2019 U.S. NATIONAL CHEMISTRY OLYMPIAD
LOCAL SECTION EXAM

Prepared by the American Chemical Society Chemistry Olympiad Examinations Task Force

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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 his or her 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 student reference.

Only non-programmable calculators are to be used on 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

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

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

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

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

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

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

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

$0 \text{ °C} = 273.15 \text{ K}$

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

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

EQUATIONS

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

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

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

PERIODIC TABLE OF THE ELEMENTS

1 1A																	18 8A
1 **H** 1.008	2 2A											13 3A	14 4A	15 5A	16 6A	17 7A	2 **He** 4.003
3 **Li** 6.941	4 **Be** 9.012											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
11 **Na** 22.99	12 **Mg** 24.31	3 3B	4 4B	5 5B	6 6B	7 7B	8 8B	9 8B	10 8B	11 1B	12 2B	13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.07	17 **Cl** 35.45	18 **Ar** 39.95
19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.88	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.69	29 **Cu** 63.55	30 **Zn** 65.39	31 **Ga** 69.72	32 **Ge** 72.61	33 **As** 74.92	34 **Se** 78.97	35 **Br** 79.90	36 **Kr** 83.80
37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.95	43 **Tc** (98)	44 **Ru** 101.1	45 **Rh** 102.9	46 **Pd** 106.4	47 **Ag** 107.9	48 **Cd** 112.4	49 **In** 114.8	50 **Sn** 118.7	51 **Sb** 121.8	52 **Te** 127.6	53 **I** 126.9	54 **Xe** 131.3
55 **Cs** 132.9	56 **Ba** 137.3	57 **La** 138.9	72 **Hf** 178.5	73 **Ta** 180.9	74 **W** 183.8	75 **Re** 186.2	76 **Os** 190.2	77 **Ir** 192.2	78 **Pt** 195.1	79 **Au** 197.0	80 **Hg** 200.6	81 **Tl** 204.4	82 **Pb** 207.2	83 **Bi** 209.0	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
87 **Fr** (223)	88 **Ra** (226)	89 **Ac** (227)	104 **Rf** (261)	105 **Db** (262)	106 **Sg** (263)	107 **Bh** (262)	108 **Hs** (265)	109 **Mt** (266)	110 **Ds** (281)	111 **Rg** (272)	112 **Cn** (285)	113 **Nh** (286)	114 **Fl** (289)	115 **Mc** (289)	116 **Lv** (293)	117 **Ts** (294)	118 **Og** (294)

58 **Ce** 140.1	59 **Pr** 140.9	60 **Nd** 144.2	61 **Pm** (145)	62 **Sm** 150.4	63 **Eu** 152.0	64 **Gd** 157.3	65 **Tb** 158.9	66 **Dy** 162.5	67 **Ho** 164.9	68 **Er** 167.3	69 **Tm** 168.9	70 **Yb** 173.0	71 **Lu** 175.0
90 **Th** 232.0	91 **Pa** 231.0	92 **U** 238.0	93 **Np** (237)	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (262)

- 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 hydrocarbon is 84.1% carbon by mass?

   (A) CH_4 (B) C_2H_6 (C) C_4H_{10} (D) C_8H_{18}

2. Lithium hydrogen carbonate, $LiHCO_3$, decomposes when heated to form Li_2O, CO_2, and H_2O. How many moles of H_2O are formed when 0.50 mol $LiHCO_3$ decomposes?

   (A) 0.25 mol   (B) 0.50 mol

   (C) 0.75 mol   (D) 1.0 mol

3. A vessel contains 66 g CO_2 and 16 g O_2 at a pressure of 10.0 atm. What is the partial pressure of CO_2?

   (A) 5.0 atm   (B) 6.0 atm

   (C) 7.5 atm   (D) 8.0 atm

4. First-generation automobile airbags were inflated by the decomposition of sodium azide ($M = 65.02$):

   $$2\ NaN_3(s) \rightarrow 2\ Na(s) + 3\ N_2(g)$$

   What mass of sodium azide would be required to inflate a 16.0 L airbag to a pressure of 1.20 atm at 17 ºC?

