UNIVERSITY OF CALIFORNIA
College of Engineering
Department of Materials Science and Engineering

Professor R. Gronsky

Fall Semester 2000

ENGINEERING 45

MIDTERM 02

NAME:____
(Please Print Clearly)

INSTRUCTIONS

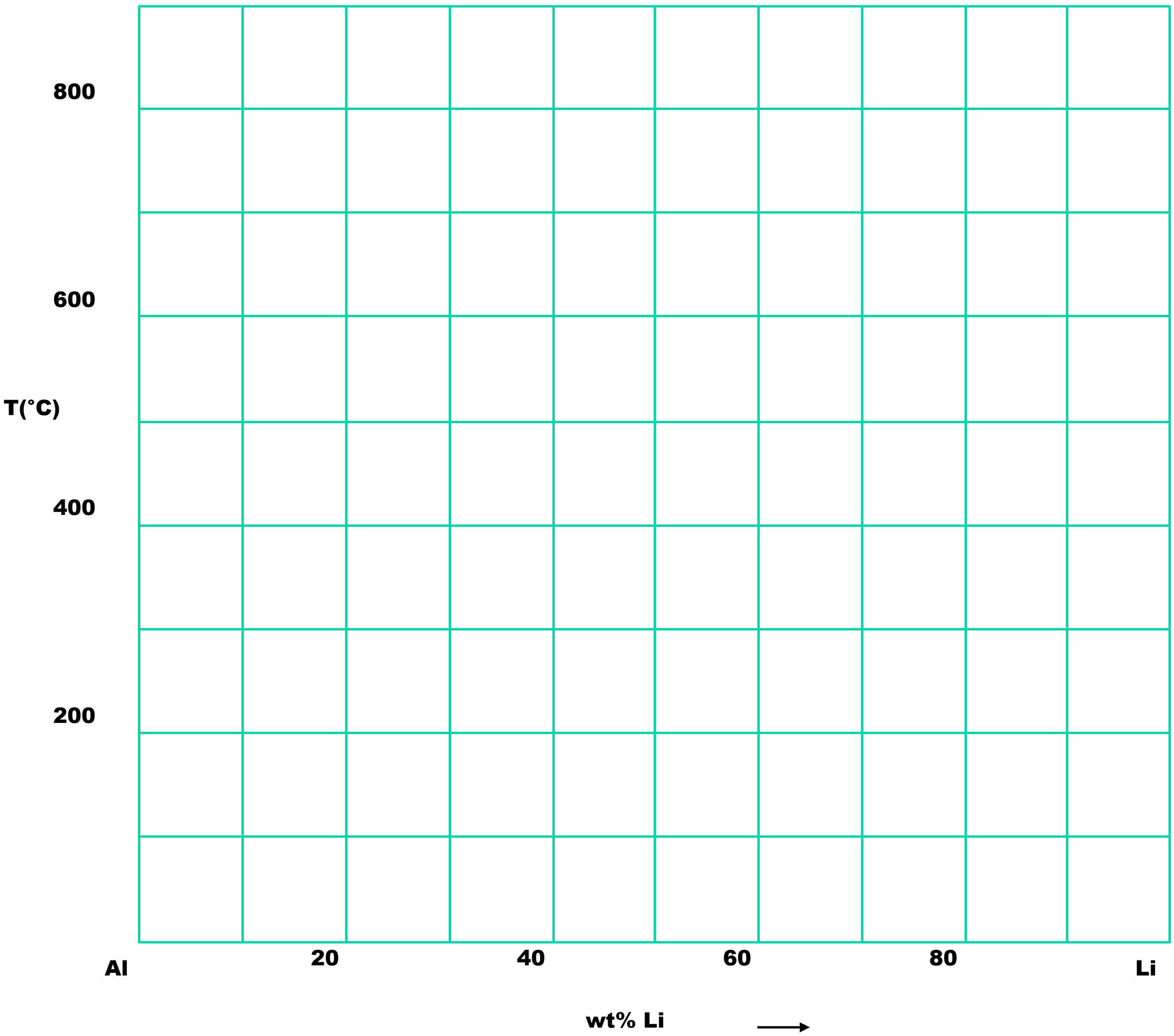
This is a *closed book* Exam. You must work independently, and no reference materials are permitted.

Please use only the pages given here, and write your answers in the spaces provided.

Question 1 (**30** points)

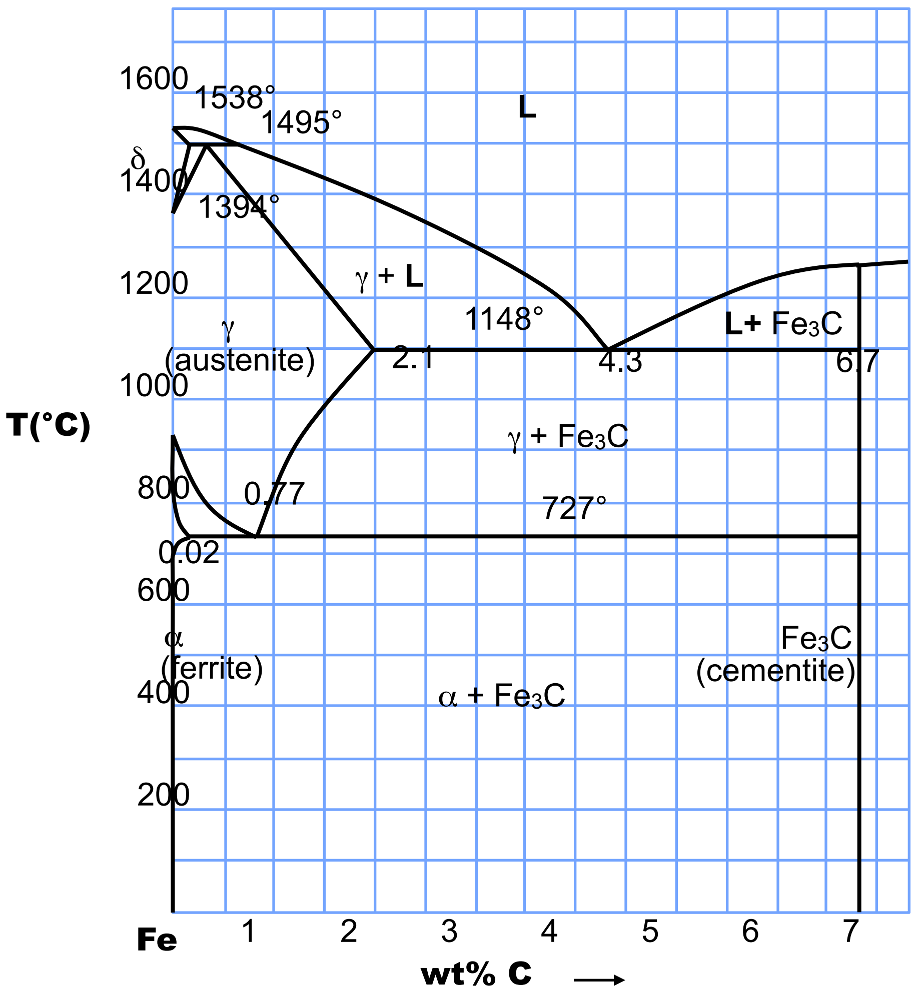
Use the grid below to *draw* the Al-Li phase diagram based upon the following experimental observations (all compositions in weight %). *Label* all phase fields.

