Allow the solution to warm back to room temperature and add more ammonium nitrate if necessary.

2. Clear 15 Well Spot Plate
3. Universal pH test paper

Setup on Test Day

1. Group the following materials together for problem one
    - Bottle of 100 mL of unknown buffer
    - pH test strips
    - 10 mL graduated cylinder
    - Two 50 mL beakers

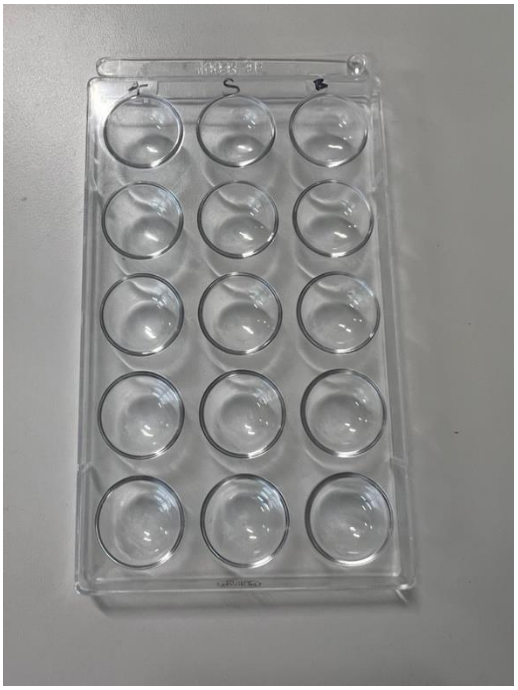
2. Group the following materials together for problem two
    - Unknown solution bottles 1-4 (10 mL each)
    - Bottle of 0.10 M NaOH (10 mL)

- Bottle of 0.10 M Na_3PO_4 (10 mL)
- Amber bottle of 0.010 M $AgNO_3$ (10 mL)
- Universal pH test paper
- One ~~Clear~~clear, 15 well spot plate

3. Group the following materials together that might be used for both problems
   - 500 mL wash bottle filled with deionized or distilled water
   - Paper towels
   - 1.0 M NaOH (30 mL)
   - 1.0 M HCl (30 mL)
   - 400 mL beaker for waste
   - pipets

