2019 U.S. NATIONAL CHEMISTRY OLYMPIAD

NATIONAL EXAM PART I

Prepared by the American Chemical Society Chemistry Olympiad Examinations Task Force

OLYMPIAD EXAMINATIONS TASK FORCE

Seth N. Brown, **Chair**, *University of Notre Dame,* Notre Dame, IN

James Ayers, Colorado Mesa University, Grand Junction, CO
Mark DeCamp, University of Michigan, Dearborn, MI (retired)
Marian DeWane, Centennial High School, Boise, ID
Xu Duan, Holton-Arms School, Bethesda, MD
Valerie Ferguson, Moore HS, Moore, OK
Julie Furstenau, Thomas B. Doherty HS, Colorado Springs, CO (retired)
Kimberly Gardner, United States Air Force Academy, CO
Paul Groves, South Pasadena HS, South Pasadena, CA
Nicolas Hamel, Clackamas Community College, Oregon City, OR
John Kotz, State University of New York, Oneonta, NY (retired)
Jane Nagurney, Scranton Preparatory School, Scranton, PA (retired)
Sheila Nguyen, Cypress College, Cypress, CA
Ronald Ragsdale, University of Utah, Salt Lake City, UT (retired)

DIRECTIONS TO THE EXAMINER – PART I

The USNCO Subcommittee is conducting a survey in an effort to determine the impact of the Olympiad program on students. At the end of the exam there are four questions, which should be answered on the same Scantron sheet students use for the exam. These questions may be administered after the 90 minutes allotted for the exam, each student should be encouraged to answer these questions.

Part I of this test is designed to be taken with a Scantron answer sheet on which the student records his or her responses. Only this Scantron sheet is graded for a score on Part I. Testing materials, scratch paper, and the Scantron sheet should be made available to the student *only* during the examination period. All testing materials including scratch paper should be turned in and kept secure until **April 29, 2019**, after which tests can be returned to students and their teachers for further study.
Allow time for students to read the directions, ask questions, and fill in the requested information on the Scantron sheet. The answer sheet must be completed using a pencil, not pen. When the student has completed **Part I**, or after **one hour and thirty minutes** has elapsed, the student must turn in the Scantron sheet, Part I of the testing materials, and all scratch paper.
There are three parts to the National Chemistry Olympiad Examination. You have the option of administering the three parts in any order, and you are free to schedule rest breaks between parts.

Part I	**60 questions**	**single answer, multiple-choice**	**1 hour, 30 minutes**
Part II	**8 questions**	**problem-solving, explanations**	**1 hour, 45 minutes**
Part III	**2 lab problems**	**laboratory practical**	**1 hour, 30 minutes**

A periodic table and other useful information are provided on page 2 for student reference**.**

Students should be permitted to use non-programmable calculators. The use of a programmable calculator, cell phone, watch, or any other device that can access the internet or make copies or photographs during the exam is grounds for disqualification.
DIRECTIONS TO THE EXAMINEE – DO NOT TURN THE PAGE UNTIL DIRECTED TO DO SO. Answers to questions in Part I must be entered on a Scantron answer sheet to be scored. Be sure to write your name on the answer sheet, an ID number is already entered for you. **Make a record of this ID number because you will use the same number on Parts II and III.** Each item in **Part I** consists of a question or an incomplete statement that is followed by four possible choices. Select the single choice that best answers the question or completes the statement. Then use a pencil to blacken the space on your answer sheet next to the same letter as your choice. You may write on the examination, but the test booklet will not be used for grading. Scores are based on the number of correct responses. When you complete **Part I** (or at the end of one hour and 30 minutes), you must turn in all testing materials, scratch paper, and your Scantron answer sheet. **Do not forget to turn in your U.S. citizenship/Green Card Holder statement before leaving the testing site today.**

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

CONSTANTS
$R = 8.314$ J mol^{-1} K^{-1}
$R = 0.08314$ L bar mol^{-1} K^{-1}
$F = 96{,}500$ C mol^{-1}
$F = 96{,}500$ J V^{-1} mol^{-1}
$N_A = 6.022 \times 10^{23}$ mol^{-1}
$h = 6.626 \times 10^{-34}$ J s
$c = 2.998 \times 10^{8}$ m s^{-1}
0 °C = 273.15 K
1 atm = 1.013 bar = 760 mm Hg
Specific heat capacity of H_2O = 4.184 J g^{-1} K^{-1}

EQUATIONS

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

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. Which sample contains the greatest number of molecules?

(A) 35.0 g C_2H_2 **(B)** 45.0 g C_2H_6

(C) 60.0 g C_4H_{10} **(D)** 100.0 g C_6H_6

2. A mixture of hydrogen and oxygen is ignited and reacts completely to form water. Which mixture will NOT produce 18 g of H_2O?

