ACS USNCO
U.S. National Chemistry Olympiad

2020 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 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 27, 2020**, 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.

The USNCO Subcommittee is conducting a survey in an effort to determine the impact of the Olympiad program on students. At the end of **Part I** 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.

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 and assigned ID number on the answer sheet. **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

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

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** 78.97	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. Iron(III) sulfide reacts with gaseous hydrogen chloride to produce iron(III) chloride and hydrogen sulfide. How much iron(III) sulfide would be required to react with 1.5 mol HCl?

(A) 0.25 mol **(B)** 0.50 mol

(C) 0.75 mol **(D)** 1.0 mol

2. How much CH_4 remains after 10.0 g of CH_4 reacts completely with 15.0 g of O_2 according to the following equation?

$$CH_4(g) + 2\ O_2(g) \rightarrow CO_2(g) + 2\ H_2O(g)$$

(A) 0.00 g **(B)** 2.50 g **(C)** 5.00 g **(D)** 6.25 g

3. A sample of 1.00 g of which compound contains the greatest number of atoms?

(A) CO (M = 28.0) **(B)** C_2H_6 (M = 30.0)

(C) C_6H_6 (M = 78.0) **(D)** Kr (M = 83.8)

4. 200.0 mL of aqueous nitric acid is mixed with 300.0 mL of 0.200 M $Mg(NO_3)_2$ solution to give a solution with a nitrate ion concentration of 0.500 M. What is the concentration of the nitric acid?

(A) 0.100 M **(B)** 0.650 M

(C) 0.950 M **(D)** 1.25 M

5. A student wishes to prepare a solution with a final concentration of Na^+ = 0.50 M and a final concentration of HCO_3^- = 0.10 M by taking some NaOH and some trona (Na_2CO_3•$NaHCO_3$•$2H_2O$) and diluting with water to a final volume of 1.00 L. How much NaOH and trona are required?

(A) 0.05 mol NaOH, 0.15 mol trona

(B) 0.20 mol NaOH, 0.10 mol trona

(C) 0.35 mol NaOH, 0.05 mol trona

(D) A solution cannot be prepared with the desired concentrations of Na^+ and HCO_3^- using only NaOH and trona.

6. As the concentration of an aqueous solution of sodium chloride increases from 1.0 M to 2.0 M, the values of which properties of the solution decrease?

I. Density
II. Freezing point

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

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

7. Which ion gives a green flame test?

(A) Potassium **(B)** Calcium

(C) Strontium **(D)** Barium

8. The equilibrium constant for the formation of $CoCl_4^{2-}$, a species that is blue in solution, is to be measured using a colorimeter. The colorimeter has wavelength settings of 470 nm ("blue"), 565 nm ("green"), and 635 nm ("red") to use in the experiment. What is the best setting to use?

(A) 470 nm

(B) 565 nm

(C) 635 nm

(D) All settings would be equally suitable for the measurement.

9. A student is using a coffee-cup calorimeter to determine the enthalpy change of the endothermic reaction of two aqueous solutions. After both solutions are added to the cup, the student neglects to put the lid on the cup. This would cause the magnitude of the calculated $\Delta H°$ value to be:

(A) too small, since some heat will escape out of the cup.

(B) too large, since some heat will escape out of the cup.

(C) too small, since the solution will absorb heat from the room.

(D) too large, since the solution will absorb heat from the room.

10. Which substance produces a toxic and explosive gas when added to strong acids?

(A) NaN_3 **(B)** Na_2CO_3

(C) $NaClO_4$ **(D)** Na_2SO_3

11. When aqueous ethanol is treated with an acidified solution of potassium dichromate, what is observed?

I. Color change
II. Gas evolution

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

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

12. Mixing which 0.1 M aqueous solutions results in formation of a colored precipitate?

(A) $BaCl_2$ and CH_3COOH

(B) $BaCl_2$ and Na_2CO_3

(C) $CuCl_2$ and CH_3COOH

(D) $CuCl_2$ and Na_2CO_3

13. Which liquid has the highest vapor pressure at 25 °C?

(A) $CHCl_3$ **(B)** $CFCl_3$

(C) CCl_4 **(D)** $CBrCl_3$

14. A sample of cyclohexane (C_6H_{12}, bp = 81 °C) is introduced into an evacuated container at 40 °C. One-third of the cyclohexane by mass is in the form of the liquid and two-thirds is in the form of the vapor. The volume of the container is then doubled, maintaining the temperature at 40 °C. What happens to the pressure as the volume is doubled?

