Name ________________________ Section # ____ Student ID # ___________

Chemistry 20B, Winter 2016, Sections 1 & 3, Midterm #1
20 January 2016
6 questions + 2 small extra credit problems, 10 pages.
Answer on these sheets only. Additional space on last page.
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Label all axes and features on graphs and diagrams.

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Table of constants and conversions
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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
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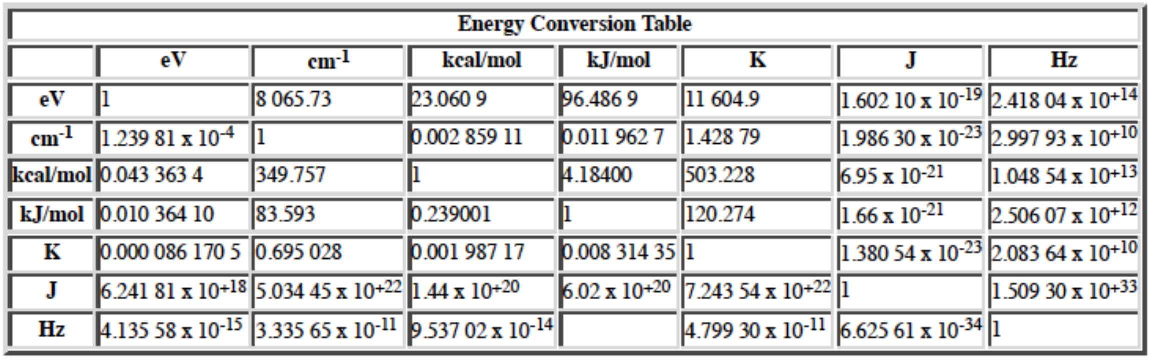
1 mole = 6.02×10^{23}



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kcal/mol	0.043 363 4	349.757	1	4.18400	503.228	6.95×10^{-21}	$1.048\ 54 \times 10^{+13}$
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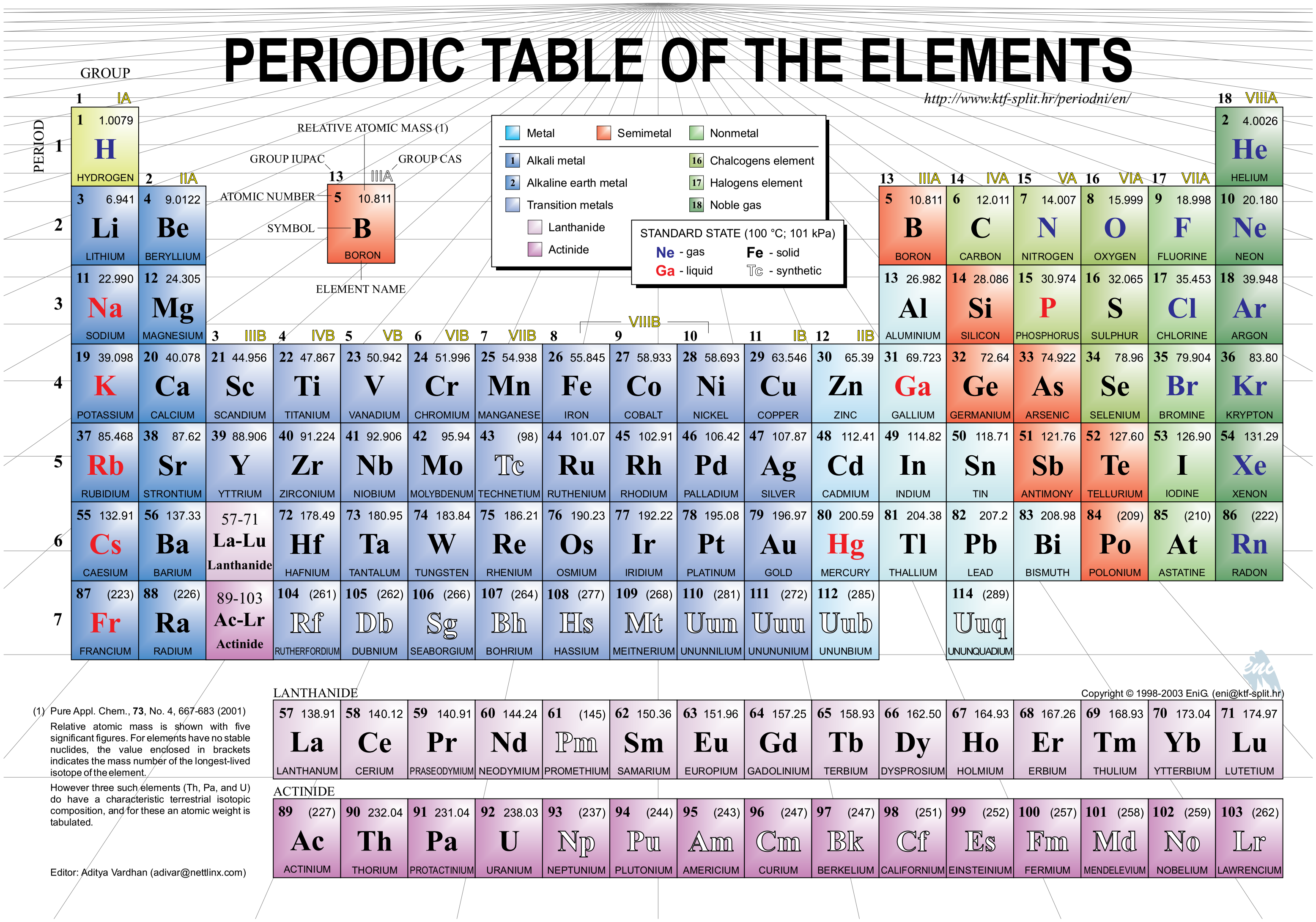

🟦 Metal 🟥 Semimetal 🟩 Nonmetal

1 Alkali metal

2 Alkaline earth metal

Transition metals

Lanthanide

Actinide

16 Chalcogens element

17 Halogens element

18 Noble gas

STANDARD STATE (100 °C; 101 kPa)

Ne - gas **Fe** - solid

Ga - liquid **Tc** - synthetic

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However three such elements (Th, Pa, and U) do have a characteristic terrestrial isotopic composition, and for these an atomic weight is tabulated.

Editor: Aditya Vardhan (adivar@nettlinx.com)

Question 1 (10 points):
In Flint, Michigan, the water supply has become contaminated with lead.
If you were worried that other metals might be in the water, how would you determine which are present?
Describe how that information is obtained from your choice.

Question 2 (15 points):
A 3-m long cylinder has three compartments with two and each compartment has a volume of 45 L. Initially, the separators are held in place and each compartment is open to the air, with the pressure in the room at 760 torr (1.0 atm), and the temperature at 0 °C. Assume that the air is an ideal gas.
a) How many moles of gas are in each compartment? (5 points)
b) The connections from the compartments to the room are sealed off and:
the pressure in the right chamber is increased to 2.0 atm,
the pressure in the left chamber is increased to 3.0 atm, and
then the separators (pistons) are released and move without friction.
What is the pressure in each chamber?
Where do the separators sit (draw a diagram) and why? (10 points)

Question 3 (30 points):
Heat is added at a constant rate to water as the temperature is raised from -20 °C to 120 °C.
Draw the **time course** of the **temperature** and **density** (two different curves) and indicate the phase(s) at each temperature.
Label and concisely explain each stage of each curve and indicate where intermolecular bonds are made or broken.

