

**Chemistry 121**  
**The University of British Columbia**  
**Final Examination 1**  
**SAMPLE FINAL**  
Time: **150 minutes**

Print the first letter of your family/last name in this box.

Family/Last Name: \_\_\_\_\_  
(printed)

First Name: \_\_\_\_\_

Signature: \_\_\_\_\_  
(in ink)

Student Number: \_\_\_\_\_

Please check  $\checkmark$  your lecture section:

___ 101 (MWF 1:00 PM)	Krems
___ 102 (MWF 2:00 PM)	Orvig
___ 103 (MWF 3:00 PM)	Orvig
___ 110 (MWF 10:00 AM)	Lindenberg
___ 111 (MWF 11:00 AM)	McIntosh
___ 122 (T,Th 2:00 PM)	Hudson
___ 133 (T,Th 3:30 PM)	Terpstra
___ 188 (T,Th 8:00 AM)	Legzdins
___ 199 (T,Th 9:30 AM)	Therrien
___ V02 (MWF 1:00 PM)	Lekhi

### INSTRUCTIONS

1. Check that this examination booklet consists of **18 PAGES PRINTED ON BOTH SIDES.**
2. Supplementary Information and the Periodic Table will be provided separately.
3. Write all answers on this examination paper.
4. The only calculators allowed are the Sharp EL-510 series. All other calculators will be confiscated.
5. Cell phones or other electronic communication devices are not permitted on the examination desks and must be powered off.
6. Unassembled molecular model kits may be used.

### RULES GOVERNING FORMAL EXAMINATIONS

1. Each examination candidate must be prepared to produce his or her UBCcard for identification.
2. Examination candidates are not permitted to ask questions of the examiners or invigilators, except in cases of supposed errors or ambiguities in examination questions, illegible or missing material, or the like.
3. No examination candidate shall be permitted to enter the examination room after the expiration of one-half hour from the scheduled starting time, or to leave during the first half hour of the examination.
4. Examination candidates must conduct themselves honestly and in accordance with established rules for a given examination, which will be articulated by the examiner or invigilator prior to the examination commencing. Should dishonest behavior be observed by the examiner(s) or invigilator(s), pleas of accident or forgetfulness shall not be received.
5. Examination candidates suspected of any of the following, or any other similar practices, may be immediately dismissed from the examination by the examiner/invigilator, and may be subject to disciplinary action:
  - i. speaking or communicating with other examination candidates, unless otherwise authorized;
  - ii. Purposely exposing written papers to the view of other examination candidates or imaging devices;
  - iii. Purposely viewing the written papers of other examination candidates;
  - iv. Using or having visible at the place of writing any books, papers or other memory aid devices other than those authorized by the examiner(s);
  - v. using or operating electronic devices including but not limited to telephones, calculators, computers, or similar devices other than those authorized by the examiner(s)—(electronic devices other than those authorized by the examiner(s) must be completely powered down if present at the place of writing).
6. Examination candidates must not destroy or damage any examination material, must hand in all examination papers, and must not take any examination material from the examination room without permission of the examiner or invigilator.
7. Notwithstanding the above, for any mode of examination that does not fall into the traditional, paper-based method, examination candidates shall adhere to any special rules for conduct as established and articulated by the examiner.
8. Examination candidates must follow any additional examination rules or directions communicated by the examiner(s) or invigilator(s).

	Page	Questions	Maximum	Marks Obtained	Initials
Part I	3	1 - 5	10		
	4	6 -10	10		
	5	11 -15	10		
	6	16 - 20	10		
	7	21 -25	10		
Part II	8	1	12		
	9	2, 3	12		
	10	4, 5	10		
	11	6	6		
	12	7	6		
	13	8 a-d	8		
	14	8 e-f	5		
	15	9, 10	10		
	16	11	10		
	17	12	10		
	18	13	8		
	<b>Total</b>		<b>147</b>		



6. Which of the following ionic compounds is predicted to have the *largest* lattice energy?

- A. NaF
- B. SrS
- C. NaCl
- D. BeO
- E. KBr

Answer:

7. Which of the following is *least soluble* in water at room temperature and pressure?

- A. CH<sub>3</sub>CH<sub>2</sub>CH<sub>3</sub>
- B. CH<sub>3</sub>OCH<sub>3</sub>
- C. CH<sub>3</sub>CH<sub>2</sub>OH
- D. CH<sub>3</sub>CO<sub>2</sub>H
- E. NaCl

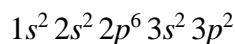
Answer:

8. Which of the following electronic configurations does *not* correspond to an atom in its ground state?

- A. [Ar] 4s<sup>2</sup> 3d<sup>2</sup>
- B. [Ar] 4s<sup>1</sup> 3d<sup>6</sup>
- C. [Ar] 4s<sup>2</sup> 3d<sup>10</sup> 4p<sup>1</sup>
- D. [Ar] 4s<sup>1</sup> 3d<sup>10</sup>
- E. None of the above.

