Supplement: The Impact of Modality Choice on Final Exam Success and Retention in a Concurrent Preparatory Chemistry Course

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Box Plot Example and Description

To visualize the distribution of performance in general chemistry, we will use box plots. An example box plot with a description of each of the respective components is provided in Figure S1. Box plots contain the minimum value, 25th percentile, 50th percentile (median), 75th percentile, and the maximum. The box itself represents the middle 50% of the data. The interquartile range (IQR) is calculated by subtracting the value of the 25th percentile from the value of the 75th percentile. Outliers are denoted with an open circle when a value from the data is greater than $1.5 * IQR$ from the middle 50% of the data. In the case of outliers, the whiskers will reach the next closest data point to the center of the distribution. For further discussion of variations of box plots, refer to McGill.[72]

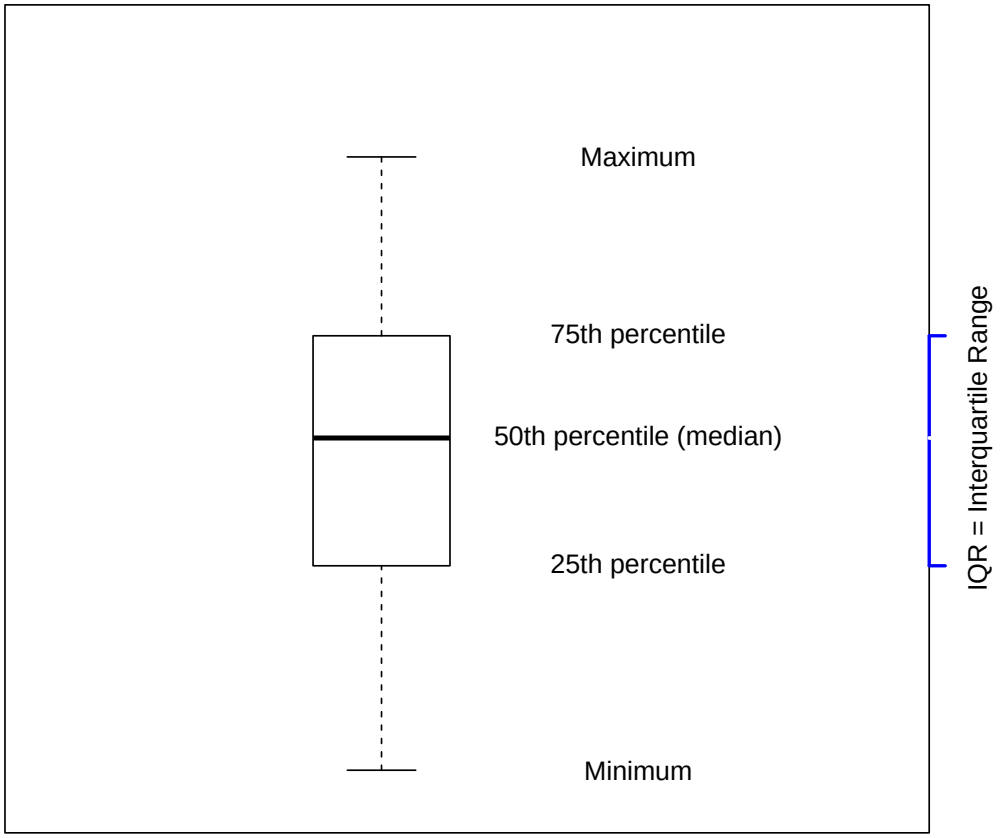


Figure S1: Box Plot Example. Box plots contain the minimum value, 25th percentile, 50th percentile (median), 75th percentile, and the maximum. The box itself represents the middle 50% of the data. The interquartile range (IQR) is calculated by subtracting the value of the 25th percentile from the value of the 75th percentile. Outliers are denoted with an open circle when a value from the data is greater than $1.5 * IQR$ from the middle 50% of the data. In the case of outliers, the whiskers will reach the next closest data point to the center of the distribution.

Performance Outcomes

Table S1: ANOVA table of performance in GC+ across the different modes of instruction.

Source	Df	Sum Sq	Mean Sq	F value	p-value
Mode of Instruction	2	17732.44	8866.22	25.92	< 0.001*
Residuals	462	158046.94	342.09		

Table S2: ANOVA table of performance in GCA (percent on common final exam) for GC+ students based on different modes of instruction.

Source	Df	Sum Sq	Mean Sq	F value	p-value
Mode of Instruction	2	6277.48	3138.74	6.62	0.002*
Residuals	415	196851.75	474.34		

Grade Outcomes

Table S3: ANOVA tables of performance in general chemistry (grade in course on first attempt) for GC+ students based on different modes of instruction.