Question 4 (15 points):
How could you differentiate between ethylene (C_2H_4), nitrogen (N_2), and carbon monoxide (CO) using mass spectrometry?

Question 5 (15 points):
Why are there warning signs indicating "ionizing radiation"?
Briefly explain in terms of energies and other related issues.
Give two examples of ionizing radiation.

Question 6 (15 points):
How would you experimentally determine the atomic radius of Xe?
Briefly explain your choice of technique in terms of length scales, energies, and related issues.

Extra credit #1 (2 points):
How are the gas constant, **R**, and the Boltzmann constant, $\boldsymbol{k_B}$, conceptually related

Extra credit #2 (2 points):
How are the energy units **Hz** and **cm^{-1}** conceptually related?

Name ______________________ Section # ____ Student ID # ___________

TOTAL = ________

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18 February 2016
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Note: Only these papers can be used; no other notes are allowed. **4)**

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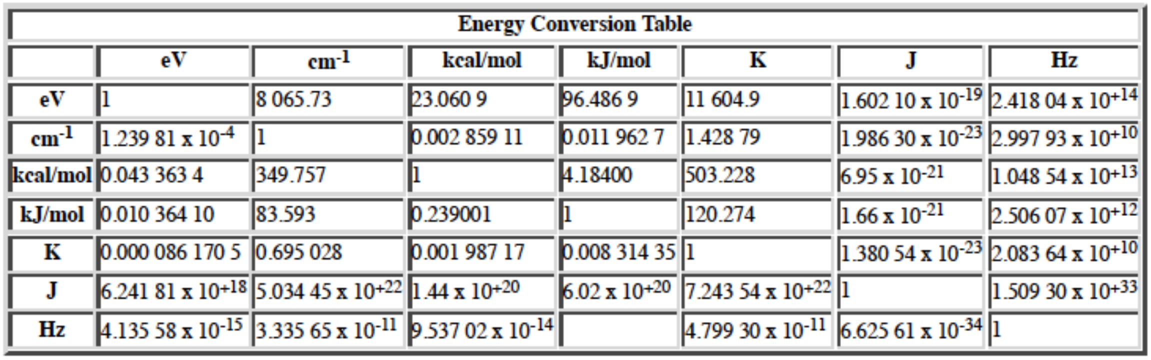

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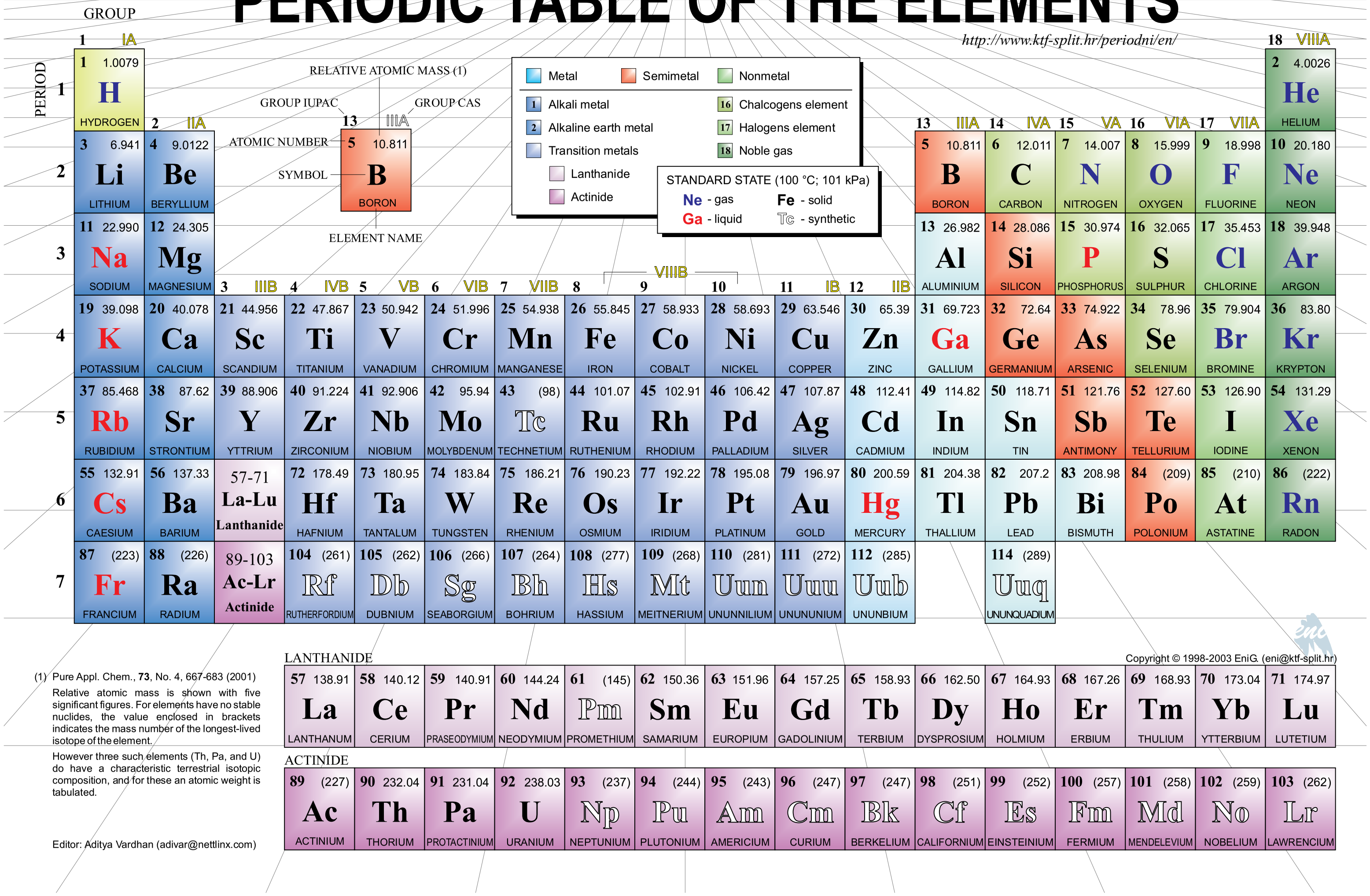

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Editor: Aditya Vardhan (adivar@netlinx.com)

Question 1 (25 points):
Limestone ($CaCO_3$) is heated to produce lime (CaO) as an inexpensive, solid base in the following reaction:

$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$

a) What are the signs of ΔH, ΔS, and ΔG for this reaction? (20 points)
Explain your answer for each.
If any of the answers depend on additional information, indicate on what and how.

b) What can you say about the equilibrium constant K_{eq}? (5 points)

Question 2 (15 points):
Referring again to the reaction:
$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$

a) Write the equilibrium constant for this reaction (in terms of concentrations, etc.).
(5 points)

b) If a sealed container, initially under vacuum, with both $CaCO_3(s)$ and $CaO(s)$ inside is allowed to reach equilibrium, how might you measure the equilibrium constant?
(5 points)

c) When the volume of the container is doubled (by opening a valve to an evacuated container), what happens? (5 points)

