

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

Periodic Table of the Elements

Periodic Table of the Elements																																								
		Atomic Number																																						
		Symbol																																						
		Name																																						
		Atomic Mass																																						
1 IA 1A	2 IIA 2A											13 IIIA 3A	14 IVA 4A	15 VA 5A	16 VIA 6A	17 VIIA 7A	18 VIIIA 8A																							
1 H Hydrogen 1.008												5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180																							
3 Li Lithium 6.941	4 Be Beryllium 9.012											11 Na Sodium 22.990	12 Mg Magnesium 24.305											13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.066	17 Cl Chlorine 35.453	18 Ar Argon 39.948											
11 Na Sodium 22.990	12 Mg Magnesium 24.305	3 IIIB 3B	4 IVB 4B	5 VB 5B	6 VIB 6B	7 VIIB 7B	8 VIII 8		9 VIII 9	10 VIII 10	11 IB 1B	12 IIB 2B											19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.88	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.833	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.39	31 Ga Gallium 69.732	32 Ge Germanium 72.61	33 As Arsenic 74.922	34 Se Selenium 78.09	35 Br Bromine 79.904	36 Kr Krypton 84.80
19 K Potassium 39.098	20 Ca Calcium 40.078	39 Y Yttrium 88.906	38 Sr Strontium 87.62	41 Zr Zirconium 91.224	40 Nb Niobium 92.906	42 Mo Molybdenum 95.94	43 Tc Technetium 98.907	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.71	51 Sb Antimony 121.760	52 Te Tellurium 127.6	53 I Iodine 126.905	54 Xe Xenon 131.29																						
37 Rb Rubidium 84.464	38 Sr Strontium 87.62	57-71 Lanthanide Series	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.85	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.967	80 Hg Mercury 200.59	81 Tl Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium (209)	85 At Astatine 209	86 Rn Radon 222.018																							
55 Cs Cesium 132.905	56 Ba Barium 137.327	89-103 Actinide Series	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (266)	107 Bh Bohrium (264)	108 Hs Hassium (265)	109 Mt Meitnerium (268)	110 Ds Darmstadtium (271)	111 Rg Roentgenium (272)	112 Cn Copernicium (277)	113 Nh Nihonium (284)	114 Fl Flerovium (289)	115 Uup Ununpentium (288)	116 Lv Livermorium (293)	117 Uus Ununseptium (294)	118 Uuo Ununoctium (294)																							
57 La Lanthanum 138.905	58 Ce Cerium 140.115	59 Pr Praseodymium 140.908	60 Nd Neodymium 144.24	61 Pm Promethium 144.913	62 Sm Samarium 150.36	63 Eu Europium 151.965	64 Gd Gadolinium 157.25	65 Tb Terbium 158.925	66 Dy Dysprosium 162.50	67 Ho Holmium 164.930	68 Er Erbium 167.26	69 Tm Thulium 168.934	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.967																										
89 Ac Actinium 227.028	90 Th Thorium 232.038	91 Pa Protactinium 231.036	92 U Uranium 238.029	93 Np Neptunium 237.048	94 Pu Plutonium 244.064	95 Am Americium 243.061	96 Cm Curium 247.070	97 Bk Berkelium 247.070	98 Cf Californium 251.080	99 Es Einsteinium (254)	100 Fm Fermium 257.095	101 Md Mendelevium 258.1	102 No Nobelium 259	103 Lr Lawrencium 262																										

Alkali Metal

Alkaline Earth

Transition Metal

Basic Metal

Semimetal

Nonmetal

Halogen

Noble Gas

Lanthanide

Actinide

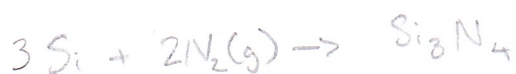
© 2015 Todd Helmenstein
chemistry.elciv.com
helmenstein.org

Constants you may need

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

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%?



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

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

$$\text{Theoretical} = 131.579 \text{ g } Si_3N_4$$

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

So the amount of Si needed is

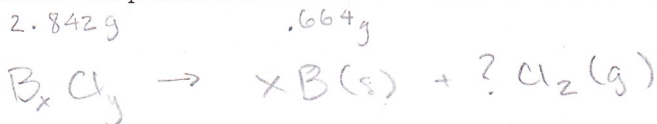
$$\frac{131.579 \text{ g } Si_3N_4}{140.286 \text{ g } Si_3N_4} \times \frac{1 \text{ mol } Si_3N_4}{1 \text{ mol } Si_3N_4} \times \frac{3 \text{ mol } Si}{1 \text{ mol } Si_3N_4} = 2.814 \text{ moles } Si$$

$$\text{or } \frac{2.814 \text{ mol } Si}{1 \text{ mol } Si} \times \frac{28.086 \text{ g } Si}{1 \text{ mol } Si} = 79.03 \text{ g } Si$$

2.814 moles of Si, or 79.03 g, is needed to form 125g 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.



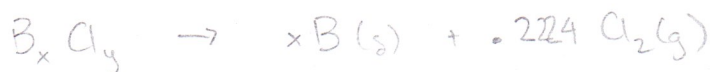
Avogadro's Hypothesis: different gases at constant temp and pressure occupy the same space.