Course	Source	Df	Sum Sq	Mean Sq	F value	p-value
GCA	Mode of Instruction	2	26.23	13.12	8.48	$<$0.001*
	Residuals	415	642.04	1.55		
GCB	Mode of Instruction	2	0.40	0.20	0.16	0.854
	Residuals	283	352.71	1.25		
GCC	Mode of Instruction	2	0.87	0.44	0.34	0.711
	Residuals	219	279.82	1.28		

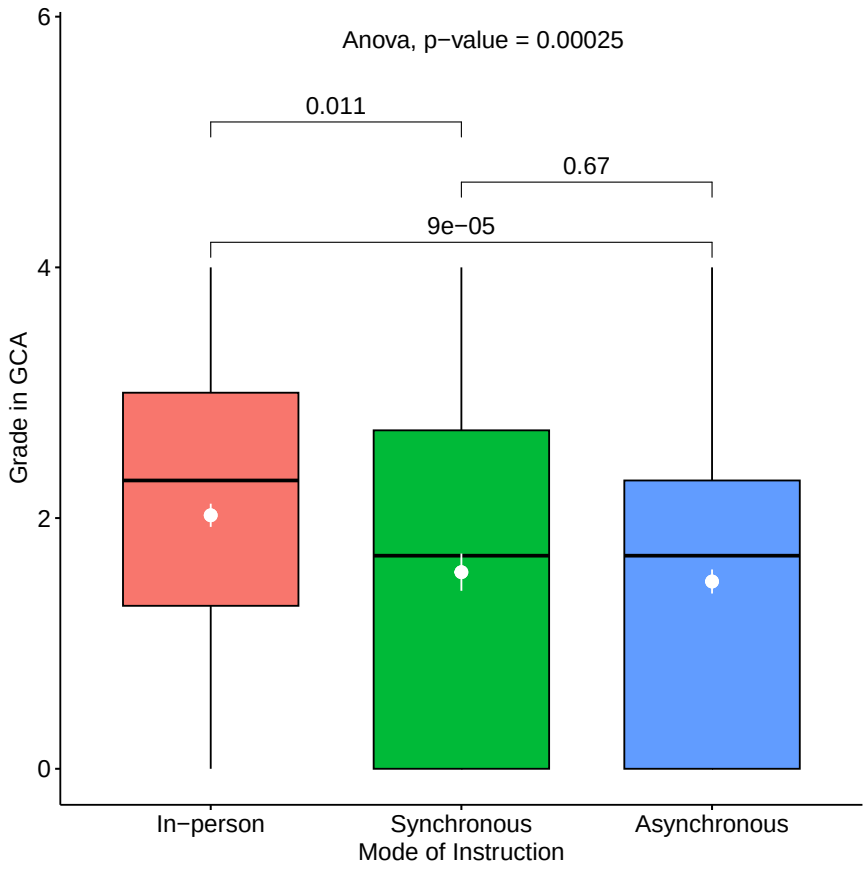


Figure S2: GC+ Student Grades in GCA. The p-value for the overall F-test for the difference in means of the GCA grades across the three modes of instruction are presented at the top of the plot. The p-values for the pairwise comparisons of the GCA percent on common final are presented on top of each horizontal bar. The mean and respective standard errors for each group are given in white.