Question 3 (20 points):
On the first exam, you described what happened when heat is added at a constant rate to water as the temperature is raised from -20 °C to 120 °C.
a) Draw the **time course** of the **temperature** again. Indicate the phase(s) present in each temperature band. Indicate what determines the slope for each section of the plot.
(10 points)

b) Describe briefly what we know (*i.e.*, signs and any other information) about ΔH, ΔS, and ΔG at each phase transition? (10 points)

Question 4 (25 points):
A lithium ion battery, such as found in a cell phone, operates at a high cell potential based on the following half-cell reactions:

$CoO_2 + Li^+ + e^- \leftrightarrow LiCoO_2$	$E° \cong 1$ V
$Li^+ + C_6$(*polymer/graphite*) $+ e^- \leftrightarrow LiC_6$(*polymer/graphite*)	$E° \cong -3$ V

Compare to:

$O_2(g) + 4H^+ + 4e^- \leftrightarrow 2H_2O$	$E° = 1.23$ V
$2H^+ + 2e^- \leftrightarrow H_2(g)$	$E° = 0.00$ V
$Li^+ + e^- \leftrightarrow Li$	$E° \cong -3$ V

a) What is the overall cell reaction for the lithium ion battery shown? (5 points)

b) What is the overall standard cell potential of the reaction you wrote in (a)? (5 points)

c) What is the *n* (number of electrons) for the overall cell reaction you wrote in (a)? (5 points)

c) Which elements of which compounds are being oxidized and which are being reduced in the overall cell reaction you wrote in (a)? Determine the oxidation states of all the species in the reaction. (5 points)

d) Can the reaction that you wrote in (a) be carried out in water (aqueous solution)? Why or why not? (5 points)

Question 5 (15 points):
a) Why do metals absorb infrared light (*i.e.*, why are they *not* transparent in the infrared)? (5 points)

b) ZnO is a direct band gap semiconductor with a band gap of 3.3 eV. Why is it colorless? (10 points, and see extra credit problem)

Extra credit #1 (5 points):
Why is ZnO used in sunscreen?

Extra credit #2 (5 points):
Estimate ΔG° for your answer to question 4b and explain your reasoning.

Name ________________________ Section # ____ Student ID # ___________

Signature ____________________

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29 February 2016
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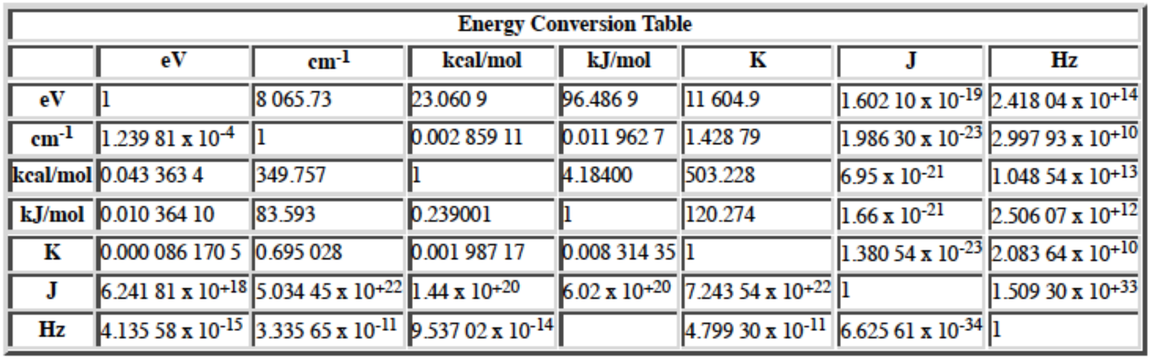

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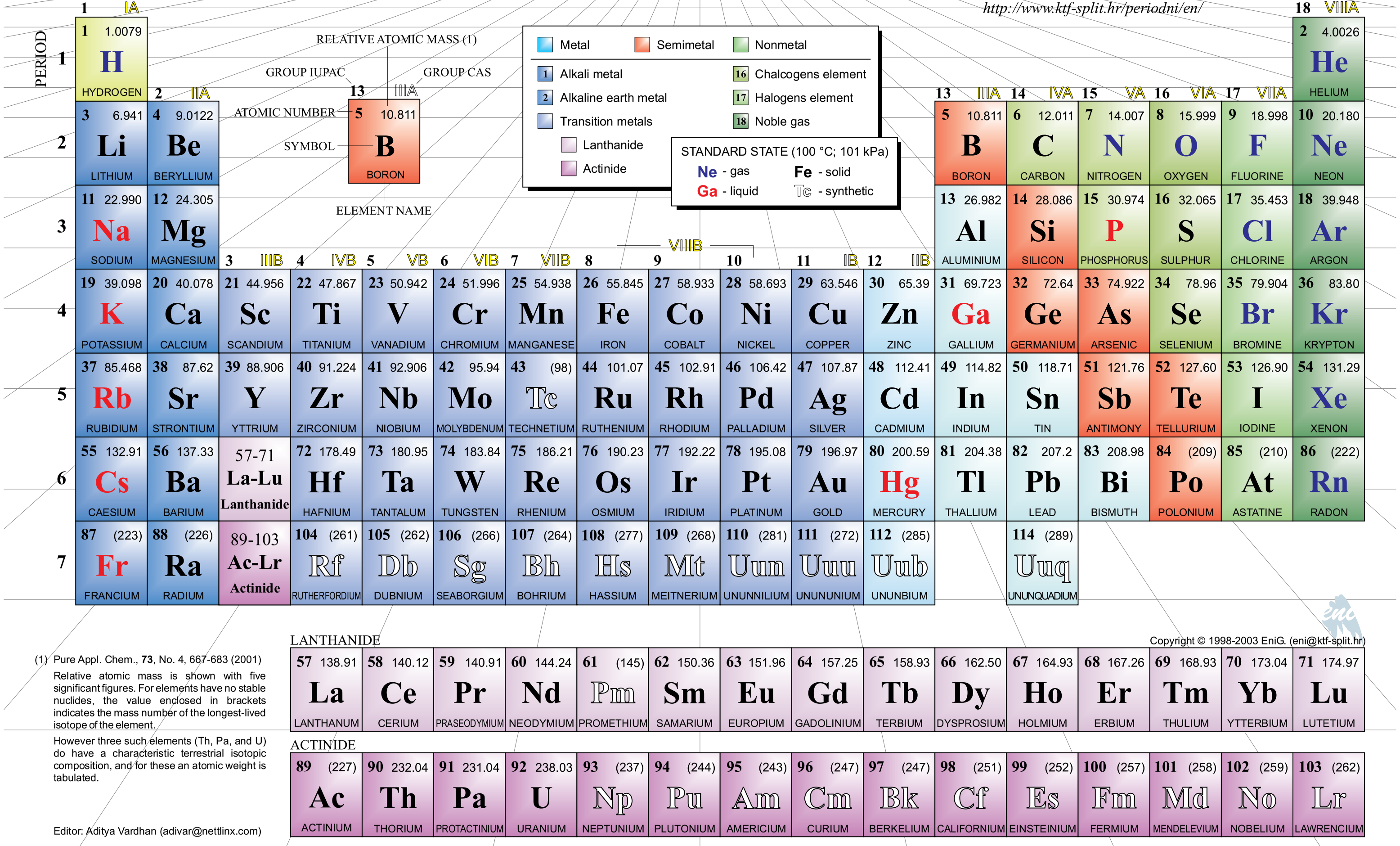

