CH301H – Principles of Chemistry I: Honors
Fall 2011, Unique 51040

Exam 1
15 September 2011

Name: Key

You may use your textbook and a calculator for arithmetic.

Honor Code:

"The core values of the University of Texas at Austin are learning, discovery, freedom, leadership, individual opportunity, and responsibility. Each member of the University is expected to uphold these values through integrity, honesty, trust, fairness, and respect toward peers and community."

I certify that the work on this exam is entirely my own.

Signature Date

1. (12 points) True / False. Indicate whether each of the following statements are true, false, or if there is no way to know (NWTK) from the information given.

a. True (False) NWTK For any atom in a molecule, the partial charge is equal to the formal charge.

b. True (False) NWTK CCl_4 has a permanent dipole moment.

c. (True) False NWTK In the Rutherford gold foil experiment, backscattered alpha particles were observed only very rarely.

d. True (False) NWTK The second ionization energy of Cs is lower than the first.

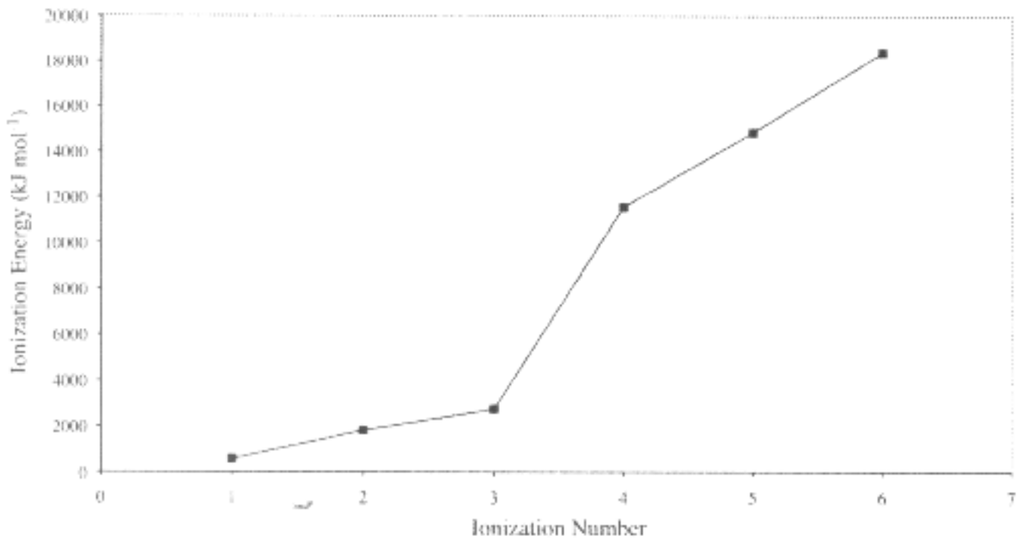
e. True (False) (NWTK) Greater differences in electronegativity between two atoms always increases the ionic character of the bond between them.

both ok

f. True (False) NWTK All molecules with polar covalent bonds have a permanent net dipole moment.

g. True (False) NWTK NO_2^- has a larger net dipole moment than SO_2.

2. (10 points) Which atom is represented by this plot?



- must be in group 3 because of the large jump between IE_3 and IE_4
- can't be B because it only has 5 e⁻, and we are removing 6 e⁻
- So must be Al, Ga, In or Tl

3. (16 points) a) Determine the bond dissociation energy, ΔE_d, for the Ca-Cl bond formed in the following reaction. The equilibrium bond length of the Ca-Cl bond is 2.10 Å.

$$Ca + 2\ Cl \rightarrow CaCl_2$$

See next page

b) The actual bond dissociation energy of the Ca-Cl bond is 107 KJ mol^{-1}. What does this tell you about the character of the Ca-Cl bond?