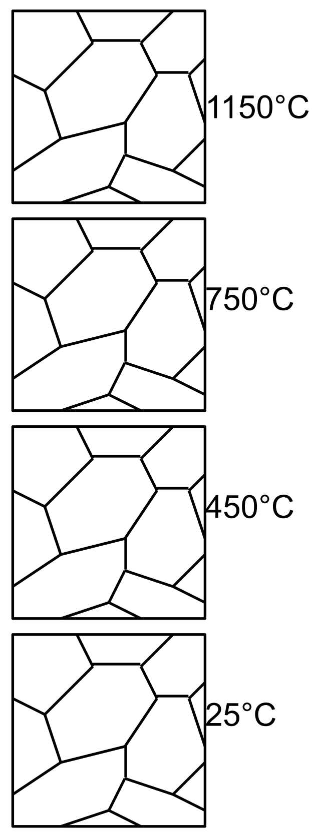
Pure Al melts at 660°C; pure Li melts at 181°C. At 600°C, liquid of 10 %Li solidifies to form α phase of 4 %Li and δ phase of 20 %Li. Pure δ phase containing 20 %Li melts congruently at 718°C. At 521°C, γ phase containing 34 %Li melts to form δ phase of 24 %Li and liquid phase of 47 %Li. At 620°C, a 30 % Li alloy has equal parts of liquid phase and δ phase, while at 260°C, a 60 %Li alloy has equal parts of liquid phase and γ phase. At 179°C, liquid containing 98 %Li solidifies to form γ phase (34 %Li) and β phase (99 %Li). At 0°C, Al can dissolve up to 3 % Li, while Li can dissolve no more than 0.5 % Al; however. Also at 0°C, the solubility of Li in the δ phase ranges from 20 to 22 %Li.



Question 2 (**20** points)

Illustrate the microstructural evolution resulting from cooling a hypereutectoid AISI 1095 steel through the eutectoid decomposition isotherm. Use the templates at right, which show the prior austenite grains, and accurately draw the equilibrium microstructures at each of the temperatures identified on the right. Label each phase, and label all relevant microstructural constituents by their common metallurgical names.



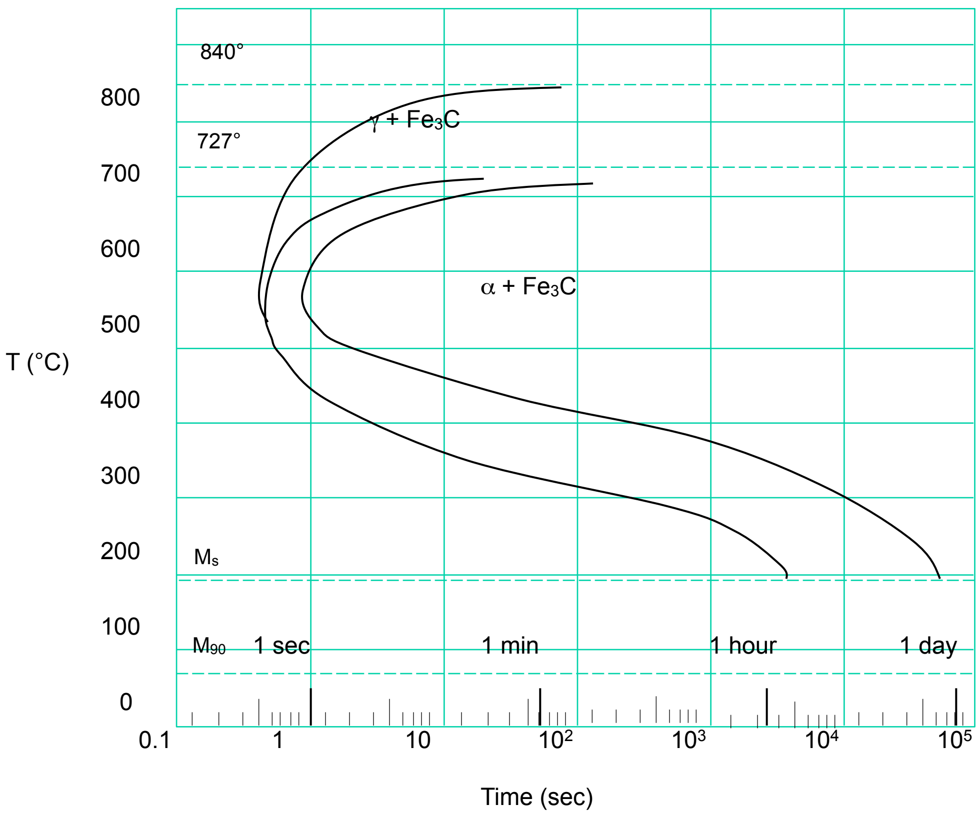


Question 3 (**30** points)

Sketch and label the isothermal cooling curves for the same AISI 1095 steel that produce the following microstructures: Note that there are *three* TTT curves here. Label the first with **a**) and **b**), the second with **c**) and **d**), and the third with **e**) and **f**).

