UNIVERSITY OF TORONTO

FACULTY OF APPLIED SCIENCE AND ENGINEERING

FINAL EXAMINATION, April 17, 2018
DURATION: **2 hrs**

First Year

MSE160H1S – Molecules and Materials

Exam Type: A

Calculator type 3

Examiner – B. Hatton

Answer the following questions in the exam booklets.

Put your name clearly below and on all exam booklets to be handed in together.

Total marks: 100

1. [10 marks]

Choose **10** of the terms or concepts below and provide brief definitions or explanations.

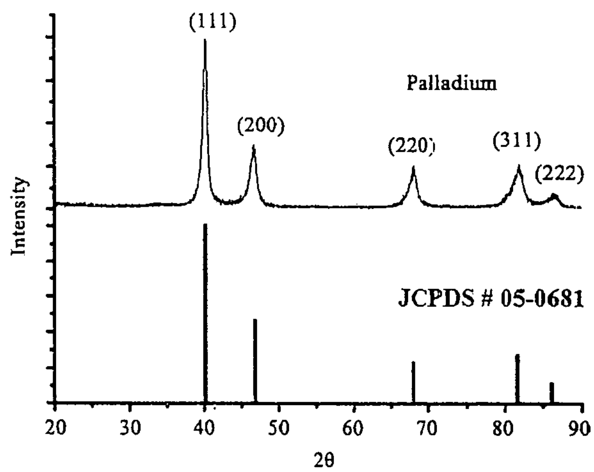
- Polymorphism
- Allotrope
- Isotope
- Anisotropic
- Planar atomic density
- Close-packed plane
- Annealing
- Solid solutions
- Alloys
- Strain, and the difference between true vs engineering strain
- Slip system
- Atomic packing factor
- Criteria for the formation of each of substitutional and interstitial solid solutions

2. [12 marks]

You need to design a device to be used at **900°C** and made of **palladium.** Your colleagues have provided you with the following x-ray diffraction data and information on the material.

The performance of the rod is directly related to the number of **vacancies** present in the lattice. Determine the vacancy density.

- The (111) plane has a diffraction peak at 40°
- Monochromatic Cu-Kα radiation was used with a wavelength of 0.1540 nm
- Palladium has an FCC structure
- The activation energy for vacancy formation is 0.98 eV atom^{-1}
- The atomic mass of palladium is 106.42 g mol^{-1}



3. [15 marks]

(a) Draw unit cells for FCC and BCC crystal structures. For each structure, which is the most likely slip plane? [5 marks]

(b) Briefly, why do FCC metals have a lower yield strength than BCC metals? [4 marks]

(c) Calculate the density of aluminum, which has an FCC structure (atomic mass = 26.98 g/mol, atomic radius = 0.143 nm). [4 marks]

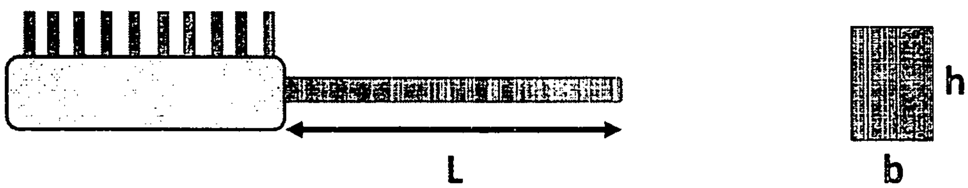
(d) What evidence do we have that materials are actually crystalline? Give 2 examples. [2 marks]

4. [10 marks]

For the following materials, state the type(s) of **bonding** involved. Also, would you expect this material to have a high or low **electrical conductivity**, and why?

a) NaCl
b) Polyethylene
c) SiC
d) C (diamond)
e) Pd

5. Materials selection [15 marks]



The Canadian Army is designing a new high performance, **lightweight** hairbrush and you are asked to select a material for the **handle**. The length of the handle (L) is fixed by the design, and must support a load (F) in bending without failure. The handle has a rectangular cross-section, of width **b**, which is fixed by the design. The height **h** is allowed to vary. You are able to choose from the following four materials:

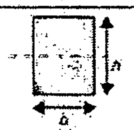
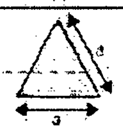
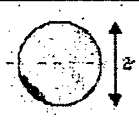
Material	Density (ρ, g-cm^{-1})	Young's Modulus (E, GPa)	Strength (σ, MPa)	Max shape Factor (ϕ)	Cost (\$ kg^{-1})
316 Steel	7.8	202	872	1.5	5
Polyethylene	1.2	5.1	85	5.1	2
Carbon fiber composite	2.7	220	980	2.75	10
Titanium	4.3	114	1250	1.2	20

a) Draw a diagram of the forces acting on the hairbrush when in use, as cantilevered beam [2 marks].

b) *Without* considering cost, derive the **materials performance index** for the hairbrush handle assuming it will have a solid cross section. (Show all your derivation) [5 marks]

c) Without considering cost, what material performs the best? [2 marks]

d) If you also have the option of making the hairbrush handle **hollow**, and if cost *is* taken into account, which material would you choose? Will the handle be hollow or solid? [6 marks]

Section Shape	Area A m^2	Moment I m^4
	bh	$\frac{bh^3}{12}$
	$\frac{\sqrt{3}}{4}a^2$	$\frac{a^4}{32\sqrt{3}}$
	πr^2	$\frac{\pi}{4}r^4$

Force of failure for a cantilever beam:

$$F = \frac{2I\sigma_f}{y_m L}$$

Where $y_m = h/2$

Shape factor, $\varphi = \frac{I}{I_0}$

6. [14 marks]

a) Would you choose to make a snow plow shovel out of a BCC or FCC metal? Why? [3 marks]

b) How is the yield strength of a material related to the ability for dislocations to move? [3 marks]

c) Why are ionic solids brittle? [2 marks]

d) What are 3 mechanisms for how to make metals stronger, and briefly explain each with 1-2 sentences. [6 marks]

7. [12 marks]

a) A glass (SiO_2) window fractured and fell from a high rise building on Bay Street. The glass had a fracture toughness of 2.1 MPa $m^{0.5}$ and was rated for a strength of 250 MPa under normal conditions. How big, in micrometers (10^{-6} m), was the defect that caused this fracture? (Assume Y = 1.0) [6 marks]

b) What kind of defect or flaw could this have been? [2 marks]

c) How could a manufacturing company search for such defects in glass, for quality control? [2 marks]

d) What kind of factors would cause the stress within exterior building windows to change throughout the day, and maybe exceed the designed stress rating? [2 marks]

8. [12 marks]

a) An electrical **wire** of 300 m length is being designed to carry a current of 3.0 Amps. You have the option of using two different wire materials, with different size and conductivity; Al wire ($\sigma = 3.5 \times 10^7$ $(\Omega m)^{-1}$, diameter 2.0 mm) or Cu wire ($\sigma = 6.07 \times 10^7$ $(\Omega m)^{-1}$, diameter 2.5 mm).

Which wire would you choose if you need to keep the operating **voltage** under 4.0 V? [5 marks]

b) During installation, if the wire was found to be heavily deformed, what could this mean for the expected (rated) conductivity? Why? [3 marks]

c) If the current was designed to be increased and decreased every 5 minutes, how could this lead to fatigue and mechanical failure (fracture) of the wire over a long period of time?

$$d_{hkl} = \frac{a}{\sqrt{h^2 + k^2 + l^2}}$$

$$n\lambda = 2d\ sin\theta$$

$$\sigma_T = \sigma\left(1+\epsilon\right)$$

$$\tau_R = \sigma \cos\phi \cos\lambda$$

$$\sigma_y = \sigma_o + k_y d^{-1/2}$$

$$\epsilon_T = \ln\left(1+\epsilon\right)$$

$$\%\text{ ionic character} = \left(1 - e^{-\frac{(X_A - X_B)^2}{4}}\right) \text{x} (100\%)$$

$$\rho = \frac{n\,A}{V_C N_A}$$

$$K_c = Y\sigma\sqrt{\pi a}$$

$$U_r = \int_0^{\epsilon_y} \sigma\ d\epsilon$$

$$\sigma_c = \left[\frac{2E\gamma_s}{\pi a}\right]^{1/2}$$

$$\sigma_m = 2\sigma_o\left(\frac{a}{\rho_t}\right)^{1/2} = K_t\sigma_o$$

$$\frac{\Delta L}{L} = \alpha_L \Delta T$$

$$\frac{N_v}{N} = \exp\left[\frac{-Q_v}{kT}\right]$$

$$\sigma_T = K(e_T)^n$$

$$\%CW = \frac{A_o - A_d}{A_o}(100)$$

$$\frac{dA}{dN} = \left(\Delta\sigma\sqrt{a}\right)^m$$

Constants

k = 1.38×10^{-23} J/atom-K

k = 8.62×10^{-5} eV/atom-K

R = 8.31 J/mol-K

$N_A = 6.022 \times 10^{23}$

Radius Ratio	CN	Coordination
1.0	12	Cubic closest packed (CCP) Hexagonal closest packed (HCCP)
1.0–0.732	8	Cubic
0.732–0.414	6	Octahedral
0.414–0.225	4	Tetragonal
0.225–0.155	3	Triangular
<0.155	2	Linear

