Question 1. *Thermite Reaction - Railroad's Lifeblood*
The thermite reaction, used to weld rails together in the building of railroads, is described by the following equation:

$$Fe_2O_3(s) + 2AL(s) \rightarrow AL_2O_3(s) + 2Fe(l) \tag{1}$$

Calculate the mass of iron metal (in grams) that can be prepared from 165.0 grams of aluminum and 355.0 grams of iron(III) oxide.

Solution 1.
The aluminum quantity seen there is 3.06 reaction units, while the iron(III) oxide is 2.22 reaction units. Thus, iron(III) oxide is the limiting reactant. $2.22 \cdot 2$ moles Fe $= 247.95$ grams FE.

Question 2. *Carbonius Maximus*

Calculate the potential energy (in Joules) of interaction between two carbon nuclei at a distance of $25.9 \cdot 10^{-12}$m.

Solution 2.

Recall Coulumb's law, which states that the force experienced by two charged particles with charges q_1 and q_2 at distance r can be written as

$$F = \frac{1}{4\pi E_0} \cdot \frac{q_1 q_2}{r^2} \tag{2}$$

Each carbon nuclei has charge +6eV, and thus by plugging in:

$$F = \frac{1}{4\pi E_0} \cdot \frac{72\text{eV}}{(25.9 \cdot 10^{-12}\text{m})^2} = 4004.577 \text{ Joules} \tag{3}$$

Question 3. *He+ is Like Google+*
Determine for He+:

(a) The radius (in m) of the electron orbit characterized by n=1.

(b) The wavelength (in m) of radiation emitted by a transition of the electron from a state characterized by n=1 to one with n=3.

Solution 3.
(a) By Bohr's postulate see that

$$r = \frac{n^2 r_0}{Z} \tag{4}$$

where r_0 is the Bohr radius, n is the energy level, and Z is the proton count;

$$r = \frac{5.29 \cdot 10^{-11}}{2} = 2.645 \cdot 10^{-11} \tag{5}$$

(b) By setting the energy of some EM radiation (given wavelength) equal to the energy of an energy change,

$$\frac{hc}{\lambda} = (-K \cdot Z^2)(\frac{1}{n_i^2} - \frac{1}{n_f^2}) \tag{6}$$

and by inserting known values (and $K = \frac{m_e e^4}{8h^2 \epsilon^2}$)

$$\frac{hc}{\lambda} = (-2.18 \cdot 10^{-18})(4)(1 - \frac{1}{9}) \implies \lambda = 2.563 \cdot 10^{-8} m \tag{7}$$

Question 4. *What is Your Potential?*
Determine the acceleration potential that must be applied to an electron so that its particle wavelength is $0.76 \cdot 10^{-10}$m.

Solution 4.
Recall the equation

$$qV = \frac{h^2}{2m_e\lambda^2_{\text{de Broglie}}} \tag{8}$$

then insert values and solve for V:

$$V = \frac{(6.63 \cdot 10^{-34})^2}{2(1.602 \cdot 10^{-19})(9.1 \cdot 10^{-31})(0.76 \cdot 10^{-10})^2} = 261.3 \text{ Volts} \tag{9}$$

Question 5. *A Tortoise's Subshells*

(a) Arrange the following subshells in the order in which they fill with electrons: 3d, 4s, 5p, 3s, 4f, 3p, 5s.

(b) Indicate the maximum number of electrons that can be accommodated in each of the following subshells: 3d, 4s, 5f, 2p.

Solution 5.

(a) 3s, 3p, 4s, 3d, 5s, 5p, 4f.

(a) 10, 2, 14, 6 correspondingly.

Question 6. *Trends are Periodic*

(a) Order the melting points of the compounds BaO, MgO, SrO, CaO.

(b) Order the lattice hardness of the compounds BaO, MgO, BeO, SrO, CaO.

Solution 6.

(a) Recall that melting point of ionic solids decreases as bond energy decreases; bond energy decreases down the periodic table, thus the proper order is MgO, CaO, SrO, BaO.

(b) Just like melting point, hardness decreases with bonding energy; the order is BeO, MgO, CaO, SrO, BaO.

Question 7. *It's Simple Really*
Aluminum fluoride AlF_3(g), exists as a simple molecular species in the gas phase at $1000°C$.

a. The Al-F bond energy is observed to be 659 kJ/mol. Calculate the Al-Al bond energy if the F-F bond energy is 154.8 kJ/mol. Express your answer in eV/bond.

Solution 7.
Recall the formula

$$E_{AB} = \sqrt{E_{AA}E_{BB}} + 96.3\frac{\text{kJ}}{\text{mol}}(X_A - X_B)^2. \tag{10}$$

Plug in given values and electronegativity values from the periodic table to see

$$118.1\frac{\text{kJ}}{\text{mol}} = E_{\text{Al}-\text{Al}}. \tag{11}$$

Convert units to conclude

$$E_{\text{Al}-\text{Al}} = 1.224\frac{\text{eV}}{\text{bond}}. \tag{12}$$

Question 8. *(As) Long (As) You Love Me*
Of the bonds As-Br, As-I, As-Cl, As-F, which

(a) Has the greatest bond energy?

(b) Has the greatest bond length?

Solution 8.
(a) Bond energy decreases down the periodic table, thus As-F has the greatest bond energy.

(b) Bond length increases down the periodic table, thus As-I has the greatest bond length.

Question 9. *Polish Your (CF)links*

Some useful PES spectrum data: Atomic C: 1s=296.4 eV, 2s=17.8 eV, 2p=11.3 eV. Atomic F: 1s=696.5 eV, 2s=40.2 eV, 2p=17.4 eV.