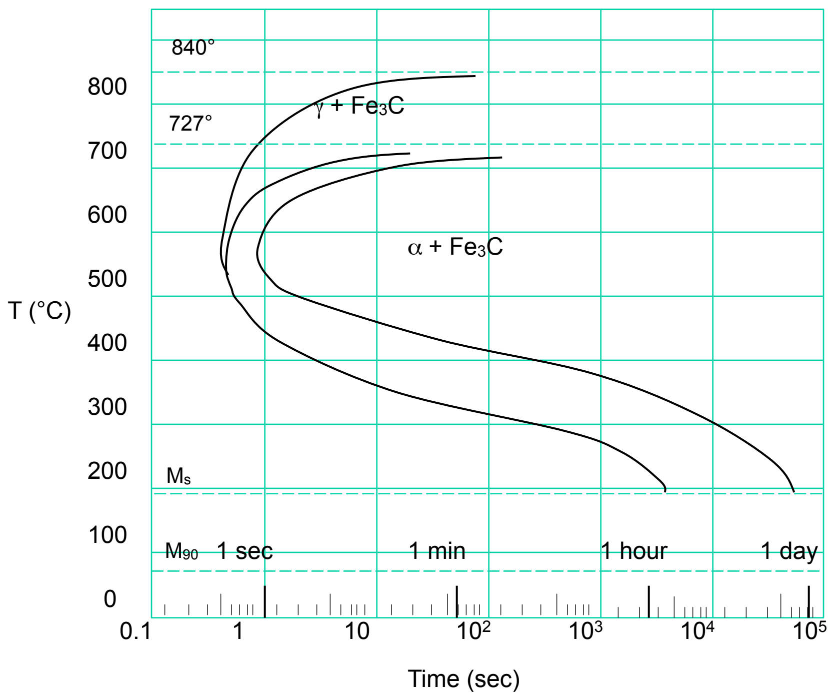
a) 100% martensite

b) 5% proeuctectoid cementite and 95% martensite



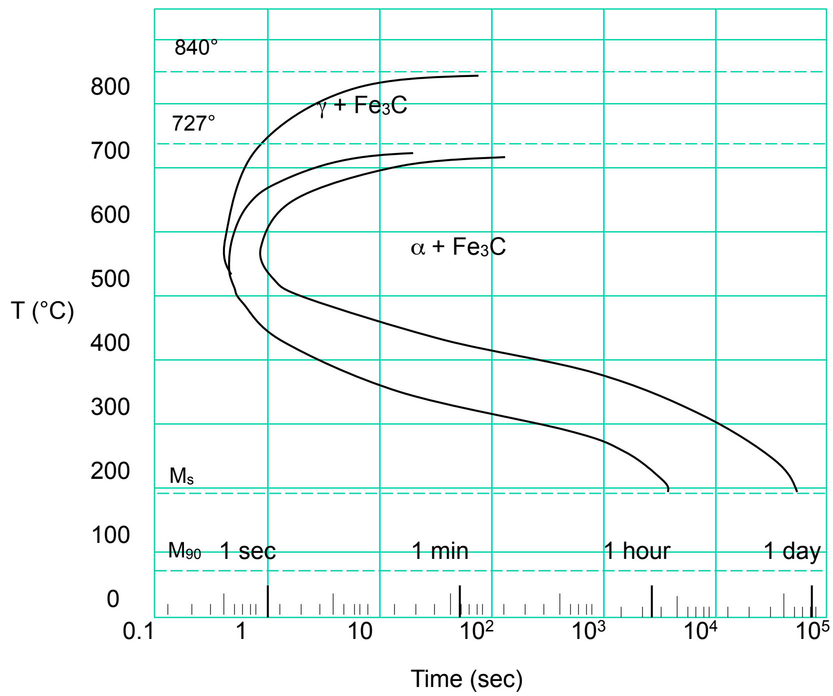
c) 25% coarse pearlite, 75% martensite

d) 100% fine pearlite



e) 25% upper bainite and 75% tempered martensite

f) 25% fine pearlite, 25% lower bainite, 50% martensite



Question 4 (**20** points)

Mark the checkbox next to the *best* answer (only one) in each case.

a) Martensite is a metastable phase produced in ferrous alloys by
holding at a specific temperature for a specific time
heating to a specific temperature over a specific time
cooling to a specific temperature over a specific time

b) Martensite can be tempered by
heating to a specific temperature over a specific time
cooling to a specific temperature over a specific time
holding at a specific temperature for a specific time

c) The microstructure of tempered martensite consists of
pearlite and bainite
only bainite
neither pearlite nor bainite

d) Martensite is strong because
it is not an equilibrium phase
it presents many obstacles to dislocation motion
it is a highly distorted arrangement of Fe and C atoms

e) Ferrous alloys can be precipitation-hardened by
holding in the austenite+ferrite two-phase field
aging to produce alloy carbides
quenching to produce martensite

f) Nonferrous metallic alloys can be precipitation-hardened by
solutionizing, quenching and aging
solutionizing slow-cooling and quenching
quenching, aging and quenching

g) Ni-base superalloys are known for their superior
strength at elevated temperatures
toughness at room temperature
wear-resistant surface finish

h) Al-base alloys are protected from oxidation by
a passivating oxide film
a high density of second phase particles
an ASTM standard requiring painted surfaces

i) During annealing, the driving force for the recovery stage is
reduction in strain energy
reduction in surface energy
reduction in chemical potential

j) During annealing, the driving force for the recrystallization stage is
reduction in strain energy
reduction in surface energy
reduction in chemical potential

k) During annealing, the driving force for the grain growth stage is
reduction in strain energy
reduction in surface energy
reduction in chemical potential

l) Ceramics are often formed into complex parts by sintering at
one-forth of the melting temperature
one-third of the melting temperature
two-thirds of the melting temperature

m) Glass-ceramics are subjected to an aging treatment in order to
provide stress-relief
remove surface cracks
precipitate a crystalline phase

n) The most significant attribute associated with a Griffith crack is
its location at the surface
its length
its tip radius

o) Addition polymerization is a reaction among small organic molecules involving
isotropic growth
chain growth
step growth

p) Condensation polymerization involves
a rapid "chain reaction"
individual chemical reactions between pairs of reactive monomers
electron transport in the condensate

q) The primary role of the initiator in a polymerization reaction is to
begin the assembly of mers into chains
convert double bonds into single bonds
nucleate the condensation reaction

r) Linear polymers are the result of bonding between
bifunctional mers
polyfunctional mers
linear mers

s) A block co-polymer can also be described as
a solid solution
a two phase alloy
a cubic crystal structure

t) A polymer is described as "viscoelastic" when it shows
slow recovery of strain
viscous fracture
negative modulus of elasticity

Do not write below this line--

Problem #	Possible	Score	Initials
1	**30**		
2	**20**		
3	**30**		
4	**20**		
Total	**100**		

UNIVERSITY OF CALIFORNIA
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Professor R. Gronsky

Fall Semester 2001

ENGINEERING 45

Midterm 02

NAME:____
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INSTRUCTIONS

This is a *closed book* Exam. You must work independently, and no reference materials are permitted.

