單選題共五十題，每題2分，請於答案卡上作答。

1. How many angular nodes are there in all orbitals of the shell n = 4 for a hydrogen atom?
   (A) 34　(B) 21　(C) 48　(D) 24　(E) 3
2. The wavefunction $\psi_{nlm_l}(r,\theta,\phi)$ of a hydrogen atom is equal to $R_{nl}(r) \times Y_{lm_l}(\theta,\phi)$, where $R_{nl}(r)$ is the radial wavefunction and $Y_{lm_l}(\theta,\phi)$ is the angular wavefunction. What is the probability density of find an electron at the distance d from the nucleus in the 3s-orbital of a hydrogen atom?
   (A) $\psi_{300}^2(d,0,0)$　(B) $R_{30}^2(d)$　(C) $d^2 \cdot \psi_{300}^2(d,0,0)$
   (D) $d^2 \cdot R_{30}^2$　(E) None of the above answers are correct.
3. For the ground-state of Au^+, what type of orbital do the electrons with the highest energy reside in?
   (A) 6s　(B) 5p　(C) 4f　(D) 6p　(E) 5d
4. Arrange the following atoms in order of increasing first ionization energy (from least to greatest): Be, B, N, O, F. Which of the following sequences is correct?
   (A) Be<B<N<O<F　(B) B<Be<O<N<F　(C) B<O<Be<N<F
   (D) B<Be<N<O<F　(E) Be<B<O<N<F
5. Which compound has the largest ONO bond angle?
   (A) NO_2^+　(B) NO_2^-　(C) NO_3^-　(D) N_2O_4　(E) N_2O_3
6. Which compound has a molecular shape that is trigonal bipyramidal?
   (A) BF_3　(B) PF_3　(C) SF_6　(D) SF_5^+　(E) BrF_5
7. Which of the following diatomic species is paramagnetic, has a bond order of 1.5, and is classified as a radical?
   (A) O_2^+　(B) C_2^+　(C) B_2　(D) CN　(E) NO
8. What is the hybridization of the bolded atoms **NNC**, from left to right, in azodicarbonamide, $H_2NC(O)\mathbf{NNC}(O)NH_2$?
   (A) sp^3, sp, sp^2　(B) sp^2, sp, sp^3　(C) sp^2, sp, sp^2　(D) sp, sp, sp^2
   (E) sp^2, sp^2, sp^2
9. A solid is found to be extremely hard, has a very high melting point, is insoluble in water, and does not conduct electricity in any state. Based on these properties, which of the following solids does it most likely represent?
   (A) $CaCl_2$　(B) I_2　(C) graphite　(D) Pb　(E) SiC
10. A metal Z with atomic radius r forms a cubic close-packed structure. Which formula correctly calculates the radius of the largest sphere that can fit in an octahedral hole without pushing any atom Z apart?
    (A) $r(\sqrt{2}-1)$　(B) $r(2\sqrt{2}-1)$　(C) $r(\sqrt{3}-1)$
    (D) $r(3/\sqrt{3}-1)$　(E) $r/(2\sqrt{2}-1)$

