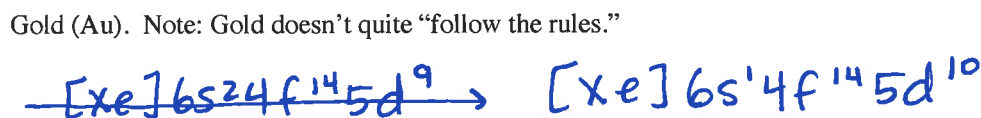
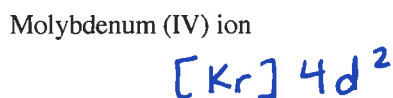
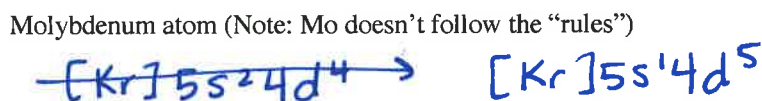
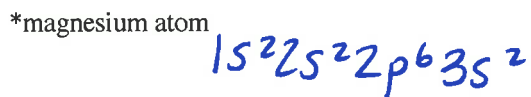
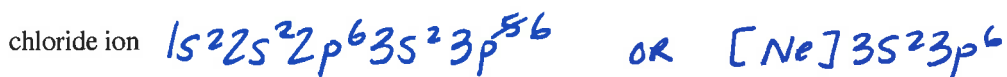


In-Class Quantum Review 2018!

1a. Write the electron configuration for each of these. * don't abbreviate for Mg or Mg ion.



* the e- will have lower Kinetic energy as n increases, but the potential energy dominates. (FYI)

b. How many **valence** electrons are in each of these?

chloride ion	Mg atom	Mo atom	Gold atom	Bismuth (Bi) atom
(8)	(2)	(1)	(1)	$[Xe] 6s^2 4f^{14} 5d^{10} 6p^3$
	↑ from the electron config, or from it being in group IIA.			(5) (or just notice that Bi is in group VIA so it has 5 valence)

2. Consider electron in 1s, 2s, 3s, and 4s orbitals.

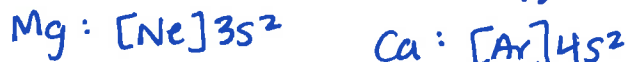
a. Which of these orbitals is the "highest energy" orbital and which is the "lowest energy" orbital?

1s = lowest energy. 4s = highest energy.

b. Explain why the electrons in the "highest energy" orbital have more energy... why is this a higher energy orbital?

Since e- are negative and the nucleus is positive, the e- are attracted to the nucleus, and so the e- will have higher potential energy when they are further away from the nucleus. * As the n-level increases from 1 to 4 (from 1s to 4s), distance from the nucleus increases, so e- energy increases.

c. How does this relate to ionization energy, for example, Which has higher ionization energy: magnesium or calcium. Why?



Mg has the higher I.E. Mg would lose a 3s electron when ionized, while Ca would lose a 4s electron. As explained in (b), 3s electrons have lower energy than 4s electrons, so Mg's 3s electrons will need a relatively large amount of additional energy to escape the atom.

(OR: since Mg's 3s electron is more attracted to the nucleus than Ca's 4s electron, Mg's 3s electron will be more strongly attracted to the positive charge of the nucleus and will need more energy to leave because of this)

3. Photoelectric effect.

a. Explain the process of the photoelectric effect.

When light with sufficient energy shines on the surface of a solid, e^- are ejected from the atoms (near the surface) of the solid.

(The photon energy must be at or above the minimum photon energy, regardless of the intensity of the light source)

b. The photoelectric effect displays the particle like properties of light. (wave or particle?) (as explained by Einstein in 1905)

Consider the work function values of 4.34×10^{-19} J, 7.73×10^{-19} J, and 1.09×10^{-18} J.

These belong to the elements gold, iodine, and calcium (not in order though.)

c. What is the meaning of the work function?

see the next page for answers to 3c-3j.

d. Which periodic trend is the work function more similar to: electron affinity or ionization energy?

e. How do metals compare to nonmetals in terms of their work function?

f. Which work function (above) corresponds to iodine?

g. Calcium is higher on the metal activity series than gold.

Determine which work function belongs to Ca and which belongs to Au.

Suppose gold is hit with monochromatic light from a 10 Watt bulb with a wavelength of 211 nm.

h. Determine the maximum kinetic energy of the ejected electrons.

i. What is the min/max (which is it?) wavelength that will be effective in causing the photoelectric effect in gold?

(3 a and 3b are on the previous page)

3, cont'd. Consider the work function values of 4.34×10^{-19} J, 7.73×10^{-19} J, and 1.09×10^{-18} J. These belong to the elements gold, iodine, and calcium (not in order though.)

c. What is the meaning of the work function?

It is the minimum photon size (energy) required for the photoelectric effect to occur.

d. Which periodic trend is the work function more similar to: electron affinity or ionization energy?

Ionization energy (IE), since both involve removing e^- from an atom. (the difference is that IE is the energy to remove an e^- from a gas phase atom/ion, whereas work fcn is the energy to remove an e^- from an atom in a solid.)

e. How do metals compare to nonmetals in terms of their work function?

metals have low IE and low work fcn values compared to nonmetals.

f. Which work function (above) corresponds to iodine?

1.09×10^{-18} J.

Iodine is the only nonmetal listed. as a nonmetal it should have the highest work fcn.

g. Calcium is higher on the metal activity series than gold.

Determine which work function belongs to Ca and which belongs to Au.

Metals that are higher on the activity series tend to have lower IE and work fcn; they lose e^- more "easily." So

$Ca = 4.34 \times 10^{-19}$ J, $Au = 7.73 \times 10^{-19}$ J

Suppose gold is hit with monochromatic light from a 10 Watt bulb with a wavelength of 211 nm.

h. Determine the maximum kinetic energy of the ejected electrons.

$$E = h\nu = h\left(\frac{c}{\lambda}\right) = \frac{(6.63 \times 10^{-34} \text{ J}\cdot\text{s})(3.00 \times 10^8 \text{ m/s})}{(211 \times 10^{-9} \text{ m})} = 9.427 \times 10^{-19} \text{ J (photon energy)}$$

$$KE = E_{\text{photon}} - E_{\text{work fcn}} = 9.427 \times 10^{-19} \text{ J} - 7.73 \times 10^{-19} \text{ J} = 1.70 \times 10^{-19} \text{ J}$$

i. What is the min (which is it?) max wavelength that will be effective in causing the photoelectric effect in gold?

$$\lambda = \frac{hc}{E} = \frac{(6.63 \times 10^{-34} \text{ J}\cdot\text{s})(3.00 \times 10^8 \text{ m/s})}{7.73 \times 10^{-19} \text{ J}} = 2.57 \times 10^{-7} \text{ m} \text{ or } 257 \text{ nm}$$

maximum wavelength

j. How will the number of electrons ejected and the kinetic energy of the ejected electrons change (relative to the 10 Watt bulb with 211 nanometers), in each case? Assume the distance to the bulb is constant

	Number e- ejected	KE of ejected e-
10 W and 280 nm	none (fewer!)	not applicable
10 W and 230 nm	same	less
10 W and 150 nm	same	more
20 W and 211 nm	more	same
20 W and 280 nm	none	not applicable
20 W and 150 nm	more	more

(longer λ , so less energy per photon, so less leftover KE, so slower e^-)

(3j is on the previous page)

4a. Consider these values for bromine: -324 kJ/mole, 2.8, 1140 kJ/mole
Which value corresponds to the ionization energy? the electron affinity? the electronegativity?
Define each term as part of your answer.