   (A) 34.9 g   (B) 52.4 g   (C) 78.6 g   (D) 157 g

5. Which of the following combinations will produce a 0.4 M NaCl solution?

   (A) Mixing 500 mL of 0.4 M NaOH with 500 mL of 0.4 M HCl

   (B) Mixing 300 mL of 1.2 M NaOH with 600 mL of 0.6 M HCl

   (C) Mixing 500 mL of 0.4 M NaCl solution with 500 mL water

   (D) Diluting 400 mL of 0.6 M NaCl with water to a final volume of 1.0 L

6. Which solute, when dissolved in 1 kg H_2O, will give the solution with the highest boiling point?

   (A) 50 g ethylene glycol, $HOCH_2CH_2OH$

   (B) 50 g hydroxyacetic acid, $HOCH_2COOH$

   (C) 50 g glycerol, $HOCH_2CHOHCH_2OH$

   (D) 50 g glyoxal, $HCOCHO$

7. A solution of which compound gives a violet flame test?

   (A) LiBr   (B) NaCl

   (C) KNO_3 (D) $B(OH)_3$

8. Addition of 1 M HBr to 0.1 M solutions of which compound results in evolution of a colorless gas?

   (A) $NaHSO_3$ (B) $NaHSO_4$

   (C) $Ce(NH_4)_2(NO_3)_6$ (D) $KBrO_3$

9. Which solid is least soluble in water at 298 K?

   (A) CaF_2 (B) AgF

   (C) $Ba(OH)_2$ (D) $CoSO_4$

10. Which methods would be suitable for determining the concentration of an aqueous solution of $KMnO_4$?
    I.   Visible spectrophotometry (colorimetry)
    II. Redox titration

    (A) I only   (B) II only

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

11. The concentration of sulfate ion in a solution is measured by precipitating the sulfate as $BaSO_4$, filtering the precipitate on ashless filter paper, and heating the filter paper and precipitate in a tared crucible with a Bunsen burner. Which error will result in a sulfate concentration that is higher than the actual concentration?

    (A) The empty crucible contains a few drops of water when it is tared.

    (B) A glass fiber filter is used instead of ashless filter paper.

    (C) Some fine precipitate is not captured by the filter.

    (D) Some of the sulfate-containing solution spills before the $BaCl_2$ solution is added.

12. Which is the best way to dispense liquids using a volumetric pipet?

(A) The pipet is immersed in the liquid to be dispensed, then lifted with a gloved finger on the top and the liquid allowed to drain to the mark. The remaining contents are then allowed to drain into the desired container.

(B) The pipet is immersed in the liquid to be dispensed, then lifted with a gloved finger on the top and the liquid allowed to drain to the mark. The remaining contents are then allowed to drain into the desired container, with a pipet bulb used to gently blow out any residual droplets.

(C) The tip of the pipet is submerged below the surface of the liquid and suction is applied using a pipet bulb until the liquid rises above the level of the mark. A gloved finger is then applied to the top of the pipet and the liquid allowed to drain to the mark. The remaining contents are then allowed to drain into the desired container.

(D) The tip of the pipet is submerged below the surface of the liquid and suction is applied by mouth until the liquid rises to the level of the mark. The contents are then allowed to drain into the desired container.

13. Which gas at 600 K has the same effusion rate as methane (CH_4) at 150 K?

(A) He   (B) O_2 (C) SO_2 (D) N_2O_4

14. Ammonia (NH_3) has a higher normal boiling point (–33 °C) than its heavier congeners PH_3 (bp –88 °C) or AsH_3 (bp –63 °C). Which is the best explanation for this difference?

(A) NH_3 is trigonal pyramidal and polar while PH_3 and AsH_3 are trigonal planar and nonpolar.

(B) NH_3 is much more acidic than PH_3 or AsH_3.