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11. There are several resonance structures of sulfate ions. Which statement about the most stable Lewis structure of the sulfate ion is invalid?
    (A) The sulfate ion has a tetrahedral geometry.
    (B) The sulfate ion is nonpolar.
    (C) The overall charge of the sulfate ion is 0 in the most stable Lewis structure.
    (D) All sulfur-oxygen bonds are equivalent.
    (E) The sulfur atom has an expanded octet.
12. Why is CO slightly polar, but not strongly polar, despite the significant electronegativity difference between carbon and oxygen?
    (A) The triple bond between carbon and oxygen is highly polar, but the molecule's symmetry reduces the overall polarity.
    (B) The triple bond in CO eliminates any dipole moment, as it localizes electrons equally between the two atoms.
    (C) Both carbon and oxygen have formal charges of zero, making the molecule nonpolar despite the electronegativity difference.
    (D) The electronegativity difference between carbon and oxygen is large, but the formal charge distribution reduces the effective dipole moment.
    (E) The molecule has a linear geometry, causing the bond dipoles to cancel each other out.
13. One ionic crystal structure contains two ions, Ca^{2+} and F^-. Ca^{2+} ions occupy the face-centered cubic lattice points, and F^- ions occupy all the tetrahedral holes. Which statement is invalid?
    (A) The ionic radius $r_{Ca^{2+}}$ of Ca^{2+} is larger than the ionic radius r_{F^-} of F^-.
    (B) The coordination numbers of Ca^{2+} and F^- are 12 and 8 respectively.
    (C) The relation between the edge length a of the unit cell and $r_{Ca^{2+}} + r_{F^-}$ is equivalent to $a \cdot \sqrt{3}/4 = r_{Ca^{2+}} + r_{F^-}$
    (D) There are 4 Ca^{2+} ions and 8 F^- ions in a unit cell.
    (E) The empirical formula of the ionic crystal structure is CaF_2.
14. Which is not the valid statement?
    (A) $2SO_3(g) \rightarrow 2SO_2(g) + O_2(g)$ $\Delta H^o_{rxn} > 0$, the reaction is spontaneous at high temperatures and is entropy driven.
    (B) $2C(s) + 2H_2(g) \rightarrow C_2H_4(g)$ $\Delta H^o_{rxn} > 0$, the reaction will be spontaneous at low temperatures and is entropy driven.
    (C) $2NO(g) + O_2(g) \rightarrow 2NO_2(g)$ $\Delta H^o_{rxn} < 0$, the reaction will be spontaneous at low temperatures and is enthalpy driven.
    (D) $N_2H_4(l) + O_2(g) \rightarrow N_2(g) + 2H_2O(g)$ $\Delta H^o_{rxn} < 0$, the reaction will be spontaneous at all temperatures.
    (E) Water slowly evaporates at 25°C. This is a spontaneous reaction that is entropy driven.

15. A real gas behaves non-ideally under certain conditions and can be described by the van der Waals equation of state. Which of the following statements best explains the relationship between the compression factor Z, van der Waals' coefficients *a* and *b*, and deviations from ideal gas behavior?
(A) For a gas with large *a* and small *b*, Z is always greater than 1, indicating the dominance of repulsive forces over attractive forces.
(B) At low pressures, the effect of *b* dominates, causing Z to decrease below 1 due to volume corrections.
(C) For a gas with large *a*, Z decreases below 1 at moderate pressures due to the strong attractive interactions between molecules.
(D) At high pressure, the influence of both *a* and *b* diminishes, and Z becomes independent of these coefficients, matching ideal gas behavior.
(E) Z is always less than 1 for any gas described by the van der Waals equation, regardless of the values of *a* and *b*.

16. Consider a gas in thermal equilibrium at two different temperatures, T_1 and T_2, where $T_2 > T_1$. Which of the following statements best explains the interplay between the Maxwell-Boltzmann distribution, temperature, and entropy for this system?
(A) At T_2, the Maxwell-Boltzmann distribution shifts to lower particle speeds, and entropy decreases because there are fewer accessible microstates.
(B) At T_2, the Maxwell-Boltzmann distribution becomes broader, indicating a greater range of particle speeds and an increase in entropy due to more accessible microstates.
(C) The Maxwell-Boltzmann distribution remains unchanged between T_1 and T_2 because the distribution depends only on the mass of the particles, not the temperature.
(D) At T_1, the narrower Maxwell-Boltzmann distribution corresponds to higher entropy, as lower temperatures increase the uniformity of particle speeds.
(E) Entropy remains constant between T_1 and T_2 because it is a state function independent of temperature changes.

17. Consider the thermodynamic properties, U, S_{surr}, T, H, w, q_{rev}, how many of them are not state functions?
(A) 6　(B) 5　(C) 4　(D) 3　(E) 2

18. Assume that CH_4 behaves as an ideal gas and its heat capacity is mainly contributed by translational and rotational motion but none of vibrational ones. Consider the irreversible compression of 1 mole of CH_4 from an initial state at $P_1 = 1$ bar and $T_1 = 300$ K to a final state at $P_2 = 4$ bar, $T_2 = 400$ K, against a constant external pressure of $P_{ext} = 4$ bar. What is the heat transfer q during the process?
(A) 2494.2 J　(B) 4157.0 J　(C) 6651.2 J　(D) -6651.2 J　(E) -4157.0 J

19. Given the standard enthalpies of formation for $Br_2(g)$ and Br(g), 30.7 and 112 kJ/mol respectively, what is the Br-Br bond enthalpy?
(A) 81.3 kJ/mol (B) 193.3 kJ/mol (C) 142.7 kJ/mol (D) 254.7 kJ/mol (E) 112 kJ/mol

20. Which is not the valid thermodynamic equation?
(A) $U = H - PV$ (B) $S = k_B \cdot \ln(W)$ (C) $H = G + ST$
(D) $A = U - ST$ (E) $\Delta G_{rxn} = \Delta G^o_{rxn} + RT \cdot \ln(K)$

21. For $CaCl_2$, the absolute value of the enthalpy of hydration is larger than the lattice enthalpy. This means that for $CaCl_2$
(A) the enthalpy of solution is exothermic.
(B) the lattice enthalpy is negative.
(C) the enthalpy of hydration is positive.
(D) the entropy changes of solution is smaller than 0.
(E) the solubility increases when the temperature increases.