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4	19 39.098 K POTASSIUM	20 40.078 Ca CALCIUM	21 44.956 Sc SCANDIUM	22 47.867 Ti TITANIUM	23 50.942 V VANADIUM	24 51.996 Cr CHROMIUM	25 54.938 Mn MANGANESE	26 55.845 Fe IRON	27 58.933 Co COBALT	28 58.693 Ni NICKEL	29 63.546 Cu COPPER	30 65.39 Zn ZINC	31 69.723 Ga GALLIUM	32 72.64 Ge GERMANIUM	33 74.922 As ARSENIC	34 78.96 Se SELENIUM	35 79.904 Br BROMINE	36 83.80 Kr KRYPTON
5	37 85.468 Rb RUBIDIUM	38 87.62 Sr STRONTIUM	39 88.906 Y YTTRIUM	40 91.224 Zr ZIRCONIUM	41 92.906 Nb NIOBIUM	42 95.94 Mo MOLYBDENUM	43 (98) Tc TECHNETIUM	44 101.07 Ru RUTHENIUM	45 102.91 Rh RHODIUM	46 106.42 Pd PALLADIUM	47 107.87 Ag SILVER	48 112.41 Cd CADMIUM	49 114.82 In INDIUM	50 118.71 Sn TIN	51 121.76 Sb ANTIMONY	52 127.60 Te TELLURIUM	53 126.90 I IODINE	54 131.29 Xe XENON
6	55 132.91 Cs CAESIUM	56 137.33 Ba BARIUM	57-71 La-Lu Lanthanide	72 178.49 Hf HAFNIUM	73 180.95 Ta TANTALUM	74 183.84 W TUNGSTEN	75 186.21 Re RHENIUM	76 190.23 Os OSMIUM	77 192.22 Ir IRIDIUM	78 195.08 Pt PLATINUM	79 196.97 Au GOLD	80 200.59 Hg MERCURY	81 204.38 Tl THALLIUM	82 207.2 Pb LEAD	83 208.98 Bi BISMUTH	84 (209) Po POLONIUM	85 (210) At ASTATINE	86 (222) Rn RADON
7	87 (223) Fr FRANCIUM	88 (226) Ra RADIUM	89-103 Ac-Lr Actinide	104 (261) Rf RUTHERFORDIUM	105 (262) Db DUBNIUM	106 (266) Sg SEABORGIUM	107 (264) Bh BOHRIUM	108 (277) Hs HASSIUM	109 (268) Mt MEITNERIUM	110 (281) Uun UNUNNILIUM	111 (272) Uuu UNUNUNIUM	112 (285) Uub UNUNBIUM		114 (289) Uuq UNUNQUADIUM				

LANTHANIDE

57 138.91 La LANTHANUM	58 140.12 Ce CERIUM	59 140.91 Pr PRASEODYMIUM	60 144.24 Nd NEODYMIUM	61 (145) Pm PROMETHIUM	62 150.36 Sm SAMARIUM	63 151.96 Eu EUROPIUM	64 157.25 Gd GADOLINIUM	65 158.93 Tb TERBIUM	66 162.50 Dy DYSPROSIUM	67 164.93 Ho HOLMIUM	68 167.26 Er ERBIUM	69 168.93 Tm THULIUM	70 173.04 Yb YTTERBIUM	71 174.97 Lu LUTETIUM

ACTINIDE

89 (227) Ac ACTINIUM	90 232.04 Th THORIUM	91 231.04 Pa PROTACTINIUM	92 238.03 U URANIUM	93 (237) Np NEPTUNIUM	94 (244) Pu PLUTONIUM	95 (243) Am AMERICIUM	96 (247) Cm CURIUM	97 (247) Bk BERKELIUM	98 (251) Cf CALIFORNIUM	99 (252) Es EINSTEINIUM	100 (257) Fm FERMIUM	101 (258) Md MENDELEVIUM	102 (259) No NOBELIUM	103 (262) Lr LAWRENCIUM

(1) Pure Appl. Chem., **73**, No. 4, 667-683 (2001)
Relative atomic mass is shown with five significant figures. For elements have no stable nuclides, the value enclosed in brackets indicates the mass number of the longest-lived isotope of the element.

However three such elements (Th, Pa, and U) do have a characteristic terrestrial isotopic composition, and for these an atomic weight is tabulated.

Editor: Aditya Vardhan (adivar@nettlinx.com)

Name _________________________

Question 1 (15 points):
HF $K_a = 7\times10^{-4}$
CuF_2 $K_{sp} = 7\times10^{-2}$
$[Cu(NH_3)_4]^{2+}$ $K_F = 2\times10^{13}$

Rank the solubility of $CuF_2(s)$ from highest to lowest in water, 0.1 M HF, 0.1 M NH_3. Concisely explain your answer, showing the reactions involved in each case. (15 points)

Question 2 (25 points):

Ethylenediamene (shown below) is a chelate that is typically abbreviated as "*en*"

The formation constants, K_F, of octahedral Ni^{2+} complex ions at 25 °C are:

$[Ni(en)_3]^{2+}$	2×10^{18}
$[Ni(NH_3)_6]^{2+}$	4×10^{8}

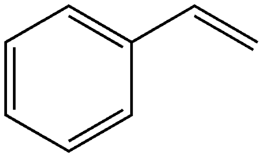
a) Write the reactions for the formation *and* the formation constants (in terms of concentrations) for each complex ion (10 points)

b) The ΔH_f of the two complex ions are the same to two significant figures. How do you explain the difference in formation constants? (5 points)

c) If NH_3 were added to an aqueous solution of $[Ni(en)_3]^{2+}$ such that both concentrations were initially 1 M after mixing, what would happen?
Write the reaction and discuss on which side the equilibrium would lie, and why.
(5 points)

d) If ethylenediamine were added to an aqueous solution of $[Ni(NH_3)_6]^{2+}$ such that both concentrations were initially 1 M after mixing, what would happen?
Again, write the reaction and discuss on which side the equilibrium would lie, and why.
(5 points)

Question 3 (20 points):
The monomer styrene (shown below)



is used to make polystyrene (styrofoam).

a) What is the structure of the polymer? You may answer by showing the repeat unit. (10 points)
b) Show how this polymerization reaction proceeds, showing both the reactants and the products as the polymer grows. Explain concisely why this reaction proceeds over other possible reactions. (10 points)

Question 4 (30 points):
a) Choose three elements from a row of the periodic table and give the order you expect for increasing oxidation half-cell potential of the neutral element. Concisely explain your answer. (5 points)

b) Choose two of the above and write one as a balanced oxidation half-cell reaction and the other as a balanced reduction half-cell reaction. Use realistic oxidation states. Combine the two such that the overall reaction is spontaneous as written. (10 points)

c) Give the signs of $\Delta G°$ and $E°$ that you expect for the reaction as written in b. What can you say about K_{eq}? (10 points)

d) Choose three elements from a column of the periodic table and give the order you expect for increasing oxidation half-cell potential of the neutral element. Concisely explain your answer. (5 points)

Question 5 (10 points):
DNA has special properties as both a polymer and the holder of our genetic code: it can be synthesized precisely, copied, and measured (sequenced).
One property of a polymer (that we discussed) is rigidity.
A quantitative measure of this rigidity is the "persistence length" – below the persistence length, the polymer behaves as a rigid rod; at larger scales, it behaves as a flexible chain.

