ACS USNCO
U.S. National Chemistry Olympiad

2024 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 Gradescope answer sheet on which the student records their responses. Only this Gradescope sheet is graded for a score on Part I. Testing materials, scratch paper, and the Gradescope 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 22, 2024,** 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 Gradescope sheet. The answer sheet must be completed using a dark pencil or dark pen. When the student has completed **Part I,** or after **one hour and thirty minutes** has elapsed, the student must turn in the Gradescope 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 Gradescope 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 or pen 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 Gradescope answer sheet.

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
$R = 8.314$ 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. What is the mole fraction of acetic acid (CH_3COOH, M = 60.05) in an aqueous solution that is 11.7% by mass acetic acid?

(A) 0.00195 **(B)** 0.0382

(C) 0.0398 **(D)** 0.195

2. Hydrogen peroxide (M = 34.02) decomposes to give water and oxygen gas. How much 3.00% by mass aqueous H_2O_2 must decompose to afford 4.00 L of dry O_2 at STP?

(A) 6.08 g **(B)** 101 g **(C)** 203 g **(D)** 405 g

3. A diamagnetic compound that contains only carbon, hydrogen, nitrogen, and oxygen is 19.99% C, 3.35% H, and 23.31% N by mass. Which is its molecular formula?

(A) CH_2N_2O **(B)** CH_2NO_2

(C) C_2H_3NO **(D)** $C_2H_4N_2O_4$

4. What is the chloride ion concentration in a solution prepared by mixing 35.0 mL of 0.35 M sodium chloride and 65.0 mL of 0.65 M calcium chloride?

(A) 0.50 M **(B)** 0.54 M

(C) 0.85 M **(D)** 0.97 M

5. 17.0 g $Ba(NO_3)_2$ (M = 261.32) is mixed with 11.5 g of an alkali metal sulfate and the precipitated $BaSO_4$ (M = 233.37) is collected by filtration, placed in a tared crucible, and the crucible heated to drive off water. The mass of $BaSO_4$ obtained is 15.4 g. Which conclusion is best supported by the data?

(A) The sulfate salt used was Na_2SO_4 (M = 142.05).

(B) The sulfate salt used was K_2SO_4 (M = 174.27).

(C) The $BaSO_4$ was not heated long enough to drive off all the water.

(D) Some of the $BaSO_4$ was spilled before it was transferred to the crucible.

6. 10.0 mL of 0.50 M potassium sulfate and 10.0 mL of 0.50 M silver nitrate solutions are mixed and the mixture is allowed to attain equilibrium. Which ordering of the concentrations of the ions in solution is correct?

(A) $[K^+] = [NO_3^-] > [Ag^+] > [SO_4^{2-}]$

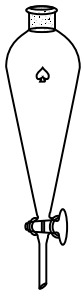
(B) $[K^+] = [NO_3^-] > [SO_4^{2-}] > [Ag^+]$

(C) $[K^+] > [NO_3^-] > [Ag^+] > [SO_4^{2-}]$

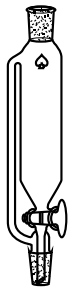
(D) $[K^+] > [NO_3^-] > [SO_4^{2-}] > [Ag^+]$

7. A neutral organic compound is to be separated from a basic impurity by washing a solution of the compound in hexane with 5% aqueous HCl. Which apparatus is best suited to this operation?

(A)



(B)



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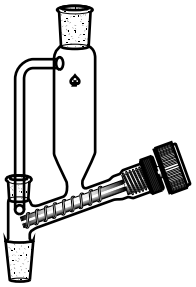
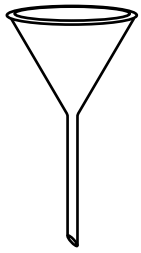


(D)



8. Which substance may be treated with bleach (sodium hypochlorite) to render it less hazardous?

(A) Sodium cyanide **(B)** Ammonia

(C) Hydrochloric acid **(D)** Ozone

9. Which indicator would be most suitable for a titration to determine the concentration of ammonia in a window cleaning solution using aqueous HCl?

