2023 U.S. NATIONAL CHEMISTRY OLYMPIAD

ORIGINAL LOCAL SECTION EXAM

Prepared by the American Chemical Society Chemistry Olympiad Examinations Task Force

OLYMPIAD EXAMINATIONS TASK FORCE

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DIRECTIONS TO THE EXAMINER

This test is designed to be taken with an answer sheet on which the student records their responses. All answers are to be marked on that sheet, not written in the booklet. Each student should be provided with an answer sheet and scratch paper, both of which must be turned in with the test booklet at the end of the examination. Local Sections may use an answer sheet of their own choice.

The full examination consists of 60 multiple-choice questions representing a fairly wide range of difficulty. A periodic table and other useful information are provided on page two of this exam booklet for students' reference.

Only non-programmable calculators are to be used during the ACS Local Section exam. The use of a programmable calculator, cell phone, or any other device that can access the internet or make copies or photographs during the exam is grounds for disqualification.

Suggested Time: 60 questions—110 minutes

DIRECTIONS TO THE EXAMINEE

DO NOT TURN THE PAGE UNTIL DIRECTED TO DO SO.

This is a multiple-choice examination with four choices for each question. There is only one correct or best answer to each question. When you select your choice, blacken the corresponding space on the answer sheet with your pencil. Make a heavy full mark, but no stray marks. If you decide to change your answer, be certain to erase your original answer completely.

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

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

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

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

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

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

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

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

0 °C = 273.15 K

1 atm = 1.013 bar = 760 mm Hg

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

EQUATIONS

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

PERIODIC TABLE OF THE ELEMENTS

1 1A	2 2A	3 3B	4 4B	5 5B	6 6B	7 7B	8 8B	9 8B	10 8B	11 1B	12 2B	13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
1 **H** 1.008																	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											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. A 1.00 g sample of which compound will produce the greatest amount of carbon dioxide after complete combustion with excess oxygen?

(A) CH_4 **(B)** C_3H_8 **(C)** C_6H_6 **(D)** C_8H_{18}

2. How many chlorine atoms are in 1.00 mL of CCl_4 (M = 153.8, density = 1.59 g mL^{-1})?

(A) 1.56×10^{21} **(B)** 6.23×10^{21}

(C) 1.57×10^{22} **(D)** 2.49×10^{22}

3. What is the molality of Na^+ in a solution containing 3.00 g NaCl (M = 58.4), 9.00 g glucose (M = 180.0), and 168 g H_2O (M = 18.0)?

(A) 5.50×10^{-3} *m* **(B)** 0.285 *m*

(C) 0.306 *m* **(D)** 0.777 *m*

4. 25.0 mL of aqueous 0.20 M HCl, 10.0 mL of 0.25 M aqueous HNO_3, and 10.0 mL of aqueous 0.30 M $Ba(OH)_2$ are mixed to give a homogeneous solution. In which are the final concentrations of species ranked in order from highest to lowest?

(A) $[Cl^-] > [Ba^{2+}] > [NO_3^-] > [H^+] > [OH^-]$

(B) $[H^+] > [OH^-] > [Cl^-] > [Ba^{2+}] > [NO_3^-]$

(C) $[Cl^-] > [H^+] > [Ba^{2+}] > [NO_3^-] > [OH^-]$

(D) $[OH^-] > [H^+] > [Ba^{2+}] > [NO_3^-] > [Cl^-]$

5. Acetanilide ($C_6H_5NHCOCH_3$, M = 135.2) can be prepared from aniline ($C_6H_5NH_2$, M = 93.1) and acetic anhydride ($[CH_3CO]_2O$, M = 102.1) according to the balanced equation below.

$$C_6H_5NH_2 + (CH_3CO)_2O \rightarrow C_6H_5NHCOCH_3 + CH_3COOH$$

If 10.0 g acetanilide is isolated from the reaction of 10.0 g aniline with 10.0 g acetic anhydride, what is the percent yield of the reaction?

