2016 U. S. NATIONAL CHEMISTRY OLYMPIAD

NATIONAL EXAM PART III

Prepared by the American Chemical Society Laboratory Practical Task Force

OLYMPIAD LABORATORY PRACTICAL TASK FORCE

Lawrence Wilkinson, *ExxonMobil*, Baton Rouge, LA

Mike Buttram, *Texarkana College*, Texarkana, TX
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
Innocent Pumure, *University of Central Missouri*, Warrensburg, MO
Kelli Slunt, *University of Mary Washington*, Fredericksburg, VA

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

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

$R = 0.0821\ L{\bullet}atm{\bullet}mol^{-1}{\bullet}K^{-1}$

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

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

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

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

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

0 °C = 273.15 K

1 atm = 760 mm Hg

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

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** 78.96	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** 95.94	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** (271)	107 **Bh** (270)	108 **Hs** (277)	109 **Mt** (276)	110 **Ds** (281)	111 **Rg** (280)	112 **Cn** (285)	113 (Uut) (284)	114 **Fl** (289)	115 (Uup) (288)	116 **Lv** (293)	117 (Uus) (294)	118 (Uuo) (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)

2016 UNITED STATES NATIONAL CHEMISTRY OLYMPIAD
PART III — LABORATORY PRACTICAL

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

You have been provided with three solutions. Solution A contains iron(III) ions, Solution B contains iodide ions, and Solution C contains thiosulfate ions (and some starch indicator).
Devise and carry out an experimental procedure to determine the kinetic order of the reaction that occurs upon mixing them with respect to [Fe^{3+}] from Solution A and with respect to [I^-] from Solution B.

NOTE: In carrying out your approved experimental plan, mix Solutions B and C before adding Solution A, and record the time required for the resulting mixture to turn a distinct, permanent color.

Lab Problem 2

You have been given a dilute solution of an unknown acid. Devise and carry out an experimental procedure to determine whether the unknown acid is monoprotic, diprotic, or triprotic.

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 kinetic order of this reaction with respect to [Fe^{3+}] is _____________.

5. The kinetic order of this reaction with respect to [I^-] is _______________.

6. Write the rate expression for this reaction, referring to the kinetic order with respect to [$S_2O_3^{2-}$] as "***x***".

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 acid that I was given is _______.

   a) monoprotic
   b) diprotic
   c) triprotic

4. Explain the basis of your conclusion (include supporting data, which may be in the form of an illustration or graph, etc.).

AMERICAN CHEMICAL SOCIETY

U.S. National Chemistry Olympiad

2016 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 2016 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 separated into the materials used for both Lab Problems #1 & #2, only for Lab Problem #, and only 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 27, 2015, 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 25, 2015*** 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:

Share Materials and Equipment (for problems #1 and #2):

- 2 – Graduated cylinders, 10 mL
- Disposable plastic transfer pipettes, 6 (can be graduated or not; e.g., Fisher 13-711-7M)
- 2 – 50 or 100 mL beakers
- Distilled water, at least 500 mL, in a wash bottle labeled "Distilled Water"
- Access to paper towels and a sink with running water

Lab Problem #1 Chemicals & Material:

- Solution A (see Note 1), 100 mL, labeled "Solution A"
- Solution B (see Note 2), 100 mL, labeled "Solution B"
- Solution C (see Note 3), 100 mL, labeled "Solution C"
- Stopwatch or time

Notes:

1) To prepare **Solution A**: Dissolve 9.6 g iron(III) chloride hexahydrate (or 14.4 g of iron(III) nitrate nonahydrate) in approximately 800 mL of 0.3 *M* nitric acid, dilute to a total volume of 1000 mL with 0.3 *M* nitric acid, and mix thoroughly.
   [To prepare 0.3 *M* nitric acid, add 20.0 mL of concentrated nitric acid (e.g., Fisher A200C-212; ***DO NOT USE fuming nitric acid***) to approximately 800 mL of distilled water, dilute to a total volume of 1000 mL with distilled water and mix thoroughly.]
   Solution A is stable for several weeks.

2) To prepare **Solution B**: Dissolve 10.0 g of KI in approximately 800 mL of distilled water, dilute to a total volume of 1000 mL with distilled water, and mix thoroughly. Stored in amber bottles, solution B is stable for several weeks.

3) Preparation of **Solution C**:
   To approximately 800 mL of distilled water, add 22.0 mL of 0.20 M sodium thiosulfate solution and 40.0 mL of 1% starch solution. Dilute to a total volume of 1000 mL with distilled water and mix thoroughly.
   [To prepare 0.2 M sodium thiosulfate, dissolve 5.0 g of sodium thiosulfate pentahydrate in approximately 50 mL of distilled water, dilute to a total volume of 100 mL with distilled water, and mix thoroughly. The 1% (by mass) starch solution can be prepared, or purchased commercially.]
   While the sodium thiosulfate solution is stable and the starch solution is relatively stable (especially if purchased), it is suggested that Solution C be prepared no earlier than one week before the exam and stored in amber bottles.

