2012 U. S. NATIONAL CHEMISTRY OLYMPIAD

NATIONAL EXAM PART III

Prepared by the American Chemical Society Laboratory Practical Task Force

OLYMPIAD LABORATORY PRACTICAL TASK FORCE

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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. You may carry out the two tasks in any order you 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 problems**	**laboratory practical**	**1 hour, 30 minutes**

Students should be permitted to use **non-programmable** scientific calculators.

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 examining site.

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2012 UNITED STATES NATIONAL CHEMISTRY OLYM
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

Vinegar is an acidic liquid produced from the fermentation process of ethanol. Fermentation of sugars produces alcohol and then a secondary fermentation of the alcohol produced acetic acid. Today, in this country, the FDA requires that any product that is called vinegar have at least 4.0% acetic acid. Depending on the type of vinegar, acetic acid concentrations vary from 4.0% to 8.0%.

Devise and carry out a process to determine which store would be more profitable making 1,000, 000 bottles of its vinegar given the following information:

Store A sells its vinegar for $0.99 for a 473mL bottle.
Store B sells its vinegar for $7.92 for a 3.78 L bottle.
The cost for acetic acid is the same for both stores.

Lab Problem 2

Hydrogen peroxide slowly decomposes on its own into oxygen gas and water.

$$2\ H_2O_2\ (aq) \rightarrow 2\ H_2O\ (l) + O_2\ (g)$$

Devise and carry out a method to rank the following substances on their ability to catalyze the decomposition of a 3% hydrogen peroxide solution: iron (III) chloride, yeast and potassium iodide. Explain your ranking.

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. Data and Observations.

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

3. Calculations.

4. Analysis and Conclusions.

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. Data and Observations.

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

3. Analysis and Conclusions.

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		

CONS[illegible]

R = 8.314 J•m[illegible]

R = 0.0821 L•atm•mo[illegible]

1 F = 96,500 C•mol[illegible]

1 F = 96,500 J•V^{-1}•mol^{-1}

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

$h = 6.626 \times 10^{-34}$ J•s

$c = 2.998 \times 10^{8}$ m•s^{-1}

0 °C = 273.15 K

1.00 atm = 760 mm Hg

EQUATIONS

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

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

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

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** (263)	107 **Bh** (262)	108 **Hs** (265)	109 **Mt** (266)	110 **Ds** (281)	111 **Rg** (272)	112 **Cn** (285)	113 (Uut) (284)	114 (Uuq) (289)	115 (Uup) (288)	116 (Uuh) (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)

2012 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 2012 USNCO laboratory practical on behalf of your Local Section. It is essential that you follow the instructions provided, in order to insure 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 so that the materials used for Lab Problem 1 are separate from those used for Lab Problem 2.

Safety: It is your responsibility to ensure that all students wear safety goggles 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.

After the students have settled, read the following instructions (in italics) 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 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 instru n. **Part III** contains student instructions and answer sheets for both laboratory problems. There table on the last page of the booklet. Allow students enough time to read the brief cover directio

Do not turn to page 2 until directed to do so. When you start to work, be sure to fill out all of 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 form Part III, the Scantron sheets from Part I, and the 'Blue Books" from Part II in the UPS Express Pak you were provided to this address:

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

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

Wednesday, April 25, 2012, 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 ***Tuesday, April 24, 2012*** for it to arrive on time.

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

Lab Problem #1: Materials and Equipment

Each student should have available the following equipment and materials:

Materials:

- 24-well plate, 1
- Beral pipets, microtip, 6
- Beral pipets, graduated, 6
- 1 mL syringes, no needle, 3
- Toothpicks, flat style, 12-15
- Small (100 mL) beakers or (125 mL) flasks, 3 or 4
- 10 mL graduated cylinder, 1
- Spatula or scoop, 1
- Distilled water, in a bottle labeled “Distilled Water”

Along with access to

- Balance, 0.01 g
- Paper towels and a sink with running water.

Chemicals:

- 25 mL each of two vinegar samples:
  Rice vinegar, labeled sample A
  White Vinegar, labeled sample B
- Potassium Hydrogen Phthalate, KHP (s), 2.5 g (label container with MM. 204.3 g/mol)
- 50 mL 1.0 M NaOH (conc. Unlabeled)
- Indicators:
  Phenolphthalein (8.2 – 10.0)
  Methyl red (4.4 – 6.2)
  Bromothymol blue (6.0 – 7.6)
  Place about 1 mL or 20 drops of each indicator in beral pipets and label pipets with indicator and transition range.