The persistence length of double-stranded, double-helix DNA is 50 nm.
The persistence length of single-stranded DNA is ~4 nm (even lower at high salt concentration, by the way).

a) Concisely explain this difference between single- and double-stranded DNA. (5 points)
b) What interactions make double-stranded DNA more rigid? (5 points)

Extra credit #1 (5 points):

In questions 2c and 2d, what would happen to the equilibria if the temperature were raised from 25 °C to 50 °C? Explain your answers.

Extra credit #2 (5 points)
In question 5, how might double-stranded DNA be rigidified further (chemically)?

Name ________________________ Section # ____ Student ID # ___________

Signature _____________________

TOTAL = ________

Chemistry 20B, Winter 2016, Sections 1 & 3, Final Exam
Saturday 12 March 2016
5 questions + >1 extra credit problem, 12 pages.
Answer on these sheets only. Additional space on last page.
If you need extra sheets, please ask your proctor or TA.

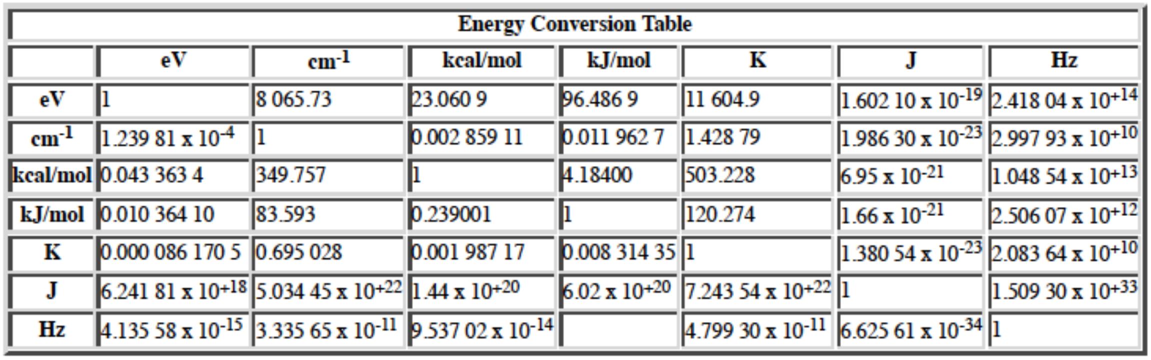
Note: Only these papers can be used; no other notes are allowed.

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)
2)
3)
4)
5)
EC)

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
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}
Faraday constant = 96500 coul/mole



Energy Conversion Table

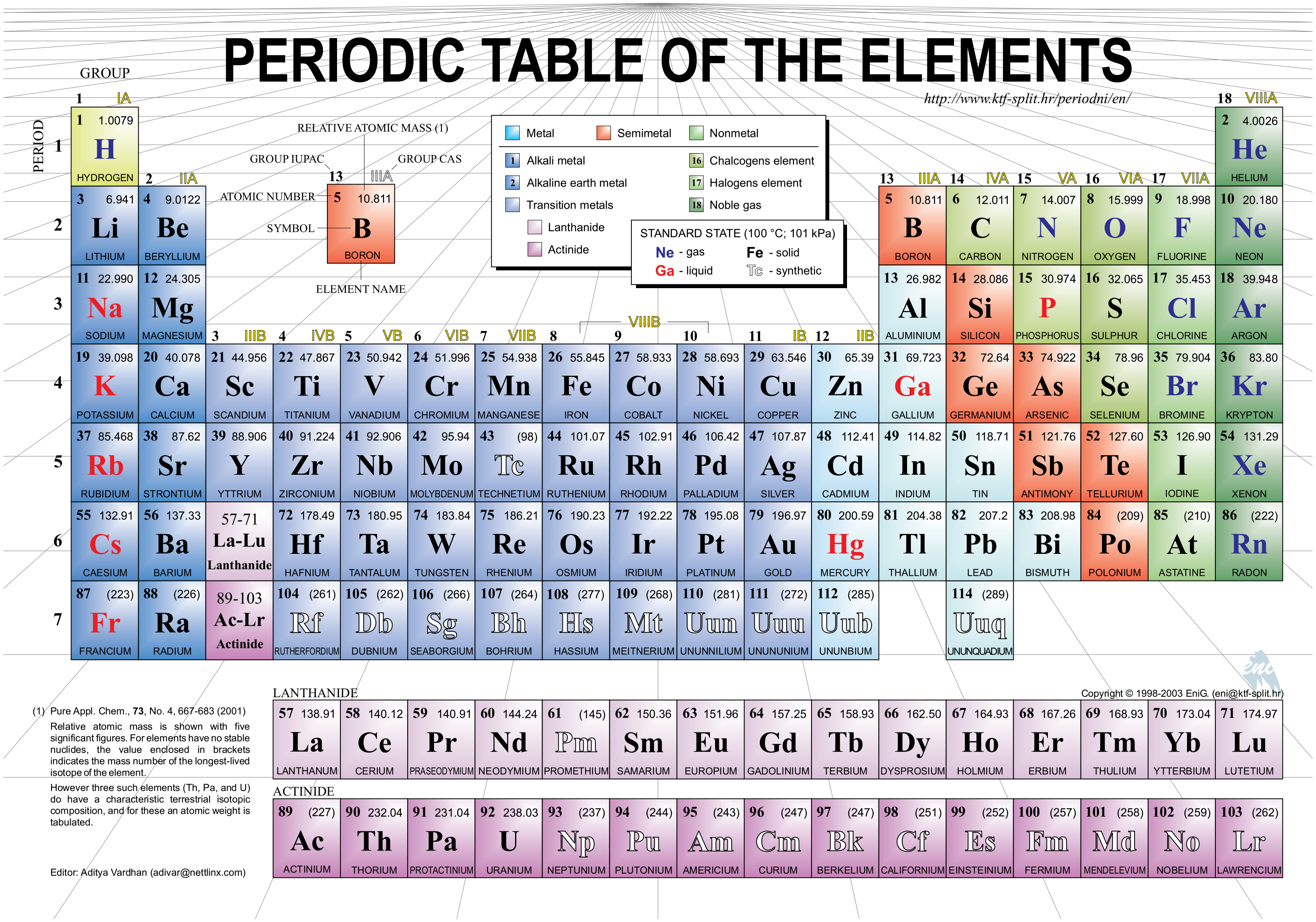
	eV	cm^{-1}	kcal/mol	kJ/mol	K	J	Hz
eV	1	8 065.73	23.060 9	96.486 9	11 604.9	$1.602\ 10 \times 10^{-19}$	$2.418\ 04 \times 10^{+14}$
cm^{-1}	$1.239\ 81 \times 10^{-4}$	1	0.002 859 11	0.011 962 7	1.428 79	$1.986\ 30 \times 10^{-23}$	$2.997\ 93 \times 10^{+10}$
kcal/mol	0.043 363 4	349.757	1	4.18400	503.228	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

$\Delta G° = -nFE° = -2.303\ RT \log_{10} K_{eq}$
$pH = pK_a - \log_{10} ([HA]/[A^-])$

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

PERIODIC TABLE OF THE ELEMENTS

http://www.ktf-split.hr/periodni/en/



PERIOD	1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8 VIIIB	9	10	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1	1 1.0079 H HYDROGEN																	2 4.0026 He HELIUM
2	3 6.941 Li LITHIUM	4 9.0122 Be BERYLLIUM											5 10.811 B BORON	6 12.011 C CARBON	7 14.007 N NITROGEN	8 15.999 O OXYGEN	9 18.998 F FLUORINE	10 20.180 Ne NEON
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(1) Pure Appl. Chem., **73**, No. 4, 667-683 (2001)
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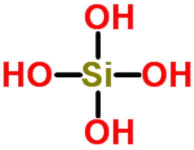
However three such elements (Th, Pa, and U) do have a characteristic terrestrial isotopic composition, and for these an atomic weight is tabulated.

