2016 U.S. NATIONAL CHEMISTRY OLYMPIAD
NATIONAL EXAM PART I

Prepared by the American Chemical Society Chemistry Olympiad Examinations Task Force

OLYMPIAD EXAMINATIONS TASK FORCE

Seth N. Brown, **Chair**, *University of Notre Dame,* Notre Dame, IN

James Ayers, *Colorado Mesa University*, Grand Junction, CO
Mark DeCamp, *University of Michigan*, Dearborn, MI (retired)
Marian DeWane, *Centennial HS*, Boise, ID
Xu Duan, *Holton-Arms School*, Bethesda, MD
Valerie Ferguson, *Moore HS*, Moore, OK
Julie Furstenau, *Thomas B. Doherty HS*, Colorado Springs, CO
Kimberly Gardner, *United States Air Force Academy,* CO
Paul Groves, *South Pasadena HS*, South Pasadena, CA
David W. Hostage, *Taft School*, Watertown, CT
Dennis Kliza, *Kinkaid School*, Houston, TX
John Kotz, *State University of New York*, Oneonta, NY (retired)
Jane Nagurney, *Scranton Preparatory School*, Scranton, PA
Ronald Ragsdale, *University of Utah,* Salt Lake City, UT (retired)

DIRECTIONS TO THE EXAMINER – PART I

The USNCO Subcommittee is conducting a survey in an effort to determine the impact of the Olympiad program on students. At the end of the exam there are four questions, which should be answered on the same Scantron sheet students use for the exam. These questions may be administered after the 90 minutes allotted for the exam, and each student should be encouraged to answer these questions.

Part I of this test is designed to be taken with a Scantron answer sheet on which the student records his or her responses. Only this Scantron sheet is graded for a score on Part I. Testing materials, scratch paper, and the Scantron sheet should be made available to the student *only* during the examination period. All testing materials including scratch paper should be turned in and kept secure until **April 25, 2016**, after which tests can be returned to students and their teachers for further study.

Allow time for students to read the directions, ask questions, and fill in the requested information on the Scantron sheet. The answer sheet must be completed using a pencil, not pen. When the student has completed **Part I**, or after **one hour and thirty minutes** has elapsed, the student must turn in the Scantron sheet, Part I of the testing materials, and all scratch paper.

There are three parts to the National Chemistry 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 problems	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 – DO NOT TURN THE PAGE UNTIL DIRECTED TO DO SO. Answers to questions in Part I must be entered on a Scantron answer sheet to be scored. Be sure to write your name on the answer sheet, an ID number is already entered for you. **Make a record of this ID number because you will use the same number on Parts II and III.** Each item in **Part I** consists of a question or an incomplete statement that is followed by four possible choices. Select the single choice that best answers the question or completes the statement. Then use a pencil to blacken the space on your answer sheet next to the same letter as your choice. You may write on the examination, but the test booklet will not be used for grading. Scores are based on the number of correct responses. When you complete **Part I** (or at the end of one hour and 30 minutes), you must turn in all testing materials, scratch paper, and your Scantron answer sheet. **Do not forget to turn in your U.S. citizenship/Green Card Holder statement before leaving the testing site today.**

EQUATIONS

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

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** 78.96	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 **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)

- When you have selected your answer to each question, blacken the corresponding space on the answer sheet using a soft, #2 pencil. Make a heavy, full mark, but no stray marks. If you decide to change an answer, erase the unwanted mark very carefully.

- There is only one correct answer to each question. Any questions for which more than one response has been blackened **will not be counted**.

- Your score is based solely on the number of questions you answer correctly. **It is to your advantage to answer every question.**

1. One mole of which hydrocarbon requires 8 mol O_2 to achieve complete combustion to give carbon dioxide and water?

   (A) C_3H_8 (B) C_4H_{10} (C) C_5H_{10} (D) C_5H_{12}

2. What is the concentration of calcium ions in 350. mL of an aqueous solution containing 7.50 g $CaCl_2$?

   (A) 0.0676 M   (B) 0.193 M

   (C) 0.284 M   (D) 0.535 M

3. 0.422 g of an element Z reacts with oxygen to form 0.797 g of the oxide Z_2O_3. What is the element Z?