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	*	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	**	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Uut	Fl	Uup	Lv	Uus	Uuo

*	La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
**	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

Materials Science & Engineering
UNIVERSITY OF TORONTO

Professor S. Ramsay

Computer Answer Form

Last Name	First Name

Student Number
Write a number in each box and completely fill the bubble below, as shown in the example

0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1
2	2	2	2	2	2	2	2	2	2
3	3	3	3	3	3	3	3	3	3
4	4	4	4	4	4	4	4	4	4
5	5	5	5	5	5	5	5	5	5
6	6	6	6	6	6	6	6	6	6
7	7	7	7	7	7	7	7	7	7
8	8	8	8	8	8	8	8	8	8
9	9	9	9	9	9	9	9	9	9

Student number example

Student Number
Write one number in each box and complete

9 8 7 6 5

Fill in the bubbles completely:

Incorrect ***Correct***

1. A B C D E
2. A B C D E
3. A B C D E
4. A B C D E
5. A B C D E
6. A B C D E
7. A B C D E
8. A B C D E
9. A B C D E
10. A B C D E
11. A B C D E
12. A B C D E
13. A B C D E
14. A B C D E
15. A B C D E
16. A B C D E
17. A B C D E
18. A B C D E
19. A B C D E
20. A B C D E

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UNIVERSITY OF TORONTO

FACULTY OF APPLIED SCIENCE AND ENGINEERING

Final Exam, April 18, 2018

First Year

MSE101 – INTRODUCTION TO MATERIALS SCIENCE

Exam Type: A

Examiner – SD Ramsay

Permissible Calculators: Casio FX-991 or Sharp EL-520

Rulers are permitted | Duration: 150 minutes

$g = 9.81\ ^{m}/_{s2}$ $\quad N_A = 6.023 \times 10^{23}\ mol^{-1}$ $\quad e = 1.602 \times 10^{-19}\ C$ $\quad \varepsilon_0 = 8.854 \times 10^{-12}\ \frac{F}{m}$

$R = 8.314\ \frac{J}{mol \cdot K}$ $\quad k = 8.62 \times 10^{-5}\ \frac{eV}{atom - K}$ $\quad k = 1.38 \times 10^{-23}\ \frac{J}{atom - K}$ $\quad LD = ^{\#}/_{Length}$

$LPF = \frac{\text{length of atoms on vector}}{\text{length of vector}}$ $\quad PD = ^{\#}/_{Area}$ $\quad PPF = \frac{\text{area of atoms on plane}}{\text{area of plane}}$ $\quad V = \frac{4}{3}\pi r^3$ $\quad A = \pi r^2$

$A_\Delta = \frac{1}{2}bh$ $\quad \rho = \frac{n \cdot A}{V_C \cdot N_A}$ $\quad \rho = \frac{m}{V}$ $\quad \rho = \frac{n'\left(\sum A_C + \sum A_A\right)}{V_C N_A}$ $\quad \rho = \frac{n_A A_A + n_C A_C}{V_C N_A}$ $\quad APF = \frac{V_S}{V_C}$

$c^2 = a^2 + b^2$ $\quad N = \frac{N_A \rho}{A}$ $\quad N_v = N \exp\left(-\frac{Q_v}{kT}\right)$ $\quad E = 2G(1+\nu)$ $\quad \sigma = \frac{F}{A_o}$ $\quad \varepsilon = \frac{\Delta l}{l_o}$ $\quad \tau = \frac{F}{A_0}$

$\gamma = \tan\theta$ $\quad \varepsilon_T = ln\frac{l_i}{l_o} = ln(1+\varepsilon)$ $\quad \sigma_T = \frac{F}{A_i} = \sigma(1+\varepsilon)$ $\quad \sigma = E\varepsilon$ $\quad \tau = G\gamma$ $\quad \nu = -\frac{\varepsilon_x}{\varepsilon_z} = -\frac{\varepsilon_y}{\varepsilon_z}$