See next page

3a) Ionize Ca: $Ca \rightarrow Ca^+ + e^-$ $\quad IE_1 = 6.11\ eV/atom$

$Ca^+ \rightarrow Ca^{2+} + e^-$ $\quad IE_2 = 11.87\ eV/atom$

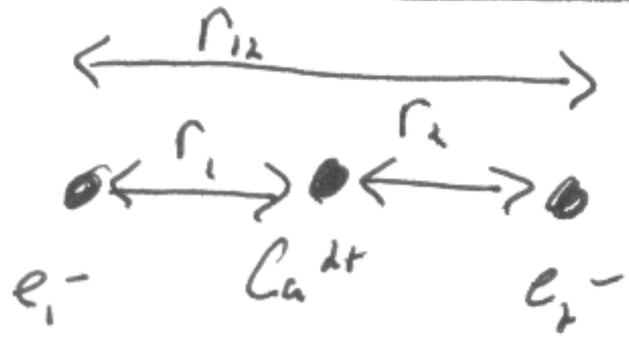
$IE_{TOT} = IE_1 + IE_2 = 17.98\ eV/atom \left(1.602\times10^{-19}\ J/eV\right)\left(6.022\times10^{23}\ atom/mol\right)$

$IE_{TOT} = 1.73\times10^6\ J/mol$

Ionize Cl: $Cl + e^- \rightarrow Cl^-$ $\quad EA = -349\times10^3\ J/mol$

this happens twice: $EA_{TOT} = 2EA_{Cl} = -6.98\times10^5\ J/mol$

$V_D = IE_{TOT} + EA_{TOT} = 1.03\times10^6\ J/mol$ energy we put in



$r_1 = r_2 = 2.1\times10^{-10}\ m$

$r_{12} = 2r_1 = 4.2\times10^{-10}\ m$

$$V_{bond} = \frac{q_{Ca}q_1}{4\pi\epsilon_0 r_1} + \frac{q_{Ca}q_2}{4\pi\epsilon_0 r_2} + \frac{q_1 q_2}{4\pi\epsilon_0 r_{12}} = \frac{e^2}{4\pi\epsilon_0}\left[\left(\frac{Z_{Ca}Z_1}{r_1}\right) + \left(\frac{Z_{Ca}Z_2}{r_2}\right) + \left(\frac{Z_1 Z_2}{r_{12}}\right)\right]$$

$$V_{bond} = \frac{(1.602\times10^{-19}\ C)^2}{4\pi\left(8.85\times10^{-12}\ C^2/J\,m\right)}\left[\frac{(+2)(-1)}{2.1\times10^{-10}\ m} + \frac{(+2)(-1)}{2.1\times10^{-10}\ m} + \frac{(-1)(-1)}{4.2\times10^{-10}\ m}\right]$$

$$V_{bond} = (2.31\times10^{-28}\ J\,m)\left[(-9.52\times10^9\ m^{-1}) + (-9.52\times10^9\ m^{-1}) + (2.38\times10^9\ m^{-1})\right]$$

$V_{bond} = -3.87\times10^{-18}\ J/atom\left(6.022\times10^{23}\ atom/mol\right)$

