Test 1 - 2011
Version 1 Solutions

1. What is the name of the element with **atomic number** equal to 5.

   .

   A) Berylium
   B) Bromine
   C) Barium
   D) Bismuth
   E) Boron

2. 3.03 g of a gas occupies a 2.00 L flask at 80.0°C and exerts a pressure of 0.522 atm. What is **the molar mass** (in g/mol) of the gas?

   .

   A) 17.0
   B) 23.4
   C) 84.1
   D) 219
   E) 9.01

Solve for the number of moles of gas using the ideal gas equation,

$$n = \frac{PV}{RT} = \frac{0.522 \text{ atm } \times \ 2.00 \text{ L}}{0.08206 \text{ L atm K}^{-1} \text{ mol}^{-1} \ \times \ 353.15 \text{ K}}$$
$$= 0.0360_3 \text{ mol}$$

The molar mass of the gas is

$$M = \frac{m}{n} = \frac{3.03 \text{ g}}{0.0360_3 \text{ mol}} = 84.1 \text{ g mol}^{-1}$$

3. Suppose we start with an ideal gas with volume, V, temperature, T, and pressure, P. If the temperature and pressure are both doubled, what is the final volume of the gas?

   .

   A) not enough information to answer the question
   B) $2V$
   C) $4V$
   D) $V/2$
   E) V

Note that the number of moles of gas is constant. Thus, we have

$$V_{\text{final}} = \frac{nRT_{\text{final}}}{P_{\text{final}}} = \frac{nR2T}{2P} = \frac{nRT}{P} = V$$

Note also that it only makes sense to speak of doubling temperature if temperature is measured in Kelvin.

4. Calculate the **mass** (in grams) of **excess reactant** remaining at the end of the reaction in which 90.0 g of SO_2 are mixed with 100.0 g of O_2 and reacted to completion.

   $2\ SO_2 + O_2 \rightarrow 2\ SO_3$

   .

   A) 67.5
   B) 11.5
   C) 40.0
   D) 22.5
   E) 77.5

First, we need to determine the limiting reactant.

$$\text{moles of } SO_2 = \frac{m_{SO_2}}{M_{SO_2}} = \frac{90.0\ \text{g}}{64.06\ \text{g mol}^{-1}} = 1.40_5\ \text{mol}$$

$$\text{moles of } O_2 = \frac{m_{O_2}}{M_{O_2}} = \frac{100.0\ \text{g}}{32.00\ \text{g mol}^{-1}} = 3.12_5\ \text{mol}$$

Since 2 moles of SO_2 react for every one mole of O_2, SO_2 is the limiting reactant.

$$\text{moles of } O_2 \text{ reacted} = \frac{1}{2} \times 1.40_5\ \text{mol} = 0.703\ \text{mol}$$

This leaves $3.12_5 - 0.703$ mol = 2.42_2 mol of O_2 unreacted. The associated mass is

$$\text{mass of } O_2 \text{ unreacted} = n_{O_2} M_{O_2} = 2.42_2\ \text{mol} \times 32.00\ \text{g mol}^{-1} = 77.5\ \text{g}$$

5. The density of water, $H_2O(l)$, is 1.0 g/mL. How many **atoms** of oxygen are present in 2.5 L of pure water?

   .

   A) 8.4×10^{25}
   B) 1.4×10^{21}
   C) 2.3×10^{-22}
   D) 1.5×10^{27}
   E) 2.7×10^{26}

The mass of 2.5 L of water is

$$\text{mass} = dV = 1.00\ \text{g mL}^{-1} \times 2500\ \text{mL} = 2500\ \text{g}$$

Note the conversion from L to mL (1 L = 1000 mL). The amount of water is thus

$$\text{moles of } H_2O = \frac{m_{H_2O}}{M_{H_2O}} = \frac{2500\ \text{g}}{18.015\ \text{g mol}^{-1}} = 13_8\ \text{mol}$$

Multiplying by the Avogadro constant gives the number of water molecules which equals the number of oxygen atoms since there is one oxygen atom per water molecule.

$$\text{number of O atoms} = 13_8\ \text{mol} \times 6.022 \times 10^{23}\ \text{atoms mol}^{-1} = 8.4 \times 10^{25}$$

6. A student takes 10.00 ml of a stock NaOH solution and adds 50.00 ml of distilled water. The NaOH is then titrated to equivalence with 23.78 ml of 0.1856 M HCl. What is the concentration of Na^+ (aq) in the **final** solution?