(A) The pressure remains the same.

(B) The pressure decreases by 25%.

(C) The pressure decreases by 33%.

(D) The pressure decreases by a factor of two.

15. The normal boiling points of ammonia, water, and hydrogen fluoride increase in the order NH_3 (bp = –33 °C) < HF (bp = 19 °C) < H_2O (bp = 100 °C). What is the best explanation for this ordering?

(A) H_2O forms a greater number of hydrogen bonds per mol than NH_3 or HF.

(B) H_2O forms stronger hydrogen bonds than NH_3 or HF.

(C) H_2O has a larger dipole moment than NH_3 or HF.

(D) H_2O has stronger London dispersion forces than NH_3 or HF.

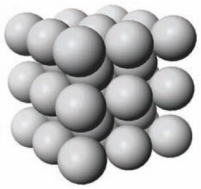
16. Which gas has the smallest molar volume at STP?

(A) He **(B)** NH_3 **(C)** N_2 **(D)** CO

17. Which solid has the highest melting point?

(A) OF_2 **(B)** MgF_2 **(C)** SiO_2 **(D)** ClO_2

18. A portion of the structure of solid potassium is shown below. In what type of unit cell are the atoms arranged?



(A) Primitive cubic

(B) Body-centered cubic

(C) Face-centered cubic

(D) Hexagonal closest packed

19. What is the standard enthalpy of formation of $C_2H_2(g)$?

	$\Delta H°_{rxn}$, kJ mol^{-1}
$C_2H_2(g) + {}^5/_2\ O_2(g) \rightarrow 2CO_2(g) + H_2O(l)$	−1229.6
$C(s,\ \text{graphite}) + O_2(g) \rightarrow CO_2(g)$	−393.5
$H_2(g) + ½\ O_2(g) \rightarrow H_2O(l)$	−285.9

(A) –2302.5 kJ mol^{-1} **(B)** –1909.0 kJ mol^{-1}

(C) 156.7 kJ mol^{-1} **(D)** 550.2 kJ mol^{-1}

20. Which reaction occurs with the greatest increase in entropy?

(A) $ClF(s) \rightarrow ClF(g)$

(B) $ClF(s) \rightarrow ClF(l)$

(C) $ClF(l) \rightarrow ClF(g)$

(D) $ClF(g) \rightarrow {}^1/_2\ Cl_2(g) + {}^1/_2\ F_2(g)$

21. A 2.00 g sample of solid $RbClO_4$ (M = 184.92) is added to 100.0 g water, both initially at 23.00 °C, in a well-insulated container. The final temperature of the solution is 21.56 °C. What is $\Delta H°_{solution}$ of $RbClO_4$? (Assume that the specific heat capacity of the solution is the same as that of pure water and neglect the heat capacity of the insulated container.)

(A) –0.615 kJ mol^{-1} **(B)** 0.615 kJ mol^{-1}

(C) 13.6 kJ mol^{-1} **(D)** 56.8 kJ mol^{-1}

22. For a reaction studied over a wide temperature range, plots of $\Delta G°_{rxn}/T$ vs. $1/T$ and of $\Delta G°_{rxn}$ vs. T are linear. Which of the following must be independent of temperature?

I. $\Delta G°_{rxn}$
II. $\Delta H°_{rxn}$

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

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

23. Elemental tin forms two allotropes, white tin and gray tin. For the conversion of white tin to gray tin, $\Delta H° = -2.02$ kJ mol^{-1} and $\Delta S° = -7.04$ J mol^{-1} K^{-1}. Which statement best describes the stability of the two phases?

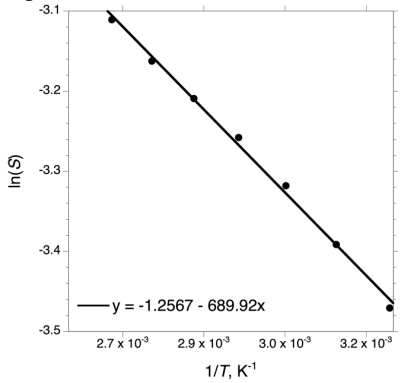
(A) White tin is stable below 13.8 °C and gray tin is stable above this temperature.

(B) Gray tin is stable below 13.8 °C and white tin is stable above this temperature.