(A) Eriochrome Black T **(B)** Ferroin

(C) Methyl orange **(D)** Phenolphthalein

10. A test tube contains 4 mL of a solution that is 0.1 M in one or more of the following salts: $AgNO_3$, $Mn(NO_3)_2$, and $Al(NO_3)_3$. 1 mL of 6 M HCl is added to the test tube, which causes neither a color change nor formation of a precipitate. After subsequent addition of 1.5 mL aqueous NaOH and 0.5 mL of 3% aqueous H_2O_2 and brief heating in a hot water bath, there is a dark precipitate in the test tube. What may be determined about the cations initially present?

	Must be present	May be present	Must be absent
(A)	Ag^+	Al^{3+}	Mn^{2+}
(B)	Al^{3+}	Mn^{2+}	Ag^+
(C)	Al^{3+}	Ag^+	Mn^{2+}
(D)	Mn^{2+}	Al^{3+}	Ag^+

11. Ethane, C_2H_6, and diborane, B_2H_6, do not adopt analogous molecular structures. Which experimental technique would be least useful in establishing this fact?

(A) Infrared spectroscopy

(B) Mass spectrometry

(C) Nuclear magnetic resonance spectroscopy

(D) X-ray crystallography

12. The concentration of a solution of potassium permanganate is determined by titrating it into an Erlenmeyer flask with solid ferrous ammonium sulfate hexahydrate ($Fe(NH_4)_2(SO_4)_2 \cdot 6\ H_2O$) dissolved in dilute sulfuric acid. Which error would result in a measured concentration of $KMnO_4$ that is lower than the actual concentration?

(A) The titration was begun before the ferrous ammonium sulfate had fully dissolved in the sulfuric acid.

(B) The sides of the Erlenmeyer flask were periodically rinsed down with deionized water during the titration.

(C) Some of the Fe(II) ions in the solid ferrous ammonium sulfate had been oxidized to Fe(III) on storage.

(D) The buret was rinsed with distilled water and then filled with $KMnO_4$ solution while still wet.

13. A sample of pentane (bp = 36 °C) is in a rigid closed container at 50 °C and 1 atm. Which best describes what happens when the container is heated?

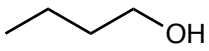
(A) Liquid pentane vaporizes.

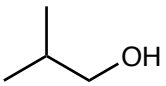
(B) The intermolecular forces between pentane molecules become stronger.

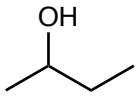
(C) The average kinetic energy of the pentane molecules increases.

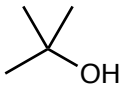
(D) The density of the sample decreases.

14. Which compound has the highest normal boiling point?

(A) 

(B) 

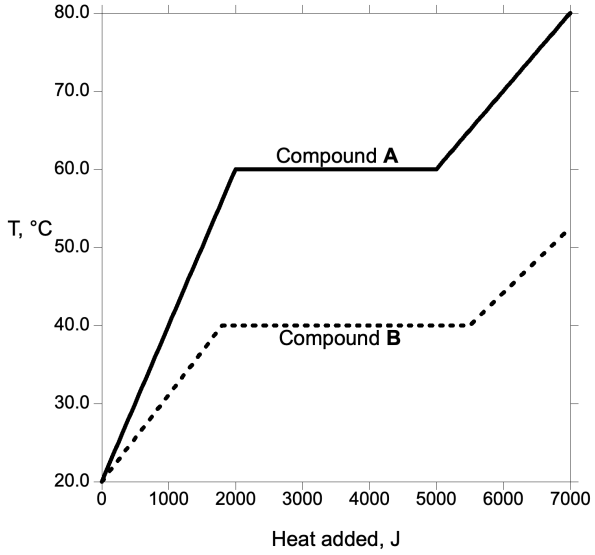
(C) 

(D) 

15. A mole of which gas has the smallest volume at 0 °C and 1 atm pressure?

(A) He **(B)** CO_2 **(C)** SO_2 **(D)** Xe

16. Two compounds, **A** and **B**, are both solids at 20 °C. In separate experiments, one mole of each is heated and its temperature measured as a function of the amount of heat added. Which statement about the compounds is correct?



