

CHEMISTRY 204  
 Hour Exam I  
 February 15, 2024  
 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 (20 pts.) \_\_\_\_\_  
 23 (20 pts.) \_\_\_\_\_  
 Total (120 pts) \_\_\_\_\_

Useful Information:

$N_A = 6.022 \times 10^{23}$

$E = hc/\lambda$

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

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

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

$\Delta x \Delta p = h$

$\lambda = h/mv$

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

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

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

$1 \text{ pm} = 10^{-12} \text{ m}$

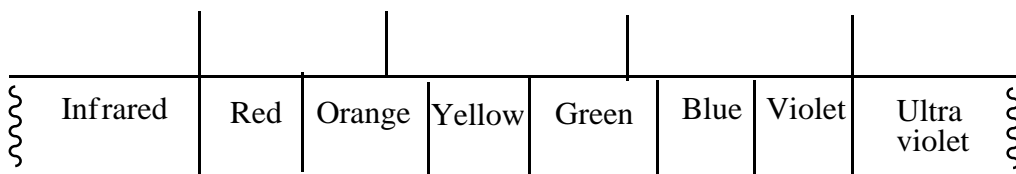
$1 \text{ nm} = 10^{-9} \text{ m}$

wavelength  $7 \times 10^{-7}$        $6 \times 10^{-7}$        $5 \times 10^{-7}$        $4 \times 10^{-7}$  meters

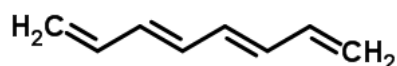
**Table 19.16**

**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

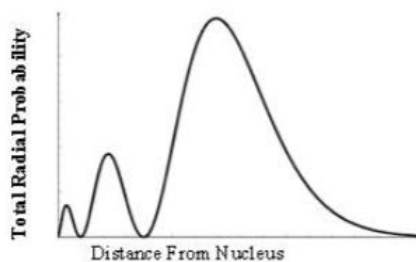


- What color of visible light is emitted when an excited electron in a hydrogen atom drops from  $n = 5$  to  $n = 2$ ?  
a) It is not visible.    b) Red    c) Orange    d) Yellow    **e) Blue**
- The ionization energy of a one-electron species is  $7.84 \times 10^{-17}$  J. Identify the element that forms this ion.  
a) Boron    **b) Carbon**    c) Oxygen    d) Fluorine    e) Chlorine
- For which of the following energy levels is the probability of finding a particle in a one-dimensional box of length  $L$  the greatest between  $x = 0$  and  $x = L/2$ ?  
a)  $n = 1$     b)  $n = 2$     c)  $n = 3$     **d) The probability is the same for these (a-c).**
- Consider electrons in an atom in the first three energy levels. How many of these electrons can have the magnetic quantum number,  $m_l$ , equal to  $-1$ ?  
a) 2    b) 4    **c) 6**    d) 10    e) 12
- Consider the **expected** ground state electron configurations for the atoms of the transition metals scandium (Sc), cobalt (Co), nickel (Ni) and zinc (Zn) and determine the **total number** of unpaired electrons.  
a) 0    b) 2    c) 4    **d) 6**    e) 9
- Recall the one-dimensional “particle-in-a-box” model we discussed and how we can use the appropriate electrons in a conjugated single-double bond system as an approximation of this model. Consider the following molecule as represented below:



Which of the following represents the energy difference between the ground state and first excited state?

- a)  $\left(\frac{h^2}{8mL^2}\right)$     b)  $7\left(\frac{h^2}{8mL^2}\right)$     **c)  $9\left(\frac{h^2}{8mL^2}\right)$**     d)  $15\left(\frac{h^2}{8mL^2}\right)$     e)  $17\left(\frac{h^2}{8mL^2}\right)$
- Consider all possible orbitals in the first four energy levels of the hydrogen atom ( $n = 1, 2, 3,$  and  $4$ ). How many of them have the following shape for their radial probability distribution?

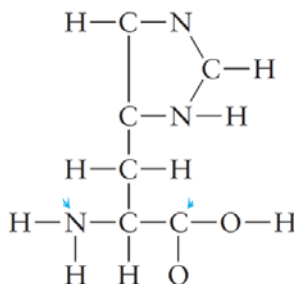


- a) 4**    b) 8    c) 12    d) 17    e) 18

8. Determine the hybridization of sulfur for each of the following. Cross out the species for which the hybridization of sulfur is unique (that is, which none of the other given molecules or ions share). How many have you **not** crossed out?