$U_r = 0.5\ \sigma_y\ \varepsilon_y$ $\quad \sigma_f = \frac{K_{IC}}{Y\sqrt{\pi a}}$ $\quad \%\ elongation = \left(\frac{l_f - l_o}{l_o}\right) x100$ $\quad u = \frac{1}{3}(2u' - v')$

$v = \frac{1}{3}(2v' - u')$ $\quad t = -(u+v)$ $\quad w = w'$ $\quad i = -(h+k)$ $\quad \theta = \cos^{-1}\left(\frac{u_1u_2 + v_1v_2 + w_1w_2}{\sqrt{\left(u_1^2 + v_1^2 + w_1^2\right)\left(u_2^2 + v_2^2 + w_2^2\right)}}\right)$

$n_w = \frac{\overline{M_w}}{\overline{m}}$ $\quad n_n = \frac{\overline{M_n}}{\overline{m}}$ $\quad n\lambda = 2d_{hkl}\sin\theta$ $\quad E_c(t) = \frac{\sigma_o}{\varepsilon(t)}$ $\quad \overline{M_w} = \sum w_i M_i$ $\quad \overline{M_n} = \Sigma x_i M_i$

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$$d_{hkl} = \frac{a}{\sqrt{h^2+k^2+l^2}} \qquad \tau_R = \sigma_{app} \cos\phi \cos\lambda \qquad \sigma_y = \frac{\tau_{CRSS}}{(\cos\phi\cos\lambda)_{\max}} \qquad \sigma_T = K\varepsilon_T{}^n \qquad a = 2\sqrt{2}R$$

$$a = \frac{4}{\sqrt{3}}R \qquad \begin{array}{l}\text{BCC}: h+k+l \text{ must be even} \\ \text{FCC}: h,k,l \text{ all odd or all even}\end{array} \qquad |b| = \frac{a}{2}\sqrt{h^2+k^2+l^2}$$

$$\%\,\text{crystallinity} = \frac{\rho_C(\rho_S-\rho_a)}{\rho_S(\rho_C-\rho_a)} \times 100 \qquad \sigma = \sigma_0 \exp(-nP) \qquad \%CW = \left(\frac{A_0-A_d}{A_0}\right) \times 100\%$$

$$E = E_0(1-1.9P+0.9P^2) \qquad \sigma_{\text{3-point bend}} = \frac{3F_f L}{2bd^2} \qquad \sigma_y = \sigma_0 + k_y d^{-1/2} \qquad C_1 = \frac{m_1}{m_1+m_2} \times 100\%$$

$$C_1 = \frac{C'_1 A_1}{C'_1 A_1 + C'_2 A_2} \times 100\% \qquad C'_1 = \frac{n_{m1}}{n_{m1}+n_{m2}} \times 100\% \qquad C'_1 = \frac{C_1 A_2}{C_1 A_2 + C_2 A_1} \times 100\%$$

$$C'_2 = \frac{C_2 A_1}{C_1 A_2 + C_2 A_1} \times 100\% \qquad \rho_{ave} = \frac{100}{\frac{C_1}{\rho_1}+\frac{C_2}{\rho_2}} \qquad \rho_{ave} = \frac{C'_1 A_1 + C'_2 A_2}{\frac{C'_1 A_1}{\rho_1}+\frac{C'_2 A_2}{\rho_2}} \qquad A_{ave} = \frac{100}{\frac{C_1}{A_1}+\frac{C_2}{A_2}}$$

$$A_{ave} = \frac{C'_1 A_1 + C'_2 A_2}{100} \qquad W_L = \frac{S}{R+S} \qquad W_\alpha = \frac{R}{R+S} \qquad x = \frac{-b \pm \sqrt{b^2-4ac}}{2a}$$

$$K_t = \frac{\sigma_m}{\sigma_0} = 2\left(\frac{a}{\rho_t}\right)^{\frac{1}{2}}$$

- Metal
- Nonmetal
- Intermediate

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

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)	Actinide 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)

Student No____________________________

First Name:______________________________

Last Name:______________________________

Please indicate your tutorial section:

