

**Chemistry 362  
FINAL EXAM  
Fall 2019**

**WEDNESDAY DECEMBER 11, 2019**

**Professor Kim R. Dunbar**

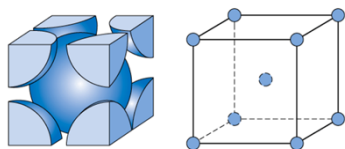
**NAME:** \_\_\_\_\_

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**Total Points on FINAL EXAM is 150 points**

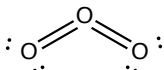
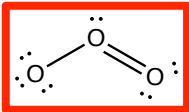
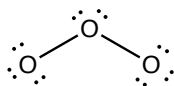
**Multiple Choice (50 points)**

1. Which element is polyatomic?  
a) Neon  
**b) Sulfur**  
c) Nitrogen
2. Which allotrope of carbon would you expect to have the greatest hardness?  
**a) Diamond**  
b) Graphite  
c) Buckminsterfullerene (bucky ball)
3. Which of the following is **NOT** a property of a metal?  
a) High thermal conductance  
b) Mechanical properties of strength and ductility  
**c) Low reflectivity**
4. What type of packing is shown in the figure below?



- a) cubic closest packed  
**b) body centered cubic**  
c) hexagonal closest packed
5. A material with a large band gap is classified as  
a) a conductor  
**b) an insulator**  
c) a semi-conductor
6. Which element has the smallest ionization energy?  
**a) Oxygen**  
b) Nitrogen  
c) Fluorine
7. Finish the following sentence with the correct statement:  
The first short row of elements,  $\text{Li} \rightarrow \text{Ne}$  are *not representative* of the rest of the groups that they head because:  
a) they do not favor the formation of pi bonds  
**b) they do not incorporate d-orbitals in their bonding**  
c) they adopt similar shapes and geometries as those in the second row
8. From the notes, what is the strict definition of a “transition element”?  
**a) elements that have partly filled d or f sub-shells**  
b) elements that have partly filled p or d sub-shells  
c) elements that have party filled p, d or f- subshells

9. Which lanthanide has the largest ionic radius?  
 a) Samarium  
**b) Cerium**  
 c) Erbium
10. What are the characteristics of a soft base?  
 a) High polarizability  
 b) Small size  
 c) Low electronegativity  
**e) a and c**  
 f) a and b
11. Which reaction would NOT be favored to proceed in the forward direction?  
**a)  $\text{Cu}_2\text{S} + \text{H}_2\text{O} \rightarrow \text{Cu}_2\text{O} + \text{H}_2\text{S}$**   
 b)  $\text{Cu}_2\text{O} + \text{H}_2\text{S} \rightarrow \text{Cu}_2\text{S} + \text{H}_2\text{O}$   
 c)  $\text{SiS}_2 + 2\text{H}_2\text{O} \rightarrow \text{SiO}_2 + 2\text{H}_2\text{S}$
12. Which isotope of hydrogen is radioactive?  
 a) Hydrogen ( $^1\text{H}$ )  
 b) Deuterium ( $^2\text{H}$ )  
**c) Tritium ( $^3\text{H}$ )**
13. Which hydrogen bond is the strongest?  
**a)  $\text{O}-\text{H}\cdots\text{X}$**   
 b)  $\text{S}-\text{H}\cdots\text{X}$   
 c)  $\text{N}-\text{H}\cdots\text{X}$
14. A clathrate is:  
 a) a compound containing discrete water molecules bound to some other molecule via hydrogen bonding and/or cation-oxygen bonds.  
**b) a cage-like compound of water in which other molecules or atoms can be trapped**  
 c) a linear arrangement of water molecules to which other molecules or atoms can bind to
15. Which of the following is **not** a property of an alkali metal?  
 a) They are easily ionized to  $\text{M}^+$  cations  
 b) Reactivity increases going down the group  
 c) Most bonding interactions are ionic
- These are all properties. This was a mistake. ☹**
16. Which alkali metal would have the largest hydration sphere?  
 a)  $\text{Na}^+$   
**b)  $\text{Li}^+$**   
 c)  $\text{Cs}^+$
17. Which ion would you expect to bind best to 18-crown-6?  
 a)  $\text{Rb}^+$   
 b)  $\text{Na}^+$   
**c)  $\text{K}^+$**

