Name ________ ______________________________ **Student ID #** __________

Signature

TOTAL = ______

Chemistry 20BH, Winter 2018
1 February 2018
5 questions + 1 small extra credit problem, 8 pages.
Answer on these sheets only. Additional space on last page.
If you need extra sheets, please ask your TA.

Note: Only these papers can be used; no other notes are allowed.

Please answer each question concisely. Show your calculations.
You may (and in some cases, must) draw explanatory diagrams.
Label all axes and features on graphs and diagrams.

1)	**/30**
2)	**/20**
3)	**/20**
4)	**/15**
5)	**/15**
EC)	**/5**

You may not use a calculator, computer, watch, smart device, or electronics of any sort.
Irrelevant and/or incorrect material will result in loss of points.

Table of constants and conversions

Speed of light: $c = 3 \times 10^{8}$ m/s
Faraday constant = 96500 coul/mole
Electron charge magnitude: $e = 1.6 \times 10^{-19}$ C
Plank's constant: $\hbar = 1.1 \times 10^{-34}$ J-s
Gas constant: R = 0.08206 L-atm/mol-K = 8.314 J/mol-K = 1.987 cal/mol-K
Boltzmann constant: $k_B = 1.4 \times 10^{-23}$ J/K
Electron rest mass: $m = 9.1 \times 10^{-31}$ kg
Proton rest mass: $M = 1.7 \times 10^{-27}$ kg
1 mole = 6.02×10^{23}

Energy Conversion Table

	eV	cm⁻¹	kcal/mol	kJ/mol	K	J	Hz
eV	1	8 065.73	23.060 9	96.486 9	11 604.9	$1.602\ 10 \times 10^{-19}$	$2.418\ 04 \times 10^{+14}$
cm^{-1}	$1.239\ 81 \times 10^{-4}$	1	0.002 859 11	0.011 962 7	1.428 79	$1.986\ 30 \times 10^{-23}$	$2.997\ 93 \times 10^{+10}$
kcal/mol	0.043 363 4	349.757	1	4.18400	503.228	6.95×10^{-21}	$1.048\ 54 \times 10^{+13}$
kJ/mol	0.010 364 10	83.593	0.239001	1	120.274	1.66×10^{-21}	$2.506\ 07 \times 10^{+12}$
K	0.000 086 170 5	0.695 028	0.001 987 17	0.008 314 35	1	$1.380\ 54 \times 10^{-23}$	$2.083\ 64 \times 10^{+10}$
J	$6.241\ 81 \times 10^{+18}$	$5.034\ 45 \times 10^{+22}$	$1.44 \times 10^{+20}$	$6.02 \times 10^{+20}$	$7.243\ 54 \times 10^{+22}$	1	$1.509\ 30 \times 10^{+33}$
Hz	$4.135\ 58 \times 10^{-15}$	$3.335\ 65 \times 10^{-11}$	$9.537\ 02 \times 10^{-14}$		$4.799\ 30 \times 10^{-11}$	$6.625\ 61 \times 10^{-34}$	1

$\Delta G° = -nFE° = -2.303\ RT \log_{10} K_{eq}$

$pH = -\log [H^+]$

$pH = pK_a - \log_{10}([HA]/[A^-])$

You will find a periodic table for your reference on the next page.

Periodic Table of the Elements

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H Hydrogen 1.008																	2 He Helium 4.003
3 Li Lithium 6.941	4 Be Beryllium 9.012											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
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
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.867	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.732	32 Ge Germanium 72.631	33 As Arsenic 74.922	34 Se Selenium 78.971	35 Br Bromine 79.904	36 Kr Krypton 84.798
37 Rb Rubidium 84.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.95	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 112.414	49 In Indium 114.818	50 Sn Tin 118.711	51 Sb Antimony 121.760	52 Te Tellurium 127.6	53 I Iodine 126.904	54 Xe Xenon 131.294
55 Cs Cesium 132.905	56 Ba Barium 137.328	57-71 Lanthanides	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.085	79 Au Gold 196.967	80 Hg Mercury 200.592	81 Tl Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium [208.982]	85 At Astatine 209.987	86 Rn Radon 222.018
87 Fr Francium 223.020	88 Ra Radium 226.025	89-103 Actinides	104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [269]	109 Mt Meitnerium [278]	110 Ds Darmstadtium [281]	111 Rg Roentgenium [280]	112 Cn Copernicium [285]	113 Nh Nihonium [286]	114 Fl Flerovium [289]	115 Mc Moscovium [289]	116 Lv Livermorium [293]	117 Ts Tennessine [294]	118 Og Oganesson [294]

