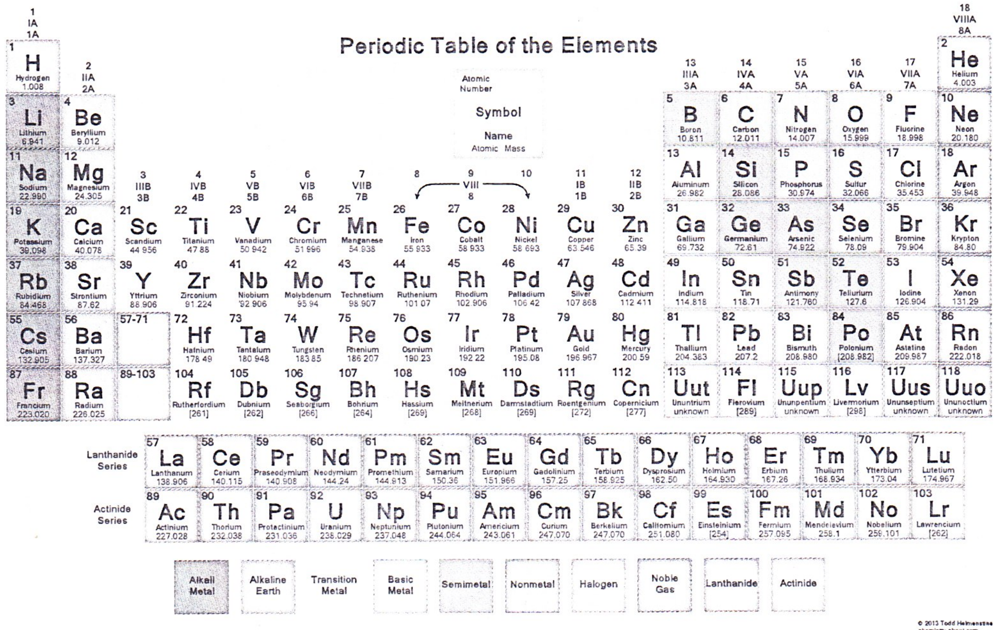
Winter 2015
Chemistry 20A
Midterm

You have two hours to complete these five problems. You may use your calculator and one page of notes.

Not all of the problems are equally complex, but all have the same number of points. Please spend your time accordingly.

Good luck!

Question	Score
1	20
2	20
3	20
4	20
5	20
Total	100 /100



Constants you may need

- Avogadro's number $N_A = 6.022 \times 10^{23}$ mol^{-1}.
- Bohr radius $a_0 = 0.529$Å$= 5.29 \times 10^{-11}$m.
- electron charge $e = 1.602 \times 10^{-19}$ C.
- Planck's constant h $= 6.626 \times 10^{-34}$ J/s.
- Permittivity of the vacuum $\epsilon_0 = 8.854 \times 10^{-12}$.
- Speed of light in the vacuum $c = 2.9979 \times 10^8$m/s.
- electron volt eV $= 1.602 \times 10^{-19}$J $= 96.49$ kJ/mol.
- Boltzmann's constant $k_B = 1.381 \times 10^{-23}$J/K.
- Mass of the electron m$_e = 9.109 \times 10^{-31}$kg.
- Mass of the proton m$_p = 1.673 \times 10^{-27}$kg.
- Mass of the neutron m$_n = 1.675 \times 10^{-27}$kg.

1. (20 points) **Making silicon nitride**

Silicon nitride Si_3N_4 is made by direct combination of silicon and nitrogen at high temperature. How much silicon must react with excess nitrogen to prepare 125g of silicon nitride, if the yield of the reaction is 95%?

$$3\,Si + 2N_2(g) \rightarrow Si_3N_4$$

$$\text{Percent Yield} = \frac{\text{Actual}}{\text{Theoretical}} \times 100$$

$$95 = \frac{125\,g\ Si_3N_4}{\text{Theoretical}} \times 100$$

Theoretical = 131.579 g Si_3N_4

(If the reaction was 100% yield, 131.579 g Si_3N_4 would have formed)

So the amount of Si needed is

$$\frac{131.579g\ Si_3N_4}{} \Big| \frac{1\,mol\ Si_3N_4}{140.286\,g\ Si_3N_4} \Big| \frac{3\,mol\ Si}{1\,mol\ Si_3N_4} = 2.814 \text{ moles Si}$$

$$\text{or } \frac{2.814\,mol\ Si}{} \Big| \frac{28.086\,g\ Si}{1\,mol\ Si} = 79.03\,g\ Si$$

2.814 moles of Si, or 79.03 g, is needed to form 125 g Si_3N_4 assuming 95% yield.

2. (20 points) **What is the molecular formula?**

A sample of a *gaseous* binary compound of boron (B) and chlorine (Cl) weighing 2.842g occupies 0.153L. This sample is decomposed to give 0.664g of solid boron and enough gaseous chlorine (Cl_2) to occupy 0.688L at the same temperature and pressure. Determine the molecular formula of the compound.

