First Name: ____

Last Name: ____

Student Number: ____________________________________

<table>
<tr><td rowspan="9">UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE AND ENGINEERING

Final Exam – December 10, 2018

First Year

APS110/164 – ENGINEERING CHEMISTRY AND MATERIALS SCIENCE

Exam Type: A

Examiners – CQ Jia, SD Ramsay

Duration: 150 minutes
Permissible Calculators: Casio FX-991 or Sharp EL-520
Rulers permitted
Answer all questions on this exam
All numerical responses must be expressed in the most appropriate units, including appropriate prefixes (ex. GPa rather than 10⁹ Pa), and be written with appropriate significant figures</td><td><u>Marks</u>
<u>Part A:</u>
(/10)</td></tr>
<tr><td><u>Part B:</u>
1.(/20)</td></tr>
<tr><td>2.(/10)</td></tr>
<tr><td>3.(/10)</td></tr>
<tr><td>4.(/10)</td></tr>
<tr><td>5.(/10)</td></tr>
<tr><td>6.(/5)</td></tr>
<tr><td>7.(/10)</td></tr>
<tr><td>TOTAL:
(/85)</td></tr>
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Part A. Please enter the correct answer for the following questions on the computer answer form. (Each question is worth 1 mark)

1. Which of the following is the best explanation of the engineering stress?

   a) The applied force divided by the initial cross-sectional area
   b) The applied force divided by the instantaneous cross-sectional area
   c) The applied force divided by the cross-sectional area within the necked region
   d) None of the above

2. Regarding a standard tensile specimen, which of the following statements is true?

   a) The gauge length is normally longer than the reduced section, but the reduced section is never longer than the gauge length
   b) The gauge length is normally less than the reduced section, but the reduced section is never less than the gauge length
   c) The reduced section and the gauge length are normally equal
   d) None of the above

3. Which of the following would be expected to cause a change in the elastic modulus?

   a) An increase in the impurity concentration in a metal
   b) An increase in the dislocation density of a metal
   c) A reduction in the grain size of a metal
   d) An increase in crystallinity of a polymer

4. Which of the following is closest to the atomic scale?

   a) 10^{-14} m
   b) 10^{-6} m
   c) 10^{-10} m
   d) 10^{-23} m

5. How many atoms are present within a single unit cell of the diamond cubic crystal structure?

   a) 4
   b) 5
   c) 6
   d) 8

6. Which of the following is the most accurate description of the direction that atoms within the BCC crystal structure touch one another?

    a) Along the face diagonals
    b) Along the cube diagonals
    c) Along the cube edges
    d) None of the above

7. Which of the following best describes the stacking sequence of close-packed planes within the HCP crystal structure?

    a) There are no close-packed planes in HCP
    b) ABCABC
    c) ABAB
    d) None of the above

8. At higher temperatures stress relaxation would occur more rapidly.

    a) False
    b) True

9. A polymer that exhibits a very subtle (small) change in relaxation modulus around the glass-transition temperature would most likely have which of the following microstructures?

    a) Fully amorphous
    b) Cross-linked
    c) Highly crystalline
    d) None of the above

10. A reaction with a positive enthalpy change and a positive entropy change will be spontaneous under which of the following conditions?

    a) At low temperature
    b) At high temperature
    c) At all temperatures
    d) Never