Answer:

9. Select the species that has the following electronic configuration:



- A. Al<sup>+</sup>
- B. N<sup>+</sup>
- C. C
- D. Si<sup>-</sup>
- E. P<sup>+</sup>

Answer:

10. Which of the following statements is **TRUE**?

- A. The kinetic energy of the electron in a ground state hydrogen atom is zero.
- B. Planck's constant can be determined from the kinetic energies of electrons ejected in a photoelectric effect experiment.
- C. An atom emits light when one or more of its electrons transition from a state of lower energy to a state of higher energy.
- D. The Pauli exclusion principle states that only two electrons in an atom can have the same four quantum numbers.
- E. In the hydrogen atom, the 2p orbital has a higher energy than the 2s orbital.

Answer:

11. Which of the following statements is **FALSE**?

- A. Forming interchain bonds increases the melting point of a polymer.
- B. Step-growth polymerization often involves the elimination of small molecules.
- C. Step-growth polymerization leads to a mixture of high molecular weight polymers, plus monomers.
- D. The first step of chain-growth polymerization is called *initiation*.
- E. The same monomers can be used to form a variety of polymers with vastly different physical properties.

**Answer:**

12. Which molecule has a central atom with  $sp^3d$  hybridization and no dipole moment?

- A.  $PCl_3$
- B.  $BF_3$
- C.  $BrF_3$
- D.  $SF_4$
- E.  $PCl_5$

**Answer:**

13. Arrange the following species in order of *increasing* oxygen-oxygen bond length.

- A.  $O_2^{2-} < O_2^- < O_2 < O_2^+ < O_2^{2+}$
- B.  $O_2^{2+} < O_2^+ < O_2 < O_2^- < O_2^{2-}$
- C.  $O_2^{2+} < O_2^+ < O_2^- < O_2^{2-} < O_2$
- D.  $O_2^{2+} < O_2^- < O_2 < O_2^+ < O_2^{2-}$
- E.  $O_2^{2-} < O_2^{2+} < O_2^- < O_2^+ < O_2$

**Answer:**

14. Which of the following orbitals can overlap to form a  $\sigma$  bond?

- A.  $2p_x$  and  $2p_z$
- B.  $3d_{x^2-y^2}$  and  $2p_y$
- C.  $3d_{xy}$  and  $2p_z$
- D.  $3d_{xy}$  and  $2d_{xy}$
- E.  $3d_{xz}$  and  $2p_z$

**Answer:**

15. Titanium releases electrons with a kinetic energy of  $4.7 \times 10^{-18}$  J when irradiated by light with a wavelength of 20 nm. What is the binding energy of titanium?

- A.  $4.7 \times 10^{-18}$  J
- B.  $5.2 \times 10^{-18}$  J
- C.  $6.4 \times 10^{-18}$  J
- D.  $8.4 \times 10^{-18}$  J
- E.  $9.9 \times 10^{-18}$  J

**Answer:**

16. Consider the ions sulfate  $[\text{SO}_4]^{2-}$ , sulfite  $[\text{SO}_3]^{2-}$  and hyposulfite  $[\text{SO}_2]^{2-}$ . Which of the following statements is **TRUE**?

- A. All three have tetrahedral molecular shape.
- B. All three have two double bonds in their best Lewis structure.
- C. All three have the same oxidation state for sulfur.
- D. All three have  $sp^3$  hybridized sulfur atoms.
- E. None of the above.

Answer:

17. Which of the following electron configurations is an *excited state* for a neutral copper atom?

- A.  $[\text{Ar}] 4s^1 3d^{10}$
- B.  $[\text{Ar}] 4s^0 3d^{10}$
- C.  $[\text{Ar}] 4s^2 3d^{10}$
- D.  $[\text{Ar}] 4s^2 3d^9$
- E.  $[\text{Ar}] 4s^2 3d^9 4p^1$

Answer:

18. The visible spectrum corresponds to light with wavelengths ranging from approximately 400 nm (blue) to 750 nm (red). In a dark room, a quantum dot that is excited with ultraviolet light and fluoresces (emits) 730 nm light will be seen as:

- A. blue
- B. green
- C. yellow
- D. red
- E. black

Answer:

19. Which of the following ions has the largest (i.e., most negative) electron affinity?

- A.  $\text{Na}^+$
- B.  $\text{Cl}^+$
- C.  $\text{Cl}^-$
- D.  $\text{Br}^+$
- E.  $\text{Br}^-$

Answer:

20. The  $d_{xz}$  orbital of a particular shell has 2 radial nodes. How many *radial nodes* does the  $s$  orbital of the same shell have?

