Felker FIS

First Midterm Examination, CH20A-1, Fall 2015

Thursday, October 29, 7 to 8:50 pm

NAME: Owen Hemminger

This examination is composed of four problems. Do all parts of all the problems. You have one hour and fifty minutes to complete the exam. You may use three pages of notes (front and back), and a noncommunicating calculator of your choice in working the exam. Only exams **worked in pen** will be eligible for any possible regrades.

Possibly useful physical constants:

Avogadro's number: $N_A = 6.022 \times 10^{23}$ mol^{-1}
Electron charge: $-e = -1.602 \times 10^{-19}$ C
Permittivity of vacuum: $\epsilon_0 = 8.854 \times 10^{-12}$ C^{2}J^{-1}m^{-1}

Two pages that may contain useful data follow this page.

Problem 1: 23 of 25 points

Problem 2: 20 of 25 points

Problem 3: 24 of 25 points

Problem 4: 24 of 25 points

TOTAL:

PERIODIC TABLE OF THE ELEMENTS

KEY

79 — Atomic number
Au — Symbol
Gold — Name
196.9665 — Atomic weight
An element

- Main group metals
- Transition metals
- Metalloids
- Nonmetals, noble gases

Period number

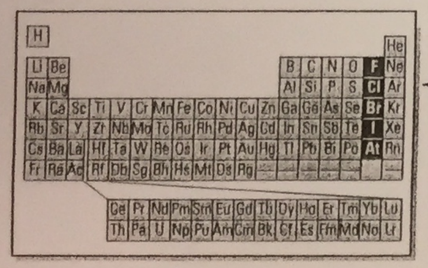
Group number, U.S. system

Group number, IUPAC system

	1A (1)	2A (2)	3B (3)	4B (4)	5B (5)	6B (6)	7B (7)	8B (8)	8B (9)	8B (10)	1B (11)	2B (12)	3A (13)	4A (14)	5A (15)	6A (16)	7A (17)	8A (18)	
1	1 H Hydrogen 1.0079																	2 He Helium 4.0026	1
2	3 Li Lithium 6.941	4 Be Beryllium 9.0122											5 B Boron 10.811	6 C Carbon 12.0107	7 N Nitrogen 14.0067	8 O Oxygen 15.9994	9 F Fluorine 18.9984	10 Ne Neon 20.1797	2
3	11 Na Sodium 22.9898	12 Mg Magnesium 24.3050											13 Al Aluminum 26.9815	14 Si Silicon 28.0855	15 P Phosphorus 30.9738	16 S Sulfur 32.065	17 Cl Chlorine 35.453	18 Ar Argon 39.948	3
4	19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.9559	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.9380	26 Fe Iron 55.845	27 Co Cobalt 58.9332	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.64	33 As Arsenic 74.9216	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.798	4
5	37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.9058	40 Zr Zirconium 91.224	41 Nb Niobium 92.9064	42 Mo Molybdenum 95.96	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.9055	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.9045	54 Xe Xenon 131.293	5
6	55 Cs Cesium 132.9055	56 Ba Barium 137.327	57 La Lanthanum 138.9055	72 Hf Hafnium 178.49	73 Ta Tantalum 180.9479	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.084	79 Au Gold 196.9666	80 Hg Mercury 200.59	81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.9804	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)	6
7	87 Fr Francium (223)	88 Ra Radium (226)	89 Ac Actinium (227)	104 Rf Rutherfordium (267)	105 Db Dubnium (268)	106 Sg Seaborgium (271)	107 Bh Bohrium (272)	108 Hs Hassium (277)	109 Mt Meitnerium (276)	110 Ds Darmstadtium (281)	111 Rg Roentgenium (280)	112 — — (285)	113 — — (284)	114 — — (287)	115 — — (288)	116 — — (293)		118 — — (294)	7

Numbers in parentheses are mass numbers of radioactive isotopes.

Lanthanides	6	58 Ce Cerium 140.116	59 Pr Praseodymium 140.9076	60 Nd Neodymium 144.242	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.9254	66 Dy Dysprosium 162.500	67 Ho Holmium 164.9303	68 Er Erbium 167.259	69 Tm Thulium 168.9342	70 Yb Ytterbium 173.054	71 Lu Lutetium 174.9668	6
Actinides	7	90 Th Thorium 232.0381	91 Pa Protactinium 231.0359	92 U Uranium 238.0289	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (262)	7



This icon appears throughout the book to help locate elements of interest in the periodic table. The halogen group is shown here.

