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.
- Make no marks on the test booklet. Do all calculations on scratch paper provided by your instructor.
- 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 of these ions is expected to be colored in aqueous solution?

I Fe^{3+} **II** Ni^{2+} **III** Al^{3+}

(A) **I** only **(B)** **III** only

(C) **I** and **II** only **(D)** **I**, **II**, and **III**

2. Which substance is stored in contact with water to prevent it from reacting with air?

(A) bromine **(B)** lithium

(C) mercury **(D)** phosphorus

3. A solution of concentrated aqueous ammonia is added dropwise to 1 mL of a dilute aqueous solution of copper(II) nitrate until a total of 1 mL of the ammonia solution has been added. What observations can be made during this process?

(A) The colorless copper(II) nitrate solution turns blue and yields a dark blue precipitate.

(B) The colorless copper(II) nitrate solution yields a white precipitate which turns dark blue upon standing.

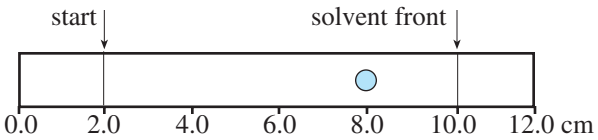
(C) The light blue copper(II) nitrate solution yields a precipitate which redissolves to form a dark blue solution.

(D) The light blue copper(II) nitrate solution turns dark blue and yields a dark blue precipitate.

4. What gas is produced when dilute HNO_3 is added to silver metal?

(A) NO **(B)** H_2 **(C)** NH_3 **(D)** N_2

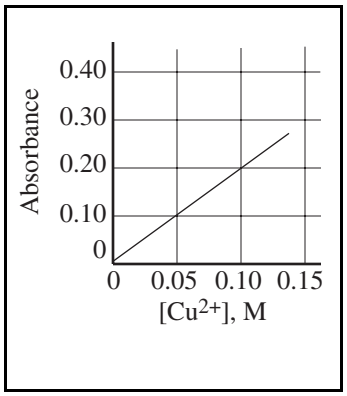
5. A substance is analyzed by paper chromatography, giving the chromatogram shown.



What is the R_f value of the substance represented by the spot at 8.0 cm?

(A) 0.80 **(B)** 0.75 **(C)** 0.67 **(D)** 0.60

6. The molarity of a Cu^{2+} solution is to be determined from its absorbance, measured under the same conditions as those used to prepare this calibration curve. What will be the percent uncertainty in the concentration of a 0.050 M solution if the uncertainty in the absorbance reading is ±0.01 absorbance units?



(A) 5% **(B)** 10% **(C)** 15% **(D)** 20%

7. A 1.50 g sample of an ore containing silver was dissolved, and all of the Ag^+ was converted to 0.124 g of Ag_2S. What was the percentage of silver in the ore?

(A) 6.41% **(B)** 7.20%

(C) 8.27% **(D)** 10.8%

8. Methyl-*t*-butyl ether, $C_5H_{12}O$, is added to gasoline to promote cleaner burning. How many moles of oxygen gas, O_2, are required to burn 1.0 mol of this compound completely to form carbon dioxide and water?

(A) 4.5 mol **(B)** 6.0 mol

(C) 7.5 mol **(D)** 8.0 mol

9. A 0.200 g sample of benzoic acid, C_6H_5COOH, is titrated with a 0.120 M $Ba(OH)_2$ solution. What volume of the $Ba(OH)_2$ solution is required to reach the equivalence point?

Substance	Molar Mass
C_6H_5COOH	122.1 g·mol^{-1}

(A) 6.82 mL **(B)** 13.6 mL

(C) 17.6 mL **(D)** 35.2 mL

10. Chlorine can be prepared by reacting HCl with MnO_2. The reaction is represented by this equation.

$$MnO_{2(s)} + 4HCl_{(aq)} \rightarrow Cl_{2(g)} + MnCl_{2(aq)} + 2H_2O_{(l)}$$

Assuming the reaction goes to completion what mass of concentrated HCl solution (36.0% HCl by mass) is needed to produce 2.50 g of Cl_2?