(A) 50.0% **(B)** 68.9% **(C)** 69.3% **(D)** 75.5%

6. 10.0 g of a metal chloride salt is dissolved in 90.0 g H_2O. This solution has a vapor pressure that is 8.6% lower than that of pure water at the same temperature. What is the identity of the metal?

(A) Li **(B)** Na **(C)** Mg **(D)** Ca

7. What is the main purpose of adding boiling chips to a solution that will be heated?

(A) To reduce the boiling point of the solution

(B) To increase the boiling point of the solution

(C) To prevent the solution from superheating

(D) To decrease the time required for the solution to reach its boiling point

8. An aqueous solution contains one or more of the metal cations Mg^{2+}, Ba^{2+}, and Pb^{2+} at concentrations of 0.1 M. Addition of an equal volume of 0.1 M sodium sulfate causes formation of a precipitate. Which inference regarding the original solution is correct?

(A) The solution must contain Mg^{2+} or Ba^{2+}.

(B) The solution must contain Mg^{2+} or Pb^{2+}.

(C) The solution must contain Ba^{2+} or Pb^{2+}.

(D) The solution must contain Mg^{2+}, Ba^{2+}, and Pb^{2+}.

9. Iron(III) nitrate is dissolved in water to form a 0.1 M Fe^{3+} solution and allowed to stand at room temperature for three days. During that time, a precipitate forms. Addition of which reagent will best prevent formation of a precipitate?

(A) Sulfuric acid **(B)** Potassium hydroxide

(C) Sodium bicarbonate **(D)** Sodium chloride

10. Adding hydrogen peroxide to which reagent will NOT result in gas evolution?

(A) Sodium hypochlorite **(B)** Copper(II) sulfate

(C) Manganese(IV) oxide **(D)** Sodium bisulfite

11. Acetylsalicylic acid is synthesized from salicylic acid, then isolated and dried. The melting point of the product is determined. If some salicylic acid is present, what will be observed? The melting point of pure acetylsalicylic acid is 136 °C and the melting point of pure salicylic acid is 159 °C.

(A) The product will melt below 136 °C.

(B) Most of the product will melt at 136 °C, with some flecks of solid remaining until the temperature reaches 159 °C, at which point the remaining material will melt.

(C) The product will melt between 136 and 159 °C.

(D) The product will melt above 159 °C.

12. A 10.00 g sample of an unknown metal is reacted with hydrochloric acid to form the divalent metal ion and hydrogen gas, which is then collected over water. The molar mass of the metal is calculated to determine the identity of the metal. Which will cause the calculated molar mass to be too large?

I. Not correcting for the vapor pressure of water
II. Not allowing the reaction to go to completion

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

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

13. A room temperature sample of xenon gas in a metal container with a piston has a volume of 1.00 L and a pressure of 4.0 atm. The piston is moved to change the volume of the container to 2.00 L, after which the pressure reads 1.75 atm. Which is the best explanation for this observation?

(A) The volume is miscalibrated and the actual final volume is 1.75 L.

(B) Some xenon has leaked out through the seal in the piston.

(C) The friction of moving the piston has caused the temperature of the gas to increase.

(D) The system is correctly calibrated, well sealed, and remains at room temperature.

14. In which are the root mean square velocities of Xe(*g*), Ne(*g*), and N_2(*g*) at 290 K and 3.0 atm ranked from lowest to highest?

(A) Xe < Ne < N_2 **(B)** Xe < N_2 < Ne

(C) N_2 < Ne < Xe **(D)** Ne < N_2 < Xe

15. In a sample of pure silane (SiH_4), which intermolecular forces are present?

I. London dispersion forces
II. Hydrogen bonding

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

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

16. The melting point of an organic compound X is 5.0 °C. How do the vapor pressures of X(*s*) and X(*l*) compare at 10.0 °C?