(C) White tin is stable below 0.3 °C and gray tin is stable above this temperature.

(D) Gray tin is stable below 0.3 °C and white tin is stable above this temperature.

24. The plot of the natural logarithm of the molar solubility (S) of Ag_2SO_4 as a function of the reciprocal of the absolute temperature is shown below.



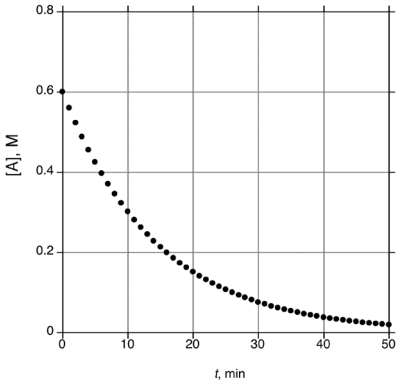
What is $\Delta H°_{rxn}$ for the following reaction?

$$Ag_2SO_4(s) \rightarrow 2\ Ag^+(aq) + SO_4^{2-}(aq)$$

(A) –19.8 kJ mol^{-1} **(B)** –10.5 kJ mol^{-1}

(C) 5.74 kJ mol^{-1} **(D)** 17.2 kJ mol^{-1}

25. A reaction A → 2 B was monitored over time. What is the average rate of disappearance of A between $t = 0$ and $t = 10$ minutes?



(A) 0.03 M min^{-1} **(B)** 0.04 M min^{-1}

(C) 0.06 M min^{-1} **(D)** 0.07 M min^{-1}

26. An irreversible reaction A + B → products is monitored in buffered aqueous solution under conditions where [B] >> [A] by measuring the concentration of A as a function of time. The decay of A is found to be first-order under these conditions, with the half-life for its disappearance varying as shown. What is the rate law for this reaction?

[B]	pH	Half-life for disappearance of A
0.100 M	1.00	120 s
0.200 M	1.00	60 s
0.200 M	1.50	190 s

(A) Rate = k[A][B][H$^+$] **(B)** Rate = k[A]/[B]

(C) Rate = k[A][H$^+$]^2/[B] **(D)** Rate = k[A][B][H$^+$]^2

27. The thermal decomposition of NOCl is a second-order process, and the rate constant k for the disappearance of NOCl at 160 °C is 0.0037 M^{-1} s^{-1}. What is the concentration of NOCl, initially at 0.043 M, after 20.0 minutes at 160 °C?

(A) 0.00051 M **(B)** 0.036 M

(C) 0.040 M **(D)** 0.042 M

28. Bismuth-212 undergoes both α decay (35.9%) and β decay (64.1%) with an overall half-life of 60.6 minutes. What is its half-life for α decay?

(A) 21.8 min **(B)** 38.8 min

(C) 94.7 min **(D)** 169 min

29. A reaction A $\rightleftharpoons$ B is reversible, with $K_{eq} = 1.00$. The forward reaction is first-order in A. In a reaction initially containing only A at an initial concentration of $[A]_0$, which plot will be linear over the course of the reaction?

(A) ln([A]) vs. time

(B) ln([A]–0.5[A]$_0$) vs. time

(C) 1/[A] vs. time

(D) 1/([A]–0.5[A]$_0$) vs. time

30. The decomposition of nitryl chloride takes place according to the following equation:

$$2\ NO_2Cl(g) \rightarrow 2\ NO_2(g) + Cl_2(g)$$

The following mechanism is proposed for this reaction:

$$NO_2Cl(g) \rightleftharpoons NO_2(g) + Cl(g)$$

$$NO_2Cl(g) + Cl(g) \rightarrow NO_2(g) + Cl_2(g)$$

Which rate laws are INCONSISTENT with the proposed mechanism, regardless of the relative rates of the two steps?

I. Rate = k[NO$_2$Cl]
II. Rate = k[NO$_2$Cl]^2

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

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

31. A sample of SO_2Cl_2 is introduced into a movable piston with the pressure maintained at 1.00 atm and the temperature at 450 K. The volume increases as the sulfuryl chloride equilibrates according to the following endothermic reaction:

$$SO_2Cl_2(g) \rightleftharpoons SO_2(g) + Cl_2(g) \qquad \Delta H° > 0$$

Which changes would decrease the number of moles of $SO_2Cl_2(g)$ present in the piston at equilibrium? In each case, the pressure is maintained at 1.00 atm.