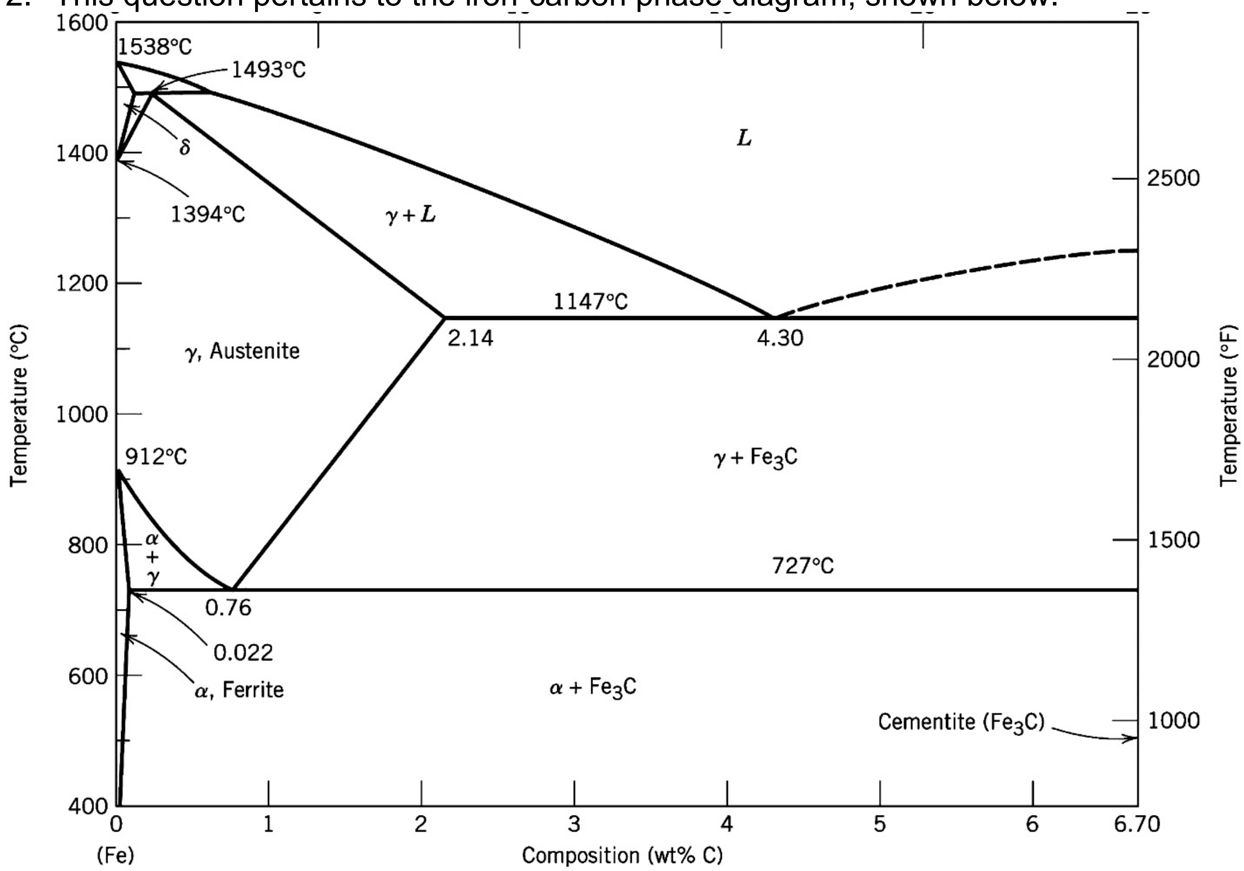
Part B.

1. (20) Many ski resorts currently utilize snowmaking systems to make snow even when there is no natural precipitation. There are many important factors involved in effective snowmaking, however in this question we will simplify the system and assume that a fine mist of spherical water droplets is sprayed into the air and allowed to freeze. Make the following assumptions: water droplets having 0.5 mm diameter are created, 15% of the water evaporates, the temperature of the water droplets is equal from surface to interior (high heat transfer).
   What is the maximum temperature the water can be maintained at in order for the droplets to remain at 0ºC after freezing completely?
   a. (10) Describe the process, conceptually, that you would follow to solve this problem.

b. (6) Calculate the temperature.

c. (4) Identify and explain two other factors that would need to be involved in a more detailed solution to this problem.

2. This question pertains to the iron-carbon phase diagram, shown below.



a. For a sample of 0.25 wt% C steel at 1200°C, what phase or phases will be present, and what will be the composition of each phase, in wt% C? (2)

b. For a 1 kg sample of 1.25 wt% C steel at 728°C, what will be the mass, in grams, of α ferrite? (2)