Notes:

- When making the vinegar samples, sample A, rice vinegar, should be 4.0% and sample B, white household vinegar, should be 5.0%.
- Using household white vinegar, dilute 800 mL of white vinegar to 1000 mL with distilled water and label as rice vinegar.
- $V1C1=V2C2$
- X mL(0.5) = 1000 mL(0.04) = 800 mL
- Sodium hydroxide is made by slowly adding 40.0 g of NaOH to 700 mL of distilled water. Once dissolved, dilute to 1000 mL. Use caution as heat will be generated as the NaOH dissolves. Take proper safety precautions including wearing safety goggles when making this solution.
- The indicators can be placed in labeled Beral pipets. Place about 1 mL or 20 drops of each indicator in beral pipets and label pipets with indicator and transition range.

Lab Problem #2: Materials and Equipment

Each student should have available the following equipment and materials:

Materials:

- 24 well-plate, 1
- Beral pipets, microtip, 3
- Beral pipets, graduated, 3
- Thermometer, (Celsius, glass, alcohol, at least 0 – 100 °C range or digital thermometers with the same range)
- Toothpicks, flat style, 6
- 10 mL graduated cylinder, 1
- Spatula or scoop, 1
- Distilled water, in a bottle labeled "Distilled Water"

Along with access to

- Balance, 0.01 g
- Timer, clock with second hand
- Paper towels and a sink with running water.

Chemicals:

- 3% hydrogen peroxide (H_2O_2) solution, freshly made, 25 mL, in labeled container. (see notes)
- Potassium iodide KI (s), 1 g
- Yeast (s), ½ package
- Iron (III) chloride, $FeCl_3$ (s), 1 g

Notes:

- The hydrogen peroxide must be freshly made.
- 27% Hydrogen peroxide may be obtained at a local pool store under the brand name SHOCK. Check label to ensure that it does contain hydrogen peroxide. Or you may purchase it from a chemical supplier like Flinn or Sargent Welch.
- To make 3% H_2O_2, dilute 100 mL of concentrated hydrogen peroxide to 1000 mL with distilled water if using 30% H_2O_2. Use 111 mL if using 27% Shock. When diluting, use proper caution. Wear gloves, apron and safety goggles.
- 3% hydrogen peroxide fresh (from previously unopened bottle) from the drug store maybe use as alternative of the freshly made H_2O_2 solution.
- Small quantities (about 1 gram) of solid KI, yeast, and $FeCl_3$ should be provided in labeled containers.

Safety Instructions for Lab Problem #1 and #2:

It is your responsibility to ensure that all students wear safety goggles 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.

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

2012 USNCO Part III Answers

Lab Problem 1

For this problem candidates were supplied with a 24-well plate, 6 microtip and 6 graduated Beral pipets along with a 1 mL syringe, several small beakers, a 10 mL graduated cylinder, a spatula, paper towels and access to d.i. water and a balance with $\pm$ 0.01 g sensitivity.
They were also given 25 mL of each of two samples of vinegar (labeled A [0.70 M] and B [0.88 M]), 1.25 g of potassium hydrogen phthalate, 50 mL of NaOH (1.0 M but unlabeled) along with the indicators; Bromothymol Blue, Methyl Red and Phenolphthalein 0.5 mL of each in Beral pipets (named and with transition range).
The task was to:
Devise and carry out a process to determine which store would be more profitable making 1,000,000 bottles of its vinegar if

Store A sells its vinegar for $0.99 for a 473 mL bottle
Store B sells its vinegar for $7.92 for a 3.78 L bottle.

The cost for acetic acid is the same for both stores.
Candidates were evaluated on: their Plan, Data and Observations, Calculations, Analysis and Conclusions.

<u>An excellent response included:</u>

Experimental Plan in which the candidate specified the volume of vinegar to be titrated and how it would be measured, the indicator to be used (with the color change expected), and the means (drops, syringe or mass) of measuring the volume of NaOH solution used,

Data and Observations with a minimum of two trials for each of the two vinegar samples presented in a clear manner,

Calculations that provided the relative or absolute concentrations of the two vinegar samples that were correct from the data obtained with a concentration ratio with a high level of accuracy ($\pm$ 5%),

Analysis and Conclusions that specified that the two vinegars were being sold for the same amount ($2.09/L) and a conclusion based on either the lower concentration of acetic acid in vinegar A or the total amount of vinegar sold by store B.