Ionization energy: (IE)

The energy required to remove an electron from a gas phase atom or ion.
IE₁ is always positive; removing an e⁻ from an atom or ion.

(EA) Electron affinity: is always endothermic.

The energy change when an e⁻ is added to a gas phase atom or ion
can be positive (endo) or negative (exo), depending on the atom.

Electronegativity:

An element's tendency to attract e⁻ to itself when bonded. (no units)

Electronegativity = 2.8 (no units)

Ioniz. energy = 1140 kJ/mole

EA = -324 kJ/mole

b. What "reaction" corresponds to the first ionization energy of bromine?
Write a balanced "reaction" that shows what is happening, including phase subscripts and the energy term.



c. What "reaction" corresponds to the electron affinity of bromine?
Write a balanced "reaction" that shows what is happening, including phase subscripts and the energy term.



5a. For each pair, circle the atom or ion with the larger radius!

Ca or Br

Same row/period, but Ca is "left-er"

Fe or Fe⁺²

when e⁻ are lost, radius decreases

Te or Te⁻²

when e⁻ are gained, radius increases

Cl⁻¹ or Ca⁺²

Isoelectronic (both have 18 e⁻). Ca⁺² has more protons, so e⁻ are pulled in closer.

P or As

Same column, but As is lower

Fe⁺³ or Mn⁺²

Isoelectronic (23 e⁻) but Fe⁺³ has 1 more proton, so e⁻ pulled closer.

F⁻¹ or Cl⁻¹

Ca or Li

Ca is one column to right and two rows down.
moving one up/down is usually a larger effect than one left/right. Ca is two below.

c. For each pair, circle the atom or ion with the higher ionization energy:

P

or

As

Ca

or

Br

Fe⁺² or

Fe⁺³

Ca⁺² or

Ca

IE₁ < IE₂ < IE₃ < IE₄

this applies to the last two choices

IE increases

c. For each pair, circle the atom or ion with the higher ionization energy:

IE increases with each e⁻ you remove.

P or As

Ca or

Br

Fe⁺² or

Fe⁺³

Ca⁺² or

Ca

*Same column
but P is higher up*

*same row
but Br is further right*

6. a. Out of Silicon and Chlorine, which element would you expect to have a higher first ionization energy? Justify your choice; explain why the element you chose should have a higher ionization energy.

b. Out of Magnesium and Strontium, which element would you expect to have a higher first ionization energy? Justify your choice; explain why the element you chose should have a higher ionization energy.

c. Explain why arsenic(As) has a higher first ionization energy than selenium (Se).

d. Explain why Cadmium (Cd) has a higher first ionization energy than Indium (In).

See the next page!

(5c is on the previous page)

IE

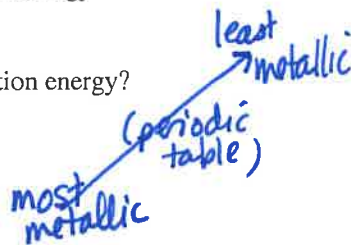
6. a. Out of Silicon and Chlorine, which element would you expect to have a higher first ionization energy? Justify your choice; explain why the element you chose should have a higher ionization energy.

b. Out of Magnesium and Strontium, which element would you expect to have a higher first ionization energy? Justify your choice; explain why the element you chose should have a higher ionization energy.

bb) since Sr has a lower IE, it is more "metallic!"

c. Explain why arsenic (As) has a higher first ionization energy than selenium (Se).

d. Explain why Cadmium (Cd) has a higher first ionization energy than Indium (In).



a) Si vs Cl. Cl has a higher IE than Si.

Si = [Ne] 3s² 3p²
 Cl = [Ne] 3s² 3p⁵

> Both Cl and Si would be losing a 3p electron. however, since Cl has 3 more protons than Si, Cl has a higher nuclear charge than Si, so Cl's 3p electrons will be more strongly attracted to its nucleus (than Si's 3p e- are to Si's nucleus), so the Cl 3p electron will need more energy to leave the atom.

b) Mg vs Sr

Mg has a higher IE than Sr.

Mg = [Ne] 3s² Sr = [Kr] 5s²

Mg and Sr are in the same column, so they have similar effective nuclear charges. But Mg would be losing a 3s electron, while Sr would lose a 5s electron.

Mg's 3s electron will be relatively close to the nucleus

(Mg has a smaller radius than Sr!) so Mg's 3s electron will be more strongly attracted to the nucleus than Sr's 5s electron,

so Mg's 3s electron will require more energy to leave the atom.

c) As = [Ar] 4s² 3d¹⁰ 4p³ Se = [Ar] 4s² 3d¹⁰ 4p⁴

(periodic trends would suggest that Se would have a higher IE, so this is an exception to the trend)

As:

1	1	1
---	---	---

Se:

1	1	1
---	---	---

4p

even though Selenium has a higher nuclear charge than Arsenic, only arsenic would be losing an electron from a half-filled 4p sublevel.

having a half-filled 4p sublevel gives Arsenic's 4p electrons relatively low potential energy, so Arsenic requires a relatively high amount of energy for its 4p electron to leave the atom.

d) Cd = [Kr] 5s² 4d¹⁰

In = [Kr] 5s² 4d¹⁰ 5p¹ (another exception!)

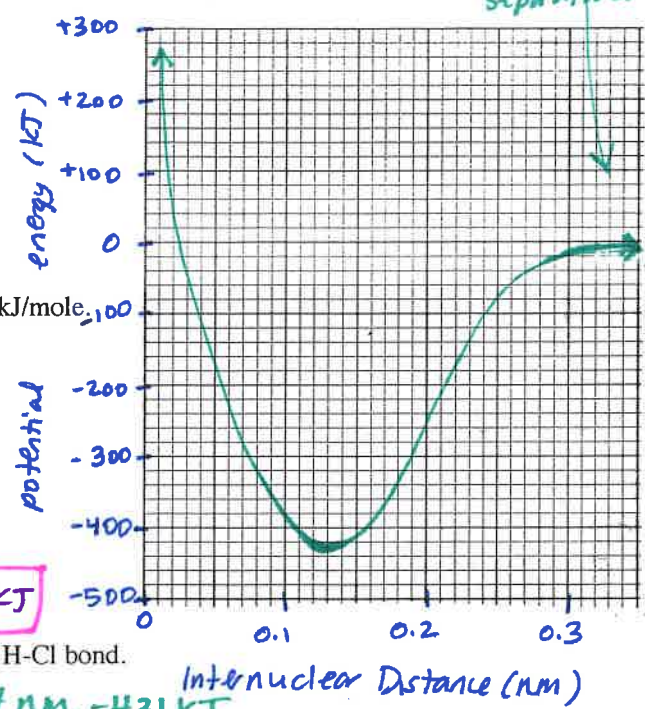
Though In has 1 more proton than Cd, (so a higher nuclear charge), Cd is losing a 5s electron, whereas In is losing a 5p electron.

5s is a lower energy level than 5p, so Cd would be losing an e- from a lower energy level, so will need more energy for the e- to leave.

7. a. The process of breaking a covalent bond into two separate atoms is always endo thermic. (energy is absorbed/required)
- b. The process of forming a covalent bond from two separate atoms is always exo thermic. (energy is released)
- c. What type(s) of EM radiation is most commonly absorbed/released in (a) and (b)? ultraviolet
- d. What type(s) of EM radiation is most commonly associated with vibration of bonds? Infrared
- e. What type(s) of EM radiation is most commonly associated with rotation of molecules? microwave
- f. When a valence electron is removed from an atom (in ionization), what type of EM radiation does this require?
ultra violet

potential energy is zero at infinite separation.