(A) 5.15 g **(B)** 14.3 g

(C) 19.4 g **(D)** 26.4 g

11. What is the Na^+ ion concentration in the solution formed by mixing 20. mL of 0.10 M Na_2SO_4 solution with 50. mL of 0.30 M Na_3PO_4 solution?

(A) 0.15 M **(B)** 0.24 M

(C) 0.48 M **(D)** 0.70 M

12. A solution prepared by dissolving a 2.50 g sample of an unknown compound dissolved in 34.0 g of benzene, C_6H_6, boils 1.38 °C higher than pure benzene. Which expression gives the molar mass of the unknown compound?

Compound	K_b
C_6H_6	2.53 °C·m^{-1}

(A) $2.53 \times \dfrac{2.50}{1.38}$

(B) $1.38 \times \dfrac{34.0}{2.53} \times 2.50$

(C) $2.50 \times 10^3 \times \dfrac{2.53}{34.0} \times \dfrac{1}{1.38}$

(D) $2.50 \times 10^3 \times \dfrac{1.38}{34.0} \times 2.53$

13. What is the total pressure in a 2.00 L container that holds 1.00 g He, 14.0 g CO, and 10.0 g of NO at 27.0 °C?

(A) 21.6 atm **(B)** 13.2 atm

(C) 1.24 atm **(D)** 0.310 atm

14. What type of solid is generally characterized by having low melting point and low electrical conductivity?

(A) ionic **(B)** metallic

(C) molecular **(D)** network covalent

15. How many nearest neighbors surround each particle in a face-centered cubic lattice?

(A) 4 **(B)** 6 **(C)** 8 **(D)** 12

16. Hydrogen is collected over water at 22 °C and a barometer reading of 740 mmHg. If 300. mL of hydrogen is collected, which expression will give the volume of dry hydrogen at the same temperature and pressure?

Compound	Vapor Pressure at 22 °C
H_2O	20. mmHg

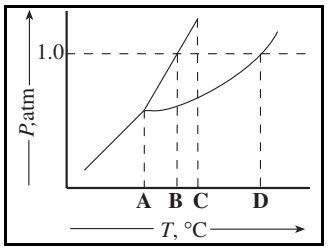
(A) $300 \text{ mL} \times \dfrac{740 \text{ mmHg} - 20 \text{ mmHg}}{740 \text{ mmHg}}$

(B) $300 \text{ mL} \times \dfrac{740 \text{ mmHg} + 20 \text{ mmHg}}{740 \text{ mmHg}}$

(C) $300 \text{ mL} \times \dfrac{740 \text{ mmHg}}{740 \text{ mmHg} - 20 \text{ mmHg}}$

(D) $300 \text{ mL} \times \dfrac{740 \text{ mmHg}}{740 \text{ mmHg} + 20 \text{ mmHg}}$

17. What is the normal melting point of the substance represented by the phase diagram?



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

18. A bomb calorimeter has a heat capacity of 783 J·°C^{-1} and contains 254 g of water, which has a specific heat of 4.184 J·g^{-1}·°C^{-1}. How much heat is evolved or absorbed by a reaction when the temperature goes from 23.73 °C to 26.01 °C?

(A) 1.78 kJ absorbed **(B)** 2.42 kJ absorbed

(C) 1.78 kJ evolved **(D)** 4.21 kJ evolved

19. Consider this equation and the associated value for ΔH^o.

$$2H_{2(g)} + 2Cl_{2(g)} \rightarrow 4HCl_{(g)} \qquad \Delta H^o = -92.3 \text{ kJ}$$

Which statement about this information is ***incorrect***?

(A) If the equation is reversed, the ΔH^o value equals +92.3 kJ.

