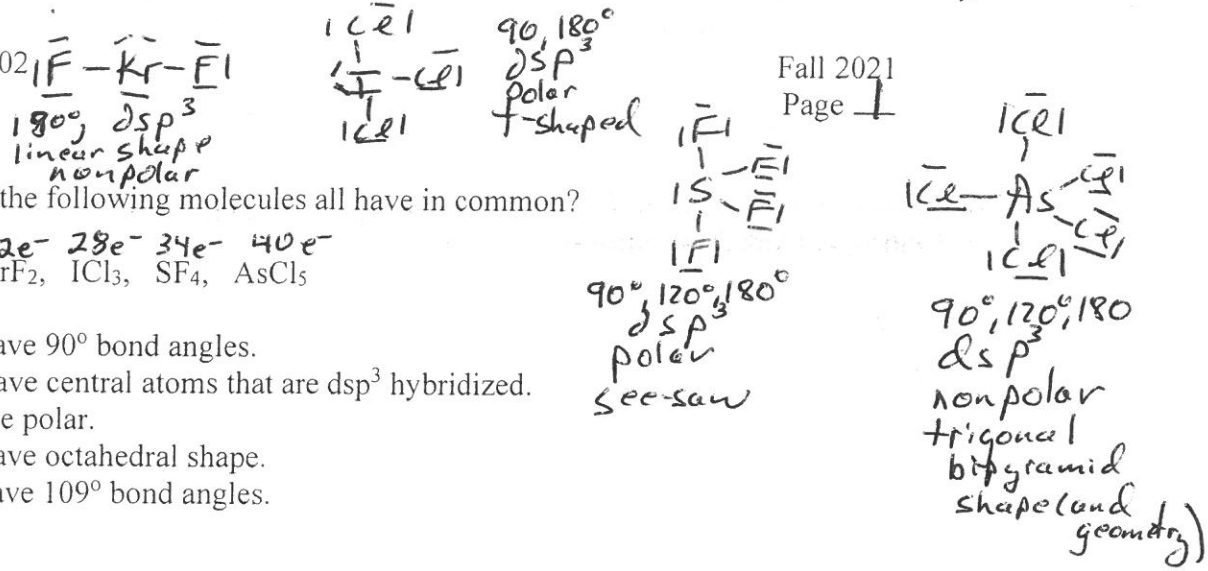
Fall 2021 Exam I Detailed Solutions

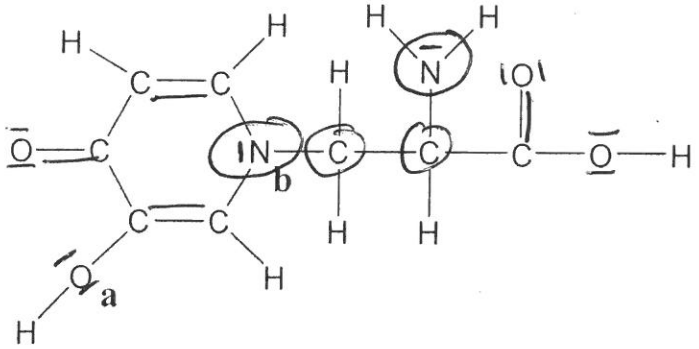


1. What do the following molecules all have in common?

22e⁻ 28e⁻ 34e⁻ 40e⁻
KrF_2, ICl_3, SF_4, $AsCl_5$

a) All have 90° bond angles.
b) All have central atoms that are dsp^3 hybridized.
c) All are polar.
d) All have octahedral shape.
e) All have 109° bond angles.

Mimosine, $C_8H_{10}N_2O_4$, is a natural **organic** compound found in large quantities in the seeds and foliage of legume plants and has been shown to inhibit hair growth and hair loss in mice. Complete the Lewis structure of mimosine and answer the next two questions.



"Organic rules"
C: 4 bonds + 0 lonepairs
N: 3 " + 1 " "
O: 2 " + 2 " "

2. How many carbon and nitrogen atoms are sp^3 hybridized?

a) 4 b) 5 c) 6 d) 7 e) 8

The circled C and N atoms are all sp^3 hybridized since they exhibit 109° bond angles (tetrahedral geometry). Note that the other carbon atoms have 120° bond angles (trigonal planar geometry), so they are sp^2 hybridized. The oxygen atom a and the nitrogen atom b both exhibit tetrahedral geometry. So their bond angles are ~109°.