2.842g .664g

$B_x Cl_y \rightarrow x B(s) + ?\, Cl_2(g)$

Avogadro's Hypothesis: different gases at constant temp and pressure occupy the same space.

→ Find ratio between moles of $B_x Cl_y$ and Cl_2

$PV = nRT$

$\frac{V_1}{V_2} = \frac{n_1}{n_2}$

$\frac{\text{Volume } B_xCl_y}{\text{Volume } Cl_2} = \frac{\text{moles } B_xCl_y}{\text{moles } Cl_2} = \frac{.153\,L}{.688\,L} = .2224$

$B_x Cl_y \rightarrow x B(s) + .224\, Cl_2(g)$

Conservation of mass:

→ Find amount of B

$.664\,g\,B \left| \frac{1\,mol\,B}{10.811\,g\,B} \right. = .06142\,mol\,B$

Total amount of Cl:

$2.842g - .664g = 2.178g\,Cl \left| \frac{1\,mol\,Cl}{35.453\,g\,Cl} \right. = .061433\,mol\,Cl$

Empirical Formula: BCl

$x = y = z$

$.061433\,mol\,Cl \left| \frac{1\,mol\,Cl_2}{2\,mol\,Cl} \right. = .0307\,mol\,Cl_2$

Answer on next page

$\frac{\text{moles } B_zCl_z}{\text{moles } Cl_2} = .2224 \Rightarrow \text{moles } B_zCl_z = .0068$

$.0068\,mol \cdot \frac{x\,g\,B_zCl_z}{1\,mol\,B_zCl_z} = 2.842g \Rightarrow 417.94\,g/mol$

Next page

For calculations

$$\frac{417.94\text{ g } B_zCl_z}{\text{mol } B_zCl_z}$$

$$z(10.811) + z(35.453) = 417.94$$

$$z \approx 9$$

Molecular Formula: B_9Cl_9

20

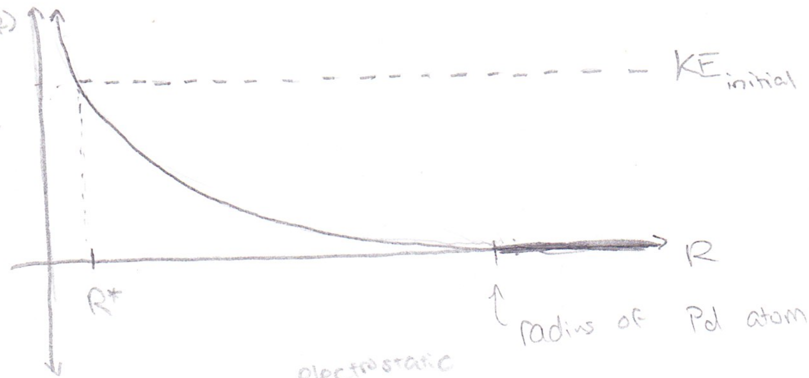
3. (20 points) **Shooting nuclei at each other**

Consider a sodium (Na) nucleus fired at a palladium (Pd) target. A large distances from the target the sodium nucleus has speed v.

a) (10 points) Sketch a graph of the electrostatic potential energy of the system as a function of internuclear distance R. Be sure to label the initial kinetic energy on your graph and, label the point of closest approach R^* using that initial kinetic energy. 10

b) (10 points) In terms of only physical constants and the initial velocity, find the solution for the distance of closest approach R^* Find the maximum value of the force of the Pd nucleus on the incoming Na^{11+} ion.

a)



b) $KE_{initial} = U(R^*)$ ← electrostatic potential Energy

e = charge of e^-

q_{Na} = charge of Na nucleus

q_{Pd} = charge of Pd nucleus

m_e = mass of Na nucleus

$$\frac{1}{2} m_{Na} v_0^2 = \frac{q_{Na} q_{Pd}}{4\pi \varepsilon_0 R^*}$$

$$R^* = \boxed{\frac{q_{Na} q_{Pd}}{2\pi \varepsilon_0 m_{Na} v_0^2}} = \frac{(11e)(46e)}{2\pi \varepsilon_0 m_{Na} v_0^2} = \boxed{\frac{253 e^2}{\pi \varepsilon_0 m_{Na} v_0^2}\ m}$$

Max force at R^* (shortest distance)

$$\|\vec{F}(R^*)\| = \boxed{\frac{q_{Na} q_{Pd}}{4\pi \varepsilon_0 (R^*)^2}} = \frac{q_{Na} q_{Pd}}{4\pi \varepsilon_0} \left(\frac{2\pi \varepsilon_0 m_{Na} v_0^2}{q_{Na} q_{Pd}}\right) \left(\frac{2\pi \varepsilon_0 m_{Na} v_0^2}{q_{Na} q_{Pd}}\right)$$

$$= \boxed{\frac{\pi \varepsilon_0 (m_{Na} v_0^2)^2}{q_{Na} q_{Pd}}} = \boxed{\frac{\pi \varepsilon_0 (m_{Na} v_0^2)^2}{506\ e^2}\ N}$$ in the direction directed away from the Pd nucleus

4. (20 points) **Name that element!**

A certain element M is a main group metal that reacts with chlorine to give a compound with the chemical formula MCl_2, and with oxygen to give the compound MO.

