

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.

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.

You may not use a calculator, computer, watch, smart device, or electronics of any sort. Irrelevant material will be ignored. 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

Planck'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	$6.241 81 \times 10^{18}$	$5.034 45 \times 10^{22}$	1.44×10^{20}	6.02×10^{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

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PERIODIC TABLE OF THE ELEMENTS

<http://www.kf-spl.it/periodicten/>

PERIOD	GROUP	REACTIVE ATOMIC MASS (1)	GROUP IUPAC	GROUP CAS	ATOMIC NUMBER	SYMBOL	ELEMENT NAME	STANDARD STATE (100 °C, 101 kPa)
1	1A	1 1.0079	1	1	1	H	HYDROGEN	16 Halogens element
2	2A	3 6.941	2	2	4	Li	LITHIUM	17 Noble gas
			10A	10	9 9.0122	Be	BERYLLIUM	18 Noble gas
			11A	11	12 24.305	B	BORON	19 Noble gas
3	1A	11 22.990	3	3	21 44.956	Na	SODIUM	20 Noble gas
			4	4	22 47.867	Mg	MAGNESIUM	21 Noble gas
			5	5	23 50.942	Al	ALUMINIUM	22 Noble gas
4	2A	19 39.098	6	6	24 51.996	Ca	POTASSIUM	23 Noble gas
			7	7	25 54.938	Sc	SCANDIUM	24 Noble gas
			8	8	26 55.845	Ti	TITANIUM	25 Noble gas
			9	9	27 58.933	V	Vanadium	26 Noble gas
			10	10	28 58.933	Cr	CHROMIUM	27 Noble gas
			11	11	29 63.546	Mn	MANGANESE	28 Noble gas
			12	12	30 65.39	Fe	IRON	29 Noble gas
			13	13	31 69.723	Co	COBALT	30 Noble gas
5	3A	37 85.468	14	14	32 72.64	Ni	NICKEL	31 Noble gas
			15	15	33 74.922	Cu	COPPER	32 Noble gas
			16	16	34 78.96	Zn	ZINC	33 Noble gas
			17	17	35 79.904	Ga	GALLIUM	34 Noble gas
			18	18	36 83.80	Cd	CADMIUM	35 Noble gas
6	4A	55 132.91	19	19	37 89.906	In	INDIUM	36 Noble gas
			20	20	38 87.62	Sn	TIN	37 Noble gas
			21	21	39 88.906	Sb	ANTIMONY	38 Noble gas
			22	22	40 91.224	Te	TELLURIUM	39 Noble gas
			23	23	41 92.906	I	IODINE	40 Noble gas
			24	24	42 95.94	Xe	XENON	41 Noble gas
7	5A	87 (223)	25	25	43 (98)	Rb	RUBIDIUM	42 Noble gas
			26	26	44 101.07	Sr	STRONTIUM	43 Noble gas
			27	27	45 102.91	Y	YTRITIUM	44 Noble gas
			28	28	46 106.42	Zr	ZIRCONIUM	45 Noble gas
			29	29	47 107.87	Nb	NIObIUM	46 Noble gas
			30	30	48 112.41	Mo	MOLYBDENUM	47 Noble gas
			31	31	49 114.82	Tc	TECHNETIUM	48 Noble gas
			32	32	50 118.71	Ru	RUTHENIUM	49 Noble gas
			33	33	51 121.76	Rh	RHODIUM	50 Noble gas
			34	34	52 127.60	Pd	PALLADIUM	51 Noble gas
			35	35	53 126.90	Ag	SILVER	52 Noble gas
			36	36	54 131.29	Cd	CADMIUM	53 Noble gas
			37	37	55 132.91	In	INDIUM	54 Noble gas
			38	38	56 137.33	Sn	TIN	55 Noble gas
			39	39	57 138.91	Sb	ANTIMONY	56 Noble gas
			40	40	58 140.12	Te	TELLURIUM	57 Noble gas
			41	41	59 140.91	I	IODINE	58 Noble gas
			42	42	60 144.24	Xe	XENON	59 Noble gas
			43	43	61 144.91	Ra	RADIUM	60 Noble gas
			44	44	62 150.36	Ac	ACTINIUM	61 Noble gas
			45	45	63 151.96	Fr	FRANCIUM	62 Noble gas
			46	46	64 157.25	U	URANIUM	63 Noble gas
			47	47	65 158.93	Np	NEPTUNIUM	64 Noble gas
			48	48	66 162.50	Pu	PLUTONIUM	65 Noble gas
			49	49	67 164.93	Am	AMERICIUM	66 Noble gas
			50	50	68 167.26	Cm	CURMIUM	67 Noble gas
			51	51	69 168.93	Bk	BERKELIUM	68 Noble gas
			52	52	70 173.04	Cf	CALIFORNIUM	69 Noble gas
			53	53	71 174.97	Es	EINSTEINIUM	70 Noble gas
			54	54	72 176.43	Fm	FERMICIUM	71 Noble gas
			55	55	73 176.43	Md	Mendelevium	72 Noble gas
			56	56	74 176.43	No	NOBELIUM	73 Noble gas
			57	57	75 176.43	Lr	LAWRENCIUM	74 Noble gas

