2017 U. S. NATIONAL CHEMISTRY OLYMPIAD

NATIONAL EXAM PART III

Prepared by the American Chemical Society Chemistry Olympiad Laboratory Practical Task Force

OLYMPIAD LABORATORY PRACTICAL TASK FORCE

Kelli Slunt, Chair, *University of Mary Washington*, Fredericksburg, VA

Alexsandra DaSilva, *SUNY*, Binghamton, NY
Kimberly Gardner, *United States Air Force Academy*, CO
Myra Halpin, *North Carolina School of Science and Mathematics*, Durham, NC
Nicolas Hamel, *Clackamas Community College*, Oregon City, OR
Lawrence Wilkinson, *ExxonMobil*, Baton Rouge, LA

DIRECTIONS TO THE EXAMINER–PART III

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 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.

Part III **2 lab questions** **laboratory practical** **1 hour, 30 minutes**

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.

DIRECTIONS TO THE EXAMINEE–PART III

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		

CONSTANTS
R = 8.314 J mol^{-1} K^{-1}
R = 0.08314 L bar mol^{-1} K^{-1}
F = 96,500 C mol^{-1}
F = 96,500 J V^{-1} mol^{-1}
N_A = 6.022 × 10^{23} mol^{-1}
h = 6.626 × 10^{-34} J s
c = 2.998 × 10^{8} m s^{-1}
0 °C = 273.15 K
1 atm = 1.013 bar = 760 mm Hg
Specific heat capacity of H_2O = 4.184 J g^{-1} K^{-1}

EQUATIONS

$$E = E^{o} - \frac{RT}{nF}\ln Q \qquad \ln K = \left(\frac{-\Delta H^{o}}{R}\right)\left(\frac{1}{T}\right) + \text{constant} \qquad \ln\left(\frac{k_2}{k_1}\right) = \frac{E_a}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

PERIODIC TABLE OF THE ELEMENTS

1 1A																	18 8A
1 **H** 1.008	2 **2A**											13 **3A**	14 **4A**	15 **5A**	16 **6A**	17 **7A**	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	3 **3B**	4 **4B**	5 **5B**	6 **6B**	7 **7B**	8 **8B**	9 **8B**	10 **8B**	11 **1B**	12 **2B**	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

Alka-Seltzer® tablets contain the primary active ingredients of citric acid and sodium bicarbonate, with other inert substances. Using the provided materials, determine the mass percent of sodium bicarbonate and the mass percent of citric acid in an Alka-Seltzer tablet. Citric acid is a triprotic acid with a molecular formula of $C_6H_8O_7$.

Lab Problem 2

You are provided with five vials (labelled A, B, C, D or E) that could contain 0.5 M solutions of calcium chloride, sodium carbonate, sodium chloride, sodium hydroxide, or sulfuric acid. Determine which solution is in which vial.

Answer Sheet for Laboratory Practical **Problem 1**

Student's Name: _____ _____

Student's School:_____**Date:** _____

Proctor's Name: _____

ACS Local Section Name: _____ **Student's USNCO ID #:**_____

1. Give a brief description of your experimental plan.

2. Record your data/observations.

Before beginning your experiment, you must get approval (for safety reasons) from the examiner	**Examiner's Initials:**

3. Show all calculations.

4. The mass percentage of sodium bicarbonate in an Alka Selzer tablet is _____.

5. The mass percentage of citric acid in an Alka Selzer tablet is _____.

Answer Sheet for Laboratory Practical **Problem 2**

Student's Name: _____

Student's School:_____ **Date:** _____

Proctor's Name: _____

ACS Local Section Name: _____ **Student's USNCO ID #:**_____

1. Give a brief description of your experimental plan.

2. Record your data and other observations.

Before beginning your experiment, you must get approval (for safety reasons) from the examiner	**Examiner's Initials:**

3. The identification of the solutions in the vials is:

Solution A _____

Solution B _____

Solution C _____

Solution D _____

Solution E _____

4. Write appropriate net ionic equations for reactions that you utilized to identify the solutions in the vials.

2017 U. S. NATIONAL CHEMISTRY OLYMPIAD

NATIONAL EXAM PART III — EXAMINER'S INSTRUCTIONS

Prepared by the American Chemical Society Chemistry Olympiad Laboratory Practical Task Force

Directions to the Examiner:

Thank you for administering the 2017 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 his/her lab station or table when the students enter the room. The equipment should be initially placed and separated the materials used for both Lab Problem #1 and Problem #2, for Lab Problem #1 and for Lab Problem #2.