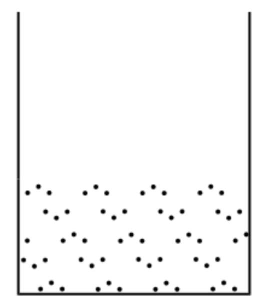
(A) The vapor pressure of X(*s*) is less than the vapor pressure of X(*l*).

(B) The vapor pressure of X(*s*) is equal to the vapor pressure of X(*l*).

(C) The vapor pressure of X(*s*) is greater than the vapor pressure of X(*l*).

(D) The relative vapor pressures cannot be determined without knowledge of the relative densities of X(*s*) and X(*l*).

17. The arrangement of atoms (represented as black dots) in a pure substance contained in a beaker is shown schematically below. Which is the best description of the phase of the substance?



(A) Crystalline molecular solid

(B) Crystalline network covalent solid

(C) Amorphous network covalent solid

(D) Liquid

18. Which statement about a sample of ammonia (NH_3) at its triple point is correct?

(A) It has a pressure of 1.0 atm.

(B) It can be at only one possible temperature.

(C) There are equal amounts of NH_3 in the solid, liquid, and gas phases.

(D) If it is in a closed, well-insulated container, it will remain at the triple point when the volume of the container is decreased by a factor of two.

19. Given the standard enthalpies of the gas-phase reactions of hydrogen sulfide, what is the standard enthalpy of reaction for the gas-phase combustion of carbon disulfide?

Reaction	$\Delta H°_{rxn}$, kJ mol^{-1}
$H_2S + 1.5\ O_2 \rightarrow SO_2 + H_2O$	–518.2
$2\ H_2S + CO_2 \rightarrow CS_2 + 2\ H_2O$	67.8
$CS_2 + 3\ O_2 \rightarrow CO_2 + 2\ SO_2$	???

(A) –450.4 kJ mol^{-1} **(B)** –586.0 kJ mol^{-1}
(C) –968.6 kJ mol^{-1} **(D)** –1104.2 kJ mol^{-1}

20. Which substance has a standard enthalpy of formation, $\Delta H°_f$, that is greater than zero?

(A) $O_2(g)$ **(B)** $F_2(g)$ **(C)** $S_2(g)$ **(D)** $Cl_2(g)$

21. For the reaction

$$N_2(g) + 3\ H_2(g) \rightarrow 2\ NH_3(g)$$

ΔG_{rxn} = –33 kJ mol^{-1} when all gases have a partial pressure of 1.0 bar. Changing the pressure of which gas to 2.0 bar will give the most negative value of ΔG_{rxn}?

(A) N_2

(B) H_2

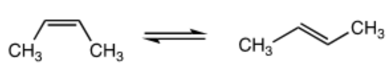
(C) NH_3

(D) The value of ΔG_{rxn} will be the same regardless of the gas pressures.

22. Gallium metal melts at 29.8 °C with $\Delta H°_{fusion}$ = 5.59 kJ mol^{-1}. If equal masses of solid gallium initially at 20.0 °C and liquid gallium initially at 35.0 °C are mixed in a well-insulated container, what percentage of the gallium will be solid after the mixture has reached equilibrium? The molar heat capacity of solid gallium is 26.2 J mol^{-1} K^{-1} and the molar heat capacity of liquid gallium is 28.0 J mol^{-1} K^{-1}.

(A) 34.7% **(B)** 49.0% **(C)** 51.0% **(D)** 65.3%

23. *cis*-2-butene isomerizes to *trans*-2-butene with $\Delta G°_{rxn}$ = –3.0 kJ mol^{-1} at 298 K.