(C) $NH_3(l)$ experiences stronger London dispersion forces than $PH_3(l)$ or $AsH_3(l)$.

(D) $NH_3(l)$ has extensive hydrogen bonding while $PH_3(l)$ and $AsH_3(l)$ do not.

15. In which are the ionic solids ranked in order of increasing melting point?

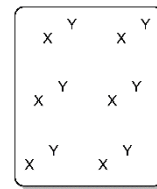(A) KBr < NaCl < NaF < MgO

(B) NaF < NaCl < MgO < KBr

(C) KBr < NaCl < MgO < NaF

(D) MgO < NaF < KBr < NaCl

16. A two-dimensional slice through the lattice of a crystalline solid containing two different elements X and Y is shown schematically and to scale below. What type of solid is it?

(A) A metallic alloy such as FeCr

(B) A molecular solid such as IBr

(C) An ionic compound such as LiCl

(D) A network covalent solid such as SiC

17. A portion of the phase diagram of uranium hexafluoride (UF_6) is shown below.
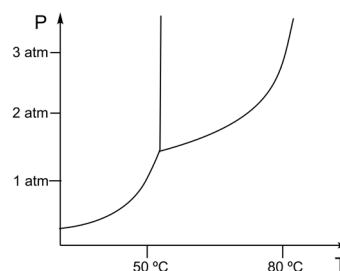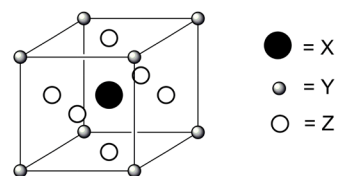

Which statements are correct?
    I. UF_6 sublimes at atmospheric pressure.
    II. At 80 °C and 1.5 atm, only $UF_6(g)$ is present at equilibrium.

(A) I only   (B) II only

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

18. One unit cell of a crystal containing elements X, Y, and Z is shown below. What is its formula?


(A) XYZ   (B) XYZ_3 (C) XY_4Z_2 (D) XY_8Z_6

19. The specific heat capacity of iron is 0.461 J g^{-1} K^{-1} and that of titanium is 0.544 J g^{-1} K^{-1}. A sample consisting of a mixture of 10.0 g Fe and 10.0 g Ti at 100.0 °C loses 200. J of heat to the environment. What is the final temperature of the sample?

(A) 89.9 °C   (B) 80.1 °C

(C) 60.2 °C   (D) 39.8 °C

20. Which sample has the greatest entropy at a given temperature?

(A) 2 mol HBr(s)

(B) 2 mol HBr(l)

(C) 2 mol HBr(g)

(D) 1 mol H_2(g) + 1 mol Br_2(l)

21. For an endothermic reaction to be spontaneous under standard conditions at constant pressure at some temperature T, which must be true?

(A) The entropy change ΔS° must be positive and greater than $\Delta H^{\circ}/T$.

(B) The entropy change ΔS° must be positive and less than $\Delta H^{\circ}/T$.

(C) The entropy change ΔS° must be negative and greater than $-\Delta H^{\circ}/T$.

(D) The entropy change ΔS° must be negative and less than $-\Delta H^{\circ}/T$.

22. For a constant-pressure process, what is the difference between the internal energy change (ΔU) and the enthalpy change (ΔH)?

(A) Heat

(B) Work

(C) Entropy

(D) Gibbs free energy

23. The standard enthalpy of reaction for the dissolution of silica in aqueous HF is 4.6 kJ mol^{-1}. What is the standard enthalpy of formation of SiF$_4$(g)?

$$SiO_2(s) + 4\ HF(aq) \rightarrow SiF_4(g) + 2\ H_2O(l)$$
$$\Delta H^{\circ}_{rxn} = 4.6\ kJ\ mol^{-1}$$
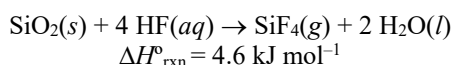
Compound	SiO$_2$(s)	HF(aq)	H$_2$O(l)	SiF$_4$(g)
ΔH°_f, kJ mol^{-1}	–910.9	–320.1	–285.8	???

