2017 U.S. NATIONAL CHEMISTRY OLYMPIAD

NATIONAL EXAM PART I

Prepared by the American Chemical Society Chemistry Olympiad Examinations Task Force

OLYMPIAD EXAMINATIONS TASK FORCE

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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, 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 26, 2017**, 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 2 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.**

ABBREVIATIONS AND SYMBOLS					
amount of substance	n	Faraday constant	F	molar mass	M
ampere	A	free energy	G	mole	mol
atmosphere	atm	frequency	ν	Planck's constant	h
atomic mass unit	u	gas constant	R	pressure	P
Avogadro constant	N_A	gram	g	rate constant	k
Celsius temperature	°C	hour	h	reaction quotient	Q
centi– prefix	c	joule	J	second	s
coulomb	C	kelvin	K	speed of light	c
density	d	kilo– prefix	k	temperature, K	T
electromotive force	E	liter	L	time	t
energy of activation	E_a	measure of pressure	mm Hg	vapor pressure	VP
enthalpy	H	milli– prefix	m	volt	V
entropy	S	molal	m	volume	V
equilibrium constant	K	molar	M		

CONSTANTS
$R = 8.314$ J mol^{-1} K^{-1}
$R = 0.08314$ L bar mol^{-1} K^{-1}
$F = 96{,}500$ C mol^{-1}
$F = 96{,}500$ J V^{-1} mol^{-1}
$N_A = 6.022 \times 10^{23}$ 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 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)

DIRECTIONS

- 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. Lithium reacts with water to form lithium hydroxide. What mass of lithium is required to produce 12 g of lithium hydroxide?

(A) 2.0 g **(B)** 3.5 g **(C)** 7.0 g **(D)** 12 g

2. Complete combustion of 1.00 g of the hydrocarbon pagodane gives 3.38 g carbon dioxide. What is the empirical formula of pagodane?

(A) CH **(B)** CH_2 **(C)** C_2H_5 **(D)** C_3H_8

3. Electrolysis of 10.00 g of a binary metal chloride deposits 6.207 g of the pure metal. What is the metal?

(A) Cu (Z = 29) **(B)** Cd (Z = 48)

(C) Ce (Z = 58) **(D)** Th (Z = 90)

4. Decomposition of 1.0 g of which of the following compounds into its constituent elements gives the greatest amount of N_2 gas?

(A) NO **(B)** NO_2 **(C)** N_2O_4 **(D)** NH_3

5. Permanganate ion oxidizes hydrogen peroxide in acidic solution according to the following equation:

$$2\ MnO_4^-(aq) + 5\ H_2O_2(aq) + 6\ H^+(aq) \rightarrow$$
$$2\ Mn^{2+}(aq) + 5\ O_2(g) + 8\ H_2O(l)$$

If 35.0 mL of an acidic 0.150 M $KMnO_4$ solution is required to consume all the H_2O_2 in 50.0 mL of a disinfectant solution, what is the concentration of H_2O_2 in the disinfectant?

(A) 0.0420 M **(B)** 0.105 M

(C) 0.263 M **(D)** 0.368 M

6. A solution containing 10 g of which substance dissolved in 100 g of water will show the greatest freezing point depression compared to pure water?

(A) Anhydrous magnesium sulfate, $MgSO_4$

(B) Magnesium sulfate heptahydrate, $MgSO_4 \cdot 7\ H_2O$

(C) Anhydrous sodium thiosulfate, $Na_2S_2O_3$

(D) Sodium thiosulfate pentahydrate, $Na_2S_2O_3 \cdot 5\ H_2O$

7. When a solution of barium hydroxide is mixed with a solution of iron(III) chloride, what is observed?

(A) Precipitation of a colored solid

(B) Precipitation of a colorless solid

(C) Evolution of a colorless gas

(D) Neither precipitation nor gas evolution

8. Which element is a liquid at 25 ºC and 1 atm pressure?

(A) Fluorine **(B)** Chlorine

(C) Bromine **(D)** Iodine

9. The concentration of which approximately 0.01 M solution could be most accurately determined by a visible spectrophotometer (or colorimeter)?