(B) The four HCl bonds are stronger than the four bonds in H_2 and Cl_2.

(C) The ΔH^o value will be –92.3 kJ if the HCl is produced as a liquid.

(D) 23.1 kJ of heat will be evolved when 1 mol of $HCl_{(g)}$ is produced.

20. Determine the heat of reaction for this process.

$$FeO(s) + Fe_2O_3(s) \rightarrow Fe_3O_4(s)$$

Given information:

$2Fe(s) + O_2(g) \rightarrow 2FeO(s)$ $\quad \Delta H^o = -544.0$ kJ

$4Fe(s) + 3O_2(g) \rightarrow 2Fe_2O_3(s)$ $\quad \Delta H^o = -1648.4$ kJ

$Fe_3O_4(s) \rightarrow 3Fe(s) + 2O_2(g)$ $\quad \Delta H^o = +1118.4$ kJ

(A) –1074.0 kJ **(B)** –22.2 kJ

(C) +249.8 kJ **(D)** +2214.6 kJ

21. For which process will ΔH^o and ΔG^o be expected to be most similar?

(A) $2Al(s) + Fe_2O_3(s) \rightarrow 2Fe(s) + Al_2O_3(s)$

(B) $2Na(s) + 2H_2O(l) \rightarrow 2NaOH(aq) + H_2(g)$

(C) $2NO_2(g) \rightarrow N_2O_4(g)$

(D) $2H_2(g) + O_2(g) \rightarrow 2H_2O(g)$

22. Use bond energies to estimate ΔH for this reaction.

$H_2(g) + O_2(g) \rightarrow H_2O_2(g)$

Bond	Bond Energy
H–H	436 kJ·mol^{-1}
O–O	142 kJ·mol^{-1}
O=O	499 kJ·mol^{-1}
H–O	460 kJ·mol^{-1}

(A) –127 kJ **(B)** –209 kJ

(C) –484 kJ **(D)** –841 kJ

23. For a particular reaction, $\Delta H^o = -38.3$ kJ and $\Delta S^o = -113$ J·K^{-1}. This reaction is

(A) spontaneous at all temperatures.

(B) nonspontaneous at all temperatures.

(C) spontaneous at temperatures below 66 °C.

(D) spontaneous at temperatures above 66 °C.

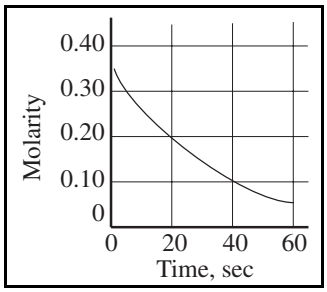
24. What is ΔG^o for this reaction?

$1/2N_2(g) + 3/2H_2(g) \rightleftharpoons NH_3(g)$ $\quad K_p = 4.42 \times 10^4$ at 25 °C.

(A) –26.5 kJ·mol^{-1} **(B)** –11.5 kJ·mol^{-1}

(C) –2.2 kJ·mol^{-1} **(D)** –0.97 kJ·mol^{-1}

25. A reaction follows this concentration-time diagram. The instantaneous rate for this reaction at 20 seconds will be closest to which value?



(A) 4×10^{-3} M·sec^{-1} **(B)** 8×10^{-3} M·sec^{-1}

(C) 2×10^{-2} M·sec^{-1} **(D)** 1×10^{-1} M·sec^{-1}

26. If the half-life of a reaction increases as the initial concentration of substance increases, the order of the reaction is

(A) zero. **(B)** first.

(C) second. **(D)** third.

27. The radioisotope N-13, which has a half-life of 10 minutes, is used to image organs in the body. If an injected sample has an activity of 40 microcuries (40 μCi), what is its activity after 25 minutes in the body?

(A) 0.75 μCi **(B)** 3.5 μCi

(C) 7.1 μCi **(D)** 12 μCi

28. Propanone reacts with iodine in acid solution as shown in this equation.

$$CH_3C(O)CH_3 + I_2 \xrightarrow{H^+} CH_3C(O)CH_2I + HI$$

These data were obtained when the reaction was studied.

