CHEMISTRY 204
Hour Exam I
February 20, 2025
Dr. D. DeCoste

Name _____**KEY**_____

Signature _____

T.A. _____

This exam contains 23 questions on 10 numbered pages. Check now to make sure you have a complete exam. You have two hours to complete the exam. Determine the **best** answer to the first 20 questions and enter these on the special answer sheet. Also, **circle your responses** in this exam booklet.

Show all of your work and provide complete answers to questions 21, 22 and 23.

1-20	(60 pts.)	_____
21	(20 pts.)	_____
22	(25 pts)	_____
23	(15 pts.)	_____
Total	(120 pts)	_____

Useful Information:
$N_A = 6.022 \times 10^{23}$

$E = hc/\lambda$

$E = -2.178 \times 10^{-18}\ J\ (Z^2/n^2) = -1312\ kJ/mol\ (Z^2/n^2)$

$c = 2.998 \times 10^8$ m/s

$h = 6.62608 \times 10^{-34}$ Js

$\Delta x \Delta p = h$

$\lambda = h/mv$

$m_e = 9.10939 \times 10^{-31}$ kg

$E_n = \dfrac{n^2h^2}{8mL^2}$

$E = \dfrac{h^2}{8m}\left[\dfrac{n_x^2}{L_x^2} + \dfrac{n_y^2}{L_y^2} + \dfrac{n_z^2}{L_z^2}\right].$

1 pm = 10^{-12} m 1 nm = 10^{-9} m

Table 19.16
Approximate Relationship of Wavelength of Visible Light Absorbed to Color Observed

Absorbed Wavelength in nm (color)	Observed Color
400 (violet)	Greenish yellow
450 (blue)	Yellow
490 (blue-green)	Red
570 (yellow-green)	Violet
580 (yellow)	Dark blue
600 (orange)	Blue
650 (red)	Green

Spectrochemical series: $CN^- > NO_2^- > en > NH_3 > H_2O > OH^- > F^- > Cl^- > Br^- > I^-$
(strong-field) (weak-field)

1. The wavelength range for visible light is 400 to 700 nm. Can visible light be used to ionize a hydrogen atom?

   a) Yes, visible light can always be used to ionize hydrogen no matter which state the hydrogen electron is in initially.
   b) Yes, but only if the electron is initially in its first excited state or higher.
   c) Yes, but only if the electron is initially in its second excited state or higher.
   d) Yes, but only if the electron is initially in its third excited state or higher.
   e) No, visible light cannot be used to ionize hydrogen no matter which state the hydrogen electron is in initially.

2, 3 The fastest tennis serve on record is about 164 miles per hour (73.2 m/s). An average tennis ball has a mass of about 58 g.

2. The most accurate radar guns have a precision of about ±0.5 m/s. Which of the following best represents the uncertainty in position of the fastest served tennis ball?

   a) 10^{-3} m b) 10^{-14} m c) 10^{-23} m d) 10^{-32} m e) 10^{-48} m

3. A tennis court is about 78 feet long (about 24 m). About how many waves does the tennis ball "make" as it is served at 164 mph across the court?

   a) 10^{10} m b) 10^{23} m c) 10^{35} d) 10^{48} e) 10^{51} m

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4. Consider a particle trapped in a one-dimensional box of length as we discussed in the videos and in lecture. Which of the following statements is correct in describing the relationship between the number of regions of maximum probability of the location of the particle and the energy level, n?

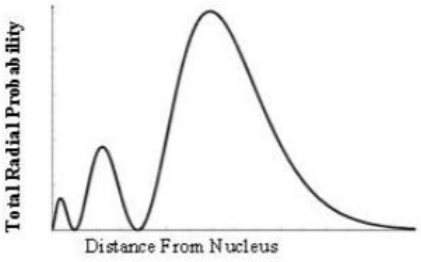
   a) The number of regions of maximum probability is equal to $n-1$.
   b) The number of regions of maximum probability is equal to $n+1$.
   c) The number of regions of maximum probability is equal to $2n-1$.
   d) The number of regions of maximum probability is equal to $2n+1$.
   e) The number of regions of maximum probability is equal to n.

5. Determine the number of electrons that can have the following quantum numbers and choose the correct order from highest to lowest.

   I. $n = 2, l = 1$
   II. $n = 3, l = 2, m_l = 1$
   III. $n = 4, l = 3, m_l = 3, m_s = ½$
   IV. $n = 5, l = 5$

   a) IV > I > II > III
   b) IV > III > II > I
   c) III > II > I > IV
   d) I = IV > II > III
   e) I > II > III > IV

6. Which of the following statements **correctly** describes the diagram below?



a) A plot of the radial probability for the hydrogen 3*s* orbital.
b) A plot of the radial probability for one of the hydrogen 2*p* orbitals.
c) A plot of the total radial probability of all three hydrogen 2*p* orbitals.
d) A plot of the radial probability of one of the hydrogen 3*d* orbitals.
e) A plot of the total radial probability for the first three energy levels of the hydrogen atom.