These materials are in addition to and separate from lab problem #1.

Each student should have available the following chemicals:

Lab Problem #2: Chemicals

- 50 mL of 0.5 N sodium hydroxide solution, labeled "Dilute NaOH Solution" and "WARNING: Corrosive; avoid contact with skin, eyes, and clothing!" A plastic bottle is recommended for NaOH solutions.
- 50 mL of a solution of an unknown acid (see Note 1)
- 10 mL of universal indicator solution in a dropping bottle or in a vial or small bottle along with a disposable dropper. Label it as "Universal Indicator Solution" (see Note 2)

Notes:

1) To prepare the **unknown acid solution,** add 16.0 mL of concentrated o-phosphoric acid (e.g., Fisher A242-500) to approximately 300 mL of distilled water, dilute to a total volume of 500 mL with distilled water, and mix thoroughly. Label this simply as "Unknown Dilute Acid" and "CAUTION: Avoid contact with skin, eyes, and clothing!" DO NOT INDICATE THAT THIS IS A SOLUTION OF PHOSPHORIC ACID.

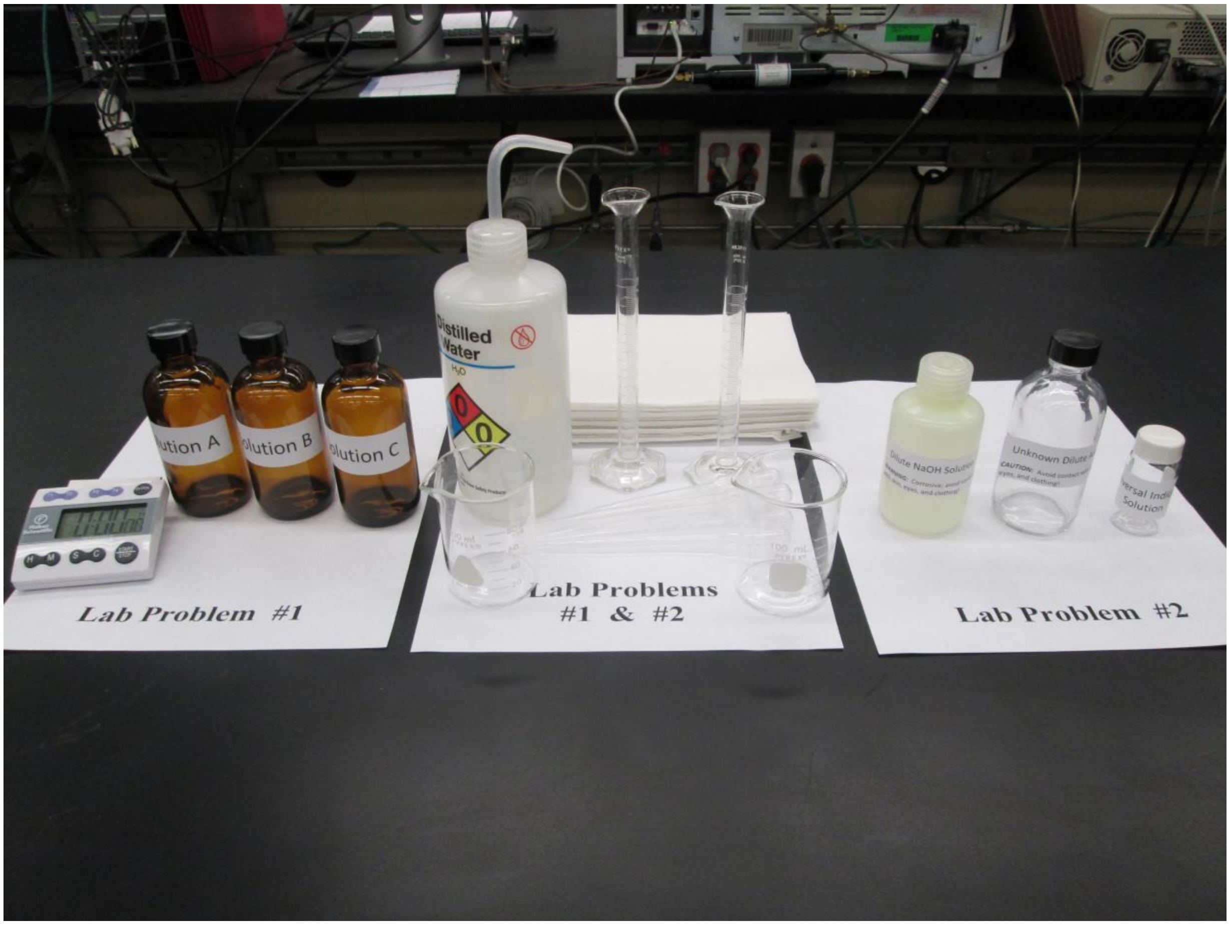
2) Universal Indicator Solution is available from a number of science supply companies (e.g., Fisher Scientific's SI60-500). If yours comes with a color chart, please provide each student with a copy of it. If it does not, give each student a copy of the color information provided by the vendor.