.

A) 1.915×10^{-1} M
B) 1.006×10^{-3} M
C) 5.268×10^{-2} M
D) 9.152×10^{-1} M
E) 4.278×10^{-3} M

The number of moles of NaOH in the sample is equal to the number of moles of HCl used to titrate to equivalence according to

$$\mathrm{NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l)}$$

Thus,

$$\text{moles of Na}^+ = \text{moles of HCl} = 0.02378\ \text{L} \times 0.1856\ \text{mol L}^{-1} = 0.004413_6\ \text{mol}$$

The volume of the final solution is 10.00 + 50.00 + 23.78 mL = 83.78 mL = 0.08378 L. Thus, the concentration of Na^+ in the final solution is

$$\text{concentration of Na}^+ = \frac{0.004413_6\ \text{mol}}{0.08378\ \text{L}} = 0.05268\ \text{mol L}^{-1}$$

7. For the following pure substances, identify the one **incorrect** chemical name from among the following:

.

A) Fe_2O_3, iron(III) oxide
B) HF, hydrogen fluoride
C) $Ca(H_2PO_4)_2$, calcium dihydrogen phosphate
D) NH_4SO_3, ammonium sulfate
E) Li_2CO_3, lithium carbonate

NH_4SO_3 is ammonium sulfite, except that its formula should be $(NH_4)_2SO_3$. The formula for ammonium sulfate is $(NH_4)_2SO_4$.

8. Determine the **FALSE** statement.

.

A) For atoms with more than one electron, all orbitals within a shell are degenerate (all equal energy).
B) An electron in carbon can have the same set of quantum numbers as an electron in gold.
C) In a ground state carbon atom, the 2p electrons have the same spin.
D) A beryllium atom in the ground state would be diamagnetic.
E) When filling orbitals with electrons, the 6s gets filled before 4f.

A is FALSE. Different subshells within a shell have different energies when there is more than one electron. Only when there is one electron do the subshells have the same energy.
B is TRUE. The six lowest energy electrons in a gold atom occupy the same orbitals (i.e. they have the same quantum numbers) as the six electrons in a carbon atom.
C is TRUE. The electron configuration for ground state carbon is

$$1s^2\ 2s^2\ 2p^2$$

According to Hund's rule, in terms of an orbital diagram, this configuration is further elaborated as

$$\underline{\uparrow\downarrow}_{1s}\quad \underline{\uparrow\downarrow}_{2s}\quad \underbrace{\underline{\uparrow}\ \underline{\uparrow}\ \underline{\ \ }}_{2p}$$

The 2p electrons have the same spin.

D is TRUE. The orbital diagram for the ground state of beryllium is

$$\underline{\uparrow\downarrow}_{1s}\quad \underline{\uparrow\downarrow}_{2s}$$

All electrons are paired. Therefore a ground state beryllium atom is diamagnetic.

E is TRUE. According to the Aufbau principle, the order that subshells are filled is given by 1s, 2s, 2p, 3s, 3p, 4s, 3d, 4p, 5s, 4d, 5p, **6s, 4f**, 5d, 6p ...

9. Determine the **FALSE** statement:
.
A) X-rays will have a shorter wavelength than radio waves.
B) Each element has an unique emission spectrum.
C) Electrons can exhibit properties associated with both waves and particles.
D) If an atom is in an excited state, upon returning to the ground state, energy will be emitted.
E) At constant velocity, as the mass of an object increases, so does its wavelength.