Equipment

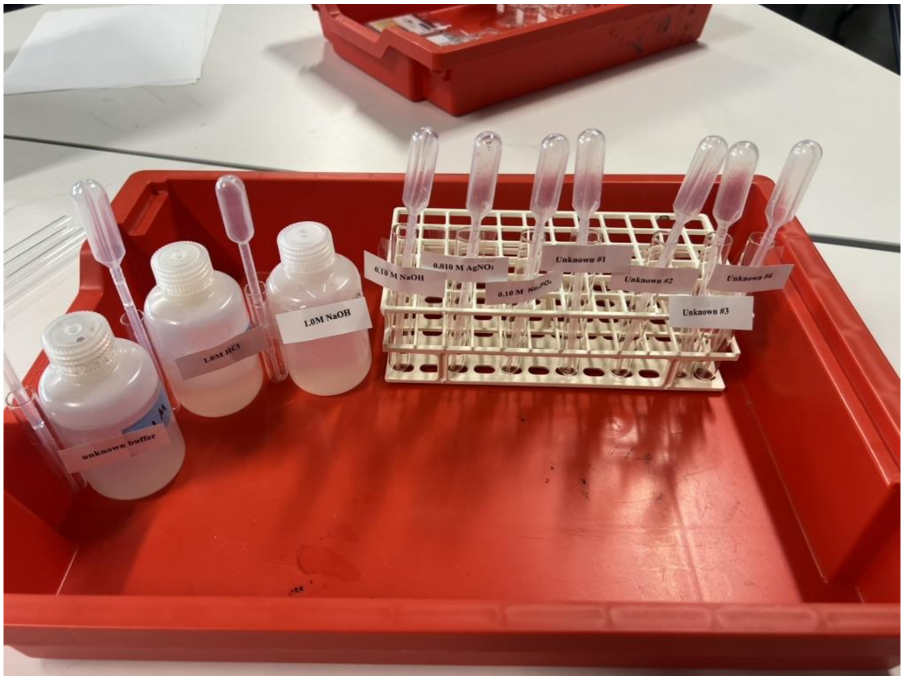
4-panel pH strips



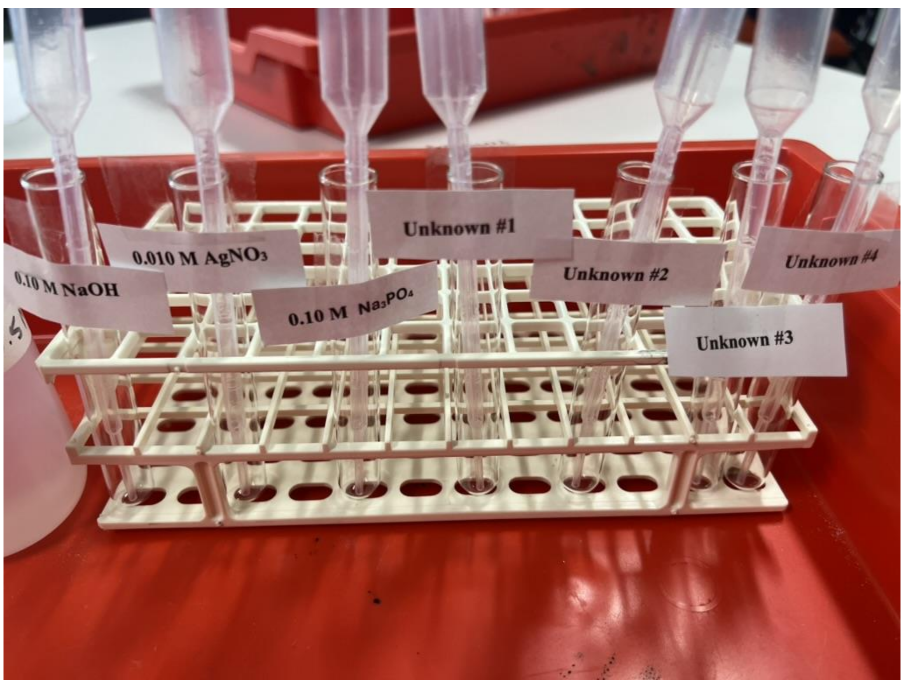
Clear spot plate

Pipet

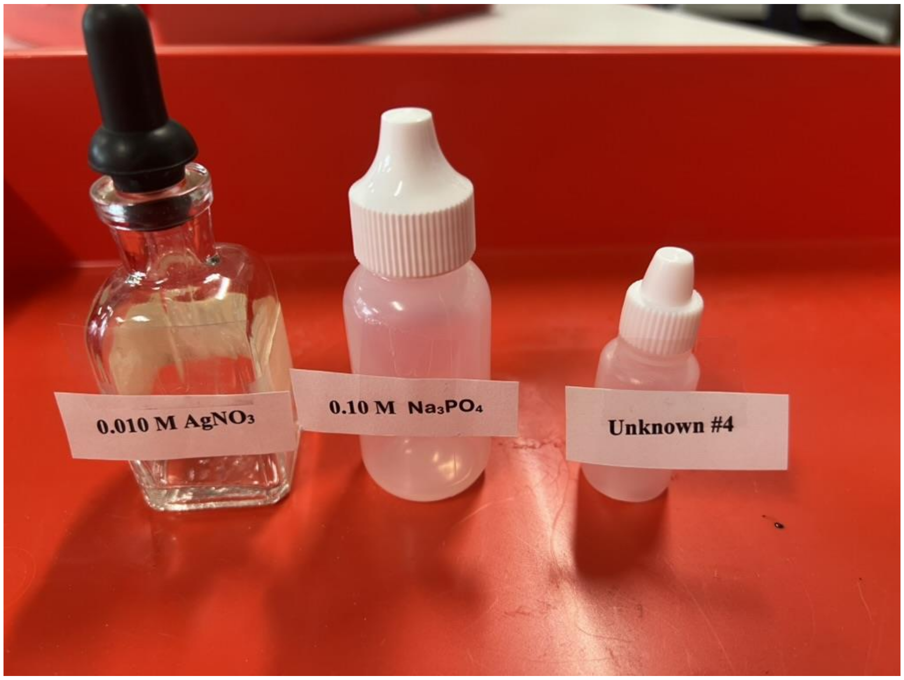
Suggested setup for larger volume solution bottles with dedicated pipet. This includes the 100 mL of unknown buffer and 30 mL of 1.0M NaOH and 1.0M HCl.