   For example, the Fisher label reads:
   pH 4.0 Red
   pH 5.0 Orange Red
   pH 6.0 Yellow
   pH 7.0 Yellow-Green
   pH 8.0 Green
   pH 9.0 Blue
   pH 10.0 Violet

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.

<u>Laboratory Practical Set-up Photo</u>



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

Lab Problem #1: **[25 points]**

You have been provided with three solutions. Solution A contains iron(III) ions, Solution B contains iodide ions, and Solution C contains thiosulfate ions (and some starch indicator). Devise and carry out an experimental procedure to determine the kinetic order of the reaction that occurs upon mixing them with respect to [Fe^{3+}] from Solution A and with respect to [I^-] from Solution B.
NOTE: In carrying out your approved experimental plan, mix Solutions B and C before adding Solution A, and record the time required for the resulting mixture to turn a distinct, permanent color.

Answer sheet questions:

1. Give a brief description of your experimental plan. **[4 points]**
   [1 point] mix & record time
   [1 point] describing how to vary concentration
   [1point] stating how volume increments will be added (e.g., pipet, grad cylinder)
   [1point] planned to do replicates (either mentioned here or actually performed, as evidenced in the answer to question #2)
   Example response:
   I will mix equal volumes of the three solutions as provided and measure the reaction time. I will dilute first solution A and then solution B, keeping the total volume of the mixture constant, and measure and record those reaction times. I will repeat each trial at least once (twice if I have time to do so).

2. Record your data/observations. **[10 points]**
   [3 points] clear data table (volumes & times)
   [2 points] need 3 trials
   [1 point] observed color change
   [2 points] observed times consistent with 1st order in [Fe^{3+}]
   [2 points] observed times consistent with 2nd order in [I^-]
   Example response:
   Observations –upon mixing, there is a brief flash of purple-blue color then the solution is colorless for about 10 seconds before turning a dark blue-black color.
   Data:

Volume of A (mL)	*Volume of B (mL)*	*Volume of C (mL)*	*Volume H_2O (mL*	*Time (s) Trial 1*	*Time (s) (Trial 2)*
10	*10*	*10*	*0*	*7*	*8*
5	*10*	*10*	*5*	*15*	*13*
10	*5*	*10*	*5*	*29*	*32*

3. Show all calculations. **[7 points]**

[3 points] comparing ratios of concentrations to ratios of rates (conc./time) for [Fe^{3+}]

[3 points] comparing ratios of concentrations to ratios of rates (conc./time) for [I^-]

[1 point] averaging data (or justifying not doing so)

Example response:

The average time for reaction when equal volumes of the 3 solutions are mixed is (7 s +8 s)/2 or 7.5 s.

The average reaction time when Solution A is diluted to one-half of its initial concentration, approximately doubles (14 s versus7.5 s). This indicates that the reaction order with respect to [Fe^{3+}] is one (first order).

The average reaction time when Solution B is diluted to one-half of its initial concentration, is approximately 4 times longer (31.5 s vs 7.5 s), indicating that this reaction is second order with respect to [I^-].

4. The kinetic order of this reaction with respect to [Fe^{3+}] is ***first (or 1st)***. **[1 point]**

5. The kinetic order of this reaction with respect to [I^-] is ***second (or 2nd)***. **[1 point]**

6. Write the rate expression for this reaction, referring to the kinetic order with respect to [$S_2O_3^{2-}$] as "***x***".

[2] answer should be based on their data (1 point for form of expression and 1 point for exponents).

$$\text{rate} = k[Fe^{3+}][I^-]^2 [S_2O_3^{2-}]^x$$

Lab Problem #2: [25 points]

You have been given a dilute solution of an unknown acid. Devise and carry out an experimental procedure to determine whether the unknown acid is monoprotic, diprotic, or triprotic.