- A. 0
- B. 1
- C. 2
- D. 3
- E. 4

Answer:

21. For the molecular ion  $[B_2]^-$ , the bond order, HOMO, and LUMO are:

- A. (BO, HOMO, LUMO) = (1.5,  $\sigma_{2p}$ ,  $\sigma_{2p}^*$ )
- B. (BO, HOMO, LUMO) = (1.5,  $\sigma_{2p}$ ,  $\pi_{2p}$ )
- C. (BO, HOMO, LUMO) = (2.5,  $\pi_{2p}$ ,  $\sigma_{2p}$ )
- D. (BO, HOMO, LUMO) = (2.5,  $\sigma_{2p}$ ,  $\pi_{2p}^*$ )
- E. None of the above

Answer:

22. Consider the molecule allene ( $H_2C=C=CH_2$ ). Which of the following statements is **FALSE**?

- A. There is exactly one unhybridized  $2p$  orbital on each C atom of allene.
- B. Allene has two  $sp^2$  hybrid carbon atoms.
- C. Allene is twisted.
- D. Allene has two  $\sigma_{(sp-sp^2)}$  bonds.
- E. There are two  $\pi$  bonds in allene.

Answer:

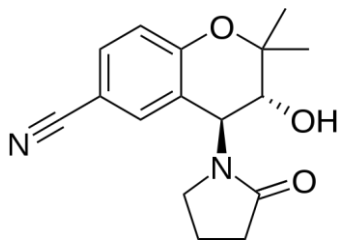
23. The boiling point of  $H_2O$  ( $100\text{ }^\circ\text{C}$ ) is greater than that of  $NH_3$  ( $-33.3\text{ }^\circ\text{C}$ ) and  $HF$  ( $19.5\text{ }^\circ\text{C}$ ) because:

- A.  $H_2O$  has a larger permanent dipole moment than  $NH_3$  and  $HF$ .
- B.  $H_2O$  is paramagnetic.
- C. In contrast to  $NH_3$  and  $HF$ ,  $H_2O$  molecules can both donate two and accept two hydrogen bonds.
- D.  $H_2O$  is a stronger acid than  $NH_3$  and  $HF$ .
- E.  $H_2O$  exhibits greater London dispersion forces than  $NH_3$  and  $HF$ .

Answer:

24. How many  $sp^2$  hybridized carbon atoms are present in cromakalim (a vasodilator)?

- A. 1
- B. 6
- C. 7
- D. 8
- E. 16



Answer:

25. A laser emits one wavelength of light that is tuned to excite a hydrogen-like (one electron) ion from the ground state to the  $n = 2$  state. Which one of the following statements is **TRUE**?

- A. If a laser with longer wavelength is used, more of the ions will be excited from the ground state to  $n = 2$ .
- B. If a laser with a higher intensity is used, the ions will be excited from  $n = 1$  to  $n = 3$  and higher values of  $n$ .
- C. If the wavelength of light emitted from the laser is doubled, the ions will be completely ionized.
- D. If a laser with lower frequency is used, none of the ground state ions will absorb the laser light.
- E. If the wavelength of light emitted from the laser is halved, the ions will be excited from the  $n = 1$  to  $n = 3$  state.

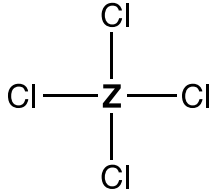
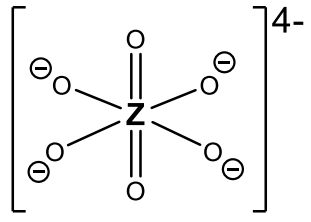
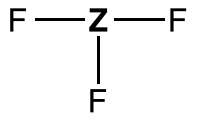
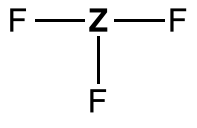
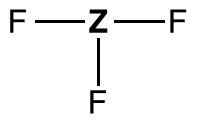
Answer:

## Part II. Short Answer Questions

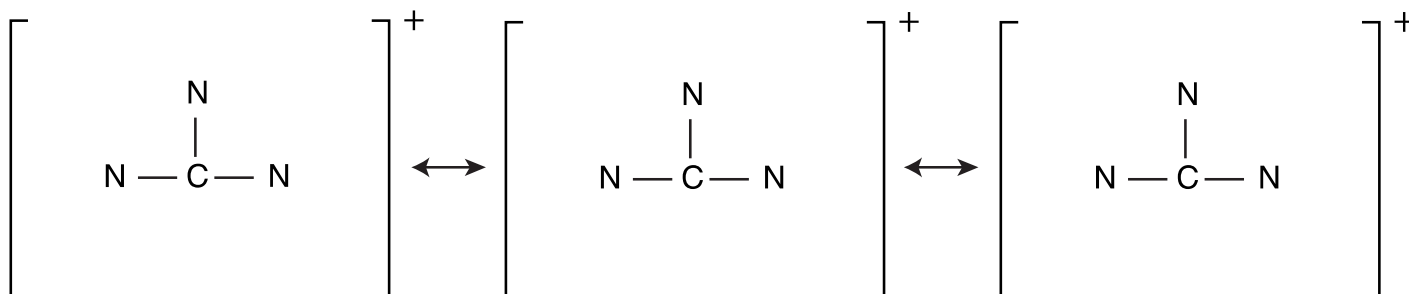
1. [12 marks] Skeletal Lewis structures, where **Z** represents a *p*-block element, are given below. All non-zero formal charges are shown, but lone pairs are *not* shown.