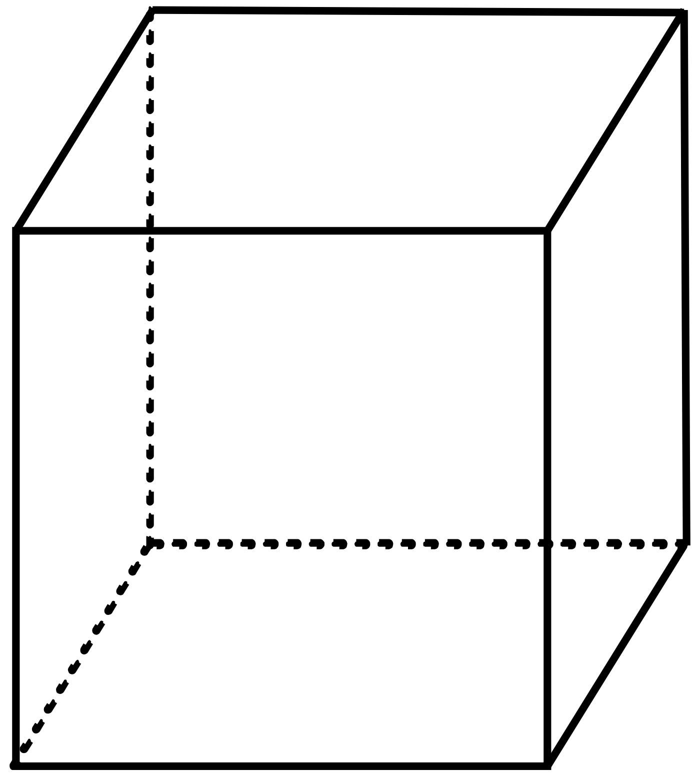
c. For a 1 kg sample of 0.75 wt% C steel at 728°C, what will be the mass, in grams, of α ferrite? (2)

d. For a 1 kg sample of 4.5 wt% C cast iron at 726°C, what will be the mass, in grams, of carbon that is present as point defects in iron? (2)

e. For a sample of 3 wt% C cast iron, what will be the minimum temperature to which this sample would need to be heated to ensure no solid remained? (2)

3. (10) A footbridge is produced from concrete. The bridge has a rectangular cross-section with height 20 cm and width 100 cm and is designed to cross a span of 3 m. Assume a typical value for the bending strength of concrete of 0.5 MPa, and an acceleration due to gravity of 9.8 N/kg.
    a. (5) What would be the maximum mass, in kg, that could be supported at the middle of this bridge?
    b. (5) Another bridge was built having the same dimensions, however with 5 lengths of steel rebar (reinforcing bar) embedded along the lower surface, aligned with the long axis, of the beam. Assume that the rebar has a 10 mm diameter and a yield strength of 500 MPa, that the entire tensile stress on the lower surface of the beam is supported by the rebar and none by the concrete. What would be the maximum mass, in kg, that could be supported at the middle of this bridge without the rebar experiencing any plastic deformation?

4. (10) This question pertains to the crystalline structure of silicon.
    a. (5) Name the crystal structure of crystalline silicon and in the unit cell below sketch the structure.



    b. (5) If the lattice parameter for solid crystalline silicon is 5.4×10^{-10} m, calculate the theoretical density of silicon.

5. (10) Methane is a widely used fuel for residential heating systems.
   a. (2) In the box below write the balanced chemical equation for the combustion of 1 mol of gaseous methane(CH_4) with 2 mols of gaseous oxygen to form carbon dioxide gas and water vapour.

   b. (2) Determine the standard combustion enthalpy for one mol of gaseous methane.

   c. (6) Assuming all of the heat from the combustion of 1 mol of methane goes to heating a 45 m^2 room with 3 m ceilings, what will the resulting temperature change be to the room? Assume a density of air of 1.225 kg/m^3.

6. (5) This question pertains to the band theory of solids. In the boxes below, sketch the generalized band structure for conductors, insulators, and intrinsic semiconductors, p-type and n-type semiconductors. On your sketches, label all important features, including donor and acceptor levels.

Conductor

Insulator

Intrinsic semiconductor

p-type semiconductor

n-type semiconductor

7. Correctly identify each of the following by indicating the matching number in the box beside each description. Numbers may be used more than once. (1 each)

1. N-type	8. 0.225	15. 8
2. P-type	9. 0.732	16. 12
3. Point defect	10. Conduction band	17. Chain orientation
4. Linear imperfection	11. Valence band	18. Increasing molecular weight
5. Interfacial defect	12. Increase	19. Cross-linking
6. Volume defect	13. 4	20. Intrinsic
7. 0.414	14. 6	

a. The crystalline imperfection responsible for plastic deformation in metals.

b. Carbon present in iron at compositions above 0.022 wt% carbon.

c. The coordination number of cations in the rock salt crystal structure.

d. The strengthening mechanism in polymers chiefly responsible for continued load bearing beyond necking.

e. The coordination number of atoms in the HCP crystal structure

f. The change that will occur to the strength of a metal when grain size is decreased

g. The donor level is close to this in a n-type semiconductor.

h. The minimum size of a cation as a fraction of the anion size for a coordination number of 6.

i. Arsenic (As) added as a dopant to silicon will create this type of semiconductor.

j. Arsenic (As) added as a dopant to silicon will create this type of crystalline imperfection.