A is TRUE. Wavelength increases as follows:
gamma rays < X-rays < UV < visible < IR < microwave, radio waves.
B is TRUE.
C is TRUE.
D is TRUE. Energy is conserved. The energy lost by the atom upon returning to its ground state appears as the energy of the emitted photon.
E is FALSE. The de Broglie formula for a particle wavelength is $\lambda = \dfrac{h}{mu}$. Thus, wavelength decreases with increasing mass.

10. A hydrogen atom in the n = 4 state absorbs a photon of wavelength 2170 nm. What would be the final state of this atom?
.
A) 7
B) 5
C) 6
D) 2
E) 3

The photon energy is

$$h\nu = \frac{hc}{\lambda} = \frac{6.626\times10^{-34}\ \text{J s} \times 2.9979\times10^{8}\ \text{m s}^{-1}}{2170\times10^{-9}\ \text{m}} = 9.154\times10^{-20}\ \text{J}$$

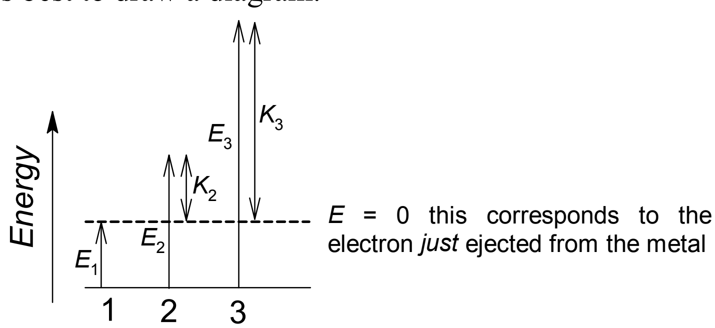
The final energy of the H atom is E_4 plus this amount – i.e.

$$\begin{aligned} E_{n_{\text{final}}} &= E_4 + 9.154\times10^{-20}\ \text{J} \\ &= -\frac{2.178\times10^{-18}\ \text{J}}{4^2} + 9.154\times10^{-20}\ \text{J} \\ &= -1.361\times10^{-19} + 9.154\times10^{-20}\ \text{J} = -4.459\times10^{-20}\ \text{J} \\ &= -\frac{2.178\times10^{-18}\ \text{J}}{n_{\text{final}}{}^2} \end{aligned}$$

Therefore, $n_{\text{final}} = \sqrt{\dfrac{2.178\times10^{-18}}{4.459\times10^{-20}}} = 6.989 \cong 7$.

11. Three photons strike a metal surface. Photon 3 has twice the energy of photon 2, which has twice the energy of photon 1. Photon 1 has just enough energy to eject an electron from the metal with no kinetic energy. How much faster is the electron ejected by photon 3 moving as compared to photon 2?
.
A) 4 times
B) 1.73 times
C) they are moving at the same speed
D) 2 times
E) 1.41 times

Its best to draw a diagram.



Since $E_2 = 2\ E_1$, the kinetic energy associated with the electron ejected by photon 2 is $K_2 = E_2 - E_1 = E_1$. Similarly, $K_3 = E_3 - E_1 = 2\ E_2 - E_1 = 4\ E_1 - E_1 = 3\ E_1 = 3\ K_2$.
Since $K_2 = \text{m}\ u_2^2/2$ and $K_3 = \text{m}\ u_3^2/2$, we have
$u_3^2 = 3\ u_2^2$ or

$u_3 = \sqrt{3}\ u_2$

12. The following electron configuration would represent a cation of which of the following elements?

.
$1s^2 2s^2 2p^6 3s^2 3p^6$
.

A) Sulfur
B) Sodium
C) Magnesium
D) Potassium
E) Chlorine

This is the electron configuration of the ground state of argon. Since it is a cation configuration, it must be for an element beyond argon in the periodic table.