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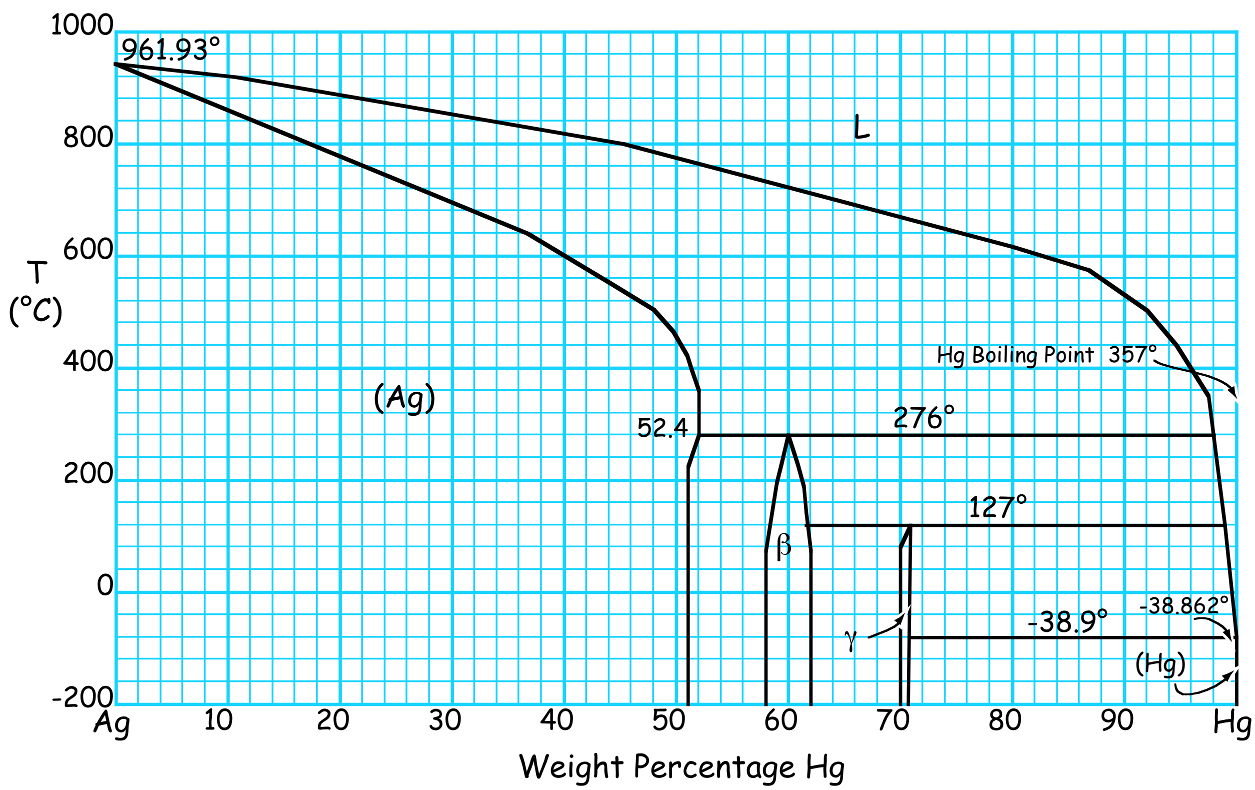
Question 1 The silver-mercury system forms the basis of an important **biomaterial** known as dental *amalgam*, which has been used for decades in restorative dental fillings. The term "amalgam" is frequently used to depict many different alloys of mercury, originating from the "amalgamation" process to refine ores of the precious metals, primarily silver and gold. The finely crushed ores in aqueous solution are mixed with mercury, allowing the mercury to alloy with the precious metals, forming an amalgam. When the amalgam is heated, the mercury is driven off as a vapor (collected and recycled of course), leaving behind pure precious metal "sponge."

Silver (*Ag*, Z = 47) is fcc and melts at 961.93°C, mercury (*Hg*, Z = 80) freezes at –38.862°C. The equilibrium β phase has AgHg stoichiometry and an hcp Bravais lattice. The equilibrium γ phase has Ag_2Hg_3 stoichiometry and a bcc Bravais Lattice.

Use this information and the equilibrium phase diagram for the silver-mercury binary system due to M. Hanson (*Constitution of Binary Alloys*, 2nd. Edition, McGraw –Hill, 1958) shown below to choose the *best* answers for 2 points each.



a. The number of components in this binary system is
one (1)
two (2)
three (3)

b. The phase called (*Ag*) is actually
pure silver
a silver-mercury solid solution
a metastable phase

c. Based upon the Gibbs Phase Rule ($P+F = C+2$), the number of degrees of freedom available to pure Hg at 357°C in this system is
zero (0)
one (1)
two (2)

d. The number of degrees of freedom available to a 40 wt.% Ag alloy at 276°C is
zero (0)
one (1)
two (2)

e. The maximum solubility of mercury in silver is
infinitesimally small
undefined because mercury is a liquid at room temperature
established by the highest temperature reaction isotherm

f. Both β phase and γ phase are in equilibrium with liquid Hg at a
monotectic
eutectic
peritectic

g. When β phase of 60 wt% Hg melts, it
disappears completely
passes through a β + L two-phase equilibrium
generates mercury vapor

h. A dental hygienist "mixes" amalgam immediately before the dentist applies it so that it will "harden" as a complete filling. The hardening process is due to
solid state diffusion
solidification of liquid Hg
dislocations created during mixing

i. An amalgam of 20 wt % Hg in equilibrium will decompose when heated above
276°C
576 °C
776°C

j. Dental fillings made of silver amalgam are at risk of leaking mercury into the mouth if the equilibrium mercury concentration exceeds
52.4%
62.4%
72.4%