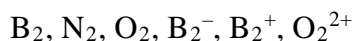


- a) 0                       b) 2                      c) 3                      d) 4                      e) 5
9. All you know about a given molecule is the shape around the central atom. For which of the following shapes could the central atom have the most possible hybridizations?
- a) trigonal pyramid  
b) see-saw  
 c) bent  
d) square planar  
e) The number of possible hybridizations for the central atom is equally great in at least two of the above (a-d).
10. The following is a skeletal structure of the amino acid histidine. Complete the Lewis structure such that **all atoms have a formal charge of zero** and answer the following question.



Of carbon, hydrogen, nitrogen, and oxygen, how many of them have more atoms that are  $sp^2$  hybridized than  $sp^3$  hybridized?

- a) 0                       b) 1                      c) 2                      d) 3                      e) 4
11. According to MO theory, for how many of the following is bond strength expected to **increase** (that is, a **stronger bond** is formed) when changing the number of electrons as shown below?



	Adding an electron	Removing an electron
a)	Three (3)	One (1)
b)	Three (3)	Three (3)
c)	Three (3)	Two (2)
d)	One (1)	Three (3)
e)	Two (2)	Three (3)

12. According to MO theory, which of the following is expected to have the **longest** bond length?
- a)  $\text{N}_2^-$                       b)  $\text{O}_2^+$                       c)  $\text{O}_2^-$                       d)  $\text{F}_2^+$                        e)  $\text{F}_2^-$
13. You are told that the ionization energy for a diatomic molecule is less than the ionization energy for the individual atom that makes it up (that is, the ionization energy for  $\text{X}_2$  is less than the ionization energy for X). Considering boron, carbon, nitrogen, oxygen, and fluorine, for how many is this true?
- a) 1                       b) 2                      c) 3                      d) 4                      e) 5
14. A cyanide contains carbon and nitrogen bonded to each other (CN). For inorganic compounds, the cyanide group is a cyanide anion,  $\text{CN}^-$ . Consider the Lewis structure and MO energy diagram for the cyanide ion.
- a) The bond order from the MO diagram is the same as the number of bonds in the Lewis structure, and MO theory predicts the ion is diamagnetic.
- b) The bond order from the MO diagram is the same as the number of bonds in the Lewis structure, and MO theory predicts the ion is paramagnetic.
- c) The bond order from the MO diagram is the different from the number of bonds in the Lewis structure, and MO theory predicts the ion is diamagnetic.
- d) The bond order from the MO diagram is the different from the number of bonds in the Lewis structure, and MO theory predicts the ion is paramagnetic.
- e) We cannot draw a Lewis structure for the cyanide ion.
15. How many of the following are **correct names** for a coordinate covalent compound?
- potassium hexacyanoferrate(III)
  - pentaamminechlorocobalt(III) chloride
  - hexachlorocobalt(II) fluoride
  - triamminebromoplatinum(II) chloride
- a) 0                      b) 1                      c) 2                       d) 3                      e) 4
16. The electron configuration of ground state  $\text{Ti}^{2+}$  is
- a)  $[\text{Ar}] 4s^2 3d^2$
- b)  $[\text{Ar}] 4s^2$
- c)  $[\text{Ar}] 4d^2$
- d)  $[\text{Ar}] 4s^1 3d^1$
- e)  $[\text{Ar}] 3d^2$
17. Consider all possible isomers of the following three species:  $[\text{Co}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$ ,  $[\text{Pt}(\text{NH}_3)_2\text{Br}_2(\text{H}_2\text{O})_2]^{2+}$ , and  $[\text{Co}(\text{en})_2\text{Cl}_2]$ , where en = ethylenediamine =  $\text{NH}_2\text{CH}_2\text{CH}_2\text{NH}_2$ . How many **optically active** isomers are there?
- a) 0                      b) 2                      c) 3                       d) 4                      e) 6



21. Full credit will be reserved for complete answers.

- a. Consider a 3-D cube of length  $L$ . What is the **minimum** number of ground state quantum particles (uncharged – not electrons – all with the same mass,  $m$ ) needed to require the **longest possible wavelength** of light to excite a particle to the **first excited state** in such a box? **Justify** your answer. **Draw and explain** the energy level diagram as **part of your explanation**. [10 pts.]
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**Minimum = 8**

**See lectures, videos, and textbook.**

21. b. Here is a snippet of dialogue from the hilarious joke I told in lecture that began “Heisenberg and Schrödinger are going for a drive and are stopped for speeding”:

Police officer: Do you know how fast you were going?