$V_{bond} = -2.33\times10^6\ J/mol$ for both Ca-Cl bonds

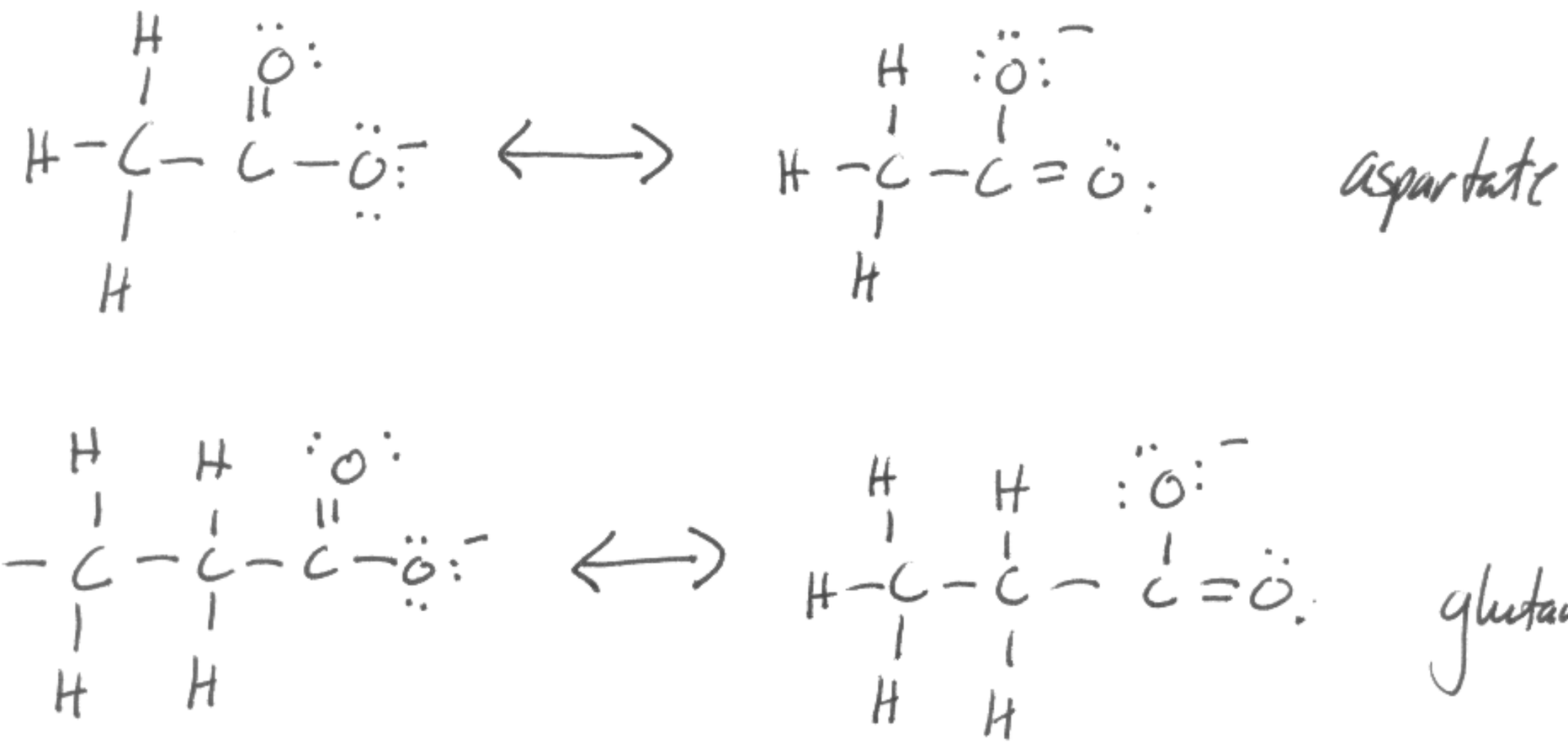
$\boxed{V_{Ca-Cl} = -1.16\times10^6\ J/mol}$ for 1 Ca-Cl bond

$$\Delta E_d = V_o + V_{bond} = -1.34 \times 10^5 \text{ J/mol}$$

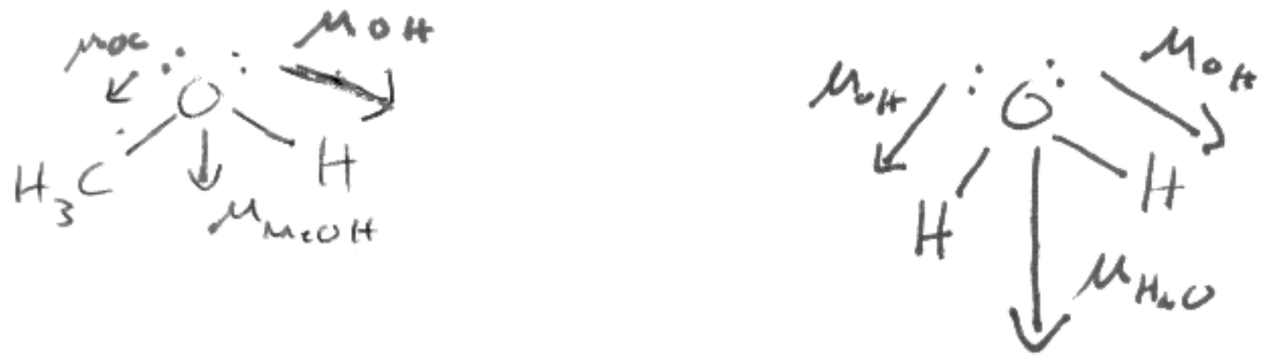
3b) The actual bond dissociation energy is < the energy calculated by assuming a 100% ionic bond. This means that our assumption that the Ca-Cl bond is 100% ionic is incorrect, and that this bond actually has some degree of covalent character