- g. Visible light is most commonly absorbed/released as Z.
- x. "hydrogen bonds" form or "break"
 - y. an atom or molecule is ionized to form a cation
 - z. electrons transition between nondegenerate d-orbitals.
- (aka "electronic transitions.")



8. In HCl, the H-Cl bond length is 0.127 nm, and the bond energy is 431 kJ/mole.
- a. What does the bond energy of 431 kJ/mole mean?

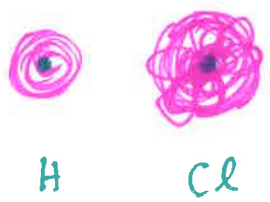
• 431 kJ are required to break 1 mole of H-Cl bonds: $\text{HCl} + 431 \text{ kJ} \rightarrow \text{H} + \text{Cl}$

• (OR) 431 kJ are released when H and Cl atoms bond to make 1 mole of HCl molecules: $\text{H} + \text{Cl} \rightarrow \text{HCl} + 431 \text{ kJ}$

- b. Sketch a graph showing potential energy vs internuclear distance for a H-Cl bond.

Note: The minimum energy is at 0.127 nm, -431 kJ

- c. When the H and Cl start out very far apart (at say, 10 nm), and then bond together at a distance of 0.127 nm, is energy absorbed or released? WHY?



energy is released. Since e- are negative and the nuclei are positive, the e- are attracted to the nuclei. So, as the nuclei get closer together, H's electrons can be closer to Cl's nucleus, and Cl's electrons can be closer to H's nucleus. energy is released as the attracted charges get closer to each other.

- d. If the H and Cl are bonded together at a distance of 0.127 nm, and they get closer together (say, at 0.10 nm), is energy absorbed or released? WHY?

energy is absorbed (potential energy increases). Since the nuclei are both positive, the nuclei repel each other. So they'll need to increase potential energy to get closer to each other.

(since 0.10 nm is closer than the optimum bond length of 0.127 nm, we know that potential energy will ~~decrease~~ increase due to the repulsion between nuclei more than it will decrease due to the attraction ~~due to the~~ between the e- and nuclei, when the atoms get close together)

8e. Convert the 431 kJ/mole (the bond energy of the H—Cl bond) to a photon energy. (Joules per photon).

$$\left(\frac{431 \text{ kJ}}{\text{mole}}\right) \left(\frac{1000 \text{ J}}{1 \text{ kJ}}\right) \left(\frac{1 \text{ mole photons}}{6.02 \times 10^{23} \text{ photons}}\right) = 7.159 \times 10^{-19} \rightarrow \boxed{7.16 \times 10^{-19} \text{ J per photon (or per bond)}}$$

f. Find the wavelength (in nm) that corresponds to this photon energy.

$$\nu = \frac{E}{h} = \frac{7.159 \times 10^{-19} \text{ J}}{6.63 \times 10^{-34} \text{ J}\cdot\text{s}} = 1.0799 \times 10^{15} \text{ s}^{-1}$$

$$\lambda = \frac{c}{\nu} = \frac{3.00 \times 10^8 \frac{\text{m}}{\text{s}}}{1.0799 \times 10^{15} \text{ s}^{-1}} = 2.78 \times 10^{-7} \text{ m} \quad \text{or} \quad \boxed{278 \text{ nm}}$$

UV = 10-400 nm so this is UV.

g. Breaking bonds usually requires photons in the ultraviolet range (and a few hundred kJ/mole).

Removing valence electrons also requires photons in the ultraviolet range. (and 100's or 1000's of kJ/mole)

However, removing a CORE electron often requires X-rays! Explain why!

Core electrons are closer to the nucleus than valence electrons, (and core electrons also "experience" ~~more~~ a higher effective nuclear charge than valence electrons, due to less shielding)

so core electrons are more strongly attracted to the nucleus, so need more energy to leave the atom. (x-rays are more energetic than UV)

h. Removing a "1s" electron from a sulfur atom requires x-rays with a wavelength of 0.501 nm (or shorter).

Calculate the photon energy of these x-rays.

$$\nu = \frac{c}{\lambda} = \frac{3.00 \times 10^8 \text{ m/s}}{0.501 \times 10^{-9} \text{ m}} = 5.988 \times 10^{17} \text{ s}^{-1}$$

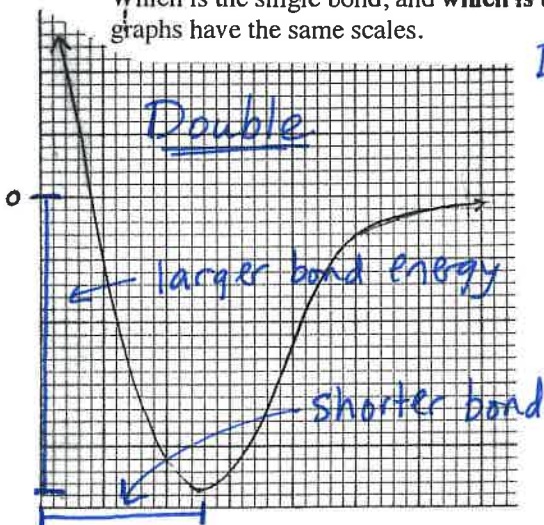
$$E = h\nu = (6.63 \times 10^{-34} \text{ J}\cdot\text{s})(5.988 \times 10^{17} \text{ s}^{-1}) = \boxed{3.97 \times 10^{-16} \text{ J}}$$

i. Convert the photon energy into kilojoules per mole.

$$\left(\frac{3.9701 \times 10^{-16} \text{ J}}{\text{photon}}\right) \left(\frac{1 \text{ kJ}}{1000 \text{ J}}\right) \left(\frac{6.02 \times 10^{23} \text{ photons}}{1 \text{ mole photons}}\right) = 238998 \text{ kJ/mole} \rightarrow \boxed{239000 \text{ kJ/mole}}$$

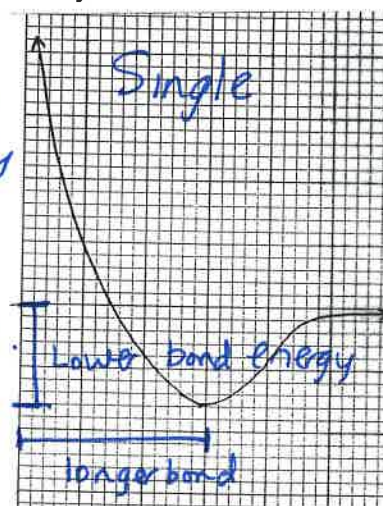
J. The graphs below show potential energy vs internuclear distance for a N-N single bond and a N-N double bond.

Which is the single bond, and which is the double bond? Explain in two different ways how you know. Assume the graphs have the same scales.




Double bonds are stronger than single bonds; Double Bonds require more energy to break. (have a "higher bond energy")

Double bonds are also shorter than single bonds.



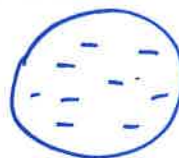
9. Names to Know: (What they did, their atomic models (if applicable), and roughly when.)

Dalton, ≈ 1800 . Atoms! The first one to use data to argue the existence of atoms. Model: billiard ball. 

Thomson, ≈ 1900 (A hard, impenetrable sphere)

- Discovered the electron, and calculated the mass/charge ratio of the electron and of several cations. Model: "plum pudding"
- Used a cathode ray tube.

Einstein, 1905 Light = particles (now called "photons")



negative e^- suspended in positive dough. neutral overall)

Explained / predicted the photoelectric effect using the idea that light is particle-like.

Rutherford,

1911 Discovered the nucleus.

gold foil expt - shot positive particles (alphas) at a thin sheet of gold foil. A tiny fraction of alphas bounced back.