Legend:

- Metal
- Alkali metal
- Semimetal
- Nonmetal
- Alkaline earth metal
- Transition metals
- Lanthanide
- Actinide
- Chalcogens element
- Halogens element
- Noble gas

STANDARD STATE (100 °C, 101 kPa)

- G - gas
- L - liquid
- S - solid
- Tc - synthetic

(1) Pure Appl. Chem., 73, No. 4, 667-683 (2001)
 Relative atomic mass is shown with five significant figures. For elements having no stable nuclides, the value enclosed in brackets indicates the mass number of the longest-lived isotope of the element.
 However, these such elements (Tl, Pa and U) do have a characteristic terrestrial isotopic composition, and for these an atomic weight is tabulated.

Editor: Aditya Varadhan (advr@rediffmail.com)

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57	58	59	60	61	62	63	64	65	66
La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy
LANTHANUM									
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ACTINIDE									
99	100	101	102	103	104	105	106	107	108
Fr	Ra	Ac-Lr	Rf	Db	Sg	Bh	Hs	Mt	Uuq
FRANCIUM									
109	110	111	112	113	114	115	116	117	118
Uue	Uub	Uut	Uuq	Uuq	Uuq	Uuq	Uuq	Uuq	Uuo
UNUNQUADIUM									

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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 (C₂H₄), nitrogen (N₂), 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, **k_B**, conceptually related

Extra credit #2 (2 points):

How are the energy units **Hz** and **cm⁻¹** conceptually related?

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TOTAL = _____

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		9.0122			4	Be	BERYLLIUM	Metal
3	3A	22.990	3	3A	11	Na	SODIUM	Metal
		24.305			12	Mg	MAGNESIUM	Metal
4	4A	39.098	4	4A	19	K	POTASSIUM	Metal
		40.078			20	Ca	CALCIUM	Metal
		87.62			38	Rb	RUBIDIUM	Metal
		88.906			39	Sr	STRONTIUM	Metal
5	5A	22.990	5	5A	21	Sc	SCANDIUM	Metal
		44.956			22	Ti	TITANIUM	Metal
		47.867			23	V	Vanadium	Metal
		50.942			24	Cr	CHROMIUM	Metal
		51.996			25	Mn	MANGANESE	Metal
		54.938			26	Fe	IRON	Metal
		55.845			27	Co	COBALT	Metal
		58.933			28	Ni	NICKEL	Metal
		58.693			29	Cu	COPPER	Metal
		63.546			30	Zn	ZINC	Metal
		65.39			31	Al	ALUMINIUM	Metal
		69.723			32	Ge	GERMANIUM	Metalloid
		72.64			33	As	ARSENIC	Metalloid
		74.922			34	Se	SELENIUM	Metalloid
		78.96			35	Br	BROMINE	Nonmetal
		79.904			36	Kr	KRYPTON	Noble gas
6	6A	10.811	6	6A	13	B	BORON	Metalloid
		12.011			14	C	CARBON	Nonmetal
		14.007			15	N	NITROGEN	Gas
		15.999			16	O	OXYGEN	Gas
		18.998			17	F	FLUORINE	Gas
		20.180			18	Ne	NEON	Noble gas
7	7A	226.025	7	7A	87	Fr	FRANCIUM	Radioactive
		227			88	Ra	RADIUM	Radioactive
		223.018			89	Ac	ACTINIUM	Radioactive

Legend for element classification:

- Metal
- Semimetal
- Nonmetal
- 1 Alkali metal
- 2 Alkaline earth metal
- 3 Transition metals
- 4 Lanthanide
- 5 Actinide
- 16 Chalcogens element
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LANTHANIDE

