ACS USNCO
U.S. National Chemistry Olympiad

2022 U.S. NATIONAL CHEMISTRY OLYMPIAD
NATIONAL EXAM PART I

Prepared by the American Chemical Society Chemistry Olympiad Examinations Task Force

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DIRECTIONS TO THE EXAMINER

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 **May 14, 2022**, 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 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	year	y

CONSTANTS

$R = 8.314 \text{ J mol}^{-1} \text{ K}^{-1}$

$R = 0.08314 \text{ L bar mol}^{-1} \text{ K}^{-1}$

$F = 96{,}500 \text{ C mol}^{-1}$

$F = 96{,}500 \text{ J V}^{-1} \text{mol}^{-1}$

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

$h = 6.626 \times 10^{-34} \text{ J s}$

$c = 2.998 \times 10^8 \text{ m s}^{-1}$

$0 \text{ °C} = 273.15 \text{ K}$

$1 \text{ atm} = 1.013 \text{ bar} = 760 \text{ mm Hg}$

Specific heat capacity of H_2O = $4.184 \text{ J g}^{-1} \text{K}^{-1}$

EQUATIONS

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

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

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

PERIODIC TABLE OF THE ELEMENTS

1 1A																	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)

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- 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. 0.125 g of strontium metal reacts with excess liquid ammonia to form strontium amide and hydrogen gas. How many moles of hydrogen are produced?

   (A) 7.13×10^{-4} mol

   (B) 1.43×10^{-3} mol

   (C) 2.14×10^{-4} mol

   (D) 2.85×10^{-3} mol

2. A diamagnetic compound is 71.4% arsenic by mass. What is its molecular formula?

   (A) CH_3AsN

   (B) C_2H_6As

   (C) $C_2H_6As_2N_2$

   (D) $C_4H_{12}As_2$

3. Weighed samples of iron are added in increments to a given amount of liquid bromine and allowed to react completely. The reaction produces a single product that is isolated and weighed. Which statement best describes the experiments summarized by the graph?
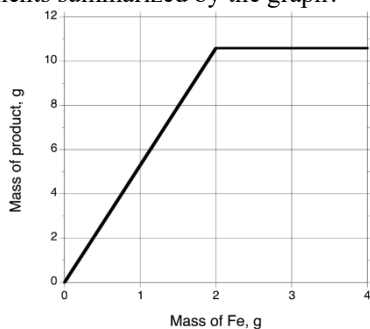

   (A) When 1.00 g of Fe is added, Fe is the limiting reactant.

   (B) When 2.00 g of Fe is added, 10.6 g of $FeBr_2$ is formed.

   (C) When 2.50 g of Fe is added, both reactants are used completely.

   (D) When 3.50 g of Fe is added, there is an excess of Br_2.

4. A copper ore consists of a mixture of Cu_2S and CuS. An 89.0 g sample of this ore is smelted to produce 67.5 g of elemental copper. What is the mass of CuS in the ore sample?

   (A) 13.3 g   (B) 26.6 g   (C) 37.5 g   (D) 64.1 g

5. The hypochlorite concentration in bleach can be determined by treating it with excess iodide ion in acidic solution, which causes the formation of triiodide ion according to the following balanced reaction:

   $$OCl^-(aq) + 3\ I^-(aq) + 2\ H_3O^+(aq) \rightarrow$$
   $$Cl^-(aq) + I_3^-(aq) + 3\ H_2O(l)$$
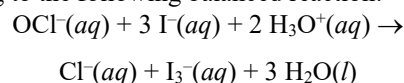
   The triiodide can then be titrated with sodium thiosulfate:
   $$I_3^-(aq) + 2\ S_2O_3^{2-}(aq) \rightarrow 3\ I^-(aq) + S_4O_6^{2-}(aq)$$
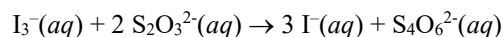
   A 75.0-mL sample of liquid bleach is treated with excess KI and acid, and then titrated with 0.0235 M sodium thiosulfate solution. The endpoint is observed on the addition of 21.23 mL of this solution. What is the hypochlorite concentration in the bleach?