(A) 2.0 g H_2, 16.0 g O_2 **(B)** 2.0 g H_2, 18.0 g O_2

(C) 4.0 g H_2, 16.0 g O_2 **(D)** 4.0 g H_2, 18.0 g O_2

3. How many oxygen atoms are in 1.00 g of the mineral troegerite, $(UO_2)_3(AsO_4)_2 \cdot 12\ H_2O$ (M = 1304.0)?

(A) 6.47×10^{21} **(B)** 8.31×10^{21}

(C) 1.20×10^{22} **(D)** 1.39×10^{22}

4. Hünig's base is a monobasic amine containing 74.34% C, 14.82% H, and 10.84% N by mass. How many hydrogen atoms are in one molecule of Hünig's base?

(A) 8 **(B)** 14 **(C)** 15 **(D)** 19

5. Magnesium metal burns in air to form a mixture of magnesium oxide (MgO, M = 40.31) and magnesium nitride (Mg_3N_2, M = 100.95). A 1.000 g sample of magnesium ribbon is burned in air to give 1.584 g of the oxide/nitride mixture. What percentage of the magnesium is present in the form of the nitride?

(A) 9.00% **(B)** 11.0%

(C) 27.1% **(D)** 90.3%

6. What is the pH of a solution formed by mixing 45.0 mL of 0.10 M HNO_3, 50.0 mL of 0.20 M HCl, and 55.0 mL of 0.10 M CH_3COOH?

(A) 0.40 **(B)** 0.88 **(C)** 1.01 **(D)** 1.52

7. Which dissolves to give a blue solution?

(A) $Na_2S_2O_4$ **(B)** K_2CrO_4

(C) $Cu(NO_3)_2$ **(D)** $Zn(OH)_2$

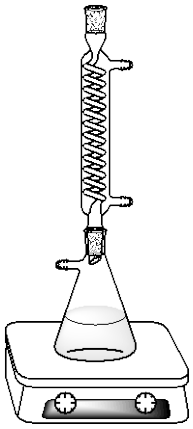
8. A 0.1 M solution of which compound is most acidic?

(A) KNO_3 **(B)** NH_4NO_3

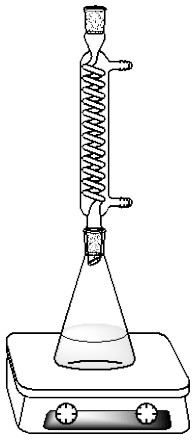
(C) $Ba(NO_3)_2$ **(D)** $Fe(NO_3)_3$

9. A chemist wishes to prepare methyl benzoate by refluxing benzoic acid in methanol overnight in the presence of a catalytic amount of sulfuric acid. Which setup is most appropriate for carrying out this reaction?

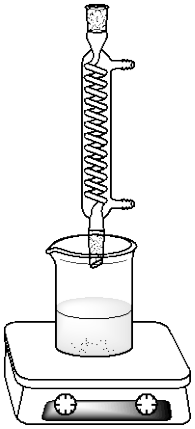
(A)



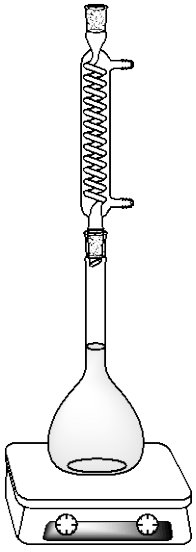
(B)



(C)



(D)



10. A pale yellow solid is insoluble in water or concentrated ammonia solution, but dissolves in concentrated $Na_2S_2O_3$ solution. What is it?

(A) AgF **(B)** AgCl

(C) AgI **(D)** $Ag(CH_3COO)$

11. A chemist has isolated a solid carboxylic acid of unknown formula from a medicinal herb. Which experiment will be most useful in assessing the purity of the isolated material?

(A) Melting point

(B) Titration with NaOH

(C) Combustion analysis

(D) UV-visible spectrophotometry

12. The ammonia concentration of a solution is determined by titrating with aqueous HCl (previously standardized against Na_2CO_3) using a pH meter. Which of the following errors will lead to a measured concentration of NH_3 that is higher than the actual concentration?

(A) Some of the Na_2CO_3 used in the standardization is spilled before being transferred to the titration flask.

(B) The glass stirring rod used to stir the ammonia solution is wiped with a paper towel after each aliquot of HCl is added.

(C) The ammonia solution is allowed to stand in an open beaker for an hour before being titrated.

(D) The pH meter has been miscalibrated so that all readings are 2.00 pH units higher than the actual pH.