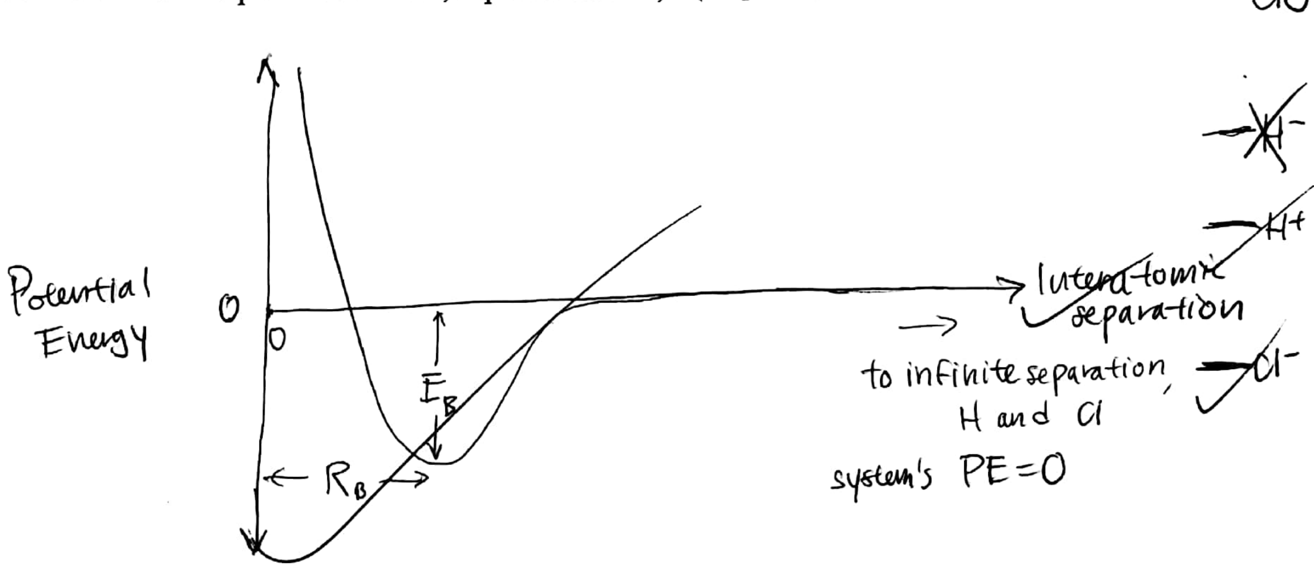
57 La Lanthanum 138.905	58 Ce Cerium 140.116	59 Pr Praseodymium 140.908	60 Nd Neodymium 144.243	61 Pm Promethium 144.913	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.925	66 Dy Dysprosium 162.500	67 Ho Holmium 164.930	68 Er Erbium 167.259	69 Tm Thulium 168.934	70 Yb Ytterbium 173.055	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 259.101	103 Lr Lawrencium [262]

Alkali Metal	Alkaline Earth	Transition Metal	Basic Metal	Semimetal	Nonmetal	Halogen	Noble Gas	Lanthanide	Actinide

Name ___ ______________________ **Student ID #** ___________

Question 1 (30 points): 30

a) Draw the gas phase potential energy level diagram for HCl (*i.e.*, energy vs. separation for isolated molecules and upon dissociation, separated atoms). (10 points)



b) Show the bond (dissociation) energy on your diagram. (5 points)
Estimate its value with a factor of 50%. (3 points)