   (A) 4.99×10^{-4} M

   (B) 1.66×10^{-3} M

   (C) 3.33×10^{-3} M

   (D) 6.65×10^{-3} M

6. Which aqueous solution has the highest normal boiling point?

   (A) 0.10 M Na_3PO_4

   (B) 0.30 M Na_2HPO_4

   (C) 0.50 M NaH_2PO_4

   (D) 0.70 M H_3PO_4

7. Which element gives a red flame test?

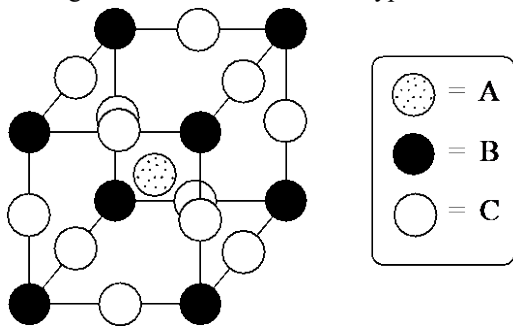   (A) Aluminum

   (B) Boron

   (C) Sodium

   (D) Strontium

8. Combining which solutions would produce a color change?

   (A) $NaCl(aq)$ and $Br_2(aq)$

   (B) $Na_2CO_3(aq)$ and $HNO_3(aq)$

   (C) $K_2C_2O_4(aq)$ and $FeCl_3(aq)$

   (D) $CH_3COOH(aq)$ and $Co(NO_3)_2(aq)$

9. Which metal resists oxidation in air because it forms a protective oxide coating?

   (A) Al   (B) Ca   (C) Fe   (D) Sr

10. Which experiment would be most appropriate for determining the number of components in a commercial nail polish remover?

    (A) Gas chromatography

    (B) Paper chromatography

    (C) Boiling point determination

    (D) Combustion analysis

11. A solution containing a divalent metal ion forms a precipitate when treated with hydrogen sulfide which does not dissolve in 1 M HCl. Which ion is present?

    (A) Ca^{2+} (B) Mn^{2+} (C) Cd^{2+} (D) Ba^{2+}

12. An unknown metal M reacts with aqueous sulfuric acid to form hydrogen gas and the divalent metal ion $M^{2+}(aq)$. A student collects the hydrogen over water and calculates the molar mass of M based on the volume of hydrogen collected. Which error will result in a value of the calculated molar mass that is higher than the true molar mass?

    (A) The concentration of sulfuric acid is 2.0 M rather than 1.0 M as recommended by the procedure.

    (B) Some of the metal sample has oxidized to the metal oxide.

    (C) The barometric pressure is assumed to be 760 torr when in fact it is 740 torr.

    (D) The vapor pressure of water is not included in the calculation.

13. A 1.0-L container with 1.00 atm Ar gas is connected by a stopcock to a 2.0-L container containing 0.5 atm Kr gas. Which statement accurately describes the system after the stopcock is opened and the system is allowed to reach equilibrium? The temperature is 25 °C throughout the experiment.

    (A) The total pressure is 1.00 atm.

    (B) The number of moles of Ar in the 2.0-L container is equal to the number of moles of Kr in the 1.0-L container.

    (C) The average speed of the Ar atoms is equal to the average speed of the Kr atoms.

    (D) The partial pressure of Ar is equal to the partial pressure of Kr.

14. The normal boiling point of CH_2Br_2 is 97 °C while the normal boiling point of $CHBr_3$ is 149 °C. Differences in which interactions are most responsible for this difference in boiling points?

    (A) London dispersion forces

    (B) Dipole-dipole interactions

    (C) Hydrogen bonding

    (D) Carbon-bromine covalent bonding

15. The triple point of ethyne, C_2H_2, is 192.4 K and 1.2 atm. What may be concluded from this information?

    (A) Solid ethyne sublimes rather than melting at 1 atm pressure.

