ACS USNCO
U.S. National Chemistry Olympiad

2024 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 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

Question: Using the provided materials, determine the enthalpy of (heat of) solution, in kJ/mol, for the three unknown solids.

Lab Problem 2

Question*:* Surface tension in a hydrophilic glass capillary tube can qualitatively provide information about intermolecular forces within a sample. Using the provided materials, design and carry out an experiment to determine the specific identity of the substance in each of five numbered vials. Each vial contains one of these substances:

Water
10% salt water
Vegetable oil
Acetone
Isopropanol

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:

STUDENT USNCO ID:

3. Show all calculations.

4. The enthalpy of solution for unknown 1 is _____ kJ/mol.

   The enthalpy of solution for unknown 2 is _____ kJ/mol.

   The enthalpy of solution for unknown 3 is _____ kJ/mol.

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:

3. Show all calculation.

4. Identify the substance in each unknown vial, giving a brief justification for your choices.

Unknown #	Contains	Justification
1		
2		
3		
4		
5		

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

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2024 U.S. NATIONAL CHEMISTRY OLYMPIAD

NATIONAL EXAM PART III
EXAMINER'S INSTRUCTIONS

Prepared by the American Chemical Society Chemistry Olympiad Examinations Task Force

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Thank you for administering the 2024 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. The equipment should be initially placed and the materials separated for Lab Problem #1 and for Lab Problem #2.

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. 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.*

(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.*

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. Read the directions on the front page. Please write your USNCO Id on the cover and pages 4-7 of the booklet. Are there any questions before we begin?

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

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

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

You may begin.

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

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

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

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

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

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

Wednesday, April 24, 2024, 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 22, 2024** 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.

(Continued on the next page)

Each student should have available the following:

Materials needed:

Each student should have available the following equipment and materials:

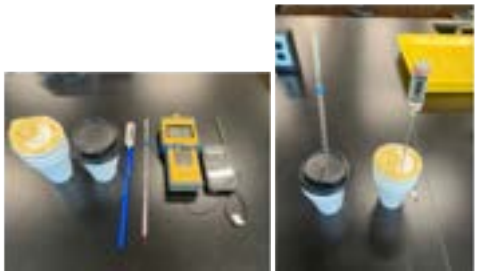
- Thermometer (alcohol or digital)
- Spatula
- Graduated cylinder (25 ml or larger)
- Beaker (250 ml or larger)
- Styrofoam cup with a cap (see picture below)
- Glass stirring rod
- Wash bottle
- Access to milligram balance
- Access to DI or distilled water
- 5 open ended glass capillary tubes – suggested ones (link)
- Ruler with mm
- Access to paper towels and a sink with running water

Chemicals needed:

- urea (5-10g)
- sodium carbonate (5-10g)
- sodium acetate (5-10g)
- DI water or distilled water (at least 1 mL)
- Acetone (at least 1 mL)
- Vegetable oil (at least 1 mL)
- Isopropanol (at least 1 mL)
- 10% salt water (at least 1 mL)

Suggested Set-up Photos





Lab Problem 1 Prompt:
Using the provided materials, determine the enthalpy of (heat of) solution, in kJ/mol, for the three unknown solids.

Equipment and materials provided:
Please see attached instructions for site coordinators.

Questions for the Examination Paper:
1. Give a brief description of your experimental plan.
2. Record your data/observations.
3. Show all calculations.
4. The enthalpy of solution for unknown 1 is ____ kJ/mol.
   The enthalpy of solution for unknown 2 is ____ kJ/mol.
   The enthalpy of solution for unknown 3 is ____ kJ/mol.

Suggested Experimental Plan and Expected Results:

Procedures will vary, but should follow the basic steps of:

1. Measure a volume, or weigh an amount, of water.
2. Place water in calorimetry cup. Some students may have weighed calorimetry apparatus before and after addition of water.
3. Take temperature of water.
4. Weigh out an amount of unknown solid.
5. Add solid to water in calorimetry cup.
6. Some form of stirring or swirling of the cup.
7. Record new temperature.

Students should create a data table, or clearly show their collected data. Students should provide more than one trial for each unknown.

	Unknown 1 – Trial 1	Unknown 1 – Trial 2	Unknown 2 – Trial 1	Unknown 2 – Trial 2	Unknown 3 – Trial 1	Unknown 3 – Trial 2
Mass of empty calorimetry cup (g)	4.36	4.36	4.36	4.36	4.36	4.36
Mass of calorimetry cup and water (g)	29.51	30.21	31.95	30.78	27.03	28.98
Mass of water (g)	25.15	25.85	27.59	26.42	22.67	24.62
Temperature of water in cup (°C)	22.4	22.3	22.5	22.4	22.2	22.3

Mass of unknown solid (g)	2.06	2.15	2.18	2.20	2.26	2.05
Final temperature of aqueous mixture (°C)	17.3	17.2	27.6	27.8	27.0	26.9

Sample Calculations:

Unknown 1 ΔH_{sol} = +13.9 kJ/mol. 60.06 g/mol. +231 J/g

q_{water} = mcΔT. q = (25.15g)(4.18 J/g* C)(17.3 C - 22.4 C) = -536.15 J

$q_{water} = -q_{hydration}$ $q_{hydration}$ = +536.15 J

ΔH_{sol} = 536.15 J / 2.06 g = +260.3 J/g or for unknown 1 +15.63 kJ/mol (Endothermic)

Unknown 2 ΔH_{sol} = -26.7 kJ/mol. 105.99 g/mol. 252 J/g

q_{water} = mcΔT. q = (27.59g)(4.18 J/g* C)(27.6 C - 22.5 C) = +588.16 J

$q_{water} = -q_{hydration}$ $q_{hydration}$ = -588.16 J

ΔH_{sol} = -588.16 J / 2.18 g = -269.8 J/g or for unknown 2 -28.60 kJ/mol (Exothermic)

Unknown 3 ΔH_{sol} = -17.3 kJ/mol 82.03 g/mol -211 J/g

q_{water} = mcΔT. q = (22.67g)(4.18 J/g* C)(27.0 C - 22.2 C) = +454.85 J

$q_{water} = -q_{hydration}$ $q_{hydration}$ = -454.85 J

ΔH_{sol} = -454.85 J / 2.26 g = -201.3 J/g or for unknown 3 -16.51 kJ/mol (Exothermic)