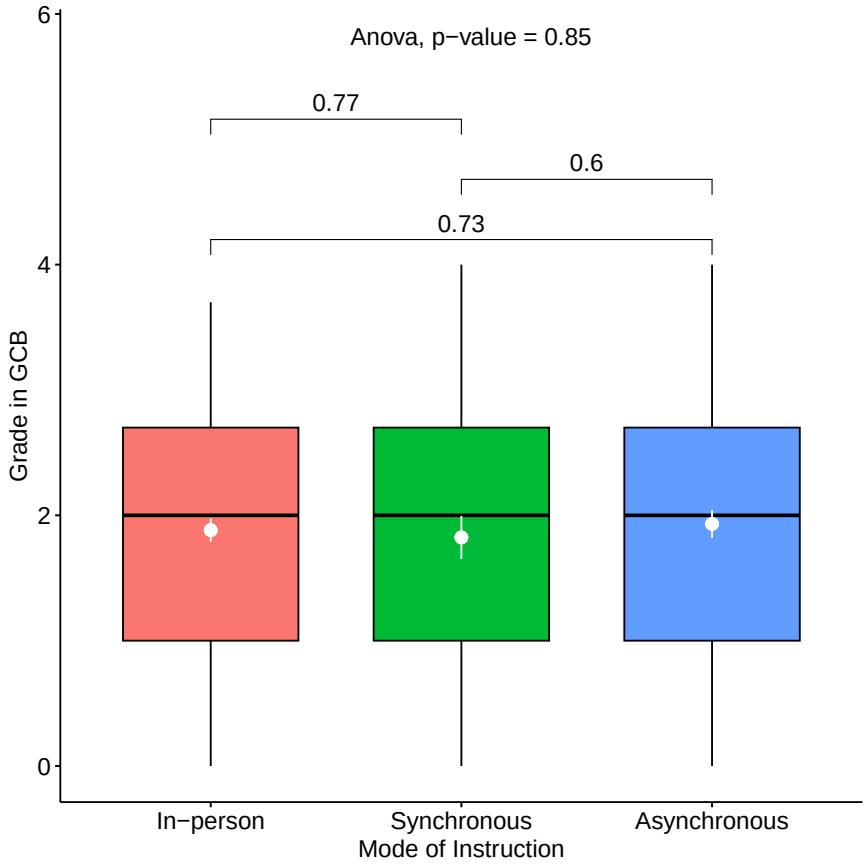


Figure S3: GC+ Student Grades in GCB. The p-value for the overall F-test for the difference in means of the GCB grades across the three modes of instruction are presented at the top of the plot. The p-values for the pairwise comparisons of the GCB grades are presented on top of each horizontal bar.

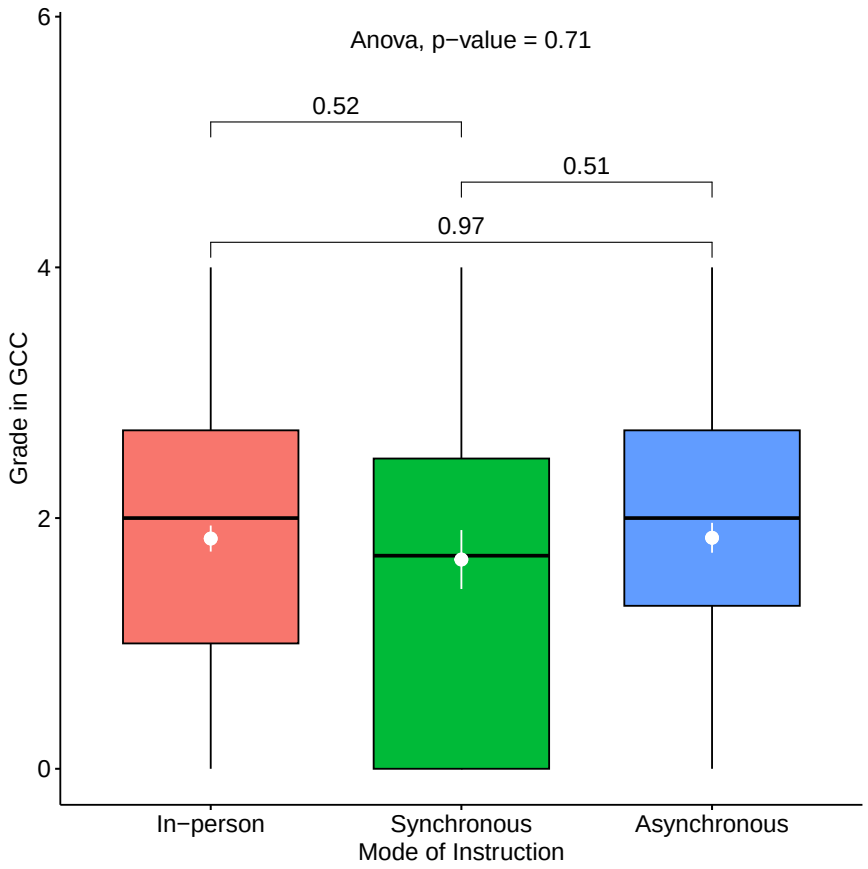


Figure S4: GC+ Student Grades in GCC. The p-value for the overall F-test for the difference in means of the GCC grades across the three modes of instruction are presented at the top of the plot. The p-values for the pairwise comparisons of the GCA percent on common final are presented on top of each horizontal bar. The mean and respective standard errors for each group are given in white.

Retention

Table S4 provides the enrollment rates across the general chemistry sequence for GC+ students across different modalities. The course outcomes are based on the first attempt in the course.

Table S4: Success of GC+ students in general chemistry.

	Enrolled		Outcome		
	No	Yes	Pass	DFW	
	%	%	%	%	n
GC+					
In-person	0	100	98	2	195
Synchronous	0	100	94	6	83
Asynchronous	0	100	86	14	187
All Students	0	100	**92**	**8**	**465**
GCA					
In-person	7	93	67	26	195
Synchronous	7	93	49	44	83
Asynchronous	10	90	48	42	187
All Students	**8**	**92**	**56**	**36**	**465**
GCB					
In-person	30	70	49	21	195
Synchronous	39	61	39	22	83
Asynchronous	45	55	36	19	187
All Students	**38**	**62**	**42**	**20**	**465**
GCC					
In-person	44	56	38	18	195
Synchronous	57	43	28	15	83
Asynchronous	59	41	30	11	187
All Students	**52**	**48**	**33**	**15**	**465**