   (A) Al   (B) Sc   (C) Cr   (D) Ga

4. At constant temperature and pressure, 5.0 L of SO_2 is combined with 3.0 L of O_2 according to the equation:

 $$2 \text{ SO}_2(g) + \text{O}_2(g) \rightarrow 2 \text{ SO}_3(g)$$
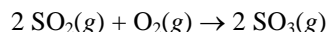
   After SO_3 formation is complete, what is the volume of the mixture?

   (A) 5.5 L   (B) 6.0 L   (C) 6.5 L   (D) 8.0 L

5. A sample of 0.040 mol hypochlorite ion is treated with varying amounts of 1.0 M aqueous H_2O_2. Which graph represents the amount of $O_2(g)$ that is evolved according to the chemical reaction shown?

   $$\text{OCl}^-(aq) + \text{H}_2\text{O}_2(aq) \rightarrow \text{Cl}^-(aq) + \text{H}_2\text{O}(l) + \text{O}_2(g)$$
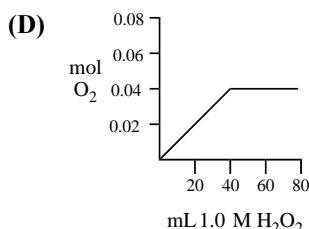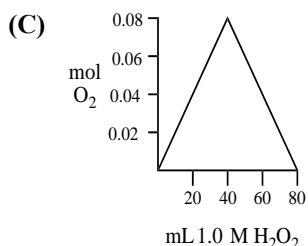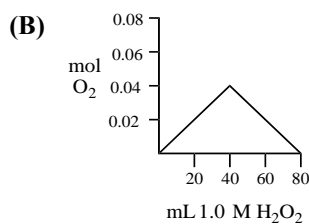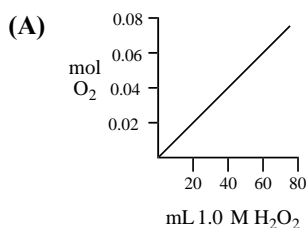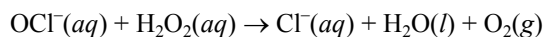
6. Equal volumes of aqueous 1.00 m glucose ($C_6H_{12}O_6$) and 1.00 m sodium chloride solutions are placed on opposite sides of a U-tube, separated by a semipermeable membrane (through which only water can diffuse). What will the setup look like at equilibrium?
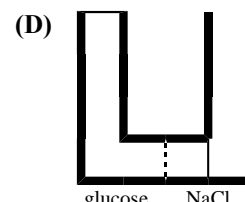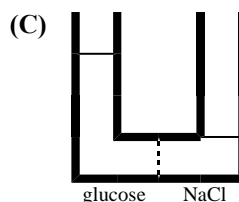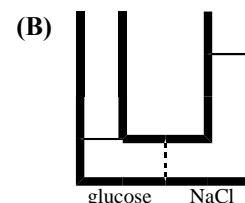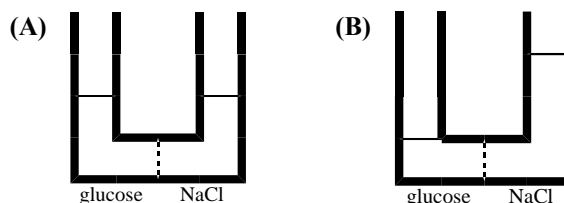

7. A student wishes to determine the molar mass of a pure solid organic compound. Which measurement would be most useful?

   (A) Melting point of the solid

   (B) Melting point depression of a mixture of the solid with 1,4-dichlorobenzene

   (C) Heat of combustion

   (D) Solubility in water

8. A student has 10 mL of a solution that might contain any or all of the following cations at 0.01 M concentrations: Mn^{2+}, Ba^{2+}, Ag^+, and Cu^{2+}. Addition of 10 mL of 1 M HCl causes a precipitate to form. After the precipitate is filtered off, 1 M H_2SO_4 is added to the filtrate and another precipitate forms. What is the second precipitate?

   (A) $MnSO_4$

   (B) $BaSO_4$

   (C) Ag_2SO_4

   (D) A mixture of $BaSO_4$ and Ag_2SO_4

9. When 6 M sodium hydroxide is added to an unknown white solid, the solid dissolves. What is a possible identity for this solid?