- ☐ 0101 (Kris, Thur 2-3 pm, GB304)
- ☐ 0102 (Kevin, Thur 12 noon -1 pm, RS208)
- ☐ 0103 (Alexander, Tue 10 – 11 am, GB304)
- ☐ 0104 (Carmen, Tues 4 – 5 pm, BA2185)
- ☐ 0105 (Bojan, Tue 4 – 5 pm, HA401)
- ☐ 0106 (Calvin, Fri 12 noon – 1 pm, WB342)

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

Final Exam, April 18, 2018

First Year

MSE101 – INTRODUCTION TO MATERIALS SCIENCE

Exam Type: A

Examiner – SD Ramsay

Permissible Calculators: Casio FX-991 or Sharp EL-520

Rulers are permitted

Duration: 150 minutes

All questions are NOT of equal value.
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>Marks
Part A:
(/15)</td></tr>
<tr><td>Part B:
1. (/10)</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. (/10)</td></tr>
<tr><td>7. (/10)</td></tr>
<tr><td>8. (/10)

TOTAL:
(/95)</td></tr>
</table>

Part A. Enter the correct answer for the following questions on the computer answer form. (Each question is worth 1 mark.)

1. Which of the following material classes generally has the lowest toughness?

    a) Metals
    b) Ceramics
    c) Polymers
    d) Impossible to determine

2. For loading beyond yielding, the true stress is always lower than the engineering stress.

    a) True
    b) False

3. Which of the following will not result in an increase in the strength of a typical metal?

    a) Careful processing to increase the number of grain boundaries
    b) Adding dissolved impurities
    c) Plastic deformation
    d) Carefully heating a metal that has previously been slowly cooled from the liquid state

4. Which of the following will not generally result in an increase in the strength of a typical polymer?

    a) Producing a fully amorphous polymer
    b) Increasing the molecular weight
    c) Adding polar bonds to the mer unit
    d) Adding secondary cross-links between chains

5. You are comparing aluminum automobile wheels from two different manufacturers. Both wheels are made from the same alloy (same composition), however one wheel is forged, while the other is cast. Both manufacturers provide the same safe service load for their wheels. Which wheel will have a lower mass?

    a) Impossible to determine
    b) They will both have the same mass
    c) The cast wheel
    d) The forged wheel

6. Which of the following polymers would you expect to have the highest resistance to chemical dissolution?

   a) Branched polyethylene
   b) Linear polyethylene

7. Which of the following metals would you expect to have the highest ductility?

   a) Cold rolled 0.25 wt% C steel
   b) Cold rolled 0.5 wt% C steel
   c) Annealled 0.25 wt% C steel
   d) Impossible to predict

8. Two batches of concrete A, and B are produced. Batch B has extra water added to make the concrete easier to pour/place. Assuming identical molds are carefully filled with both batches and allowed to harden for 28 days. Which concrete would you expect to be stronger?

   a) Batch A
   b) Batch B

9. Is it possible for hydrogen bonding to occur between molecules of PVC?

   a) Yes
   b) No

10. Which planes in BCC has the same planar packing fraction as the slip planes in FCC?

    a) {001}
    b) {011}
    c) {111}
    d) None of the above

11. The magnetic quantum number m_l may have only the values:

    a) $0, 1, 2, 3 \ldots m_l$
    b) $-l \leq m_l \leq l$
    c) $0, 1, 2, 3 \ldots (m_l - 1)$
    d) None of the above

12. The geometrically ideal size (R_C/R_A) of the tetrahedral interstitial site is one of the following options. Which is it?

    a) 0.732
    b) 0.414
    c) 0.225
    d) 0.155

13. 3D printers are commonly extrude a filament of a thermoplastic polymer to produce a three-dimensional part. So-called stereolithography printers use ultraviolet light to cure thermosetting polymers into the desired final shape. Which type of 3D printer will be able to print a stronger final part?

    a) Extruder type
    b) Stereolithography

14. You are designing a metallic bracket to secure an engine component in a high-speed ferry (ship). The bracket is to be produced from an aluminum alloy that has been cast and then plastically deformed to its final shape. The bracket is to be welded (melted together) to another aluminum plate. Which of the following would you expect to happen to the strength of the aluminum bracket following the welding operation?

    a) Decrease and then increase
    b) Unable to determine
    c) Increase
    d) Decrease