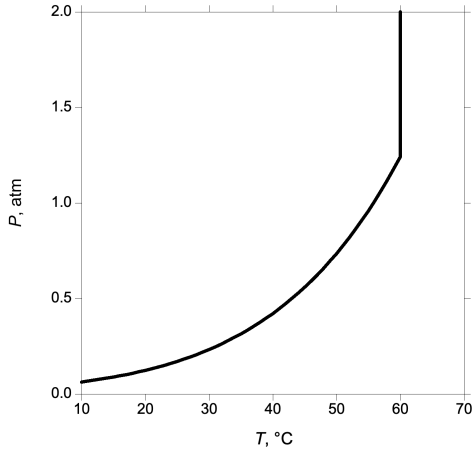
(A) The molar heat capacity of solid **A** is greater than that of solid **B**.

(B) The molar heat capacity of liquid **A** is greater than that of liquid **B**.

(C) The melting point of **A** is less than that of **B**.

(D) The heat of fusion of **A** is less than that of **B**.

17. A sample of a pure substance is placed in a sealed, rigid container and the pressure is measured as a function of temperature. Which is the best explanation for the result shown?



(A) At lower temperatures, the substance is a mixture of solid and vapor, while at 60 °C the solid melts to give a mixture of liquid and vapor.

(B) At lower temperatures, the substance is a mixture of liquid and vapor, while at 60 °C only liquid is present.

(C) At lower temperatures, the substance is a mixture of liquid and vapor, while at 60 °C only a supercritical fluid is present.

(D) At lower temperatures, the substance consists of vapor only, while at 60 °C only a supercritical fluid is present.

18. Cesium chloride (M = 168.4) crystallizes in a primitive cubic unit cell with each cesium ion surrounded by eight chloride ions arranged in a cube. The density of solid CsCl is 3.988 g cm^{-3}. What is the Cs–Cl distance?

(A) 206.2 pm **(B)** 291.6 pm

(C) 357.1 pm **(D)** 412.4 pm

19. Steam turbines convert heat energy into mechanical work. Which statement best describes the efficiency of this process?

(A) 100%, because energy is conserved

(B) Less than 100%, because the steam decreases in temperature

(C) Greater than 100%, because the turbine increases in kinetic energy

(D) Can be greater than, less than, or equal to 100% depending on the design of the turbine.

20. At what temperatures is the decomposition of tungstic acid, $H_2WO_4(s)$, to tungsten trioxide and water vapor spontaneous under standard conditions?

$$H_2WO_4(s) \rightarrow WO_3(s) + H_2O(g)$$

Compound	$\Delta H°_f$, kJ mol^{-1}	$S°$, J mol^{-1} K^{-1}
$H_2WO_4(s)$	–1130	140
$WO_3(s)$	–840	80
$H_2O(g)$	–240	190

(A) $T > 385$ K

(B) $T < 385$ K

(C) The reaction is spontaneous at all temperatures.

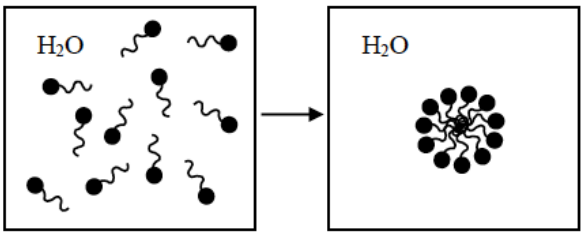
(D) The reaction is not spontaneous at any temperature.

21. In a well-insulated container, 10.0 g solid octane at its freezing point (–56.9 °C) is added to 300.0 mL liquid octane at 0.0 °C (density = 0.71 g mL^{-1}). After equilibrium is achieved, the temperature is –6.3 °C. When the experiment is repeated under the same conditions except with 100.0 g solid octane, what is the final temperature?

(A) –39.7 °C **(B)** –44.9 °C

(C) –51.7 °C **(D)** –56.9 °C

22. Amphiphilic species like $CH_3(CH_2)_{10}COO^-$ can aggregate into micelles in water, as depicted schematically below. ΔS for micelle formation is positive. Which best explains why?