Heisenberg: No.

Police officer: You were going 85 miles per hour.

Heisenberg: Great – now we’re lost.

The best way to make a funny joke even funnier is to explain it, and that’s what you are to do in this problem. **[10 pts.]**

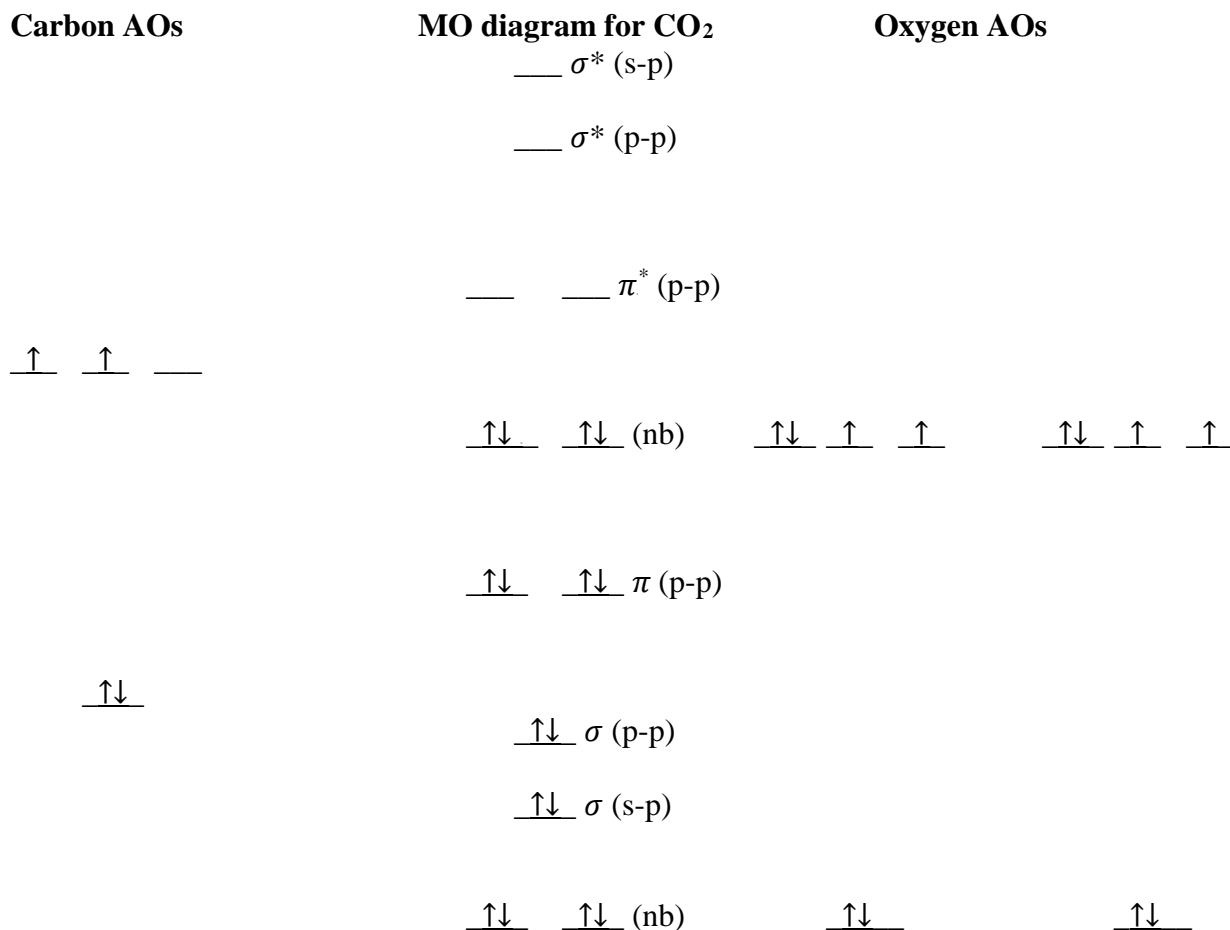
- i. Explain why Heisenberg said that they were lost. What does he mean by “lost” and what prompted him to say this? **Explain.**
  - ii. It is often humorous when we say things that are exaggerations. Use reasonable estimations to provide **quantitative support** that the two were not actually lost. Conversions that may be of use: there are about 1600 meters in a mile, 3600 seconds in an hour, about two pounds to a kilogram on earth, and an average atomic radius is about 100 pm. **Show and explain** all work.
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**See lectures, videos, and textbook.**