I. The temperature of the system is increased to 500 K.

II. A sample of Ar(g) is injected into the piston.

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

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

32. Equal volumes of 0.500 M HCO_2H and 0.100 M $Na(O_2CCH_3)$ are mixed. What is the pH of the resulting solution? The pK_a of HCO_2H is 3.75 and the pK_a of CH_3CO_2H is 4.75.

(A) 2.18 **(B)** 3.15 **(C)** 3.75 **(D)** 4.25

33. The formation constant K_f of the hexamminecadmium ion, $Cd(NH_3)_6^{2+}$, is 2.6×10^5. In a solution whose ammonia concentration is 0.12 M, what percentage of the cadmium in solution is in the form of $Cd(NH_3)_6^{2+}$?

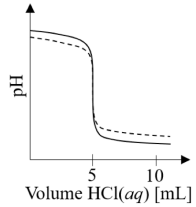
(A) 44% **(B)** 51% **(C)** 78% **(D)** > 99%

34. The K_{sp} of $Sr(OH)_2$ is 2.0×10^{-3}. What is the pH of a saturated solution of $Sr(OH)_2$?

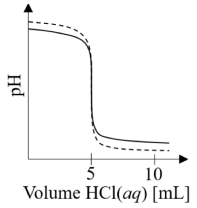
(A) 11.30 **(B)** 12.65 **(C)** 12.90 **(D)** 13.20

35. When 0.100 M HCl was added to a 10.0 mL sample of aqueous NaOH, it generated the titration curve shown as a solid line. If the same number of moles of NaOH, but initially at a volume of 20.0 mL, were titrated with 0.100 M HCl, which of the dashed curves would best describe this new titration?

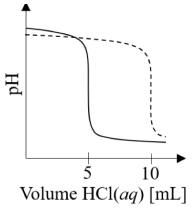
(A)



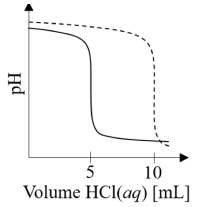
(B)



(C)



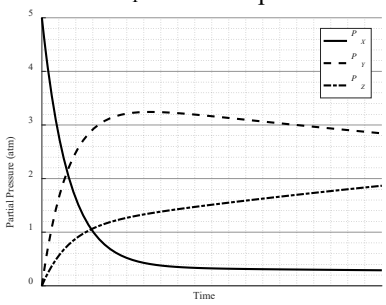
(D)



36. A gas X reacts reversibly and independently to form two different gases, Y and Z:

$$X(g) \rightleftarrows Y(g) \qquad K_Y$$
$$X(g) \rightleftarrows Z(g) \qquad K_Z$$

At a certain temperature, the time evolution of the pressures of the three gases are shown. What is the equilibrium constant K_Y at this temperature?



(A) 3.0

(B) 8.0

(C) 9.3

(D) It cannot be determined because the system has not yet reached equilibrium.

37. When the following reaction is balanced under basic conditions, what is the ratio of the coefficients of $Mn(OH)_2(s)$ to $MnO_4^{2-}(aq)$?

$$Mn(OH)_2(s) + MnO_4^-(aq) \rightarrow MnO_4^{2-}(aq)$$

(A) 3 : 1 **(B)** 1 : 3 **(C)** 1 : 4 **(D)** 1 : 5

38. What is the standard reduction potential for the reduction of permanganate ion to managanese dioxide in acidic solution?

Half-Reaction	$E°$, V
$MnO_4^-(aq) + 8\ H^+(aq) + 5\ e^- \rightarrow Mn^{2+}(aq) + 4\ H_2O(l)$	+1.51
$MnO_2(s) + 4\ H^+(aq) + 2\ e^- \rightarrow Mn^{2+}(aq) + 2\ H_2O(l)$	+1.23
$MnO_4^-(aq) + 4\ H^+(aq) + 3\ e^- \rightarrow MnO_2(s) + 2\ H_2O(l)$	???

(A) +0.28 V **(B)** +1.37 V

(C) +1.43 V **(D)** +1.70 V

39. A current of 1.20 A passed through a solution of a metal nitrate for 153 minutes plates out 3.92 g of the metal. What is the metal?

