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: \( v \)
- pressure: \( P \)
- atomic mass unit: \( u \)
- gas constant: \( R \)
- rate constant: \( k \)
- Avogadro constant: \( N_A \)
- gram: \( g \)
- reaction quotient: \( Q \)
- Celsius temperature: °C
- joule: \( J \)
- second: \( s \)
- centi- prefix: \( c \)
- kelvin: \( K \)
- speed of light: \( c \)
- density: \( d \)
- kilo- prefix: \( k \)
- temperature, K: \( T \)
- electromotive force: \( E \)
- liter: \( L \)
- vapor pressure: \( VP \)
- energy of activation: \( E_a \)
- measure of pressure mm Hg
- enthalpy: \( H \)
- milli- prefix: \( m \)
- volt: \( V \)
- entropy: \( S \)
- molal: \( m \)
- volume: \( V \)
- equilibrium constant: \( K \)
- molar: \( M \)

**CONSTANTS**

- \( R = 8.314 \text{ J mol}^{-1}\text{K}^{-1} \)
- \( h = 0.0821 \text{ L atm mol}^{-1}\text{K}^{-1} \)
- \( 1 \text{ F} = 96,500 \text{ C mol}^{-1} \)
- \( 1 \text{ F} = 96,500 \text{ J V}^{-1}\text{mol}^{-1} \)
- \( N_A = 6.022 \times 10^{23} \text{ mol}^{-1} \)
- \( h = 6.626 \times 10^{-34} \text{ J s} \)
- \( c = 2.998 \times 10^8 \text{ m s}^{-1} \)
- \( 0 \degree \text{C} = 273.15 \text{ K} \)
- \( 1 \text{ atm} = 760 \text{ mm Hg} \)

**EQUATIONS**

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

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**PERIODIC TABLE OF THE ELEMENTS**

<table>
<thead>
<tr>
<th>Period</th>
<th>Group 1A</th>
<th>Group 2A</th>
<th>Group 3A</th>
<th>Group 4A</th>
<th>Group 5A</th>
<th>Group 6A</th>
<th>Group 7A</th>
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<td>36 Bi</td>
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<td>50 Cd</td>
<td>51 In</td>
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<td>53 Sb</td>
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<td>56 Xe</td>
<td>57 Cs</td>
<td>58 Ba</td>
<td>59 La</td>
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<td>69 Er</td>
<td>70 Tm</td>
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<td>72 Lu</td>
<td>73 Hf</td>
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<td>77 Os</td>
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<td>79 Pt</td>
<td>80 Au</td>
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<td>83 In</td>
<td>84 Sn</td>
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<td>86 Te</td>
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<td>88 Xe</td>
<td>89 Rn</td>
<td>90 Th</td>
<td>91 Pa</td>
<td>92 U</td>
<td>93 Np</td>
<td>94 Pu</td>
</tr>
</tbody>
</table>

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| 2  | He  | 8A  |
| 18 | Ar  |     |

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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. When this equation is balanced using the smallest possible integers, what is the sum of the coefficients?

\[(\text{NH}_4)_3\text{PO}_4(\text{aq}) + \boxed{\text{CaCl}_2(\text{aq})} \rightarrow \text{Ca}_3(\text{PO}_4)_2(s) + \boxed{\text{NH}_4\text{Cl}(\text{aq})}\]

(A) 8 (B) 9 (C) 11 (D) 12

2. A solution of KNO₃ in water is prepared for which the following data have been obtained:

- masses of solute and solvent
- molar masses of solute and solvent

Which of these quantitative descriptions of the solution can be determined?

I. molarity II. molality III. density of solution

(A) I. only (B) II. only (C) I. and II. only (D) I., II. and III.

3. What mass of the compound CrO₃ \((M = 100.0)\) contains \(4.5 \times 10^{23}\) oxygen atoms?

(A) 2.25 g (B) 12.0 g (C) 25.0 g (D) 75.0 g

4. An 18.5 g sample of tin \((M = 118.7)\) combines with 10.0 g of sulfur \((M = 32.07)\) to form a compound. What is the empirical formula of this compound?

(A) SnS (B) SnS₂ (C) Sn₂S (D) Sn₃S₃

5. A mixture is prepared by adding 50.0 mL of 0.200 M NaOH to 75.0 mL of 0.100 M NaOH. What is the \([\text{OH}^-]\) in the mixture?