(A) $Mn(NO_3)_2$ **(B)** $Co(NO_3)_2$

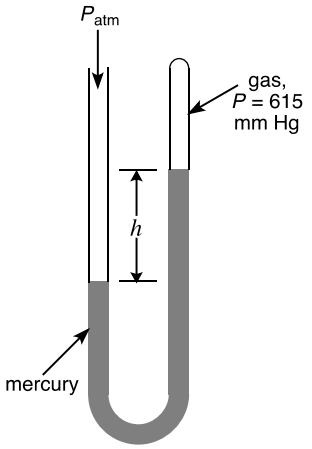
(C) $Zn(NO_3)_2$ **(D)** $Pb(NO_3)_2$

10. A 0.1 M solution of which salt is the most acidic?

(A) $Al(NO_3)_3$ **(B)** $MgBr_2$

(C) $NaHCO_3$ **(D)** $NaHCO_2$

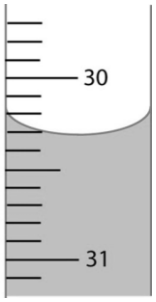
11. A gas with P = 615 mm Hg is contained in the U-tube as shown. If h = 65 mm, what is the atmospheric pressure P_{atm}?



(A) 550 mm Hg **(B)** 615 mm Hg

(C) 680 mm Hg **(D)** 760 mm Hg

12. What is the reading of the buret shown?



(A) 30.20 mL **(B)** 30.25 mL

(C) 30.30 mL **(D)** 31.75 mL

13. A beaker containing 25 mL of liquid 1-aminopentane, $CH_3(CH_2)_4NH_2$, is placed on a hotplate and brought to a boil. As the 1-aminopentane boils,

(A) the total energy of the system stays constant.

(B) the hydrogen bonding between the 1-aminopentane molecules is disrupted.

(C) the ion-dipole forces between the 1-aminopentane molecules are disrupted.

(D) pentane and ammonia gas are formed.

14. Into both ends of a meter-long glass tube samples of gases are introduced simultaneously. One end receives hydrogen chloride gas (HCl) while the other end receives ammonia gas (NH_3). When the gases meet in the tube, they react to form solid ammonium chloride (NH_4Cl). Where in the tube does the NH_4Cl form?

(A) At the center of the tube

(B) Closer to the end where the hydrogen chloride is inserted

(C) Closer to the end where the ammonia is inserted

(D) Uniformly at all positions in the tube

15. At its normal boiling point of –1.0 ºC, a sample of gaseous butane at 1.0 atm occupies a volume of 1.0 L. What is the pressure if the volume is decreased to 0.70 L while maintaining the temperature at –1.0 ºC?

(A) 0.70 atm **(B)** 1.0 atm

(C) 1.4 atm **(D)** 2.0 atm

16. What is the principal energetic factor in the lack of miscibility between $C_6H_{14}(l)$ and $H_2O(l)$?

(A) The strength of intermolecular forces of attraction between $C_6H_{14}(l)$ molecules

(B) The strength of intermolecular forces of attraction between $H_2O(l)$ molecules

(C) The difference between the molecular weights of the molecules

(D) The difference in electronegativity between carbon and hydrogen

17. The melting point of silicon dioxide (1713 ºC) is higher than the melting point of silicon (1414 ºC). What is the best explanation for this difference?

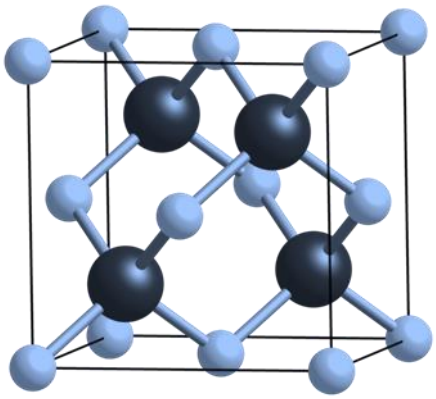
(A) Silicon-oxygen bonds are stronger than silicon-silicon bonds.