It is your responsibility to ensure that all students wear approved eye protection at all times during this laboratory practical. A lab coat or apron for each student is desirable but not mandatory. 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 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. 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.*

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.*

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

_____
_____
_____
_____

We are about to begin the lab practical. Please do not turn the page until directed to do so, but read the directions on the front page. Are they 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 3 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 his or her name 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. After this discussion, please take a few minutes to complete the Post-Exam Questionnaire; this information will be extremely useful to the USNCO subcommittee as they prepare for next year's exam.

Please remember to return the post-exam Questionnaire, the answer sheets from Part III, the Scantron sheets from Part I, and the 'Blue Books" from Part II 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 811
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 26, 2017, 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 24, 2017*** 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 equipment and materials:

Materials needed for Problem #1:

- Balances that can measure to the 0.01 g - if one balance per student is not available 2 to 3 students could share a balance – make sure that the balance can tolerate the mass of the beakers
- One (1) graduated cylinder, 50 mL
- Two (2) 250 mL or 400 mL beakers
- One (1) spatula
- Two (2) watch glasses
- Two (2) beral pipets (2)

Chemicals for Problem #1:

- Six original formula effervescent Alka-Seltzer® tablets (images of Alka-Seltzer packets included on page 6) placed in a labelled Ziploc bag – Do not gummies, chews, extra strength, lemon-lime, heartburn, or gold – make sure that the tablets are recently purchased – after time on the shelf the amount of bicarbonate appears to decrease in the tablet. Do not leave the tablets in the original package as it contains composition information.
- Acetic acid, 4.5-5% by mass, vinegar – can use commercial white vinegar, 150 mL in a bottle labelled 4.5-5% acetic acid (by mass)
- Sodium bicarbonate, 3 g in a vial labelled sodium bicarbonate

Materials needed for Problem #2:

- Five (5) beral style pipets
- 24 – well plate

Chemicals for Problem #2:

- Five (5) vials containing the following solutions – each student should be provided with 5 mL of each solution in vials labelled as A, B, C, D, E
  - calcium chloride (0.5 M)
  - sodium carbonate (0.5 M)
  - sodium chloride (0.5 M)
  - sodium hydroxide (0.5 M)
  - sulfuric acid (0.5 M)

Materials for both Problem #1 and 2:

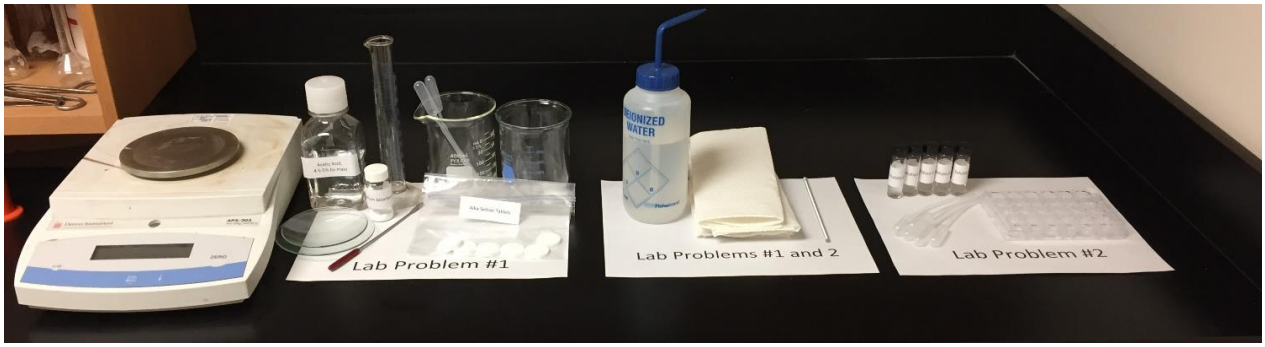
- One (1) Glass stirring rod
- Distilled water, at least 500 mL, in a wash bottle labelled "Distilled water"
- Access to paper towels and a sink with running water