3. What are the approximate bond angles about the oxygen atom labeled **a** and nitrogen atom labeled **b**, respectively?

a) 109°; 109° b) 180°; 120° c) 180°; 90° d) 109°; 120° e) 180°; 109°

K: [Ar] $4s^1$, $\frac{\uparrow}{4s}$ 1 unpaired electron; Zn^{2+}: [Ar] $4s^0 3d^{10}$, $\frac{\uparrow\downarrow}{4s}$ $\frac{\uparrow\downarrow}{3d}$ $\frac{\uparrow\downarrow}{3d}$ $\frac{\uparrow\downarrow}{3d}$ $\frac{\uparrow\downarrow}{3d}$ 0 unpaired electrons. Note that Zn^{2+} is an exception to the typical filling order of electrons.

4. Which of the following atoms/ions has the largest number of unpaired electrons in the ground state?

Mn: [Ar] $4s^2 3d^5$ $\frac{\uparrow}{4s}$ $\frac{\uparrow}{3d}$ $\frac{\uparrow}{3d}$ $\frac{\uparrow}{3d}$ $\frac{\uparrow}{3d}$ $\frac{\uparrow}{3d}$ 5 unpaired electrons

a) K b) Zn^{2+} c) Mn d) Cr e) As

As: [Ar] $4s^2 3d^{10} 4p^3$ $\frac{\uparrow}{4p}$ $\frac{\uparrow}{4p}$ $\frac{\uparrow}{4p}$ 3 unpaired electrons

Cr: [Ar] $4s^1 3d^5$ $\frac{\uparrow}{4s}$ $\frac{\uparrow}{3d}$ $\frac{\uparrow}{3d}$ $\frac{\uparrow}{3d}$ $\frac{\uparrow}{3d}$ $\frac{\uparrow}{3d}$ 6 unpaired electrons.

Note: Cr is another exception to the typical filling order.

5. Which of the following is **not** the correct chemical formula for the compound named?

a) phosphorus trioxide P_2O_3 diphosphorus trioxide is correct. b) sodium sulfite Na_2SO_3 $Na^+ + SO_3^{2-}$ ions

c) ammonium nitrate NH_4NO_3 ok NH_4 and NO_3^- ions d) perchloric acid $HClO_4$ ok

e) copper(II) acetate $Cu(C_2H_3O_2)_2$ ok Cu^{2+} and $C_2H_3O_2^-$ ions.

6. How many of the following four statements (I-IV) is/are **true**?

I. T One reason covalent bonds form is that the shared electrons between two atoms are simultaneously attracted by two different nuclei.

II. T The ionic compound NaCl does not exist as Na^{2+} and Cl^{2-} ions because it takes too much energy to form the Na^{2+} and Cl^{2-} ions.

III. T As the electronegativity difference between two elements increases, the bond between those two elements becomes more ionic.

IV. F The bond between any two different nonmetals is always a polar covalent bond. P and H have identical electronegativities. So a P-H bond is a nonpolar (pure) covalent bond.

a) 0 (None are true.) b) 1 c) 2 d) 3 e) 4 [All four statements (I-IV) are true]

IE trend ↑ $E = h\nu = \frac{hc}{\lambda}$, $\lambda\nu = c$; wavelength and photon energy are inversely related.

7. Which of the following statements regarding ionization energies is **true**? From trend, $IE_{Cl} > IE_{Cs}$; Cl needs more energetic photon to remove an electron, which will be a shorter wavelength.

F a) Longer wavelength electromagnetic radiation is required to ionize Cl as compared to Cs. $IE_S > IE_{Se}$; A shorter wavelength (more energetic photon) of light is needed to ionize S.

T b) Shorter wavelength electromagnetic radiation is required to ionize S as compared to Se. $IE_{Mg} > IE_K$; More energetic photon needed to ionize Mg.

F c) More energetic photons of electromagnetic radiation are required to ionize K as compared to Mg. $IE_P > IE_{Ca}$; Higher frequency (more energetic photon) light needed to ionize P.

F d) Higher frequency electromagnetic radiation is required to ionize Ca as compared to P. $IE_{Ne} > IE_{Cl}$ More energetic light needed to ionize Ne.

F e) Electromagnetic radiation having a faster velocity is required to ionize Cl as compared to Ne. All EMR travel at the same speed.