(B) Silicon dioxide is an ionic solid while silicon is a metallic solid.

(C) Silicon dioxide is polar while silicon is nonpolar.

(D) Silicon dioxide forms tetragonal crystals while silicon forms cubic crystals.

18. A unit cell of the cubic form of ZnS is shown below (large spheres = Zn, small spheres = S). How many of each type of atom are present in one unit cell?



(A) 1 Zn, 1 S **(B)** 2 Zn, 4 S

(C) 4 Zn, 4 S **(D)** 4 Zn, 14 S

19. What is ΔH^o for the reaction shown?

$$2\ H_2S(g) + 3\ O_2(g) \rightarrow 2\ H_2O(l) + 2\ SO_2(g)$$

Compound	ΔH^o_f, kJ mol^{-1}
$H_2S(g)$	–20.15
$H_2O(l)$	–285.8
$SO_2(g)$	–296.4

(A) –19.4 kJ mol^{-1} **(B)** –374.7 kJ mol^{-1}

(C) –562.1 kJ mol^{-1} **(D)** –1124.1 kJ mol^{-1}

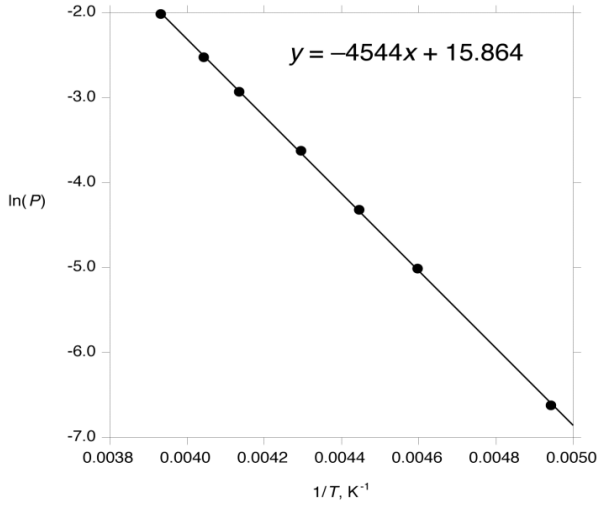
20. Upon which factors can the Gibbs free energy change for a reaction (ΔG_{rxn}) depend?

I. Temperature
II. Concentration of species in solution

(A) I only **(B)** II only

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

21. The natural logarithm of the vapor pressure (in bar) of HCN(*s*) as a function of the reciprocal of the absolute temperature is plotted below.



What is the heat of sublimation of HCN?

(A) 4.54 kJ mol^{-1} **(B)** 15.9 kJ mol^{-1}

(C) 37.8 kJ mol^{-1} **(D)** 132 kJ mol^{-1}

22. Which has the greatest entropy at 0 ºC?

(A) 1.0 mol $H_2O(s)$

(B) 1.0 mol $H_2O(l)$

(C) 1.0 mol $H_2O(g)$

(D) 1.0 mol $H_2(g)$ + 0.5 mol $O_2(g)$

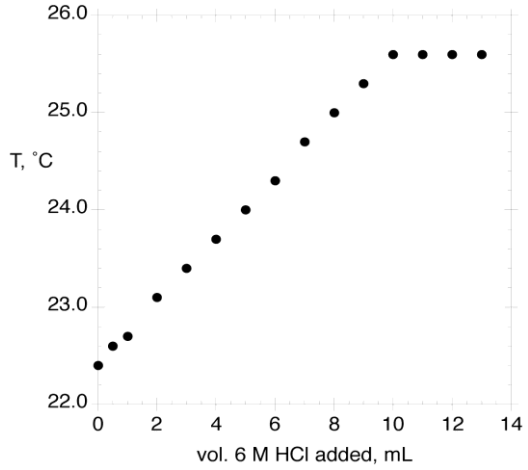
23. What is ΔG^o_f of $CH_4(g)$ at 298 K? (All data are given at 298 K.)