(A) $Mg(OH)_2$ (B) $Al_2(SO_4)_3$

(C) $BaCO_3$ (D) $AgBr$

10. A student standardizes a solution of aqueous NaOH against a measured mass of solid potassium hydrogen phthalate. She then uses this NaOH solution to titrate a measured mass of an unknown monocarboxylic acid to its phenolphthalein endpoint to determine its molar mass. Which errors will lead to a value of the molar mass that is too high?

I. The potassium hydrogen phthalate is partially hydrated.

II. The NaOH solution is allowed to stand after being standardized and absorbs some carbon dioxide from the air.

(A) I only   (B) II only

(C) Both I and II   (D) Neither I nor II

11. A student has crystallized acetylsalicylic acid from a mixture of ethanol and water. Which apparatus is best suited for isolation of the crystalline material? (The point of addition of the solid/liquid mixture is indicated by the arrow.)
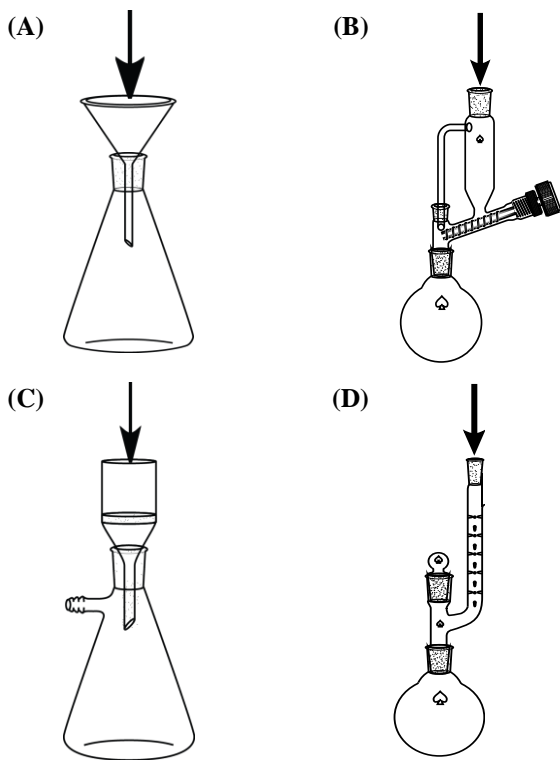
12. Which is the safest method for performing a flame test?

(A) Dissolve the metal salt in methanol, then squirt the solution into a lit Bunsen burner from at least 1 meter away.

(B) Dissolve the metal salt in methanol, then pour the methanol into a crystallizing dish, igniting it with the flame from a Bunsen burner.

(C) Soak a wooden splint in an aqueous solution of the metal salt, then burn the splint in the flame from a Bunsen burner.

(D) Soak a wooden splint in an aqueous solution of the metal salt, then heat the splint on top of a ceramic hotplate.

13. Which compound has the highest normal boiling point?

(A) CH_3CH_2COOH (B) $CH_3CH_2CH_2OH$

(C) CH_3COOCH_3 (D) $HCOOCH_2CH_3$

14. Nitrogen, N_2, has the following properties:
normal melting point: 63.2 K
normal boiling point: 77.4 K
triple point: 0.127 atm, 63.1 K
critical point: 33.5 atm, 126.0 K

Which statement about N_2 is correct?

(A) Liquid N_2 is denser than solid N_2.

(B) At sufficiently high pressure, N_2 can be liquefied at 150 K.

(C) Liquid N_2 and gaseous N_2 can coexist at 63.1 K and 1 atm.

(D) If N_2 is heated from 60 K to 70 K at 0.100 atm, it sublimes.

15. The vapor pressure of iodomethane, CH_3I ($M = 141.9$), is 110. mm Hg at 266 K. A 0.824 g sample of iodomethane is placed in a closed, evacuated 370. mL container at 266 K. At equilibrium, what will be the pressure in the container?

(A) 96.4 mm Hg   (B) 110. mm Hg

(C) 260. mm Hg   (D) 292. mm Hg

16. Which statement about the properties of barium chloride and mercury(II) chloride is correct?

(A) $BaCl_2$ has a higher melting point than $HgCl_2$.

(B) $BaCl_2$ has a higher solubility in nonpolar solvents than $HgCl_2$.

(C) $BaCl_2$ has a higher vapor pressure than $HgCl_2$.

(D) Molten $BaCl_2$ has a lower electrical conductivity than molten $HgCl_2$.