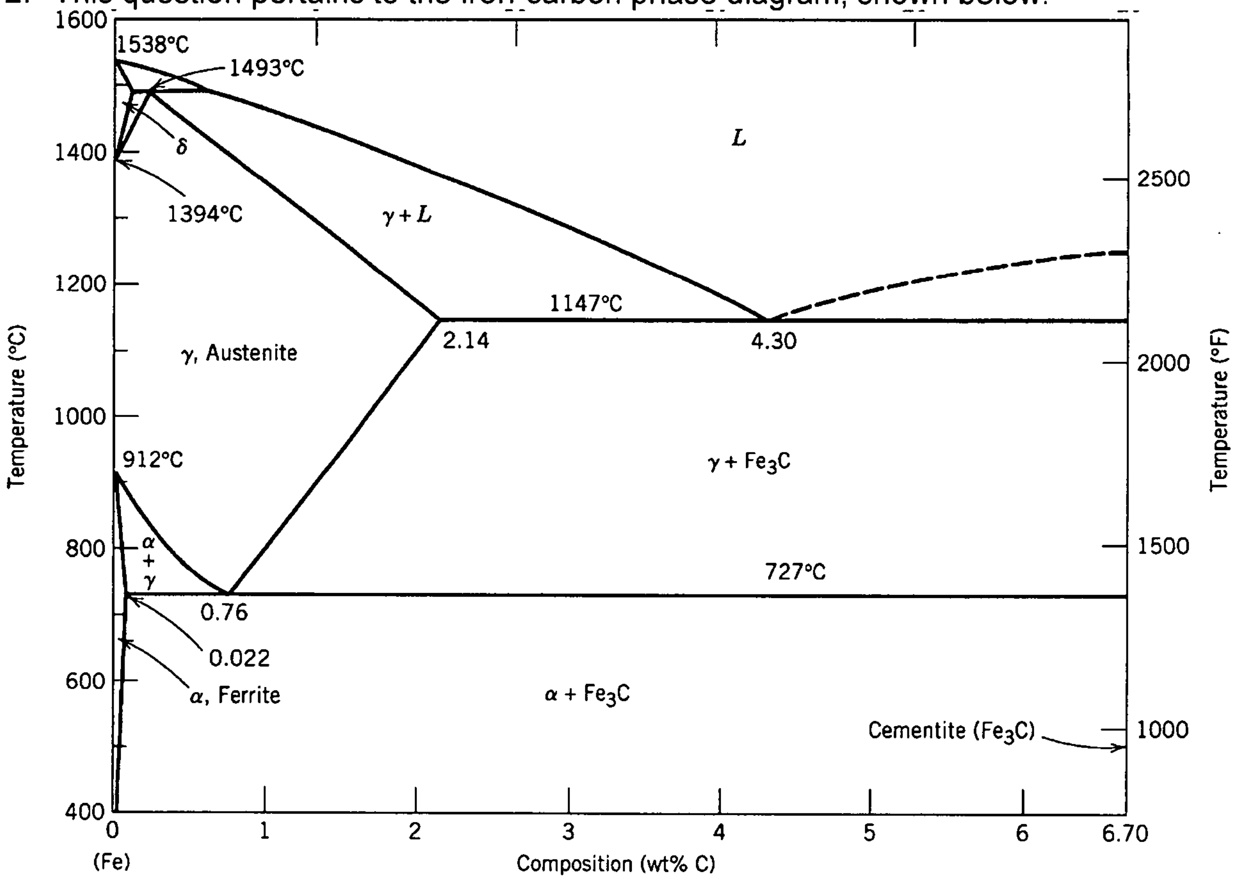
15. A central theme of this course is that structure affects properties. Which of the following is the best description of that statement in the context of this course?

    a) Neither b) nor c)
    b) That the macroscopic structure of a design influences the properties of that structure
    c) That the features of the microstructure of a material influence mechanical properties as well as other properties

Part B

1. You are designing a metallic bracket to be used as part of an assembly to secure a bulkhead in an aircraft. The bracket is to be produced from a precipitation hardening aluminum alloy. In an ordered point form list, describe the sequence of steps that you would use in order to efficiently achieve the highest strengthening possible.