Solutions using the test tube option.



Setup for smaller volume solutions in test tubes; labels can be taped securely. This includes the 0.10M NaOH, 0.010M $AgNO_3$, 0.10M Na_2PO_4, and Unknowns 1-4. You can also use bottles similar to the larger volume setup or various dropper bottles shown below.



Small volume solution dropper bottle examples. If silver nitrate solution is stored more than a couple of days, it is recommended to use an amber bottle or store in a dark cabinet.

STUDENT USNCO ID:

2025 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 all the required information at the top of each answer sheet. 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: *Using the provided materials, determine the buffer capacity, concentrations of the conjugate acid and base, and the Ka of the conjugate acid for the unknown buffer solution.*

Lab Problem 2

Question*: You have been given four unknown solutions, each containing one salt. These salts may contain ions of sodium, calcium, magnesium, ammonium, acetate, carbonate, chloride, and nitrate. Using the provided materials, determine the chemical formula for the salt contained in each unknown solution. Each unknown solution only contains one salt, and of the possible ions listed, each cation and anion are used only once in the four unknown solutions.*

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. **(5 pts)**

Procedure should include:

1. Method for determining volume of a drop. This may be omitted if the student already has the volume memorized. Note: The student may elect to use the graduations on the side of the pipet. However, this is less desirable (and accurate) than what is described in the first two sentences above.
2. Volume of buffer used. Probably best to use a smaller volume (10mL) and titrate with 1.0M HCl or NaOH, then repeat with the other. If done dropwise, larger buffer volumes would take too long.
    - Students may also do a survey trial to find an approximate volume of acid/base that destroys the buffer.
3. Adding a drop of designated reagent (NaOH or HCl) ***with stirring***. The pH should be determined after each drop's addition.
4. The addition of drops should be continued until the pH stabilizes at a higher or lower value depending on the reagent (NaOH or HCl) added.
5. A data table should be constructed that shows the pH after the addition of each drop.
6. If a student chooses to continue with the same buffer solution rather than a fresh sample: After concluding a titration, an equivalent volume of the complementary solution (NaOH if HCl was used in the titration or HCl if NaOH was used in the titration) to return to the starting point of the titration.
7. Repeat steps 2-5 above but for the complementary titrant (NaOH if HCl was used in the first titration or HCl if NaOH was used in the first titration).
8. Repeat steps 2-7 for multiple trials.