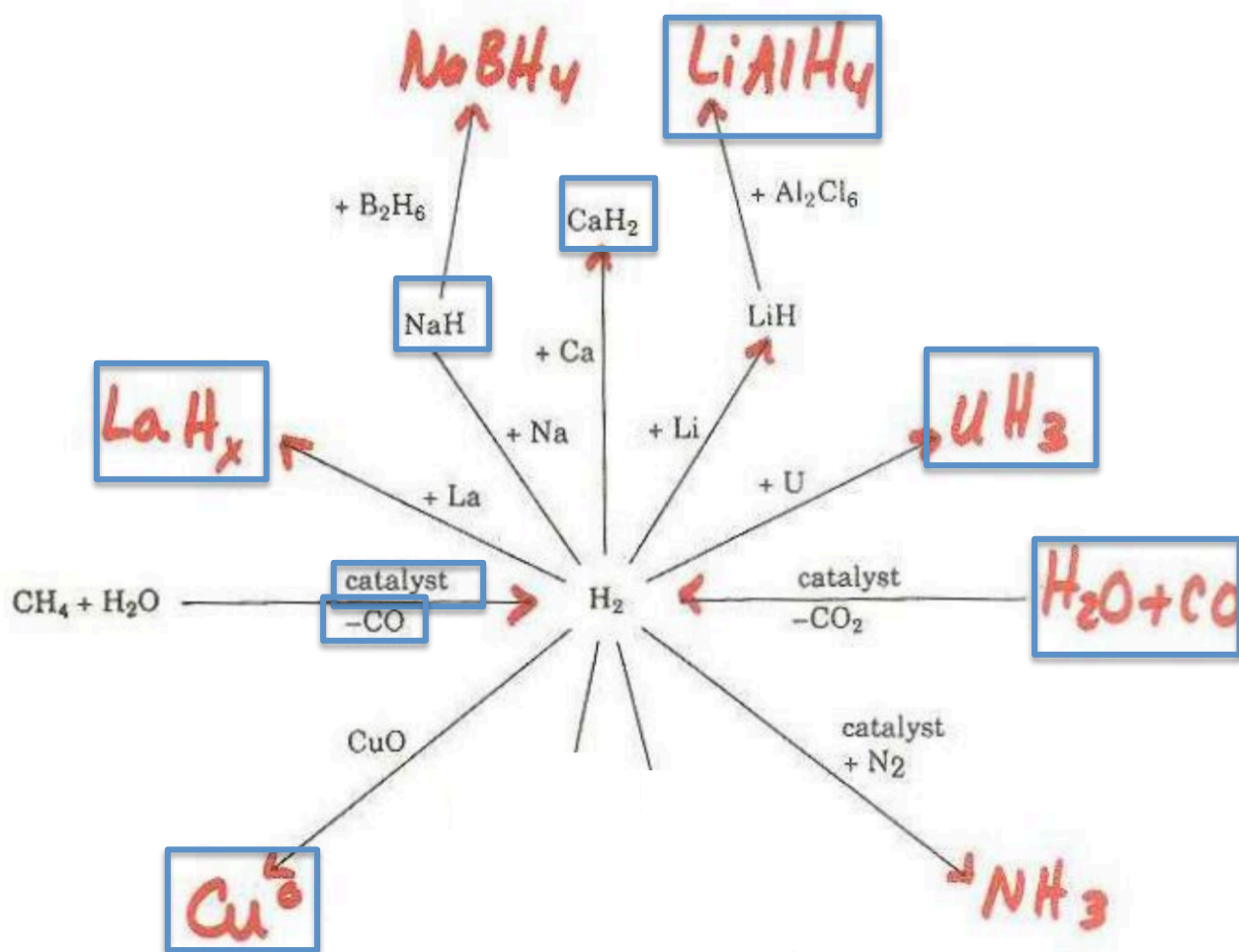
18. Of the Alkaline Earth Metals, which exhibits the most covalent character when bonding to other elements?  
**a) Beryllium**  
b) Strontium  
c) Radium
19. What is the geometry about the Be atom in a polymerized  $\text{BeX}_2$  compound?  
**b) Tetrahedral**  
c) Square planar
20. Which of the following halide compounds is the least soluble?  
a)  $\text{MgCl}_2$   
b)  $\text{CaCl}_2$   
**c)  $\text{BaCl}_2$**
21. Which of the following is **not** a use for carbon monoxide?  
**a) the preparation of urea**  
b) reducing agent  
c) a fuel in the “water gas” reaction
22. Which of the following is **not** a primary use for nitrogen ( $\text{N}_2$ )?  
a) Coolant  
b) Inert gas used as a blanketing atmosphere  
**c) Fire extinguisher**
23. Which of the following is a property of an amide?  
a) Powerful acid  
**b) Reactions with water are highly exothermic**  
c) Chemical formula is  $\text{NH}_3$
24. Which of the following is the correct Lewis dot structure of ozone ( $\text{O}_3$ )?  
a)   
b)   
c) 
25. Which of the following is **not** a use for oxygen ( $\text{O}_2$ )?  
a) Plastics  
b) Fuel  
c) Sewage treatment  
**d) None of the above.**