    (B) Solid ethyne is less dense than liquid ethyne.

    (C) Solid ethyne is not thermodynamically stable at 193.0 K.

    (D) A sample of ethyne at 192.4 K must have a pressure of 1.2 atm.

16. The volume of a sample of gaseous SF_6 would increase by more than a factor of two under which of these conditions?

    I. It is heated from 300.0 K to 600.0 K at a pressure of 1.00 atm.

    II. The pressure is decreased from 2.00 atm to 1.00 atm at 300 K.

    (A) I only   (B) II only

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

17. A pure sample of benzene (C_6H_6) melts sharply at 5.5 °C, while a pure sample of hexafluorobenzene (C_6F_6) melts sharply at 5.2 °C. However, an equimolar mixture of C_6H_6 and C_6F_6 melts sharply at 23.7 °C. Which is the best explanation for this observation?

    (A) C_6H_6 and C_6F_6 are immiscible in the liquid phase.

    (B) C_6H_6 and C_6F_6 form a crystal containing equal amounts of the two substances.

    (C) Fluorocarbons characteristically show negative freezing point depression constants.

    (D) The enthalpy of mixing of C_6H_6 and C_6F_6 is negative.

18. A unit cell of a crystalline compound with the formula ABC_3 is shown below. What is the arrangement of nearest neighbors around the atoms of type C?


- **(A)** Linear arrangement of B atoms
- **(B)** Square planar arrangement of A atoms
- **(C)** Cubic arrangement of A atoms
- **(D)** Cubic arrangement of C atoms

19. When a helium-filled balloon is immersed in liquid nitrogen, which statements accurately describe the changes as the balloon deflates?
  I. The nitrogen does work on the balloon.

  II. The entropy of the nitrogen increases.

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

20. Solid KOH ($M = 56.11$, $\Delta H^\circ_{soln} = -57.6$ kJ mol^{-1}) is slowly added to distilled water contained in a well-insulated vessel, initially at 25.0 °C. What is the pH when the temperature of the solution reaches 26.0 °C? You may assume that the density of the solution remains at 1.00 g mL^{-1} and its heat capacity remains at 4.184 J g^{-1} K^{-1} throughout the experiment.

- **(A)** 9.1
- **(B)** 9.9
- **(C)** 12.1
- **(D)** 12.9

21. What is ΔG°_f (at 298 K) for $ClF_3(g)$?

Substance	ΔH°_f, kJ mol^{-1}	S°, J mol^{-1} K^{-1}
$F_2(g)$	0	202.8
$Cl_2(g)$	0	223.1
$ClF_3(g)$	−158.9	281.6

- **(A)** −78.9 kJ mol^{-1}
- **(B)** −83.9 kJ mol^{-1}
- **(C)** −118.9 kJ mol^{-1}
- **(D)** −242.8 kJ mol^{-1}

22. The triple point of bromine is 265.9 K and 0.058 bar, and the standard entropy of vaporization of bromine is 89.0 J mol^{-1} K^{-1}. What is the standard enthalpy of vaporization of bromine?

- **(A)** 17.4 kJ mol^{-1}
- **(B)** 23.7 kJ mol^{-1}
- **(C)** 26.5 kJ mol^{-1}
- **(D)** 30.0 kJ mol^{-1}

23. The graph below shows how the standard entropy of vaporization, ΔS°_{vap}, varies with molar mass for straight-chain alkanes $CH_3(CH_2)_nCH_3$.
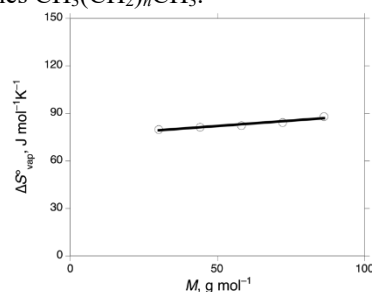
Which of the following graphs best shows how ΔS°_{vap} (solid squares, dashed line) varies with molar mass for straight-chain primary alcohols $CH_3(CH_2)_nOH$?