Common Final Exam Questions

1. How many electrons, protons, and neutrons are there in the ion ${}^{102}_{44}X^{4+}$?

2. All of the formulas below are correct EXCEPT: Choices: LiO, MgS, K_3N, Ga_2O_3

3. Green light has a wavelength of 501 nm. What is the energy of a pulse of green light containing 1.0 mol of photons?

4. The hybrid orbitals used in the central atom of BrF_3 is:

5. A sample of $Ti_3O_5(s)$ has a mass of 28.0 g. How many atoms of titanium are in this sample?

6. The mass of silver in 9.000 g of silver chloride, AgCl(s), is:

7. What is the coefficient for $NaAlO_2(s)$ when the following equation is balanced?

$HF(g) + NaAlO_2(s) \rightarrow Na_3AlF_6(s) + H_2O(l) + Al_2O_3(s)$

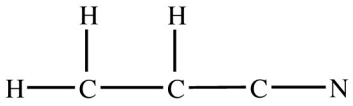
8. The atomic mass of silver is 107.9 amu. It has two naturally occurring isotopes. Given that 51.8

9. The formula of manganese(IV) oxide is:

10. A common anti-inflammatory drug is 75.69% C, 8.80% H, and 15.51% O. What is its empirical formula?

11.Which of the following has the largest bond energy? A. A carbon oxygen triple bond B. A carbon carbon double bond C. A carbon hydrogen single bond D. A carbon fluoride single bond

12. The "skeleton structure" for a covalent molecule is shown here. It shows how the atoms are connected but does not show double/triple bonds or lone pairs. Complete the Lewis structure for this molecule. How many sigma and pi bonds are present.



13. Calcium arsenate has the formula $Ca_3(AsO_4)_2$. Based on this information, the formula for potassium arsenate is:

14. Which of the following processes, with all species in the gas phase, would require the most energy?

- $Sr \rightarrow Sr^+ + e^-$
- $Mg^{2+} \rightarrow Mg^{3+} + e^-$
- $Ca \rightarrow Ca^+ + e^-$
- $Mg \rightarrow Mg^+ + e^-$

- $Mg^{+} \rightarrow Mg^{2+} + e^{-}$

15. Rank the following bonds in order of increasing polarity: C—F, C—N, N—F.

16. The ground-state electron configuration of Rh^{3+} (Z = 45) is

17. Which statement is true?

- Sr^{2+} is smaller in size than I^{-}.
- Sr has a higher electronegativity value than I.
- Sr has a higher first ionization energy than I.
- Sr forms a covalent compound with I.
- Sr has a smaller atomic radius than I.

18. Which of the following has the smallest radius? Choices:$K, S^{2-}, Rb, Cl^{-}, K^{+}$

19. Which main group element forms a positive ion having the ground state-state electron configuration [Ar]? Choices: potassium, chlorine, strontium, phosphorus, scandium.

20. Which statements about oxygen are TRUE?

- O has a lower ionization energy than N.
- The size of O^{2-} is larger than the size of Be^{2+}.
- O bonds with halogens to form polar covalent compounds.
- The atomic radius of O is smaller than that of Be.
- O is more electronegative than N.

21. Atom M has the electron configuration $[Ne]3s^2 3p^1$. Atom X has the electron configuration $[Ar]3d^{10}4s^2 4p^3$. What is the likely formula of the compound formed between M and X?

22. Name the compound IF_7.

23. Which of the these statements is FALSE?

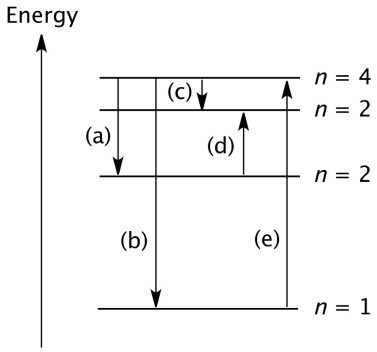
- The importance of the de Broglie equation is that electromagnetic radiation has wave-like properties.
- The wavelike character of ordinary objects like a thrown baseball cannot be detected because their wavelengths are so short.
- Electromagnetic radiation can be thought of as a stream of particles called photons.
- Energy can only occur in discrete units called quanta.
- The energy of matter is not continuous and is actually quantized.

24. The atomic orbital for an electron in an atom with the quantum numbers n = 4, l = 1, $m_l = 0$, $m_s = \frac{1}{2}$ is: Choices: 4p, 4d, 4s, 4f, 3d

25. Consider the following reaction: $6HNO_3(aq) + 2Al(s) \rightarrow 3H_2(g) + 2Al(NO_3)_3(aq)$ If 3.0 mol of HNO3 and 3.0 mol of Al react, how many moles of H2 are produced?