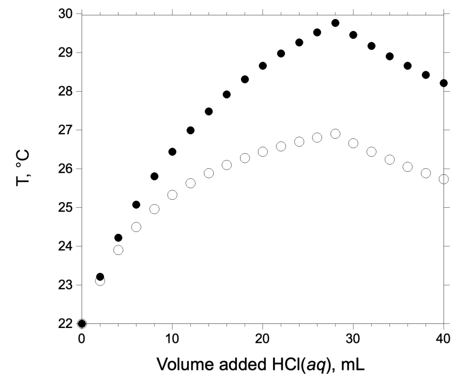
cis-2-butene *trans*-2-butene

$$\Delta G°_{rxn} = –3.0 \text{ kJ mol}^{-1}$$

Some *cis*-2-butene is introduced into a vessel maintained at 298 K, along with a catalyst for isomerization. After equilibrium is attained, what is the mole fraction of *cis*-2-butene in the vessel?

(A) 0.00 **(B)** 0.23 **(C)** 0.30 **(D)** 0.50

24. A certain volume of NaOH(*aq*) is titrated against HCl(*aq*) in a well-insulated vessel with constant stirring. Each solution is initially at 22.0 °C, and the temperature of the reaction mixture is monitored after each 2.0 mL of hydrochloric acid is added.



The data in closed circles correspond to an experiment conducted with 20.0 mL NaOH solution and 1.0 M HCl. The open circles were carried out using the same concentration but a different volume of NaOH solution, and using a different concentration of aqueous HCl. Which volume of NaOH and concentration of HCl correspond to the conditions that give the open circles?

	Volume NaOH	Concentration HCl
Closed circles:	20 mL	1.0 M
Open circles:		
(A)	40 mL	2.0 M
(B)	30 mL	2.0 M
(C)	15 mL	0.5 M
(D)	10 mL	0.5 M

25. Hydrogen and nitrogen react according to the following equation:

$$N_2(g) + 3\ H_2(g) \rightarrow 2\ NH_3(g)$$

If the concentration of $H_2(g)$ is changing at a rate of –12 mol L^{-1} s^{-1}, at what rate is the concentration of $NH_3(g)$ changing?

(A) –6.0 mol L^{-1} s^{-1} **(B)** –4.0 mol L^{-1} s^{-1}
(C) +8.0 mol L^{-1} s^{-1} **(D)** +12 mol L^{-1} s^{-1}

26. An irreversible reaction R → P has the rate law Rate = k[R]^2. Which graph will be a straight line?

(A) ln([R]) as a function of t

(B) [R] as a function of ln(t)

(C) 1/[R] as a function of t

(D) [R] as a function of 1/t

27. For the reaction

$$O_2(g) + 4\ HBr(g) \rightarrow 2\ H_2O(g) + Br_2(g)$$

the following mechanism is proposed:

$O_2(g) + HBr(g) \rightleftarrows HOOBr(g)$ *fast, unfavorable*

$HOOBr(g) + HBr(g) \rightarrow 2\ HOBr(g)$ *slow*

$HOBr(g) + HBr(g) \rightarrow H_2O(g) + Br_2(g)$ *fast*

What rate law is predicted by this mechanism?

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

(C) Rate = $k[O_2][HBr]^2$ **(D)** Rate = $k[O_2][HBr]^4$

28. The radioisotope ^{99m}Tc undergoes gamma decay with a rate constant $k = 0.116\ h^{-1}$. How much time is required for its activity to decrease to 10.0% of its original activity?

(A) 19.8 h **(B)** 7.76 h **(C)** 5.98 h **(D)** 1.16 h

29. A cotton ball burns more brightly in a jar of 80% O_2 than in the air, which is 20% O_2. Which is the best explanation for this observation?

(A) The cotton collides more frequently with the O_2 inside the jar.

(B) The excited state of O_2 is formed more efficiently inside the jar.

(C) The temperature is higher inside the jar.

(D) The jar acts as a catalyst for the reaction.

30. A reaction has an activation energy of 75.0 kJ mol^{-1}. At what temperature will the rate constant be twice as large as it is at 298 K?

(A) 305 K **(B)** 307 K **(C)** 311 K **(D)** 319 K

31. Lead(II) fluoride is sparingly soluble ($K_{sp} = 4.0 \times 10^{-8}$). Which, when added to a saturated solution of PbF_2, would increase its solubility to the greatest extent?