(A)

(B)

(C)

(D)
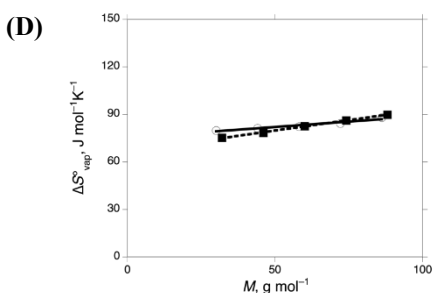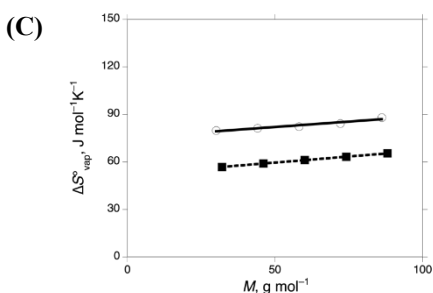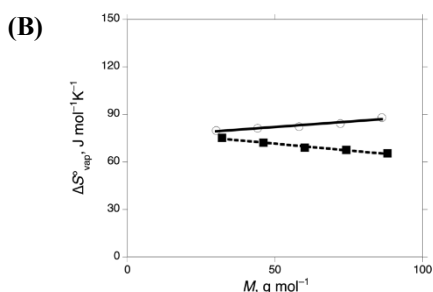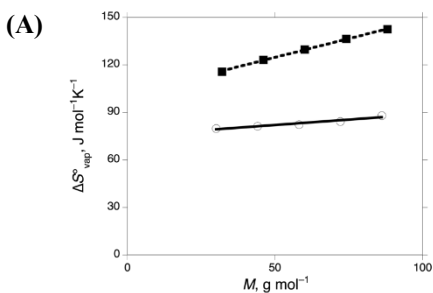
24. The natural logarithm of the molar solubility S of sodium iodate monohydrate as a function of the reciprocal of the absolute temperature is plotted below.
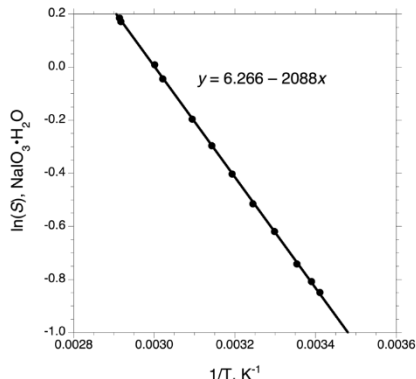
What is the standard enthalpy of dissolution for $NaIO_3 \cdot H_2O$?

(A) 2.1 kJ mol^{-1}

(B) 17.4 kJ mol^{-1}

(C) 26.0 kJ mol^{-1}

(D) 34.7 kJ mol^{-1}

25. The isotope actinium-226 undergoes both beta decay, with a half-life of 35.4 d, and electron capture, with a half-life of 173 d. What is the overall half-life for the radioactive decay of ^{226}Ac?

(A) 29.4 d **(B)** 78.3 d **(C)** 104 d **(D)** 208 d

26. The rate of the gas-phase reaction of nitrogen dioxide with carbon monoxide at 177 °C was measured under three different sets of concentrations as shown. What is the rate law for this reaction under these conditions?

$$NO_2(g) + CO(g) \rightarrow NO(g) + CO_2(g)$$
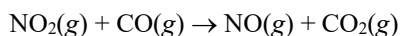
	Initial [NO$_2$], mol L^{-1}	Initial [CO], mol L^{-1}	Initial rate, mol L^{-1} min^{-1}
Ex 1	4.0×10^{-4}	1.7×10^{-2}	1.70×10^{-7}
Ex 2	4.0×10^{-4}	3.4×10^{-2}	1.70×10^{-7}
Ex 3	1.2×10^{-3}	3.4×10^{-2}	1.53×10^{-6}

(A) Rate = $k[NO_2]$

(B) Rate = $k[NO_2]^2$

(C) Rate = $k[CO]$

(D) Rate = $k[NO_2][CO]$

27. Which statement best describes the properties of the activation energy of a reaction?

(A) It increases in the presence of a catalyst.