Elements for which the International Union of Pure and Applied Chemistry (IUPAC) has officially sanctioned the discovery and approved a name are indicated by their chemical symbols in this table. Elements that have been reported in the literature but not yet officially sanctioned and named are indicated by atomic number. The name copernicium was proposed for element 112 in July 2009, but at that time this name had not been officially accepted by IUPAC.

APPENDIX F

PHYSICAL PROPERTIES OF THE ELEMENTS

Hydrogen and the Alkali Metals (Group I Elements)

	Hydrogen	Lithium	Sodium	Potassium	Rubidium	Cesium	Francium
Atomic number	1	3	11	19	37	55	87
Atomic mass	1.00794	6.941	22.98976928	39.0983	85.4678	132.9054519	(223.0197)
Melting point (°C)	−259.14	180.54	97.81	63.65	38.89	28.40	25
Boiling point (°C)	−252.87	1347	903.8	774	688	678.4	677
Density at 25°C (g cm^{-3})	0.070 (−253°C)	0.534	0.971	0.862	1.532	1.878	
Color	Colorless	Silver	Silver	Silver	Silver	Silver	
Ground-state electron configuration	$1s^1$	$[He]2s^1$	$[Ne]3s^1$	$[Ar]4s^1$	$[Kr]5s^1$	$[Xe]6s^1$	$[Rn]7s^1$
Ionization energy†	1312.0	520.2	495.8	418.8	403.0	375.7	≈400
Electron affinity†	72.770	59.63	52.867	48.384	46.884	45.505	est. 44
Electronegativity	2.20	0.98	0.93	0.82	0.82	0.79	0.70
Ionic radius (Å)	1.46(H^-)	0.68	0.98	1.33	1.48	1.67	≈1.8
Atomic radius (Å)	0.37	1.52	1.86	2.27	2.47	2.65	≈2.7
Enthalpy of fusion†	0.1172	3.000	2.602	2.335	2.351	2.09	
Enthalpy of vaporization†	0.4522	147.1	97.42	89.6	76.9	67.8	
Bond enthalpy of M_2†	436	102.8	72.6	54.8	51.0	44.8	
Standard reduction potential (volts)	0 H^+/H_2	−3.045 Li^+/Li	−2.7109 Na^+/Na	−2.924 K^+/K	−2.925 Rb^+/Rb	−2.923 Cs^+/Cs	≈2.9 Fr^+/Fr

†In kilojoules per mole.

1(a) Benzene (C_6H_6) reacts with molecular bromine (Br_2) to produce bromobenzene (C_6H_5Br) and hydrogen bromide (HBr). (i) (8 points) What is the maximal amount of bromobenzene that can be produced when 30.0 g of benzene reacts with 65.0 g of Br_2? (ii) (2 points) If the actual amount of bromobenzene produced from the above mixture is 42.3 g, what is the percentage yield of the reaction?

(b) If a hydrocarbon (a compound containing only C and H) combusts in a limited amount of O_2 then, in addition to H_2O, both CO and CO_2 are produced as products. Suppose 0.900 g of a hydrocarbon is burned in a limited O_2 environment to produce 0.934 g of CO, 1.466 g of CO_2 and 0.900 g of H_2O. (a) (8 points) Determine the empirical formula for the hydrocarbon. (b) (2 points) Determine the mass of O_2 consumed in the reaction. (c) (5 points) Determine the mass of O_2 that would have been required to effect complete combustion (i.e., only CO_2 and H_2O as products, no CO).

a) i) $1C_6H_6 + 1Br_2 \rightarrow 1C_6H_5Br + 1HBr$ ✓+1

$30.0\,g\ C_6H_6 \cdot \frac{1\ mol\ C_6H_6}{78.1116\ g\ C_6H_6} \cdot \frac{1\ mol\ C_6H_5Br}{1\ mol\ C_6H_6} \cdot \frac{157.0077\ g\ C_6H_5Br}{1\ mol\ C_6H_5Br} = \boxed{60.3\ g\ C_6H_5Br}$ ✓+5