22. A mixture of two liquids, A and B, forms a minimum boiling azeotrope. Which of the following statements is correct regarding this mixture?
(A) The vapor pressure of the mixture is lower than that predicted by Raoult's law.
(B) The intermolecular forces between A and B molecules are stronger than those between A-A and B-B molecules.
(C) Fractional distillation may be used to completely separate A and B from the azeotropic mixture.
(D) The boiling point of the azeotrope is lower than that of either pure A or pure B.
(E) The above statements are all correct.

23. Which of the following statements is true?
(A) When the value of reaction quotient Q is large, the equilibrium lies on the product side of the equilibrium reaction.
(B) An equilibrium constant value significantly less than 1 indicates that the equilibrium concentrations of the products are much smaller than those of the reactants.
(C) When the value of K is large, the equilibrium lies on the reactant side of the equilibrium reaction.
(D) A large value of Q means that the equilibrium concentrations of the reactants are small compared to the equilibrium concentrations of the products.
(E) When the value of Q is small, the forward reaction is spontaneous.

24. What is the relationship between K_P and K_C for the reaction below?

$$N_2H_4(l) + O_2(g) \rightarrow N_2(g) + 2H_2O(g)$$

(A) $K_P = (RT)^2K_C$ (B) $K_P = RTK_C$ (C) $K_P = K_C$
(D) $K_C = RTK_P$ (E) $K_C = (RT)^2K_P$

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25. At constant temperature, consider a equilibrium reaction,
$3\ Fe(s) + 4\ H_2O(g) \rightleftharpoons 4\ H_2(g) + Fe_3O_4(s)$. If the volume of the container is reduced
(A) ΔS_{rxn} is increased. (B) ΔG_{rxn} is decreased. (C) $\Delta S°_{rxn}$ is increased.
(D) $\Delta G°_{rxn}$ is decreased. (E) The above answers are all incorrect.

26. The reaction $2\ NO(g) + 2\ H_2(g) \rightarrow N_2(g) + 2\ H_2O(g)$ is first order in H_2 and second order in NO. Starting with equal concentrations of H_2 and NO, the rate after 30% of the H_2 has reacted is what percent of the initial rate?
(A) 3% (B) 27% (C) 34% (D) 49% (E) 70%

27. The superheavy synthetic element Tennessine (Ts) is the most recently discovered element so far. The nuclear fusions reaction for producing Ts:

$$^{249}_{97}Bk + X \rightarrow {}^{294}_{117}Ts + 3\ n$$

Berkelium (Bk) used in this reaction is also a synthetic element. What is the element X?
(A) $^{45}_{20}Ca$ (B) $^{48}_{20}Ca$ (C) $^{47}_{21}Sc$ (D) $^{45}_{23}V$ (E) $^{48}_{23}V$

28. Which of the following amino acids has a thiol side chain and forms disulfide bonds that play an important role in the folding and stability of proteins
(A) asparagine (B) cysteine (C) lysine (D) methionine (E) threonine

29. The high density (> 19 g/cm^3) of tungsten, rhenium, osmium, iridium, platinum, and gold metals is due to
(A) Born-Oppenheimer approximation (B) iron group effect
(C) island of stability theory (D) lanthanide contraction
(E) lazy pair effect

30. The rate law for the following mechanism is

$Cl_2(g) \rightleftharpoons 2\ Cl(g)$ both fast, equilibrium constant K_1,
$Cl(g) + CO(g) \rightleftharpoons COCl(g)$ both fast, equilibrium constant K_2
$COCl(g) + Cl_2(g) \rightarrow COCl_2(g) + Cl(g)$ k_3, slow|

(A) rate = $k_3K_1^{0.5}K_2[Cl_2]^{1.5}[CO]$ (B) rate = $k_3K_1^{0.5}K_2[Cl_2]^{0.5}[CO]$
(C) rate = $k_3K_1K_2[Cl_2][CO]$ (D) rate = $k_3[CO][Cl_2]$
(E) rate = $K_1K_2k_3[CO]$

31. In the reaction mechanism in Question 30,
(A) COCl is the activated complex.
(B) COCl is the steady state between step 2 and 3.
(C) both Cl atom and COCl are reaction intermediates.
(D) the transition state is the mixture of $Cl_2(g)$, Cl(g), and CO(g).
(E) Cl atom is not the reaction intermediate, because it is very unstable.