(B) It decreases with increasing temperature.

(C) It must be larger than the energy change for forming any intermediates in the reaction.

(D) It must be positive for endothermic reactions and negative for exothermic reactions.

28. The kinetics of the reaction of crystal violet with excess sodium hydroxide to form colorless products is monitored using a spectrophotometer. A plot of the natural logarithm of the absorbance of green light by the system as a function of time is linear with a negative slope. Which conclusions may be drawn from the data?

   I.   The reaction is first-order in crystal violet.

   II.   The reaction is first-order in hydroxide ion.

(A) I only

(B) II only

(C) Both I and II

(D) Neither I nor II

29. A reaction initially contains pure reactant **R**, which forms product **P** reversibly. Which reaction coordinate diagram corresponds to the reaction in which **P** achieves a concentration within 5% of its equilibrium value the fastest?
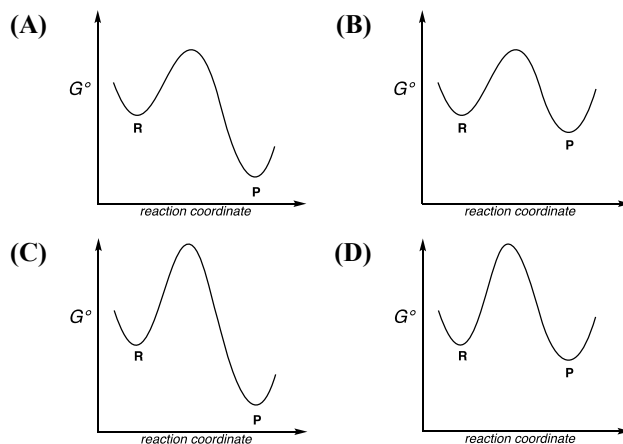

Continued on next page

30. The reaction between **A** and **B** involves an intermediate **I** whose concentration remains very low throughout the reaction. The initial rates of a reaction as a function of [**B**] (at constant [**A**]) are shown below. Which statement about the mechanism is most consistent with the data?
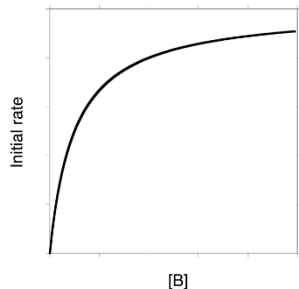
(A) **A** initially reacts reversibly to form the intermediate **I**, which then reacts irreversibly with **B** in a process that is first-order in **B**.

(B) **A** initially reacts reversibly to form the intermediate **I**, which then reacts irreversibly with **B** in a process that is second-order in **B**.

(C) **B** initially reacts reversibly in a first-order process to form the intermediate **I**, which then reacts irreversibly with **A**.

(D) **B** initially reacts reversibly in a second-order process to form the intermediate **I**, which then reacts irreversibly with **A**.

31. Carbon monoxide reacts with hydrogen in the presence of a catalyst to give methanol:

$$CO(g) + 2\ H_2(g) \leftrightarrows CH_3OH(g)$$
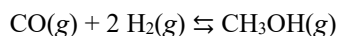
A metal container at 400 K is charged with 2.00 bar of an equimolar mixture of CO and H_2. A catalyst for the reaction is introduced and the pressure falls to 1.29 bar once equilibrium is achieved. What is K_p for this reaction at 400 K?

(A) 1.32　　(B) 6.54　　(C) 8.44　　(D) 29.1

32. A 0.10 M solution of glycolic acid is 3.8% ionized. What is the percent ionization of a 0.50 M solution of glycolic acid?