Complete the following table by indicating the following. The first row is filled in as an example.

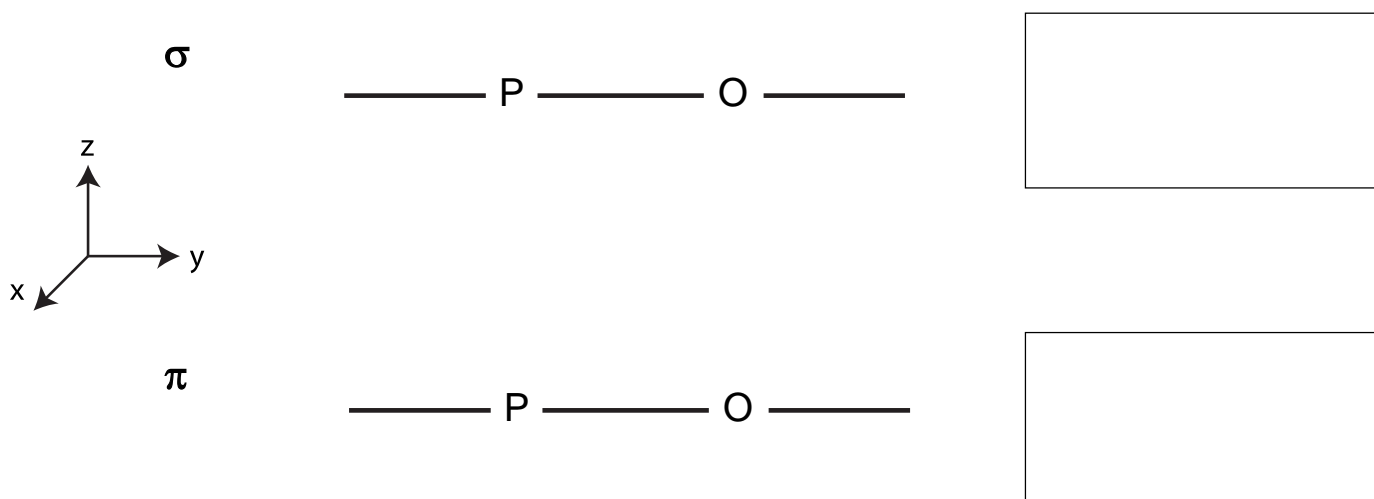
- (a) One possible identity of **Z**.  
 (b) The hybridization of **Z**.  
 (c) Whether the compound is polar or non-polar.  
 (d) The molecular shape.

Lewis structure	Possible identity of <b>Z</b>	Hybridization of <b>Z</b>	Polar? Yes or No	Molecular shape
	Si	$sp^3$	No	tetrahedral
			Not required	
		$sp^3d$		
		$sp^3$		
			No	

2. [6 marks] The guanidinium cation,  $\text{CN}_3\text{H}_6^+$ , is planar. On the templates below, complete three valid Lewis structures for guanidinium by **adding hydrogens**, showing any additional *bonds as lines*, and showing all lone pairs of electrons as *pairs of dots*. Write any non-zero *formal charges* on the appropriate atoms.



3. [6 marks] (a) Using valence bond theory, draw the *orbital overlap diagrams* on the axes below for the  $\sigma$  and  $\pi$  bonds that form the P=O *double bond* in  $\text{POCl}_3$  (P is the central atom). Use (+) and (-) to indicate relative phases for the  $\pi$  bond. In the boxes to the right, *name the bonds* (e.g.,  $\sigma_{(1s-sp)}$ ).