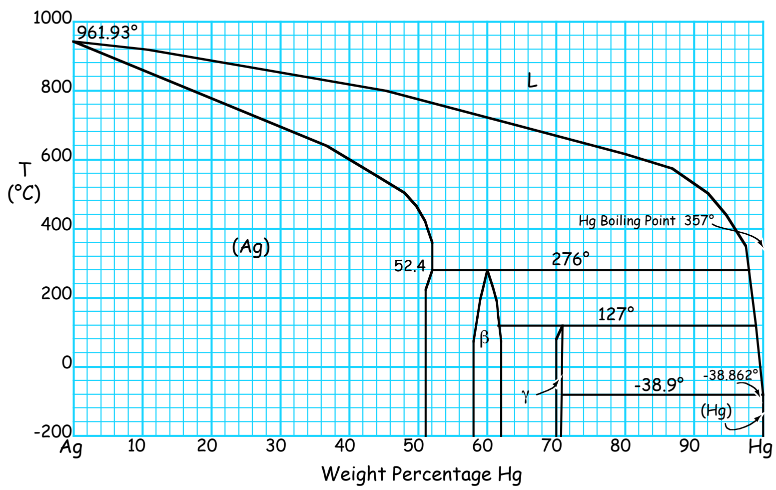
Question 2 Use the same phase diagram to now sketch the microstructures expected during equilibrium solidification of the following alloys. The *lever rule* construction is important here. Draw a vertical line on the phase diagram for the specified composition and show all tie lines used to establish your equilibrium microstructures. Remember that the high temperature microstructure influences the lower temperature microstructure. Clearly label all phases for full credit.

Each sketch is worth 5 points.

a. Ag-55 wt% Hg

T = 500°C

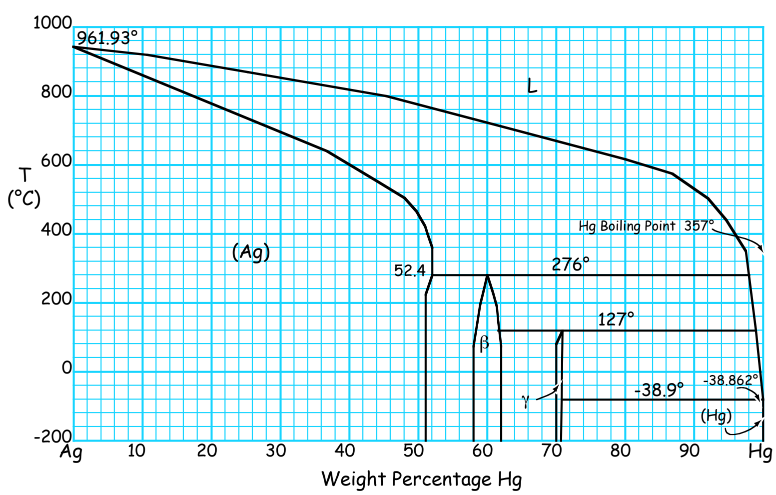
T = 25°C



b. Hg-20 wt% Ag

T = 200°C

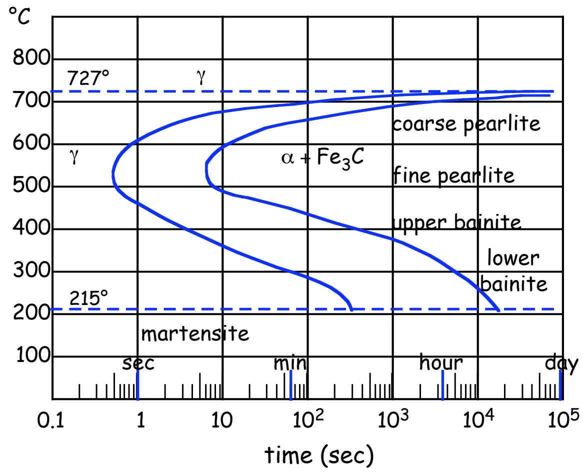
T = 25°C



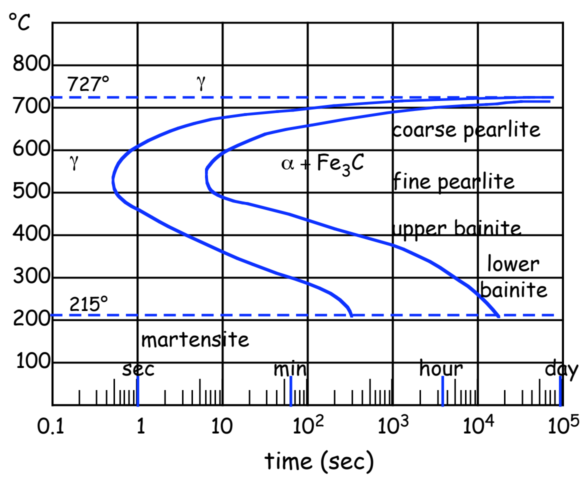
Question 3 The same TTT curve for a plain carbon steel of eutectoid composition is reproduced multiple times below. Draw directly on these plots the cooling curves corresponding to the specified treatments. Remember that TTT curves are appropriate for *isothermal transformations* only. The actual start and termination of the decomposition of austenite during continuous cooling occurs at slightly lower temperatures and longer times than shown here.

Each curve is worth 5 points.

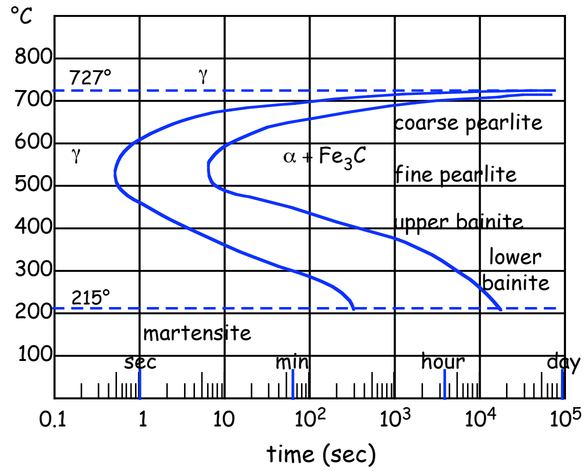
a. Austempering, a commercial treatment used to avoid quench cracking. Show and label the curves corresponding to both the surface and the interior of a thick cross section steel beam.