$65.0\,g\ Br_2 \cdot \frac{1\ mol\ Br_2}{159.808\ g} \cdot \frac{1\ mol\ C_6H_5Br}{1\ mol\ Br_2} \cdot \frac{157.0077\ g\ C_6H_5Br}{1\ mol\ C_6H_5Br} = 63.9\ g\ C_6H_5Br$

ii) $\%\ yield = \frac{42.3\ g\ C_6H_5Br}{60.3\ g\ C_6H_5Br} \cdot 100 = \boxed{70.1\ \%}$ ✓+2

b) i) $.934\ g\ CO \cdot \frac{12.0107\ g\ C}{28.0101\ g\ CO} = .40050\ g\ C$

$1.466\ g\ CO_2 \cdot \frac{12.0107\ g\ C}{44.0095\ g\ CO_2} = .40009\ g\ C$

$.40050\ g\ C + .40009\ g\ C = .80059\ g\ C$

$.80059\ g\ C \cdot \frac{1\ mol\ C}{12.0107\ g\ C} = .06666\ mol\ C$

$.900\ g\ H_2O \cdot \frac{2.0158\ g\ H}{18.0152\ g\ H_2O} = .10070\ g\ H \cdot \frac{1\ mol\ H}{1.0074\ g\ H} = .09992$

$\frac{.06666\ mol\ C}{.06666} = 1\ mol\ C \cdot 2 = 2\ mol\ C$

$\frac{.09992\ mol\ H}{.09992} = 1.4998\ mol\ H \cdot 2 = 2.998\ mol\ H \approx 3\ mol\ H$

$\boxed{C_2H_3}$ ✓+8

ii) $.934\ g\ CO - .40050\ g\ C = .5335\ g\ O$

$1.466\ g\ CO_2 - .40009\ g\ C = 1.0659\ g\ O$

$.900\ g\ H_2O - .10070\ g\ H = .7993\ g\ O$

$2.39871\ g\ O \cdot \frac{1\ g\ O_2}{2\ g\ O} = \boxed{1.199\ g\ O_2}$ consumed

iii) $4C_2H_3 + 11O_2 \rightarrow 8CO_2 + 6H_2O$

$.900\ g\ C_2H_3 \cdot \frac{1\ mol\ C_2H_3}{27.0451\ g} \cdot \frac{11\ mol\ O_2}{4\ mol\ C_2H_3} \cdot \frac{31.9988\ g\ O_2}{1\ mol\ O_2} = \boxed{2.93\ g\ O_2}$ ✓+5

2(a) (12 points) A sample containing only $CaCO_3(s)$ and $SrCO_3(s)$ has a mass of 0.600 g. Upon dissolution in strong acid the sample produces 0.220 g of $CO_2(g)$. Determine the mass percentage of $CaCO_3$ in the original sample under the assumption that all the C in the original sample is converted to CO_2 in the dissolution process.

(b) Acrylonitrile (C_3H_3N), an important industrial chemical, can be produced by the reaction of propylene (C_3H_6) with ammonia (NH_3) and diatomic oxygen to produce acrylonitrile and water. (i) (2 points) Write a balanced chemical equation for this reaction. (ii) (8 points) A mixture containing 30 kg each of propylene, ammonia, and oxygen react to produce acrylonitrile. What mass of acrylonitrile is produced, assuming a yield of 100%? (iii) (3 points) What is the limiting reagant for the reaction described in (ii)?

a) $.220\ g\ CO_2 \cdot \frac{12.0107\ g\ C}{44.0095\ g\ CO_2} \cdot \frac{1\ mol\ C}{12.0107\ g\ C} = .004999\ mol\ C$ +1

x^2 how did you get this equations?

$\left(x\ mol\ C \cdot \frac{1\ mol\ CaCO_3}{1\ mol\ C} \cdot \frac{100.0869\ g\ CaCO_3}{1\ mol\ CaCO_3}\right) + \left((.004999 - x)\ mol\ C \cdot \frac{1\ mol\ SrCO_3}{1\ mol\ C} \cdot \frac{147.6289\ g\ SrCO_3}{1\ mol\ SrCO_3}\right) = .600\ g\ sample$

$100.0869x\ g\ CaCO_3 + (.73799 - 147.6289x)\ g\ SrCO_3 = .600\ g\ sample$

$-47.542x = -.13799$

$x = .0029024$ +2

$.0029024\ mol\ C \cdot \frac{1\ mol\ CaCO_3}{1\ mol\ C} \cdot \frac{100.0869\ g\ CaCO_3}{1\ mol\ CaCO_3} = .29049\ g\ CaCO_3$