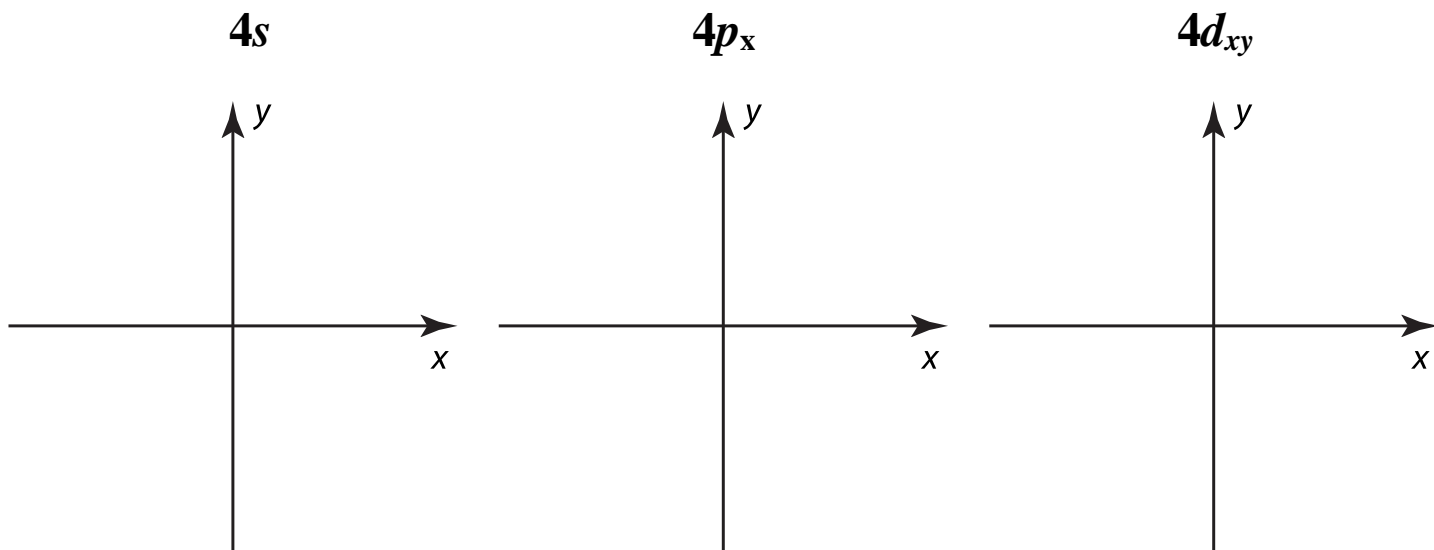


- (b) Using the axis system shown above, which *specific orbitals* on the P and O atoms form the  $\pi$  bond?

P orbital:

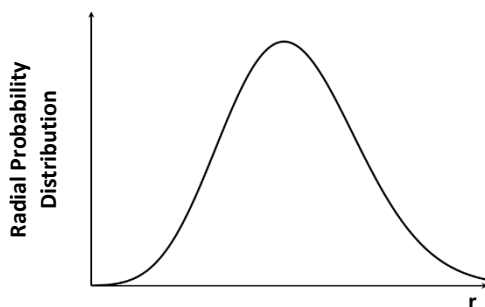
O orbital:

4. [6 marks] Draw cross-sections for the following atomic orbitals on the axis systems given below. Show relative phases as (+) and (-).



5. [4 marks] The sketches below show the radial probability distributions for two different atomic orbitals. **CIRCLE** which orbital is being represented by the radial probability distribution.

Orbital **A**

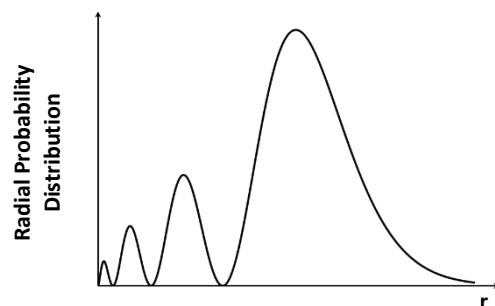


**CIRCLE:**

**3p<sub>y</sub>**      **5f<sub>xyz</sub>**      **2s**

**3d<sub>x<sup>2</sup>-y<sup>2</sup></sub>**      **4p<sub>y</sub>**

Orbital **B**

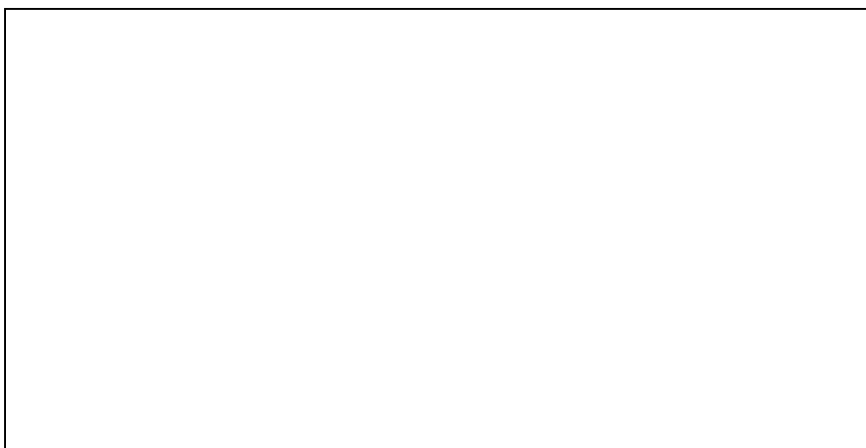
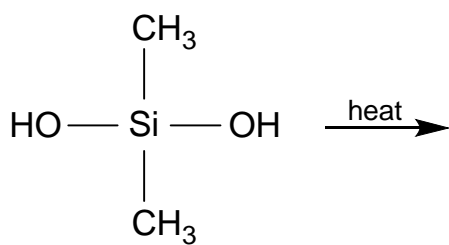
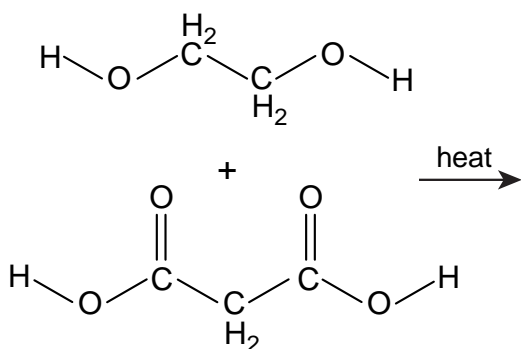
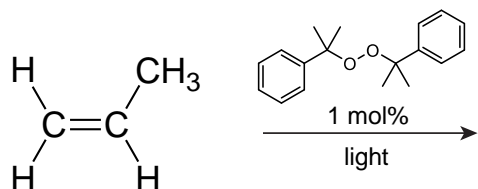