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

$$PV = nRT$$

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

$$\frac{\text{Volume } B_x Cl_y}{\text{Volume } Cl_2} = \frac{\text{moles } B_x Cl_y}{\text{moles } Cl_2} = \frac{.153L}{.688L} = .2224$$



Conservation of mass:

→ Find amount of B

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

Total amount of Cl:

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

Empirical Formula: BCl

$$\frac{.061433 \text{ mol Cl}}{2 \text{ mol Cl}} \left| \frac{1 \text{ mol } Cl_2}{1} \right. = .0307 \text{ mol } Cl_2 \quad x=y=z$$

$$\frac{\text{moles } BCl_2}{\text{moles } Cl_2} = \frac{.061433}{.0307} \Rightarrow \text{moles } BCl_2 = .0068$$

$$.0068 \text{ mol} \cdot \frac{x g B_2 Cl_2}{1 \text{ mol } B_2 Cl_2} = 2.842g \Rightarrow 417.94g/mol$$

→ next page

Answer on next page

For calculations

$$\frac{417.94 \text{ g } B_2Cl_2}{\text{mol } B_2Cl_2}$$

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

$$z \approx 9$$

Molecular Formula : B_9Cl_9

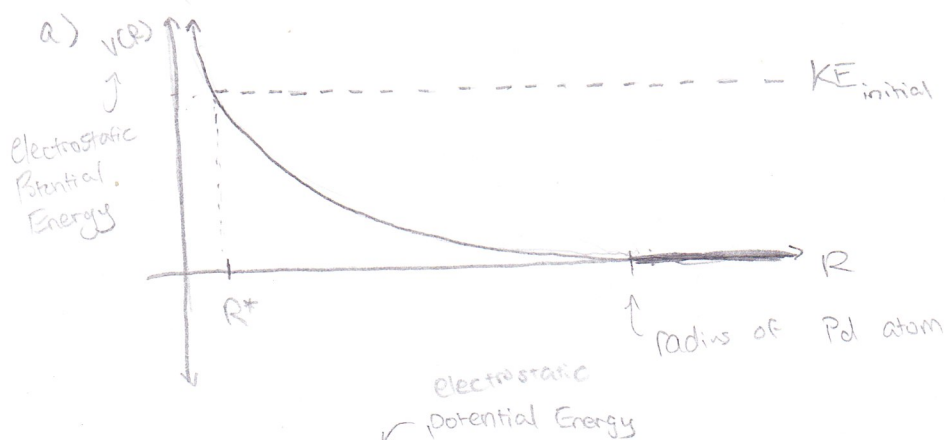
20

3. (20 points) Shooting nuclei at each other

Consider a sodium (Na) nucleus fired at a palladium (Pd) target. A large distance 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) $KE_{initial} = U(R^*)$

$$\frac{1}{2} m_{Na} v_0^2 = \frac{q_{Na} q_{Pd}}{4\pi\epsilon_0 R^*}$$

$$R^* = \frac{q_{Na} q_{Pd}}{2\pi\epsilon_0 m_{Na} v_0^2} = \frac{(11e)(46e)}{2\pi\epsilon_0 m_{Na} v_0^2} = \frac{253e^2}{\pi\epsilon_0 m_{Na} v_0^2} \text{ m}$$

$e =$ charge of e^-
 $q_{Na} =$ charge of Na nucleus
 $q_{Pd} =$ charge of Pd nucleus
 $m_e =$ mass of Na nucleus

Max force at R^* (shortest distance)

$$\begin{aligned} \|\vec{F}(R^*)\| &= \frac{q_{Na} q_{Pd}}{4\pi\epsilon_0 (R^*)^2} = \frac{q_{Na} q_{Pd}}{4\pi\epsilon_0} \left(\frac{2\pi\epsilon_0 m_{Na} v_0^2}{q_{Na} q_{Pd}} \right)^2 \left(\frac{2\pi\epsilon_0 m_{Na} v_0^2}{q_{Na} q_{Pd}} \right) \\ &= \frac{\pi\epsilon_0 (m_{Na} v_0^2)^2}{q_{Na} q_{Pd}} = \frac{\pi\epsilon_0 (m_{Na} v_0^2)^2}{506 e^2} \text{ N} \end{aligned}$$

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 .

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). ✓ $\frac{10}{10}$
Nice explanation

b) $MCl_2 \rightarrow$ assume 100g of compound

$$44.7\% Cl \rightarrow \frac{44.7 \text{ g Cl} / 1 \text{ mol Cl}}{35.453 \text{ g Cl}} = 1.2608 \text{ mol Cl}$$

$$\frac{1.2608 \text{ mol Cl}}{2 \text{ mol Cl}} \left| \frac{1 \text{ mol M}}{1 \text{ mol Cl}} \right. = 0.6304 \text{ mol M}$$

$$55.3\% M \rightarrow \frac{55.3 \text{ g M}}{0.6304 \text{ mol M}} = 87.72 \text{ g/mol M}$$

M is Strontium (Sr) ✓ $\frac{10}{10}$

20

5. (20 points) Making Lewis diagrams and picking the good one

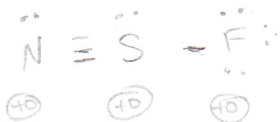
A stable triatomic molecule can be formed that contains one atom each of nitrogen, sulfur, and fluorine. Three bonding structures are possible, depending on which is the central atom: NSF, SNF, SFN.

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

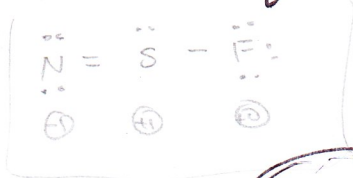
(b) (5 points) Often, the structure with the least separation of formal charge is the most stable. Is this statement consistent with the observed structure for this molecule - namely, NSF, which has a central sulfur atom.

(c) (5 points) Now, consider the electronegativities 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.

a) NSF:



↑
breaks octet rule



S

SNF:



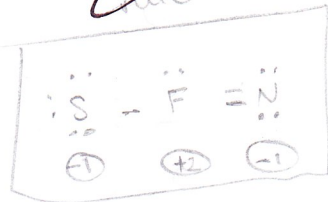
10

Ne = 18

SFN:



↑
breaks octet rule



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.

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