17. Thallium(I) bromide ($M = 284.3$) adopts the cubic unit cell shown below, with an edge length $a = 397$ pm. What is the density of TlBr?
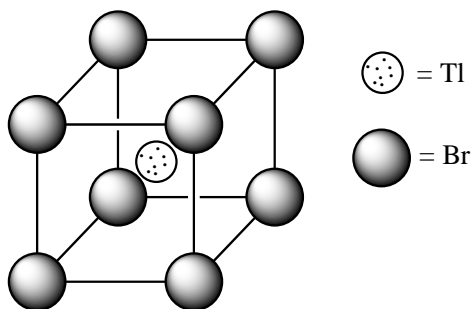
(A) 5.42 g cm^{-3} (B) 7.55 g cm^{-3}

(C) 18.0 g cm^{-3} (D) 22.4 g cm^{-3}

18. Which of the following properties is not typical of metallic solids?

(A) High vapor pressure

(B) High coordination number of atoms in the lattice

(C) High electrical conductivity

(D) High thermal conductivity

19. Given

$O(g) + e^-(g) \rightarrow O^-(g)$ $\Delta H° = -142$ kJ mol^{-1}

$O(g) + 2\ e^-(g) \rightarrow O^{2-}(g)$ $\Delta H° = +702$ kJ mol^{-1}

What is $\Delta H°$ for the following reaction?

$$O^-(g) + e^-(g) \rightarrow O^{2-}(g)$$

(A) –844 kJ mol^{-1} (B) –560 kJ mol^{-1}

(C) +560 kJ mol^{-1} (D) +844 kJ mol^{-1}

20. For which reaction is $\Delta S° < 0$?

(A) $NH_4Br(s) \rightarrow NH_3(g) + HBr(g)$

(B) $C_2H_5OH(l) \rightarrow C_2H_5OH(g)$

(C) $2\ NO_2(g) \rightarrow 2\ NO(g) + O_2(g)$

(D) $2\ BrCl(g) \rightarrow Cl_2(g) + Br_2(l)$

21. A hot metal coin is dropped into cold water in a well-insulated container. Which statements are true as the system approaches equilibrium?

     I. $|q_{metal}| = |q_{water}|$

     II. $|\Delta S_{metal}| = |\Delta S_{water}|$

(A) I only   (B) II only

(C) Both I and II   (D) Neither I nor II

22. What is $\Delta G°_f$ of $C_6H_6(g)$ at 298 K?

	$C_6H_6(l)$	$C_6H_6(g)$
$\Delta H°_f$, kJ mol^{-1}	49.0	82.9
$S°$, J mol^{-1} K^{-1}	173.3	269.0
$\Delta G°_f$ (298 K), kJ mol^{-1}	124.3	

(A) 2.7 kJ mol^{-1} (B) 121.6 kJ mol^{-1}

(C) 127.0 kJ mol^{-1} (D) 129.7 kJ mol^{-1}

23. Assuming that $\Delta H°$ and $\Delta S°$ do not vary significantly with temperature, at what temperature will graphite and diamond be in equilibrium at 1 atm pressure?

	$\Delta H°_f$, kJ mol^{-1}	$S°$, J mol^{-1} K^{-1}
C (s, graphite)	0.0	5.9
C (s, diamond)	2.1	2.5

(A) 0.62 K

(B) 620 K

(C) 2400 K

(D) Graphite is more stable than diamond at all temperatures.

24. The K_{sp} of AgCl is 9.5×10^{-11} at 14 °C and is 7.8×10^{-10} at 42 °C. What is $\Delta H°$ for the dissolution of AgCl(s)?

$$AgCl(s) \rightarrow Ag^+(aq) + Cl^-(aq)$$

(A) –0.49 kJ mol^{-1} (B) +0.37 kJ mol^{-1}

(C) +57 kJ mol^{-1} (D) +220 kJ mol^{-1}

25. Cyclopropane isomerizes to propene in an irreversible, first-order reaction. At 700 K, a sample of 22.0 mm Hg of cyclopropane is introduced into a reaction vessel. After 1.0 min, the partial pressure of the product, propene, was found to be 17.5 mm Hg. What is the rate constant for the isomerization at this temperature?