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You may use this page for rough calculations, however,
NO work written on this page will be graded.

You may remove these pages from your test.

Constants

1 atm = 101.325 kPa = 1.01325 bar = 14.696 psi $N_A = 6.022 \times 10^{23}\ mol^{-1}$ $e = 1.602 \times 10^{-19}$ C

1 eV = 1.602×10^{-19} J $\varepsilon_0 = 8.854 \times 10^{-12}\ \frac{F}{m}$ $R = 8.314\ \frac{J}{mol \cdot K} = 0.082067\ \frac{L \cdot atm}{mol \cdot K}$

$T_{(K)} = T_{(°C)} + 273.15$ $k = 8.62 \times 10^{-5}\ \frac{eV}{atom \cdot K}$ $k = 1.38 \times 10^{-23}\ \frac{J}{atom \cdot K}$ F = 96486 C·mol^{-1}

Microstructure

LD = #/Length $LPF = \frac{\text{length of atoms}}{\text{length of vector}}$ PD = #/Area $PPF = \frac{\text{area of atoms}}{\text{area of plane}}$ $V = \frac{4}{3}\pi r^3$

$A = \pi r^2$ $A_\Delta = \frac{1}{2}bh$ $\rho = \frac{n \cdot A}{V_C \cdot N_A}$ $\rho = \frac{m}{V}$ $\rho = \frac{n_A A_A + n_C A_C}{V_C N_A}$ $APF = \frac{V_S}{V_C}$

$N = \frac{N_A \rho}{A}$ $N_v = N \exp\left(-\frac{Q_v}{kT}\right)$ $a = 2\sqrt{2}R$ $a = \frac{4}{\sqrt{3}}R$

Mechanical Behaviour

$\sigma = \frac{F}{A}$ $\varepsilon = \frac{\Delta l}{l_o}$ $\sigma = E\varepsilon$ $\sigma_{3-point\ bend} = \frac{3FL}{2w \cdot h^2}$ $x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

Electrical Behaviour

$\sigma = n|e|\mu_e + h|e|\mu_h$ $\sigma = n|e|\mu_e$ $\sigma = h|e|\mu_h$

Thermodynamics

PV = nRT $\Delta U = q + w$ $\Delta U = q - P_{ext}\Delta V$ $H \equiv U + PV$ $G \equiv H - TS$ $\Delta S = \frac{q_{rev}}{T}$

For process at constant T: $\Delta G = \Delta H - T\Delta S$ $q = mc\Delta T = nC_p\Delta T$ $\Delta G = \Delta H - T\Delta S$

$W_{phase} = \frac{length\ of\ opposite\ side\ of\ lever}{total\ length\ of\ lever}$ For $aA + bB \rightarrow cC + dD$, $Q = \frac{a_C^c \cdot a_D^d}{a_A^a \cdot a_B^b}$

υ_i: stoichiometric coefficient   Assuming no phase change, constant C_p:

$$\Delta H^\circ_{reaction} = (\Sigma \upsilon_i \Delta H^\circ_{f,i})_{products} - (\Sigma \upsilon_i \Delta H^\circ_{f,i})_{reactants}$$

$$\Delta S^\circ_{reaction} = (\Sigma \upsilon_i \Delta S^\circ_{m,i})_{products} - (\Sigma \upsilon_i \Delta H^\circ_{m,i})_{reactants}$$

$$\Delta G^\circ_{reaction} = \Delta H^\circ_{reaction} - T\Delta S^\circ_{reaction} \qquad \Delta G_{reaction} = \Delta G^\circ + RTlnQ$$

$$\Delta G^\circ = -RTlnK$$

Electrochemistry

$E = E^\circ - \frac{RT}{nF} lnQ$ $E = E^\circ - \frac{0.0592}{n} lnQ$, at 25°C $I = \frac{nC}{t}$ $w = nFE^\circ$