(A) 1.7%　　(B) 3.8%　　(C) 8.5%　　(D) 19.0%

33. The K_{sp} of $BaCrO_4$ is 1.2×10^{-10}. What is the minimum volume of 1.5×10^{-5} M Na_2CrO_4 that would need to be added to 1.0 L of 1.5×10^{-5} M $Ba(NO_3)_2$ solution to induce precipitation of $BaCrO_4$?

(A) 0.53 L

(B) 0.73 L

(C) 1.0 L

(D) No amount of this Na_2CrO_4 solution will cause precipitation of $BaCrO_4$.

34. A reaction has $K_{eq} = 0.020$ at 300 K, and its K_{eq} value increases with increasing temperature. What can be inferred about the values of $\Delta H°_{rxn}$ and $\Delta S°_{rxn}$, assuming that they are independent of temperature?

I.　　$\Delta H°_{rxn} < 0$

II.　　$\Delta S°_{rxn} < 0$

(A) I only　　　　　　(B) II only

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

35. Silver ion forms the complex $Ag(CN)_2^-$ with $K_f = 9.8 \times 10^{21}$. What is the minimum amount of HCN that would need to be added to 1.00 L of a suspension of 0.010 mol AgCl in order to dissolve all the solid? The K_{sp} of AgCl is 1.8×10^{-10} and the K_a of HCN is 6.2×10^{-10}.

(A) 0.020 mol　　　　(B) 0.079 mol

(C) 0.26 mol　　　　 (D) 1.7 mol

36. A vessel containing an equilibrium mixture of $NO_2(g)$ and $N_2O_4(g)$ at a certain temperature and 1.00 bar total pressure is represented below.
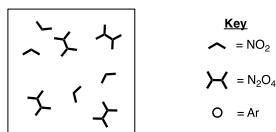

Which is the best representation of the system at equilibrium after a certain amount of argon is added to the vessel, while keeping both the temperature and the total pressure constant?

(A)

(B)

(C)

(D)

37. In which species does the underlined element have the highest oxidation state?

(A) H$\underline{P}$O$_4^{2-}$ **(B)** $\underline{Mn}$O$_4^{2-}$

(C) H$\underline{S}$O$_3^-$ **(D)** $\underline{N}$O$_3^-$

38. Oxalic acid reacts with acidified potassium permanganate according to the unbalanced equation below. What is the coefficient for H_2O when the equation is balanced with the smallest whole number coefficients?

$$\_H_2C_2O_4 + \_MnO_4^- + \_H^+ \rightarrow$$

$$\_CO_2 + \_Mn^{2+} + \_H_2O$$
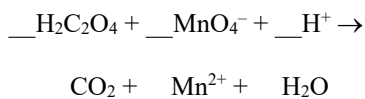
(A) 2 **(B)** 3 **(C)** 5 **(D)** 8

39. An aqueous solution containing both Cu(II) ions and Rh(III) ions is electrolyzed. After passage of 0.153 A for 16400 s, 0.826 g of metal has been deposited. What is the composition of the deposited metal?

(A) Cu only

(B) Rh only

(C) A mixture of Cu and Rh

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

40. Which statements about the following cell are correct?

$$Zn(s) + 2\ AgI(s) \rightarrow Zn^{2+}(aq) + Ag(s) + 2\ I^-(aq)$$
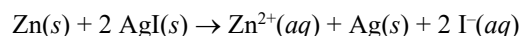
Species	$\Delta H°_f$, kJ mol^{-1}	$S°$, J mol^{-1} K^{-1}
Zn(s)	0	41.6
AgI(s)	−61.84	115.5
Zn^{2+}(aq)	−153.89	−112.1
Ag(s)	0	42.6
I$^-$(aq)	−55.19	111.3