When ions are present, ionic bonding occurs. Only in P_2O_5 are there no ions.

8. Which of the following plant fertilizer compounds contains only covalent bonds?

$NH_4^+ + SO_4^{2-}$ $Ca^{2+} + PO_4^{3-}$ $K^+ + O^{2-}$ $K^+ + Cl^-$ covalent - no ions only nonmetals present.

a) $(NH_4)_2SO_4$ b) $Ca_3(PO_4)_2$ c) K_2O d) KCl e) P_2O_5

$[O=\ddot{N}-\ddot{O}]^-$ + 1 other ~120° $[\ddot{N}=N=\ddot{N}]^+$ 2 others 180° ← correct answer to question

9. In each of the following, nitrogen is/are the central atom(s). In which compound/ion are the bond angles about the central nitrogen(s) **not** approximately 120°?

$[O=\ddot{N}-\ddot{O}]^-$ 2 others 120°

a) NO_3^- 24 e⁻ b) NO_2^- 18 e⁻ c) N_3^- 16 e⁻ d) H–N–N–H 12 e⁻ e) NFO 18 e⁻

$H-\ddot{N}=\ddot{N}-H$ ~120° about each N

NO_3^-, NO_2^-, N_2H_4, and NFO all exhibit trigonal planar geometry and ~120° bond angle.

$O=\ddot{N}-\ddot{F}$ ~120°

N_3^- exhibits linear geometry and 180° bond angles

Only 1s orbitals exist. The others are all forbidden energy levels (they do not exist).

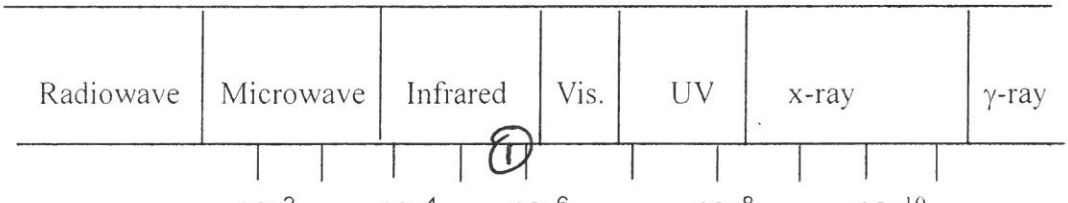
10. Which of the following orbitals can hold the most electrons?

a) 1s (2e) b) ~~2p~~ c) ~~3d~~ d) ~~4d~~ e) ~~5f~~

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

F a) Calcium is an ~~alkali metal~~ alkaline earth metal.
T b) Bromine is a nonmetal.
T c) A fifty pound sample of rocks is a heterogeneous mixture. - visibly distinguishable parts
T d) When water is heated until it boils, a physical change has occurred. goes from $H_2O(l)$ to $H_2O(g)$; no formulas change.
T e) A compound consists of atoms of more than one type of element.

12. Consider the following electromagnetic radiation spectrum.



$\lambda\nu = c$, $\lambda = \frac{c}{\nu} = \frac{2.998 \times 10^8 \text{ m/s}}{2 \times 10^{14} \text{ s}^{-1}} = 1.5 \times 10^{-6} \text{ m}$

What type of electromagnetic radiation has a frequency of 2×10^{14} s^{-1}?
From spectrum, $\lambda = 1.5 \times 10^{-6}$ m light is Infrared.

a) microwave (b) infrared c) ultraviolet (UV)

d) x-ray e) γ-ray

IE trend ↑ There is an exception to the IE trend between groups 2A and 3A and between 5A and 6A.

13. Which of the following correctly ranks the elements beryllium, boron, nitrogen and oxygen in order of **increasing** ionization energy?
So B has a lower IE than Be and O has a lower IE than N.

a) Be < B < N < O b) O < N < Be < B c) N < O < B < Be

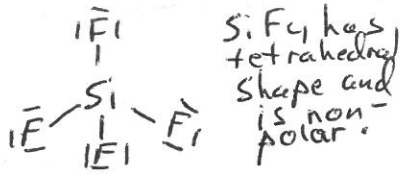
d) Be < B < O < N (e) B < Be < O < N

Only answer e has both of these exceptions correct.