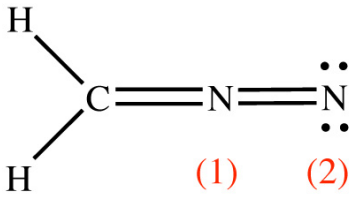
26. Which of the following is an ionic compound?
- $(NH_4)_2CO_3$
- PCl_5
- SCl_2
- SeO_2
- None of these

27. In the figure shown below, which arrow represents the emission of a photon of light with the longest wavelength?



28. Which of the following represents a possible set of quantum numbers for an electron in an atom?
- $n = 3, l = 2, m_l = -1, m_s = \frac{1}{2}$
- $n = 4, l = 3, m_l = 0, m_s = 0$
- $n = 2, l = 0, m_l = +1, ms = +\frac{1}{2}$
- $n = 3, l = 3, m_l = -2, m_s = -\frac{1}{2}$
- $n = 3, l = 4, m_l = +4, m_s = -\frac{1}{2}$

29. What are the formal charges on nitrogen atom (1) and nitrogen atom (2), respectively, in this Lewis structure?



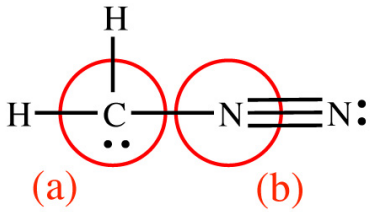
30. Consider the molecular orbital description of C_2^{2-}. Which of the following statements is TRUE?

- C_2^{2-} is diamagnetic
- The highest occupied molecular orbitals (HOMO) are antibonding molecular orbitals
- The bond order is 2.5
- The lowest unoccupied molecular orbitals (LUMO) are bonding molecular orbitals.
- There are two unpaired electrons.

31. Which of the following statements is/are correct?

- An orbital can accommodate at most two electrons.
- Three quantum numbers are needed to uniquely describe an electron.
- When two or more orbitals of equal energy are available, electrons will occupy them singly and with parallel spins before filling them in pairs.
- The exact location of an electron and its velocity cannot be simultaneously determined with precision.
- In the usual order of filling, the 4d orbital is filled before the 5s orbital.

32. The hybrid orbitals used by the circled atoms (a) and (b) in the following molecule are:



33. Which of the following ions would least likely form? Choices:

$K^{2+}, Be^{2+}, Si^{2+}, Se^{2-}, Fe^{2+}$

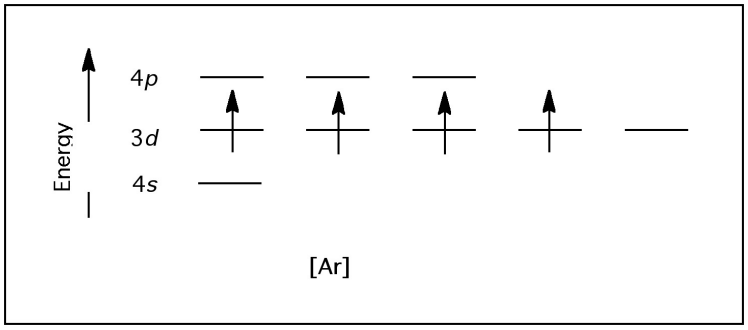
34. For the ground-state Sn^{3+} ion, what type of orbital do the electrons with the highest energy reside?

35. Given the following elements and three values of possible first ionization energies:

Atoms: S, Al, P and Possible 1st Ionization energies: 578, 1000, and 1012 kJ·mol–1

Match the atoms with their ionization energies.

36. The ground-state electron energy level diagram for a monatomic species with a +4 charge is shown below.



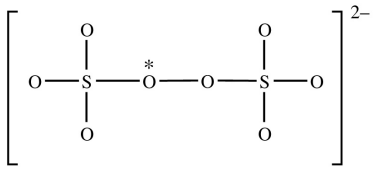
37. A 25.0 g sample of an element contains 6.19 1023 atoms. Identify the element. Choices: Mg, Fe, Cr, Al, S

38. Which of the following formulas must be an empirical formula?

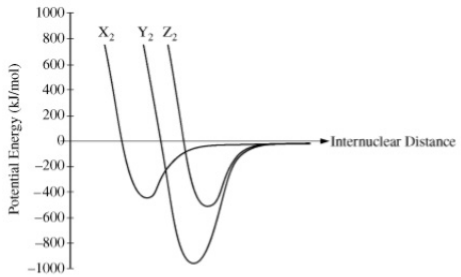
- $Al_2(SO_4)_3$
- As_4O_6
- Na_2O_2
- P_4O_10
- $Na_2S_2O_4$

39. Calculate the frequency of a photon emitted by a hydrogen atom when an electron makes a transition from the state with n = 5 to n = 2.

