Part I: Single choice (50%)

1. Which of the following point groups does not exist?
   (a) C₁  (b) D₂  (c) S₅  (d) O₁

2. Which of the following symmetry elements is the best criterion for chirality?
   (a) inversion center  (b) mirror plane  (c) proper rotation axis  (d) improper rotation axis

3. Which of the following trends is incorrect for atomic orbitals?
   (a) Relative energies for hydrogen-like atom: 2s = 2p, 3s = 3p = 3d.
   (b) Relative energies for many-electron atom: 2s < 2p, 3s < 3p < 3d.
   (c) Average distance from the nucleus: 2s < 2p, 3s < 3p < 3d.
   (d) Penetration effect: 2s > 2p, 3s > 3p > 3d.

4. Which of the following orbital hybridizations will break the axial symmetry?
   (a) sp²  (b) dₓ²−ᵧ²  (c) pₓ  (d) sp³.

5. Which of the following silver halides has largest covalent character?
   (a) AgF  (b) AgCl  (c) AgBr  (d) AgI

6. Which of the following transition metals has the largest ionic radii?
   (a) l.s. Mn³⁺  (b) h.s. Mn²⁺  (c) h.s. Fe³⁺  (d) l.s. Fe²⁺

7. Which of the following statements is incorrect for constructing Lewis structure?
   (a) The more electronegative atom will be surrounded by more atoms.
   (b) Elements beyond the second period may have expanded octet.
   (c) Lewis structures with low formal charges are preferred.
   (d) Lewis structures with maximum number of bonds are preferred.

8. Given the reduction potentials of O₂ that
   \[ O₂ → \text{HO}_2^{−} \quad 1.68 \quad \text{H}_2\text{O}_2^{−} \quad 0.80 \quad \text{HO}^+ + \text{H}_2\text{O} \quad 2.74 \quad 2\text{H}_2\text{O} \]
   (a) H₂O₂ will not undergo disproportionation.
   (b) HO₂ is unstable and will undergo disproportionation.
   (c) One-electron reduction of O₂ is unfavorable thermodynamically.
   (d) Four-electron reduction of O₂ is most favorable thermodynamically for O₂ reduction.

9. Which of the following complexes do you expect to show the smallest number of ν CO bands?
   (a) cis-[M(CO)₃L₂]  (b) trans-[M(CO)₃L₂]  (c) M(CO)₅L  (d) M(CO)₄L.

10. Which of the following molecules will absorb light of longest wavelength?
    (a)  (b)  (c)  (d)  (e)  (f)  (g)  (h)  (i)  (j)  (k)  (l)  (m)  (n)  (o)  (p)  (q)  (r)  (s)  (t)  (u)  (v)  (w)  (x)  (y)  (z)

11. Which of the following molecules has the largest HOMO-LUMO gap?
    (a) F₂  (b) Cl₂  (c) Br₂  (d) I₂.

12. Based on molecular orbital theory, which of the following factors are not important to the bonding interactions between two atoms?
    (a) electronegativity difference  (b) orbital symmetry  (c) orbital size  (d) all of them are important.

13. It is not necessary to include which of the following concepts in MO theory?
    (a) resonance  (b) symmetry adapted linear combination  (c) linear combination of atomic orbital  (d) antibonding interaction.

14. Which of the following statements is not correct?
    (a) Ionization energy of H₂ is larger than that of H.
    (b) Ionization energy of He is larger than that of H.
    (c) Ionization energy of HF is larger than that of F.
    (d) Ionization energy of HF is larger than that of F₂.
15. Based on the frontier orbital concept, which of the following statements is correct?

(a) For a reaction \( H_2 + H^+ \rightarrow H_3 \), \( H_3^+ \) should be triangular.
(b) For a reaction \( H_2 + H^+ \rightarrow H_3^+ \), \( H_3^+ \) should be linear.
(c) For a reaction \( HF + F \rightarrow HF_2^- \), \( HF_2^- \) should be linear and symmetrical \( F-H-F^- \).
(d) For a reaction \( ClIF + Cl^+ \rightarrow Cl_2F^+ \), \( Cl_2F^+ \) should be linear and symmetrical \( Cl-F-Cl^+ \).

16. Which of the following species has the smallest bond order?

(a) \( O_2^+ \)  
(b) \( O_2 \)  
(c) \( O_2^- \)  
(d) \( O_2^{2-} \).

17. Acidity of \( BB_3 > BC_3 > BF_3 \) is determined by

(a) inductive effect  
(b) resonance effect  
(c) F-strain  
(d) B-strain.

18. Which of the following hybrid orbitals will form chemical bonds with bent shape?

(a) \( p_xd_z \)  
(b) \( sd_z \)  
(c) \( sp_z \)  
(d) \( p_xd_z \).

19. Which of the following atoms has the highest electron affinity?

(a) F  
(b) Cl  
(c) Br  
(d) I.

20. Which of the following molecules has the strongest C-H bond?

(a) \( CH_4 \)  
(b) \( H_2C=CH_2 \)  
(c) \( H-C=CH \)  
(d) \( CH_3 \) radical.