$[CH_3C(O)CH_3]$, M	$[I_2]$, M	$[H^+]$, M	Relative Rate
0.010	0.010	0.010	1
0.020	0.010	0.010	2
0.020	0.020	0.010	2
0.020	0.010	0.020	4

What is the rate equation for the reaction?

(A) rate = $k[CH_3C(O)CH_3]\,[I_2]$

(B) rate = $k[CH_3C(O)CH_3]^2$

(C) rate = $k[CH_3C(O)CH_3]\,[I_2]\,[H^+]$

(D) rate = $k[CH_3C(O)CH_3]\,[H^+]$

29. A particular reaction rate increases by a factor of five when the temperature is increased from 5 °C to 27 °C. What is the activation energy of the reaction?

(A) 6.10 kJ·mol^{-1} **(B)** 18.9 kJ·mol^{-1}

(C) 50.7 kJ·mol^{-1} **(D)** 157 kJ·mol^{-1}

30. Consider this reaction.

$$2H_2(g) + 2NO(g) \rightarrow N_2(g) + 2H_2O(g)$$

The rate law for this reaction is rate = $k\,[H_2]\,[NO]^2$. Under what conditions could these steps represent the mechanism?

Step 1. $2NO \rightleftharpoons N_2O_2$

Step 2. $N_2O_2 + H_2 \rightarrow N_2O + H_2O$

Step 3. $N_2O + H_2 \rightarrow N_2 + H_2O$

(A) These steps cannot be the mechanism under any circumstances.

(B) These steps could be the mechanism if step 1 is the slow step.

(C) These steps could be the mechanism if step 2 is the slow step.

(D) These steps could be the mechanism if step 3 is the slow step.

31. A reaction has a forward rate constant of $2.3 \times 10^6\ s^{-1}$ and an equilibrium constant of 4.0×10^8. What is the rate constant for the reverse reaction?

(A) $1.1 \times 10^{-15}\ s^{-1}$ **(B)** $5.8 \times 10^{-3}\ s^{-1}$

(C) $1.7 \times 10^{2}\ s^{-1}$ **(D)** $9.2 \times 10^{14}\ s^{-1}$

32. For the reaction $2\mathbf{A}(g) + 2\mathbf{B}(g) \rightleftharpoons 3\mathbf{C}(g)$ at a certain temperature, K is 2.5×10^{-2}. For which conditions will the reaction proceed to the right at the same temperature?

	[**A**], M	[**B**], M	[**C**], M
(A)	0.10	0.10	0.10
(B)	1.0	1.0	1.0
(C)	1.0	0.10	0.10
(D)	1.0	1.0	0.10

33. What is the K_b of a weak base that produces one OH^- per molecule if a 0.050 M solution is 2.5% ionized?

(A) 7.8×10^{-8} **(B)** 1.6×10^{-6}

(C) 3.2×10^{-5} **(D)** 1.2×10^{-3}

34. What is the $[OH^-]$ of a 0.65 M solution of NaOCl?

Acid	K_a
HOCl	2.8×10^{-8}

(A) 4.8×10^{-4} M **(B)** 1.3×10^{-4} M

(C) 3.5×10^{-7} M **(D)** 2.1×10^{-11} M

35. Which acid is the strongest?

(A) H_3BO_3 **(B)** H_3PO_4

(C) H_2SO_3 **(D)** $HClO_3$

36. What is the conjugate acid of HPO_4^{2-}?

(A) $H_3PO_4(aq)$ **(B)** $H_2PO_4^-(aq)$

(C) $H_3O^+(aq)$ **(D)** $PO_4^{3-}(aq)$

37. The amount of sodium hydrogen carbonate, $NaHCO_3$, in an antacid tablet is to be determined by dissolving the tablet in water and titrating the resulting solution with hydrochloric acid. Which indicator is the most appropriate for this titration?