(A) 0.0600 M (B) 0.0800 M (C) 0.140 M (D) 0.233 M

6. What mass of NaHCO₃ \((M = 84.0)\) is required to completely neutralize 25.0 mL of 0.125 M H₂SO₄?

(A) 0.131 g (B) 0.262 g (C) 0.525 g (D) 1.05 g

7. A solid can be separated from a liquid by all the following means EXCEPT

(A) decantation (B) distillation (C) filtration (D) hydration

8. A student determined the density of a solid to be 2.90, 2.91 and 2.93 g·cm⁻³. If the actual density of this solid is 2.70 g·cm⁻³, how should the student's results be described?

(A) high accuracy and high precision (B) low accuracy and high precision (C) high accuracy and low precision (D) low accuracy and low precision

9. Which cation forms an insoluble chloride and an insoluble sulfide?

(A) Ba²⁺ (B) Cu²⁺ (C) Mn²⁺ (D) Pb²⁺

10. Which 0.10 M aqueous solution exhibits the lowest electrical conductivity?

(A) HC₂H₃O₂(aq) (B) HNO₃(aq) (C) NH₄C₂H₃O₂(aq) (D) Ca(NO₃)₂(aq)

11. Which graph best represents the vapor pressure of water as a function of temperature from 0 °C to 100 °C?

(A) ![Graph A] (B) ![Graph B] (C) ![Graph C] (D) ![Graph D]
12. The table below shows the data for three titrations to determine the concentration of a NaOH solution with standard 0.200 M HCl solution using phenolphthalein as the indicator.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Vol HCl, mL</th>
<th>Vol NaOH, mL</th>
<th>$M_{NaOH, \text{calc.}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>21.43</td>
<td>19.26</td>
<td>0.223</td>
</tr>
<tr>
<td>2</td>
<td>18.57</td>
<td>16.73</td>
<td>0.222</td>
</tr>
<tr>
<td>3</td>
<td>22.20</td>
<td>21.14</td>
<td>0.210</td>
</tr>
</tbody>
</table>

Which explanation best accounts for the lower value of the NaOH M in Trial 3?

(A) Some of the neutralized solution from Trial 2 was left in the flask for Trial 3.

(B) The number of drops of phenolphthalein was doubled in Trial 3.

(C) The HCl concentration was used as 0.250 M in the NaOH molarity calculation.

(D) A few drops of NaOH solution were spilled on the desktop in Trial 3.

13. A sample of an ideal gas has a volume of 0.500 L at 25 °C and 1.20 atm pressure. What is its volume at 75 °C and 3.60 atm?

(A) 0.143 L

(B) 0.195 L

(C) 0.500 L

(D) 1.75 L

14. In a mixture of N₂ and O₂ gases, the mol fraction of N₂ is found to be 0.700. The total pressure of the mixture is 1.42 atm. What is the partial pressure of O₂ in the mixture?

(A) 0.211 atm

(B) 0.426 atm

(C) 0.493 atm

(D) 0.994 atm

15. The substances below have molar masses that are the same within ± 2 g/mol. Which substance has the lowest boiling point?

(A) CH₃CH₂CH₃

(B) CH₃OCH₃

(C) CH₃CH₂OH

(D) CH₃CHO

16. Which statement is correct about the critical point of a phase diagram?

(A) Solid, liquid and gas are present in equilibrium.

(B) Liquid and vapor are indistinguishable from one another.

(C) Liquid can be produced by a change in pressure.

(D) Vapor can be produced by a change in temperature.

17. When equal volumes of the following pairs of liquids are mixed thoroughly and allowed to stand, which pair is most likely to separate into two layers?

(A) ethanol and methanol

(B) carbon tetrachloride and methanol

(C) hexane and pentane

(D) carbon tetrachloride and hexane

18. For the same atoms at the lattice points, which lattice exhibits the lowest density?

(A) body-centered cubic

(B) face-centered cubic

(C) hexagonal

(D) simple cubic

19. A sample of NaOH(s) was added to water in a calorimeter. The temperature was monitored as the NaOH dissolved to give the data below. Determine the heat released during the solution process. (Assume the solution specific heat is 4.18 J•g⁻¹•K⁻¹)

<table>
<thead>
<tr>
<th>Mass of water</th>
<th>100.00 g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of NaOH(s)</td>
<td>10.00 g</td>
</tr>
<tr>
<td>Initial Temperature of water</td>
<td>24.0 °C</td>
</tr>
<tr>
<td>Final Temperature of solution</td>
<td>48.2 °C</td>
</tr>
</tbody>
</table>