(a) (10 points) To which group in the periodic table does element M belong?

(b) (10 points) The chloride contains 44.7%chlorine by mass. Name the element M.

✓ 10/10

a) The element belongs to Group II, the alkaline earth metals. We know this because this element M has 2 valence electrons and "donates" them to O (Group VI so it needs 2 to fulfill an octet) and 1 to Cl (Group VII so it needs 1 electron to make an octet).

nice explanation

b) MCl_2 → assume 100g of compound

44.7% Cl → $\frac{44.7 \text{ g Cl} \mid 1 \text{ mol Cl}}{\mid 35.453 \text{ g Cl}}$ = 1.2608 mol Cl

$\frac{1.2608 \text{ mol Cl} \mid 1 \text{ mol M}}{\mid 2 \text{ mol Cl}}$ = .6304 mol M

55.3 % M → $\frac{55.3 \text{ g M}}{.6304 \text{ mol M}}$ = 87.72 g/mol M

M is Strontium (Sr)

✓ 10/10

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5.(20 points) **Making Lewis diagrams and picking the good one**
A stable triatomic molecule can be formed that contains one atom each of nitrogen, sulfur, and fluorine. Three bonding structures are possible, depending on which is the central atom: NSF, SNF, SFN.

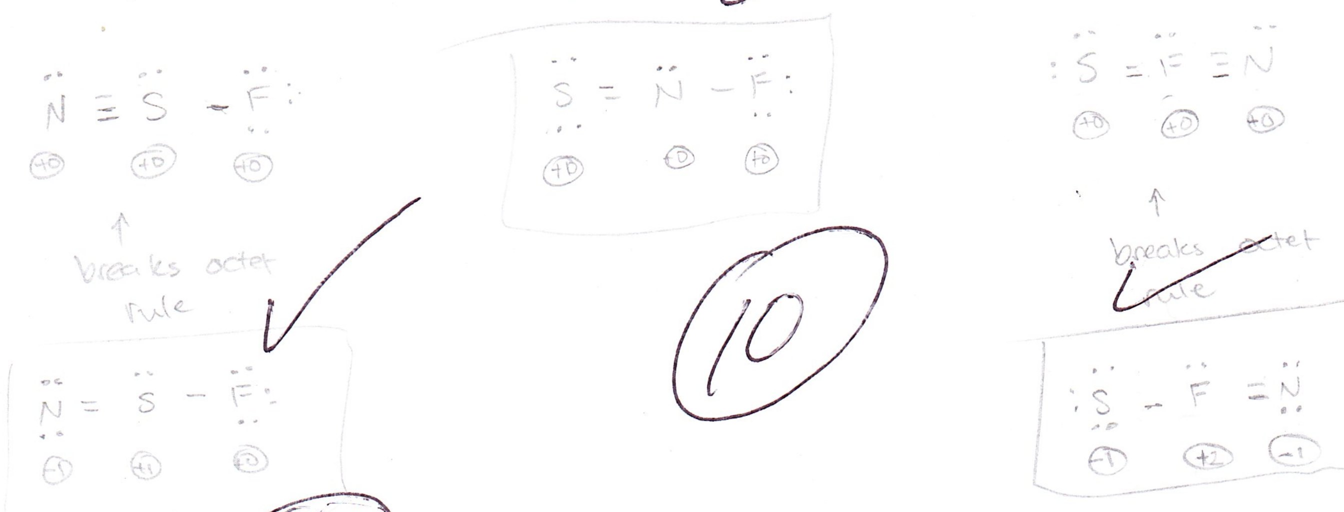
(a) (10 points) Write a Lewis structure for each of the proposed molecules, and label the formal charges on each atom.

(b) (5 points) Often, the structure with the least separation of formal charge is the most stable. Is this statement consistent with the observed structure for this molecule – namely, NSF, which has a central sulfur atom.

(c) (5 points) Now, consider the electronegativies of the atoms – N (3.04), S (2.58), F (3.98). Do they help to rationalize the observed structure of NSF? Please explain in **one sentence**.

$N_e = 18$

a) NSF: SNF: SFN:



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b) NSF has formal charges (-1) and (+1) next to each other which is not ideal. It appears that SNF is more ideal because a Lewis structure without breaking the octet is possible. The statement is not consistent with NSF.

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c) Yes Nitrogen is more electronegative than Sulfur which explains why the electron would be pulled more toward Nitrogen than Sulfur and usually the least electronegative (more electropositive) atom is the central atom which reasons why NSF is preferred over SNF.