Bohr,

1913. Discovered / proposed Quantized energy levels.

(e^- can only be at certain energy levels within the atom.) his model (at first) is the mini solar system.

e^- orbit the nucleus at distinct energy levels called n-levels.

as n increases, distance from the nucleus and energy increase.

de Broglie,

1924. Matter waves -

e^- have wave properties.

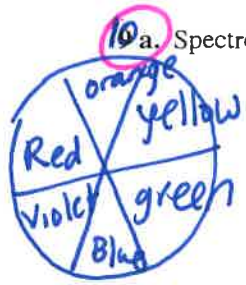
< Schrodinger > ≈ 1927 these 2
Heisenberg > invented Quantum

Mechanics
(s, p, d, f orbitals)

↑
Heisenberg (1927)

uncertainty principle: you can't determine the precise momentum and position of an e^- in ~~an~~ an atom.

(Chadwick - actually you don't need to know Chadwick. but FYI he discovered the neutron in 1932)



10a. Spectrophotometry, Beer's Law, Complementary Colors:

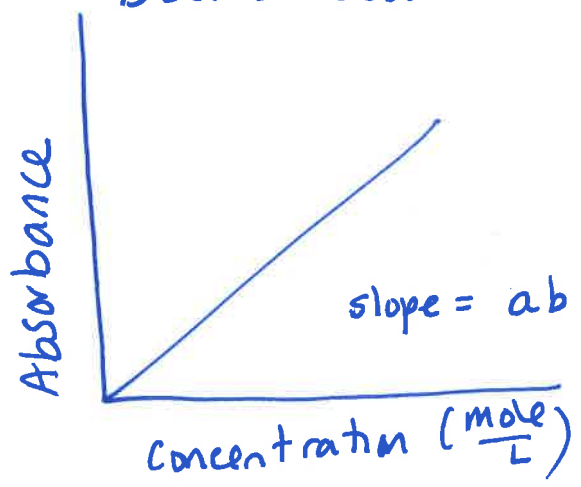
Red and Green are complementary colors
 Orange and Blue are complementary colors
 Violet and yellow " " "
 (continued below)

b. Which of these would you expect to be colored?

	Fe ²⁺	Ti ²⁺	Ti ⁴⁺	Ca ²⁺	Cr ³⁺	Zn ²⁺
e- of atom	[Ar]4s ² 3d ⁶	[Ar]4s ² 3d ²	[Ar]4s ² 3d ²	[Ne]3s ² 3p ⁶ 4s ²	[Ar]4s ¹ 3d ⁵	[Ar]4s ² 3d ¹⁰
e- of ion	[Ar]3d ⁶	[Ar]3d ²	[Ar]	[Ne]3s ² 3p ⁶	[Ar]3d ³	[Ar]3d ¹⁰
partially filled d-orbitals?	yes	yes	no	no	yes	no
colored?	yes	yes	no	no	yes	no

a) *cmtd* A solution will appear as the complementary color of the light it absorbs. For example, if a solution absorbs violet more strongly than the other colors, the solution will appear yellow.
 If the solution doesn't absorb visible light, it will be colorless.

Beer's Law: $A = abc$



The more concentrated a solution, the more light it will absorb (Absorbance is directly proportional to concentration), (and the darker color it will have) so long as you test it at a wavelength that the solution significantly absorbs*.

The more length of solution ("path length") the light goes through, the higher the absorbance.

* for example, if a solution is yellow, it probably absorbs violet light very strongly, so you'd set the spectrophotometer to a wavelength in the violet range. (Though it also might absorb UV.....)

(#10, continued)

An experiment is done to measure the absorbance of a solution of $\text{Fe}(\text{NO}_3)_3$, which is orange.

c. What type of wavelength of light (what color) should be used in the spectrophotometer? Why?

Blue!



Blue is the complementary color of orange.

Since the solution appears orange, it must absorb blue light strongly.

d. A student creates a ferric nitrate solution by dissolving 10.0 grams of ferric nitrate into a total solution volume of 250.0 mL (in a volumetric flask) and then mixing the solution thoroughly. They then fill a clean, dry cuvette about halfway up with the ferric nitrate solution, wipe the cuvette to remove any fingerprints, and then correctly measure the absorbance.

How would the reported absorbance change (increase, decrease, or no change?) if the student did the following things?

$$A = abc \quad (\text{Absorbance (A) is directly proportional to concentration (c)})$$

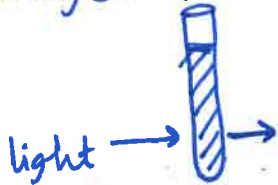
Decrease They dissolved the 10.0 grams into a 500.0 mL flask instead of a 250. mL flask (and filled it to the line)

They doubled the solution volume while keeping moles solute the same, so the molarity is half as large as the original solution's molarity. Lower concentration \rightarrow lower absorbance.

Increase They didn't wipe off the cuvette, so it had fingerprints on it.

Fingerprints block the beam of light (by scattering and reflecting it) so less light will be transmitted to the detector. Since transmittance is lower, the machine will report a higher absorbance.

No change They filled the cuvette $\frac{3}{4}$ of the way, instead of $\frac{1}{2}$ of the way.



So long as there is enough solution in the cuvette that the beam is actually passing through the solution (and not the air above the solution) the depth of liquid is irrelevant.

Decrease Right before adding the ferric nitrate solution, they rinsed the cuvette with distilled water, and did not dry it.

Amateurs! The water in the cuvette will dilute their solution to a lower molarity.

Lower concentration \rightarrow Lower absorbance

no change They dissolved 20.0 grams of ferric nitrate instead of 10.0 grams, and 500.0 mL instead of 250.0 mL (and filled it to the line).

$$\text{Molarity} = \frac{\text{moles solute}}{\text{Liters solution}}$$

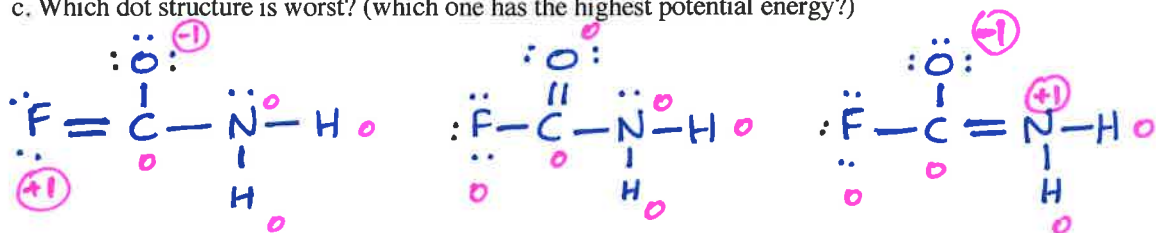
they doubled the moles of solute and the liters solution, so the "new" molarity is the same.

Increase After pouring the ferric nitrate solution into the cuvette, they waited a day before testing it in the spectrophotometer. (It was a hot day, so 10% of the liquid evaporated)

If H_2O evaporates (and $\text{Fe}(\text{NO}_3)_3$ does not evaporate, which it shouldn't since it is ionic and non-volatile.) the solution will become more concentrated. Higher concentration \rightarrow higher absorbance.

11. Three possible dot structures for a compound are shown below.

- Determine the formal charge for each atom in each structure.
- Which dot structure is best? (which one has the lowest potential energy?)
- Which dot structure is worst? (which one has the highest potential energy?)