(A) 1.01 × 10⁶ Joules

(B) 2.66 × 10⁶ Joules

(C) 1.01 × 10⁵ Joules

(D) 1.11 × 10⁵ Joules

20. For which of the reactions below is(are) the heat of reaction equal to the heat of formation?

I. \(\frac{1}{2} \text{N}_2(\text{g}) + \frac{1}{2} \text{O}_2(\text{g}) \rightarrow \text{NO}_2(\text{g}) \quad \Delta H > 0\)

II. \(\text{SO}_2(\text{g}) + \frac{1}{2} \text{O}_2(\text{g}) \rightarrow \text{SO}_3(\text{g}) \quad \Delta H < 0\)

(A) I. only

(B) II. only

(C) Both I. and II.

(D) Neither I. nor II.

21. CH₄(g) + Cl₂(g) → CH₃Cl(g) + 2 HCl(g)

Use the data in the table below to calculate the standard enthalpy, \(\Delta H^\circ\), for the reaction above.

<table>
<thead>
<tr>
<th>Substance</th>
<th>CH₄(g)</th>
<th>CH₃Cl(g)</th>
<th>HCl(g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\Delta H^\circ), kJ•mol⁻¹</td>
<td>-74.6</td>
<td>-94.5</td>
<td>-92.3</td>
</tr>
</tbody>
</table>

(A) -205 kJ•mol⁻¹

(B) -113 kJ•mol⁻¹

(C) 113 kJ•mol⁻¹

(D) 205 kJ•mol⁻¹

22. C₂H₅OH(l) + 3 O₂(g) → 2 CO₂(g) + 3 H₂O(g)

During an experiment 10.00 g of ethanol is completely burned in air to release CO₂(g) and H₂O(g) as shown in the equation above. During the combustion, 296.6 kJ of heat energy is released. What is the molar enthalpy of combustion, \(\Delta H_{\text{comb}}\)?

(A) -2966 kJ•mol⁻¹

(B) -1366 kJ•mol⁻¹

(C) -64.36 kJ•mol⁻¹

(D) -29.66 kJ•mol⁻¹
23. Which reaction has the greatest positive change in entropy, ΔS?

(A) 2 Mg(s) + O_2(g) → 2 MgO(s)
(B) 2 C_2H_2(g) + 5 O_2(g) → 4 CO_2(g) + 2 H_2O(l)
(C) 2 KClO_3(s) → 2 KCl(s) + 3 O_2(g)
(D) 2 SO_2(g) + O_2(g) → 2 SO_3(g)

24. Which statement is correct for the reaction represented below?

2 NOCl(g) → 2 NO(g) + Cl_2(g) ΔH^o_{rxn} > 0

This reaction is

(A) spontaneous at all temperatures.
(B) spontaneous only at high temperatures.
(C) spontaneous only at low temperatures.
(D) not spontaneous at any temperature.

25. For the reaction:
2 A + 3 B → C, [A] is found to decrease at a rate of 2.0 M*s^-1. If the rate law is rate = k[A], how fast does [B] decrease under the same conditions?

(A) 0.66 M*s^-1
(B) 1.3 M*s^-1
(C) 2.0 M*s^-1
(D) 3.0 M*s^-1

26. What are the units for the rate constant of a second-order reaction?

(A) s^-1
(B) M^-1*s^-1
(C) M^-2*s^-1
(D) M^-2*s^-1

27. A sample containing a radioactive isotope produces 2000 counts per minute in a Geiger counter. After 120 hours, the sample produces 250 counts per minute. What is the half-life of the isotope?

(A) 15 h
(B) 30 h
(C) 40 h
(D) 60 h

28. In the rate-limiting approximation for a two-step reaction, the overall rate of the reaction is always equal to the rate of the _______ step in the reaction mechanism.

(A) first
(B) second
(C) fastest
(D) slowest

29. Which of the following examples demonstrate homogeneous catalysis?

I. Pt(s) catalyzing the reaction of O_2(g) with CO(g)
II. Cl(g) catalyzing the decomposition of O_3(g)
III. H_2O_2(aq) decomposition catalyzed by Br^- (aq)

(A) I. only
(B) II. only
(C) I. and III. only
(D) II. and III. only

30.

![Reaction Progress]

The diagram above represents the energy profile for the reaction: A + B → C + D. What is the value of the activation energy for the reaction: C + D → A + B?