13. Which of the following would be a possible sum for all of the quantum numbers (n, ℓ, m_ℓ and m_s) representing **one** of the valence electron in a p orbital for tellurium?

.

A) 4.5
B) 2.5
C) 4
D) 3
E) 3.5

The orbital diagram for the valence shell of Te is

$$\underline{\uparrow\downarrow} \quad \underline{\uparrow\downarrow}\,\underline{\uparrow\,}\,\underline{\uparrow\,}$$
$$5s \qquad 5p$$

Summing the quantum numbers of one of the 5p electrons gives $5 + 1 + m_\ell + m_s = 6 + m_\ell + m_s$
The smallest such sum occurs for $m_\ell = -1$ and $m_s = -\frac{1}{2}$. In this case, we get $6 - 1 - \frac{1}{2} = 4\frac{1}{2}$.
The quantum numbers of any other 5p electron would have a larger sum.

14. Put the following atoms in order of **increasing ionization energy**: B, Be, C, F, Na

.

A) Na < B < Be < C < F
B) Na < Be < C < B < F
C) B < Be < C < F < Na
D) F < C < B < Be < Na
E) Be < B < C < F < Na

According to the general trend, ionization energy increases from left to right across a period. This suggests that we have

$$\text{Be} < \text{B} < \text{C} < \text{F}$$

However, Be has a filled 2s subshell, whereas B has its last (i.e. highest energy) electron in the higher energy 2p subshell. Consequently, we have

$$\text{B} < \text{Be} < \text{C} < \text{F}$$

Since Li would appear to the far left of this ordering and Na has an even lower ionization energy, we finally get

$$Na < B < Be < C < F$$

15. Select the two **most electronegative** atoms from the following list: Be, Br, Cl, Na, O
.
A) Cl and Na
B) Na and Be
C) Br and O
D) O and Cl
E) Be and Br

EN increases to the right and going up the periodic table.

16. Which of the following is **TRUE** regarding the relative strengths of the halogens as oxidizing agents?
.
A) Br_2 oxidizes Cl^- and I^-.
B) Cl_2 cannot oxidize Br^- and I^-.
C) Br_2 cannot oxidize Cl^- and I^-.
D) I_2 oxidizes Cl^- and Br^-.
E) Cl_2 oxidizes Br^- and I^-.

The order of oxidizing strength of the halogens is

$$F_2 > Cl_2 > Br_2 > I_2.$$

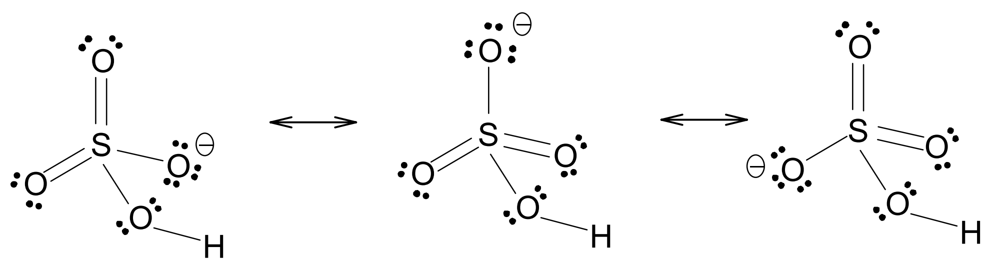
Consequently, Cl_2 can oxidize Br^- and I^-, whereas Br_2 oxidizes only I^-. I_2 cannot oxidize any of the other halides.

17. Which one of the following generally **decreases** in magnitude across a row of the periodic table, from left to right?
.
A) Electron affinity
B) Electronegativity
C) Effective nuclear charge
D) Atomic radius
E) Ionization energy

Moving from left to right across a row of the periodic table corresponds to increasing effective nuclear charge. This generally gives rise to increasing ionization energy (it is harder to remove a valence electron held by a larger effective nuclear charge), magnitude of electron affinity (it is generally more favorable to add an electron when it can be held be a larger effective nuclear charge), and electronegativity (an element with greater effective nuclear charge pulls more strongly on electrons in bonds around the atom). However, a larger effective nuclear charge correlates with smaller atomic radius – the stronger pull on the valence electrons keeps them closer to the nucleus (i.e. a smaller atomic radius).