14. An ion has an excited state electron configuration of $[Ar]4s^2 3d^{10} 4p^4 5s^1 4f^1$. Which of the following could be this ion? This ion has 2 + 10 + 4 + 1 + 1 = 18 = 36 electrons.

a) Ga^{4-} (35e⁻) b) As^{3+} (30e⁻) c) Kr^{+} (35e⁻) d) Ge^{2+} (30e⁻) (e) Br^{-} (36e⁻)

Only Br^- has 36 e⁻, so it is only possible correct answer. Any element or ion having 36 e⁻ could have this excited state electron configuration.



15. Consider the following molecules:

32e⁻ 36e⁻
SiF_4, SeF_4, XeF_4
34e⁻

Which molecule(s) has/have tetrahedral shape and which molecule(s) is/are polar?

a) SeF_4 has tetrahedral shape and XeF_4 is polar.
(b) SiF_4 has tetrahedral shape and SeF_4 is polar.
c) XeF_4 has tetrahedral shape and SiF_4 is polar.
d) All of these molecules have tetrahedral shape and all of these molecules are polar.
e) All of these molecules have tetrahedral shape and all of these molecules are nonpolar.

16. Which of the following shapes do **not** require the central atom to use d orbital(s) to form the hybrid orbitals? Trigonal bipyramid shapes and octohedral shapes all require d orbitals to form hybrids.

a) T-shape dsp^3 b) see-saw dsp^3 c) square planar d^2sp^3
d) square pyramid d^2sp^3 (e) trigonal pyramid sp^3; trig. pyramid shape has tetrahedral geometry, so it is sp^3 hybridized

17 The table below gives the numbers of electrons, protons, and neutrons in atoms or ions of several elements (A-G). Which statement is **incorrect** regarding these atoms or ions?

Identity	$^{19}_{9}F$	$^{2}_{1}H$	$^{39}_{19}K^{+}$	$^{35}_{17}Cl^{-}$	$^{3}_{1}H$	$^{16}_{8}O^{2-}$	$^{207}_{82}Pb$
Atom or Ion of Element	A	B	C	D	E	F	G
# of electrons	9	1	18	18	1	10	82
# of protons	9	1	19	17	1	8	82
# of neutrons	10	1	20	18	2	8	125

T a) D and F are anions. Both have more electrons than protons.
T b) C is a cation. Has more protons than electrons.
T c) B and E are isotopes of each other. Both are hydrogen, but have different mass numbers.
T d) G is $^{207}_{82}Pb$.
F e) The compound formed between A and E would be ~~ionic~~ covalent.
A is fluorine and E is hydrogen. The compound between those two nonmetals will be covalent.

18. A piece of indium with a mass of 16.6 g is submerged in 46.3 cm^3 of water in a graduated cylinder. The water level increases to 48.6 cm^3. From this data, what is the density of indium to the correct number of significant figures?

density = mass/volume ; volume = $48.6\ cm^3 - 46.3\ cm^3 = 2.3\ cm^3$ (2 sig figs by subtraction rule.)

a) 7.217 g/cm^3 b) 7.22 g/cm^3 (c) 7.2 g/cm^3
d) 0.139 cm^3/g e) 0.1 cm^3/g

$$\text{density} = \frac{16.6\ g}{2.3\ cm^3} = 7.2\ g/cm^3$$

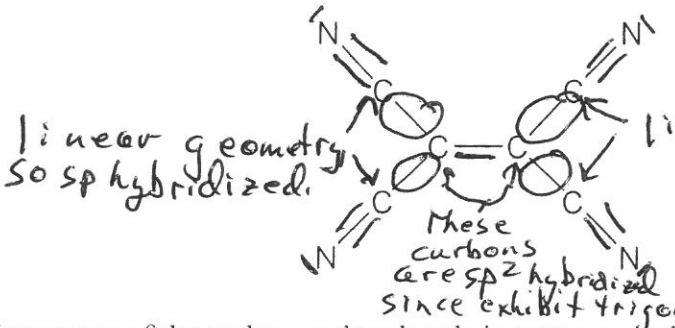
2 sig figs in density value due to division rule.

When the nonmetal P reacts with these metals, an ionic compound forms. P forms 3− anions. Determine the formula knowing the charges on the ions. Then see which salt has a molar mass of 148 g/mol.