(A) –1624.3 kJ mol^{-1}

(B) –1615.1 kJ mol^{-1}

(C) –949.8 kJ mol^{-1}

(D) –940.6 kJ mol^{-1}

24. The K_{sp} of BaSO$_4$ at 298 K is 1.1×10^{-10}. What is ΔG° at 298 K for the following reaction?

$$Ba^{2+}(aq) + SO_4^{2-}(aq) \rightleftharpoons BaSO_4(s)$$
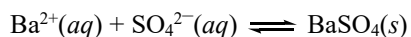
(A) –57 kJ mol^{-1}

(B) –25 kJ mol^{-1}

(C) 25 kJ mol^{-1}

(D) 57 kJ mol^{-1}

25. The following data were collected for the reaction of A and B:

[A]$_0$ (M)	[B]$_0$ (M)	Initial rate (M/s)
0.20	0.20	600
0.60	0.40	7200
0.60	0.80	28800

What is the order of the reaction with respect to A and B?

(A) 0th order in A, 2nd order in B

(B) 1st order in A, 1st order in B

(C) 2nd order in A, 1st order in B

(D) 1st order in A, 2nd order in B

26. A sample of 0.900 mol N$_2$O is placed in a sealed container, where it decomposes irreversibly to N$_2$ and O$_2$ in a first-order reaction. After 42.0 min, 0.640 mol N$_2$O remains. How long will it take for the reaction to be 90.0% complete?

(A) 13.0 min

(B) 85.4 min

(C) 131 min

(D) 284 min

27. The rate of a reaction is 2.3 times faster at 60 ºC than it is at 50 ºC. By what factor will the rate increase on going from 60 ºC to 70 ºC?

(A) By less than a factor of 2.3

(B) By a factor of 2.3

(C) By more than a factor of 2.3

(D) The rate increase cannot be determined from the information given.

28. How may an enzyme inhibitor decrease the rate of a reaction catalyzed by the enzyme?

I. The inhibitor may bind to the enzyme and block the active site.

II. The inhibitor may shift the equilibrium of the reaction toward the starting materials.

(A) I only

(B) II only

(C) Both I and II

(D) Neither I nor II

29. An irreversible reaction, A + B → products, is studied under conditions where [B] >> [A]. When [B] = 0.10 M, a plot of 1/[A] vs. time is linear. When [B] = 0.30 M, the plot of 1/[A] vs. time is indistinguishable from the first plot within experimental error. What is the rate law for this reaction?

(A) Rate = k[A][B]

(B) Rate = k[A]^2

(C) Rate = k[A]^2[B]

(D) Rate = k[A][B]^2

30. *Tert*-butyl alcohol reacts with aqueous hydrochloric acid to give *tert*-butyl chloride.

$$(CH_3)_3COH(aq) + H^+(aq) + Cl^-(aq) \rightarrow$$
$$(CH_3)_3CCl(aq) + H_2O(l)$$
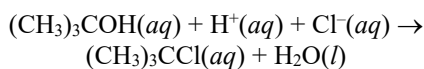
For this reaction, Rate = $k[(CH_3)_3COH][H^+]$. With which mechanism is this rate law consistent?

(A)	$(CH_3)_3COH(aq) + H^+(aq) \rightleftharpoons$ $(CH_3)_3C(OH_2)^+(aq)$	*fast*
	$(CH_3)_3C(OH_2)^+(aq) + Cl^-(aq) \rightarrow$ $(CH_3)_3CCl(aq) + H_2O(l)$	*slow*
(B)	$(CH_3)_3COH(aq) + H^+(aq) \rightleftharpoons$ $(CH_3)_3C(OH_2)^+(aq)$	*fast*
	$(CH_3)_3C(OH_2)^+(aq) \rightarrow (CH_3)_3C^+(aq) +$ $H_2O(l)$	*slow*
	$(CH_3)_3C^+(aq) + Cl^-(aq) \rightarrow (CH_3)_3CCl(aq)$	*fast*
(C)	$(CH_3)_3COH(aq) + Cl^-(aq) \rightarrow (CH_3)_3CCl(aq)$ $+ OH^-(aq)$	*slow*
	$OH^-(aq) + H^+(aq) \rightarrow H_2O(l)$	*fast*
(D)	$(CH_3)_3COH(aq) \rightarrow (CH_3)_3C^+(aq) + OH^-(aq)$	*slow*
	$(CH_3)_3C^+(aq) + Cl^-(aq) \rightarrow (CH_3)_3CCl(aq)$	*fast*
	$OH^-(aq) + H^+(aq) \rightarrow H_2O(l)$	*fast*