18. How many **charge-minimized resonance structures** are required to describe the bonding in the HSO_4^- anion? (S is the central atom, and is bonded only to O).
.
A) 6
B) 4
C) 1
D) 3
E) 2

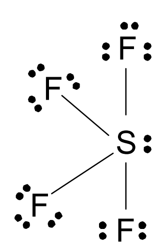
There are three equivalent SO bonds – there are three terminal O atoms about the S atom. This gives rise to three equivalent charge-minimized resonance structures:



Note that S can expand its valence shell to accommodate more than 8 electrons, allowing the cancelation of adjacent opposite formal charges to get these structures.

19. What is the **molecular shape** of SF_4?
.
A) square pyramidal
B) seesaw
C) T-shaped
D) square planar
E) tetrahedral

The Lewis structure shows a lone pair of electrons on the S atom, in addition to four single SF bonds:

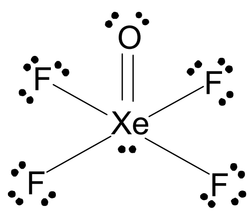


Therefore, the VSEPR class is AX_4E about S. The molecular shape is seesaw.

20. Find the **FALSE** statements regarding $XeOF_4$.
    i. The shape is square pyramidal.
    ii. The O-Xe-F bond angles are less than 90º.
    iii. There are 14 lone electron pairs.
    iv. The electron pair geometry around Xe is octahedral.
    v. There are 10 electrons involved in bonds.

    .
    A) ii, iii, iv
    B) ii, iii, v
    C) i, iv, v
    D) iv, v
    E) i, iii

The Lewis structure shows four single SF bonds and a SO double bond. Additionally, there is one lone pair on the Xe atom.

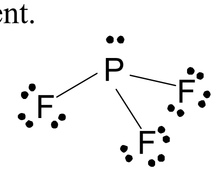


The VSEPR class is AX_5E. The molecular shape is square pyramidal. There are 6 pairs of bonding electrons – i.e. 12 bonding electrons – and 15 lone electron pairs. The double bond repels more than the single bonds, and more than the lone pair. Consequently, the F-Xe-O bond angles are greater than 90° - the ideal angle value.
i is TRUE. **ii** is FALSE. **iii** is FALSE. **iv** is TRUE. **v** is FALSE.

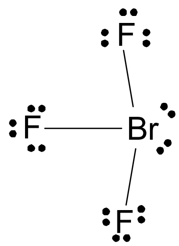
21. Which of the following statements is **FALSE** regarding molecular shape and polarity, according to the VSEPR model?

    .
    A) PF_3 has a net dipole moment.
    B) BrF_3 has a net dipole moment.
    C) PF_3 and BrF_3 have different molecular shapes.
    D) The F-Br-F bond angles in BrF_3 are less than 90º.
    E) The shape of BrF_3 is trigonal pyramidal.

A is TRUE. PF_3 is AX_3E and is therefore trigonal pyramidal. Thus, it is asymmetrical with polar bonds, and has a net dipole moment.



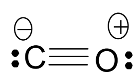
B is TRUE. BrF_3 is AX_3E_2 and is therefore T-shaped. Thus, it is asymmetrical with polar bonds, and has a net dipole moment.

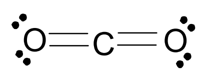


C is TRUE.
D is TRUE. The greater repulsion of the lone pairs (in comparison with the bonding pairs) bends the F-Br bonds to the left (as shown in the above figure). The F-Br-F bond angles are less than 90°.
E is FALSE. BrF_3 is T-shaped.