40. The "skeleton structure" for a covalent ion is shown here. It shows how the atoms are connected, but does not show double/triple bonds or lone pairs. Complete the Lewis structure for this molecule. The S—O—O bond angle (or the angle about the O atom labeled LaTeX: $*)is$:



41. The three graphs show plots of the potential energy as a function of internuclear distance for three diatomic molecules, X2, Y2, and Z2.



Based on the data in the graph, which of the following correctly identifies the diatomic molecules, X2, Y2, and Z2?

	X_2	Y_2	Z_2
(a)	O_2	H_2	N_2
(b)	H_2	O_2	N_2
(c)	N_2	O_2	H_2
(d)	H_2	N_2	O_2
(e)	O_2	N_2	H_2

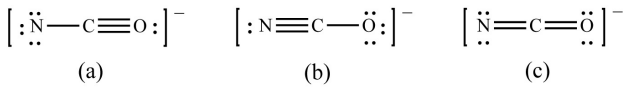
42. Which of these molecules has a net dipole moment? Choices: $IF_4^+, PF_5, SF_6, I_3^-$

43. In the most plausible Lewis structure for SO2F2, there are:
    - 2 single bonds and 2 double bonds around S.
    - 3 single bonds, 1 double bond, and 1 lone pair electrons around S.
    - 4 single bonds and 1 lone pair electrons around S.
    - 4 single bonds around S.
    - 3 single bonds and 1 double bond around S.

44. Using molecular orbital theory, predict the bond order for the N^{2-} ion.

45. How many unpaired electrons are in the ground state of the Cu+ ion?

46. The NCO– ion has the following three resonance structures:



When ranked from the most preferred resonance structure to the least preferred one, the order is:

47. Which statement(s) about IF4— are TRUE?

- The molecular geometry (or shape) is tetrahedral.
- The electron geometry around the central atom is octahedral.
- Has a net dipole moment of zero.
- The hybridization about the central atom is sp3.
- The approximate bond angles are 109.5°.

48. Which one of the following ions has the ground-state electron configuration $[Xe]4f^{14}5d^{10}6s^2$?. Options $Bi^{3+}, Pb^{3+}, Tl^{3+}, Po^{3+}, Hg^{+}$

49. Using the molecular orbital theory, predict how many unpaired electrons are in the O^{2+} ion.

50. Which of the following species is isoelectronic with Kr? Choices:

$Sr^{2+}, Cl^{-}, K^{+}, Xe, P^{3-}$

Sample Weekly Homework

Below is an example of the weekly Friday homework. This is for week 4. 1. Select the correct full electron configurations for the following atoms.

P

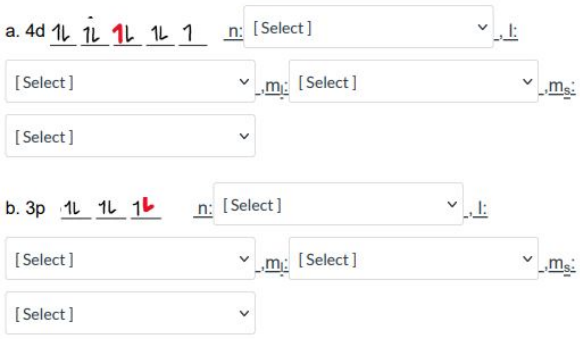
Fe

2. Select the full electron configuration for the following ions.

Br^{-1+}

K^{+}

3. What are the quantum numbers for the electron in red? Write the values of n, l m_l and m_s



4. Rank the following elements in order of increasing atomic radius.

a. B, C, N, O

b. Li, Na, K, Rb

5. Rank the following elements in order of increasing first ionization energy.

a. Li, Be, B, C

b. Be, Mg, Ca, Sr

6. Rank the following elements in order of increasing electronegativity.

a. C, N, O, F

b. F, Cl, Br, I

7. Rank the following elements in order of increasing electron affinity.

a. Si, P, S, Cl

b. Li, Na, K, Rb

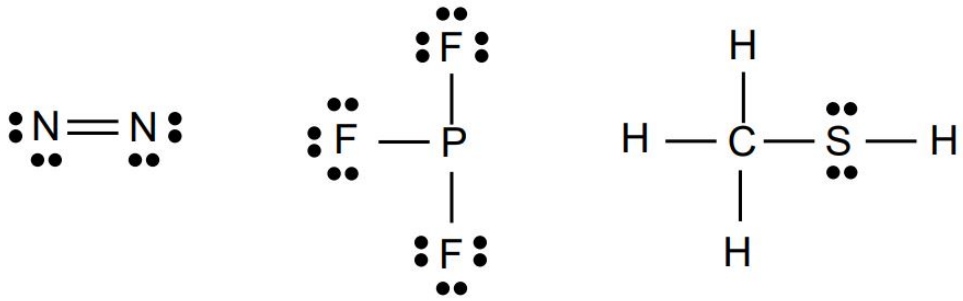
8. Rank the following elements in order of increasing effective nuclear charge

a. Be, Mg, Ca, Sr

b. Si, P, S, Cl

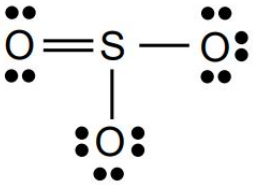
Sample PollEverywhere Questions

Which one of these Lewis structures is correct?