(A) KNO_3 **(B)** $Pb(NO_3)_2$

(C) KF **(D)** HNO_3

32. The pH of a 0.045 M solution of the monoprotic acid boric acid is 5.30. What is the K_a of boric acid?

(A) 1.1×10^{-4} **(B)** 5.0×10^{-6}

(C) 2.0×10^{-9} **(D)** 5.6×10^{-10}

33. NOBr decomposes to NO and Br_2 gas in a closed container as shown.

$$2\ NOBr(g) \rightleftarrows 2\ NO(g) + Br_2(g) \qquad \Delta H°_{rxn} = +16.3\ kJ\ mol^{-1}$$

Which changes will result in an increase in the number of moles of NO present at equilibrium?

I. Increasing the temperature
II. Decreasing the volume of the container

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

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

34. At a certain temperature, SO_2Cl_2 decomposes into SO_2 and Cl_2 as shown below.

$$SO_2Cl_2(g) \rightleftarrows SO_2(g) + Cl_2(g) \qquad K_p = 0.50$$

An equal number of moles of SO_2Cl_2, SO_2, and Ar are introduced into a sealed flask to give a total pressure of 1.80 bar. The flask is maintained at the same temperature until equilibrium is attained. What is the final pressure of $Cl_2(g)$?

(A) 0.23 bar **(B)** 0.27 bar

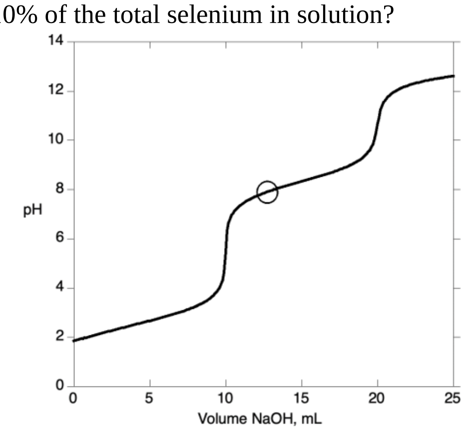
(C) 0.35 bar **(D)** 0.50 bar

35. A buffer solution consists of 0.100 mol Na_3PO_4 and 0.100 mol Na_2HPO_4 dissolved in water. How much of which component of the buffer must be added to change the pH to 12.25? The pK_a of HPO_4^{2-} is 12.37.

(A) 0.032 mol Na_2HPO_4 **(B)** 0.032 mol Na_3PO_4

(C) 0.132 mol Na_2HPO_4 **(D)** 0.132 mol Na_3PO_4

36. A 0.100 M aqueous solution of H_2SeO_3 is titrated with 1.000 M NaOH solution. At the point marked with a circle on the titration curve, which species comprise at least 10% of the total selenium in solution?



(A) H_2SeO_3 only **(B)** H_2SeO_3 and $HSeO_3^-$

(C) $HSeO_3^-$ only **(D)** $HSeO_3^-$ and SeO_3^{2-}

37. What is the average oxidation state of sulfur in calcium tetrathionate, CaS_4O_6?

(A) –2.0 **(B)** +2.0 **(C)** +2.5 **(D)** +3.0

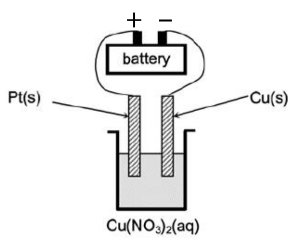
38. When the equation for the oxidation of Cu(*s*) by NO_3^-(*aq*) to give Cu^{2+}(*aq*) and NO(*g*) in acidic aqueous solution is balanced using smallest whole number coefficients, what is the coefficient for NO_3^-(*aq*)?

(A) 1 **(B)** 2 **(C)** 3 **(D)** 6

39. Water is electrolyzed with a current of 10.0 A until 132 L of hydrogen gas (after drying, measured at STP) has been produced. How much time does this take?