(A) 3.8×10^{-3} s^{-1} (B) 2.6×10^{-2} s^{-1}

(C) 0.23 s^{-1} (D) 1.6 s^{-1}

26. Which statements about the collision theory of reactions are correct?

  I. Molecules must have the correct spatial orientations for collisions to lead to reactions.

  II. Only collisions with an energy greater than a certain threshold lead to reactions.

(A) I only   (B) II only

(C) Both I and II   (D) Neither I nor II

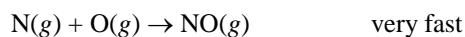**27.** Triiodide reacts with acetone in acidic aqueous solution:

$$I_3^-(aq) + CH_3COCH_3(aq) \rightarrow CH_3COCH_2I(aq) + 2\ I^-(aq)$$
$$+ H^+(aq)$$
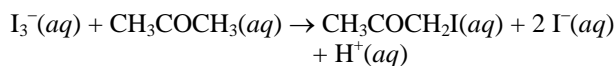
The reaction is carried out twice, both times with $[I_3^-]_0 = 1.0 \times 10^{-3}$ M and $[H^+]_0 = 1.00$ M, but with two different concentrations of acetone, and the concentration of triiodide is found to vary with time as shown:
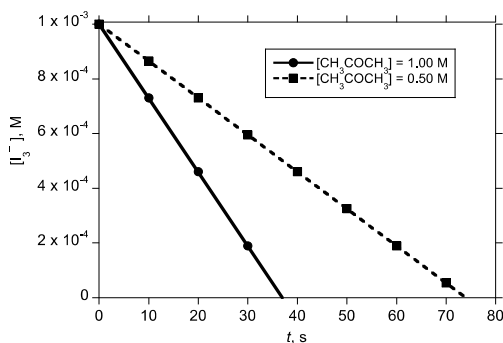
What are the orders of triiodide and acetone in the reaction?

(A) First-order in I_3^-, first-order in CH_3COCH_3

(B) Zeroth-order in I_3^-, first-order in CH_3COCH_3

(C) First-order in I_3^-; the order in CH_3COCH_3 cannot be determined from the available data

(D) First-order in CH_3COCH_3; the order in I_3^- cannot be determined from the available data

28. Nitric oxide is formed at high temperature in the presence of oxygen and nitrogen. A proposed mechanism for its formation is shown:

$$O_2(g) \rightleftharpoons 2\ O(g) \qquad \text{fast, unfavorable}$$

$$N_2(g) + O(g) \rightarrow NO(g) + N(g) \quad \text{slow}$$

$$N(g) + O(g) \rightarrow NO(g) \qquad \text{very fast}$$

What rate law is predicted by this mechanism?

(A) Rate = $k[O_2]$ **(B)** Rate = $k[N_2][O_2]$

(C) Rate = $k[N_2][O_2]^{1/2}$ **(D)** Rate = $k[N_2][O_2]^2$

29. At 400.0 K, the rate constant of a reaction is 3.2×10^{-2} s^{-1}. The activation energy of the reaction is 41.0 kJ mol^{-1}. What is the rate constant at 410.0 K?

(A) 2.4×10^{-2} s^{-1} **(B)** 3.2×10^{-2} s^{-1}

**(C)** 4.3×10^{-2} s^{-1} **(D)** 3.9×10^{-1} s^{-1}

30. In a reaction between two substances A and B, the rate is found to be proportional to the concentration of A at all concentrations studied. At low concentrations of B, the rate of the reaction is found to be proportional to [B], but to level off at high concentrations of B. What is a reasonable explanation for the observed dependence of rate on [B]?

(A) B binds to A prior to the rate-determining step.

(B) The reaction has an order of –1 in B.

(C) The reaction involves a 1:2 stoichiometry of A:B.

(D) The reaction is catalyzed by one of its products.

31. What is the correct equilibrium expression for the following reaction?

$$8\ H_2S(aq) + 4\ O_2(g) \rightleftharpoons S_8(s) + 8\ H_2O(l)$$
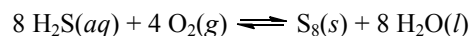
(A) $K = \dfrac{[S_8][H_2O]}{[H_2S] \cdot P(O_2)}$

(B) $K = \dfrac{[S_8](8 \cdot [H_2O])^8}{(8 \cdot [H_2S])^8 \cdot (4 \cdot P(O_2))^4}$

(C) $K = \dfrac{[S_8][H_2O]^8}{[H_2S]^8 \cdot P(O_2)^4}$

(D) $K = \dfrac{1}{[H_2S]^8 \cdot P(O_2)^4}$

32. The reaction below is exothermic.

$$PCl_3(g) + Cl_2(g) \rightleftharpoons PCl_5(g)$$
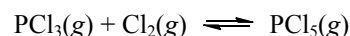
Which change will increase the number of moles of $PCl_5(g)$ present at equilibrium?