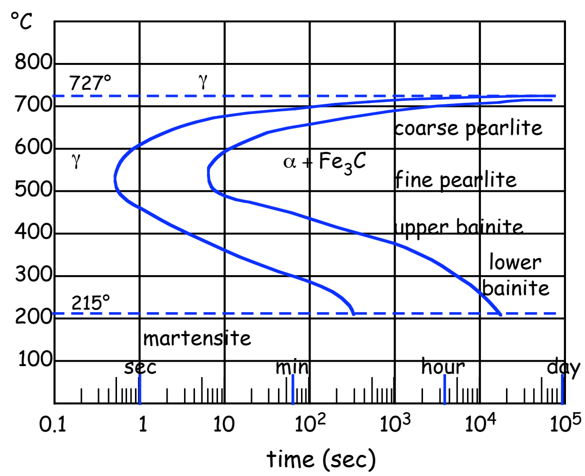
b. Martempering, a commercial treatment used to avoid quench cracking. Show and label the curves corresponding to both the surface and the interior of a thick cross section steel beam.



c. An "interrupted quench" technique that would generate a final microstructure of 50% lower bainite and 50% fine pearlite. In this case the workpiece is a small diameter rod to be used as an axle in a motor-generator set.



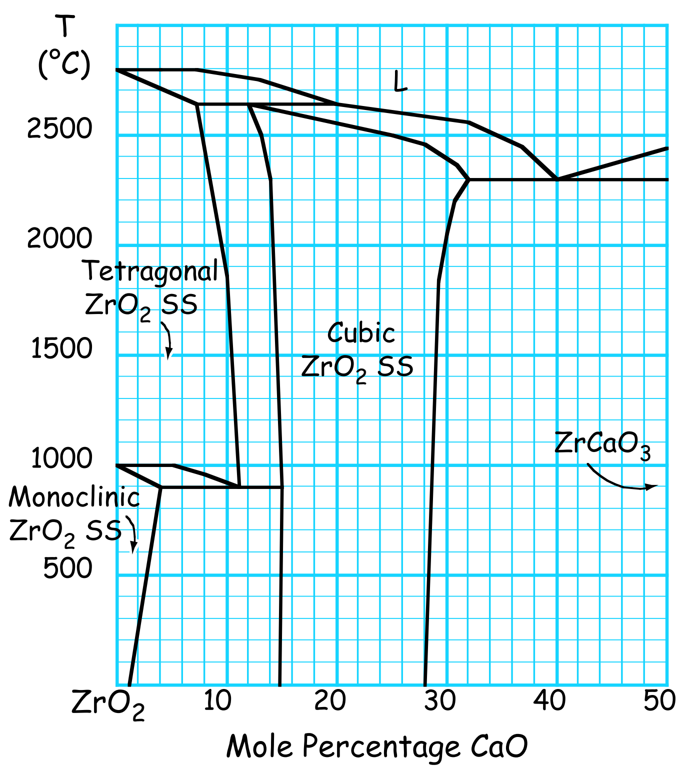
d. An approximation. Show without compensation for continuous cooling the T-t trajectory for a sample that was left in the furnace during a power outage. The initial temperature was 800°C at midnight when the power failed. The cooling rate for the well-insulated furnace was previously calibrated at 100°C / minute. The sample was recovered 8 hours later at the start of the daylight shift.



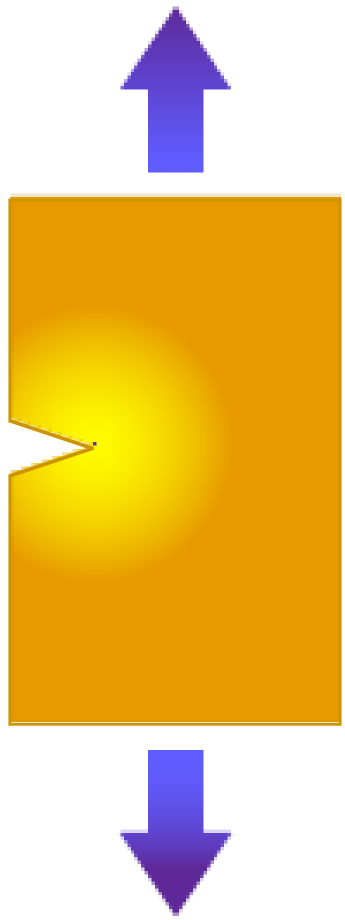
Question 4 Pure zirconia undergoes an allotropic transformation at 1000°C from a high temperature tetragonal structure to a low temperature monoclinic structure. A massive volume expansion upon cooling through the tetragonal-to-monoclinic transformation literally results in the self destruction of the crystal. Thermal cycling through the transformation temperature pulverizes the material into a fine powder.

However, alloying zirconia with 25 mol % calcia yields a cubic phase that persists up to its melting point with no structural instabilities. This "stabilized" zirconia is a very popular structural ceramic for that reason.

a. Using this information, explain how "partially-stabilized" zirconia, which contains some cubic, some tetragonal, and some monoclinic phases, is prepared. Be specific, using the equilibrium phase diagram above and your understanding of phase transformation kinetics for 10 points.



b. For another 10 points, explain in detail how the partially-stabilized zirconia structure leads to "transformation toughening" of an otherwise brittle ceramic material. Comment specifically on the volume expansion associated with the tetragonal to monoclinic transformation, and its role in causing an increase in fracture toughness. Recall that fracture toughness refers to the performance of a material with pre-existing flaws, and focus your attention on the crack shown in the following sketch.

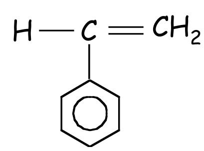


Question 5 Polymers or "many mers" may result from chain growth, also known as addition polymerization, which generates linear or branched polymers, or from step growth, also known as condensation polymerization, which generates network polymers. The mechanical properties of polymers are, like all materials, linked to their structure.