I. The standard cell potential at 298 K is 0.54 V.

II. The cell potential increases with increasing temperature.

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

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

41. The cell potential of the following at 298 K is 1.05 V.

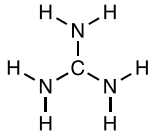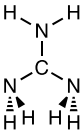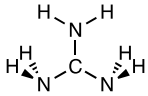$$Ni(s)|Ni^{2+}(aq, 1.00\ M)\|Ag^+(aq, 1.00\ M)|Ag(s)$$

Sodium cyanide is added to each half-cell until the concentration of free CN^- reaches 1.00 M. What is the new observed cell potential? The K_f of Ni(CN)$_4^{2-}$ is 2.0×10^{31} and the K_f of Ag(CN)$_2^-$ is 9.8×10^{21}.

(A) 0.68 V **(B)** 0.78 V **(C)** 1.33 V **(D)** 1.43 V

42. What is the standard reduction potential of hydrogen selenate ion to form elemental selenium under acidic conditions at 298 K?

Half-reaction	$E°$, V
$H_2SeO_3(aq) + 4\ H^+(aq) + 4e^- \rightarrow$ Se(s) + 3 H$_2$O(l)	0.74
$HSeO_4^-(aq) + 3\ H^+(aq) + 2e^- \rightarrow$ H$_2$SeO$_3$(aq) + H$_2$O(l)	1.15
$HSeO_4^-(aq) + 7\ H^+(aq) + 6e^- \rightarrow$ Se(s) + 4 H$_2$O(l)	???

(A) 0.88 V **(B)** 0.94 V **(C)** 1.56 V **(D)** 1.89 V

43. What is the ground-state electron configuration of $Ni^{2+}(g)$?

(A) $1s^22s^22p^63s^23p^63d^64s^2$

(B) $1s^22s^22p^63s^23p^63d^84s^2$

(C) $1s^22s^22p^63s^23p^63d^{10}4s^2$

(D) $1s^22s^22p^63s^23p^63d^8$

44. Question removed

45. Which diatomic molecule has the greatest bond dissociation enthalpy?

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

46. Which of the following best describes the trend in the amount of energy released on addition of an electron to the gas-phase atoms (electron affinity) of the group 1 and group 2 elements in the same period?

(A) More energy is released by the group 1 elements because there is less electron-electron repulsion in the ions.

(B) More energy is released by the group 1 elements because the added electron enters an s orbital rather than a p orbital.

(C) More energy is released by the group 2 elements because they have more protons in the nucleus.

(D) More energy is released by the group 2 elements because addition of an electron to a group 1 element disrupts an unusually stable half-filled s subshell.

47. Two atomic orbitals have the same shape and orientation but have a different number of nodes. Which statement about the quantum numbers of these orbitals is correct?

(A) They have the same value of l but different values of n.

(B) They have the same value of l but different values of m_l.

(C) They have the same value of m_l but different values of l.

(D) They have the same value of m_s but different values of m_l.

48. A gas-phase hydrogen atom absorbs a photon of visible light and then emits a photon of ultraviolet light. What may be concluded about its initial and its final values of the principal quantum number n?

(A) Initially $n = 1$ and finally $n = 2$

(B) Initially $n = 2$ and finally $n = 1$

(C) Initially $n = 2$ and finally $n = 4$

(D) This scenario is impossible because ultraviolet light is more energetic than visible light.

49. Which molecule has the shortest carbon-nitrogen bond length?

(A) HCNO   (B) HNCO

(C) H_3CNO (D) H_3CNO_2

50. Which statements about the structure of ClF_3 are correct?

  I.   All F–Cl–F angles are equal.

  II.   All Cl–F bond lengths are equal.

(A) I only   (B) II only

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

51. How many unpaired electrons are there in a ground-state NF molecule in the gas phase?

(A) 0   (B) 1   (C) 2   (D) 4

52. The ionization energy of a ground-state nitrogen atom is 14.5 eV, while the ionization energy of a ground-state fluorine atom is 17.4 eV. What is the ionization energy of a ground-state NF molecule?