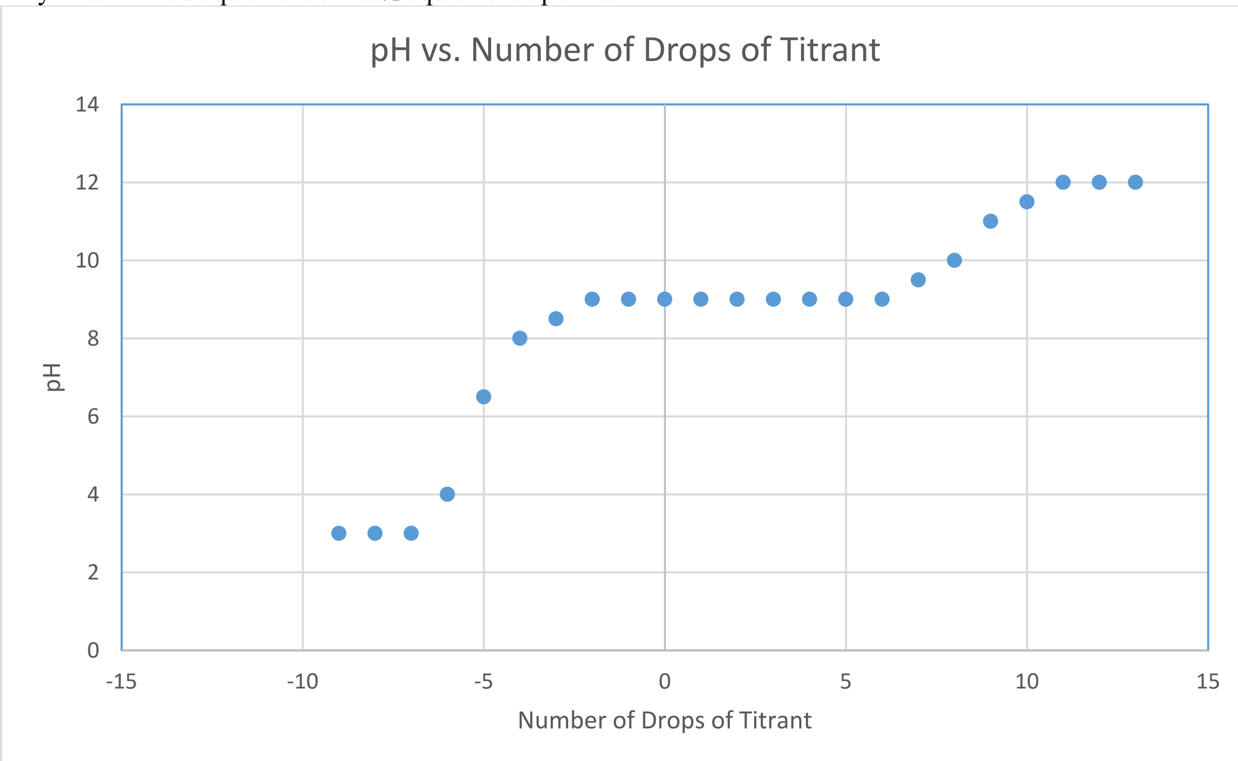
2. Record your data/observations. **(5 pts)**

Data should include:

1. Volume (mL) of buffer used in each titration.
2. Data table with number of drops of titrant (NaOH or HCl) added with corresponding pH. Note: Students may elect to use the volume markings on their graduated pipets instead. This should not receive as much credit as it is less precise.
3. Sample Data - the values found below will be used in subsequent sample calculations and represents a titration where 10.0 mL of buffer is titrated. The values that each student obtains will undoubtedly vary slightly.

Number of Drops NaOH	pH	Number of Drops HCl	pH
0	9	0	9
1	9	1	9
2	9	2	9
3	9	3	8.5
4	9	4	8
5	9	5	6.5
6	9	6	4
7	9.5	7	3
8	10	8	3
9	11	9	3
10	11.5		
11	12		
12	12		
13	12		

Plots will vary based on methods, but have some resemblance to the following:
Multiple plots for multiple trials.
Students may have marked equivalence and ½ equivalence points.



3. Show all calculations for:**(sample calculations may differ for sections as there may be variance in prepared buffers)**

a) buffer capacity **5pts**

a. Students should identify that buffer capacity is calculated by mol/L buffer divided by the change in pH (ΔpH) in the buffering region (part of graph shown in #1 above ***before*** a dramatic change in pH).
b. Students should identify 4-10 drops of acid/base are added in the buffering region between pH values of ~10.0 and ~8.0.
c. Students should identify that approximately 4-10 drops of acid/base added corresponds to 0.0005 moles of acid/base or buffer being neutralized. This results in a concentration of 0.005 mol/L.