$mass\ \%\ CaCO_3 = \frac{.29049\ g\ CaCO_3}{.600\ g\ sample} \cdot 100 = \boxed{48.4\%\ CaCO_3}$ +2

b) i) $\boxed{2C_3H_6 + 2NH_3 + 3O_2 \longrightarrow 2C_3H_3N + 6H_2O}$

ii) $30\ kg\ C_3H_6 \cdot \frac{1000\ g}{kg} \cdot \frac{1\ mol\ C_3H_6}{42.0795\ g\ C_3H_6} \cdot \frac{2\ mol\ C_3H_3N}{2\ mol\ C_3H_6} \cdot \frac{53.0625\ g\ C_3H_3N}{1\ mol\ C_3H_3N} = 37830\ g\ C_3H_3N$

$= 37.8\ kg\ C_3H_3N$

$30\ kg\ NH_3 \cdot \frac{1000\ g}{kg} \cdot \frac{1\ mol\ NH_3}{17.0304\ g\ NH_3} \cdot \frac{2\ mol\ C_3H_3N}{2\ mol\ NH_3} \cdot \frac{53.0625\ g\ C_3H_3N}{1\ mol\ C_3H_3N} \cdot \frac{1\ kg}{1000\ g} = 93.5\ kg\ C_3H_3N$

$30\ kg\ O_2 \cdot \frac{1000\ g}{1\ kg} \cdot \frac{1\ mol\ O_2}{31.9988\ g\ O_2} \cdot \frac{2\ mol\ C_3H_3N}{3\ mol\ O_2} \cdot \frac{53.0625\ g\ C_3H_3N}{1\ mol\ C_3H_3N} \cdot \frac{1\ kg}{1000\ g} = \boxed{33.2\ kg\ C_3H_3N}$

iii) O_2 produced the least C_3H_3N, so $\boxed{O_2 \text{ is the limiting reagant}}$

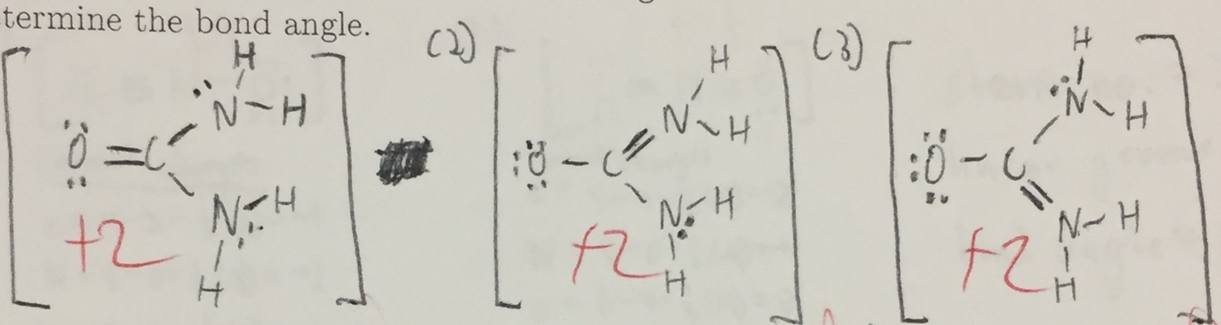
+13

3(a) Urea has the chemical formula $OC(NH_2)_2$. It has one CO bond and two CN bonds. Each of the N atoms is also bonded to two H atoms. (i) (7 points) Draw the three most important Lewis-structure resonance forms for the molecule (these need not all be equivalent resonance structures). (ii) (3 points) Based on a formal charge analysis predict which resonance structure(s) is(are) likely to contribute most to the bonding in the molecule. (iii) (5 points) It happens that urea is a planar species with all its bond angles equal to roughly 120°. Is this geometry consistent with the "dominant" resonance structure from (ii)? Explain your answer fully by making reference to VSEPR theory.

(b) (10 points) Draw two acceptable (i.e., all valence shells filled) Lewis structures for both (i) NCO^- (the C is bonded to the N and to the O) and (ii) CNO^- (the N is bonded to the C and to the O). For each identify the Lewis structure that would be expected to contribute most to the bonding in the molecule and apply VSEPR to determine the bond angle.