(A) 7.90 h **(B)** 15.8 h **(C)** 31.6 h **(D)** 63.2 h

40. A 1.0 M solution of $Cu(NO_3)_2$ is electrolyzed using the setup shown below. What reaction occurs at the cathode?



(A) $Pt^{2+}(aq) + 2\,e^- \rightarrow Pt(s)$

(B) $Cu^{2+}(aq) + 2\,e^- \rightarrow Cu(s)$

(C) $O_2(g) + 2\,H_2O(l) + 4\,e^- \rightarrow 4\,OH^-(aq)$

(D) $2\,H_2O(l) + 2\,e^- \rightarrow H_2(g) + 2\,OH^-(aq)$

41. What is *E*° for the oxidation of mercury(I) ion by silver ion?

$$2\,Ag^+(aq) + Hg_2^{2+}(aq) \rightarrow 2\,Ag(s) + 2\,Hg^{2+}(aq)$$

Half-reaction	*E*°, V
$Ag^+(aq) + e^- \rightarrow Ag(s)$	+0.80
$2\,Hg^{2+}(aq) + 2e^- \rightarrow Hg_2^{2+}(aq)$	+0.91

(A) –0.11 V **(B)** 0.69 V

(C) 1.71 V **(D)** 2.51 V

42. What is the standard reduction potential of $PbF_2(s)$ at 298 K? The K_{sp} of PbF_2 at 298 K is 4.0×10^{-8}.

Half-reaction	*E*°, V
$Pb^{2+}(aq) + 2e^- \rightarrow Pb(s)$	–0.13
$PbF_2(s) + 2e^- \rightarrow Pb(s) + 2\,F^-(aq)$	???

(A) –0.35 V **(B)** –0.22 V

(C) –0.13 V **(D)** –0.04 V

43. Which species has the largest ionic radius?

(A) S^{2-} **(B)** Cl^- **(C)** K^+ **(D)** Ca^{2+}

44. Which of the following statements regarding ionization energy of gas-phase atoms is correct?

(A) The first ionization energy of a group 1 element is always greater than the first ionization energy of the group 2 element in the same row of the periodic table.

(B) In the second row of the periodic table, the first ionization energy is directly proportional to the atomic radius.

(C) Among the elements from Al (Z = 13) to Ar (Z = 18), the first ionization energy increases monotonically with atomic number.

(D) Among the elements of group 16, the first ionization energy decreases monotonically with atomic number.

45. How many electrons in a ground state gas-phase Al atom have the quantum number $l = 1$?

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

46. What is the ground-state electron configuration of a gas-phase Mn^{2+} ion?

(A) $1s^22s^22p^63s^23p^63d^5$ **(B)** $1s^22s^22p^63s^23p^63d^34s^2$

(C) $1s^22s^22p^63s^23p^63d^7$ **(D)** $1s^22s^22p^63s^23p^63d^54s^2$

47. What wavelengths of light are capable of breaking a bond with a bond strength of 425 kJ mol^{-1}?

(A) Only λ < 281 nm **(B)** Only λ > 281 nm

(C) Only λ < 355 nm **(D)** Only λ > 355 nm

48. When ^{105}Te decays by alpha emission, how many protons are in the daughter nuclide that is produced?

(A) 48 **(B)** 50 **(C)** 52 **(D)** 53

49. Which species has the largest O–N–O angle?

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

50. Which molecule has the shortest bond?

(A) H_2 **(B)** N_2 **(C)** O_2 **(D)** F_2

51. Which molecules are described by molecular orbital theory as having a bond order of 2.0?

I. CO II. NO

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

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

52. Which is the best description of the geometry of IF_7?

(A) Heptagonal planar

(B) Hexagonal monopyramidal

(C) Pentagonal bipyramidal

(D) Capped trigonal prismatic

53. Carbon monoxide, CO, has a very small dipole moment. Which is the best explanation for this observation?

(A) The carbon-oxygen π bonds are polarized in the opposite direction from the carbon-oxygen σ bonds, so the bond dipoles tend to cancel each other out.