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, and MO diagrams for linear molecules can be approximated similarly to what we do for diatomics. In this problem you will consider carbon dioxide (CO<sub>2</sub>). [20 pts.]

The unlabeled MO diagram for carbon dioxide is shown below. Note that the 2s orbitals for the oxygen atoms have been included, and that these **do not participate** in bonding (they are nonbonding orbitals). **Draw and label the remainder of the atomic orbitals (AOs)** for the carbon atom to the left of the MO diagram, and those for the oxygen atoms to the right of the MO diagram, making sure to pay attention to their **relative energy levels**. Use **dotted lines to show** which AOs **overlap** to form the MOs. Fill in the **proper number of electrons** and **label the MO diagram** (using  $\sigma$ ,  $\sigma^*$ ,  $\pi$ ,  $\pi^*$ , and *nb* for “nonbonding”, if appropriate). It is a good idea to take some time determining these on scratch paper before completing the MO diagram below.

**On the following page, justify** your completion of the diagram, explaining/showing the appropriate AO overlap and **providing support** for any MOs you label as nonbonding. Finally, draw a Lewis structure for the carbon dioxide molecule and **explain** how the MO diagram is **consistent** with this Lewis structure.



[Please write your discussion of the MO diagram on the next page]



22. b. Please discuss your answer below. **Justify** your completion of the MO diagram on the previous page, explain/show the appropriate AO overlap, and **provide support** for any MOs you label as nonbonding. Finally, draw a Lewis structure for the carbon dioxide molecule and **explain** how the MO diagram is **consistent** with this Lewis structure.
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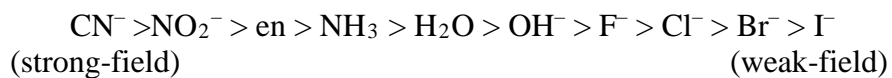
**See lectures, videos, and textbook.**

23. In this problem you will be considering coordinate covalent complex ions.
- a. We developed the crystal field theory (CFT) from the MO diagrams of octahedral transition metal complexes. These MOs can be drawn because of the symmetry of the ions (as discussed in class and in question #22 on this exam). Sketch the MO diagram for a general octahedral complex ion  $[ML_6]^{n+}$ . Include the **relative energies** of the free metal ion orbitals and those of the ligands, and use **dotted lines to show** which AOs **overlap** to form the MOs. **Label the MO diagram** (using  $\sigma$ ,  $\sigma^*$ ,  $\pi$ ,  $\pi^*$ , and *nb* for “nonbonding”, if appropriate). Finally, **explain why** we are able to simplify this diagram to the type of diagram we use in Crystal Field Theory. **Justify** your answer. **[10 pts.]**
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See lectures, videos, and textbook.

23. b. Consider the following cobalt complexes:  $[\text{Co}(\text{NH}_3)_6]^{3+}$ ,  $[\text{CoF}_6]^{3-}$ ,  $[\text{Co}(\text{H}_2\text{O})_6]^{3+}$ , and  $[\text{Co}(\text{CN})_6]^{3-}$ . The colors of the four complex ions are (in no particular order): green, blue, yellow, and green-yellow. **Match these colors** with the complex ions, **fill in** the colors in the table below, and **justify** your answer. A **complete** answer will **discuss** the **origin of the color** of an aqueous solution. [10 pts.]

The spectrochemical series is as follows:



Complex Ion	Color
$[\text{Co}(\text{NH}_3)_6]^{3+}$	<b>yellow</b>
$[\text{CoF}_6]^{3-}$	<b>green</b>
$[\text{Co}(\text{H}_2\text{O})_6]^{3+}$	<b>blue</b>
$[\text{Co}(\text{CN})_6]^{3-}$	<b>green-yellow</b>

See lectures, videos, and textbook.