10 drops(0.05 mL/drop)(1 liter/1,000 mL)(1.00 mol/L)=0.0005 mol of acid/base or buffer

$$\frac{0.0005\ mol}{.0100\ L} = 0.05\ \text{mol/L}$$

d. Students should recognize that the ΔpH = 1.0 from pKa in the buffering region on the graph.

8-10=1.0

e. Students should calculate a buffering capacity equal to ~0.005 (no units) when "c" above is divided by "d" above.

$$\frac{0.05\ mol/L}{1.0} = 0.050$$

b) concentrations of the conjugate acid and base **5pts**

a. Students should identify the equivalence point for the NaOH titration (occurs at ~8.5 drops of base added to buffer).
b. Students should identify that 8.5 drops of base added corresponds to 0.0004 moles of NaOH being added or HA being neutralized.
8.5 drops(0.05 mL/drop)(1 liter/1,000 mL)(1.00 mol/L)=0.0004 mol of NaOH (or HA)
c. Students should calculate [HA]=0.0040.

$$\frac{0.0004\ mol}{.0100\ L} = 0.040\ \text{mol/L}$$

d. Students should identify the equivalence point for the HCl titration (occurs at ~5 drops of acid added to buffer).
e. Students should identify that 5 drops of acid added corresponds to 0.00025 moles of HCl being added or A^- being neutralized.

5 drops(0.05 mL/drop)(1 liter/1,000 mL)(1.00 mol/L)=0.00025 mol HCl (or A^-)

f. Students should calculate $[A^-]$=0.025.

$$\frac{0.00025\ mol}{.0100\ L} = 0.025\ \text{mol/L}$$

c) K_a of the conjugate acid **5pts**

a. Students may elect to use the Henderson/Hasselbach equation (see "b" below) or use an approach not utilizing this tool (see "c" below).
b. Use the initial pH (pH=9) from the data table, initial [HA] calculated in 3c above, the initial $[A^-]$ calculated in 4c above and the Henderson-Hasselbach equation to calculate the K_a. The value should be ~6 x 10^{-10}.

$$9 = -\log K_a + \log\frac{[0.025]}{[0.04]}$$

$$K_a = 6 \times 10^{-10}$$

c. Determine the initial $[H^+]$ which should be 1 x 10^{-9}. Using this and the answers from 3c and 4c along with the acid ionization constant expression to calculate the K_a. The value should be ~6 x 10^{-10}.

$$10^{-9} = [H^+] = 1 \times 10^{-9}$$

$$K_a = ([H^+][A^-])/[HA] = ([1 \times 10^{-9}][0.025])/[0.04]$$

$$K_a = 6 \times 10^{-10}$$

Note: The rules for significant figures have been largely ignored to focus on the process used by each student.

4. The buffer capacity is ____

Range of pH 8-10.

The concentration of the conjugate acid is ________________

Around $4.0*10^{-3}$ M

The concentration of the conjugate base is ________________

Around $2.5*10^{-3}$ M

The K_a of the conjugate acid is ________________

Around $6.0*10^{-10}$

Proctor, please indicate the item replaced or refilled provided (if any):

STUDENT USNCO ID:

Answer Sheet for Laboratory Practical **Problem 2**

Examinor's Name:____

ACS Local Section Name:____________________________________

1. Give a brief description of your experimental plan. (4pts)

Students should include:

- Using provided solutions to qualitatively test unknowns for chemical change.
- Use of spot plates
- Testing with pH strips (ok if they didn't put it in procedure but did it in trials)
- Use process of elimination for determining anions and cations.
- Record observations on table?