(A) The volume of the reaction vessel is tripled.

(B) The reaction vessel is cooled.

(C) Some of the $Cl_2(g)$ is removed.

(D) Krypton gas is added to the reaction vessel.

33. Which of the following has the greatest molar solubility in water?

(A) ZnC_2O_4 ($K_{sp} = 2.7 \times 10^{-8}$)

(B) $BaCrO_4$ ($K_{sp} = 2.3 \times 10^{-10}$)

(C) CaF_2 ($K_{sp} = 3.9 \times 10^{-11}$)

(D) $AgBr$ ($K_{sp} = 5.0 \times 10^{-13}$)

34. A 0.100 M solution of a weak monoprotic acid HX is 3.5% ionized. What is the pH of a 0.500 M solution of HX?

(A) 0.30   (B) 1.76   (C) 2.10   (D) 2.46

35. A sample of a washing powder that contains a mixture of Na_2CO_3 and $NaHCO_3$ is titrated with aqueous HCl and the following result is obtained:
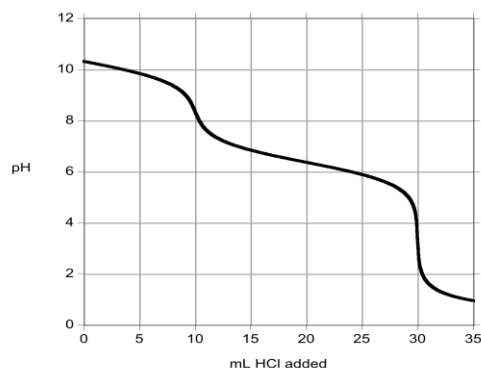
What is the mole ratio of CO_3^{2-} to HCO_3^- in the washing powder?

(A) 2 mol CO_3^{2-} : 1 mol HCO_3^-

(B) 1 mol CO_3^{2-} : 1 mol HCO_3^-

(C) 1 mol CO_3^{2-} : 2 mol HCO_3^-

(D) 1 mol CO_3^{2-} : 3 mol HCO_3^-

36. Hydrocyanic acid, HCN, is a weak acid with $K_a = 4.9 \times 10^{-10}$. Nickel(II) ion complexes strongly with cyanide ion to form $Ni(CN)_4^{2-}$, $K_f = 1.0 \times 10^{22}$. What is the pH of 1.00 L of a 0.100 M solution of HCN to which 0.025 mol $NiCl_2$ has been added?

(A) 1.00   (B) 4.05   (C) 5.15   (D) 8.92

37. What is the oxidation state of nitrogen in magnesium nitride?

(A) −3   (B) −2   (C) +3   (D) +5

38. For the galvanic cell

$$Zn(s) \mid Zn^{2+}(aq) \parallel Cu^{2+}(aq) \mid Cu(s)$$

the standard cell potential is 1.10 V. What is the potential at 25 °C if the concentrations of Zn^{2+} and Cu^{2+} are 2.5 M and 0.10 M respectively?

(A) 1.14 V   (B) 1.10 V   (C) 1.06 V   (D) 1.02 V

39. Which of the following metals is most likely to be produced through electrolysis?

(A) Aluminum   (B) Gold

(C) Iron   (D) Mercury

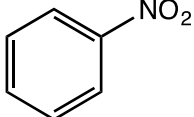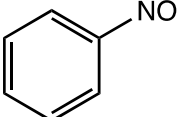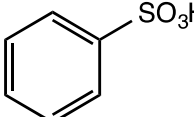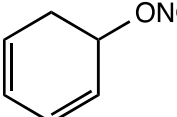**40.** What is the standard reduction potential for $Cr^{2+}(aq)$ to $Cr(s)$?