(B) Carbon and oxygen each have the same number of lone pairs despite the fact that carbon has fewer valence electrons than oxygen, partially canceling the bond dipoles.

(C) Neither carbon nor oxygen has a formal charge in the Lewis structure of CO, giving an electron distribution that is minimally asymmetric.

(D) Carbon is *sp*-hybridized in CO, making it more electronegative than a typical carbon atom.

54. Which species has the smallest tendency to dimerize?

(A) NO **(B)** NO_2 **(C)** CO_2^- **(D)** SO_2^-

55. How many stable one-carbon molecules contain both hydrogen and chlorine and no other elements?

(A) 2 **(B)** 3 **(C)** 4 **(D)** 5

56. Which property best accounts for the fact that acetic acid (CH_3COOH) is far more acidic than ethanol (CH_3CH_2OH) in aqueous solution?

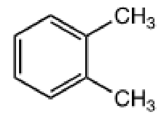
(A) Acetic acid is more soluble in water than ethanol.

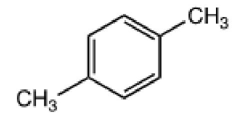
(B) Acetic acid has two hydrogen bond acceptors that can interact with water, while ethanol has only one.

(C) Acetic acid's conjugate base has its negative charge delocalized over two oxygens, while ethanol's conjugate base has its negative charge localized on one oxygen.

(D) Acetic acid can form a hydrate $CH_3C(OH)_3$ in water, while ethanol cannot react with water in this way.

57. Which isomers of xylene would produce only a single mononitration product on treatment with HNO_3/H_2SO_4?

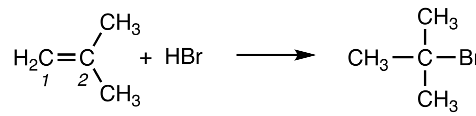
I. 

II. 

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

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

58. Under certain conditions, HBr adds to 2-methylpropene to give predominantly 2-bromo-2-methylpropane rather than isomeric 1-bromo-2-methylpropane. Which is the best mechanistic explanation for this regioselectivity?



(A) H^+ adds preferentially to C-1 to form the more stable carbocation.

(B) Br^- adds preferentially to C-2 to form the more stable carbanion.

(C) H• adds preferentially to C-1 to form the more stable radical.

(D) Br• adds preferentially to C-2 to form the more stable radical.

59. Which will most reliably distinguish between an alcohol and an ether with the formula $C_4H_{10}O$?

(A) The alcohol will have the higher normal boiling point.

(B) The alcohol will rapidly decolorize bromine while the ether will not.

(C) The alcohol will absorb visible light while the ether will not.

(D) The alcohol will form an electrically conductive aqueous solution while the ether will not.

60. Which form of the amino acid alanine is most abundant in aqueous solution at pH = 7.0?

(A) $CH_3CH(NH_2)(COOH)$

(B) $CH_3CH(NH_2)(COO^-)$

(C) $CH_3CH(NH_3^+)(COOH)$

(D) $CH_3CH(NH_3^+)(COO^-)$

END OF TEST

Olympiad 2023
USNCO Local Section Exam
KEY

Number	Answer	Number	Answer
1.	C	31.	D
2.	D	32.	D
3.	C	33.	A
4.	A	34.	A
5.	D	35.	A
6.	A	36.	D
7.	C	37.	C
8.	C	38.	B
9.	A	39.	C
10.	D	40.	B
11.	A	41.	A
12.	B	42.	A
13.	B	43.	A
14.	B	44.	D
15.	A	45.	D
16.	C	46.	A
17.	A	47.	A
18.	B	48.	B
19.	D	49.	B
20.	C	50.	A
21.	B	51.	D
22.	C	52.	C
23.	B	53.	B
24.	D	54.	A
25.	C	55.	B
26.	C	56.	C
27.	C	57.	B
28.	A	58.	A
29.	A	59.	A
30.	A	60.	D