19. A metal, M, reacts with phosphorus forming a binary compound M_xP_y. If the molar mass of the binary compound is about 148 g/mol, which of the following is the metal?

a) sodium (Na^+) Na_3P, molar mass = $3(23)+31 = 100$ g/mol
b) potassium (K^+) K_3P, molar mass = $3(39)+31 = 148$ g/mol
c) aluminum (Al^{3+}) AlP, molar mass = $27+31 = 58$ g/mol
d) calcium (Ca^{2+}) Ca_3P_2, molar mass = $3(40)+2(31) = 182$ g/mol
e) barium (Ba^{2+}) Ba_3P_2, molar mass = $3(137.3)+2(31) = 474$ g/mol

20. The **organic** compound tetracyanoethylene has the following skeletal structure:



linear geometry so sp hybridized.

linear geometry, so sp hybridized.

These carbons are sp^2 hybridized since exhibit trigonal planar geometry.

How many of the carbon-carbon bonds in tetracyanoethylene is/are formed from overlap of an sp hybrid orbital on one carbon with an sp^2 hybrid orbital on the other carbon?

a) 0 (none) b) 1 c) 2 d) 4 e) 5

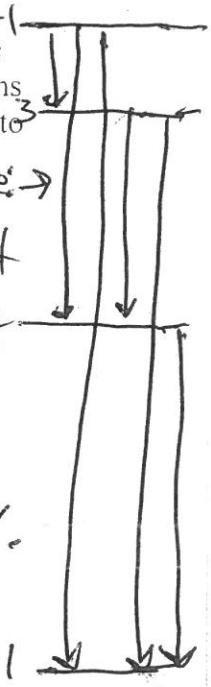
The 4 circled bonds are all formed from an sp hybrid orbital on 1 carbon with an sp^2 hybrid orbital on the other carbon.

Note that the energy levels get closer together as n increases.

21. Consider a sample of hydrogen atoms where every hydrogen atom in the sample has the electron in the n = 4 energy state. What is the total number of different energetic photons of electromagnetic radiation that could possibly be emitted as the n = 4 electron returns to the ground state for the various hydrogen atoms?

a) 1 b) 3 c) 4 d) 6 e) 10

The six possible transitions are shown here →



Each has a different ΔE, so has a different wavelength. The possible transitions are

22. Consider a sample of hydrogen atoms where every hydrogen atom in the sample has the electron in the n = 4 energy state. Of all the possible transitions as the n = 4 electron returns to the ground state, calculate λ for the longest wavelength emission.

$4\to3$, $4\to2$, $4\to1$, $3\to2$, $3\to1$, and $2\to1$.

a) 6.57×10^{-7} m b) 1.88×10^{-6} m c) 4.05×10^{-6} m

Since $4\to3$ transition has smallest ΔE, it has longest λ.

d) 9.73×10^{-8} m e) 1.22×10^{-7} m

$$\Delta E = -R_H\left(\frac{1}{n_2^2} - \frac{1}{n_1^2}\right) \quad n_1 = 4,\ n_2 = 3$$

$$\Delta E = -2.178 \times 10^{-18}\text{ J}\left(\frac{1}{3^2} - \frac{1}{4^2}\right) = -1.05875 \times 10^{-19}\text{ J}$$

$$E_{photon} = |\Delta E|,\quad \lambda = \frac{hc}{E} = \frac{6.626 \times 10^{-34}\text{ J·s}\,(2.998 \times 10^{8}\text{ m/s})}{1.05875 \times 10^{-19}\text{ J}} = 1.88 \times 10^{-6}\text{ m}$$

$Ca_3(PO_4)_2$ = calcium phosphate

$3(40.08)+2(30.97)+8(16.00) = 310.18\ g/mol$

$3.10\ g\ Ca_3(PO_4)_2 \left(\frac{1\ mol\ Ca_3(PO_4)_2}{310.18\ g}\right)\left(\frac{8\ mol\ O}{1\ mol\ Ca_3(PO_4)_2}\right)\left(\frac{6.022\times10^{23}\ O\ atoms}{1\ mol\ O}\right) = 4.81\times10^{22}\ O\ atoms$

23. How many atoms of oxygen are in 3.10 g of calcium phosphate?

(a) 4.81×10^{22} O atoms b) 1.26×10^{19} O atoms c) 7.50×10^{20} O atoms

d) 6.02×10^{22} O atoms e) 6.02×10^{21} O atoms

molecules that exhibit resonance, where multiple bonds can be in different places, all exhibit resonance.