57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
LANTHANUM	CERIUM	PRASEODYMIUM	NEODYMIUM	PROMETHIUM	SAMARIUM	EUROPIUM	GADOLINIUM	TERBIUM	DYSPROSIUM	HOLMIUM	ERBIUM	THULIUM	YTERBIUM	LUTETIUM

ACTINIDE

89	90	91	92	93	94	95	96	97	98	99	100	101	102	103
Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr
ACTINIUM	THORIUM	PROACTINIUM	URANIUM	NEPTUNIUM	PLUTONIUM	AMERICIUM	CURIUM	BERKELIUM	CALIFORNIUM	EINSTEINIUM	FERMIUM	MERCEOVIUM	NOBELIUM	LAWRENCIUM

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Question 1 (25 points):

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



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:



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 $\text{CaCO}_3(s)$ and $\text{CaO}(s)$ 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 $-20\text{ }^\circ\text{C}$ to $120\text{ }^\circ\text{C}$.

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)

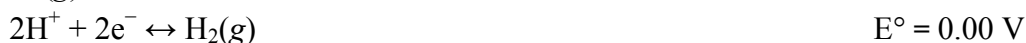
b) Describe briefly what we know (*i.e.*, signs and any other information) about ΔH , ΔS , and ΔG at each phase transition? (10 points)

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:



Compare to:



- What is the overall cell reaction for the lithium ion battery shown? (5 points)
- What is the overall standard cell potential of the reaction you wrote in (a)? (5 points)
- What is the n (number of electrons) for the overall cell reaction you wrote in (a)? (5 points)
- 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)
- 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):

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

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Signature _____

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3	1	Na	2	Mg	3	Al	4	Si	5	P	6	S	7	Cl	8	Ar																				
4	1	K	2	Ca	3	Sc	4	Ti	5	V	6	Cr	7	Mn	8	Fe	9	Co	10	Ni	11	Cu	12	Zn	13	Ga	14	Ge	15	As	16	Se	17	Br	18	Kr
5	1	Rb	2	Sr	3	Y	4	Zr	5	Nb	6	Mo	7	Tc	8	Ru	9	Rh	10	Pd	11	Ag	12	Cd	13	In	14	Sn	15	Sb	16	Te	17	I	18	Xe
6	1	Cs	2	Ba	3	La-Lu	4	Hf	5	Ta	6	W	7	Re	8	Os	9	Ir	10	Pt	11	Au	12	Hg	13	Tl	14	Pb	15	Bi	16	Po	17	At	18	Rn
7	1	Fr	2	Ra	3	Ac-Lr	4	Rf	5	Db	6	Sg	7	Bh	8	Hs	9	Mt	10	Uu	11	Uu	12	Uu	13	Uu	14	Uu	15	Uu	16	Uu	17	Uu	18	Uu

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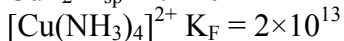
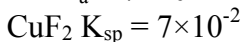
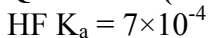
(1) Pure Appl. Chem., 73, No. 4, 697-683 (2001)
 Relative atomic mass is shown with five significant figures. For elements having no stable nuclides, the value enclosed in brackets indicates the mass number of the longest-lived isotope of the element.
 However, three such elements (Tl, Pa, and U) are shown with their standard atomic weights and composition, and for these an atomic weight is tabulated.

Editor: Aditya Vardhan (advan@vsnl.com)

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Name _____

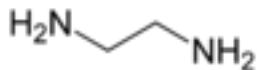
Question 1 (15 points):



Rank the solubility of $\text{CuF}_2(s)$ 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):

Ethylenediamine (shown below) is a chelate that is typically abbreviated as “en”



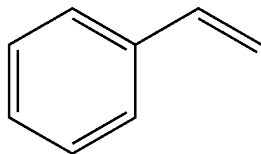
The formation constants, K_F , of octahedral Ni^{2+} complex ions at 25 °C are:



- 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 $[\text{Ni}(\text{en})_3]^{2+}$ 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 $[\text{Ni}(\text{NH}_3)_6]^{2+}$ 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 ΔG° 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 1)

Saturday 12 March 2016

5 questions + >1 extra credit problem, 12 pages. 2)

Answer on these sheets only. Additional space on last page. 3)

If you need extra sheets, please ask your proctor or TA. 3)

Note: 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.