Half-Reaction	$E°$, V
$Cr^{3+}(aq) + 3\ e^- \rightarrow Cr(s)$	−0.73
$Cr^{3+}(aq) + e^- \rightarrow Cr^{2+}(aq)$	−0.50

(A) −0.23 V   (B) −0.85 V

(C) −1.23 V   (D) −1.69 V

41. What is observed if a piece of lead is placed in an aqueous solution of $Cu(NO_3)_2$?

Half-Reaction	$E°$, V
$Pb^{2+}(aq) + 2e^- \rightarrow Pb(s)$	−0.13
$Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$	+0.34

I. The mass of the metal piece increases.

II. The blue color of the solution becomes less intense.

(A) I only   (B) II only

(C) Both I and II   (D) Neither I nor II

42. If water is electrolyzed for 2.0 hr with a current of 10.0 A, what volume of dry oxygen gas is collected at STP?

(A) 4.2 L   (B) 4.6 L   (C) 8.4 L   (D) 17 L

**43.** Which graph best describes the radial wavefunction of a 2p orbital?
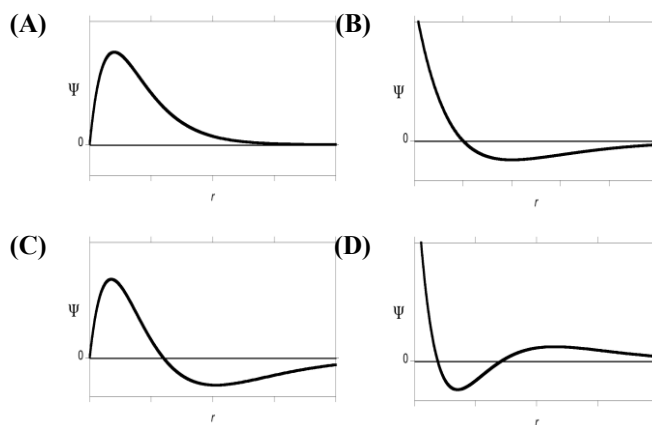
44. In a hydrogen atom, which transition requires the greatest input of energy?

(A) $n = 7 \rightarrow n = 3$ (B) $n = 2 \rightarrow n = 1$

(C) $n = 3 \rightarrow n = 7$ (D) $n = 1 \rightarrow n = 2$

45. How many unpaired electrons does a ground-state gas-phase Mn^{2+} ion have?

(A) 1   (B) 3   (C) 5   (D) 7

46. Which elements are most similar in atomic size?

(A) H ($Z = 1$) and Li ($Z = 3$)

(B) C ($Z = 6$) and Si ($Z = 14$)

(C) Mn ($Z = 25$) and Tc ($Z = 43$)

(D) Zr ($Z = 40$) and Hf ($Z = 72$)

47. Which halogen has the greatest first ionization energy?

(A) F   (B) Cl   (C) Br   (D) I

48. The isotope ^{69}Zn undergoes what mode of radioactive decay?

(A) Alpha emission   (B) Beta emission

(C) Gamma emission   (D) Positron emission

49. What is the bond order of carbon monoxide, CO?

(A) 1.5   (B) 2.0   (C) 2.5   (D) 3.0

50. Which statements about the Lewis structure of the fulminate ion, CNO^-, are correct?

I. The nitrogen atom has a positive formal charge.

II. The nitrogen atom has a lone pair of electrons.

(A) I only   (B) II only

(C) Both I and II   (D) Neither I nor II

51. In which molecule are there two distinct sets of sulfur-fluorine bond lengths?

(A) SF_2 (B) SOF_2 (C) SF_4 (D) SF_6

52. Which species contains three sigma bonds and one pi bond?

(A) PF_3 (B) NH_4^+ (C) C_2H_2 (D) CO_3^{2-}

53. How many stereoisomers of octahedral $CoCl_2(NH_3)_2(CN)_2^-$ are possible?

(A) 3   (B) 4   (C) 5   (D) 6

54. What is the best description of the geometry of the nitrogen atoms in dimethylnitrosamine, $(CH_3)_2NNO$?

	N bonded to CH_3 groups	N bonded to O
(A)	Trigonal planar	Linear
(B)	Trigonal planar	Bent
(C)	Trigonal pyramidal	Linear
(D)	Trigonal pyramidal	Bent

55. A student wishes to prepare ethyl acetate from the reaction of ethanol and acetic acid. To be successful, this reaction requires

(A) an acidic catalyst.   (B) a basic catalyst.