(A) Ni **(B)** Cu **(C)** Rh **(D)** Ba

40. Which changes will lead to an increase in the theoretical cell potential for a hydrogen-oxygen fuel cell?

I. A more efficient catalyst is used at the cathode.
II. The temperature is increased from 298 K to 320 K.

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

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

41. Metallic gold will not dissolve in nitric acid alone, but will dissolve in a mixture of nitric and hydrochloric acids. Which is the best explanation for this observation?

(A) Chloride ion complexes gold(III), stabilizing it as $AuCl_4^-$.

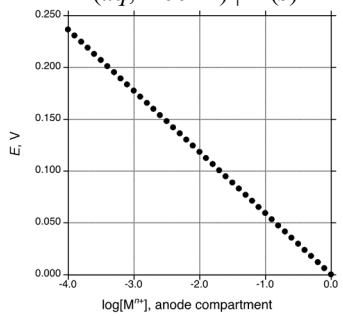
(B) Nitric acid is a stronger oxidant in more acidic solution.

(C) Nitric and hydrochloric acids react to form NO_2Cl, which reacts readily with metallic gold.

(D) Nitric and hydrochloric acids react to form Cl_2, which reacts readily with metallic gold.

42. A concentration cell is set up with a metal M and aqueous solutions of the M^{n+} ion. The cell potential at 298 K as a function of the logarithm of the $[M^{n+}]$ in the anode is graphed below. What may be concluded about the value of n?

$M(s) \mid M^{n+}(aq, \text{variable concentration}) \parallel M^{n+}(aq, 1.00\ M) \mid M(s)$



(A) $n = 1$

(B) $n = 2$

(C) $n = 3$

(D) n cannot be determined from the information given.

43. A hydrogen atom emits light as it changes from a state with a principal quantum number n+3 to a state with principal quantum number n. Which change causes the greatest change in the energy of the emitted photon?

(A) The initial state is changed to n+4.

(B) The initial state is changed to n+2.

(C) The final state is changed to n+1.

(D) The final state is changed to n–1.

44. The first three ionization energies (in kJ mol^{-1}) of four metallic elements are listed below. Which element would form the chloride salt with the lattice energy that is largest in magnitude?

(A) 419, 3052, 4420 **(B)** 503, 965, 3600

(C) 520, 7298, 11815 **(D)** 590, 1145, 4912

45. Which element releases the greatest amount of energy upon addition of an electron to a gas-phase atom?

(A) N **(B)** O **(C)** P **(D)** S

46. Which species is the strongest oxidant in aqueous solution?

(A) TcO_4^- **(B)** RuO_4

(C) ReO_4^- **(D)** OsO_4

47. Which gas-phase atom contains the greatest number of unpaired electrons in its ground state?

(A) Be **(B)** Al **(C)** Ti **(D)** Cu

48. A clean sample of magnesium metal is irradiated under vacuum with a 1 W laser. If the laser wavelength is 400 nm, nothing happens, but if the wavelength is 300 nm, then electrons with 45.6 kJ mol^{-1} of energy are ejected from the Mg surface. What happens if a 2 W laser is used instead?

(A) There is no change at 400 nm, but at 300 nm twice as many electrons are emitted at 45.6 kJ mol^{-1}.

(B) There is no change at 400 nm, but at 300 nm, electrons are emitted at 91.2 kJ mol^{-1}.

(C) There is no change at 400 nm, but at 300 nm, electrons are emitted at 444 kJ mol^{-1}.

(D) At 400 nm, electrons are emitted at 245 kJ mol^{-1}, while at 300 nm, electrons are emitted at 444 kJ mol^{-1}.

49. Which species has the strongest bond?

(A) HF **(B)** HCl **(C)** HBr **(D)** HI

50. Which species has the smallest bond angle?

(A) NO_3^- **(B)** NO_2^- **(C)** FNO_2 **(D)** NF_3

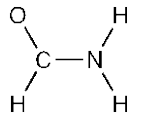
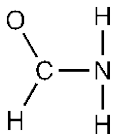
51. Which ions are linear?

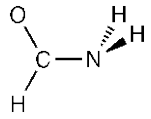
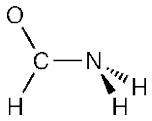
I. N_3^-
II. $N_2O_2^{2-}$

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

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

52. Which is the most stable arrangement of the atoms in space in formamide, $HC(O)NH_2$?

(A)  **(B)** 

(C)  **(D)** 

53. Molecular chlorine, Cl_2, has a smaller ionization energy than atomic chlorine, Cl (IE = 1108 kJ mol^{-1} for Cl_2 and 1256 kJ mol^{-1} for Cl). Which is the best explanation for this difference?