## Chemical Reactions (35 points)

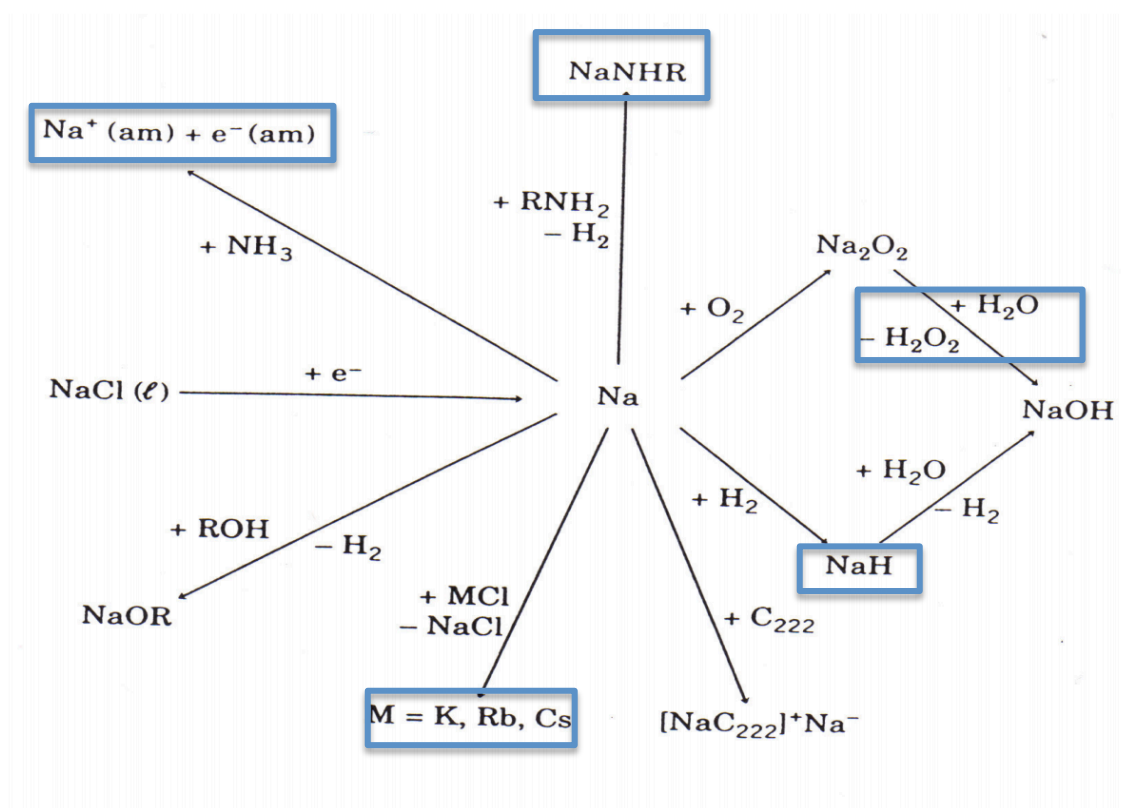
1. (18 points)