<u>A good response would include:</u>

Experimental Plan in which the candidate stated two or three of the detailed aspects of the plan given above,

Data and Observations with a minimum of two trials for one of the two vinegar samples but in a manner that required some interpretation on the part of the reader,

Calculations with the relative/absolute concentrations of the two vinegar samples from the data obtained by the candidate with a reasonable accuracy ($\pm$ 10%)

Analysis and Conclusions that either omitted or miscalculated the selling prices of the two vinegars and provided a reasonable discussion of the profitability of the two stores.

Lab Problem 2

For this second lab problem, candidates were asked to determine the effectiveness of three different substances as catalysts for the decomposition of hydrogen peroxide. They were provided: a 24-well plate, micro-tip and graduated beral pipets, thermometer, graduated cylinder, scoops, toothpicks, paper towels and access to a timer, balance, distilled water along with small beakers and a 1 mL syringe (from problem 1).

Students were given 25 mL of H_2O_2 (freshly made), 1 g of solid potassium iodide, 1 g of iron III chloride and ½ package of yeast.

Candidates were evaluated on their experimental design, the quality of their data and observations and the conclusions they reached based on their data and observations.

<u>An excellent response included:</u>

Experimental Plan: A well designed experimental plan that indicated that the volume of hydrogen peroxide used in each trial was held constant and that the amount of the catalyst was equal in each trial. Also indicated in the plan was how the volume of hydrogen peroxide and the amount of catalyst used was determined. The plan also indicated what was being measured, i.e., the number of bubbles, the time until the reaction stopped, the change in temperature, etc. and how that quantity would be measured.

Data and Observations: Data and observations collected were organized in a table format with proper units. Also present in the data table was the volume of hydrogen peroxide and amount of catalyst used in each trial. The data showed multiple trials of each catalyst and was precise. Along with the data collected, there were many, good qualitative observations that could be used to support the ranking along with the quantitative observations.

Analysis and Conclusions: The conclusions drawn included the ranking of the catalysts agreeing with the data collected and a discussion of how the observations and data supported that ranking, e.g. “Yeast produced the greatest number of bubbles so it was the most effective catalyst.” An excellent response also included some discussion of the chemistry involved in the experiment, i.e. “A catalyst is a substance that speeds up the rate of a reaction usually by lowering the activation energy without itself being used up in the reaction.
For example, for the reaction:

$2\ H_2O_2\ (aq) \rightarrow\ 2\ H_2O\ (l) + O_2\ (g)$,
the process occurs very slowly. However the addition of KI provides for an alternate reaction pathway with lower activation energy so the decomposition occurs faster according for this pathway:
$H_2O_2 + I^-\ (aq) \rightarrow IO^-\ (aq) + H_2O\ (l)$ and
$IO^-\ (aq) + H_2O_2 \rightarrow I^-\ (aq) + H_2O + O_2$.
The second reaction regenerated the I^- which therefore acts as a catalyst.
The same type of thing happens with the iron III chloride as the Fe^{3+} ion is reduced to Fe^{2+} ion and oxygen gas is formed by the peroxide. The Fe^{2+} is oxidized back to the Fe^{3+} ion in the acidic environment to act as a catalyst.
$H_2O_2 + 2\ Fe^{3+} \rightarrow 2\ H^+ + O_2 + 2\ Fe^{2+}$ and
$2Fe^{2+} + H_2O_2 + 2 \rightarrow 2\ Fe^{3+} + 2H_2O$.
Yeast is a biological enzyme and thus would increase the rate of decomposition of hydrogen peroxide."

A good response would include:

Experimental Plan: An experimental plan that indicated that a constant volume of hydrogen peroxide was used in each trial and that the amount of the catalyst was constant in each trial. The plan also indicated what quantity was being measured, i.e., the number of bubbles, the time until the reaction stopped, the change in temperature, etc. and how that quantity would be measured.

Data and Observations: Data and observations collected were organized in some manner with proper units included. The data showed multiple trials of each catalyst and was precise. Along with the data collected, there were some qualitative observations to support the quantitative data.

Analysis and Conclusions: The conclusions drawn included the ranking of the catalysts based on experimental results and a discussion of how the observations and data supported that ranking, e.g. Yeast produced the greatest number of bubbles so it was the most effective catalyst.