21. Which of the following species has the largest energy difference between \( 3d \) and \( 4p \)?

(a) \( K \)  
(b) \( Ca^+ \)  
(c) \( Sc^{2+} \)  
(d) \( Ti^{3+} \).

22. Which of the following bases has the largest proton affinity in aqueous solution?

(a) \( OH^- \)  
(b) \( CH_3O^- \)  
(c) \( i-PrO^- \)  
(d) \( t-BuO^- \).

23. For a homonuclear diatomic molecule lying along z axis, which of the following orbital interactions will form bond?

(a) \( dy_z-dy_z \)  
(b) \( d_{xy}-d_{xy} \)  
(c) \( d_{y^2}-d_{z^2} \)  
(d) \( d_{x^2-y^2}-d_{x^2-y^2} \).

24. Transition metal complexes with which of the following geometries will not be subjected to Jahn-Teller effect just by changing bond length to lower the symmetry?

(a) octahedral  
(b) tetrahedral  
(c) square planar  
(d) linear.

25. Which of the following statements is incorrect?

(a) Trans effect is a transition-state effect.  
(b) Trans influence is a ground-state effect.  
(c) Kinetic trans effect is to weak the bond between the metal and the trans ligand.  
(d) Trans effect may be applicable to the preparation of the geometric isomers of square planar complexes of Pt(II).

Part II: Single choice (30%)

1. Which one has the lowest water exchange rate?

(a) \([Na(H_2O)_6]^{2+}\)  
(b) \([Mg(H_2O)_6]^{2+}\)  
(c) \([Al(H_2O)_6]^{2+}\)  
(d) \([Cr(H_2O)_6]^{3+}\)  
(e) \([Fe(H_2O)_6]^{3+}\).

2. Which one has the highest splitting energy in \([Co(NH_3)_6X]^n^+\)?

(a) \([Co(NH_3)_6]^{3+}\)  
(b) \([Co(NH_3)_6Cl]^{2+}\)  
(c) \([Co(NH_3)_6(OH)]^{2+}\)  
(d) \([Co(NH_3)_6I]^{3+}\)  
(e) \([Co(NH_3)_6(PPh_3)]^{3+}\).

3. Which one of the following compounds is paramagnetic?

(a) \([PtCl_2(PPh_3)_2]\)  
(b) \([PdCl_2(PPh_3)_2]\)  
(c) \([NiCl_2(PPh_3)_2]\)  
(d) \([PtCl_2(C_2H_4)]\)  
(e) \([Co(NH_3)_6]^{3+}\).

4. Which of the following complexes will be colorless based on selection rules?

(a) \([Ti(H_2O)_6]^3^+\)  
(b) \([Cr(H_2O)_6]^{3+}\)  
(c) \([Fe(H_2O)_6]^{3+}\)  
(d) \([NiCl_4]^{2^-}\)  
(e) \([CuCl_4]^{3^-}\).
5. Which of the following statements is incorrect?
   (a) CrMe₆ is more stable than WMe₆.
   (b) trans-Cr(CO)₆(PPh₃)₂ is more stable than cis-Cr(CO)₆(PPh₃)₂.
   (c) (η⁶-C₆H₁₂CO₂H)Cr(CO)₃ is a more stronger acid than C₆H₁₂CO₂H.
   (d) The substitution of Mn(CO)₆Br with CO is higher than that of Mn(CO)₆.
   (e) CO is a stronger Lewis base than H₂O toward Ni²⁺.

6. Which of the following complexes will undergo Jahn-Teller distortion?
   (a) [Fe(CN)₆]⁴⁻  
   (b) [MnCl₆]⁴⁻  
   (c) [CrCl₆]³⁻  
   (d) [Cu(NH₃)₄]²⁺  
   (e) [Co(NH₃)₆]³⁺  

7. What is the ligand field stabilization energy for [Co(NH₃)₆]³⁺?
   (a) 10 Dq  
   (b) 12 Dq  
   (c) 20 Dq  
   (d) 24 Dq  
   (e) 0 Dq

8. Which of the following complexes has the highest C-O stretching frequency?
   (a) [Mn(CO)₆]⁷⁻  
   (b) Cr(CO)₆  
   (c) [V(CO)₆]⁻  
   (d) [Ti(CO)₆]²⁻  
   (e) [Co(CO)₄]⁻  

9. What is the metal-metal bond order for [(CO)₄Cr(μ-PR₃)₂Cr(CO)₄]?
   (a) 0  
   (b) 1  
   (c) 2  
   (d) 3  
   (e) 4

10. How many infrared-active carbonyl stretching bands would you expect for [Mn(CO)₆Cl]?
    (a) 1  
    (b) 2  
    (c) 3  
    (d) 4  
    (e) 5

Part III: Answer the questions (20%)

1. Design a rational synthetic procedure for the following compounds, starting with a neutral homoleptic metal carbonyl complex. You may use any commercially available organic or inorganic reagents. (10%)
   (a) Mn(CH₃)(CO)₅  
   (b) HCo(CO)₃(PMe₃)

2. Which of the following compounds is a good oxidizing agent and which is a good reducing agent: Cp₂Mn, Cp₂Fe and Cp₂Co? Rationalize your choice using molecular orbital theory. (10%)

Appendix

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