Fill in all of the blanks in the figures below

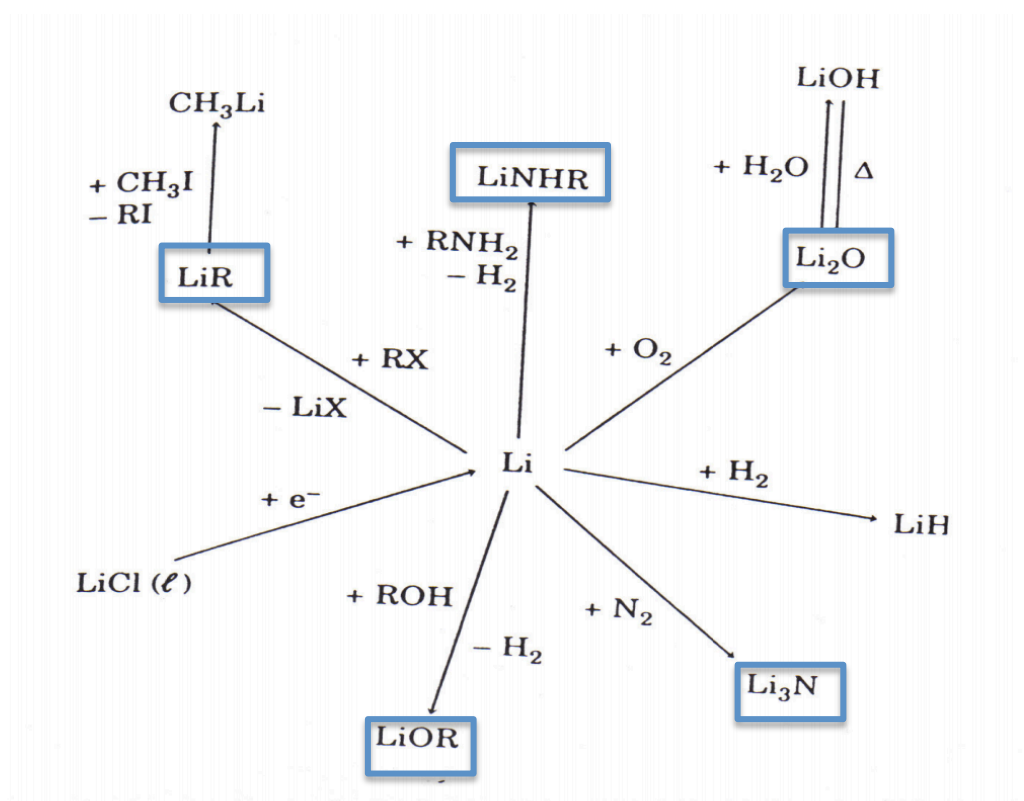
a) Reactions of hydrogen



b) Reactions of Sodium



c) Reactions of lithium



2. (9 points)

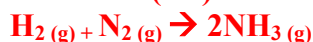
A number of industrially relevant were discussed in lecture. Pick **3 of the 4 listed below** and

i) give the balanced chemical equation

ii) explain the historical or industrial relevance and give at least one major use of the product.

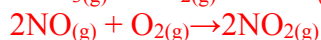
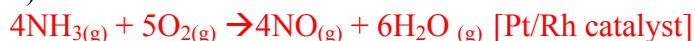
a) Haber-Bosch Process

(cat)



The development of the Haber-Bosch process resulted in the ability for industrial scale production of ammonia, which is incredibly relevant for agriculture and global food supply. Ammonia is used in fertilizers. Ammonia is also used for the production of plastics, fibers, explosives, nitric acid and intermediates for dyes and pharmaceuticals.

b) Ostwald Process



The Ostwald process is industrially significant in terms of the production of nitric acid. Nitric acid is used to make fertilizers and explosives. It's discovery is thought to have prolonged WWI because Germany had been cut off from importing nitrate salts from Chile by the Allies. Nitrates are used in explosives.

c) Fischer-Tropsch Synthesis

(cat)



This process uses CO as a building block and converts it into a mixture of hydrocarbons. These hydrocarbons have a number uses commercially, as the alkanes produced are suitable for fuel. This process was used by Germany during World War II to manufacture gasoline from coal.

d) Synthesis of urea



It is of importance that urea can be synthesized on an industrial scale, as urea is a solid and so is easily transported. Urea is used for agriculture applications – it reacts with water to produce ammonia

3. (8 points)

Write the balanced chemical equation for the reaction of the following with **water (H<sub>2</sub>O)**



**Short/Medium/Long Answer (65 points)**

1. (3 points)  
Briefly describe the structure and bonding of each allotrope of carbon

**Graphite: 2D sheets held together by weak van der Waals forces. Carbon atoms are  $sp^2$  hybridized**  
**Diamond: 3D network of strong covalent bonding between  $sp^3$  hybridized carbon atoms**  
**Buckminsterfullerene: Covalently bonded carbon atoms in the shape of a sphere. The  $C_{60}$  “Bucky Ball” has 60 vertices and 32 faces with 20 hexagons and 12 pentagons**

2. (5 points)  
Lithium is different than the other Group I elements.