24. Molecules that exhibit delocalization of bonding electrons have surprising stability. Which of the following is **not** a characteristic of molecules that exhibit delocalization?

It is the π electrons that are delocalized. All multiple bonds have π electrons.

T a) Molecules with delocalized bonding electrons contain one or more multiple bonds. Must have π bonds present.

T b) Molecules with delocalized bonding electrons have unhybridized p atomic orbitals. Need unhybridized p atomic orbitals to form π bonds.

(F) c) The electrons that form the sigma (σ) bonds are the delocalized bonding electrons. π electrons are the ones which can be delocalized.

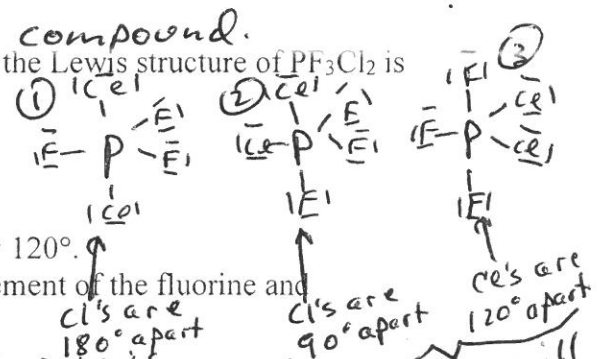
T d) Molecules with delocalized bonding electrons contain sp^2 and/or sp hybridized atoms. Need sp^2 and/or sp hybridized atoms to form π bonds (must have unhybridized p atomic orbitals).

T e) Molecules that exhibit resonance generally exhibit delocalization of bonding electrons.

There are 3 different arrangements of the Cl atoms about the central P atom. Each is a different compound.

25. Which of the following four statements (a-d) concerning the Lewis structure of PF_3Cl_2 is **false**? Phosphorus is the central atom.

PF_3Cl_2: $5+3(7)+2(7) = 40\ e^-$



These two will be polar since the individual bond dipoles will not cancel each other.

T a) The molecular shape of PF_3Cl_2 is trigonal bipyramid.

T b) Phosphorus must violate the octet rule in PF_3Cl_2.

T c) Some of the bond angles in PF_3Cl_2 are approximately 120°.

T d) The polarity of PF_3Cl_2 depends on the spatial arrangement of the fluorine and chlorine atoms.

(e) None of the above statements (a-d) is false.

26. A solution of NaOH was standardized with KHP with the following results.

Trial 1	0.095 ± 0.001 *M* NaOH
Trial 2	0.096 ± 0.001 *M* NaOH
Trial 3	0.095 ± 0.001 *M* NaOH

Results are close to each other so they are precise. Results are far away from the actual molarity, so they are not accurate.

Later it was determined that the actual molarity of the solution was 0.159 *M* NaOH. The results of the three trials were:

a) accurate but not precise

(b) precise but not accurate

c) accurate and precise

d) neither precise nor accurate

Ca^{2+} and S^{2-} are isoelectronic (both have 18 e^-). Ca^{2+}, with more protons in nucleus, will be smaller than S^{2-}.

27. Which of the following statements is **false**?

T a) The radius of I^- is larger than the radius of I. I^-, with more electrons, will be larger than I.

T b) The electronegativity of chlorine is greater than the electronegativity of potassium. follows trend. EN trend ↑ Electron Affinity equation for F: $F + e^- \rightarrow F^-$ $\Delta H < 0$ All halogens have exothermic EA values.

T c) In general, the electron affinity of the halogens is more exothermic (more negative) than the electron affinity of the noble gases. $Ne + e^- \rightarrow Ne^-$ $\Delta H > 0$, the EA value for noble gases are endothermic. Noble gases don't want to add another electron.

F d) The radius of Ca^{2+} is larger than the radius of S^{2-}. see above for explanation.

e) The radius of K is larger than the radius of K^+. K, with more electrons than K^+, will be larger.

28. In theory, how many different elements in the ground state can have exactly 12 electrons in various s orbitals, have exactly 30 electrons in various d orbitals, and have two or more unpaired electrons?

Elements Hg – Rn (elements #80–86) all have 12 e⁻ in various s orbitals and 30 electrons in various d orbitals. Of these elements from 80–86, Pb ($6p^2$), Bi ($6p^3$), and Po ($6p^4$) all have 2 or more unpaired electrons. Tl ($6p^1$) and At ($6p^5$) have 1 unpaired e^-, while Rn ($6p^6$) has 0 unpaired electrons

a) 0 b) 1 c) 2 d) 3 e) 5

29. Which of the following four statements (a-d) from Dalton's atomic theory is no longer true?

T a) Elements are made up of tiny particles called atoms.