13. Which set of characteristics describes a metal?

(A) Melting point 180 ºC, soft, electrically conductive as a solid

(B) Melting point 388 ºC, soluble in CCl_4

(C) Melting point 801 ºC, dissolves in water to give an electrically conducting solution

(D) Melting point 1400 ºC, insoluble in water, has electrical conductivity that is low at room temperature but rises sharply as temperature increases

14. A test tube is filled with 5 mL water, 5 mL carbon tetrachloride (CCl_4), and a few crystals of iodine (I_2). After the tube is capped and shaken, what is the final appearance of the system after it is allowed to stand for a few minutes?

(A) A single layer of violet liquid.

(B) A single layer of colorless liquid under violet vapor.

(C) A colorless liquid layer above a violet liquid layer.

(D) A violet liquid layer above a colorless liquid layer.

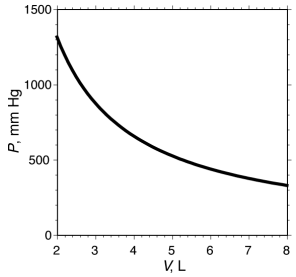
15. Which substance has the highest normal boiling point?

(A) CH_2CH_2 **(B)** NH_2NH_2

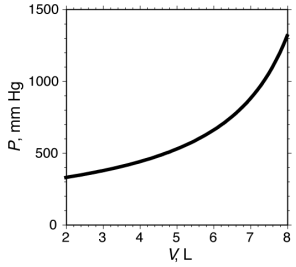
(C) CH_3NH_2 **(D)** CH_3OH

16. An adjustable-volume container holds 10.0 g pentane (M = 72.15, normal boiling point = 36.1 ºC). The pressure in the container is measured as a function of volume while maintaining the temperature at 30 ºC. Which graph shows the results of this experiment?

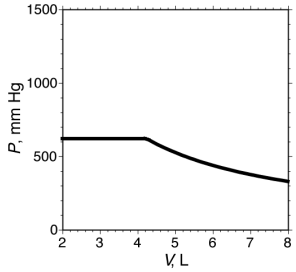
(A)



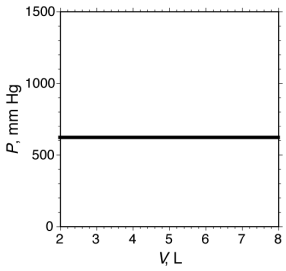
(B)



(C)



(D)



17. Cotton balls soaked in concentrated solutions of HBr and CH_3NH_2 are placed at the same time in opposite ends of a glass tube. What is observed?

(A) A white ring of $(CH_3NH_3)Br$ forms in the tube closer to the side with the HBr.

(B) A white ring of $(CH_3NH_3)Br$ forms in the tube closer to the side with the CH_3NH_2.

(C) A white ring of NH_4Br forms in the tube closer to the side with the HBr.

(D) A white ring of NH_4Br forms in the tube closer to the side with the CH_3NH_2.

18. A metal with a face-centered cubic (fcc) lattice has a unit cell edge length a = 380.3 pm and a density of 12.45 g cm^{-3}. What metal is it?

(A) K (Z = 19) **(B)** V (Z = 23)

(C) Rh (Z = 45) **(D)** Pb (Z = 82)

19. The process of liquid water freezing at –10 °C and 1 atm pressure is

(A) spontaneous and exothermic

(B) spontaneous and endothermic

(C) nonspontaneous and exothermic

(D) nonspontaneous and endothermic

20. What is ΔH^{o}_{rxn} for the fermentation of glucose as shown below?

$$C_6H_{12}O_6(s) \rightarrow 2\ C_2H_5OH(l) + 2\ CO_2(g)$$
$$\Delta H^{o}_{rxn} = ???$$

$$C_2H_5OH(l) + O_2(g) \rightarrow CH_3COOH(l) + H_2O(l)$$
$$\Delta H^{o}_{rxn} = -492.6\ kJ\ mol^{-1}$$

$$CH_3COOH(l) + 2\ O_2(g) \rightarrow 2\ CO_2(g) + 2\ H_2O(l)$$
$$\Delta H^{o}_{rxn} = -874.2\ kJ\ mol^{-1}$$

$$C_6H_{12}O_6(s) + 6\ O_2(g) \rightarrow 6\ CO_2(g) + 6\ H_2O(l)$$
$$\Delta H^{o}_{rxn} = -2805.0\ kJ\ mol^{-1}$$