(a) Why?

**Lithium is smaller and as a result, its compounds are more covalent**

- (b) Give an example of how this difference impacts the reactivity of lithium with respect to the other Group 1 elements

**Any of the examples given on page 405 of the notes is acceptable**

3. (6 points)  
There are four main uses of  $CO_2$  that were presented in lecture.  
i) Name **3** of the 4 main uses  
ii) Describe why they are used for that particular application.  
iii) If there is a reaction or reactions required to explain the particular use, provide the equation.

- 1. Largest use of  $CO_2$  (~50%) is not a chemical use but a refrigerant as “dry ice”**  
 **$CO_2(s)$  “dry ice”**
- 2.  $CO_{2(l)}$  is used to extract caffeine from coffee because it leaves no harmful residues.**
- 3.  $CO_{2(l)}$  is used in fire extinguishers. The more dense  $CO_2$  will displace air around the burning material and keep  $O_2$  from fueling the flames.**
- 4.  $CO_2$  produced is used in carbonation of beverages**  
 $CO_{2(aq)} + H_2O \rightarrow H_2CO_{3(aq)}$   
 $H_2CO_{3(aq)} + H_2O \rightarrow HCO_3^-(aq) + H_3O^+$  (equilibrium arrows!)

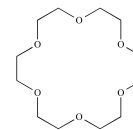
4. (4 points)  
Of the compounds  $N_2$ ,  $O_2$  and  $F_2$  which one is paramagnetic? Why?

**Oxygen ( $O_2$ ) is paramagnetic. From an MO theory point of view, oxygen has 6 valence electrons, and so the orbitals are filled such that each  $1\pi^*$  orbital contains a single unpaired electron.**



5. (4 points)  
(a) What is the basic structure of a crown ether and how are they named? Sketch an example of one.

**A crown ether is a cyclic ethers. The number of O atoms and the total number of atoms in the ring are specified in the name: for example “18-crown-6”**



(b) Why are crown ethers useful and what are they used for?

**M<sup>+</sup> alkali metals are not easily dissolved in their salts into non-aqueous solvents. They need polar (usually H<sub>2</sub>O molecules) to stabilize them in their solvated forms. To circumvent this, chemists used crown ethers.**

6. (5 points)  
a) Classify the following oxides as basic, amphoteric or acidic

i) Na<sub>2</sub>O **Basic**

ii) SO<sub>3</sub> **Acidic**

iii) Al<sub>2</sub>O<sub>3</sub> **Amphoteric**

- b) What is the trend for whether a transition metal oxide will be basic, amphoteric, or acidic?

**The higher the oxidation state of the metal, the more covalent (acidic) it will be.  
The lower the oxidation state of the metal, the more ionic (basic) it will be.**

7. (5 points)  
Classify the following as hard or soft, acid or base

a) Ag<sup>+</sup> **SA**

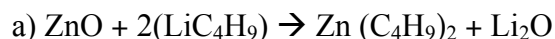
b) Ti<sup>4+</sup> **HA**

c) CN<sup>-</sup> **SB**

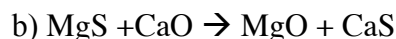
d) NH<sub>3</sub> **HB**

e) Al<sup>3+</sup> **HA**

8. (4 points)  
Using the concept of HSAB theory, predict which way the following reactions will proceed. *Show your work*



**Zn(II) < Li (I) acid hardness, C<sub>4</sub>H<sub>9</sub> < O base hardness – reaction will proceed to the right**

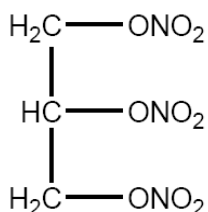


**Mg(II) > Ca(II) acid hardness, O<sup>2-</sup> > S<sup>2-</sup> base hardness – reaction will proceed to the right.**

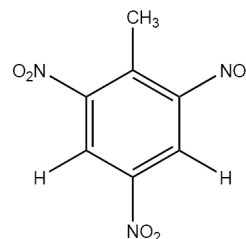
9. (5 points)