(A) 25 kJ  (B) 55 kJ  (C) 85 kJ  (D) –30 kJ

31. What is the equilibrium expression for this reaction?

2 HgO(s) ⇌ 2 Hg(l) + O_2(g)

(A) K = [Hg][O_2]/[HgO]
(B) K = [Hg]^2[O_2]/[HgO]^2
(C) K = [Hg]^2[O_2]
(D) K = [O_2]

32. For the exothermic reaction

4 NH_3(g) + 7 O_2(g) ⇌ 4 NO_2(g) + 6 H_2O(g)

which change will increase the quantity of NO_2 in the mixture?

(A) increasing temperature
(B) decreasing container volume
(C) adding Ne(g)
(D) adding H_2O(g)

33. Weak acids include which of the following?

I. HF(aq)  II. HI(aq)  III. HNO_2(aq)

(A) I. only  (B) II. only  (C) III. only  (D) I. and III. only

34. H_2CO_3(aq) + H_2O(l) ⇌ HCO_3^(-)(aq) + H_3O^+(aq)
HCO_3^- (aq) + H_2O(l) ⇌ CO_3^{2-}(aq) + H_3O^+(aq)

According to the equations above, what is the conjugate base of HCO_3^-?

(A) H_2CO_3(aq)  (B) H_2O(l)  (C) H_3O^+(aq)  (D) CO_3^{2-}(aq)
35. A saturated solution of which salt will have the highest [Ag⁺]?
   (A) AgCl \( (K_{sp} = 1.8 \times 10^{-10}) \)
   (B) Ag₂CrO₄ \( (K_{sp} = 1.1 \times 10^{-12}) \)
   (C) Ag₃PO₄ \( (K_{sp} = 1.8 \times 10^{-18}) \)
   (D) Ag₂S \( (K_{sp} = 6.0 \times 10^{-31}) \)

36. A saturated solution of manganese(II) carbonate \( (M = 114.95) \) contains \( 5.44 \times 10^{-5} \) g of MnCO₃ per 100 mL at 25 °C. What is its \( K_{sp} \) at this temperature?
   (A) 4.7 \times 10^{-6}  
   (B) 3.0 \times 10^{-9}  
   (C) 2.2 \times 10^{-11}  
   (D) 2.2 \times 10^{-13}  

37. Three metals, A, B and C, with solutions of their respective cations are tested in a voltaic cell with the following results:
   A and B: A is the cathode
   B and C: C is the cathode
   A and C: A is the anode
   What is the order of the reduction potentials from highest to lowest for the cations of these metals?
   (A) A > B > C  
   (B) B > C > A  
   (C) C > A > B  
   (D) B > A > C  

38. In which pair of substances do the nitrogen atoms have the same oxidation state?
   (A) HNO₃ and N₂O₃  
   (B) NO and HNO₂ 
   (C) N₂ and N₂O  
   (D) HNO₂ and HNO₃ 

39. In the equation below, which species acts as the oxidizing agent? \( \text{Pb(s) + PbO}_2(s) + 2 \text{H}^+(aq) + 2 \text{HSO}_4^-(aq) \rightarrow 2 \text{PbSO}_4(s) + 2 \text{H}_2\text{O}(l) \)
   (A) Pb(s)  
   (B) PbO₂(s)  
   (C) H⁺(aq)  
   (D) HSO₄⁻(aq) 

40. A standard voltaic cell is constructed using Cu metal in 1.0 M Cu(NO₃)₂(aq) and an unknown metal in a 1.0 M solution of its nitrate salt. The cell voltage is 0.47 V when the Cu half-cell is the cathode. What is the standard reduction potential of the unknown metal? \[ E°_{\text{Cu}} = 0.34 \text{ V} \]
   (A) –0.81 V  
   (B) –0.13 V  
   (C) 0.13 V  
   (D) 0.81 V 

41. A voltaic cell is constructed with the overall reaction:
   \( \text{Sn}^{2+}(aq) + 2 \text{Ag}^+(aq) \rightleftharpoons \text{Sn}^{4+}(aq) + 2 \text{Ag}(s) \)
   Which change will increase the voltage of the cell?
   (A) increasing [Sn²⁺]  
   (B) increasing [Sn⁴⁺]  
   (C) decreasing [Ag⁺]  
   (D) reducing the size of the Ag electrode 