Substance	ΔH^o_f, kJ mol^{-1}	S^o, J mol^{-1} K^{-1}	ΔG^o_f, kJ mol^{-1}
$CH_4(g)$	–74.8	186.3	
$H_2(g)$	0.0	130.7	0.0
$CO_2(g)$	–393.5	213.7	–394.4
$H_2O(g)$	–241.8	188.8	–228.6

(A) –50.7 kJ mol^{-1} **(B)** –75.7 kJ mol^{-1}

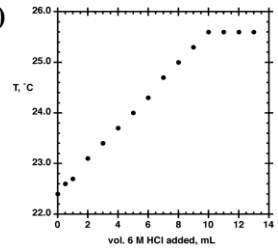
(C) –98.0 kJ mol^{-1} **(D)** –130.3 kJ mol^{-1}

24. A solution containing 0.060 mol NaOH dissolved in 200 g water was treated with successive aliquots of 6.0 M aqueous HCl in a well-insulated flask, and the temperature was measured after each aliquot to give the following data:

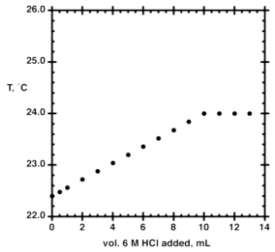


The same experiment was repeated, again using 0.060 mol NaOH and 6.0 M aqueous HCl, but this time the NaOH was initially dissolved in 400 g water. Which graph represents the data obtained in this experiment?

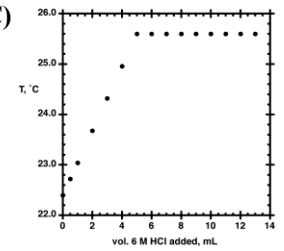
(A)



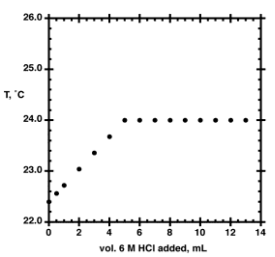
(B)



(C)



(D)



25. For the reaction A + B → products, the rate law is rate = $k[A]^2[B]$. Which change will cause the greatest decrease in reaction rate?

(A) Decreasing [A] by a factor of 2

(B) Decreasing [B] by a factor of 2

(C) Decreasing both [A] and [B] by a factor of 2

(D) Decreasing [B] by a factor of 4

26. For a reaction with an activation energy of 65 kJ mol^{-1}, by what percentage is the rate constant decreased if the temperature is decreased from 37 °C to 22 °C?

(A) 13% **(B)** 27% **(C)** 51% **(D)** 72%

27. A plot of ln[A] as a function of time in an irreversible reaction A → products is linear, with a slope of –0.0175 s^{-1}. What conclusions may be drawn from these observations?

I. The reaction is first-order in A.
II. The rate constant for the reaction is 0.0175 s^{-1}.

(A) I only **(B)** II only

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

28. A sample containing only the isotope ^{99}Mo undergoes radioactive decay as shown:

$$^{99}Mo \xrightarrow[t_{1/2} = 65\ h]{\beta} {}^{99m}Tc \xrightarrow[t_{1/2} = 6\ h]{\gamma} {}^{99}Tc$$

Which of the following statements about the relative activity of ^{99}Mo and ^{99m}Tc in the sample is correct?

(A) The activity of ^{99m}Tc exceeds that of the ^{99}Mo after about 20 h.

(B) The activity of ^{99m}Tc exceeds that of the ^{99}Mo after about 120 h.

(C) The activity of ^{99m}Tc becomes roughly equal to that of the ^{99}Mo after about 20 h.

(D) The activity of ^{99m}Tc becomes roughly equal to that of the ^{99}Mo after about 120 h.