7. For which of the following does the ground state +1 ion have a **greater number** of unpaired electrons than the ground state neutral atom?

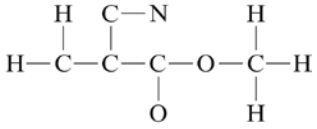
a) B b) C c) N d) O e) None of these.

8. How many of the following sets give the correct order of either ionization energy or atomic radius from largest to smallest?

- Ionization energy: F > O > N
- Ionization energy: S > S^+ > S^{2+}
- Ionization energy: C > B > Be
- Atomic radius: Ca > P > O
- Atomic radius: F^+ > F > F^-

a) 1 b) 2 c) 3 d) 4 e) 5

9. Consider the following incomplete Lewis structure of the molecule methyl cyanoacrylate (the main ingredient in Super Glue):



Determine the hybridization of each of the carbon atoms and the nitrogen atom in methyl cyanoacrylate. How many of the carbon atoms have the **same hybridization** as the nitrogen atom?

a) 0 b) 1 c) 2 d) 3 e) 4

10. Consider the five smallest hydrocarbons (compounds consisting of only carbon and hydrogen) for which the carbon-carbon bonds are all double bonds. That is, the general formula is $H_2CC_xCH_2$, and the five smallest have x = 0, 1, 2, 3, and 4. For how many of these do all four hydrogen atoms lie in the **same plane**?

a) 0 b) 1 c) 2 d) 3 e) 4

11. A molecule or ion with the general formula MX_2 is known to have a linear shape. Which of the following is **not** a possible hybridization for M?

a) sp b) sp^2 c) dsp^3 d) d^2sp^3 e) At least two (a-d) are not possible.

12. The diatomic molecule M_2 has a bond strength of x, while M_2^+ has a bond strength of x+100. The diatomic molecule R_2 has a bond strength of y, while R_2^+ has a bond strength of y–100. Which of the follow statements is correct?

a) M could be fluorine and R could be nitrogen, and x > y.
b) M could be fluorine and R could be nitrogen, and x < y.
c) M could be nitrogen and R could be fluorine, and x > y.
d) M could be nitrogen and R could be fluorine, and x < y.
e) None of these could possibly be correct.

13. Consider the following species of nitrogen and oxygen: N_2, N_2^{2-}, N_2^-, O_2, and O_2^{2+}. Which of the following statements concerning ionization energy values is correct?

a) A nitrogen species and oxygen species have equally low ionization energies.
b) The species with the highest ionization energy and the one with the lowest ionization energy both consist of oxygen.
c) The species with the highest ionization energy and the one with the lowest ionization energy both consist of nitrogen.
d) One of the nitrogen species has the highest ionization energy, and one of the oxygen species has the lowest ionization energy.
e) One of the oxygen species has the highest ionization energy, and one of the nitrogen species has the lowest ionization energy.

14. Which of the following could be the identity of X if the given set, X_2^{2+}, X_2^+, X_2, X_2^-, and X_2^{2-}, is predicted to consist of **exactly four (4)** species with a bond order greater than zero?

a) H b) N c) O d) F e) At least two (a-d).

15. How many of the following statements are **correct**?

- The molecule F_2 is expected to have a have a higher ionization energy than the atom F.
- The molecule C_2 is expected to be paramagnetic (have unpaired electrons).
- Removing or adding an electron has the same effect on bond order for the molecule N_2.
- The bond order of the molecule oxygen monofluoride (OF) is expected to be 1.5.

a) 0 b) 1 c) 2 d) 3 e) 4

16. How many of the following are **incorrect or impossible names** for a coordinate covalent compound?

- potassium hexaammineferrate(III)
- amminepentachlorocobalt(III) chloride
- bis(aqua)cobalt(II) fluoride
- triamminebromoplatinate(II) chloride

a) 0 b) 1 c) 2 d) 3 e) 4

17. What is the total number of geometric and linkage isomers exhibited by $Co(NH_3)_4(NO_2)_2$?

a) 2 b) 4 c) 6 d) 8 e) 10

18. How many of the isomers in problem #17 are optically active?

a) 0 b) 2 c) 4 d) 6 e) 8

19. Given that the complex ion $[PdCl_4]^{2-}$ is known to have no unpaired electrons (that is, it is diamagnetic), what can we say about its structure?

a) The complex ion $[PdCl_4]^{2-}$ is tetrahedral.
b) The complex ion $[PdCl_4]^{2-}$ is square planar.
c) The complex ion $[PdCl_4]^{2-}$ is octahedral.
d) The complex ion $[PdCl_4]^{2-}$ is either tetrahedral or square planar, but not octahedral.
e) We cannot deduce the structure from the magnetism.