(a) Order the following diatomic molecules according to increasing bond length: CF, CF+, CF-

(b) Classify each of the following molecules as diamagnetic or paramagnetic: CF, CF+, CF-

(c) Calculate the bond orders of each molecule: CF, CF+, CF-.

(d) What is the highest occupied molecular orbital in CF+?

Solution 9.

(a) CF+, CF, CF-

(b) CF+ is diamagnetic due to having strictly paired electrons, while CF and CF- have unpaired electrons and are thus paramagnetic.

(c) Respectively, 2.5, 3, 2

(d) By drawing a molecular orbital diagram, we see that σ-2p is the highest occupied.

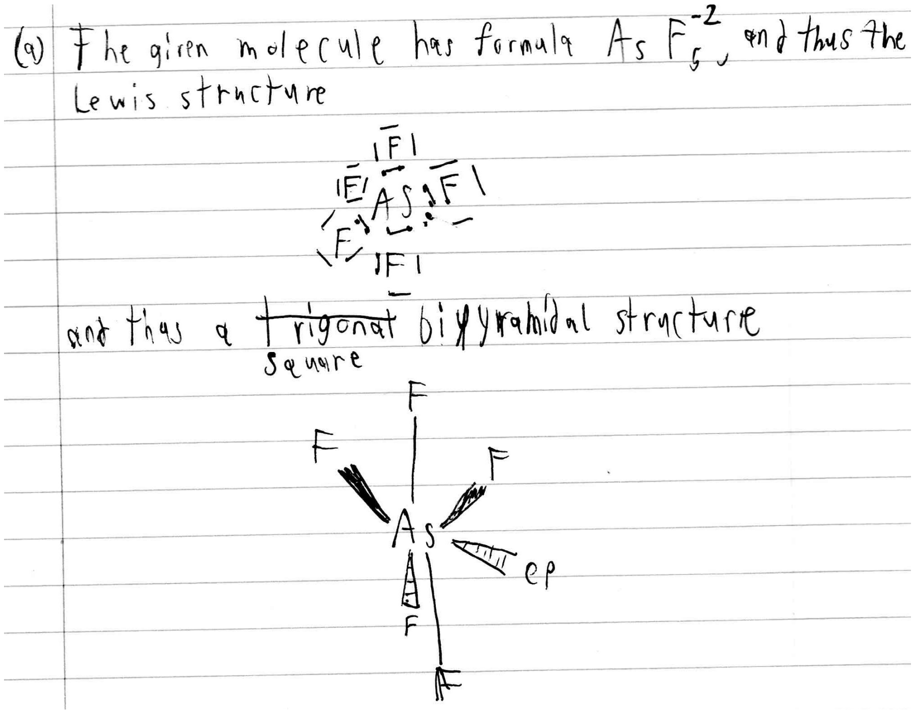
Question 10. *VSEPR AsF5(-2)*
(a) Draw the VSEPR model of AsF_5^{-2}.

(b) What is the atomic geometry of this molecule?

(c) What type of hybrid orbitals exist on the central atom?

(d) Is the molecule polar?

Solution 10.
(a)


(a) The given molecule has formula AsF_5^{-2}, and thus the Lewis structure

and thus a ~~trigonal~~ square bipyramidal structure

(b) Square bipyramidal.

(c) sp^3d^2

Question 11. *Someone Keep an Eye on These Molecules...*
(a) For each molecule below, identify the strongest intermolecular force in the liquid state. The forces to choose from are: 1. ionic 2. london dispersion 3. hydrogen bonding 4. dipole-dipole

(1) CCl_4

(2) H2O

(3) BF3

(4) NH3

(5) Br2

(6) BrF3

(b) Which compound in each pair will have the higher boiling point?

(1) CH3CH2CH2CH2CH3 or (CH3)4C

(2) CH3OCH3 or CH3CH2OH

(3) HF or HCl

Solution 11.
(a)

(1) London Dispersion

(2) Hydrogen Bonding

(3) London Dispersion

(4) Hydrogen Bonding

(5) London Dispersion

(6) Dipole-dipole

(b)

(1) The former maximizes contacts between molecules due to shape and thus has a higher boiling point.

(2) The latter exhibits hydrogen bonding due to the O-H bond, and thus has a higher boiling point.

(3) The former exhibits hydrogen bonding due to the F-H bond, and thus has a higher boiling point.

Question 12. *Find this Exactly*
The rate constants for a reaction are found to be $k(1428C) = 12.1 \cdot 10^{-6}s^{-1}$ and $k(1702C) = 38.1 \cdot 10^{-5}s^{-1}$

At what temperature (in degrees C) will the rate constant be 73.3*10-2 s-1?

Solution 12.
We recall the equation

$$\frac{k_1}{k_2} = \exp\left(-\frac{\Delta H}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)\right) \tag{13}$$

and insert all known values (temperatures converted to kelvin, rates, and the gas constant),

$$\frac{12.1 \cdot 10^{-6}}{38.1 \cdot 10^{-5}} = \exp\left(-\frac{\Delta H}{8.314}\left(\frac{1}{1701} - \frac{1}{1975}\right)\right) \tag{14}$$

which then implies

$$\Delta H = 3.516 \cdot 10^5 \tag{15}$$

and by inserting into the Arrhenius equation for $k(1482\,C)$,

$$12.1 \cdot 10^{-6} = A \cdot \exp\left(\frac{-3.516 \cdot 10^5}{8.314(1701)}\right) \implies A = 7.61 \cdot 10^5 \tag{16}$$

And thus by solving the equation

$$73.3 \cdot 10^{-2} = \exp\left(\frac{-3.516 \cdot 10^5}{8.314(T_3)}\right) \implies T_3 = 3053\,K = 2780\,C \tag{17}$$