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



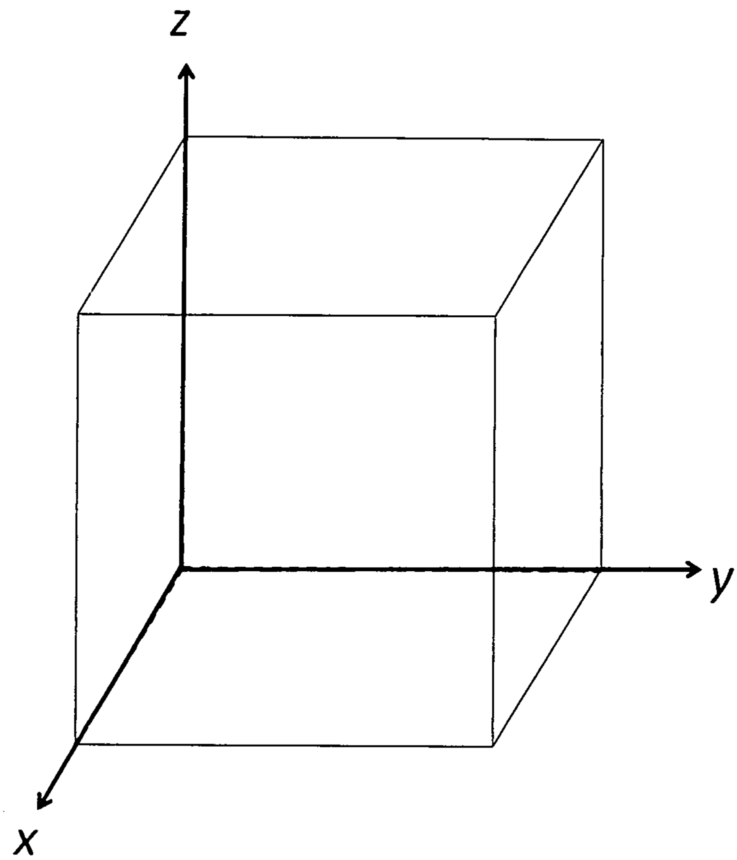
a. For a sample of 2.1 wt% C steel at 726°C, what will the proeutectoid phase be? What will be the composition of the proeutectoid phase? (2)

b. For a 1 kg sample of 2.1 wt% C steel at 726°C, what will the mass of the proeutectoid phase be, in grams? (2)

c. For a 1 kg sample of **1.8 wt% C** steel at 726°C, what will be the mass of cementite in pearlite (pearlitic or eutectoid cementite) in grams? (4)

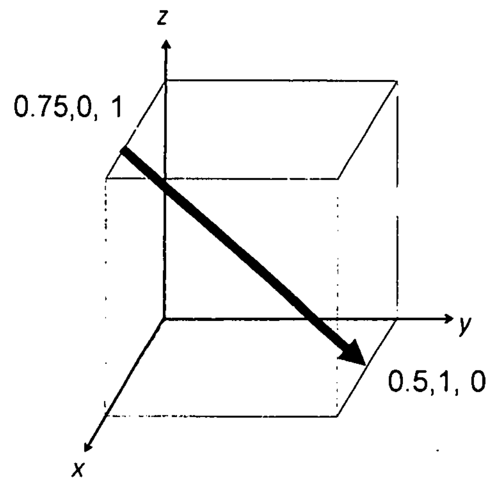
d. For a 1 kg sample of 0.75 wt% C steel at 726°C, what will the mass of the proeutectoid phase be, in grams? (2)

3. A stress of 45 MPa is applied along the [011] direction of a single crystal of an aluminum (FCC) single crystal.
   a. In the unit cell below, sketch the applied stress direction. (2)
   b. In the unit cell below, sketch the (111) plane. (2)
   c. In the unit cell below, sketch and correctly label each of the unique slip systems on the (111) plane. (3)

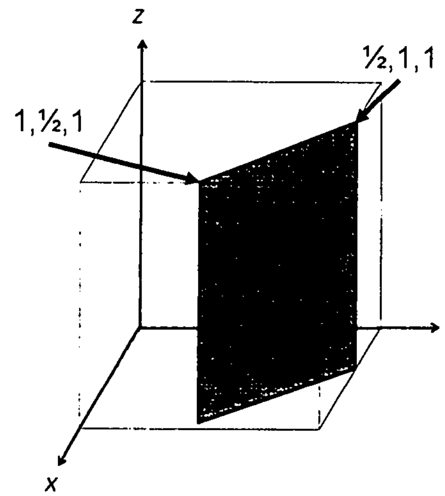


   d. What is the highest value of the resolved shear stress for the slip systems that you identified in part c. above? (3)