32. How many of the structural isomers of C_6H_{14} have only primary and tertiary hydrogens?
(A) 0 (B) 1 (C) 2 (D) 3 (E) 4

33. Which of the following descriptions about $[CoCl_6]^{4-}$ is not correct?
    (A) The ligand field splitting Δ_O of $[CoCl_6]^{4-}$ is smaller that that of $[Co(NH_3)_6]^{2+}$
    (B) The ground-state d-electron configuration of $[CoCl_6]^{4-}$ is $t_{2g}^5e_g^2$.
    (C) $[CoCl_6]^{4-}$ has 3 unpaired electrons.
    (D) $[CoCl_6]^{4-}$ is paramagnetic.
    (E) $[CoCl_6]^{4-}$ is low-spin.

34. What are the products of the electrolysis of 1 M $CuSO_4$ aqueous solution?
    (A) $H_2(g)$ and $S_2O_8^{2-}(aq)$　(B) $H_2(g)$ and $O_2(g)$
    (C) Cu(s) and S(s)　(D) Cu(s) and $O_2(g)$
    (E) $SO_2(g)$ and $O_2(g)$

35. Which of the following aromatic compounds undergo nitration faster than benzene?
    [i] aniline　[ii] benzonitrile　[iii] benzoic acid　[iv] phenol
    [v] benzaldehyde
    (A) [i] and [ii]　(B) [i] and [iv]　(C) [iii] and [v]
    (D) [i], [ii], and [iv]　(E) [iii], [iv], and [v]

36. How many of the following oxides of Group 13, 14, and 15 elements are amphoteric?
    As_2O_3, Ga_2O_3, PbO, Sb_2O_3, SnO_2 , Tl_2O
    (A) 1　(B) 2　(C) 3　(D) 5　(E) 6

37. Which of the following are coordination isomers? ?
    (A) *cis*-$[CoCl_2(en)_2]Cl$ and *trans*-$[CoCl_2(en)_2]Cl$
    (B) $[CrCl(OH_2)_5]Cl_2{\cdot}H_2O$ and $[CrCl_2(OH_2)_4]Cl{\cdot}2H_2O$
    (C) $[CoNCS(NH_3)_5]Cl_2$ and $[CoSCN(NH_3)_5]Cl_2$
    (D) $[Cr(NH_3)_6][Fe(CN)_6]$ and $[Fe(NH_3)_6][Cr(CN)_6]$
    (E) $[CoBr(NH_3)_5]SO_4$ and $[CoSO_4(NH_3)_5]Br$

38. The enzymatic oxidation of ethanol to acetaldehyde in human body is a zeroth-order reaction:

$$CH_3CH_2OH + NAD^+ \xrightarrow{\text{alcohol dehydrogenase}} CH_3COH + H^+ + NADH$$

    The blood alcohol concentration (BAC) of a man who drank some wine drops from 120 mg/dL to 60 mg/dL within 2.0 hours. How much time is required for his BAC drops from 60 mg/dL to 30 mg/dL?
    (A) 45 min　(B) 1.0 hour　(C) 2.0 hours　(D) 3.3 hours　(E) 4.0 hours

39. The Cu^{2+} ion can be separated from Ag^+, Ca^{2+}, and Zn^{2+} in aqueous solution by
    (A) precipitation of Cu^{2+} with Na_2S solution
    (B) precipitation of Cu^{2+} with NaF solution
    (C) precipitation of Ag^+, Ca^{2+}, and Zn^{2+} with Na_2CO_3 solution
    (D) precipitation of Ag^+, Ca^{2+}, and Zn^{2+} with NaOH solution
    (E) None of above methods.

40. What are X, Y, and Z in the following reactions?

$$CaO(s) + C(s) \xrightarrow{\Delta} X(s) + Y(g)$$
$$X(s) + H_2O(l) \rightarrow Ca(OH)_2(s) + Z(g)$$

The reactions are not balanced.