20. Given the spectrochemical series on the front of the exam, which of the following statements **correctly** describes the relationship between the complex ions $[FeCl_6]^{4-}$ and $[Fe(H_2O)_6]^{2+}$?

a) If we know that $[FeCl_6]^{4-}$ is diamagnetic, then we can predict that $[Fe(H_2O)_6]^{2+}$ is diamagnetic.
b) If we know that $[FeCl_6]^{4-}$ is diamagnetic, then we can predict that $[Fe(H_2O)_6]^{2+}$ is paramagnetic.
c) If we know that $[FeCl_6]^{4-}$ is paramagnetic, then we can predict that $[Fe(H_2O)_6]^{2+}$ is diamagnetic.
d) If we know that $[FeCl_6]^{4-}$ is paramagnetic, then we can predict that $[Fe(H_2O)_6]^{2+}$ is paramagnetic.
e) Two of the above (a-d) statements are true.

21. Consider a molecule with the general formula $CH_2–(CH)_x–CH_2$, where *x* is an even number (0, 2, 4, 6, etc.) and the average carbon-carbon bond length is 140 pm. Apply the "particle-in-a-box" model to this molecule to answer the following questions. Take some time to **think this through** first – it would be better to do this **systematically** than through trial-and-error!

    a. As ***x* increases**, does the **largest wavelength** of electromagnetic radiation (light) **absorbed** by the molecule **increase or decrease**? **Show all work** and **briefly explain** how you are applying the particle-in-a-box model to support your answer. **[10 points]**

As x increases, change in energy decreases, meaning **absorbed wavelength increases**.

21. b. Is it possible for such a compound with this formula to absorb light in the visible spectrum (400 nm to 700 nm)? If not, explain/support why not. If so, for which values of *x*? **Explain** and **show all work**. **[10 points]**

For values of x = 8 and x = 10, the compound will absorb visible light.

22. The molecular orbital (MO) model is very powerful but can be complicated even for simple molecules like water. As we discussed, this complexity is often due to the shape. In this problem you will consider hydrogen cyanide (HCN). Before we get to the MO model, let's consider the simple valence bond theory (VBT) and the concept of hybridization as applied to HCN.

a. Draw the Lewis structure for HCN. Discuss **in general how VBT describes/explains** the nature of the chemical bonds. Also discuss a limitation in using VBT for HCN. Use atomic orbital diagrams,  , in your explanation. **[6 points]**

b. Now consider **how hybridization describes/explains** the nature of the chemical bonds. **Sketch and label the hybridization** of each atom where it is appropriate. Describe how **hybridization is consistent with the Lewis structure**. Name **one factor** that **hybridization adds** from VBT. **[6 points]**

22. c. You've probably noticed (if not, turn back a page and fix this) that HCN is a linear molecule. As we discussed, MO diagrams for linear molecules can approximated similarly to what we do for diatomics. **Sketch the molecular orbital energy diagram for HCN** (using σ, σ^*, π, π^*, and *nb* and including electrons). **Include sketches of the relative energies** of the valence **atomic orbitals for H, C, and N** given the following data. It is a good idea to plan out your sketches first on scratch paper. **[10 points]**

- Ionization energies (kJ/mol) for H, C, and N are about 1300, 1100, and 1400, respectively.
- The difference in energy between 2s and 2p orbitals (in C and in N) is about 200 kJ/mol.

d. As we have stated, a better model does not necessarily contradict simpler models, but it should explain more. First, explain **one way** in which the **MO model is consistent with hybridization**. Next, we know that the molecule is polar. Explain how your MO diagram supports this observation. **[3 points]**

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23. Consider three different complex ions with the **same first-row transition metal ion** and the **same geometry**. The colors of solutions of these complex ions are different: one is **blue**, one is **yellow**, and one is **green**. We determine that two of these complex ions are diamagnetic and one is paramagnetic. Please address the following (and use the next page, if needed) and use **crystal-field theory energy level diagrams** for support: **[15 points]**

- **Identify** the first-row transition metal ion and **support your answer**. If there is more than one possibility, **support** this.
- **Determine the number of unpaired electrons** in the paramagnetic complex ion. **Support your answer**.
- What is the **color** of the solution with the **paramagnetic** complex ion? **Support your answer**. Please refer to Table 19.16 on the front of the exam.
- **Provide a possible structure** for each of the complex ions (with **ligands**) and **support** your answer.
- Determine the **colors** of the two **diamagnetic** complex ions from your structures. **Support your answers**. Please refer to Table 19.16 and the spectrochemical series on the front of the exam.

Possibilities: **$[Co(NH_3)_6]^{2+}$ (yellow), $[Co(H_2O)_6]^{2+}$ (blue), $[CoF_6]^{4-}$ (green)**

23. Please include any addition work on this page.