Why are nitroglycerine and trinitrotoluene (TNT) so explosive? Explain in terms of enthalpy and entropy

Nitroglycerine  
 $C_3H_5N_3O_9$   
(liquid)



TNT – trinitrotoluene (solid)  
 $C_7H_5N_3O_6$  (s)



**These molecules are highly explosive because when they decompose, they form a large number of molecules (moles) of gas molecules from one molecule of explosive. The entropy of the system increases dramatically. These reactions are also exothermic, in other words, a negative delta H.**

10. (3 points)

Name **3** of the many characteristics of transition metals as discussed in lecture.

**(1) All are metals**

**(2) Practically all are hard, high melting, high boiling elements that are good conductors**

**(3) They form alloys with each other**

**(4) Many are highly electropositive such that they dissolve in mineral acids (oxidized)**

**(5) They exhibit variable valence**

**(6) They form paramagnetic compounds**

11. (5 points)

a) Why is ice less dense than water?

**The liquid form of water, although engaged in transient hydrogen bonding, is not as open and expanded as when held into its solid form by the rigid, semi-permanent hydrogen bonding in ice**

b) Give 3 reasons why water is essential for life on earth, and briefly explain *why*

**Very high boiling point – if not for this, water would be a gas at room temperature (life on earth would be impossible, our bodies need liquid water, nature needs liquid water to penetrate the soil, we need oceans etc.**

**Very low density of the solid form (ice) – if not the case there would be no aquatic life as lakes would freeze from the bottom up as instead of freezing from the top down.**

**Hydrogen bonding – this forms the “glue” that holds proteins and DNA together, without it we would quite literally “fall apart**

12. (5 points)

a) Describe how metals bond. How is this different than other elements?

**A continuum of energy bands spreads over the entire metal → the electrons are delocalized. The overlapping atomic orbitals form closely spaced orbitals in the metal called bands**

b) Why are alkali metals relatively softer and more volatile than alkaline earth metals?

**Alkali metals possess only one valence electron per atom to share in the close packed structure resulting in a weaker interaction than in other metals.**

13. (4 points)  
A number of elements and compounds were discussed in lecture that are biologically or physiologically relevant. Pick **2** of the following ( $\text{Na}^+$ , CO,  $\text{CO}_2$ ,  $\text{CN}^-$ , Be,  $\text{NH}_3$ ) and briefly describe their role or their effect in biology.
- $\text{Na}^+$ : part of the  $\text{Na}^+/\text{K}^+$  pump system, used in generating gradient potentials for cell signaling**  
**CO: competitively binds to hemoglobin in place of oxygen, is poisonous**  
 **$\text{CO}_2$ : product of aerobic respiration, reagent for photosynthesis**  
 **$\text{CN}^-$ : competitively binds to heme in mitochondria, is poisonous**  
**Be: very toxic, causes lesions in lungs**  
 **$\text{NH}_3$ : used as fertilizer, important for the growth of plants.**
14. (4 points)  
For the following, indicate whether Group1A or GroupIIA elements would have a larger magnitude, and *explain* your reasoning.
- a) Density  
**GroupIIA – smaller size (decreasing ionic radius due to increased  $Z_{\text{eff}}$ ) and increased atomic mass result in a larger density (mass/volume)**
- c) Ionization energy  
**GroupIIA – it is more favourable and easier to remove one electron in order to return to the noble gas configuration. IE increases  $L \rightarrow R$**
15. (3 points)  
Why is the existence of a silicon analogue of graphite unlikely?
- $\pi$ - $\pi$  overlap between silicon atoms would be much weaker than between carbon atoms due to the size of Si (3p orbitals) as well as as well as increased repulsion between silicon atoms due to fully filled 2p orbitals. Graphite is made up of  $\text{sp}^2$  hybridized carbon atoms with  $\pi$  bonding character. Therefore, in a system where the structure involves a degree of  $\pi$ -bonding, such a phenomenon would be unlikely for silicon.**

**\*\*Have an enjoyable and safe holiday! Best wishes with your future endeavors in the new year! \*\***