T b) Atoms are neither created nor destroyed in chemical reactions. – this is why mass is conserved in a chemical rxn.

F c) All atoms of a given element are identical. – there are isotopes for elements. Isotopes have different # of neutrons.

T d) A given compound always has the same relative numbers and types of atoms. compounds have constant composition.

e) All of these statements (a-d) are true according to modern atomic theory.

30. Consider the following **unbalanced** reaction:

$$Eu(s) + HF(g) \rightarrow EuF_3(s) + H_2(g)$$

What is the sum of the coefficients of the reactants and products in the best balanced equation?

a) 6 b) 8 c) 10 d) 13

e) The sum of the coefficients in the best balanced equation is greater than 13.

Balanced equation is

$$2\,Eu + 6\,HF \rightarrow 2\,EuF_3 + 3\,H_2$$

$2 + 6 + 2 + 3 = 13$

The average mass of naturally occurring bromine is 79.90 (← from periodic table). This 79.90 mass is about halfway between the masses of the 2 isotopes (78.95 vs 80.95).

31. Bromine exists naturally as a mixture of ^{79}Br (atomic mass = 78.95 amu) and ^{81}Br (atomic mass = 80.95 amu). Which of the following is the approximate relative abundance of each bromine isotope in nature? Assume natural bromine contains only these two isotopes. Hint: reference the periodic table for the average atomic mass of Br.

a) 5% ^{79}Br and 95% ^{81}Br
b) 25% ^{79}Br and 75% ^{81}Br
c) 50% ^{79}Br and 50% ^{81}Br
d) 75% ^{79}Br and 25% ^{81}Br
e) 95% ^{79}Br and 5% ^{81}Br

Since the average mass is about halfway between the mass of the 2 isotopes that make up Br, we must have about equal amounts of each isotope (50/50 split).

In 100.00 g compound: $\text{mol E} = 8.73\text{g H}\left(\frac{1\text{mol H}}{1.008\text{g H}}\right)\left(\frac{3\text{mol E}}{8\text{mol H}}\right) = 3.248\text{mol E}$

32. A 100.00-g sample of a binary compound between an unknown element E and hydrogen contains 91.27 g E and 8.73 g H by mass. If the formula is E_3H_8, what is the identity of element E? $\text{molar mass E} = \frac{91.27\text{g E}}{3.248\text{mol E}} = 28.1\text{g/mol}$ ← This is Si (see periodic table).

a) boron b) silicon c) bromine d) phosphorus e) zirconium (Zr)

All atoms follow octet rule in TeS_2.

33. How many of the following compounds/ions must be exceptions to the octet rule? Te is element #52.

$TeBr_2^{2-}$ (22 e⁻), TeS_2 (18 e, ok), $TeBr_3^-$ (28 e), TeS_4^{2-} (32 e⁻, ok), $TeBr_6^-$ (48 e⁻)

Does not follow octet rule for Te.

a) 1 b) 2 c) 3 d) 4

Does not follow octet rule for Te.

e) 5 (All must be exceptions to the octet rule.)

Does not follow octet rule for Te.

follows octet rule for all atoms in TeS_4^{2-}.

34. Place the following elements and ions in order of increasing size (smallest to largest).

As^-, Se, Cl, Ar^+

radii trend ↓

a) $Ar^+ < Cl < Se < As^-$
b) $Se < As^- < Cl < Ar^+$
c) $Cl < As^- < Se < Ar^+$
d) $Cl < Se < As^- < Ar^+$
e) $Ar^+ < Cl < As^- < Se$

The radius trend only works for neutral charged atoms. So for Se and Cl, Cl is smaller than Se (Se > Cl). As^- is isoelectronic with Se (34 electrons). Se with 1 more proton in nucleus, will be smaller than As^- ($As^- > Se$).

Ar^+ is isoelectronic with Cl (17 e⁻). Ar^+ has 1 more proton in nucleus as compared to Cl. So Ar^+ will be smaller than Cl ($Cl > Ar^+$). Putting all this together gives an ordering of:

$Ar^+ < Cl < Se < As^-$