(A) –71.4 kJ mol^{-1} **(B)** –945.6 kJ mol^{-1}

(C) –1438.2 kJ mol^{-1} **(D)** –5528.7 kJ mol^{-1}

21. The solubility of Li_2CO_3 in water at 298 K is 0.175 mol L^{-1}, and its solubility decreases with increasing temperature. What are the signs of ΔH^{o} and ΔS^{o} for the dissolution of Li_2CO_3?

$$Li_2CO_3(s) \rightarrow 2\ Li^{+}(aq) + CO_3^{2-}(aq)$$

(A) $\Delta H° > 0$, $\Delta S° > 0$ **(B)** $\Delta H° > 0$, $\Delta S° < 0$

(C) $\Delta H° < 0$, $\Delta S° > 0$ **(D)** $\Delta H° < 0$, $\Delta S° < 0$

22. A system confined in a rigid, well-insulated container undergoes a spontaneous change. What statement about the system must be true?

(A) Its Gibbs free energy increases during the change.

(B) Its Gibbs free energy decreases during the change.

(C) Its entropy increases during the change.

(D) Its entropy decreases during the change.

23. What is ΔG for the decomposition of $CaCO_3$ at 298 K and a partial pressure of CO_2 of 4.00 × 10^{-4} bar?

$$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$$
$$\Delta G_{rxn}\ (298\ K,\ P_{CO2} = 0.400\ mbar) = ???$$

Compound	$CaCO_3(s)$	$CaO(s)$	$CO_2(g)$
$\Delta G°_f$ (kJ mol^{-1})	–1129	–604	–394

(A) –131 kJ mol^{-1} **(B)** 112 kJ mol^{-1}

(C) 131 kJ mol^{-1} **(D)** 150 kJ mol^{-1}

24. A 10.0 g sample of solid NH_4NO_3 (M = 80.05) is added to 100.0 g H_2O in a well-insulated container. Both the solid and the water are initially at 24.00 ºC, but after the NH_4NO_3 dissolves, the temperature of the mixture is 17.11 ºC. What is ΔH^{o}_{rxn} for the dissolution of $NH_4NO_3(s)$? Assume that the specific heat capacity of the NH_4NO_3 solution is the same as that of pure water, 4.184 J g^{-1} ºC^{-1}.

(A) –3.17 kJ mol^{-1} **(B)** 0.559 kJ mol^{-1}

(C) 3.17 kJ mol^{-1} **(D)** 25.4 kJ mol^{-1}

25. Acetone is brominated in acidic solution according to the following reaction:

$$CH_3COCH_3(aq) + Br_2(aq) \rightarrow CH_3COCH_2Br(aq) + H^{+}(aq) + Br^{-}(aq)$$

What is the rate law implied by the mechanism given below?

$$CH_3COCH_3(aq) + H^{+}(aq) \rightleftharpoons CH_3C(OH)CH_3^{+}(aq)$$
fast, reversible

$$CH_3C(OH)CH_3^{+}(aq) \rightarrow CH_3C(OH)=CH_2(aq) + H^{+}(aq)$$
slow

$$CH_3C(OH)=CH_2(aq) + Br_2(aq) \rightarrow CH_3C(OH)CH_2Br^{+}(aq) + Br^{-}(aq)$$
fast

$$CH_3C(OH)CH_2Br^{+}(aq) \rightarrow CH_3COCH_2Br(aq) + H^{+}(aq)$$
fast

(A) Rate = $k[CH_3COCH_3][H^{+}]$

(B) Rate = $k[CH_3COCH_3]$

(C) Rate = $k[CH_3COCH_3][Br_2]$

(D) Rate = $\dfrac{k[CH_3COCH_3][Br_2]}{[H^{+}]}$

26. A rule of thumb is that a reaction's rate roughly doubles for every 10 °C increase in temperature. What is the activation energy of a reaction whose rate exactly doubles between 25.0 °C and 35.0 °C?

(A) 52.9 kJ mol^{-1} **(B)** 153 kJ mol^{-1}

(C) 504 kJ mol^{-1} **(D)** 523 kJ mol^{-1}

27. At 650 K, β-pinene isomerizes to form either 4-isopropenyl-1-methylcyclohexene or myrcene. The former reaction has a rate constant of 0.22 s^{-1} and the latter a rate constant of 0.13 s^{-1}. What is the overall rate law for the isomerization of β-pinene?