**CIRCLE:**

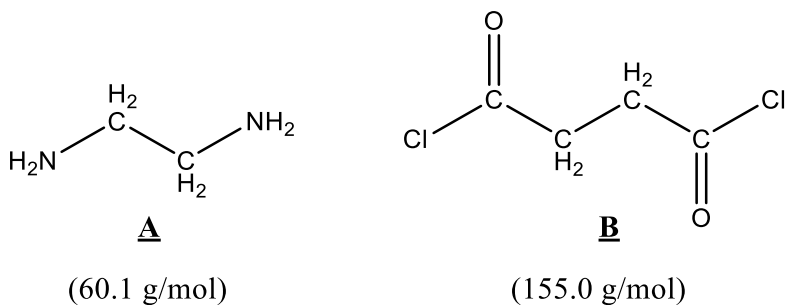
**3d<sub>xy</sub>**      **4d<sub>z<sup>2</sup></sub>**      **3p<sub>z</sub>**

**4f<sub>x<sup>2</sup>y</sub>**      **4s**

6. [6 marks] Below are 3 reactions to form polymers. In each case, draw the structure of the polymer that is expected to form (one repeat unit is sufficient). You may draw a Lewis structure or line-bond representation. You do not need to show end groups or other products.



7. [6 marks] In a condensation polymerization between two different monomers, the average molecular weight of the product depends on the ratio of the monomers used. This question illustrates the effect of using different ratios of ethylenediamine (**A**) and 1,4-butanoyl chloride (**B**):



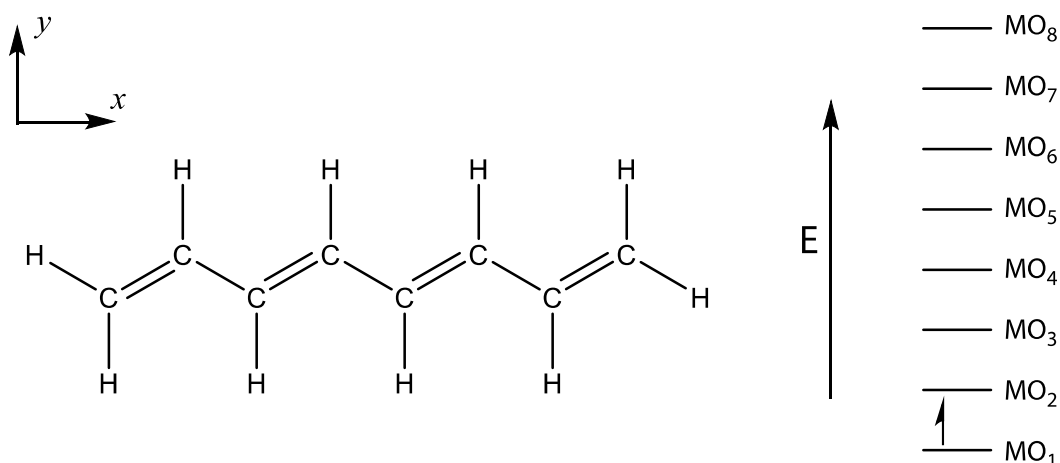
(a) The reaction of **A** (2 mol) with **B** (1 mol) gives a compound with molecular weight 202.3 g/mol as the major product. Draw the Lewis structure or line-bond representation of this product.

(b) The reaction of **A** (1 mol) with **B** (2 mol) gives a compound with molecular weight 297.1 g/mol as the major product. Draw the Lewis structure or line-bond representation of this product.

(c) What mass of **B** (in grams) should be combined with 400 g of pure **A** in order to obtain a high molecular weight polymer?

**Answer:**

8. [8 marks] (a) The structure of 1,3,5,7-octatetraene is shown below, drawn in the  $xy$ -plane. There are 8 molecular orbitals that arise from mixing the  $2p_z$  orbitals. Complete the MO diagram on the right for the ground state of 1,3,5,7-octatetraene by adding electrons, as needed, to  $MO_1 - MO_8$ . The first electron is added as an example.



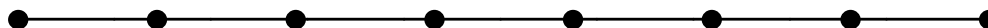
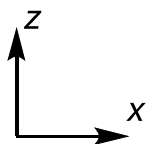
- (b) Which molecular orbital is the **LUMO** of 1,3,5,7-octatetraene?

**LUMO:**

- (c) How many *nodes* does molecular orbital **MO<sub>7</sub>** have (ignore any nodes in the  $xy$ -plane)?