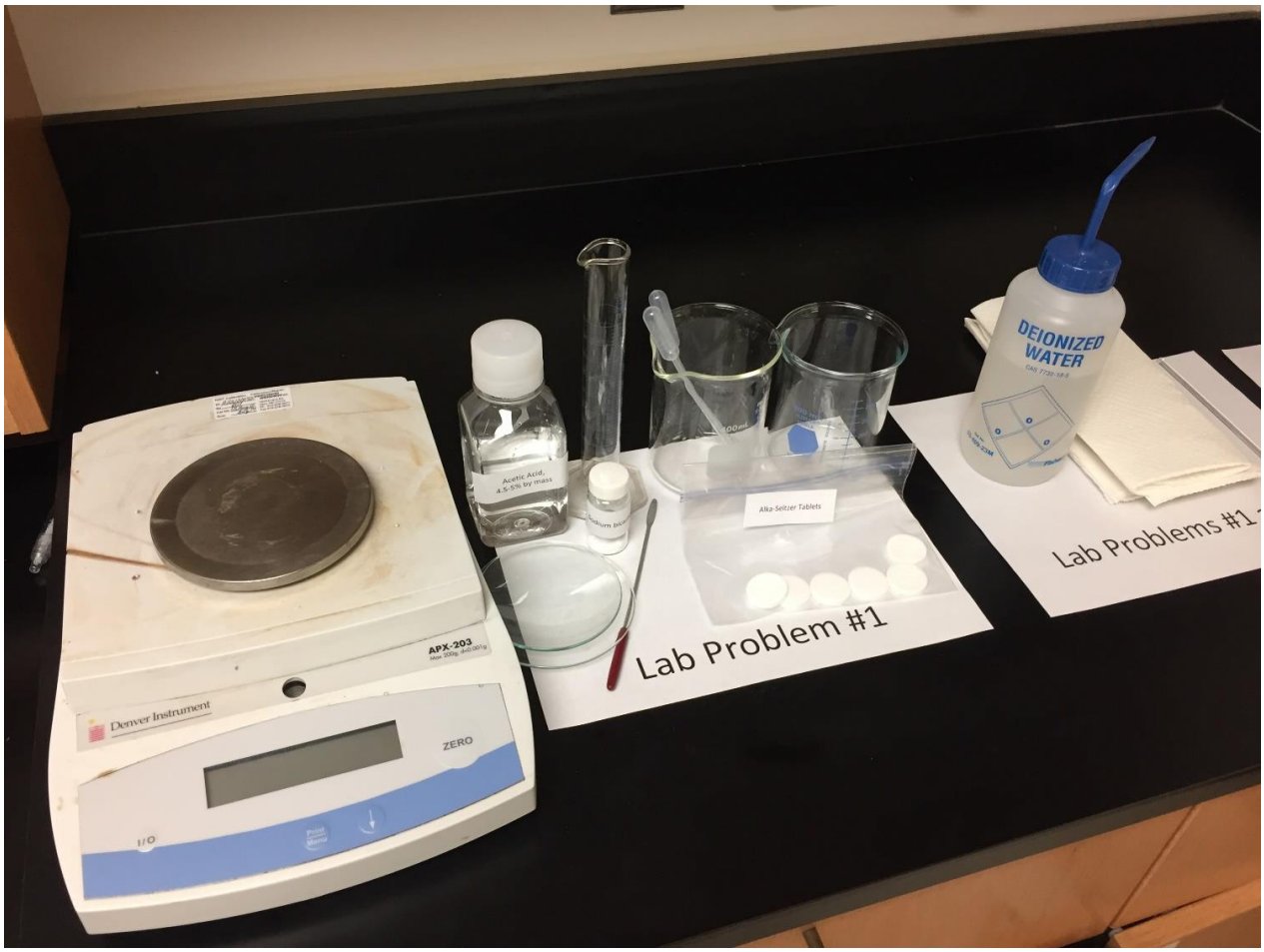
Safety Instructions for Lab Problems #1 and #2:

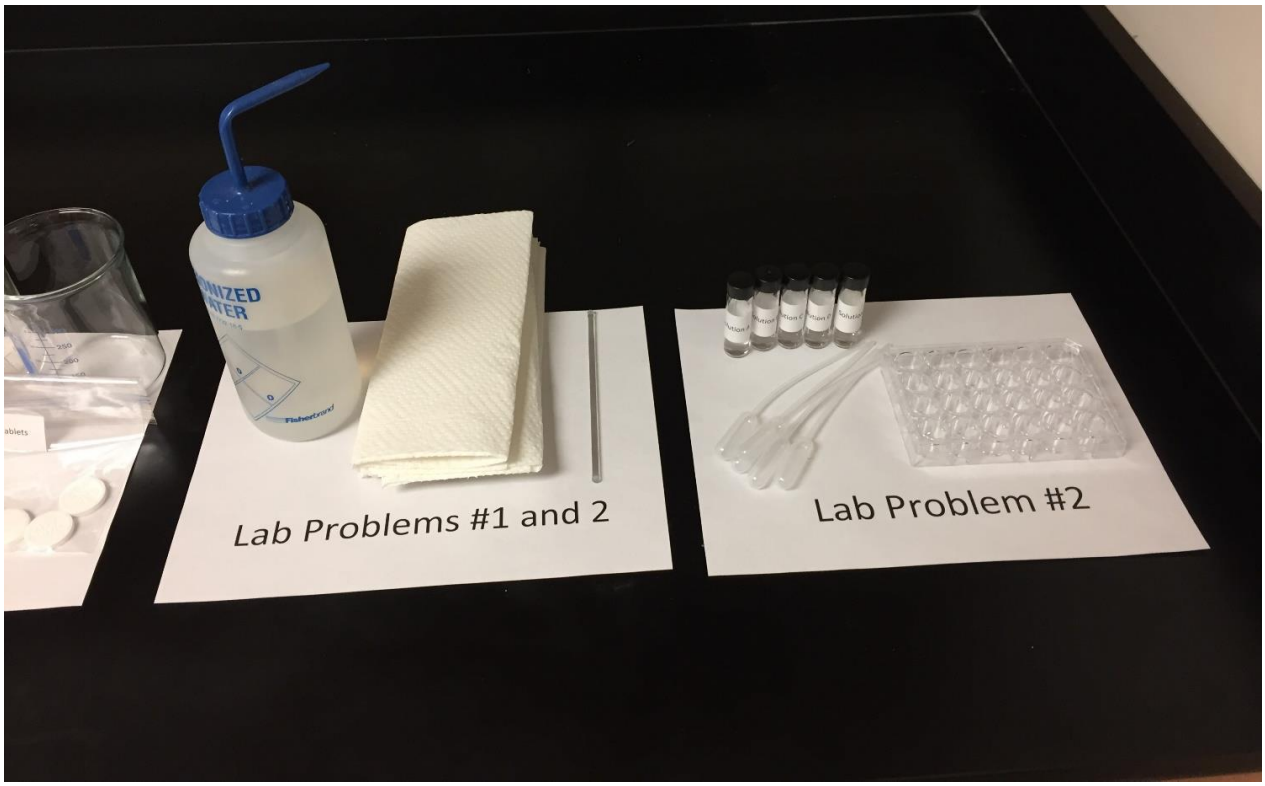
It is your responsibility to ensure that all students wear safety goggles at all times during the lab practical. A lab coat or apron for each student is desirable but not mandatory. You will also need to give students explicit directions for handling spills and for disposing of waste materials, following approved safety practices for your examination site. Please check and follow procedures appropriate for your site.

Laboratory Practical Set-up Photo

If you have any questions regarding Part III, please contact USNCO office immediately at USNCO@acs.org.






Lab Problems #1 and 2
Lab Problem #2


Alka-Seltzer Tablets

Do not leave the tablets in the original package as it contains composition information.

PART III – LABORATORY ANSWER KEY

Lab Problem 1

Alka-Seltzer® tablets contain the primary active ingredients of citric acid and sodium bicarbonate, with other inert substances. Using the provided materials, determine the mass percent of sodium bicarbonate and the mass percent of citric acid in an Alka-Seltzer tablet. Citric acid is a triprotic acid with a molecular formula of $C_6H_8O_7$.

Answer Sheet Questions (25 points)

1. Give a brief description of your experimental plan. (4 points)
    - Mass of all of the items before mixing – making sure to include the beaker, watch glass, tablet, solution
    - Mass of the items after mixing
    - Allow time for the reaction to occur – stirring and waiting until no visible gas remains in the solution
    - Indication of conditions under which the tablet will be reacted (water alone, with vinegar)

2. Record your data/observations (10 points)
    - Clear data table including starting and ending masses and the volumes of water/vinegar used with at least two separate experiments (one with water and one with vinegar) – duplicate trials
    - Must react the tablet with water alone and then with at least enough vinegar that it is in the state where the sodium bicarbonate is the limiting reagent
    - Observations – could include that the solution bubbled, the final masses were recorded after all visible gas was removed, a small amount of solid in the beaker (possibly the aspirin)

Experimental Calculations

The student should determine which active ingredient in the tablet is the limiting reagent, which in the tablet is the citric acid. Once the limiting reagent is determined, the most direct way to determine the amount of sodium bicarbonate is to react the tablet with excess vinegar and determine the mass of carbon dioxide lost, which is equivalent to the amount of bicarbonate present in the tablet.

Dissolving the tablet in only water, allows the reaction to occur between the citric acid and the sodium bicarbonate in the tablet. As the citric acid is limiting, the mass of carbon dioxide lost is equivalent, as long as you consider the molar stoichiometry, to the mass of citric acid in the tablet.