Acid	K_a
H_2CO_3	2.5×10^{-4}
HCO_3^-	2.4×10^{-8}

(A) methyl orange, $pK_{in} = 3.7$

(B) bromothymol blue, $pK_{in} = 7.0$

(C) phenolphthalein, $pK_{in} = 9.3$

(D) alizarin yellow, $pK_{in} = 12.5$

38. How many moles of NaOCl must be added to 150 mL of 0.025 M HOCl to obtain a buffer solution with a pH = 7.50?

Acid	K_a
HOCl	2.8×10^{-8}

(A) 2.6×10^{-5} **(B)** 1.1×10^{-3}

(C) 3.3×10^{-3} **(D)** 2.2×10^{-2}

39. If equal volumes of $BaCl_2$ and NaF solutions are mixed, which of these combinations will ***not*** give a precipitate?

Substance	K_{sp}
BaF_2	1.7×10^{-7}

(A) 0.0040 M $BaCl_2$ and 0.020 M NaF

(B) 0.010 M $BaCl_2$ and 0.015 M NaF

(C) 0.015 M $BaCl_2$ and 0.010 M NaF

(D) 0.020 M $BaCl_2$ and 0.0020 M NaF

40. What takes place when zinc metal is added to a aqueous solution containing magnesium nitrate and silver nitrate?

1. Zn is oxidized.
2. Mg^{2+} is reduced.
3. Ag^+ is reduced.
4. No reaction takes place.

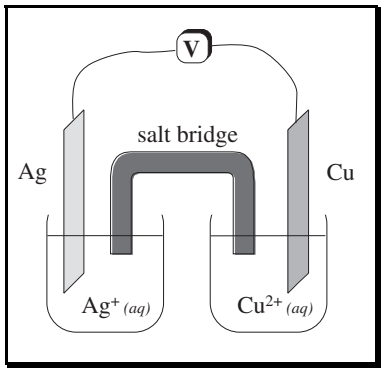
(A) **1** and **2** only **(B)** **1** and **3** only

(C) **1, 2,** and **3** only **(D)** **4** only

Questions **41**, **42**, and **43** should be answered with reference to this information and diagram.

$Ag^+(aq) + e^- \rightarrow Ag(s)$ $\quad E^o = 0.80$ V

$Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$ $\quad E^o = 0.34$ V



41. What is the value for $\Delta G°$ when $[Ag^+] = [Cu^{2+}] = 1.0$ M?

(A) –44.4 kJ **(B)** –88.8 kJ

(C) –243 kJ **(D)** –374 kJ

42. Which expression gives the voltage for this cell if $[Cu^{2+}] = 1.00$ M and $[Ag^+] = 0.010$ M?

(A) 0.46 V + 0.0591 V

(B) 0.46 V + 2 × 0.0591 V

(C) 0.46 V – 0.0591 V

(D) 0.46 V – 2 × 0.0591 V

43. Which increases immediately if the surface area of the silver electrode is increased?

(A) overall cell voltage

(B) rate of change of $[Ag^+]$

(C) mass of Cu electrode

(D) change in ratio of electrode masses; $\Delta\left(\frac{\text{mass of Cu}}{\text{mass of Ag}}\right)$

44. In the galvanizing process, iron is coated with zinc. The resulting chemical protection is most similar to that provided when

(A) a magnesium bar is connected to an iron pipe.

(B) an iron can is plated with tin.

(C) copper pipes are connected using lead solder.

(D) a copper pipe is covered with epoxy paint.