31. The diagrams below represent the progress of a reaction of A → B, with molecules of A represented by solid circles and molecules of B represented by open circles. Which statement best describes the reaction at $t = 1000$ s?

$t = 0$ s $t = 10$ s $t = 100$ s $t = 1000$ s
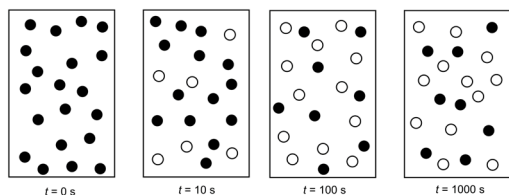
(A) The reaction is at equilibrium because the concentrations of A and B are no longer changing.

(B) The reaction is not at equilibrium because not all of the A has been consumed.

(C) The reaction is not at equilibrium because the concentrations of A and B are not equal.

(D) The reaction is not at equilibrium because the positions of the molecules are still changing.

32. What is the pH of a 0.10 M solution of NaCN? The K_a of HCN is 4.9×10^{-10}.

(A) 2.85   **(B)** 5.15   **(C)** 8.85   **(D)** 11.15

33. For which of the following reactions would the yield of products at equilibrium NOT increase at a higher pressure?

(A) $N_2(g) + O_2(g) \rightleftharpoons 2 NO(g)$

(B) $Ti(s) + 2 Cl_2(g) \rightleftharpoons TiCl_4(g)$

(C) $2 C_2H_4(g) + 2 H_2O(g) \rightleftharpoons 2 C_2H_6(g) + O_2(g)$

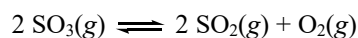**(D)** $4 HCl(g) + O_2(g) \rightleftharpoons 2 H_2O(l) + 2 Cl_2(g)$

34. Chromium(III) hydroxide has $K_{sp} = 1.6 \times 10^{-30}$. What is the molar solubility of $Cr(OH)_3$ in a solution whose pH is maintained at 6.00?

(A) 1.6×10^{-12} mol L^{-1} **(B)** 1.6×10^{-8} mol L^{-1}

(C) 3.6×10^{-8} mol L^{-1} **(D)** 1.6×10^{-6} mol L^{-1}

**35.** At 400 K, this reaction has $K_p = 8.2 \times 10^{-4}$.

$$SO_3(g) \rightleftharpoons SO_2(g) + \tfrac{1}{2} O_2(g)$$

What is K_p at 400 K for the following reaction?

$$2 SO_3(g) \rightleftharpoons 2 SO_2(g) + O_2(g)$$

(A) 6.7×10^{-7} **(B)** 8.2×10^{-4}

**(C)** 1.6×10^{-3} **(D)** 2.9×10^{-2}

36. An unknown monoprotic carboxylic acid RCOOH is mixed in a 1:1 mole ratio with its sodium salt, Na(RCOO). A 1.000 g sample of this 1:1 mixture is dissolved in 50 mL water and titrated with 0.5000 M NaOH solution. The pH is measured as a function of added titrant to give the following titration curve:

pH

mL 0.5000 M NaOH added
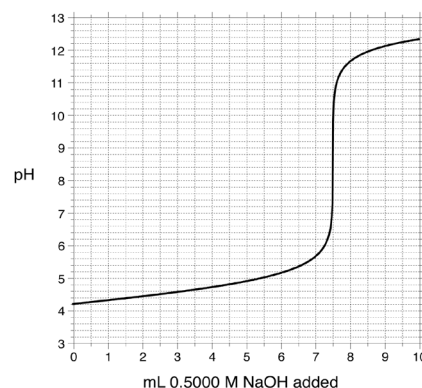
Which statements are correct?
I.   The molar mass of RCOOH is within 5% of 265 g mol^{-1}.
II. The pKa of RCOOH is within 0.1 unit of 4.2.