- Have examiner's intial. (1 pt separate)

2. Record your data/observations. (10pt)

Students should include:

- A data table
- Record observations for bubbling, precipitation, smell
- Recording pH may be useful
- Maybe include statements of justification

STUDENT USNCO ID:

-1 in tables if you do not mention concentrations: i.e different NaOH concentrations

Continue: Record your data/observations.

	pH	0.01 M $AgNO_3$	1.0 M HCl	0.1 M NaOH	1.0 M NaOH	0.1 M Na_3PO_4
Unknown Solution 1 (0.1 M $MgCl_2$)	6-7	ppt	No Reaction	ppt	ppt	ppt
Unknown Solution 2 (0.1 M $Ca(OAc)_2$	6	No Reaction. A slightly more concentrated solution will give faint ppt	No Reaction. Faint smell of vinegar/acetic acid	no ppt, maybe very little	ppt with 1M	ppt
Unknown Solution 3 (Sat. NH_4NO_3)	4-5	No Reaction	No Reaction	No Reaction. Maybe faint smell of ammonia	May not clearly make out bubbles but looked like something more than other tests. Smell of ammonia	No Reaction
Unknown Solution 4 (0.5 M Na_2CO_3)	11	ppt	bubbles		No Reaction	No Reaction

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

3. Identify the salt in each unknown solution, giving a brief justification for your choices. (10 pts)

Unknown #	Contains	Justification
1	$MgCl_2$	0.01 M $AgNO_3$ – big precipitate - could be Cl^-, CO_3^{2-} 1.0 M HCl – NR – rules out CO_3^{2-} 0.1 M Na_3PO_4 – big precipitate – Could be Mg^{2+}, Ca^{2+} 1.0 M NaOH – big precipitate – Could be Mg^{2+}, Ca^{2+}. 0.1M NaOH - precipitates Mg^{2+} but not the 0.1M Ca^{2+} (Introductory Solubility Rules indicate $Ca(OH)_2$ is soluble, however the solubility is low) pH 6-7; vague, but fits literature range. Would think $MgCl_2$ would be lower pH than $Ca(OAc)_2$ but they were very similar. Possible ion combinations: Mg^{2+} Ca^{2+} NH_4^+ Na^+ Cl^- OAc^- NO_3^- CO_3^{2-}
2	$Ca(OAc)_2$	0.01 M $AgNO_3$ – no or very small amount of ppt; this is important for I.D. between nitrate and acetate. While acetates as a "general rule" are considered soluble, silver acetate has a Ksp of $2*10^{-3}$ 1.0 M HCl –No Reaction – rules out CO_3^{2-} smell indicates acetate 1.0 M NaOH – precipitate– Could be Mg^{2+}, Ca^{2+} 0.1 M NaOH – no or faint precipitate–Ca^{2+} 0.1 M Na_3PO_4 – precipitate – Could be Mg^{2+}, Ca^{2+} pH 6;pKa of H_2O for Mg^{2+} is about 12 and for Ca^{2+} is about 11. Probably not different enough to tell the difference with pH paper. Other reaction data should be able to determine ion presence. Possible ion combinations: Mg^{2+} Ca^{2+} NH_4^+ Na^+ Cl^- OAc^- NO_3^- CO_3^{2-}
3	NH_4NO_3	0.01 M $AgNO_3$ – No Reaction – rules out Cl^-, CO_3^{2-} 1.0 M HCl – No Reaction – rules out CO_3^{2-} 1.0 M NaOH – no clear bubbling, but visual evidence suggesting a reaction. Smell of ammonia. Suggests NH_4^+. No ppt rules out Mg^{2+}, Ca^{2+} 0.1 M NaOH – N.R. visible maybe faint NH_3 smell 0.1 M Na_3PO_4 – ppt – rules out Mg^{2+}, Ca^{2+} pH 4 – indicates an acidic cation. Possible ion combinations: Mg^{2+} Ca^{2+} NH_4^+ Na^+ Cl^- OAc^- NO_3^- CO_3^{2-}
4	Na_2CO_3	0.01 M $AgNO_3$ – precipitate - Cl^-, CO_3^{2-} 1.0 M HCl – bubbles indicates CO_3^{2-} 1.0 M NaOH – No Reaction 0.1 M NaOH - No Reaction 0.1 M Na_3PO_4 – No Reaction pH 11 – indicates a basic anion. Possible ion combinations: Mg^{2+} Ca^{2+} NH_4^+ Na^+ Cl^- OAc^- NO_3^- CO_3^{2-}

Proctor, please indicate the item replaced or refilled provided (if any):

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