(A) Amphiphilic compounds are solvated by an ordered layer of water molecules.

(B) Micelle formation involves converting many independent amphiphilic compounds into a single large micelle.

(C) Water molecules are trapped in the hydrophobic interior of micelles.

(D) Water molecules form ordered structures around the exterior of micelles.

23. What is $\Delta G°_f$ of $C_2H_4(g)$ at 25 °C?

Substance	$\Delta H°_f$, kJ mol^{-1}	$S°$, J mol^{-1} K^{-1}
$C_2H_4(g)$	52.4	219.3
$H_2(g)$	0	130.7
C(s, graphite)	0	5.7

(A) –13.0 kJ mol^{-1} **(B)** 27.7 kJ mol^{-1}

(C) 46.9 kJ mol^{-1} **(D)** 68.3 kJ mol^{-1}

24. The $\Delta H°_f$ of $CH_4(g)$ is –74.6 kJ mol^{-1} and the bond dissociation enthalpies (BDEs) of several bonds are given in the table.

Bond	BDE, kJ mol^{-1}
C–C	347
C–H	413
H–H	432

Based on these data, what is the molar enthalpy of sublimation of C(s,graphite) to form C(g)?

(A) 713 kJ mol^{-1} **(B)** 788 kJ mol^{-1}

(C) 1061 kJ mol^{-1} **(D)** 1135 kJ mol^{-1}

25. For a reaction X + Y → Z, data for three experiments are given.

$[X]_0$, M	$[Y]_0$, M	Initial rate, M^{-1} min^{-1}
0.10	0.10	2.0×10^{-4}
0.30	0.10	6.0×10^{-4}
0.30	0.30	5.4×10^{-3}

Which mechanism is consistent with the above data? (Reactions shown as reversible are assumed to be rapid and unfavorable.)

(A) X + Y → Z

(B) 2 X ⇌ X_2
X_2 + Y → Z + X

(C) 2 Y ⇌ Y_2
Y_2 + X → Z + Y

(D) X + Y ⇌ XY
XY → Z

26. ^{208}Po undergoes α decay to form stable ^{204}Pb with a half-life of 2.90 years. A sample of ^{208}Po was measured with a Geiger counter 5.20 years ago as having an activity of 1320 disintegrations per second. What is its activity today?

(A) 137 s^{-1} **(B)** 381 s^{-1}

(C) 736 s^{-1} **(D)** 1320 s^{-1}

27. A reversible reaction occurs as follows:

2 A(g) + B(g) ⇌ C(g) + D(g)

Under a certain set of conditions, the rate law for the forward reaction is determined to be Rate = k_f[A][B]. Under these conditions, what is the rate law for the reverse reaction?

(A) Rate = k_r[C][D]

(B) Rate = = $\dfrac{k_r[C][D]}{[A]}$

(C) Rate = = $\dfrac{k_r[C][D]}{[A]^2[B]}$

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

28. A compound A reacts by two independent irreversible pathways to give two products, B and C. At 300 K, 35% of the product is B, while at 320 K, 70% of the product is B. What may be concluded about the activation energy of the pathway to form B compared to the activation energy of the pathway to form C?

(A) The E_a for the pathway to form B is higher by 28 kJ mol^{-1}.

(B) The E_a for the pathway to form B is higher by 59 kJ mol^{-1}.

(C) The E_a for the pathway to form B is lower by 28 kJ mol^{-1}.

(D) The E_a for the pathway to form B is lower by 59 kJ mol^{-1}.

29. The irreversible reaction A + B → C takes place by the following two-step mechanism involving an intermediate X whose concentration is low throughout the reaction:

$$A \underset{k_{-1}}{\overset{k_1}{\rightleftharpoons}} X$$

$$X + B \xrightarrow{k_2} C$$

Which statement cannot be correct regardless of the values of k_1, k_{-1}, and k_2?

(A) The reaction is 0th order in A.

(B) The reaction is 1st order in A.

(C) The reaction is 0th order in B.