(A) X = Ca, Y = CO_2, Z = H_2　(B) X = Ca, Y = CO, Z = H_2

(C) X = CaC, Y = CO_2, Z = CH_4　(D) X = CaC_2, Y = CO, Z = C_2H_2

(E) X = CaC_2, Y = CO, Z = CH_4

41. Ms. Usagi wants to determine the standard potential of ozone.

$$O_3(g) + H_2O(l) + 2\ e^- \rightarrow O_2(g) + 2\ OH^-(aq)$$

She uses a saturated calomel electrode (SCE) as the anode, and for the cathode she bubbles O_3 gas through a NaOH solution with a Pt electrode. The cell diagram should be expressed as:

(A) $Hg(s)|Hg^{2+}(aq)||OH^-(aq),O_2(g),O_3(g)|Pt(s)(s)$

(B) $Hg(s),Hg_2Cl_2(s)|Cl^-(aq)||OH^-(aq),O_2(g),O_3(g)|Pt(s)$

(C) $Hg(s)|Hg_2Cl_2(s)|Cl^-(aq)||OH^-(aq)|O_2(g),O_3(g)|Pt$

(D) $Pt(s)|OH^-(aq)|O_2(g),O_3(g)||Hg^{2+}(aq)|Hg(s)$

(E) $Pt(s)|OH^-(aq),O_2(g),O_3(g)||Cl^-(aq)|Hg_2Cl_2(s),Hg(s)$

42. Estimate the effective pH range of a pyridine/pyridinium chloride buffer. For pyridine, the value of K_b is 1.8×10^{-9}.

(A) 4.3–6.3　(B) 5.3-7.3　(C) 7.7–9.7　(D) 8.5–9.0

(E) 9.2–11.2

43. Which of the following compounds can not be a monomer of an addition polymer?

(A) styrene　(B) ethyne

(C) adenine (6-aminopurine)　(D) 2-chloro-1,3-butadiene

(E) methyl 2-methylpropenoate (methyl methacrylate)

44. Which of the following reactions is not feasible?

(A) $2\ FeTiO_3 + 7\ Cl_2 + 6\ C \rightarrow 2\ TiCl_4 + 2\ FeCl_3 + 6\ CO$

(B) $TiCl_4 + 2\ Mg \rightarrow Ti + 2\ MgCl_2$

(C) $V_2O_5 + 5\ Ca \rightarrow 2\ V + 5\ CaO$

(D) $Cr_2O_3 + 3\ Cu \rightarrow 2\ Cr + 3\ CuO$

(E) $NiO + H_2 \rightarrow Ni + H_2O$

45. The lattice enthalpies of ionic compounds of fluoride tends to be very high because

(A) the ionic radius of fluoride ion is small.

(B) fluoride is a "soft" anion.

(C) the electron affinity of fluorine is high.

(D) fluoride ion is a weak field ligand.

(E) the standard reduction potential of fluorine is high.

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46. At 298 K, the ΔG° for combustion of 1 mole of $CH_4(g)$ is −818 kJ, calculate the standard voltage that could be obtained from a methane-oxygen fuel cell using this reaction.
(A) 1.06 V (B) 1.41 V (C) 2.12 V (D) 8.48 V (E) −2.12 V

47. Why does the oxygen isotopic composition $^{18}O/^{16}O$ in the ice cores provide a good record of the climate?
(A) $C^{18}O_2$ is a more powerful greenhouse gas than $C^{16}O_2$.
(B) The ^{18}O-water dissolves a little more CO_2 than ^{16}O-water.
(C) The half-life of radioactive ^{18}O is a function of temperature.
(D) The more intense the sun's nuclear fusion reaction, the more ^{18}O will be produced.
(E) There are slight differences in the evaporation and condensation of $H_2{}^{16}O$ and $H_2{}^{18}O$.

48. Any chemicals added to a waste container must not react with one another or result in unsafe conditions at any time during handling, storage, or while being shipped to a disposal facility. The followings are incompatible chemicals and should not be added to the same waste container, except
(A) H_2O_2 and H_2SO_4 (B) Al and NaOH (C) HCl and Na_2S
(D) oleic acid and xylene (E) ethanol and $KMnO_4$

49. Which of the followings is not the property of saline hydrides?
(A) They react with water.
(B) They are oxidizing agents.
(C) They can be used as strong bases.
(D) The atoms of a saline hydride are bonded ionically.
(E) They are insoluble in low polarity organic solvents.

50. The reaction of iodine and thiosulfate ion in aqueous solution produces:
(A) iodate ion (B) iodide ion (C) sulfur (D) persulfate ion
(E) no reaction