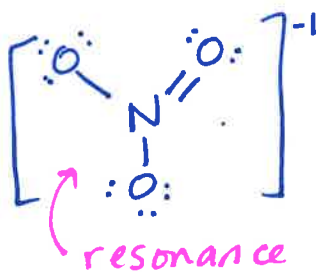


↑
Best. All the formal charges are zero.
 ↑
worst. out of O, F, and N, Fluorine has the highest electronegativity. (and is the most electronegative element) so Fluorine shouldn't have a positive formal charge.

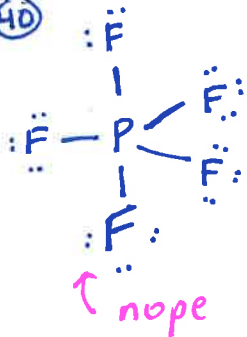
12. Which of these molecules/ions have resonance? Draw the dot structure of each to tell.

(They must have a double bond that can be in 2 or more equivalent locations in the molecule/ion)

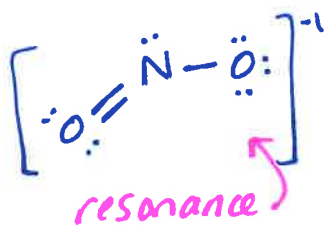
NO₃⁻¹
 (24)



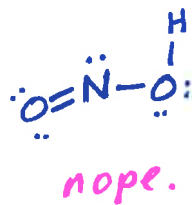
PF₅
 (40)



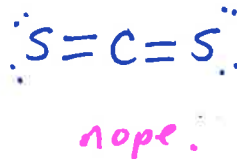
NO₂⁻¹
 (18)



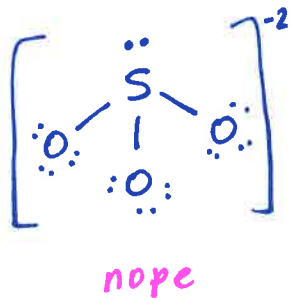
HNO₂
 (18)



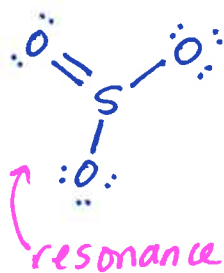
CS₂ (16)



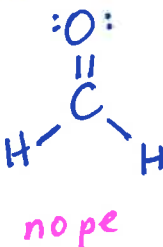
SO₃⁻²
 (26)



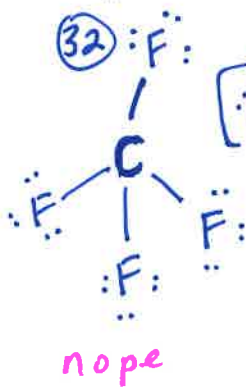
SO₃
 (24)



CH₂O (C is central)
 (12)



CF₄
 (32)



IBr₂⁻¹
 (22)



PO₂⁻¹ (18)



13a. Draw the dot structures or the carbonate ion (CO_3^{2-}), and carbonic acid (H_2CO_3). Which of these have resonance?

b. There should be 3 different C—O bond lengths (total) in the structures you drew.

Indicate which C—O bond is expected to be the shortest, and which is expected to be the longest.

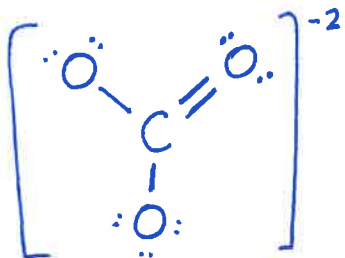
c. There should be 3 different C—O bond strengths (total) in the structures you drew.

Indicate which C—O bond should be the strongest, and which should be the weakest.

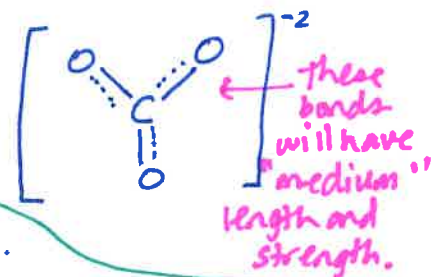
Also, which C—O bond should have the highest "bond energy", and which is expected to be the lowest "bond energy"?

d. Determine all bond angles in carbonate ion and in carbonic acid.

(If they are more or less than the ideal bond angles, you will need to estimate the actual angles.)

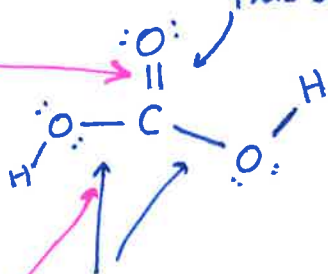


← carbonate ion has resonance. The double bond has 3 possible equivalent positions, so the double bond will actually be spread out overall all 3 positions, so each bond is more like a " $1\frac{1}{3}$ " bond instead of a strict single or double bond:



The double bond is the shortest and strongest bond. It has the highest bond energy (needs the most energy to break)

this bond is strictly a double bond.



so these 2 C—O bonds are strictly single bonds

these C—O single bonds will be the longest. They are also the weakest, and have the lowest

Bond energy (they require the least energy to break)

Carbonic acid does not have resonance.

(If you put the double bond in the other C—O positions you'd be giving that oxygen a positive formal charge, so the C—O positions are not equivalent) The C—O double bond is in one specific "location."

14. Do the following for NF_3 , BCl_3 , CH_2S (C is the central atom), PF_5 , SO_2 , ICl_4^- , CS_2 , and IF_5

a. Lewis Dot structure

b. Identify VSEPR shape name(s) and bond angles, and sketch it

(If the bond angles are not the "ideal" angles, you'll need to estimate what the angles would be.)

c. Is it polar? If so, draw the net polarity arrow. (Don't worry about the polarity of the ion...)

(all the bonds have at least a 0.5 ΔEN except those in CH_2S)

d. Determine the hybridization of the central atom, unless it has an expanded octet (more than 8 v.e.).

e. Draw the orbital filling diagram for the central atom in NF_3 , BCl_3 , CH_2S , SO_2 and CS_2 before and after hybridization.

f. Which of the molecules have at least 1 pi bond? Is/are the pi bond(s) localized or delocalized?

The Key is on the next pages.

(The rest of this review sheet would be relevant for the quantum part of the FINAL EXAM, but not for the test on tuesday. So for now you can ignore the hybridization and polarity parts on the answer key for this problem)

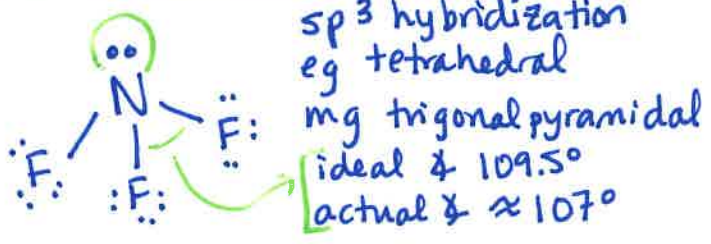
14

- Do the following for NF_3 , BCl_3 , CH_2S (C is the central atom), PF_5 , SO_2 , ICl_4^- , CS_2 , and IF_5
 - Lewis Dot structure
 - Identify VSEPR shape name(s) and bond angles, and sketch it (If the bond angles are not the "ideal" angles, you'll need to estimate what the angles would be.)
 - Is it polar? If so, draw the net polarity arrow. (Don't worry about the polarity of the ion...)