(A) Cl_2 has a covalent bond while Cl does not.

(B) Cl_2 has no unpaired electrons while Cl has one unpaired electron.

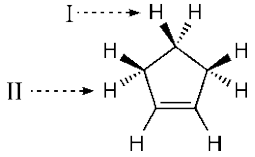
(C) The electron ionized from Cl_2 comes from an orbital that has antibonding character.

(D) The electron ionized from Cl_2 comes from an orbital that has *d* orbital character.

54. How many stereoisomers are possible for the complex ion $[Co(NH_3)_2(CN)_2Cl_2]^-$?

(A) 4 **(B)** 5 **(C)** 6 **(D)** 8

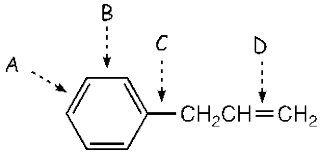
55. Replacing which hydrogens with chlorine would give a chiral molecule?



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

(C) Either I or II **(D)** Neither I nor II

56. Which carbon-carbon bond is the shortest?



(A) A **(B)** B **(C)** C **(D)** D

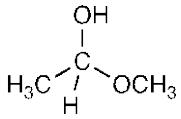
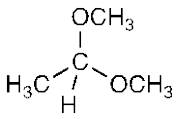
57. What is the best description of the geometry at carbon in the transition state of the following reaction?

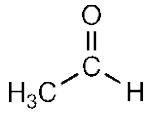
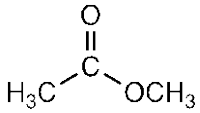
$$OH^- + CH_3Br \rightarrow CH_3OH + Br^-$$

(A) Trigonal planar **(B)** Tetrahedral

(C) Trigonal bipyramidal **(D)** Square pyramidal

58. Which compound will NOT react readily in aqueous sodium hydroxide solution?

(A)  **(B)** 

(C)  **(D)** 

59. Treatment of acetyl chloride with an equimolar amount of diethylamine at room temperature in diethyl ether gives no more than a 50% yield of *N*,*N*-diethylacetamide. Which is the best explanation for this observation?

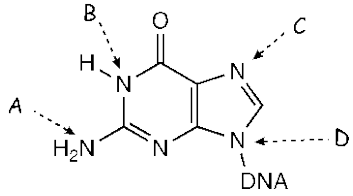
(A) Half of the diethylamine is consumed by the neutralization of HCl produced in the reaction.

(B) Hydrogen bonding between diethylamine molecules makes the reaction second-order in diethylamine.

(C) Traces of water in the solvent convert at least half of the acetyl chloride into acetic acid.

(D) Diethylamine is a strong base, but a weak nucleophile.

60. Guanine, one of the bases in DNA, is susceptible to attack by alkylating agents. Which nitrogen in guanine is most prone to alkylation?



(A) A **(B)** B **(C)** C **(D)** D

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.

Questions on the next page.

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 2020
USNCO National Exam Part I
KEY

Question	Correct Answer	%Correct Answers
1.	A	85%
2.	D	78%
3.	B	60%
4.	B	65%
5.	A	19%
6.	B	75%
7.	D	62%
8.	C	46%
9.	C	47%
10.	A	41%
11.	A	48%
12.	D	70%
13.	B	13%
14.	B	26%
15.	A	47%
16.	B	32%
17.	C	59%
18.	B	59%
19.	C	87%
20.	A	91%
21.	D	61%
22.	B	51%
23.	B	65%
24.	D	28%
25.	A	93%
26.	A	57%
27.	B	73%
28.	D	28%
29.	B	26%
30.	B	48%

Question	Correct Answer	%Correct Answers
31.	C	17%
32.	B	31%
33.	A	33%
34.	D	59%
35.	A	62%
36.	B	8%
37.	D	41%
38.	D	30%
39.	C	48%
40.	D	25%
41.	A	48%
42.	A	40%
43.	D	61%
44.	D	36%
45.	D	35%
46.	B	32%
47.	C	76%
48.	A	51%
49.	A	88%
50.	D	66%
51.	A	61%
52.	A	39%
53.	C	53%
54.	C	53%
55.	B	54%
56.	D	74%
57.	C	39%
58.	B	28%
59.	A	47%
60.	C	40%