I indicated w/ E_B; length gives magnitude of bond diss. energy, which is energy required to change state from bonding (equilibrium) to completely separate, i.e. dissociated. Typical diatomic, nonmetal bond energy is 5 eV.

c) Show the bond length on your diagram. (5 points)
Estimate its value with a factor of 50%. (3 points)

I indicated with R_B; equilibrium bond length corresponds to where potential well occurs. Typical diatomic, nonmetal bond length is 1.5 Å

d) For the separated atoms (*i.e.*, for the dissociated molecule), on your plot, show whether the ionized and reduced forms (cations and anions, respectively) of the atoms are more or less stable than the neutral atoms. (4 points, 1 for each)
You are not being asked the magnitudes, only the signs of the energy changes.

unstable!? H^- — H^+ (proton) slightly less stable?

more stable Cl^- — Cl^+ unstable !!

Name ____________

Question 2 (20 points): 20

a) When iron rusts, it reacts with the oxygen in air (in contact with water) to make Fe_2O_3. Write the balanced reaction. (12 points)

Ox. #s: $\overset{0}{Fe} + \overset{0}{O_2} \rightarrow \overset{+3}{Fe_2}\overset{-2}{O_3}$

Balance O: $Fe + 3H_2O \rightarrow Fe_2O_3$ $\quad H_2O + O_2 \rightarrow Fe_2O_3$ $\quad O_2 + 2OH^- \rightarrow Fe_2O_3 + H_2O$

(assume basic solution...?)

Balance H: ~~$Fe + O_2 + H_2O + 2OH^- \rightarrow Fe_2O_3 + 2H_2O$~~ $\quad Fe + 6OH^- \rightarrow Fe_2O_3 + 3H_2O$

~~$Fe + O_2 + 2OH^- \rightarrow Fe_2O_3 + H_2O$~~ oops $\quad$ Electrons: $Fe + 6OH^- \rightarrow Fe_2O_3 + 3H_2O + 6e^-$

$O_2 + 2OH$

Well at least...

$$4Fe + 3O_2 \rightarrow 2Fe_2O_3$$ ✓

b) Assign the oxidation states of each element in the reactants and the products. (8 points)

Ox. state $\overset{0}{4Fe} + \overset{0}{3O_2} \rightarrow 2\overset{+3}{Fe_2}\overset{-2}{O_3}$ ✓

Name _______

Question 3 (20 points):

I was looking for simple reaction of $HClO_4$ where it served as an oxidizing agent, and I found that it:

1) Explosively reacts with bismuth (but not related elements – weird, but not really useful here) and
2) Is used in dissolving (graphitic) carbon rods used for nuclear reactor fuel.

In the latter case, the trace metals, impurities, fuel and nuclear products (like Pb, Hg, Zn, Se, As, Cu, Co, Ag, Sb, Mo, Cr, Cd, Sr, and Fe).

a) What kind of spectroscopy might you use to identify and to quantify these elements once the rods are dissolved and what energy levels are involved? (10 points)
[Note that it is ok if your answer was not discussed in class.]

I might use mass spectrometry, [illegible] but some of the nuclear products may not easily be converted to vapor and may have similar mass-charge ratios – especially with

OH WAIT that isn't "spectroscopy"

+8

X-ray or deep (high energy) UV spectroscopy, since core electron excitation energies are better indicators of elemental identity than e.g. valence electron excitation energies. Here, energy levels of many keV are involved.

X keV
UV ~100
V 1.24

b) What are the carbon-containing reaction products when the carbon in the rods is reacted with perchloric acid? (5 points)

$HClO_4$ as oxidizing agent; H gains electrons
Carbon is oxidized, loses electrons?

CCl

$C + 2HClO_4 + H_2O$

CH_4?? $CClO_4^-$??

CO_2 +4

...I am not sure how this reaction would proceed.

this is ok

c) Rank these acids from weakest to strongest: H_2O, HCl, $HClO_2$, NH_3 (5 points)

Weak — Strong

H_2O, NH_3, , HCl, $HClO_2$

+5

$NH_3 + H_2O \rightarrow NH_4^+ + ...$?