(A) 13.1 eV   (B) 15.1 eV

(C) 16.8 eV   (D) 18.8 eV

53. Which is the best representation of the three-dimensional structure of the guanidinium ion, $C(NH_2)_3^+$?

(A)

(B)

(C)

(D)

54. Which complex ion absorbs visible light of the longest wavelength?

(A) $Co(NH_3)_6^{3+}$ (B) $Co(CN)_6^{3-}$

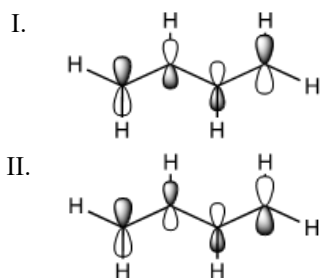(C) CoF_6^{3-} (D) $Co(NO_2)_6^{3-}$

55. How many isomers have the formula $C_3H_6Cl_2$?

(A) 4 **(B)** 5 **(C)** 6 **(D)** 7

56. Which compound produces a nitrile when treated with sodium cyanide in DMSO?
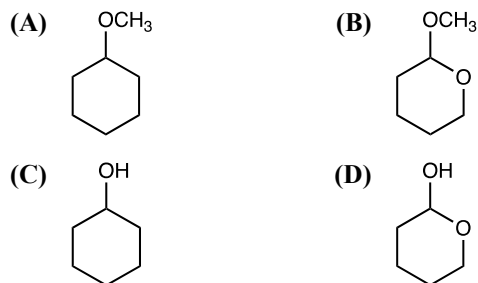
(A) 2-Methylbutane

(B) 3-Methyl-1-butanol

(C) 3-Methyl-1-butene

(D) 1-Bromo-3-methylbutane

57. Which molecular orbitals are occupied in the ground state of 1,3-butadiene?

I.

II.

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

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

58. Which compound reacts readily with water under acidic but not basic conditions?

(A)

(B)

(C)

(D)

59. Which $C_5H_{10}O$ isomer exhibits a strong infrared absorption band at 1717 cm^{-1}?

(A)

(B)

(C)

(D)

60. The peptide hormone insulin becomes biologically inactive after being treated with a mild reducing agent. Which is the best explanation for this observation?

(A) The reducing agent cleaves disulfide bonds, which alters the structure of the hormone.

(B) The reducing agent cleaves peptide (amide) bonds, breaking the hormone into smaller polypeptides.

(C) The reducing agent modifies the alcohol-containing side chains of some of the amino acids, decreasing the affinity of the hormone for its cellular receptor.

(D) The reducing agent decreases the overall charge on the hormone, causing it to bind unselectively to cell membranes.

END OF TEST

Olympiad 2022
USNCO Local Section Exam
KEY

Question	Correct Answer	% Correct Answers	Question	Correct Answer	% Correct Answers
1.	B	58%	31.	B	62%
2.	D	40%	32.	A	46%
3.	A	60%	33.	D	34%
4.	B	63%	34.	D	54%
5.	C	66%	35.	C	36%
6.	C	41%	36.	D	25%
7.	D	71%	37.	B	91%
8.	C	54%	38.	D	74%
9.	A	67%	39.	A	50%
10.	A	23%	40.	A or D	56%
11.	C	41%	41.	A	17%
12.	B	41%	42.	A	37%
13.	D	63%	43.	D	67%
14.	A	50%	44.	removed	
15.	A	67%	45.	B	25%
16.	C	25%	46.	B	41%
17.	B	46%	47.	A	46%
18.	A	75%	48.	B	59%
19.	C	39%	49.	A	56%
20.	D	36%	50.	D	19%
21.	C	46%	51.	C	49%
22.	D	15%	52.	A	26%
23.	A	47%	53.	A	30%
24.	D	27%	54.	C	31%
25.	A	40%	55.	B	34%
26.	B	90%	56.	D	28%
27.	C	76%	57.	B	36%
28.	A	70%	58.	B	28%
29.	B	47%	59.	C	44%
30.	A	25%	60.	A	31%