(A) Rate = (0.029 s^{-1})[β-pinene]

(B) Rate = (0.082 s^{-1})[β-pinene]

(C) Rate = (0.17 s^{-1})[β-pinene]

(D) Rate = (0.35 s^{-1})[β-pinene]

28. How is the rate of change of the ClF_3 concentration related to the rate of change of the F_2 concentration?

$$Cl_2(g) + 3\ F_2(g) \rightarrow 2\ ClF_3(g)$$

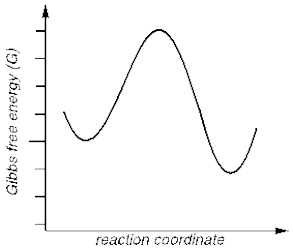
(A) $\Delta[ClF_3]/\Delta t = (3/2)(\Delta[F_2]/\Delta t)$

(B) $\Delta[ClF_3]/\Delta t = \Delta[F_2]/\Delta t$

(C) $\Delta[ClF_3]/\Delta t = -(2/3)(\Delta[F_2]/\Delta t)$

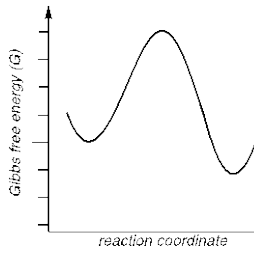
(D) $\Delta[ClF_3]/\Delta t = -(3/2)(\Delta[F_2]/\Delta t)$

29. A reaction takes place by an uncatalyzed pathway whose reaction coordinate diagram is shown below.

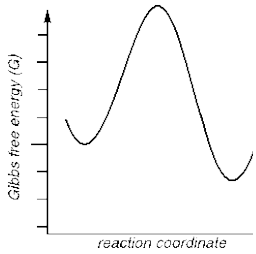


The reaction is accelerated by addition of a small amount of a catalyst. Which reaction coordinate diagram (drawn to the same scale as the one above) best describes the catalyzed reaction?

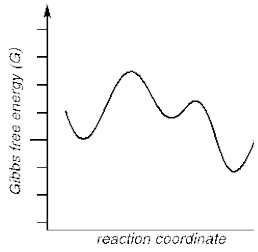
(A)



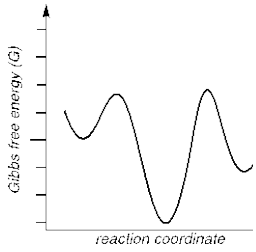
(B)



(C)



(D)



30. Methyl iodide reacts irreversibly with azide ion with rate = $k[CH_3I][N_3^-]$.

$$CH_3I(aq) + N_3^-(aq) \rightarrow CH_3N_3(aq) + I^-(aq)$$

The reaction is carried out with an initial concentration of CH_3I of 0.01 M. Which statement about the reaction is correct?

(A) The time it takes for $[CH_3I]$ to decrease to 0.005 M is independent of $[N_3^-]$, as long as $[N_3^-] >> [CH_3I]$.

(B) If the initial concentrations of azide and CH_3I are equal, then it takes half as long for $[CH_3I]$ to decrease to 0.005 M as it does for it to decrease from 0.005 M to 0.0025 M.

(C) The reaction rate is significantly smaller if excess I^- is added to the solution.

(D) The reaction cannot take place in a single elementary step.

31. The molar solubility of PbF_2 is 2.1×10^{-3} mol L^{-1}. What is its K_{sp}?

(A) 4.4×10^{-6} **(B)** 8.8×10^{-6}

(C) 3.7×10^{-8} **(D)** 9.3×10^{-9}

32. What is the pH of a 0.10 M solution of ammonium acetate, $NH_4(CH_3COO)$? The K_a of NH_4^+ is 5.6×10^{-10} and the K_a of CH_3COOH is 1.8×10^{-5}.

(A) 2.87 **(B)** 5.13 **(C)** 7.00 **(D)** 8.87

Problems 33 and 34 both concern the dissociation of phosphorus pentachloride into chlorine and phosphorus trichloride, which has $K_p = 0.015$ at 450 K.

$$PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)\ ,\ K_p = 0.015$$

33. A closed container at 450 K initially contains only $PCl_5(g)$ and $PCl_3(g)$, each with a partial pressure of 2.7 bar. After the system reaches equilibrium, what is the partial pressure of $Cl_2(g)$?

(A) 0.015 bar **(B)** 0.12 bar

(C) 0.20 bar **(D)** 2.7 bar

34. Which change will decrease the number of moles of $Cl_2(g)$ present in this system at equilibrium?

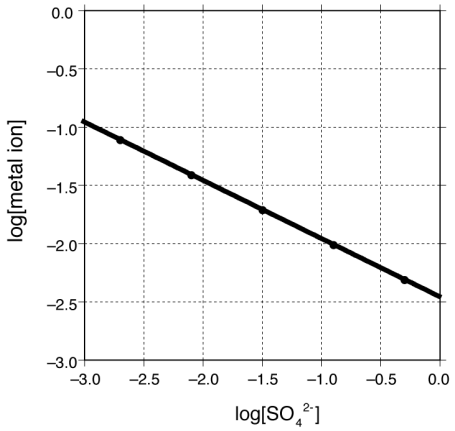
(A) Increasing the volume of the container.