Label all axes and features on graphs and diagrams. 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	$6.241 81 \times 10^{18}$	$5.034 45 \times 10^{22}$	1.44×10^{20}	6.02×10^{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

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

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

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

PERIODIC TABLE OF THE ELEMENTS

<http://www.kj-spl.it/periodic/en/>

PERIOD	GROUP	RELATIVE ATOMIC MASS (1)	GROUP TYPIC	ATOMIC NUMBER	SYMBOL	ELEMENT NAME
1	IA	1.0079	1	1	H	HYDROGEN
2	IIA	6.941	2	3	Li	LITHIUM
3	IIIA	9.0122	13	4	Be	BERYLLIUM
4	IVB	12.24305	14	11	B	BORON
5	VIB	22.990	15	12	C	CARBON
6	VIB	24.305	16	13	N	NITROGEN
7	VIB	24.305	17	14	O	OXYGEN
8	VIB	24.305	18	15	F	FLUORINE
9	VIB	24.305	19	16	Ne	NEON
10	VIB	24.305	20	17	Ar	ARGON
11	VIB	24.305	21	18	Kr	KRYPTON
12	VIB	24.305	22	19	Xe	XENON
13	VIB	24.305	23	20	Rn	RADON

Legend for element classification:

- 1 Alkali metal
- 2 Alkaline earth metal
- 3 Transition metals
- 4 Lanthanide
- 5 Actinide
- 6 Chalcogens element
- 7 Halogens element
- 8 Noble gas
- 9 Semimetal
- 10 Nonmetal

STANDARD STATE (100 °C, 101 kPa):