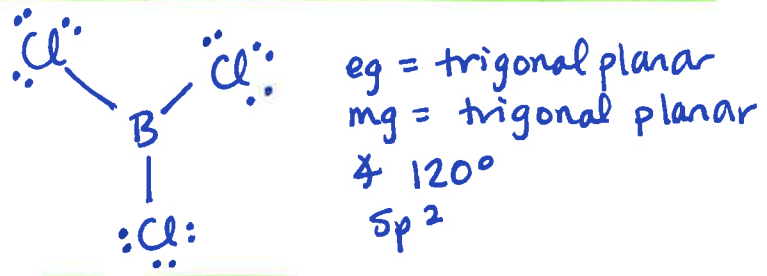
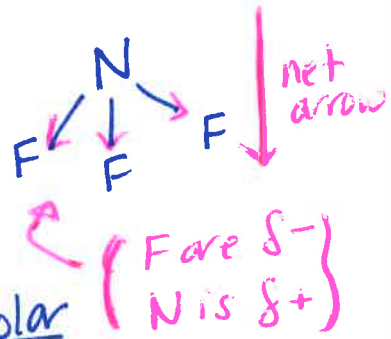
(all the bonds have at least a 0.5 ΔEN except those in CH_2S)

 - Determine the hybridization of the central atom, unless it has an expanded octet (more than 8 v.e.).
 - Draw the orbital filling diagram for the central atom in NF_3 , BCl_3 , CH_2S , SO_2 and CS_2 before and after hybridization.
 - Which of the molecules have at least 1 pi bond? Is/are the pi bond(s) localized or delocalized?

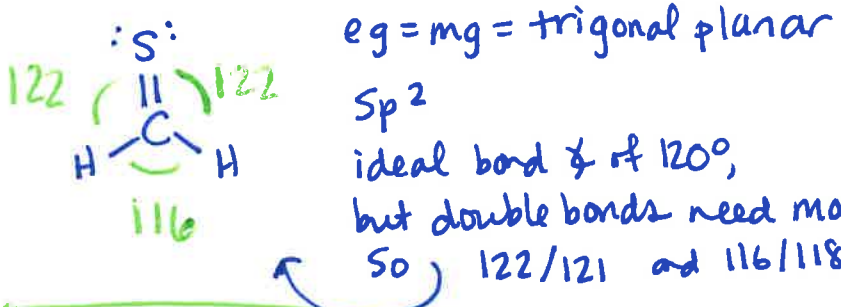
eg = electron geometry
mg = molecular geometry



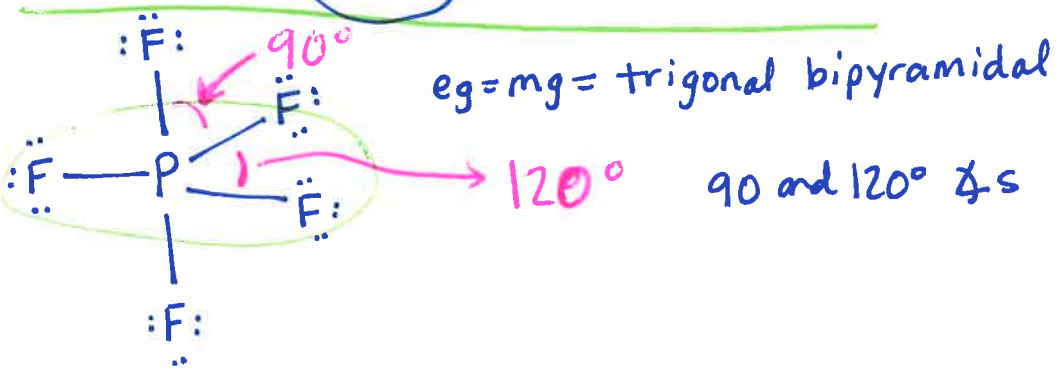
NF_3 is polar



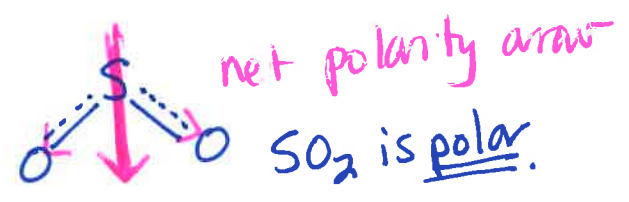
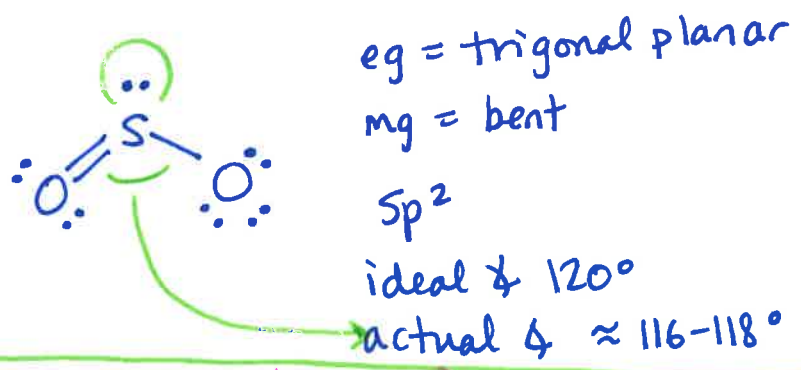
BCl_3 is nonpolar
(symmetrical)



nonpolar
due to low ΔEN



nonpolar due to symmetry



(Cont'd, next page)

14. Do the following for NF_3 , BCl_3 , CH_2S (C is the central atom), PF_5 , SO_2 , ICl_4^- , CS_2 , and IF_5

a. Lewis Dot structure

b. Identify VSEPR shape name(s) and bond angles, and sketch it

(If the bond angles are not the "ideal" angles, you'll need to estimate what the angles would be.)

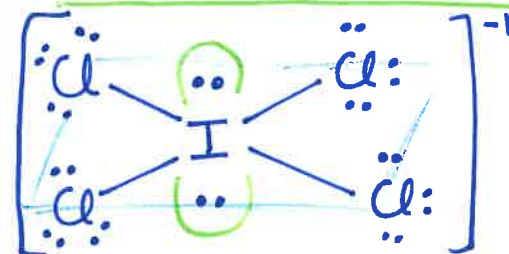
c. Is it polar? If so, draw the net polarity arrow. (Don't worry about the polarity of the ion...)

(all the bonds have at least a 0.5 ΔEN except those in CH_2S) — oops: and CS_2

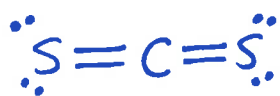
d. Determine the hybridization of the central atom, unless it has an expanded octet (more than 8 v.e.).

e. Draw the orbital filling diagram for the central atom in NF_3 , BCl_3 , CH_2S , SO_2 and CS_2 before and after hybridization.

f. Which of the molecules have at least 1 pi bond? Is/are the pi bond(s) localized or delocalized?

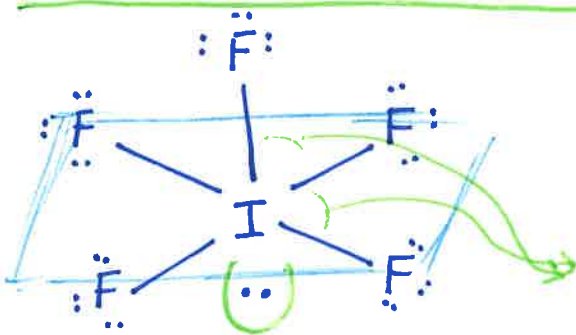


eg = octahedral
mg = square planar
all \angle are 90°

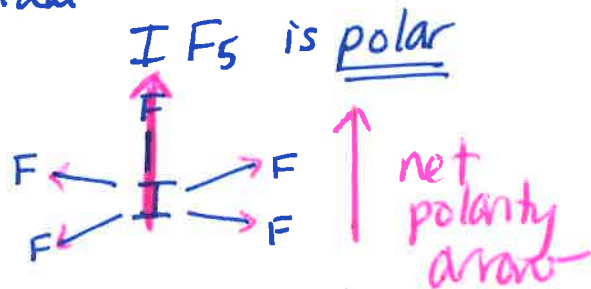


eg = mg = linear
sp
 180°

CS_2 is nonpolar
due to symmetry
(also has a low ΔEN)



eg = octahedral
mg = square pyramidal
ideal \angle 90°
actual $\angle \approx 89^\circ$



f) CS_2 has two π bonds. (localized; no resonance)

CH_2S has one π bond (~~the~~ localized; no resonance)

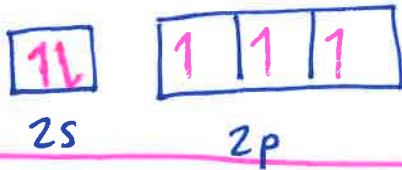
SO_2 has one π bond. it is delocalized over both S-O bonds
(SO_2 has resonance).