(**a**) The styrene mer is shown schematically below. Show how polystyrene results from a polymerization reaction by sketching the final product containing at least five mers. Is polystyrene a (check all that apply)

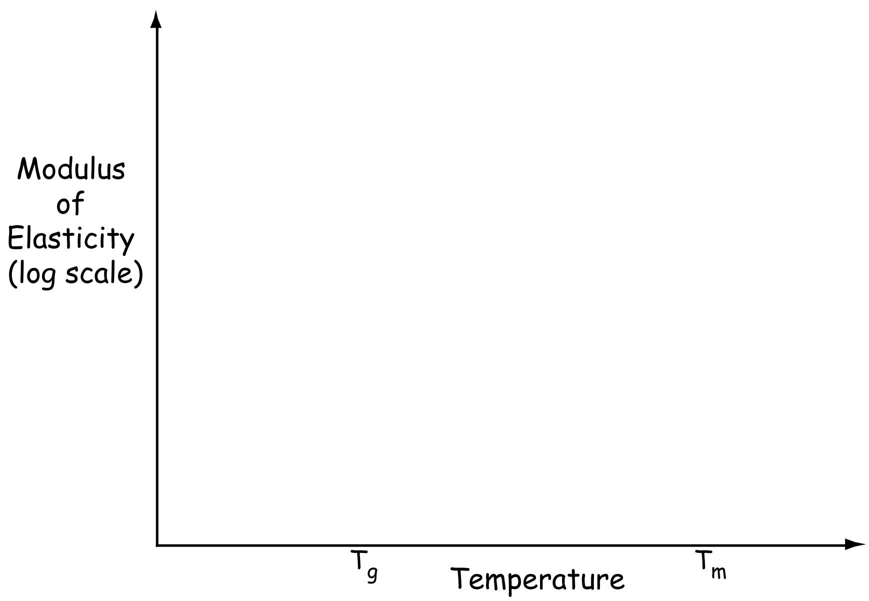
linear,
branched, or
network polymer?

Showing the correct polymeric structure and checking the correct box(es) above earns 10 points.



(**b**) Polymers, like metals and ceramics, can be described by a lattice and motif, but they are never fully crystalline. In fact, numerous polymers are completely amorphous. Those that possess some crystallinity have their polymeric chains arranged in a regular, parallel alignment, and these crystallites or "fringed micelles" are embedded in an amorphous matrix.

A partially crystallized thermoplastic polymer shows "viscoelastic" mechanical behavior. Using the coordinate axes below, plot the elastic modulus as a function of temperature for a viscoelastic polymer. Note particularly the changes seen at the glass transition temperature and the melting temperature. On your plot, label the four distinct regions of behavior associated with viscoelasticity, that is, rubbery, viscous, leathery, and rigid (or elastic). A correctly labeled plot is worth 10 points.



NAME:________________________________

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Problem #	Possible	Score	Initials
1	20		
2	20		
3	20		
4	20		
5	20		
Total	100		

UNIVERSITY OF CALIFORNIA
College of Engineering
Department of Materials Science & Engineering

Professor R. Gronsky Fall Semester, 2005

Engineering 45 Midterm 02

Name: (Please print)

INSTRUCTIONS

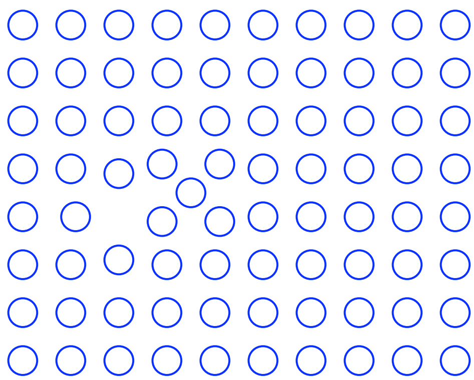
LATTICE seating.................Please be seated with *occupied* seats to your front and back, *vacant* seats to your left and right.
CLOSED BOOK format...... All you need are writing instruments and a straightedge. Please store all books, reference materials, calculators, PDAs, cell phones (OFF), and iPods.
NO DISRUPTION rule.........Questions cause too much of a disturbance to others in the room. Instead of asking questions, write any concerns or alternative interpretations in your answers.
PROFESSIONAL protocol...Engineers do not cheat on the job and they certainly don't cheat on exams.

Do not open until "START" is announced.

1. Defects in Solids (10 points)
Mark ☒ the ballot box corresponding to the best answer. Two (**+2**) points for correct answers, **-1** if wrong, **0** if blank.

(**a**) Point defects in solids include
☐ vacancies
☐ dislocations
☐ both

(**b**) The defect known as a "Frenkel pair" is shown in this sketch to have



☐ body-centered symmetry
☐ an extended strain field
☐ both

(**c**) Vacancies in solids
☐ participate in diffusion
☐ increase the entropy of a material
☐ both

(**d**) Dislocations in solids
☐ participate in plastic deformation
☐ decrease the entropy of a material
☐ both

(**e**) Fick's First Law for diffusion flux

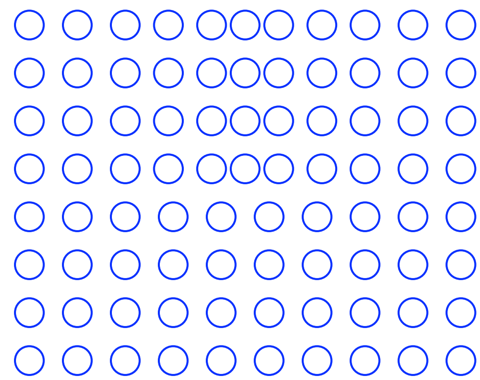
$$J_x = -D\,\frac{\partial c}{\partial x}$$

expresses the fact that
☐ diffusion requires a negative diffusivity
☐ mass flows down a concentration gradient
☐ both

2. Defects in Solids (10 points)
For this problem you must draw and label all requested features directly on the figures provided.