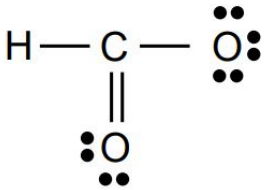


Which of these Lewis structures is likely to have a resonance structure?

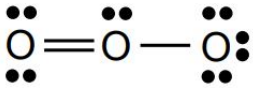
A). SO_3 molecule



C). Formate ion HCO_2^-

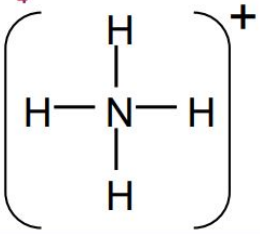


B). O_3 molecule



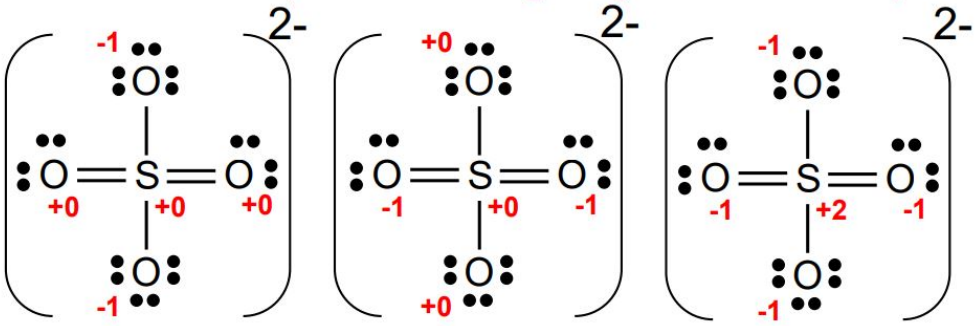
What are the formal charges on each atom in NH_4^+?

A. N atom = +1; each H atom = 0
B. N atom = 0; each H atom = +0.25
C. N atom = 0; each H atom = 0
D. N atom = -3; each H atom = +1
E. None of the above



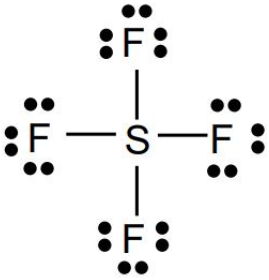
(# of valence electrons) – [(# of nonbonding electrons) + (1/2 × # of bonding electrons)]

What are the formal charges on each atom in SO_4^{2-} sulfate anion?
Pick the correct one. (Note that we are ignoring resonance for now.)

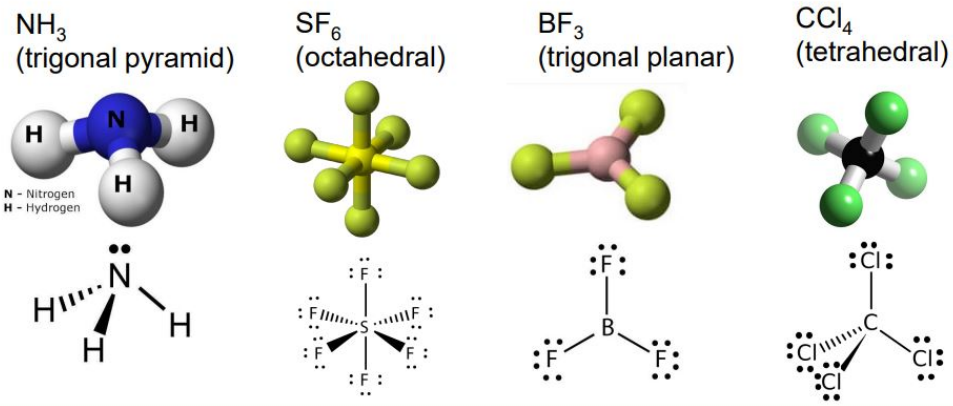


What is wrong with this Lewis structure for SF_4?
How can you fix it?

A. 2nd row elements can't have over 8 electrons.
B. Not all electrons are accounted for
C. Octet rule not followed for some of the atoms
D. Formal charges do not add up to zero
E. A and C
F. B and D



Click on the molecule that is likely to be polar



Sample Monday Pre-class Quiz

Below is an example of a Pre-class Quiz. This one is from Monday Week 5. 1. The "What is a polyatomic ion and how do we name ionic compounds?" video goes over polyatomic

ions and oxides. Which of the following are examples of compounds containing polyatomic ions? Select all that apply.