C: $4e^- \cdot 1 = 4e^-$
O: $6e^- \cdot 1 = 6e^-$
N: $5e^- \cdot 2 = 10e^-$
H: $1e^- \cdot 4 = 4e^-$
Total valence e: 24e

a) i) (1) (2) (3)



ii) (1) $FC(O) = 6-4-\frac{1}{2}(4) = 0$
$FC(C) = 4-0-\frac{1}{2}(8) = 0$
$FC(N_1) = 5-2-\frac{1}{2}(6) = 0$
$FC(N_2) = 5-2-\frac{1}{2}(6) = 0$
$FC(H) = 1-0-\frac{1}{2}(2) = 0$

N_1 is top N, N_2 is bottom N

(2) $FC(O) = 6-6-\frac{1}{2}(2) = -1$
$FC(C) = 4-0-\frac{1}{2}(8) = 0$
$FC(N_1) = 5-0-\frac{1}{2}(8) = +1$
$FC(N_2) = 5-2-\frac{1}{2}(6) = 0$
$FC(H) = 1-0-\frac{1}{2}(2) = 0$

(3) $FC(O) = 6-6-\frac{1}{2}(2) = -1$
$FC(C) = 4-0-\frac{1}{2}(8) = 0$
$FC(N_1) = 5-2-\frac{1}{2}(6) = 0$
$FC(N_2) = 5-0-\frac{1}{2}(8) = +1$
$FC(H) = 1-0-\frac{1}{2}(2) = 0$

Since structure (1) has all atoms with formal charges of zero as well as the sum of the formal charges equal to zero, it will contribute most to the bonding in the molecule. Though (2) and (3) have sums of zero, each has a formal charge of −1 on the O atom and a formal charge of +1 on an N atom, making each less dominant than structure (1).

iii) In structure (1), the geometry at the C atom will be planar as its steric number of 3 and lack of lone pairs gives it trigonal planar geometry. However, at each N atom, the geometry will be trigonal pyramidal due to the steric number of 4 with one lone pair. This causes the H atoms to break from the plane created by the geometry about the C atom at an angle of approximately 109.5°. This means the geometry of the urea molecule is inconsistent with the geometry of the "dominant" resonance structure from (ii).

(Part b on next page)

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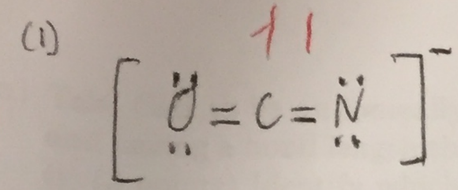
b) i) NCO^-

$5e^-$
$C: 4e^-$
$O: 6e^-$
charge: $1e^-$
total $16\ e^-$ valence

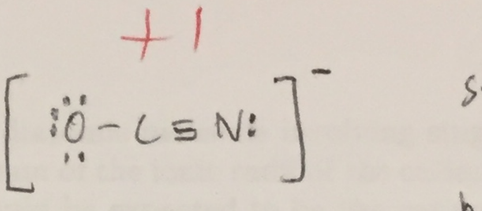
Same

(1) +1



Formal charges:
$O = 6 - 4 - \frac{1}{2}(4) = 0$
$C = 4 - 0 - \frac{1}{2}(8) = 0$
$N = 5 - 4 - \frac{1}{2}(4) = -1$

(2) +1



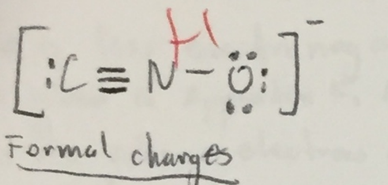
Formal charges:
$O = 6 - 6 - \frac{1}{2}(2) = -1$
$C = 4 - 0 - \frac{1}{2}(8) = 0$
$N = 5 - 2 - \frac{1}{2}(6) = 0$

steric no. = 2
linear geometry
bond angle = 180°
+1

Structure (2) expected to contribute most since O is more electronegative than N, so it is more likely to adopt a formal charge of −1, Both are likely to contribute, though. +1

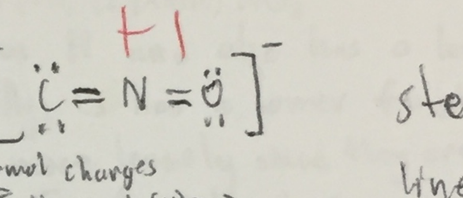
ii) CNO^-

(1) +1



Formal charges
$C = 4 - 2 - \frac{1}{2}(6) = -1$
$N = 5 - 0 - \frac{1}{2}(8) = +1$
$O = 6 - 6 - \frac{1}{2}(2) = -1$