(B) Increasing the pressure by injecting Ar(g).

(C) Increasing the pressure by injecting $PCl_5(g)$.

(D) Decreasing the temperature.

35. A metal M forms a sparingly soluble sulfate salt. The logarithm of the concentration of the dissolved metal ion in a solution saturated in the metal sulfate is plotted below as a function of the logarithm of the concentration of sulfate ion in solution. What is the formula of the metal sulfate?



(A) M_2SO_4 **(B)** MSO_4

(C) $M_2(SO_4)_3$ **(D)** $M(SO_4)_2$

36. A 1.00 g pill contains morphine (M = 285.34), a monobasic compound whose conjugate acid has pK_a = 8.21, in addition to an unknown amount of inert material. To analyze the morphine content of the pill, it is dissolved in 50.0 mL 0.1000 M aqueous HCl and the unreacted acid in the resulting solution back-titrated with 0.1000 M NaOH. Which of the following statements about this experiment are correct?

I. If the pill contains only morphine, the titration will require 35.0 mL NaOH solution to reach the endpoint.

II. Methyl red, which changes color from red to yellow between pH = 4.4 and pH = 6.2, would be a suitable indicator for this titration.

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

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

37. The cathode of an electrolytic cell is placed in 100 mL of a solution that is 0.01 M in both $AgNO_3$ and $Cu(NO_3)_2$. A current of 0.5 A is passed through the cell for 250 s. What deposits on the cathode?

(A) Ag only

(B) Cu only

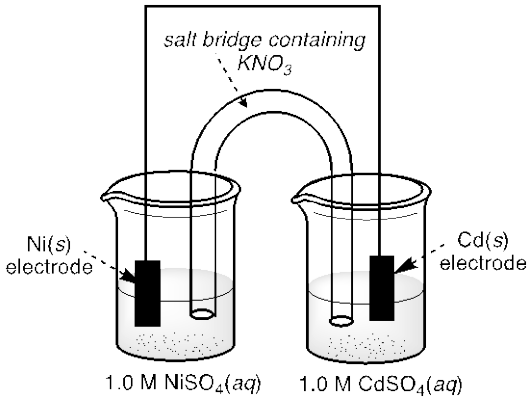
(C) 1×10^{-3} mol Ag and some of the Cu

(D) 1×10^{-3} mol Cu and some of the Ag

38. What is the oxidation state of sulfur in $Na_2S_2O_4$?

(A) –2 **(B)** +3 **(C)** +4 **(D)** +6

39. Which statement about the electrochemical cell is correct?



Half-Reaction	E^o, V
$Cd^{2+}(aq) + 2\ e^- \rightarrow Cd(s)$	–0.40
$Ni^{2+}(aq) + 2\ e^- \rightarrow Ni(s)$	–0.25

(A) Ni(s) is the anode.

(B) As the cell discharges, K^+ ions migrate toward the $NiSO_4$ solution.

(C) Using a thinner Ni(s) electrode would increase the magnitude of the cell potential.

(D) Adding $NiSO_4$ to the beaker on the left would decrease the magnitude of the cell potential.

40. What is the standard reduction potential for the reduction of $V^{3+}(aq)$ to V(s)?

$$V^{3+}(aq) + 3\ e^- \rightarrow V(s)$$
$$E^o = ???$$

Half-Reaction	E^o, V
$V^{2+}(aq) + 2\ e^- \rightarrow V(s)$	–1.13 V
$V^{3+}(aq) + e^- \rightarrow V^{2+}(aq)$	–0.26 V

(A) –0.70 V **(B)** –0.84 V

(C) –1.39 V **(D)** –1.65 V

41. For the cell,

$$Ag(s) \mid Ag(NH_3)_2^+(aq, 0.010\ M) \mid NH_3(aq, 0.40\ M) \parallel Ag^+(aq, 0.010\ M) \mid Ag(s)$$

What is the cell potential? The K_f of $Ag(NH_3)_2^+$ is 1.6×10^7.