(D) The reaction is 1st order in B.

30. Nitramide decomposes to nitrous oxide in aqueous solution:

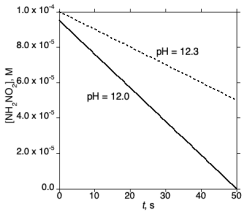
$$NH_2NO_2(aq) \rightarrow N_2O(g) + H_2O(l)$$

In solutions with pH ≥ 12, the rate law for this reaction is:

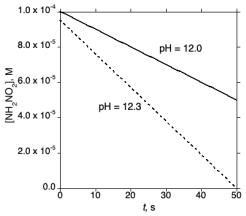
$$\text{Rate} = k\frac{[NH_2NO_2]}{[H_3O^+]}$$

The reaction is monitored with pH = 12.0 (solid line) and with pH = 12.3 (dashed line). Which graph best represents the time-dependence of the nitramide concentrations in the two experiments?

(A)



(B)



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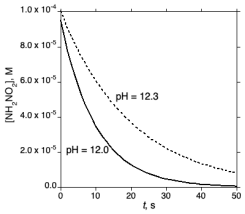

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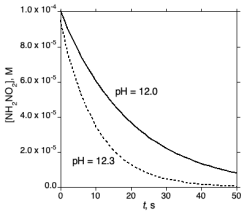


31. A sample of 0.320 mol of a weak monoprotic acid in 1.00 L of solution is 10.2% ionized. What is K_a for this acid?

(A) 3.3×10^{-3} **(B)** 3.7×10^{-3}

(C) 3.2×10^{-2} **(D)** 1.1×10^{-1}

32. Typically, the molar solubility x of an ionic compound in pure water and its K_{sp} are related by a simple formula. Which formula is not expected for K_{sp} for an ionic compound?

(A) $K_{sp} = 4x^3$ **(B)** $K_{sp} = 4x^4$

(C) $K_{sp} = 27x^4$ **(D)** $K_{sp} = 81x^5$

33. Equal volumes of 0.1 M solutions of NaH_2PO_4 and Na_3PO_4 are mixed. What is the pH of the resulting solution? For H_3PO_4, $pK_{a1} = 2.12$, $pK_{a2} = 7.21$, $pK_{a3} = 12.32$.

(A) 4.66 **(B)** 6.66 **(C)** 7.21 **(D)** 9.76

34. 5.00 g of nitrogen dioxide is introduced into an evacuated, rigid 1.00 L container. It is allowed to equilibrate according to the reaction below at 310 K, and the total pressure in the vessel is 1.71 bar. What is K_p for the reaction at 310 K?

$$N_2O_4(g) \rightleftharpoons 2\ NO_2(g)$$

(A) 0.35 **(B)** 0.57 **(C)** 2.28 **(D)** 2.92

35. A mixture containing $CO(g)$, $H_2O(g)$, $CO_2(g)$, and $H_2(g)$ is allowed to reach equilibrium at 120 °C in a container that maintains a constant total pressure of 1.0 bar.

$$CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g)$$

5.0 g of H_2O is added to this container, which is allowed to reattain equilibrium (still at 120 °C and 1 bar total pressure). How does the partial pressure of $H_2(g)$ change as a result of the addition of H_2O?

(A) The partial pressure of $H_2(g)$ increases.

(B) The partial pressure of $H_2(g)$ decreases.

(C) The partial pressure of $H_2(g)$ does not change.

(D) The effect on the partial pressure of $H_2(g)$ cannot be determined from the information given.

36. 0.01 mol of $AgNO_3$ is dissolved in 1.00 L of 1.00 M aqueous NH_3. What is the minimum amount of HCl that would need to be added to this solution to induce precipitation of AgCl? The K_{sp} of AgCl is 1.8×10^{-10}; the K_f of $Ag(NH_3)_2^+$ is 1.6×10^7; and the K_a of NH_4^+ is 5.6×10^{-10}.