Possible choices: $Na_2SO_4, FeCl_3, KF, KNO_2, NaOH, NH_4Cl, NaNO_3, LiCl, CaO$

2. The "What is a polyatomic ion and how do we name ionic compounds?" shows examples of ionic bonds. Select all bonds below that can be regarded as ionic bonds.

Possible choices:

- ☐ O=O
- ☐ Li-F
- ☐ H_3C-CH_3
- ☐ Na-Cl
- ☐ Rb-NO_3
- ☐ Ca-SO_4
- ☐ K-Br

3. The Covalent bonding video provides some examples of molecules with covalent bonds. Which of the following molecules would all be good examples of covalent compounds? Multiple answers are possible.

Possible choices:

- ☐ CaO, CaH_2, and CO
- ☐ PbO_2, CuF_2, and NaCl
- ☐ Cl_2, Br_2, and I_2
- ☐ H_2O, CH_4, and glucose
- ☐ BF_3, NH_3, and PCl_3
- ☐ O_2, N_2, and Cl_2

4. The "Covalent bonding" video discusses metals and non-metals. Using a periodic table,

determine if each is a metal or nonmetal. Li, O, N, S, P, Ca, Ti, Cl, Au, Ar

5. The "Molar mass, and using molar mass to convert b etween grams and mols and number of atoms/molecules" video gives examples of various molar mass and molar amount caclulations. You have 299.0 mg of a compound with a chemical formula $C_9H_8O_4$. How many millimoles is that? Enter the value in mmol.

Sample Weekly Quiz

Below is an example of the a weekly quiz. This one is week 8 quiz.

1. What is the name of the hypothetical compound called PS_2. (It is hypothetical because the normal oxidation state for P is 3 or 5, not 4, but for the purposes of naming, we will ignore this fact.

2. Monsters are extra scare due to a compound coating their fur called sodium monsterate (Na_2MrO_4). What would be the formula for a related compound excreted in their urine called sodium monsterite?

- ○ Na_2MrO_5
- ○ NaMr
- ○ Na_3MrO_4
- ○ $Na_2Mr_2O_7$
- ○ Na_2Mr
- ○ $NaMrO_4$
- ○ Na_2MrO_2
- ○ Na_2MrO_3

3. Tennessine, element 117, is the most recently discovered element in the periodic table. Assuming it behaves as a halogen, what would be the name of the rubidium salt with the

tennessine anion?

- ○ tennessine dirubidiide
- ○ rubidium monotennesside
- ○ dirubidium monotennesside
- ○ rubidium ditennesside
- ○ rubidium tennesside
- ○ tennessine rubidiide
- ○ monorubidium monotenneside
- ○ dirubidium ditennesside

4. You have made up a new non-metal element, Lolium, and produced a gaseous compound from it with a formula Lo_3H_5. What is the correct name for your new compound Lo_3H_5?

- ○ lolium hydride
- ○ trilolium hydride
- ○ lolium pentahydride
- ○ trilolium(V) pentahydride
- ○ lolium(III) hydride
- ○ lolium(V) hydride
- ○ monololium dihydride
- ○ trilolium heptahydride
- ○ trilolium pentahydride

5. Match each acid with its name: $H_2SO4, H_2CO_3, H_3PO_3, HNO_2$

6. Dragonium is an element only found in the scales of dragons. it is known to exist only in

the oxidation state of +3, and it is a metal. After dragons go for their morning swim in the Pacific Ocean, their scales change color due to the formation of a chlorine salt of dragonium which crystallizes out with four water molecules per each dragonium atom. Select the name of the compound.

- ○ hydrated dragonium chloride
- ○ tetradragonium chloride hydrate
- ○ dragonium (III) chloride tetrahydrate
- ○ dragonium chloride tetrahydrate
- ○ dragonium hydrate
- ○ dragonium chloride hydrate
- ○ dragonium(III) trichloride tetrahydrate
- ○ dragonium trichloride tetrahydrate
- ○ tetradragonium chloride
- ○ dragonium trichloride hydrate

7. What is the concentration of F- ions when 353.914 mg of MgF_2 (62.3018 g/mol) completely dissociates in 2.865 L of water? Enter the numeric answer only in the units of mM (millimolar).

8. How many grams of chlorine are in 159 milliliters of a 1.542 M $MgCl_2$ solution?

9. You are making a rubbing alcohol (isopropyl alcohol) solution to disinfect surfaces. You start with 486.3 mL of a 6.537 M isopropyl alcohol solution, and dilute it wiht pure water. After the dilution, you end up with a 1.647 M solution. What is the final volume of the solution after the water has been added?

10. Unit conversion challenge: A local water retention pond was found to have elevated mass concentration of mercury of 14 ng per liter. How many moles of mercury are contained in the entire volume of 1250 m^3 of the water in the pond? Look up necessary conversion factors and other information online.