- Ne - gas
- Fe - solid
- Ti - synthetic
- Ga - liquid

PERIOD	GROUP	RELATIVE ATOMIC MASS (1)	GROUP TYPIC	ATOMIC NUMBER	SYMBOL	ELEMENT NAME
14	IIIA	26.982	13	13	Al	ALUMINIUM
15	IIIA	28.086	14	14	Si	SILICON
16	IIIA	30.974	15	15	P	PHOSPHORUS
17	IIIA	32.065	16	16	S	SULFUR
18	IIIA	35.453	17	17	Cl	CHLORINE
19	IIIA	39.948	18	18	Ar	ARGON
20	IIIA	40.078	19	19	K	POTASSIUM
21	IIIA	44.956	20	20	Ca	CALCIUM
22	IIIA	47.867	21	21	Sc	SCANDIUM
23	IIIA	50.942	22	22	Ti	TITANIUM
24	IIIA	51.996	23	23	V	VANADIUM
25	IIIA	54.938	24	24	Cr	CHROMIUM
26	IIIA	55.845	25	25	Mn	MANGANESE
27	IIIA	58.933	26	26	Fe	IRON
28	IIIA	58.693	27	27	Co	COBALT
29	IIIA	63.546	28	28	Ni	NICKEL
30	IIIA	65.39	29	29	Cu	COPPER
31	IIIA	69.723	30	30	Zn	ZINC
32	IIIA	72.64	31	31	Ga	GALLIUM
33	IIIA	74.922	32	32	Ge	GERMANIUM
34	IIIA	78.96	33	33	As	ARSENIC
35	IIIA	79.904	34	34	Se	SELENIUM
36	IIIA	83.80	35	35	Br	BROMINE
37	IIIA	85.47	36	36	Kr	KRYPTON
38	IIIA	87.62	37	37	Rb	RUBIDIUM
39	IIIA	88.906	38	38	Sr	STRONTIUM
40	IIIA	91.224	39	39	Y	YTRITIUM
41	IIIA	92.906	40	40	Zr	ZIRCONIUM
42	IIIA	95.94	41	41	Nb	NIOBIUM
43	IIIA	98.906	42	42	Mo	MOLYBDENUM
44	IIIA	101.07	43	43	Tc	TECHNETIUM
45	IIIA	102.91	44	44	Ru	RUTHENIUM
46	IIIA	106.42	45	45	Rh	RHODIUM
47	IIIA	107.87	46	46	Pd	PALLADIUM
48	IIIA	112.41	47	47	Ag	SILVER
49	IIIA	114.82	48	48	Cd	CADMIUM
50	IIIA	118.71	49	49	In	INDIUM
51	IIIA	121.76	50	50	Sn	TIN
52	IIIA	127.60	51	51	Sb	ANTIMONY
53	IIIA	126.90	52	52	Te	TELLURIUM
54	IIIA	131.29	53	53	I	IODINE
55	IIIA	132.91	54	54	Xe	XENON
56	IIIA	137.33	55	55	Rb	RUBIDIUM
57	IIIA	138.91	56	56	Ba	BARIUM
58	IIIA	140.12	57	57	La	LANTHANUM
59	IIIA	140.91	58	58	Ce	CERIUM
60	IIIA	144.24	59	59	Pr	PRASEODYMIUM
61	IIIA	144.91	60	60	Nd	NEODYMIUM
62	IIIA	150.36	61	61	Pm	PROMETHIUM
63	IIIA	151.96	62	62	Sm	SAMARIUM
64	IIIA	157.25	63	63	Eu	EUROPIUM
65	IIIA	158.93	64	64	Gd	GAULINIUM
66	IIIA	162.50	65	65	Tb	TERBIUM
67	IIIA	164.93	66	66	Dy	DYSPROSIUM
68	IIIA	167.26	67	67	Ho	HOLMIUM
69	IIIA	168.93	68	68	Er	ERBIUM
70	IIIA	173.04	69	69	Tm	THULIUM
71	IIIA	174.97	70	70	Yb	YTERBIUM
72	IIIA	175.07	71	71	Lu	LUTETIUM
73	IIIA	180.95	72	72	Hf	HAFNIUM
74	IIIA	183.84	73	73	Ta	TANTALUM
75	IIIA	186.21	74	74	W	TUNGSTEN
76	IIIA	190.23	75	75	Re	RHENIUM
77	IIIA	192.22	76	76	Os	OSMIUM
78	IIIA	195.08	77	77	Ir	IRIDIUM
79	IIIA	196.97	78	78	Pt	PLATINUM
80	IIIA	200.59	79	79	Au	GOLD
81	IIIA	204.38	80	80	Hg	MERCURY
82	IIIA	207.2	81	81	Tl	THALLIUM
83	IIIA	208.98	82	82	Pb	LEAD
84	IIIA	209	83	83	Bi	BISMUTH
85	IIIA	210	84	84	Po	POLONIUM
86	IIIA	210	85	85	At	ASTATINE
87	IIIA	223	86	86	Rn	RADON
88	IIIA	226	87	87	Fr	FRANCIUM
89	IIIA	227	88	88	Ra	RADIUM
90	IIIA	232.04	89	89	Ac	ACTINIUM
91	IIIA	231.04	90	90	Th	THORIUM
92	IIIA	238.03	91	91	Pa	PROTACTINIUM
93	IIIA	237	92	92	U	URANIUM
94	IIIA	244	93	93	Np	NEPTUNIUM
95	IIIA	243	94	94	Pu	PLUTONIUM
96	IIIA	247	95	95	Am	AMERICIUM
97	IIIA	247	96	96	Cm	CURMIUM
98	IIIA	251	97	97	Bk	BERKELIUM
99	IIIA	252	98	98	Cf	CALIFORNIUM
100	IIIA	257	99	99	Es	EINSTEINIUM
101	IIIA	258	100	100	Fm	FERMILIUM
102	IIIA	259	101	101	Md	MENDELEVIUM
103	IIIA	262	102	102	No	NOBELIUM
104	IIIA	262	103	103	Lr	LAVRENCIUM

(1) Pure Appl. Chem., 73 No. 4, 667-683 (2001)
 Relative atomic mass is shown with five significant figures. For elements having stable nuclei, the value enclosed in brackets is the mass number of the longest-lived isotope of the element.
 However, these such elements (Th, Pa, and U) do have a characteristic terrestrial isotopic composition, and for these an atomic weight is tabulated.
 Editor: Aditya Vardhan (advr@netlix.com)

Question 1 (15 points):

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

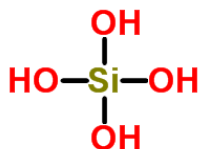
Question 2 (25 points):

For the reaction of $\text{Si}(s) + \text{O}_2(g) \rightarrow \text{SiO}_2(s)$

a) What are the signs of ΔH , ΔS , and ΔG ? Explain each of your answers concisely. (15 points)