H–N–H (H) 3Hs per molecule!

H–O (H)

H–Cl

OH > NH...

$HClO_2$ – electronegative O makes H even more weakly bound than in HCl?

Name ______________ ___

Question 4 (15 points):

a) When liquid water freezes, is heat given off? (10 points)
Explain your logic

When a liquid, like water, freezes, kinetic energies of molecules decrease such that they eventually lose most translational movement, characteristic of solids; during this process heat is given off. (That is, thermal energy is transferred to the surroundings.)

b) When dry ice, $CO_2(s)$, sublimes, is heat given off? (5 points)
Explain your logic

When solid CO_2 sublimes, energy put into the system does not increase its temperature but breaks strong intermolecular forces between CO_2 molecules such that they directly enter the gas phase; thus heat is not given off but rather uptaken (?).

Name ___ ____________

Question 5 (15 points):

a) From the density of water and the periodic table, estimate (to within 30%) the molarity of pure water. (10 points)
Show briefly how you reached this value.

$2H_2O_{(l)} \rightleftharpoons OH^-_{(aq)} + H_3O^+_{(aq)}$
num

H: 1.008 $\frac{g}{mol}$
O: 16.00 $\frac{g}{mol}$
H_2O: 18.02 $\frac{g}{mol}$

Density of water: ~ 1 g/mL

Molar mass of water: ~18.02 g/mol

Molarity: $\frac{\text{moles}}{L}$ (not a solution if pure water, so interpret as moles water per liter water)

1g/mL = 1000 g/L

$\frac{1000 \text{ g } H_2O}{1 \text{ L } H_2O} \cdot \frac{1 \text{ mol } H_2O}{18.02 \text{ g } H_2O} \approx \boxed{55 \frac{\text{mol } H_2O}{L\ H_2O}}$

18 × 5 = 90

$18 \overline{)1000}$ = 55.5...
90
100
90
10

b) What is the approximate density of gas in 1 atm N_2 at room temperature (to within 50%)? (5 points)
Show briefly how you reached this value.

N_2 is pretty small and room temp / 1 atm are not extreme (lower the pressure, higher the temp, more ideal)

so assume gas is ideal:

1 mol occupies 22.4 L at STP. → 1 atm, room temp

~~PV=nRT~~

Molar mass of N_2: $2(14.01 \frac{g}{mol}) = 28.02 \frac{g}{mol}$

$1 \text{ mol} (28.02 \frac{g}{mol}) = 28.02 \text{ g}$

density = $\frac{M}{V} = \frac{28.02 g}{22.4 L} \approx \boxed{1.3 \frac{g}{L}}$ N_2 gas in 1 atm at room temp.

$\frac{6}{22} = \frac{3}{11}$

Name _

Extra credit #1 (5 points):
Describe in two to three sentences one of the seminars in science, engineering, or medicine that you attended this quarter and one concept from our class that was included in it.
Name the speaker, their institution, and the department and seminar program, if you remember them; otherwise, describe them as best you can and we will figure it out with you later.

As part of an Introduction to Comp. & Systems Biology seminar class, Dr. Hong Zhou (CNSI, probably biochemistry...?) spoke about different methods of imaging biomolecules – X-ray crystallography and Nuclear Magnetic Resonance among others. He focused on proteins and nucleic acids and introduced the concept of structural biology, which has major applications in e.g. drug development/discovery, given the importance of complex molecular structures to their function. I will attempt to elaborate on X-ray crystallography (which I think was used for this cool ~~picture~~ model of a virus):

M184:
Hong Zhou ←
Scott Keeney
Aerosols
QCB Intro to Modern Stats??
Don Vaughn

Continue any answers below if you need more room.

Continuation of problem #_____

Sample must be crystallized, and its crystal form has unique diffractive properties that provide information about relative distances, angles, etc. when X-rays are shone through it. A detector records a 2D image of diffraction pattern, and then the crystal can be rotated and re-imaged so that a 3D profile can be produced.

according to Bragg's law, which I only understand to involve constructive interference of the incident light and to provide structural information