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

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

37. When the chemical equation is balanced, what is the ratio of the coefficient of Ag(s) to the coefficient of $H_2O(l)$?

$$\_\_ Ag(s) + \_\_ NO_3^-(aq) + \_\_ H^+(aq) \rightarrow$$
$$\_\_ Ag^+(aq) + \_\_ NO(g) + \_\_ H_2O(l)$$
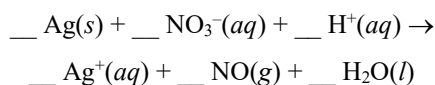
(A) 1 : 1   (B) 2 : 1   (C) 3 : 1   (D) 3 : 2

38. A current of 0.44 A is passed through a solution of a ruthenium nitrate salt, causing reduction of the metal ion to the metal. After 25.0 minutes, 0.345 g of Ru(s) has been deposited. What is the oxidation state of ruthenium in the nitrate salt?

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

**39.** What is the K_{sp} of $Ca(OH)_2$ at 298 K?

Half-Reaction	E^o, V
$Ca^{2+}(aq) + 2\ e^- \rightarrow Ca(s)$	–2.87 V
$Ca(OH)_2(s) + 2\ e^- \rightarrow Ca(s) + 2\ OH^-(aq)$	–3.02 V

(A) 1.6×10^{-6} (B) 3.1×10^{-6}

(C) 8.4×10^{-6} (D) 2.9×10^{-3}

40. Electrolysis of water containing sulfuric acid as an electrolyte is carried out as shown and the gases produced at the electrodes collected in two identical tubes, both initially filled with the sulfuric acid solution. After electrolysis has been carried out for a certain time, which picture best represents the appearance of the tubes?
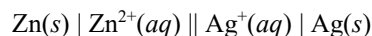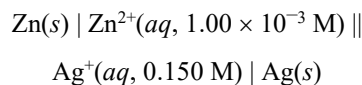

41. What is ΔE^o for this reaction?

$$2\ Ag(s) + Cu^{2+}(aq) + 2\ Cl^-(aq) \rightarrow 2\ AgCl(s) + Cu(s)$$
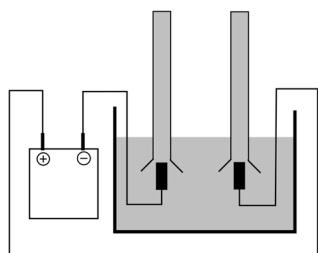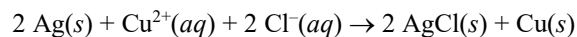
Half-Reaction	E^o, V
$AgCl(s) + e^- \rightarrow Ag(s) + Cl^-(aq)$	0.222 V
$Cu^{2+}(aq) + 2\ e^- \rightarrow Cu(s)$	0.337 V
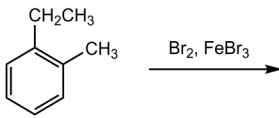
(A) –0.115 V   (B) –0.107 V

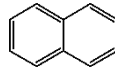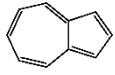(C) 0.107 V   (D) 0.115 V

42. The standard cell potential of the following galvanic cell is 1.562 V at 298 K.

$$Zn(s) \mid Zn^{2+}(aq) \parallel Ag^+(aq) \mid Ag(s)$$

What is the cell potential of the following galvanic cell at 298 K?

$$Zn(s) \mid Zn^{2+}(aq, 1.00 \times 10^{-3}\ M) \parallel$$
$$Ag^+(aq, 0.150\ M) \mid Ag(s)$$

(A) 1.602 V   (B) 1.626 V

(C) 1.642 V   (D) 1.691 V

43. Which statement regarding the relative energies of monochromatic light with $\lambda = 800$ nm and monochromatic light with $\lambda = 400$ nm is correct?