(e) is on the next page

14 e

NF₃ (sp³)

N atom

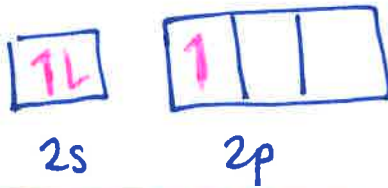


hybridized N



BCl₃ (sp²)

B atom



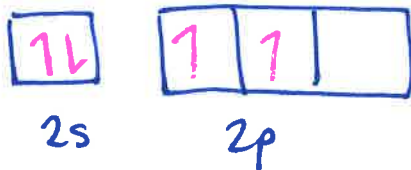
hybridized B



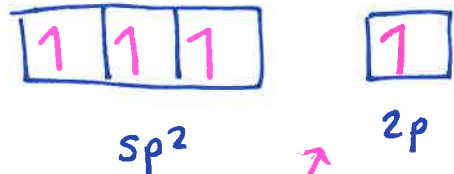
nothing in here (no π bond)

CH₂S (sp²)

Carbon atom



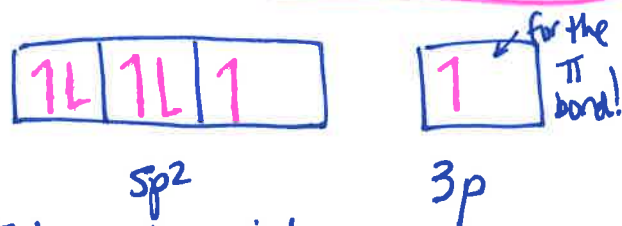
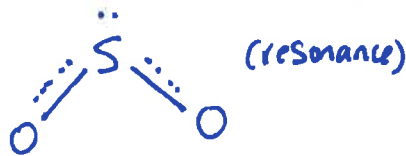
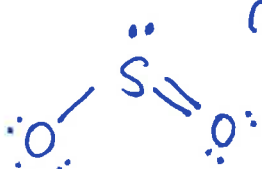
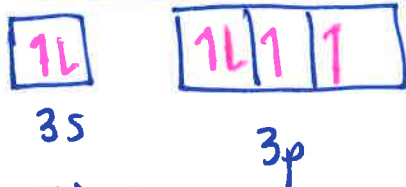
hybridized carbon



the carbon needs one half filled 2p orbital to make one π bond

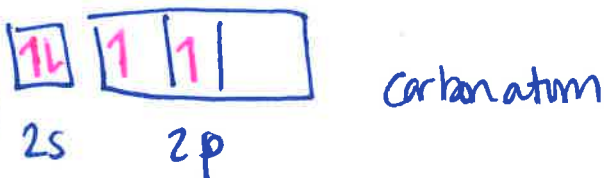
SO₂

(sp²) unhybridized S (S atom)



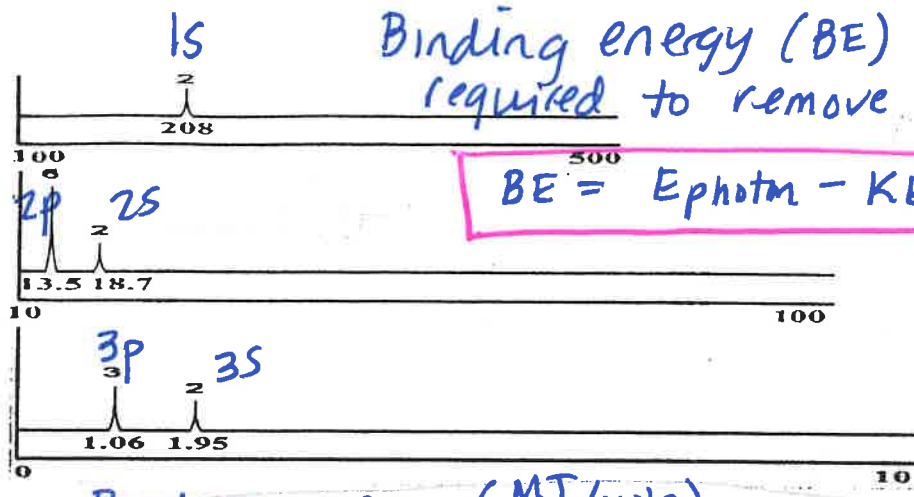
This one is weird... According to dots, S is involved in 2 σ and 1 π bond... and to make the 2 σ bonds it would need 2 half filled sp² orbitals.. but S has a positive F.C., so it contributes both the e⁻ to one of the bonds

CS₂ (sp)



The carbon needs two half filled p orbitals to make the two π bonds

relative # of electrons



Binding energy (BE) is the energy required to remove an electron from an atom.

$$BE = E_{\text{photon}} - KE \text{ of ejected } e^-$$

Start w/ lowest potential energy (PE) need the most energy to leave (have highest BE)

Binding energy (MJ/mole)

- 15 Consider this spectrum acquired by doing photoelectron spectroscopy with Phosphorus. $1s^2 2s^2 2p^6 3s^2 3p^3$
- Label each axis. Assume that the energy units are MJ/mole.
 - Label each peak - which electrons correspond to which peak?
 - How do the peak heights correspond to the orbitals/configuration/electrons? Explain.

The peak height is proportional to the number of electrons in the particular orbital type. (or "sublevel")
 For example the $2p^6$ peak is 3x taller than the $2s^2$ peak.

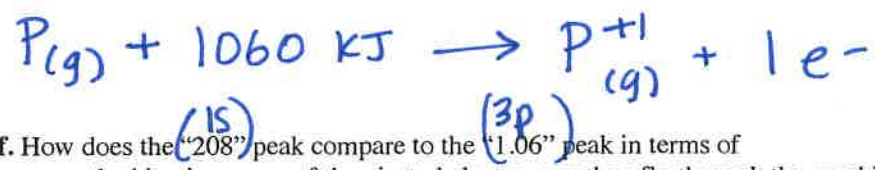
start w/ highest PE need least E to leave lowest BE

- d. What is the "IE1" ("first ionization energy") of phosphorus, in kJ/mole?

$$\frac{6}{2} = \frac{3}{1}$$

1.06 MJ/mole 1060 kJ/mole

- e. Write the chemical equation that corresponds to IE1 of phosphorus, including phase subscripts and the energy term.



- f. How does the "208" peak compare to the "1.06" peak in terms of

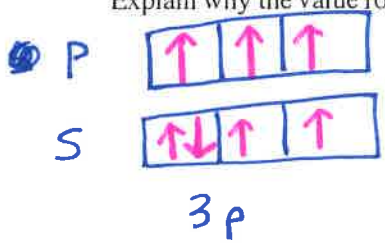
The "208" e^- will have least kinetic energy.. and the slowest speed.
 The 208 peak is for 1s electrons.. These start with the lowest potential energy
 In the "208" peak, the e^- require more energy to leave than (208 MJ vs 1.06 MJ!) with the 1.06 peak.