**Answer:**

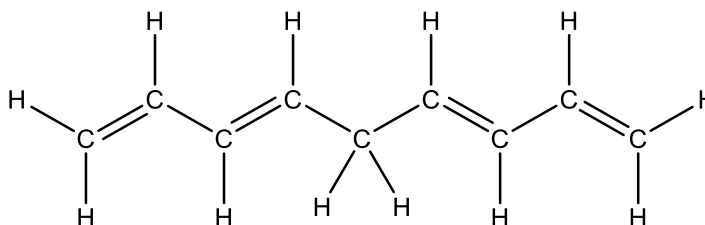
- (d) On the template below, draw the *highest energy* MO. Indicate phases (+) and (-) in your drawing. The dots represent the carbon nuclei of 1,3,5,7-octatetraene.



**[5 marks]** (e) 1,3,5,7-Octatetraene absorbs light with a wavelength of 304 nm, which corresponds to the HOMO to LUMO transition. Using the particle-in-a-box model, estimate the *length* of conjugated 1,3,5,7-octatetraene (in Å).

**Answer:**

(f) Consider the molecule 1,3,6,8-nonatetraene, whose structure is shown below.



What wavelength of light would you predict 1,3,6,8-nonatetraene to absorb in order to excite electrons from its HOMO to LUMO?

- A. Wavelength less than 304 nm
- B. Wavelength equal to 304 nm
- C. Wavelength greater than 304 nm

**Answer:**

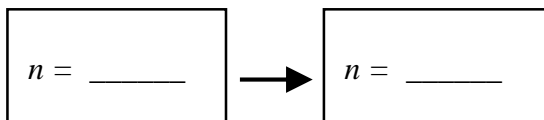
9. [4 marks] Calculate the de Broglie wavelength (in nm) of a fluorine atom with a velocity of  $5.60 \times 10^3$  m/s.

Answer:

10. [6 marks] (a)  $\text{He}^+$  ions are excited to the  $n = 4$  state. These ions decay to lower energy states by one or more transitions, emitting light in the process. How many emission bands will be observed?

Answer:

- (b) Identify from part (a) the transition that will produce the **second most** energetic photons.



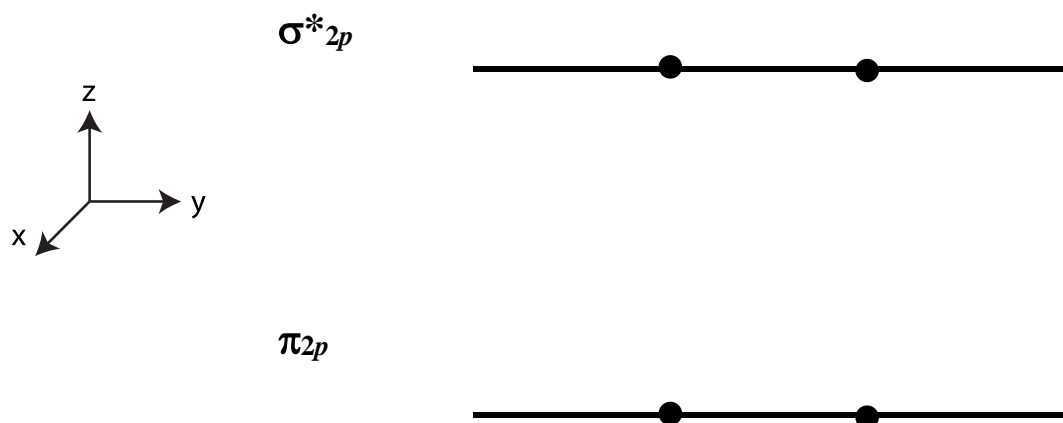
- (c) Calculate the *electron affinity* (in kJ/mol) of  $\text{He}^{2+}$  ions in the ground state.

Answer:

11. [10 marks] (a) Write the molecular orbital electronic configuration for  $[\text{F}_2]^{2+}$ .

Answer:

(b) Assuming that the  $[\text{F}_2]^{2+}$  nuclei (represented by dots) lie along the  $y$ -axis, sketch a *cross-section* of the  $\sigma^*_{2p}$  molecular orbital on the templates below. Also, sketch a cross-section of the  $\pi_{2p}$  molecular orbital that results from the overlap of two  $2p_z$  orbitals. Show relative orbital phases as (+) and (-).



(c) Which of the following statements is **TRUE** regarding the *ground state* of  $[\text{F}_2]^{2+}$  ?