(C) an oxidizing agent.   (D) a reducing agent.

56. Which alkyl halide reacts most rapidly with aqueous sodium hydroxide solution?

(A) CH_3Cl (B) CH_3I

(C) $(CH_3)_3CCH_2Cl$ (D) $(CH_3)_3CCH_2I$

57. How many isomers are there with the formula C_6H_{14}?

(A) 3   (B) 4   (C) 5   (D) 6

58. What is the product of the reaction of benzene with a solution of nitric acid in sulfuric acid at 50 °C?

(A) NO_2 (B) NO

(C) SO_3H (D) ONO_2

59. An enzyme catalyzes the hydrolysis of an ester with a certain activity, but this activity is lost in a 3 M urea solution. What is the most likely explanation for the loss of activity?

(A) Urea binds to the active site of the enzyme competitively with the substrate.

(B) Urea causes the cleavage of the peptide bonds in the enzyme.

(C) Urea causes the enzyme to denature and lose its specific three-dimensional shape.

(D) Urea reacts with disulfide bonds in the enzyme.

60. Tollens' reagent, basic diamminesilver(I) solution, gives a positive test (in the form of a silver mirror) in the presence of aldehydes. Which sugars give a positive Tollens' test?

I.   Sucrose,
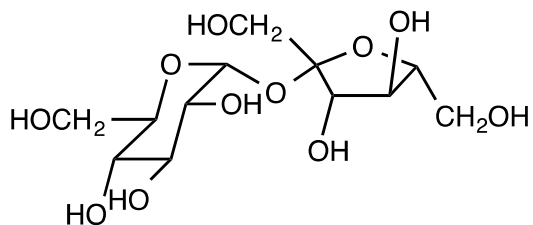
II. Lactose,
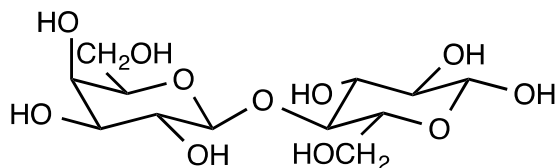
(A) I only	**(B)** II only
(C) Both I and II	**(D)** Neither I nor II

END OF TEST

When you have finished answering this examination or time has been called by the Examiner, please provide responses to the following 4 items. Your answers will not affect your score on the exam but will help with a study being conducted by the U.S. National Chemistry Olympiad (USNCO) Subcommittee.

61. The amount of time I spend doing experiments in the laboratory per week on average during my chemistry course was/is?
  (A) less than ½ hour
  (B) between ½ and 1 hour
  (C) between 1 and 2 hours
  (D) more than 2 hours

The following questions should be answered using the scale
  (A) Strongly agree
  (B) Agree
  (C) Disagree
  (D) Strongly disagree

62. As a result of my participation in the USNCO program, I plan to study more chemistry.

63. As a result of my participation in the USNCO program, I plan to major in chemistry in college.

64. As a result of my participation in the USNCO program, I have a more positive view of chemistry than I did before participating.

2016 USNCO National Exam Part I
ANSWER KEY
(with the percentage of correct answers given by 983 students)

Question	Correct Answer	% Correct Answers	Question	Correct Answer	% Correct Answers
1	D	86%	31	D	87%
2	B	93%	32	B	86%
3	A	86%	33	C	49%
4	A	69%	34	C	37%
5	D	84%	35	B	30%
6	B	61%	36	B	33%
7	B	49%	37	A	73%
8	B	64%	38	C	55%
9	B	31%	39	A	44%
10	D	18%	40	B	10%
11	C	45%	41	B	64%
12	C	70%	42	A	36%
13	A	56%	43	A	27%
14	D	63%	44	D	58%
15	B	57%	45	C	55%
16	A	40%	46	D	30%
17	B	57%	47	A	84%
18	A	90%	48	B	49%
19	D	89%	49	D	57%
20	D	93%	50	A	40%
21	A	70%	51	C	31%
22	D	33%	52	D	76%
23	D	36%	53	D	24%
24	C	62%	54	B	18%
25	B	33%	55	A	37%
26	C	91%	56	B	24%
27	B	43%	57	C	42%
28	C	67%	58	A	51%
29	C	60%	59	C	44%
30	A	49%	60	B	21%