Answer sheet questions:

1. Give a brief description of your experimental plan. **[5 points]**
   Equipment to be used in the experiment should be articulated. Strategy must indicate that the student understands that this is a titration experiment. Plan must state that increments of base will be added to a measured volume of acid and student will look for color changes.
   Example response (volumes, etc. may vary; dilution not required):
   I will measure out 10 mL of the unknown acid and place it in the beaker. I will add 3-5 drops of Universal Indicator Solution and approximately 30 mL of distilled water. I will add NaOH solution 0.5 mL at a time, stir, and record the color (pH) of the solution after each addition. I will keep adding NaOH solution until all of the acid has reacted (the solution is strongly basic due to excess NaOH). I will repeat this titration, adding smaller amounts of NaOH at a time if it didn't take very many additions to yield an excess of NaOH.

2. Record your data and other observations. **[8 points]**
   Students must report their data in the form of a legible data table. Each trial should indicate that a sufficient number of data points were collected (small increments of NaOH added). Correct color sequence must be evidenced. Data from two or more trials should be presented.
   Example response (colors may vary due to different formulations of Universal Indicator Solution):
   The initial color of the mixture of unknown acid, distilled water and Universal Indicator Solution is red.

mL of NaOH added	*Trial #1 Color and pH*	*mL of NaOH added*	*Trial #2 Color and pH*
0.5	**The table should show all**	*0.5*	
1.0	**volume additions & the**	*1.0*	**Smaller incremental**
1.5	**color and pH after each,**	*1.5*	**volumes of NaOH may**
2.0	**for at least 2 trials.**	*2.0*	**have been added during**
2.5		*2.5*	**the second trial.**
3.0		*3.0*	
3.5		*3.5*	
4.0	***…and so on***	*4.0*	***…and so on***

3. The acid that I was given is _c__. **[3 points; 2 points if diprotic and data supports]**

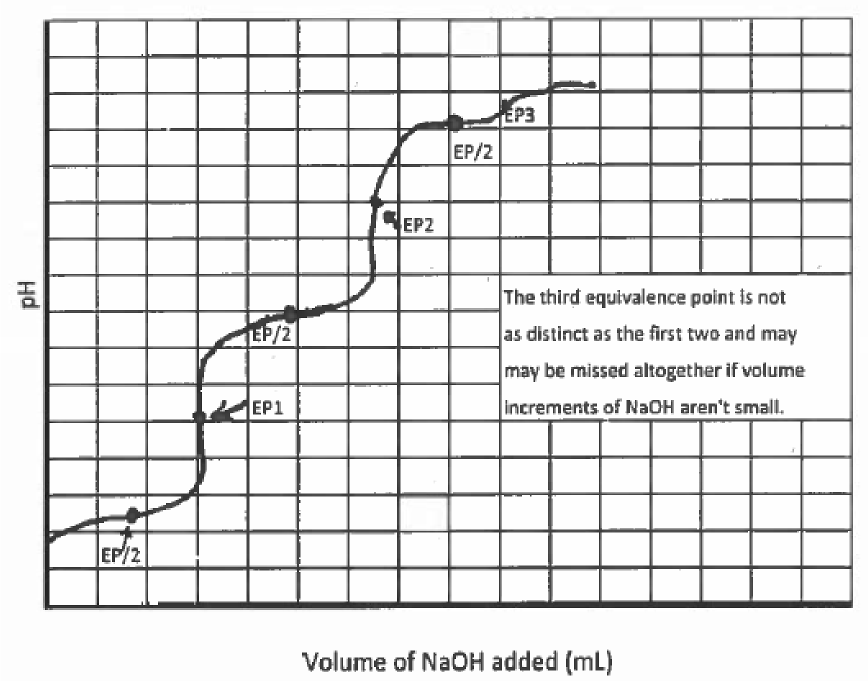
a) monoprotic

b) diprotic

c) triprotic

4. Explain the basis of your conclusion (include supporting data, which may be in the form of an illustration or graph, etc.). **[9 points]**

Graph or illustration must reflect the data that the student actually collected. Interpretation must show an understanding of titration chemistry. For full credit, the student must identify the equivalence points and explain the significance of the equivalence and half-equivalence points such that the claim of triprotic, diprotic or monoprotic was justified. [Graph not to scale; also, student graph would not be expected to be as neat as the example, but should be similar in form.]



A rough graph of my data shows that there are three regions where there is a significant (readily observable) increase in pH with the addition of a small amount of NaOH solution. I've labeled these equivalence points as EP1, EP2 and EP3. Each represents the pH of this acid solution upon reaction with enough NaOH to remove one available proton. There are three equivalence points (although the third is not as distinct as the first two), which indicates that the unknown acid is triprotic. The EP/2 (half-equivalence points or midpoints) indicate where the pH = the pK_a *for the reaction of each of the three available protons in a triprotic acid with NaOH.*