29. Hydrogen peroxide disproportionates to water and molecular oxygen in the presence of iodide in neutral solution according to a mechanism consisting of two elementary steps:

$H_2O_2(aq) + I^-(aq) \rightarrow IO^-(aq) + H_2O(l)$ reaction 1
$H_2O_2(aq) + IO^-(aq) \rightarrow I^-(aq) + O_2(g) + H_2O(l)$ reaction 2

The rate constant for reaction 1 is much larger than the rate constant for reaction 2. Which statement is correct?

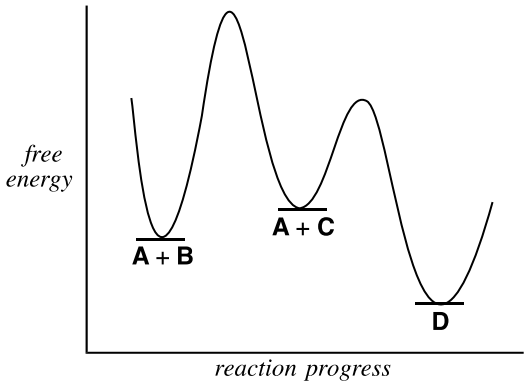
(A) As the reaction proceeds, the predominant form of iodine in solution is $IO^-(aq)$.

(B) Adding more iodide to the reaction will not increase the rate of production of O_2.

(C) The reaction is zeroth-order in H_2O_2.

(D) The reaction will go more slowly at higher O_2 pressures.

30. Which of the following are true about the overall reaction **A** + **B** → **D** illustrated in the diagram?



I. The reaction displays second-order kinetics.
II. The reaction has two intermediates.

(A) I only **(B)** II only

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

31. What is the pH of a 0.25 M solution of NaCN? (The pK_a of HCN is 9.21.)

(A) 4.91 **(B)** 8.61 **(C)** 11.30 **(D)** 13.40

32. The autoionization constant of water at 60 ºC is $K_w = 1.0 \times 10^{-13}$. Which of the following statements are correct?

I. Autoionization of water is exothermic.
II. A sample of pure water at 60 ºC is slightly acidic.

(A) I only **(B)** II only

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

33. Barium carbonate, $BaCO_3$, is stable at ambient temperatures, but decomposes to barium oxide and carbon dioxide at higher temperatures.

$$BaCO_3(s) \rightleftharpoons BaO(s) + CO_2(g)$$

At a certain temperature, this system is in equilibrium in a closed system and contains appreciable amounts of all three compounds. Which changes will lead to an increase in the pressure of CO_2 present at equilibrium?

I. Adding more $BaCO_3(s)$
II. Increasing the volume of the container

(A) I only **(B)** II only
(C) Both I and II **(D)** Neither I nor II

34. If 0.10 mol solid NaOH is added to 1.00 L of a saturated solution of $Ca(OH)_2$ ($K_{sp} = 8.0 \times 10^{-6}$), what percentage of the calcium hydroxide will precipitate at equilibrium?

(A) Roughly 50% **(B)** Roughly 75%
(C) Roughly 95% **(D)** Over 99%

35. The concentration of formic acid ($pK_a = 3.75$) is being determined by titration with sodium hydroxide solution. Which indicators are suitable for this titration?

I. Bromophenol blue (pH transition range 3.0 – 4.6)
II. Neutral red (pH transition range 6.8 – 8.0)

(A) I only **(B)** II only
(C) Both I and II **(D)** Neither I nor II

36. The ionization of ammonium ion is endothermic:

$$NH_4^+(aq) + H_2O(l) \rightarrow NH_3(aq) + H_3O^+(aq)$$
$$\Delta H^o > 0$$

Which changes will result in the increase in $[H_3O^+]$ of a 0.100 M solution of NH_4Cl?