(A) 800 nm light has half as much energy per mole of photons as 400 nm light.

(B) 800 nm light has the same energy per mole of photons as 400 nm light.

(C) 800 nm light has twice as much energy per mole of photons as 400 nm light.

(D) No conclusion may be drawn regarding the relative energy per mole of photons without knowing the intensity of the light.

44. How many electrons in a ground-state As atom in the gas phase have quantum numbers $n = 3$ and $l = 1$?

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

45. In which list are the elements in order of increasing first ionization energy?

(A) Ca < Si < P < N   (B) N < P < Si < Ca

(C) Ca < N < P < Si   (D) N < Si < P < Ca

46. What mode of radioactive decay does ^{66}Cu undergo?

(A) Alpha decay   (B) Beta decay

(C) Electron capture   (D) Positron emission

47. Which gas-phase atoms in their ground states are diamagnetic?
    I. Fe
    II. Zn

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

48. The boiling points of the alkali metals decrease from lithium to cesium. Which trend is most closely related to the decreasing boiling points?

    (A) Increasing atomic radius down the group
    (B) Increasing atomic mass down the group
    (C) Decreasing electronegativity down the group
    (D) Decreasing electron affinity down the group

49. Which statements correctly describe the geometry of the carbonate ion, CO_3^{2-}?
    I. All three carbon-oxygen bond distances are the same.
    II. All three bond angles are 120°.

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

50. Which molecule has a trigonal pyramidal geometry?

    (A) PCl_3
    (B) BCl_3
    (C) IF_3
    (D) SO_3

51. The bond in F_2 has a smaller bond dissociation enthalpy than the bond in Cl_2. Which is the best explanation for this difference?

    (A) Fluorine is more electronegative than chlorine.
    (B) Lone pair-lone pair repulsions are stronger in F_2 than in Cl_2.
    (C) The F-F bond is longer than the Cl-Cl bond.
    (D) Chlorine has energetically accessible d orbitals while fluorine does not.

52. Which resonance structure contributes the most to the overall bonding in nitrous oxide, N_2O?

    (A) $:N\equiv N - O:$ (with charges ⊕ and ⊖)
    (B) $N - N = O$
    (C) (N=N=O cyclic-type structure)
    (D) $N = N = O$ (with charges ⊖ and ⊕)

53. How many σ bonds and how many π bonds are present in allene, H_2CCCH_2?

    (A) One σ, one π
    (B) Five σ, one π
    (C) Six σ, two π
    (D) Seven σ, two π

54. Which aspect of metallic bonding best accounts for the characteristic malleability of metals?

    (A) Metals have few valence electrons.
    (B) Metals contain a lattice of positive ions.
    (C) Metals contain delocalized electrons.
    (D) Metals have low electronegativity.

55. Which compound can exhibit geometric isomerism?

    (A) 1-butene
    (B) 2-butene
    (C) 1-butyne
    (D) 2-butyne

56. Which structural features contribute to the low strain energy of cyclohexane?
    I. All bond angles are close to 109.5°.
    II. All C–H bonds on adjacent carbon atoms are staggered.

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

57. What reaction conditions most effectively convert a carboxylic acid to a methyl ester?

    (A) CH_3OH, HCl
    (B) CH_3I, HCl
    (C) CH_3OH, NaOH
    (D) CH_3I, $SOCl_2$

58. What is the maximum number of monosubstitution products of the aromatic substitution reaction shown?

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

59. Which compound is NOT considered aromatic?

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

60. To what elements are the phosphorus atoms in DNA bonded?
    I. C
    II. H

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

END OF TEST

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Olympiad 2019
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KEY

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