Key: 29 ← Atomic number; Cu ← Symbol; 63.54 ← Atomic weight

Metal

Nonmetal

Intermediate

IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIII	VIII	VIII	IB	IIB	IIIA	IVA	VA	VIA	VIIA	0
1 H 1.0080																	2 He 4.0026
3 Li 6.939	4 Be 9.0122											5 B 10.811	6 C 12.011	7 N 14.007	8 O 15.999	9 F 18.998	10 Ne 20.183
11 Na 22.990	12 Mg 24.312											13 Al 26.982	14 Si 28.086	15 P 30.974	16 S 32.064	17 Cl 35.453	18 Ar 39.948
19 K 39.102	20 Ca 40.08	21 Sc 44.956	22 Ti 47.90	23 V 50.942	24 Cr 51.996	25 Mn 54.938	26 Fe 55.847	27 Co 58.933	28 Ni 58.71	29 Cu 63.54	30 Zn 65.37	31 Ga 69.72	32 Ge 72.59	33 As 74.922	34 Se 78.96	35 Br 79.91	36 Kr 83.80
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc (99)	44 Ru 101.07	45 Rh 102.91	46 Pd 106.4	47 Ag 107.87	48 Cd 112.40	49 In 114.82	50 Sn 118.69	51 Sb 121.75	52 Te 127.60	53 I 126.90	54 Xe 131.30
55 Cs 132.91	56 Ba 137.34	Rare earth series	72 Hf 178.49	73 Ta 180.95	74 W 183.85	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.09	79 Au 196.97	80 Hg 200.59	81 Tl 204.37	82 Pb 207.19	83 Bi 208.98	84 Po (210)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra (226)	Acti-nide series															

Rare earth series	57 La 138.91	58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm (145)	62 Sm 150.35	63 Eu 151.96	64 Gd 157.25	65 Tb 158.92	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.04	71 Lu 174.97
Actinide series	89 Ac (227)	90 Th 232.04	91 Pa (231)	92 U 238.03	93 Np (237)	94 Pu (242)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (249)	99 Es (254)	100 Fm (253)	101 Md (256)	102 No (254)	103 Lw (257)

STANDARD FORMATION ENTHALPY, STANDARD ENTROPY AND STANDARD FORMATION GIBBS ENERGY AT 298.15 K

Species	$\Delta_f H^\circ$ [kJ/mol]	S° [J/mol·K]	$\Delta_f G^\circ$ [kJ/mol]
C (s, graphite)	0	5.74	0
CH_4 (g)	-74.81	186.2	-50.75
C_2H_2 (g)	226.7	200.93	
C_3H_8 (g)	-103.8	269.9	-23.49
CaC_2 (s)	-59.8	70.3	
CaF_2 (s)	-1225	68.87	-1162
CaF_2 (l)	-1186	92.6	
$Ca(OH)_2$ (s)	-987.0	83.0	
CO_2 (g)	-393.5	213.6	-394.4
Cu_2O (s)	-168.6	93.1	
Cu_2O (l)	-154.79		
Cu (s)		33.2	
Fe (s)	0	27.3	0
Fe_2O_3 (s)	-824.2	87.4	
H_2 (g)		130.68	
H_2O (g)	-241.8	188.7	-228.6
H_2O (l)	-285.8	69	
O_2 (g)	0	205.0	0

MISCELLANEOUS ENTHALPIES

Substance	Reaction	ΔH [kJ/mol]
F-F	Bond dissociation	157
F	Electron affinity F (g) $\rightarrow$ F^- (g)	-328
Ca	Second Ionization energy Ca (g) $\rightarrow$ Ca^{2+} (g)	1734

SPECIFIC HEATS AND HEAT CAPACITIES

Substance	Specific Heat c [J/g·K]	Molar Heat Capacity C_p [J/mol·K]
CO_2 (g)	0.843	37.1
Air (g)	1.0	
H_2O (g)	2.03	36.4
H_2O (l)	4.184	75.3
H_2O (s)	2.09	37.7

TEMPERATURES AND ENTHALPIES OF PHASE CHANGES

Substance	Melting Point [°C]	$\Delta_{fus}H^\circ$ [kJ/mol]	Boiling Point [°C]	$\Delta_{vap}H^\circ$ [kJ/mol]
Al	658	10.6	2467	284
Ca	851	9.33	1487	162
CH_4	-182	0.92	-164	8.18
H_2O	0	6.01	100	40.7
Fe	1530	14.9	2735	354