I. Diluting the solution from 1.00 L to 2.00 L
II. Raising the temperature from 25 ºC to 35 ºC

(A) I only **(B)** II only
(C) Both I and II **(D)** Neither I nor II

37. Which changes to this galvanic cell increase the measured potential?

$$Cu(s) \mid Cu^{2+}(aq),\ 0.10\ M \parallel Ag^+(aq),\ 1.0\ M \mid Ag(s)$$

I. Increasing $[Cu^{2+}]$ in the Cu/Cu^{2+} half-cell to 0.50 M
II. Adding Cl^- to the Ag^+/Ag half-cell until $[Cl^-] = 0.01$ M

(A) I only **(B)** II only
(C) Both I and II **(D)** Neither I nor II

38. When the following skeleton equation is balanced with smallest whole number coefficients, what is the coefficient and location of $H_2O(l)$? The reaction takes place in basic solution.

$$Cu(s) + MnO_4^-(aq) \rightarrow Cu(OH)_2(s) + MnO_2(s)$$

(A) 2, on reactant side **(B)** 4, on reactant side
(C) 2, on product side **(D)** 4, on product side

39. Which of the following species contains the element in the highest oxidation state?

(A) OsO_4 **(B)** $Mn_2(CO)_{10}$
(C) N_5^+ **(D)** XeF_8^{2-}

40. What is the standard reduction potential of $Hg^{2+}(aq)$ to $Hg(l)$?

Half Reaction	E^o, V
$2\ Hg^{2+}(aq) + 2e^- \rightarrow Hg_2^{2+}(aq)$	+0.90
$Hg_2^{2+}(aq) + 2e^- \rightarrow 2\ Hg(l)$	+0.80

(A) +1.70 V **(B)** +0.85 V
(C) +0.10 V **(D)** –0.10 V

41. The lead-acid storage battery consists of the following two half-cells:

$$PbO_2(s) + 4\ H^+(aq) + SO_4^{2-}(aq) + 2\ e^- \rightarrow PbSO_4(s) + 2\ H_2O(l)$$
$$Pb(s) + SO_4^{2-}(aq) \rightarrow PbSO_4(s) + 2\ e^-$$

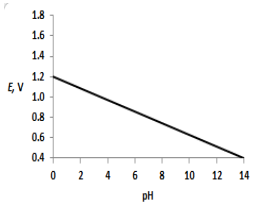
Which of the following concentrations decrease as the battery is discharged?

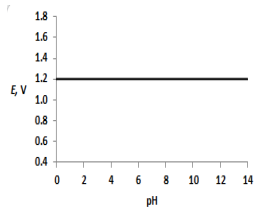
I. $[H^+]$ II. $[Pb^{2+}]$

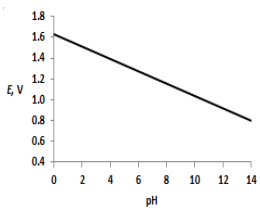
(A) I only **(B)** II only
(C) Both I and II **(D)** Neither I nor II

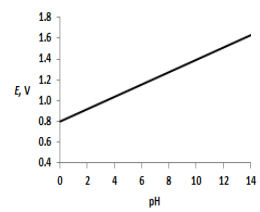
42. Which graph represents the reduction potential of O_2 (at 1 bar pressure and 25 ºC) as a function of pH?

$$O_2(g) + 4\ H^+(aq) + 4\ e^- \rightarrow 2\ H_2O(l) \qquad E^o = 1.23\ V$$

(A)


(B)


(C)


(D)


43. In a ground-state P atom in the gas phase, how many electrons have quantum numbers $n = 3$, $l = 1$, $m_l = -1$?

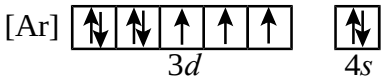
(A) 0 **(B)** 1 **(C)** 2 **(D)** 3

44. Rank the elements Si, P, Ge, and As in increasing order of their first ionization energies.

(A) Si < P < Ge < As **(B)** As < Ge < P < Si

(C) Ge < Si < As < P **(D)** Ge < As < Si < P

45. Which gas-phase atom or ion has the following ground state?



(A) Mn **(B)** Co **(C)** Fe^{+} **(D)** Cu^{2+}

46. Which change in principal quantum number for an electron in a hydrogen atom would correspond to emission of the longest-wavelength photon?