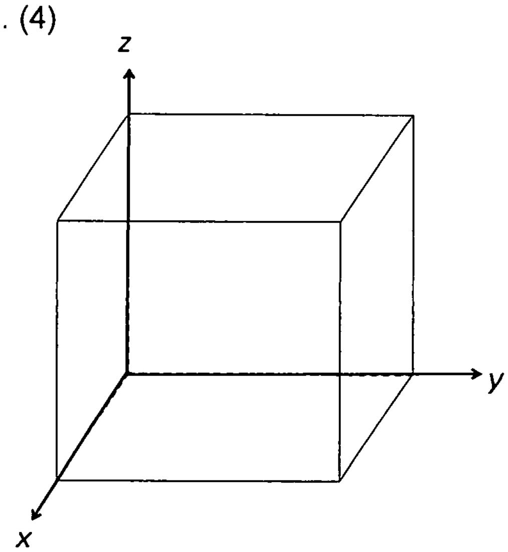
4. Please complete the following questions pertaining to crystallographic directions and planes.
   a. Correctly label the direction shown in the sketch below. Draw and label any atoms or ions within the rock salt ceramic crystal structure that reside on this direction. (3)



   b. Correctly identify the family of planes to which the plane drawn below belongs. (3)



   c. Within the unit cell below, please carefully draw both the [321] direction and the (331) plane. (4)



5. A hypothetical FCC metal is examined via XRD. Derive an expression for the theoretical density of the metal as a function of the atomic weight (molar mass) A, the diffraction angle θ, the x-ray wavelength λ, Avagadro's number N_A, and the Miller indices h, k, and l, for first order reflection. (10)

6. This question pertains to crystalline imperfections.
   a. Provide two specific examples of a point defect. (2)

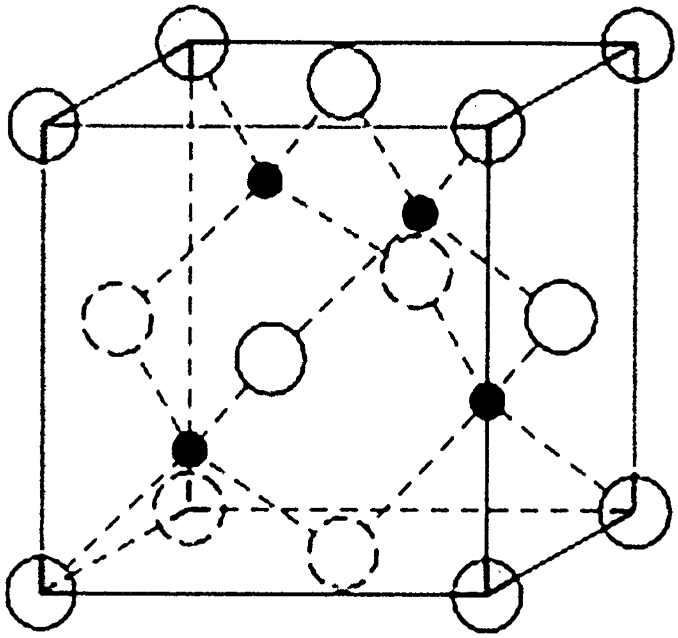
   b. Provide two specific examples of 2-dimensional imperfections. (2)

   c. Provide one specific example of a 3-dimensional imperfection. (1)

   d. Complete the following table by writing either parallel, perpendicular, or neither in each box. (5)

	Relationship between burgers vector and dislocation line	Relationship between burgers vector and motion of dislocation line
Edge dislocation		
Screw dislocation		
Mixed dislocation		

7. This question relates to the ceramic crystal structure below.



a. What is the common name for this ceramic crystal structure? (2)

b. What is the stoichiometric ratio of anions to cations in this crystal structure? (1)

c. What are the coordination number and name of the interstitial site occupied by cations in this ceramic crystal structure? (2)

d. Derive an expression for the lattice parameter for this structure in terms of the anion and cation radii. (5)

8. A tensile load of 32 500 N is applied to a AA2024 T3 aluminum rod that is initially 0.725 cm in diameter and 184 cm in length. How long will the rod be while the load is applied? The yield strength and elastic modulus of AA2024 T3 are 345 MPa, and 72.4 GPa, respectively. The strain hardening coefficient, K for this alloy is 780 MPa, and the strain hardening exponent n, is 0.17.