(A) 1.8×10^{-8} mol **(B)** 1.3×10^{-5} mol

(C) 0.18 mol **(D)** 0.28 mol

37. In which compound does the oxidation number of oxygen differ from –2?

(A) $NaBO_3$ **(B)** $NaNO_3$

(C) K_3PO_4 **(D)** $K_2Cr_2O_7$

38. Copper metal reacts with nitric acid to form $NO(g)$ as shown in the unbalanced reaction shown below. When the reaction is balanced using lowest whole number coefficients, what is the coefficient of $H^+(aq)$?

$$Cu(s) + H^+(aq) + NO_3^-(aq) \rightarrow Cu^{2+}(aq) + NO(g) + H_2O(l)$$

(A) 2 **(B)** 4 **(C)** 6 **(D)** 8

39. In the Hall-Héroult process for producing aluminum, aluminum is electrolytically reduced from Al_2O_3 dissolved in molten cryolite, Na_3AlF_6, while a graphite anode is oxidized to CO_2. What is the ratio of the mass of Al deposited on the cathode to the mass of C lost from the anode?

(A) 1.50:1 **(B)** 2.25:1 **(C)** 3.00:1 **(D)** 3.36:1

40. The cathode of an electrolytic cell with a copper electrode initially has 100.0 mL of a solution that is 1.00 M in both $Cu^{2+}(aq)$ and $Fe(CN)_6^{3-}(aq)$. The solution is electrolyzed with a constant current of 0.500 A at a constant temperature of 298 K. How much time elapses before Cu(*s*) begins to deposit on the electrode?

Half-reaction	$E°$, V
$Fe(CN)_6^{3-}(aq) + e^- \rightarrow Fe(CN)_6^{4-}(aq)$	0.370
$Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$	0.337

(A) 0 min **(B)** 89.4 min

(C) 252 min **(D)** 322 min

41. A molecule absorbs a photon of light to form an excited state. How do the redox properties of the excited state compare to those of the ground state?

(A) The excited state is both a stronger oxidizing agent and a stronger reducing agent than the ground state.

(B) The excited state is both a weaker oxidizing agent and a weaker reducing agent than the ground state.

(C) The excited state is a stronger oxidizing agent but a weaker reducing agent than the ground state.

(D) The excited state is a weaker oxidizing agent but a stronger reducing agent than the ground state.

42. What is $\Delta G°$ at 298 K for the disproportionation of PbO(*s*)?

$$2\ PbO(s) \rightarrow PbO_2(s) + Pb(s) \qquad \Delta G° = ???$$

Half-reaction	$E°$, V
$PbO_2(s) + 4\ H^+(aq) + 4e^- \rightarrow Pb(s) + 2\ H_2O(l)$	0.671
$PbO(s) + H_2O(l) + 2e^- \rightarrow Pb(s) + 2\ OH^-(aq)$	–0.580

(A) 163 kJ mol^{-1} **(B)** 241 kJ mol^{-1}

(C) 403 kJ mol^{-1} **(D)** 483 kJ mol^{-1}

43. For which gas-phase atoms is addition of an electron endothermic?

I. Li II. N

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

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

44. Which atom has the lowest first ionization energy?

(A) Be **(B)** B **(C)** Mg **(D)** Al

45. How many electrons in a ground-state gas-phase atom of arsenic (As) have a quantum number $m_l = 1$?

(A) 5 **(B)** 7 **(C)** 15 **(D)** 18

46. Which orbital has the same number of radial nodes as a 3*s* orbital?

(A) 3*p* **(B)** 4*s* **(C)** 4*f* **(D)** 5*d*

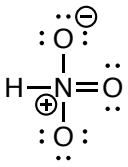
47. Which lanthanide has a common oxidation number different from +3?

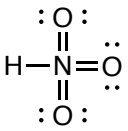
(A) Ce **(B)** Gd **(C)** Er **(D)** Lu

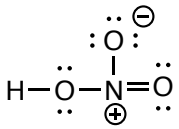
48. Which radioisotope decays by beta (β^-) emission?