(A) $n = 4 \rightarrow n = 1$ **(B)** $n = 5 \rightarrow n = 2$

(C) $n = 1 \rightarrow n = 5$ **(D)** $n = 2 \rightarrow n = 4$

47. Which pair of elements has the most similar electronegativities?

(A) B and C **(B)** B and Al

(C) B and Si **(D)** Al and C

48. The permanganate ion, MnO_4^-, is purple while the pertechnetate ion, TcO_4^-, is colorless. This difference is most closely related to which difference between manganese and technetium?

(A) Manganese(VII) is a stronger oxidant than technetium(VII).

(B) Manganese consists of a stable isotope while all isotopes of technetium are radioactive.

(C) The Mn–O bond in permanganate is shorter than the Tc–O bond in pertechnetate.

(D) Elemental manganese is less dense than elemental technetium.

49. Which ion has the longest N–O bond?

(A) NO_3^- **(B)** NO_2^- **(C)** NO_2^+ **(D)** NO^+

50. Which pair of species has the same shape?

(A) CO_2 and SO_2 **(B)** CCl_4 and $TiCl_4$

(C) C_2H_6 and B_2H_6 **(D)** NO_3^- and PO_3^{3-}

51. How many distinct C–O bond lengths are present in the oxalate ion, $C_2O_4^{2-}$?

(A) 1 **(B)** 2 **(C)** 3 **(D)** 4

52. Which statement about the molecular orbitals in a molecule is correct?

(A) No molecular orbital may have a net overlap with any other molecular orbital.

(B) Each molecular orbital must have a different number of nodes than every other molecular orbital.

(C) The number of molecular orbitals is equal to half the number of atomic orbitals of the atoms that make up the molecule.

(D) The lowest-energy molecular orbitals are the most antibonding in character and the highest-energy molecular orbitals are the most bonding in character.

53. NF_3 has a bond angle of 102.5º, while PF_3 has a bond angle of 96.3º. What is the best explanation for the larger bond angle in NF_3?

(A) The nitrogen 2*s* orbital participates more in bonding than does the phosphorus 3*s* orbital.

(B) Nitrogen is more electronegative than phosphorus.

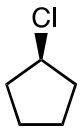
(C) NF_3 has no unpaired electrons while PF_3 has two unpaired electrons.

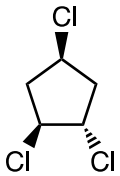
(D) NF_3 is an ionic compound while PF_3 forms covalent bonds.

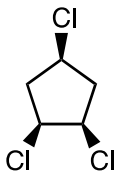
54. Allene has the structure $H_2C{=}C{=}CH_2$. What is the best description of the geometry of allene?

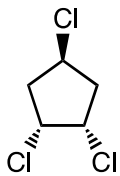
	Geometry at central carbon	Positions of hydrogen atoms
(A)	Linear	All in the same plane
(B)	Linear	In two perpendicular planes
(C)	Bent	All in the same plane
(D)	Bent	In two perpendicular planes

55. Which of the following molecules is chiral?

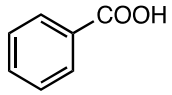
(A) 

(B) 

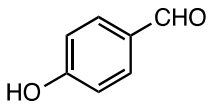
(C) 

(D) 

56. A chemist wishes to separate benzoic acid from 4-hydroxybenzaldehyde. Which is the best method to achieve this separation?



benzoic acid



4-hydroxybenzaldehyde

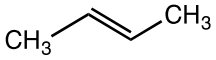
(A) Partitioning the mixture between diethyl ether and water

(B) Partitioning the mixture between diethyl ether and 1 M aqueous $NaHCO_3$

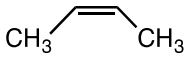
(C) Partitioning the mixture between diethyl ether and 1 M aqueous NaOH

(D) Partitioning the mixture between diethyl ether and 1 M aqueous HCl

57. (*E*)-2-butene and (*Z*)-2-butene (shown below) each react with bromine to form compounds with the formula $C_4H_8Br_2$. What is the relationship between the products?