(2) +1



Formal charges
$C = 4 - 4 - \frac{1}{2}(4) = -2$
$N = 5 - 0 - \frac{1}{2}(8) = +1$
$O = 6 - 4 - \frac{1}{2}(4) = 0$

steric no. = 2
linear geometry
bond angle = 180° +1

Structure (1) will be favored since there is a more even distribution of formal charge across the molecule, with no atom's charge having a magnitude greater than 1, whereas structure (2) has a magnitude of 2 in the negative on carbon. +1

9

4(a) Take CsH to be an ionically bonded diatomic molecule involving singly-charged ions and having a bond length that is the sum of the ionic radii of the cation and the anion. (i) (3 points) Identify which atom would be expected to be the cation. Support your answer fully. (ii) (6 points) Estimate the energy required to dissociate the diatomic to form the separated neutral atoms. In making this estimate neglect the short-range repulsion contribution to the diatomic's energy. (iii) (7 points) Sketch a diagram of the potential energy of the diatomic as a function of the distance between the nuclei. On this diagram set the zero of the potential energy to that of the separated neutrals. Indicate on the diagram the energy of dissociation from part (ii) and the equilibrium bond distance of the diatomic.

(b) Assign oxidation numbers to the atoms in each of the following species: (i) (2 points) $Zn(OH)_4^{2-}$, (ii) (2 points) $Ca_5(PO_4)_3F$, (iii) (1 point) $Cr_2O_7^{2-}$, (iv) (1 point) KO_2, (v) (1 point) CsH, (vi) 1 point) NH_4^+, and (vii) (1 point) NO_3^-.

a) i) Cs is less electronegative than H and also has a lower electron affinity as given in Appendix F. Additionally, Cs has a lower first ionization energy as its valence electrons are held more loosely since they are farther from the nucleus, as evidenced again by Appendix F. As such, Cs is expected to lose an electron and become the cation while H gains an electron and becomes the anion.

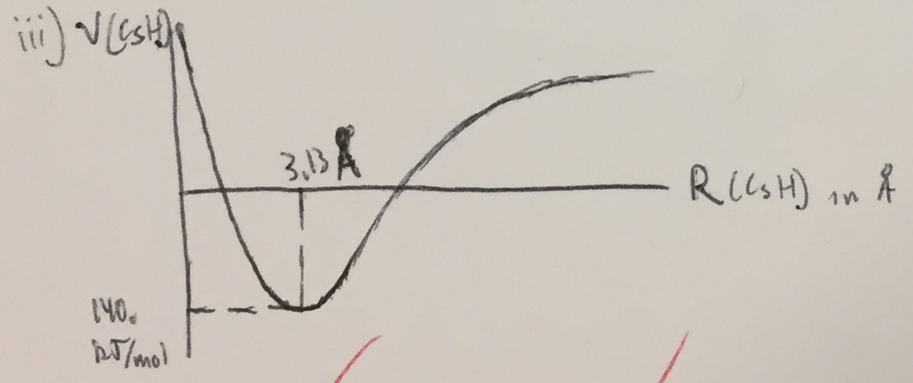
ii) $\Delta E_d = \frac{-q_1 q_2}{4\pi\varepsilon_0 r} \cdot \frac{N_A}{\frac{10^3\ J}{kJ}} - E_\infty$, $E_\infty = IE_1(Cs) - EA_1(H) = 302.93\ kJ/mol$

$$\Delta E_d = \frac{-(-1.602\times10^{-19}\ C)(1.602\times10^{-19}\ C)}{4\pi(8.854\times10^{-12}\ C^2J^{-1}m^{-1})(3.13\times10^{-10}\ m)} \cdot \frac{6.022\times10^{23}}{\frac{1000\ J}{kJ}} - 302.93\ kJ/mol$$

$$= 443.64\ \frac{kJ}{mol} - 302.93\ kJ/mol$$

$$= \boxed{140.\ kJ/mol}$$

iii)



b) i) $Zn(OH)_4^{2-}$ (+2, −2, +1) ii) $Ca_5(PO_4)_3F$ (+2, +5, −2, −1) iii) $Cr_2O_7^{2-}$ (+6, −2) iv) KO_2 (+1, $-\frac{1}{2}$) v) CsH (−1, +1)

vi) NH_4^+ (+5, −1) vii) NO_3^- (+5, −2)

-1