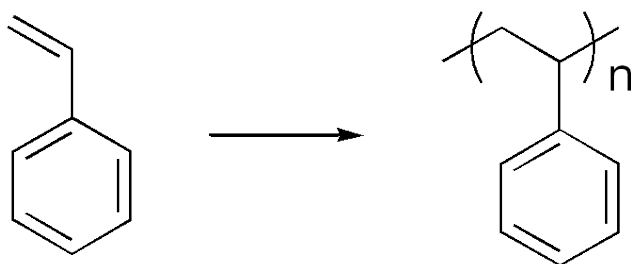
[Hint: what would C do, in place of Si?]

b) Petrified wood comes from dehydration (loss of water) of silicic acid, $\text{Si}(\text{OH})_4$ (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)

**Question 3 (10 points):**

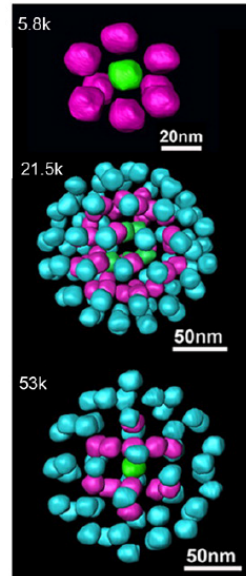
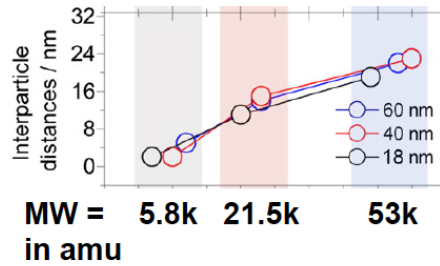
Recall from the third midterm that the monomer styrene (left) is used to make polystyrene (middle), the main component of Styrofoam.

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).

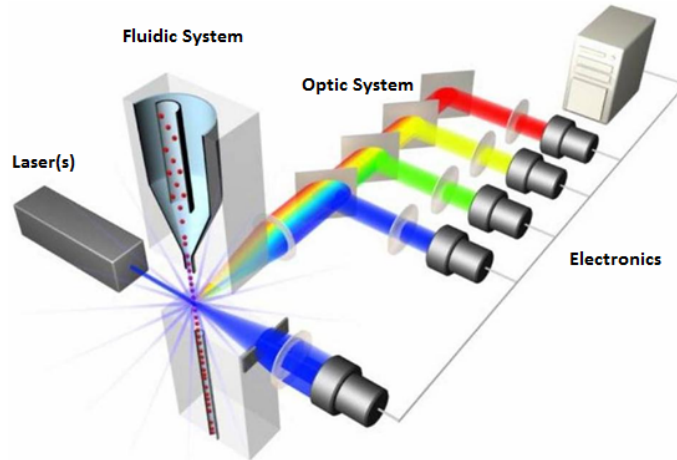


- Why are the Au nanoparticle spacings different and in this order, in terms of the attached polymer molecular weight? (Ignore the points in the plot for the different sizes of nanoparticles.) (5 points)
- Estimate the average polymer chain lengths in each case in terms of number of monomer units. Recall 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.



- 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 🍷🍷🍷)
- 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)
- 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 $^{14}\text{C}/^{12}\text{C}$ in the atmosphere is approximately 1.2×10^{-12} .

If a tree was seeded and started to grow 17,100 ($=3 \times 5700$) 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):

- Draw and concisely explain a plot of the $^{14}\text{C}/^{12}\text{C}$ ratio in the tree for the last 17,100 years. (15 points)
- 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)
- What is the reaction order in $[^{14}\text{C}]$ for the 11,400 years since the tree died? Explain concisely. (5 points)
- What is the $^{14}\text{C}/^{12}\text{C}$ 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)

Note: 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.

Label all axes and features 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: $c = 3 \times 10^8$ 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	$1.602 10 \times 10^{-19}$	$2.418 04 \times 10^{14}$
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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	$6.241 81 \times 10^{18}$	$5.034 45 \times 10^{22}$	1.44×10^{20}	6.02×10^{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