22. Which of the following statements about bonds is/are **TRUE**?
    (i) The bond in CO is shorter than the carbon oxygen bonds in CO_2.
    (ii) The bond order in CO is the same as the bond order in CO_2.
    (iii) The bond energy in CO is higher than the carbon oxygen bond energy in CO_2.
    .
    A) ii, iii
    B) i, iii
    C) i
    D) iii
    E) i, ii

The C-O bond in carbon monoxide is a triple bond. The C-O bond in carbon dioxide is a double bond. Triple bonds are stronger (larger bond energy) and shorter than double bonds.

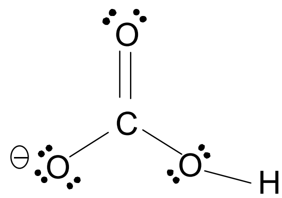




i is TRUE. **ii** is FALSE. **iii** is TRUE.

23. Which type of bonding is **absent** in $NaHCO_3$?
    .
    A) Ionic
    B) Pure Covalent, Polar Covalent, Ionic are <u>all</u> absent.
    C) Polar Covalent
    D) Pure Covalent
    E) Pure Covalent, Polar Covalent, Ionic are <u>all</u> present.

$NaHCO_3$ is an ionic compound that consists of Na^+ and HCO_3^- ions arranged in an alternating pattern in a lattice. Within the HCO_3^- anion, there is polar covalent bonding. The bonds are polar because they are between different atoms; C and O, and O and H. There is no pure covalent bonding – covalent bonding between identical atoms.



24. Which of the following species has the **largest magnitude average formal charge** on the oxygen atoms, assuming charge minimized Lewis structures?

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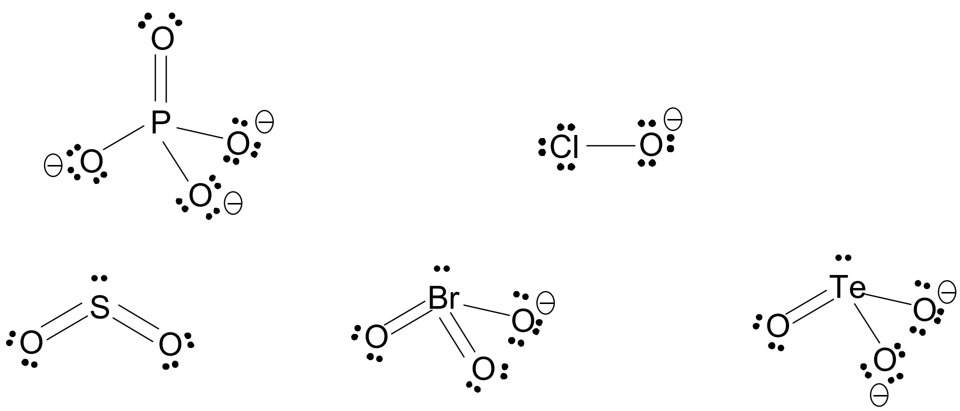
A) PO_4^{3-}
B) ClO^-
C) SO_2
D) BrO_3^-
E) TeO_3^{2-}



The average formal charges on the O atoms in these species are −3/4, −1, 0, −1/3 and −2/3, respectively. Thus, ClO^- has the largest magnitude formal charge on O.

25. Which of the following VSEPR classes have a net molecular dipole moment of **zero**? Assume that all X atoms are the same.

i. AX_5E
ii. AX_4E_2
iii. AX_2E
iv. AX_3E_2
v. AX_2

.

A) ii, iii, v
B) i, iii, iv
C) ii, v
D) i, v
E) ii, iv

i.	AX_5E	square pyramidal	asymmetrical	
ii.	AX_4E_2	square planar	symmetrical	zero net dipole moment
iii.	AX_2E	bent	asymmetrical	
iv.	AX_3E_2	T-shaped	asymmetrical	
v.	AX_2	linear	symmetrical	zero net dipole moment