45. How many unpaired electrons are in a gaseous Fe^{2+} ion in the ground state?

(A) 0 **(B)** 2 **(C)** 4 **(D)** 6

46. Which element has the smallest first–ionization energy?

(A) Mg **(B)** Al **(C)** Si **(D)** P

47. Which set of orbitals is listed in the sequential order of filling in a many-electron atom?

(A) 3*s*, 3*p*, 3*d* **(B)** 3*d*, 4*s*, 4*p*

(C) 3*d*, 4*p*, 5*s* **(D)** 4*p*, 4*d*, 5*s*

48. Which set is expected to show the smallest difference in first–ionization energy?

(A) He, Ne, Ar **(B)** B, N, O

(C) Mg, Mg^+, Mg^{2+} **(D)** Fe, Co, Ni

49. When the atoms Li, Be, B, and Na are arranged in order of increasing atomic radius, what is the correct order?

(A) B, Be, Li, Na **(B)** Li, Be, B, Na

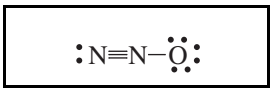
(C) Be, Li, B, Na **(D)** Be, B, Li, Na

50. Which species has the same shape as the NO_3^- ion?

(A) SO_3 **(B)** SO_3^{2-}

(C) ClF_3 **(D)** ClO_3^-

51. What is the formal charge on the central atom in N_2O?



(A) +1 **(B)** 0 **(C)** –1 **(D)** –2

52. How many bonding pairs and lone pairs surround the central atom in the I_3^- ion?

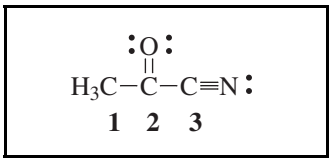
	Bonding Pairs	Lone Pairs
(A)	2	2
(B)	2	3
(C)	3	2
(D)	4	3

53. The nitrogen atoms in NH_3, NH_2^-, and NH_4^+ are all surrounded by eight electrons. When these three species are arranged in order of increasing H–N–H bond angle, what is the correct order?

(A) NH_3, NH_2^-, NH_4^+ **(B)** NH_4^+, NH_2^-, NH_3

(C) NH_3, NH_4^+, NH_2^- **(D)** NH_2^-, NH_3, NH_4^+

54. What hybrid orbitals are employed by carbon atoms **1**,**2**, and **3**, respectively, as labeled in the compound shown?



(A) sp^3, sp, sp **(B)** sp^2, sp^2, sp

(C) sp^3, sp^2, sp **(D)** sp^3, sp^2, sp^2

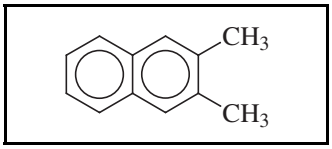
55. In which pair, or pairs, is the stronger bond found in the first species?

1. O_2^-, O_2 **2.** N_2, N_2^+ **3.** NO^+, NO^-

(A) **1** only **(B)** **2** only

(C) **1** and **3** only **(D)** **2** and **3** only

56. What is the molecular formula of this chemical structure?



(A) $C_{10}H_{12}$ **(B)** $C_{10}H_{14}$

(C) $C_{12}H_{12}$ **(D)** $C_{12}H_{14}$

57. Which is the formula for an alkyne?

(A) C_2H_4 **(B)** C_3H_6

(C) C_3H_8 **(D)** C_4H_6

58. How many isomers have the formula C_3H_8O?

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

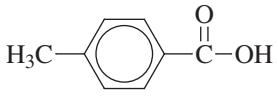
59. Which type of organic compound is most resistant to oxidation by acidified potassium dichromate?

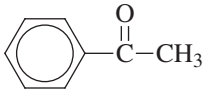
(A) acid **(B)** alcohol

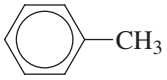
(C) aldehyde **(D)** alkene

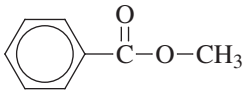
60. What product, in addition to water, is produced by this reaction?

$CH_3OH + C_6H_5COOH \rightarrow$

(A) 

(B) 

(C) 

(D) 

END OF TEST

US National Chemistry Olympiad – 2000
National Examination—Part I
SCORING KEY

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