42. Use the standard reduction potentials to determine what is observed at the cathode during the electrolysis of a 1.0 M solution of KBr that contains phenolphthalein. What observation(s) is(are) made?
   \( \text{O}_2(g) + 4 \text{H}^+(aq) + 4 \text{e}^- \rightarrow 2 \text{H}_2\text{O}(l) \quad E° = 1.23 \text{ V} \)
   \( \text{Br}_2(l) + 2 \text{e}^- \rightarrow 2 \text{Br}^- (aq) \quad E° = 1.07 \text{ V} \)
   \( 2 \text{H}_2\text{O}(l) + 2 \text{e}^- \rightarrow \text{H}_2(g) + 2 \text{OH}^- \quad E° = -0.80 \text{ V} \)
   \( \text{K}^+(aq) + \text{e}^- \rightarrow \text{K}(s) \quad E° = -2.92 \text{ V} \)
   (A) Solid metal forms.  
   (B) Bubbles form and a pink color appears. 
   (C) Dark red Br₂(aq) forms.  
   (D) Bubbles form and the solution remains colorless. 

43. To whom is the discovery of the nuclear atom attributed?  
   (A) Neils Bohr  
   (B) Louis deBroglie  
   (C) Robert Millikan  
   (D) Ernest Rutherford 

44. Each of the following atomic orbitals is possible except 
   (A) 1s.  
   (B) 2p.  
   (C) 3f.  
   (D) 4d. 

45. The ion \( ^{55}\text{Mn}^{2+} \) contains which combination of protons, neutrons and electrons?
   \[
   \begin{array}{ccc}
   \text{protons} & \text{neutrons} & \text{electrons} \\
   \text{A} & 25 & 30 & 23 \\
   \text{B} & 25 & 55 & 23 \\
   \text{C} & 27 & 30 & 25 \\
   \text{D} & 30 & 25 & 28 \\
   \end{array}
   \]
   (A) A  
   (B) B  
   (C) C  
   (D) D 

46. What is the characteristic color of the flame test for potassium?
   (A) yellow  
   (B) red  
   (C) green  
   (D) violet 

47. Which atom has the highest electronegativity?
   (A) Na  
   (B) P  
   (C) Cl  
   (D) Br 

48. In which set are both elements metalloids?
   (A) Cr and Mo  
   (B) Ge and As  
   (C) Sn and Pb  
   (D) Se and Br 

49. The silicon-oxygen bonds in SiO₂ are best described as
   (A) coordinate covalent.  
   (B) ionic.  
   (C) nonpolar covalent.  
   (D) polar covalent. 

50. Which bond is strongest?
   (A) C=C  
   (B) C=N  
   (C) C=O  
   (D) C=S
51. What is the relationship between the two species shown below?

\[ \begin{array}{c}
\dot{\text{N}} \equiv \text{N} \equiv \ddot{\text{O}} \\
\dot{\text{N}} \equiv \text{N} \equiv \ddot{\text{O}}
\end{array} \]

They are

(A) geometric isomers.  (B) enantiomers.
(C) resonance forms.  (D) structural isomers.

52. If A represents the central atom, in which molecule is the F-A-F angle the smallest?

(A) BF₃  (B) CF₄  (C) NF₃  (D) OF₂

53. On the basis of VSEPR theory, what geometry is predicted for the central sulfur atom in SOCl₂?

(A) bent  (B) T-shaped
(C) trigonal planar  (D) trigonal pyramidal

54. How many sigma (σ) and pi (π) bonds are in a molecule of ethyne (acetylene), HCCH?

(A) 1 σ and 1 π  (B) 2 σ and 1 π
(C) 2 σ and 3 π  (D) 3 σ and 2 π

55. What is the number of structural isomers with the molecular formula C₆H₁₄?

(A) three  (B) four  (C) five  (D) six

56. All of the following are condensation polymers except

(A) nylon  (B) polyethylene
(C) protein  (D) starch

57. Methanol can be gently oxidized with hot copper metal. What is/are the product(s) of this oxidation?

(A) acetic acid  (B) carbon dioxide + water
(C) ethanol  (D) methanal

58. Which statement does not describe benzene, C₆H₆?

(A) It is an aromatic hydrocarbon.
(B) It exists in two isomeric forms.
(C) It undergoes substitution reactions.
(D) It can react to form three different products with the formula C₆H₄Cl₂.

59. All of the following atoms comprise part of a peptide functional group except

(A) hydrogen.  (B) nitrogen.
(C) oxygen.  (D) phosphorus.

60. Which vitamin is the most soluble in water?

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

END OF TEST
# Olympiad 2013

## USNCO Local Section Exam

### KEY

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