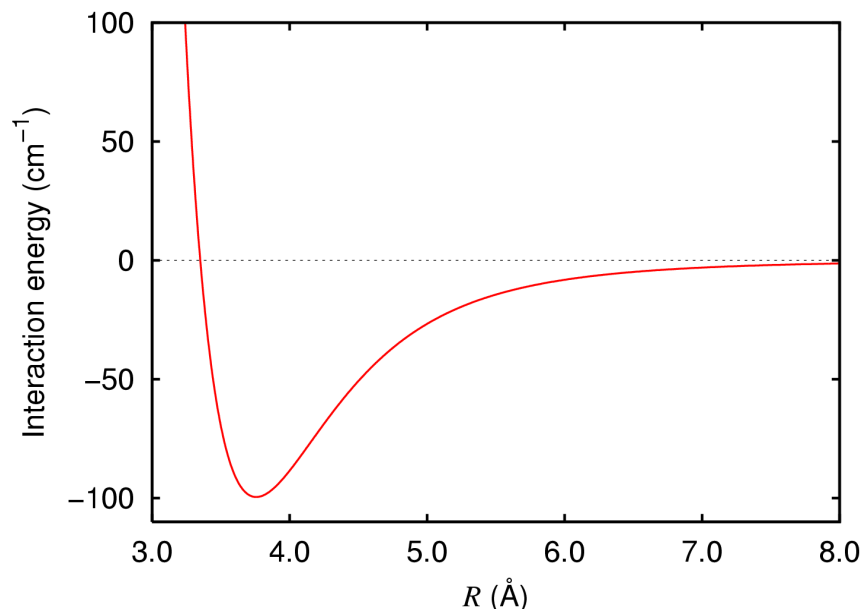
$$\Delta G^\circ = -nFE^\circ = -2.303 RT \log_{10}K_{eq}$$

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

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):

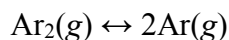
- What is the approximate bond energy for Ar₂ in cm⁻¹ *and* in your favorite energy units (which must be one of the following: eV, kcal/mol, kJ/mol, or J)? (10 points)
- What is the approximate bond length of Ar₂? (5 points)

Question 2 (25 points):

Explain each of your answers concisely.

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

- For the reaction:

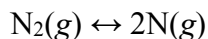


What are the signs of ΔH , ΔS , and ΔG at room temperature and (concisely) why?

In what form is most of the argon at 1 atm pressure (pure argon) at room temperature – Ar or Ar₂? (10 points)

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

- For the reaction:



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 N₂?

Question 3 (20 points):

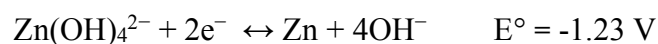
a) Rank these (eight different) solutions by pH, indicating which are the high and low ends, and concisely explain your reasoning.

(Your reasoning, which should be based on interactions with water, is worth more than the correct order.)

1 M FeCl₂, 1 M FeCl₃, 1 M HClO₃, 1 M HClO₄, 0.1 M NaCl, 1 M NaCl, 0.1 M NH₃, 1 M NH₃

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:



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)

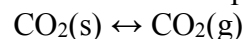
c) What is the n (number of electrons) for the overall cell reaction you wrote in (a)?

(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, CO₂(s), is -78 °C.



The absolute value of enthalpy of sublimation, $|\Delta H| \sim 20 \text{ kJ/mol}$.

a) What are the signs of ΔH , ΔS , and ΔG for CO₂ 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, Ar₂ or Ar₂⁺, and why?

Extra credit #2 (2 points):

Estimate by what factor the N₂ bond strength is larger than the Ar₂ bond strength and concisely give your reasoning.

Name _____ Section # _____ Student ID # _____

Signature _____

TOTAL = _____

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.

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: $c = 3 \times 10^8$ 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	$6.241 81 \times 10^{18}$	$5.034 45 \times 10^{22}$	1.44×10^{20}	6.02×10^{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

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

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

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

Name _____ Section # _____ Student ID # _____

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 called "intrinsic").

Question 3 (25 points):

For the transition metal complex $\text{Ag}(\text{NH}_3)_2^+$:

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_a s are:

$$\text{pK}_{a1} = 2.2$$

$$\text{pK}_{a2} = 7.2$$

$$\text{pK}_{a3} = 12.7$$

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 H₃PO₄, 1 M H₃PO₄

0.001 M NH₃, 1 M NH₃

Water

Solids: Fe, Na, NaCl, NaH, NaOH

Question 5 (20 points):

For Cu(OH)₂, $K_{sp}=2.2\times 10^{-20}$

Also, for Cu(NH₃)₄²⁺, $K_F=5\times 10^{12}$

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(NO₃)₂, 1 M NaOH, 1 M NH₃

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?