Editor: Aditya Vardhan (adivar@netlinx.com)

Question 1 (15 points):
Can an infrared photon break a typical covalent bond? Why or why not? (15 points)

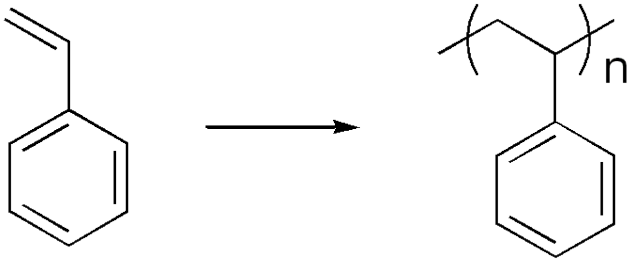
Question 2 (25 points):
For the reaction of Si(*s*) + O_2(*g*) → SiO_2(*s*)
a) What are the signs of ΔH, ΔS, and ΔG? Explain each of your answers concisely.
(15 points)
[Hint: what would C do, in place of Si?]

b) Petrified wood comes from dehydration (loss of water) of silicic acid, $Si(OH)_4$ (shown below), ultimately to form quartz, SiO_2 (after the silicic acid has replaced the organic matter in the plant; the colors from metal ions that are left in the quartz crystals).
Show the first step in the polymerization reaction, starting with the reaction of two silicic acid molecules, including showing the reaction products. (10 points)



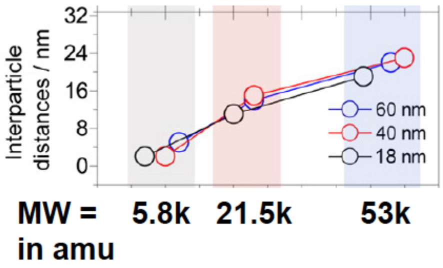
$HO-\overset{\displaystyle OH}{\underset{\displaystyle OH}{Si}}-OH$

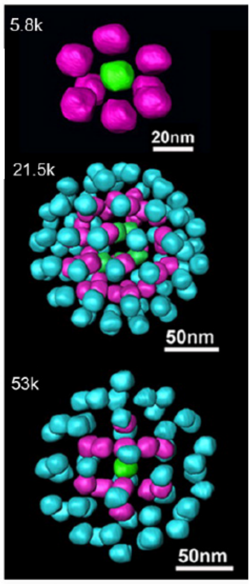
Question 3 (10 points):
Recall from the third midterm that the monomer styrene (left) is used to make polystyrene (middle), the main component of Styrofoam.
Last Wednesday, at the International Conference on Nanostructures on Kish Island, Iran, in the talk before mine, Prof. Luis Liz-Marzán (right, one of the world's leading nanoscientists, the director of the nanocenter CIC biomaGUNE, San Sebastian, Spain, who has been knighted by the King of Spain) showed that he could make crystalline lattices of Au nanoparticles that were coated with polystyrene.



In each of the three electron microscope images below, all the 18-nm Au nanoparticles (which appear as spots) are the same, other than their polystyrene coating.
Each polystyrene chain is chemically attached to the 18-nm Au nanoparticle at one end, so each particle has the same number of attached chains. The only difference from top to bottom in the images is the molecular weight (MW) of the polymer chains: 5800, 21,500 and 53,000 amu. Each spot in the electron microscopy image is an 18-nm Au

nanoparticle within a small crystal of nanoparticles; the polymer surrounding each nanoparticle is not observed (because C and H do not interact with electrons as strongly as Au does).

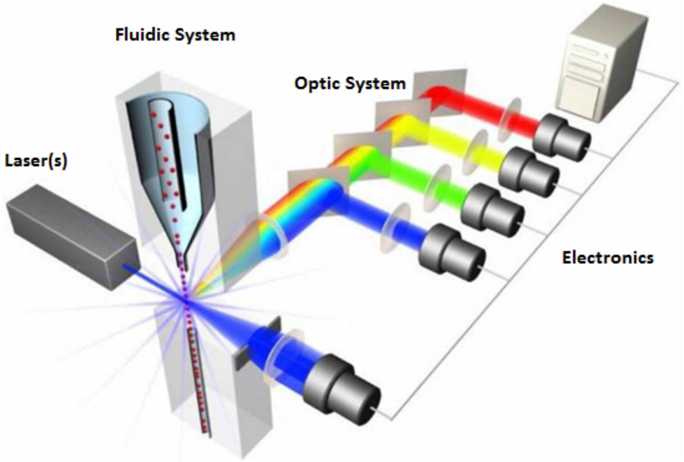




a) Why are the Au nanoparticle spacings different and in this order, in terms of the attached polymer molecular weight? (Ignore the points in the plot for the different sizes of nanoparticles.) (5 points)

b) Estimate the average polymer chain lengths in each case in terms of number of monomer units. Recall that each carbon has four bonds and the H atoms are not shown in the molecular structures above. Show your work. (5 points)

Question 4 (20 points, extra points are possible):
Fluorescence is a widely used *quantitative* method of detection.
For example, in flow cytometry, two different dyes can be used and separately interrogated to label DNA in terms of the total amount of C-G *vs* A-T content in individual chromosomes. This is shown schematically below.



a) Explain concisely how we can tell the two dyes apart. (10 points, + bonus points if you correctly draw, use, and explain energy level diagrams for both 🪙🪙🪙)
b) Explain concisely how we can tell how much of each type of base pair (C-G and A-T) and dye is present. (5 points)
c) If a piece of a chromosome is missing, what happens to the two signals? (5 points)

Question 5 (30 points):
The half-life of ^{14}C is approximately 5700 years.
The ratio of $^{14}C/^{12}C$ in the atmosphere is approximately 1.2×10^{-12}.
If a tree was seeded and started to grow 17,100 (=3×5700) years ago and lived for 5700 years (ok, I know that is a long life for a tree, but nobody was carving their initials in it):

a) Draw and concisely explain a plot of the $^{14}C/^{12}C$ ratio in the tree for the last 17,100 years. (15 points)
b) For the first 5700 years since the tree was seeded and started to grow and for the time since, give the functional form of the plot. (5 points)
c) What is the reaction order in $[^{14}C]$ for the 11,400 years since the tree died? Explain concisely. (5 points)
d) What is the $^{14}C/^{12}C$ ratio in the (dead) tree now? Show your calculation. (5 points)

Extra credit #1 (10 points):
For question 2a, write balanced half-cell redox reactions that could be used to measure the E_{cell} and ΔG for this reaction. Label the oxidation and reduction half-cell reactions.