(A) 0.12 V **(B)** 0.38 V **(C)** 0.40 V **(D)** 0.44 V

42. What is the equilibrium constant for the reaction at 298 K?

$$3\ Cl_2(g) + 2\ Cr^{3+}(aq) + 7\ H_2O(l) \rightleftharpoons Cr_2O_7^{2-}(aq) + 6\ Cl^-(aq) + 14\ H^+(aq)$$

Half-Reaction	E^o, V
$Cr_2O_7^{2-}(aq) + 14\ H^+(aq) + 6\ e^- \rightarrow 2\ Cr^{3+}(aq) + 7\ H_2O$	1.33
$Cl_2(g) + 2\ e^- \rightarrow 2\ Cl^-(aq)$	1.36

(A) 3.2 **(B)** 1100

(C) 3.2×10^{46} **(D)** 1.1×10^{279}

43. A hydrogen atom with principal quantum number $n = 3$ can emit light with $\lambda = 656$ nm. Which statement about a hydrogen atom with quantum number $n = 4$ is correct?

(A) It can only emit light with $\lambda < 656$ nm.

(B) It can only emit light with $\lambda = 656$ nm.

(C) It can only emit light with $\lambda > 656$ nm.

(D) It can emit light with wavelengths either less than or greater than 656 nm, but cannot emit light with $\lambda = 656$ nm.

44. In which list are the ions ranked in order of increasing ionic radius?

(A) $K^+ < Rb^+ < Ca^{2+} < Sr^{2+}$

(B) $K^+ < Ca^{2+} < Rb^+ < Sr^{2+}$

(C) $Ca^{2+} < Sr^{2+} < K^+ < Rb^+$

(D) $Ca^{2+} < K^+ < Sr^{2+} < Rb^+$

45. Which element is the most electronegative?

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

46. How many orbitals are filled or partially filled in a gas-phase Ti atom in its ground state?

(A) 11 **(B)** 12 **(C)** 13 **(D)** 14

47. ^{41}Ca undergoes radioactive decay by electron capture. Which statements about its decay product are correct?

I. The decay product is an isotope of Sc.

II. The decay product has a slightly larger mass than ^{41}Ca.

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

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

48. Aluminum has a smaller first ionization energy than magnesium. Which is the best explanation for this observation?

(A) Al has an odd number of electrons, while Mg has an even number of electrons.

(B) Al has more valence electrons than Mg.

(C) The highest-energy electron in Al has less electron density near the nucleus than the highest-energy electron in Mg.

(D) The highest-energy electron in Al is on average farther from the nucleus than the highest-energy electron in Mg.

49. Which molecule has a dipole moment of zero?

(A) CH_2Cl_2 **(B)** $CHCl_3$

(C) SO_2 **(D)** SO_3

50. The carbon-oxygen bond in CO has a higher bond dissociation enthalpy than a carbon-oxygen bond in CO_2. Which is the best explanation for this difference?

(A) CO has a bond order of 3 while each carbon-oxygen bond in CO_2 has a bond order of 2.

(B) CO is a polar molecule while CO_2 is a nonpolar molecule.

(C) CO contains one carbon-oxygen bond while CO_2 contains two carbon-oxygen bonds.

(D) CO has a lone pair on carbon while CO_2 does not.

51. What value is closest to the bond angle in the triiodide ion, I_3^-?

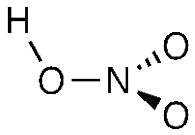
(A) 180° **(B)** 120° **(C)** 109.5° **(D)** 90°

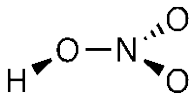
52. Which species is the strongest Brønsted acid?

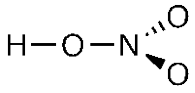
(A) HBrO **(B)** $HBrO_2$

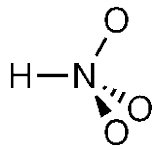
(C) $HBrO_3$ **(D)** $HBrO_4$

53. Which is the best depiction of the three-dimensional arrangement of the atoms in nitric acid, HNO_3?

(A) 

(B) 

(C) 

(D) 

54. Which of these is NOT a correct statement about the ferrioxalate ion, $Fe(C_2O_4)_3^{3-}$?

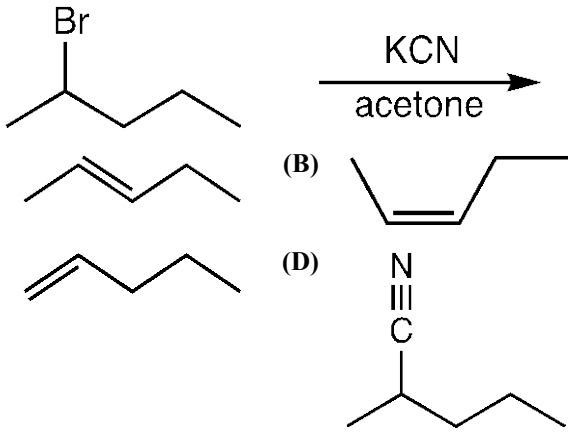
(A) It is chiral.

(B) There are two different carbon-oxygen bond distances in the ion.

(C) There are two different iron-oxygen bond distances in the ion.