- A. Bond order = 1, diamagnetic
- B. Bond order = 1.5, diamagnetic
- C. Bond order = 1.5, paramagnetic
- D. Bond order = 2, diamagnetic
- E. Bond order = 2, paramagnetic

Answer:

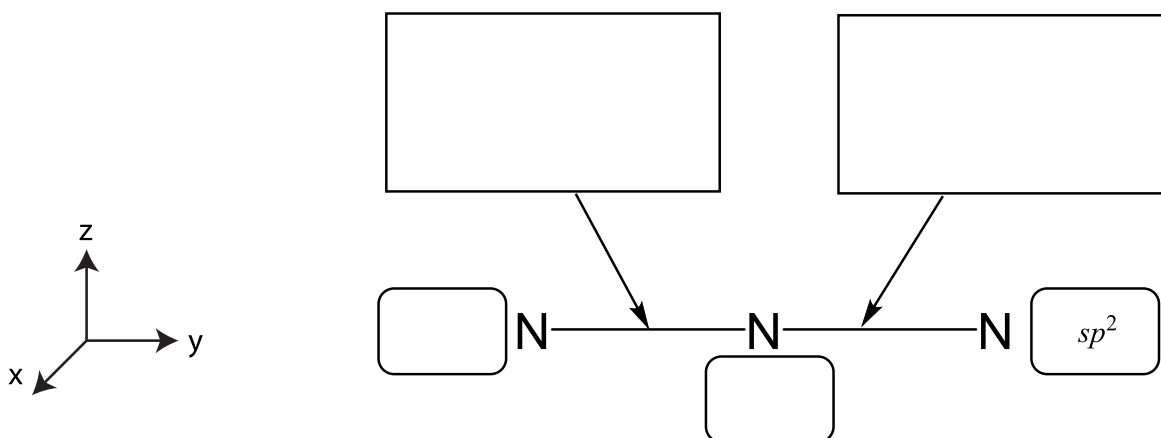
(d) What is the bond order of  $[\text{F}_2]^{2+}$  in its *first excited state*?

Answer:

12. [10 marks] Valence bond theory may be used to describe the bonding in azide,  $[\text{N}_3]^-$ .

(a) Draw the best Lewis structure for azide. Write any non-zero *formal charges* on the appropriate atoms, show all *bonds* as lines, and show all lone pairs of electrons as *pairs of dots*.

(b) Based on the best Lewis structure for azide, label the *hybridization* of the central and terminal nitrogen atoms in the rounded boxes below. The hybridization of one terminal nitrogen is shown. *Describe* the bonding in azide (e.g.,  $\sigma_{(1s-sp^3)}$ ) in the square boxes provided on the skeletal structure. Assume the nuclei lie along the y-axis.

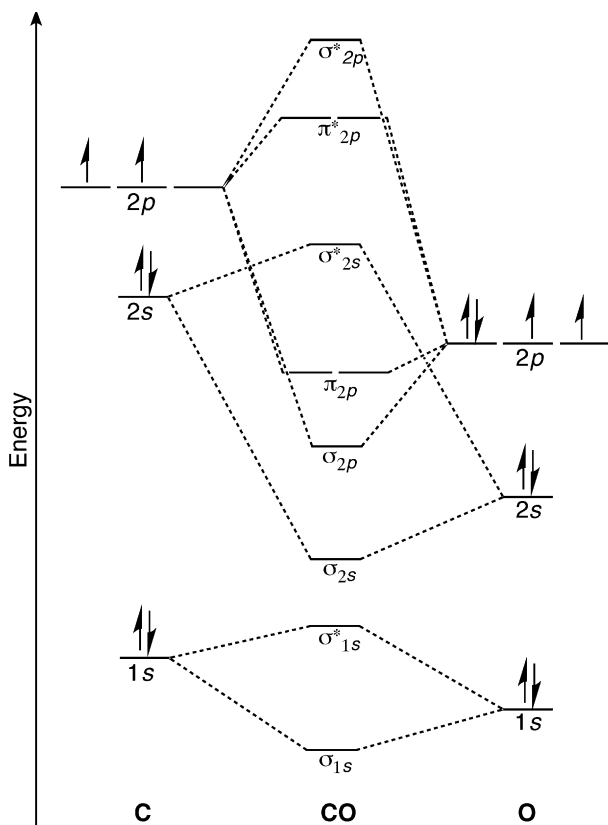


(c) Based on the best Lewis structure for azide, sketch the *orbital overlap diagrams* for the  $\sigma$  bonds and  $\pi$  bonds. Indicate relative phases as necessary. Assume the nuclei lie along the y-axis.

$\sigma$  bonds (orbital overlap diagram)

$\pi$  bonds (orbital overlap diagram)

13. [8 marks] Complete the orbital interaction diagram for carbon monoxide (CO) below.



(a) Determine the *bond order* of CO.

Answer:

(b) Identify the highest occupied molecular orbital (HOMO) of CO.

Answer:

(c) The reaction of the Lewis acid  $\text{BH}_3$  (1 mol) with CO (1 mol) forms a new compound A (1 mol) as the only product. The boron in compound A is  $sp^3$  hybridized. In the box provided, draw the best Lewis structure of A. Write any non-zero formal charges on the appropriate atoms, show all bonds as lines and all lone pairs of electrons as pairs of dots.

Answer: Best Lewis structure of A

(d) The C–O bond length of carbon monoxide is 112.8 pm. To bond with  $\text{BH}_3$ , CO uses the electrons in its HOMO. Consider the effects of this interaction on the bond order of CO in A. Based on this consideration, predict the C–O *bond length* in molecule A. **Circle** the correct answer.

less than 112.8 pm

112.8 pm

greater than 112.8 pm

**END OF EXAMINATION**