- g. In the PES spectrum for sulfur, Sulfur's highest energy peak is at 239 MJ/mole. What orbital does this correspond to? $1s$ #16 $1s^2 2s^2 2p^6 3s^2 3p^4$

Explain why the maximum value for sulfur (239) is greater than the max value for phosphorus (208).
 Sulfur has 1 more proton than phosphorus, so Sulfur has a more positively charged nucleus, so sulfur's 1s electrons will be more attracted to Sulfur's nucleus than Phosphorus's 1s electrons will be attracted to the phosphorus nucleus. So sulfur's electrons will require more energy to leave the atom/nucleus.

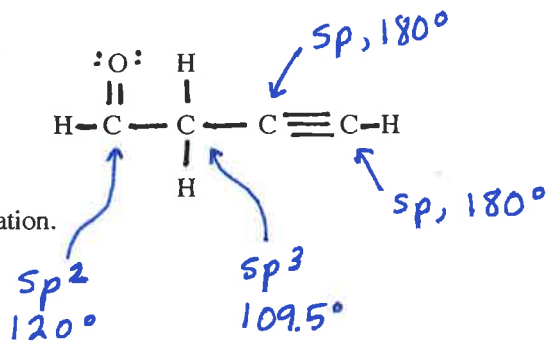
- h. Sulfur's lowest energy peak is at 1.00 MJ/mole. What orbital does this correspond to? $3p$

Explain why the value for sulfur (1.00) is less than the value for phosphorus (1.06) for these electrons.

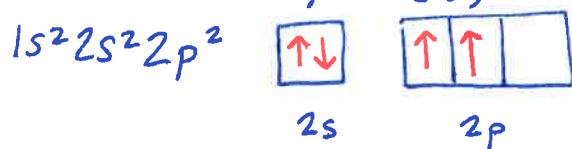


← P has a half-filled 3p sublevel (S doesn't) which gives Phosphorus's 3p electrons relatively low potential energy, so P's 3p electrons will need a relatively large amount of energy to leave; Sulfur's e^- will need a relatively small energy to leave.

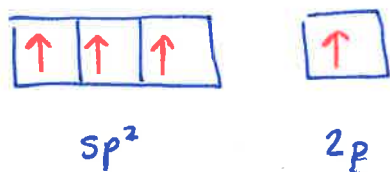
16. How many total sigma and pi bonds in this? $8\sigma, 3\pi$
 What is the hybridization of each carbon?
 What is the ideal bond angle at each carbon?
 Does this molecule have resonance? *no.*
 Draw the orbital diagram for an unhybridized carbon atom.
 For the first three carbons, draw the orbital diagram after hybridization.



Carbon atom (unhybridized)

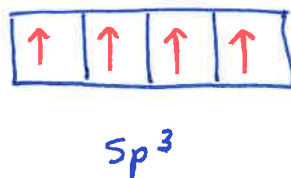


First carbon (on the left) is sp^2 ; 120°

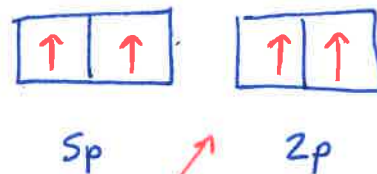


The left carbon is involved in one π bond so it needs one half-filled p-orbital.

Second carbon is sp^3 , 109.5°



third carbon is sp , 180°



The 3rd carbon is involved in two π bonds, so it needs two half-filled p-orbitals.

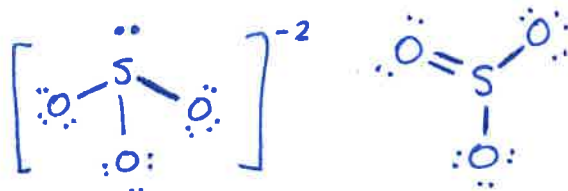
17a. Consider the species SO_3^{2-} and SO_3 . Which one(s) of these exhibit resonance?

b. Another way I could have asked (a), is, which one(s) of these have a delocalized π bond.

c. Explain your answers to (a) and (b).

d. How do the S-O bond strengths compare in the above two things?

e. Identify the hybridization of the sulfur in the each species in (a).



(a) only SO_3 has resonance.

(c) SO_3^{2-} has no double bond, so it can't have resonance. SO_3 has a double bond, and there are 3 equivalent positions the double bond could occupy. So SO_3 has resonance; the π bond in SO_3 is delocalized (spread out) over all 3 S-O bonds, so the S-O bonds in SO_3 are the same length + strength.

(d) SO_3^{2-} has longer bonds and weaker bonds.

SO_3 has shorter and stronger bonds: All 3 S-O bonds in SO_3 are between a single and double bond in terms of length and strength, and double bonds are shorter and stronger than singles.

(e) $SO_3^{2-}: sp^3$

$SO_3: sp^2$

this formula will be given on the test.

18a. If an electron in a hydrogen atom "jumps" from $n=5$ to $n=2$, what will be the change in energy?

$$\Delta E = -2.18 \times 10^{-18} \text{ J} \left(\frac{1}{n_f^2} - \frac{1}{n_i^2} \right) = -2.18 \times 10^{-18} \left(\frac{1}{2^2} - \frac{1}{5^2} \right) = -4.578 \times 10^{-19} \text{ J}$$

(ΔE is negative, which means energy is released)

$$\boxed{-4.58 \times 10^{-19} \text{ J}}$$

b. Will the atom *absorb* or *release* energy as this change occurs? (which one?) why?

The atom releases energy. The electron "moved" closer to the nucleus when it went from $n=5$ to $n=2$. Since electrons are negative and the nucleus is positive, the e^- are attracted to the nucleus, so will have relatively low energy when close to the nucleus. So the e^- must release energy when it approaches the nucleus, as it did here.

Suppose an electron in a hydrogen atom starts at $n=1$, and then leaves the atom.

This means that the final n -level is essentially ∞ !

c. How much energy must the atom absorb to do this, in Joules?

$$\Delta E = -2.18 \times 10^{-18} \text{ J} \left(\frac{1}{\infty^2} - \frac{1}{1^2} \right) = -2.18 \times 10^{-18} \text{ J} (-1) = \boxed{2.18 \times 10^{-18} \text{ J}}$$

d. Find the frequency and wavelength of the photon that the atom must absorb (starting with the energy from part(c)).

$$E = h\nu$$

$$\nu = E/h = \frac{2.18 \times 10^{-18} \text{ J}}{6.626 \times 10^{-34} \text{ J}\cdot\text{s}}$$

$$\nu = 3.29 \times 10^{15} \text{ s}^{-1} \text{ or Hz (frequency)}$$

$$c = \lambda\nu$$

$$\lambda = \frac{c}{\nu} = \frac{3.00 \times 10^8 \text{ m/s}}{3.2901 \times 10^{15} \text{ s}^{-1}}$$

$$\lambda = 9.12 \times 10^{-8} \text{ m}$$

$$\text{or } \underline{91.2 \text{ nm (wavelength)}}$$

e. What type of light is this? (What part of the EM spectrum?)

(hint, it is the same type of EM radiation that is typically required to ionize an atom!)

Ultraviolet! Nearly all atoms and molecules require UV radiation to knock out valence electrons, or to break bonds.

f. Convert the energy required to kJ/mole.

$$(2.18 \times 10^{-18} \text{ J}) \left(\frac{1 \text{ kJ}}{1000 \text{ J}} \right) \left(\frac{6.02 \times 10^{23}}{\text{mole}} \right) = 1312.36 \rightarrow \boxed{1310 \text{ kJ/mole}}$$

(and this is indeed the IE of hydrogen!)