Name _______________________ Section # ____ Student ID # ___________

Signature ____________________

TOTAL = ________

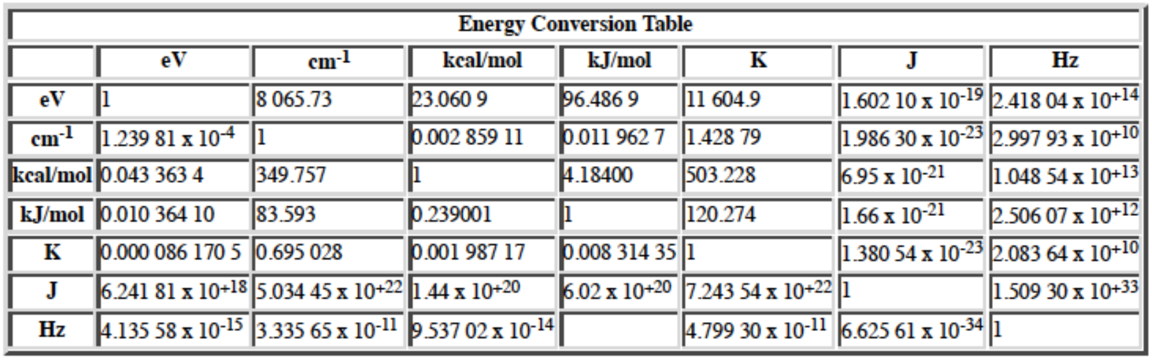
Chemistry 20B, Winter 2017, Sections 2 & 3, Midterm #1 **1)**
7 February 2017
5 questions + 2 small extra credit problems, 10 pages. **2)**
Answer on these sheets only. Additional space on last page.
If you need extra sheets, please ask your proctor or TA. **3)**

<u>Note</u>: Only these papers can be used; no other notes are allowed. **4)**

Please answer each question concisely. Show your calculations. 5)
You may (and in some cases, must) draw explanatory diagrams.
<u>Label all axes and features</u> on graphs and diagrams. **EC1+2)**

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 × 10^8 m/s
Faraday constant = 96500 coul/mole
Electron charge magnitude: e = 1.6 × 10^{-19} C
Plank's constant: $\hbar$ = 1.1 × 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 × 10^{-23} J/K
Electron rest mass: m = 9.1 × 10^{-31} kg
Proton rest mass: M = 1.7 × 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 x 10^{-19}	2.418 04 x 10^{+14}
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kcal/mol	0.043 363 4	349.757	1	4.18400	503.228	6.95 x 10^{-21}	1.048 54 x 10^{+13}
kJ/mol	0.010 364 10	83.593	0.239001	1	120.274	1.66 x 10^{-21}	2.506 07 x 10^{+12}
K	0.000 086 170 5	0.695 028	0.001 987 17	0.008 314 35	1	1.380 54 x 10^{-23}	2.083 64 x 10^{+10}
J	6.241 81 x 10^{+18}	5.034 45 x 10^{+22}	1.44 x 10^{+20}	6.02 x 10^{+20}	7.243 54 x 10^{+22}	1	1.509 30 x 10^{+33}
Hz	4.135 58 x 10^{-15}	3.335 65 x 10^{-11}	9.537 02 x 10^{-14}		4.799 30 x 10^{-11}	6.625 61 x 10^{-34}	1

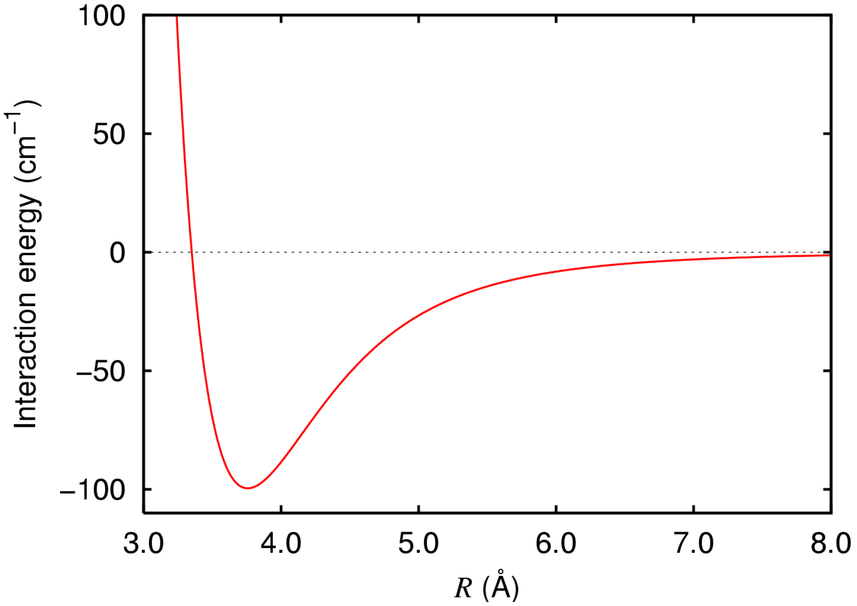
$\Delta G° = -nFE° = -2.303\ RT\ \log_{10}K_{eq}$

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

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

Name _________________________ Section # ____ Student ID # ____________

For questions 1 and 2, refer to this figure, which is the interaction potential energy level diagram for Ar-Ar. Explain your answers concisely.



Question 1 (15 points):

a) What is the approximate bond energy for Ar_2 in cm^{-1} *and* in your favorite energy units (which must be one of the following: eV, kcal/mol, kJ/mol, or J)? (10 points)

b) What is the approximate bond length of Ar_2? (5 points)

Question 2 (25 points):

Explain each of your answers concisely.

Referring again to the figure above for questions 2a and 2b:

a) For the reaction:

$Ar_2(g) \leftrightarrow 2Ar(g)$

What are the signs of ΔH, ΔS, and ΔG at room temperature and (concisely) why?

In what form is most of the argon at 1 atm pressure (pure argon) at room temperature – Ar or Ar_2? (10 points)

b) What is the value of ΔH for this reaction? (5 points)

c) For the reaction:

$N_2(g) \leftrightarrow 2N(g)$

What are the signs of ΔH, ΔS, and ΔG at room temperature and (concisely) why? (10 points)

In what form is most of the nitrogen at 1 atm pressure (pure nitrogen) at room temperature - N or N_2?

Question 3 (20 points):

a) Rank these (eight different) solutions by pH, indicating which are the high and low ends, and concisely explain your reasoning.
(Your reasoning, which should be based on interactions with water, is worth more than the correct order.)
1 M $FeCl_2$, 1 M $FeCl_3$, 1 M $HClO_3$, 1 M $HClO_4$, 0.1 M NaCl, 1 M NaCl, 0.1 M NH_3, 1 M NH_3

Question 4 (25 points):
Prof. Bruce Dunn in the UCLA Materials Science & Engineering Department is working on a zinc-air battery based on the following half-cell reactions:

$Zn(OH)_4^{2-} + 2e^- \leftrightarrow Zn + 4OH^-$ $E° = -1.23$ V

$O_2 + 2H_2O + 4e^- \leftrightarrow 4OH^-$ $E° = 0.34$ V

Zinc-air batteries have high energy densities in part because one of the reactants is air, and thus does not add to the weight of the cell.
a) What is the overall cell reaction for the zinc-air battery when it is being used to produce power (discharged)? Indicate which is the reduction half-reaction and which is the oxidation half-cell reaction. (10 points)
b) What is the overall standard cell potential of the reaction you wrote in (a)? (5 points)
c) What is the *n* (number of electrons) for the overall cell reaction you wrote in (a)?
(4 points)
d) Which elements of which compounds are being oxidized and which are being reduced in the overall cell reaction you wrote in (a)? Determine the oxidation states of all the species in the reaction. (6 points)

Question 5 (15 points):
The sublimation point of dry ice, $CO_2(s)$, is -78 °C.
$CO_2(s) \leftrightarrow CO_2(g)$
The absolute value of enthalpy of sublimation, $|\Delta H| \sim 20$ kJ/mol.
a) What are the signs of ΔH, ΔS, and ΔG for CO_2 sublimation at -78 °C? (10 points)
b) What intramolecular and/or intermolecular interactions are relevant to sublimation and why?
(3 points)
c) Estimate ΔS for this reaction (in kJ/mol-K). (2 points)

Extra credit #1 (2 points):
Which do you expect to have a stronger bond, Ar_2 or Ar_2^+, and why?