4. (16 points) Aspartic acid (CH_3COOH) and glutamic acid (CH_3CH_2COOH) are both natural amino acids. Both acids have pK_a values less than 7, and so under physiological conditions, both molecules lose the acidic proton. Draw the Lewis dot structure of these two molecules under physiological conditions.

Both acids are deprotonated:

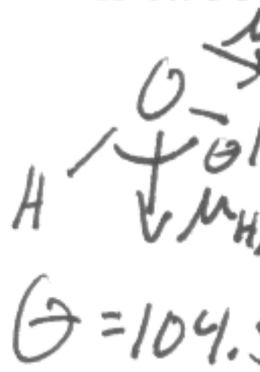


5. (10 points) Methanol (CH_3OH) is like water with a CH_3- group (methyl) in place of one hydrogen. Which molecule, water or methanol, will have a larger molecular dipole moment? You must explain your reasoning in complete sentences and clear English.



Although C + H have similar EN, the EN difference between O–H is still larger than O–C. Therefore water has 2 large dipole moments, while methanol has one large and one small dipole. So water will have the larger molecular dipole moment.

6. (12 points) The dipole moment of water is 1.85 D. Given that the O-H bond length in water is 0.958 Å, what are the partial charges on the hydrogen atoms?



From your homework, $\mu(H_2O) = 2\mu_{OH}\cos\left(\frac{\theta}{2}\right)$

$$\mu_{OH} = \frac{\mu(H_2O)}{2\cos\left(\frac{\theta}{2}\right)} = \frac{1.85\ D}{2\cos\left(\frac{104.5}{2}\right)}$$

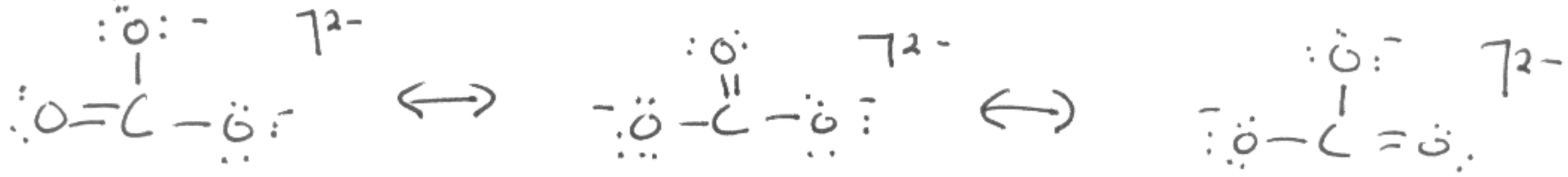
$\mu_{OH} = 1.51\ D$

$$\delta = \frac{\mu_{OH}}{\frac{r}{0.2082\ \text{Å}}} = \frac{1.51\ D}{\left(\frac{0.9581\ \text{Å}}{0.2082\ \text{Å}}\right) D}$$

$\delta = 0.33 = 33\%$ ionic character. So assume this is evenly split over the O + H atoms. $\delta^+(H) = +0.33\,e$, $\delta^-(O) = -0.33\,e$.

7. (24 points) Carbonate (CO_3^{2-}) is an important ion in much of chemistry.

a) Draw the Lewis dot structure for the carbonate ion.



b) Given that the a C-O bond length is generally 1.43 Å and a C=O bond is generally 1.20 Å, what bond lengths would you expect to observe in the carbonate ion?

The resonance structures show that all 3 C-O bonds are an average of double + single bond. So lets say $C\text{-}O = \frac{2}{3}(1.43\ \text{Å}) + \frac{1}{3}(1.2\ \text{Å}) = 1.35\ \text{Å}$

c) Do you expect the carbonate ion to have a permanent dipole moment? Justify your answer.

no - charge evenly distributed around molecule.