$H_3A + 3\ NaHCO_3 \rightarrow Na_3A + 3\ CO_2 + 3\ H_2O$

Sample Student Data

Exp	water (mL)	acid (mL)	mass tablet (g)	mass CO_2 (g)	mass $NaHCO_3$ reacted (g)	mass %
1	35	0	3.227	0.603	1.151	35.67
2	30	5	3.229	0.818	1.562	48.35
3	25	10	3.244	0.912	1.741	53.67
4	20	15	3.234	0.972	1.856	57.41
5	15	20	3.231	0.980	1.870	57.88
6	10	25	3.254	0.999	1.909	58.57
7	5	30	3.266	1.018	1.943	59.50
8	0	35	3.263	0.955	1.822	55.73

For determining citric acid:

Exp	water (mL)	acid (mL)	mass tablet (g)	mass CO_2 (g)	Mass of citric acid reacted (g)	mass %
1	35	0	3.227	0.603	0.877	27.19

Actual composition of Alka Seltzer Tablets:
1916 mg sodium bicarbonate (59.1% by mass)
1000 mg citric acid (30.9% by mass)
325 mg aspirin

3. Show all calculations (9 points)
   - Mass of carbon dioxide lost in each experiment
   - Mass of sodium bicarbonate reacted
   - Using the trial with the water, determine the mass of citric acid consumed
   - Calculating the mass percentage of the sodium bicarbonate and the citric acid
   - Accuracy of data

4. The mass percentage of sodium bicarbonate in an Alka Selzer tablet is _____. (1 point)
5. The mass percentage of citric acid in an Alka Selzer tablet is _____. (1 point)

Reference for Lab experiment 1:

Chen, Y.-H. and Yaung, J.-F. *J.Chem.Educ.* **2002**, *79*, 848-850.

Lab Problem 2

You are provided with five vials (labelled **A, B, C, D or E**) that could contain 0.5 M solutions of calcium chloride, sodium carbonate, sodium chloride, sodium hydroxide, or sulfuric acid). Determine which solution is in which vial.

Answer Sheet Questions (25 points)

1. Give a brief description of your experimental plan. (4 points)
   - A systematic plan to mix the solutions together to see if a reaction occurs
   - Indication of observations to look for (i.e. precipitation, heat evolution, bubbling, or no change)

2. Record your data/observations (7 points)
   - Clear table indicating the mixtures created and the observations made.
   - Solutions should be mixed systematically together.

Sample Data

	B ($CaCl_2$)	C (Na_2CO_3)	D (H_2SO_4)	E (NaOH)
A (NaCl)	No observed change	No observed change	No observed change	No observed change
B ($CaCl_2$)	XXXX	White precipitate but thicker than the one with B reacting with E	No observed change	White fine ppt (cloudy solution
C (Na_2CO_3)		XXXX	Gas is evolved – fizzes	No observed change
D (H_2SO_4)			XXXX	No observed change
E (NaOH)				XXXX

3. The identification of the solutions in the vials is: (5 points)
   1 points for each correct identification.

   Solution A ____sodium chloride_____
   Solution B ____calcium chloride_____
   Solution C ___sodium carbonate_____
   Solution D ___sulfuric acid_____
   Solution E ___sodium hydroxide_____

4. Write appropriate net ionic equations for reactions that you utilized to identify the solutions in the vials. (9 points)

   Ca^{2+} (aq) + CO_3^{2-} (aq) → $CaCO_3$ (s)

   Ca^{2+} (aq) + 2 OH^- (aq) → $Ca(OH)_2$ (s)

   CO_3^{2-} (aq) + 2 H^+ (aq) → CO_2 (g) + H_2O (l)

   H^+ (aq) + OH^- (aq) → H_2O (l) + heat

Precipitation reactions to form insoluble carbonate and hydroxide

- $CaCl_2$ (aq) + Na_2CO_3 (aq) → $CaCO_3$ (s) + 2NaCl (aq)
- $CaCl_2$ (aq) + 2 NaOH (aq) → $Ca(OH)_2$ (s) + 2 NaCl (aq)
- No reactions with NaCl as chlorides are soluble except for AgCl, $PbBr_2$, and Hg_2Cl_2
- No precipitation reactions with H_2SO_4 as most sulfates are soluble except $BaSO_4$, $PbSO_4$, Ag_2SO_4 and $SrSO_4$

Acid-base reactions

- Neutralization reactions between H^+ and OH^- do not exhibit a visible change, except possible detection of heat, that can be noted without an indicator
- Na_2CO_3 reacting with an acid would result in the evolution of carbon dioxide – fizzing

  Na_2CO_3 (aq) + H_2SO_4 (aq) → Na_2SO_4 (aq) + CO_2 (g) + H_2O (l)