Extra credit #2 (2 points):
Estimate by what factor the N_2 bond strength is larger than the Ar_2 bond strength and concisely give your reasoning.

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Signature ____________________

Chemistry 20B, Winter 2017, Sections 2 & 3, Midterm #2
2 March 2017
5 questions + 2 small extra credit problems, 8 pages.
Answer on these sheets only. Additional space on last page.
If you need extra sheets, please ask your proctor or TA.
If you continue a problem on an additional page, please indicate that on the original problem page.
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.

TOTAL = ________
1)

2)

3)

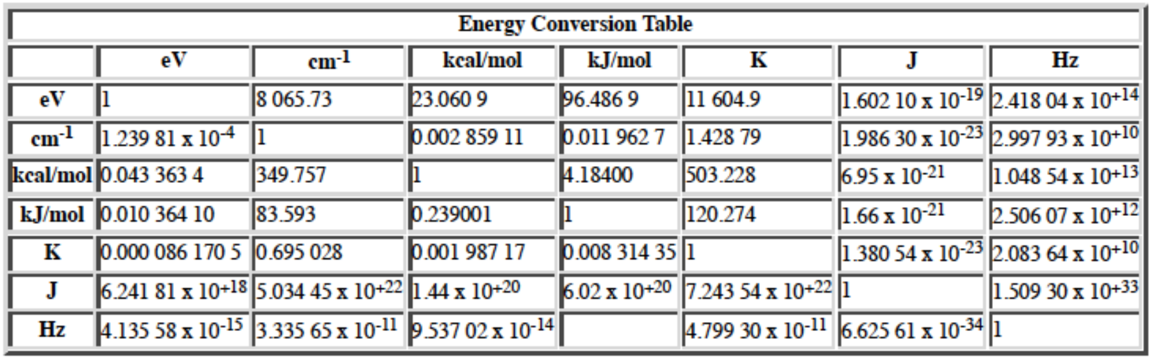
4)

5)

EC1+2)

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.
➔ Only exam answers in pen will be considered for regrading.

Table of constants and conversions
Speed of light: c = 3 × 10^8 m/s
Faraday constant = 96500 coul/mole
Electron charge magnitude: e = 1.6 × 10^{-19} C
Plank's constant: $\hbar$ = 1.1 × 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 × 10^{-23} J/K
Electron rest mass: m = 9.1 × 10^{-31} kg
Proton rest mass: M = 1.7 × 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 x 10^{-19}	2.418 04 x 10^{+14}
cm^{-1}	1.239 81 x 10^{-4}	1	0.002 859 11	0.011 962 7	1.428 79	1.986 30 x 10^{-23}	2.997 93 x 10^{+10}
kcal/mol	0.043 363 4	349.757	1	4.18400	503.228	6.95 x 10^{-21}	1.048 54 x 10^{+13}
kJ/mol	0.010 364 10	83.593	0.239001	1	120.274	1.66 x 10^{-21}	2.506 07 x 10^{+12}
K	0.000 086 170 5	0.695 028	0.001 987 17	0.008 314 35	1	1.380 54 x 10^{-23}	2.083 64 x 10^{+10}
J	6.241 81 x 10^{+18}	5.034 45 x 10^{+22}	1.44 x 10^{+20}	6.02 x 10^{+20}	7.243 54 x 10^{+22}	1	1.509 30 x 10^{+33}
Hz	4.135 58 x 10^{-15}	3.335 65 x 10^{-11}	9.537 02 x 10^{-14}		4.799 30 x 10^{-11}	6.625 61 x 10^{-34}	1

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

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

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

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Question 1 (10 points):
a) Which of the following photons have sufficient energy to break typical covalent chemical bonds? (8 points)
X-rays, microwaves, visible, infrared
b) With what molecular transitions are the photons you selected in (a)? (2 points)

Question 2 (20 points):
Silicon can be reacted to form SiO_2 (an insulator) or metal silicides such as Ni_2Si that are metallic.

Draw and concisely compare simple energy level (band) diagrams for Si, SiO_2, and Ni_2Si.

(It may be helpful to draw the three diagrams on one line.)

Indicate where bands are filled and where they are empty.

Indicate the Fermi energy on each diagram.

Label your axes.

You do not need to include dopants in any of the above, just the pure material (which is call "intrinsic").

Question 3 (25 points):
For the transition metal complex $Ag(NH_3)_2^+$:
a) Identify the Lewis acid(s) and Lewis base(s). (5 points)
b) Write the formation reaction from the (aqueous) metal ion and the ligands. Give the formation (equilibrium) constant (in terms of concentrations). (5 points)
c) Give the signs of ΔH, ΔS, and ΔG for the reaction that you wrote above. Indicate what you expect for the formation constant (*i.e.*, is it greater or less than some number?) Is the reaction spontaneous? (Please be sure your answers are consistent!) (10 points)
d) Do you expect the reduction half-cell potential of the metal ion or that of the complex to be larger (reduction to the solid metal)? Explain your answer concisely. (5 points)

Question 4 (25 points):
For phosphoric acid, H_3PO_4, the pK_as are:
$pK_{a1} = 2.2$
$pK_{a2} = 7.2$
$pK_{a3} = 12.7$

a) Write the reaction associated with K_{a2}. (10 points)
b) Write K_{a2} in terms of concentrations of the reactants and products in the reaction above? (5 points)
c) To make a buffer that is close to neutral pH, how would you use *some* of the following. Be precise in terms of what you would use and how much of each. (10 points)

(You do *not* have to use all of these chemicals. Assume that you have glassware to measure volumes and scales to measure weights.)
0.001 M HCl, 1 M HCl, 10 M HCl
0.001 M H_3PO_4, 1 M H_3PO_4
0.001 M NH_3, 1 M NH_3
Water
Solids: Fe, Na, NaCl, NaH, NaOH

Question 5 (20 points):
For $Cu(OH)_2$, $K_{sp}=2.2\times10^{-20}$
Also, for $Cu(NH_3)_4^{2+}$, $K_F=5\times10^{12}$
a) Write the equilibrium expression for K_{sp} in terms of concentrations (5 points)
b) Rank the order from highest to lowest in which $Cu(OH)_2(s)$ will dissolve and concisely explain your answers. (15 points)
Water, 1 M $Cu(NO_3)_2$, 1 M NaOH, 1 M NH_3

Extra credit #1 (2 points):
ZnO is a colorless semiconductor that is used in sunscreen.
What can you say about its bandgap?

Extra credit #2 (2 points):
What combinations of the chemicals in 4c could you use to start a fire and how would each combination you name react?