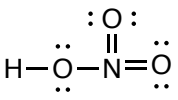
(A) ^{20}Na **(B)** ^{52}V **(C)** ^{54}Co **(D)** ^{62}Cu

49. Which is a valid Lewis structure for nitric acid, HNO_3?

(A) 

(B) 

(C) 

(D) 

50. Which statements about carbon-oxygen bond lengths are correct?

I. The carbon-oxygen bond in carbon dioxide, CO_2, is shorter than the carbon-oxygen bond in carbonyl sulfide, COS.

II. The carbon-oxygen bond in phosgene, $COCl_2$, is shorter than the carbon-oxygen bond in urea, $CO(NH_2)_2$.

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

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

51. Which statement best describes the relative Lewis acidity of BF_3 and BCl_3?

(A) BF_3 is a weaker Lewis acid than BCl_3 because F is more electronegative than Cl.

(B) BF_3 is a weaker Lewis acid than BCl_3 because F is a better π donor than Cl.

(C) BF_3 is a stronger Lewis acid than BCl_3 because F is more electronegative than Cl.

(D) BF_3 is a stronger Lewis acid than BCl_3 because F is a better π donor than Cl.

52. Which comparisons of bond angles are correct?

I. The bond angle in NH_3 is greater than the bond angle in NF_3.

II. The bond angle in NH_3 is greater than the bond angle in PH_3.

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

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

53. The gas-phase molecules B_2 and O_2 are both paramagnetic. Which statement about the relative energies of their molecular orbitals explains these observations?

I. The σ_{2p} MO is higher in energy than the π_{2p} MO's.

II. The σ^*_{2p} MO is higher in energy than the π^*_{2p} MO's.

(A) I for B_2, II for O_2 **(B)** I for O_2, II for B_2

(C) I for both B_2 and O_2 **(D)** II for both B_2 and O_2

54. How many stereoisomers are there of the octahedral coordination complex $Co(NH_2CH_2CO_2)_3$?

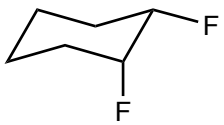
(A) 1 **(B)** 2 **(C)** 3 **(D)** 4

55. How many tertiary alcohols have the formula $C_5H_{12}O$?

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

56. Which difluorocyclohexanes are optically active?

I. 

II. 

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

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

57. Which best describes the outcome of extracting a dilute solution of benzoic acid in diethyl ether with 5% aqueous $NaHCO_3$?

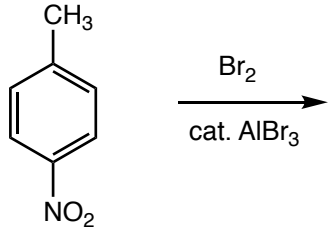
(A) Benzoic acid is present in the bottom layer.

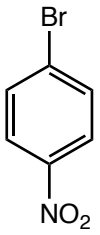
(B) Benzoate ion is present in the bottom layer.

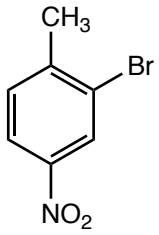
(C) Benzoic acid is present in the top layer.

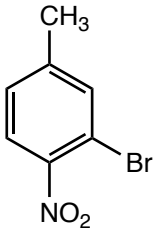
(D) Benzoate ion is present in the top layer.

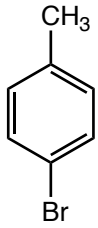
58. Which product would be obtained in the greatest quantity from bromination of 4-nitrotoluene using an aluminum bromide catalyst?



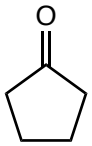
(A) 

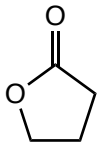
(B) 

(C) 

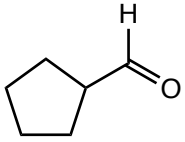
(D) 

59. Which compound is least reactive toward ethylmagnesium bromide, CH_3CH_2MgBr?

(A) 

(B) 

(C) 

(D) 

60. Which statements describe significant differences between RNA and DNA?

I. The bases used in RNA include three purines and one pyrimidine, while those in DNA include two purines and two pyrimidines.

II. Hydrolysis of RNA frequently involves cyclic phosphate intermediates, while hydrolysis of DNA never does.

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

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

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