(*E*)-2-butene

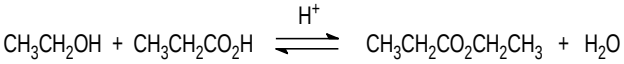


(*Z*)-2-butene

(A) Structural isomers **(B)** Enantiomers

(C) Diastereomers **(D)** Identical

58. What is the role of the acid catalyst in the Fischer esterification reaction below?



(A) Shifts the equilibrium in the right-hand direction

(B) Neutralizes the base formed as a side product in the reaction

(C) Converts ethanol to a more reactive nucleophile

(D) Converts propanoic acid to a more reactive electrophile

59. The isoelectric point of a protein is the pH at which it is electrically neutral. Which mutation of an amino acid $NH_2CHRCOOH$ in the protein would have the greatest effect on its isoelectric point, assuming that the mutation does not significantly affect the protein's overall structure?

(A) Serine (R = CH_2OH) → Lysine (R = $CH_2CH_2CH_2CH_2NH_2$)

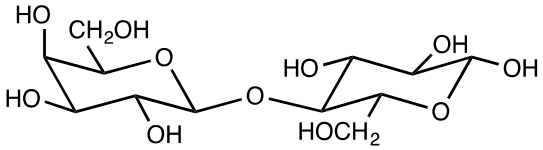
(B) Glutamine (R = $CH_2CH_2CONH_2$) → Methionine (R = $CH_2CH_2SCH_3$)

(C) Isoleucine (R = $CH[CH_3]CH_2CH_3$) → Valine (R = $CH[CH_3]_2$)

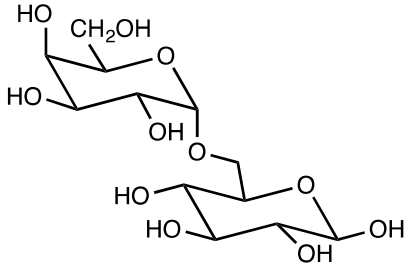
(D) Alanine (R = CH_3) → Glycine (R = H)

60. Hydrolysis of which disaccharide with dilute acid gives only a single type of monosaccharide as a product?

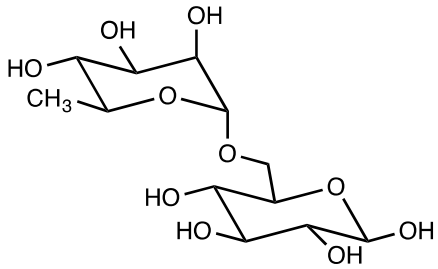
(A) Lactose,



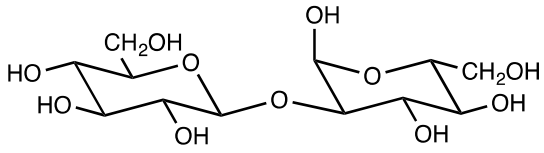
(B) Melibiose,



(C) Rutinose,



(D) Sophorose,



END OF TEST

PLEASE ANSWER THE FOLLOWING FOUR QUESTIONS

THANK YOU!

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.

Olympiad 2017
USNCO National Exam Part I
KEY

Number	Answer
1.	B
2.	A
3.	D
4.	D
5.	C
6.	C
7.	A
8.	C
9.	B
10.	A
11.	C
12.	C
13.	B
14.	B
15.	B
16.	B
17.	A
18.	C
19.	D
20.	C
21.	C
22.	D
23.	A
24.	B
25.	C
26.	D
27.	C
28.	C
29.	A
30.	D

Number	Answer
31.	C
32.	D
33.	D
34.	C
35.	B
36.	B
37.	D
38.	B
39.	A
40.	B
41.	A
42.	A
43.	B
44.	C
45.	B
46.	B
47.	C
48.	A
49.	A
50.	B
51.	A
52.	A
53.	A
54.	B
55.	B
56.	B
57.	C
58.	D
59.	A
60.	D