(D) There are six iron-oxygen bonds in the ion.

55. What is the major organic product of the reaction of potassium cyanide with 2-bromopentane?



56. How many distinct compounds of the formula $C_5H_{11}Cl$ can be formed by free radical chlorination of 2-methylbutane?

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

57. A compound with the formula C_5H_8O has exactly one π bond. How many rings does this compound have?

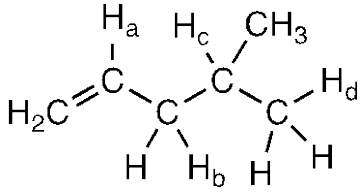
(A) Zero

(B) One

(C) Two

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

58. Which C–H bond has the smallest bond dissociation enthalpy?



(A) $C–H_a$ **(B)** $C–H_b$ **(C)** $C–H_c$ **(D)** $C–H_d$

59. What compounds are formed on hydrolysis of a typical fat with aqueous sodium hydroxide (saponification)?

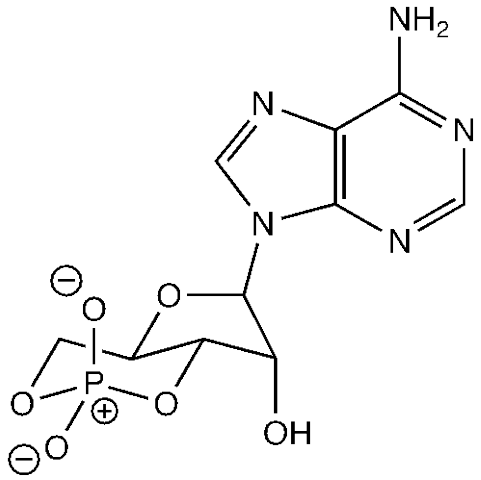
(A) One equivalent each of an alcohol and the salt of a monocarboxylic acid

(B) Three equivalents of alcohols and one equivalent of the salt of a tricarboxylic acid

(C) One equivalent of a triol and three equivalents of the salt of monocarboxylic acids

(D) One equivalent each of a triol and the salt of a tricarboxylic acid

60. The structure of cyclic adenosine monophosphate (cAMP) is shown below. What is its principal biochemical role?



(A) A signaling molecule

(B) A source of energy

(C) A synthetic precursor of DNA

(D) A product of DNA degradation

END OF TEST

PLEASE ANSWER THE FOLLOWING FOUR QUESTIONS

THANK YOU!

When you have finished answering this examination or time has been called by the Examiner, please provide responses to the following 4 items. Your answers will not affect your score on the exam but will help with a study being conducted by the U.S. National Chemistry Olympiad (USNCO) Subcommittee.

61. The amount of time I spend doing experiments in the laboratory per week on average during my chemistry course was/is?

(A) less than ½ hour
(B) between ½ and 1 hour
(C) between 1 and 2 hours
(D) more than 2 hours

The following questions should be answered using the scale

(A) Strongly agree
(B) Agree
(C) Disagree
(D) Strongly disagree

62. **As a result of my participation in the USNCO program**, I plan to study more chemistry.

63. **As a result of my participation in the USNCO program**, I plan to major in chemistry in college.

64. **As a result of my participation in the USNCO program**, I have a more positive view of chemistry than I did before participating.

Olympiad 2019
USNCO National Exam Part I
KEY

Question	Correct Answer	% Correct Answer	Question	Correct Answer	% Correct Answer
1.	B	87%	31.	C	71%
2.	D	75%	32.	C	46%
3.	C	85%	33.	A	71%
4.	D	83%	34.	D	42%
5.	C	59%	35.	A	28%
6.	C	52%	36.	B	27%
7.	C	89%	37.	C	44%
8.	D	34%	38.	B	83%
9.	B	41%	39.	B	68%
10.	C	42%	40.	B	29%
11.	A	19%	41.	B	35%
12.	A	39%	42.	B	57%
13.	A	58%	43.	D	36%
14.	C	51%	44.	C	17%
15.	B	46%	45.	B	72%
16.	C	20%	46.	B	61%
17.	A	41%	47.	D	33%
18.	C	43%	48.	C	28%
19.	A	78%	49.	D	58%
20.	A	81%	50.	A	76%
21.	D	34%	51.	A	53%
22.	C	23%	52.	D	75%
23.	B	27%	53.	B	24%
24.	D	52%	54.	C	25%
25.	A	70%	55.	D	41%
26.	A	54%	56.	C	33%
27.	D	34%	57.	B	57%
28.	C	67%	58.	B	14%
29.	C	77%	59.	C	46%
30.	B	35%	60.	A	48%