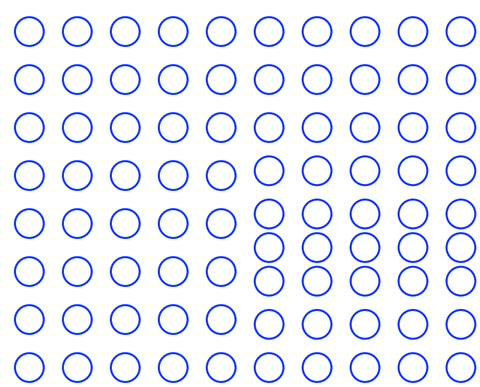
(**a**) (**2 points**) Fill in the atoms comprising the extra-half plane and label with the conventional symbol (⊥) the edge of the extra half-plane that establishes the line direction vector of the edge dislocation shown below.

(**b**) (**3 points**) On the same figure below, trace and label a Burgers circuit in finish-start-right-hand (FSRH) convention, and identify the resulting Burgers vector (***b***).

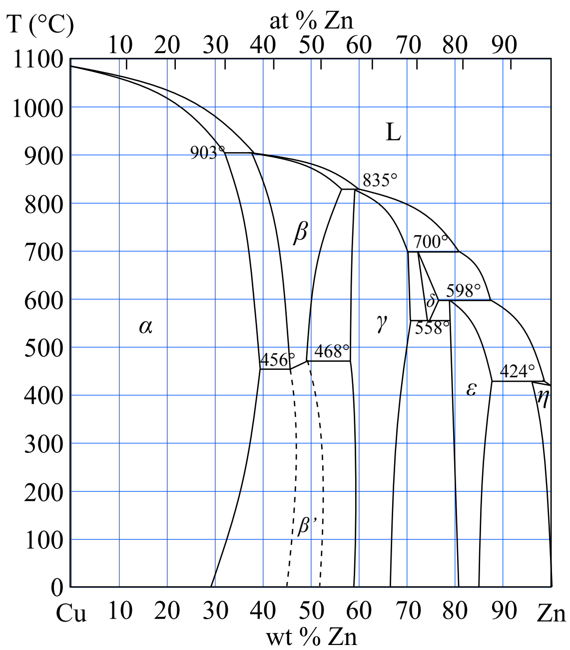


(**c**) (**2 points**) Fill in the atoms comprising the extra-half plane and label with the conventional symbol (⊥) the edge of the extra half-plane that establishes the line direction vector of the edge dislocation shown below.

(**d**) (**3 points**) On the same figure, draw in and label the location of the slip plane on which this edge dislocation glides.



3. Phases and Phase Equilibria (10 points)
Refer to the Cu-Zn binary phase diagram below (from *ASM Metals Handbook*, 8th edition, Vol. 8, (1973), p. 301) to answer the following questions. Recall that "brass" is the common name applied to this alloy.



(a) (**2 points**) What is the maximum concentration of Zn that can be dissolved in α brass?

(b) (**2 points**) Apply the phase rule (F = C-P+1) to calculate the number of degrees of freedom available to a 40 wt% Zn alloy at room temperature.

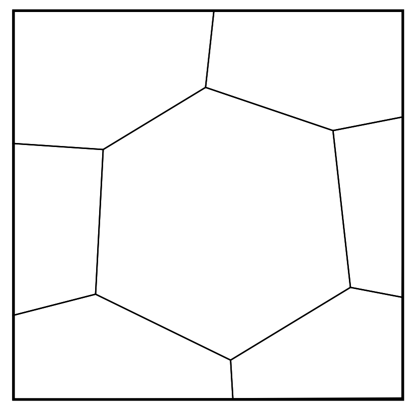
(c) (**2 points**) What phase(s) is (are) in equilibrium when β brass (50:50 composition) is held at 500°C.

(d) (**2 points**) Write the reaction that occurs on cooling through the 700°C peritectic isotherm.

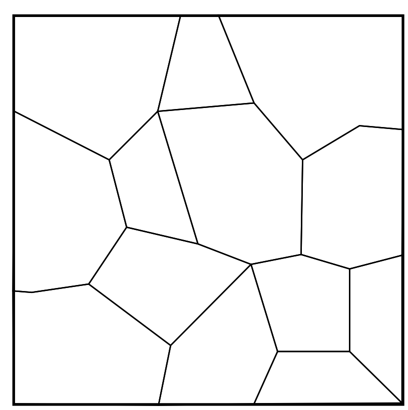
(e) (**2 points**) Both the ε and η phases of brass have hexagonal crystal structures. What composition would yield equal weight fractions of the these two phases in equilibrium at 100°C?

4. Phases and Phase Equilibria (10 points)
These questions refer to the same Cu-Zn binary phase diagram from Problem 3.

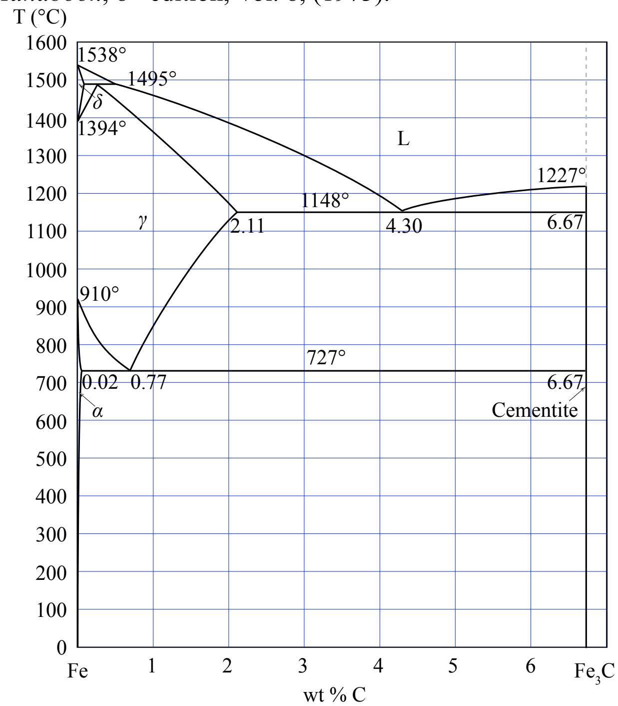
(a) (**5 points**) Sketch the microstructure resulting when a 70 wt% Zn alloy with initially large γ grains at 550°C, as shown below, is cooled slowly to room temperature. Label all phases.



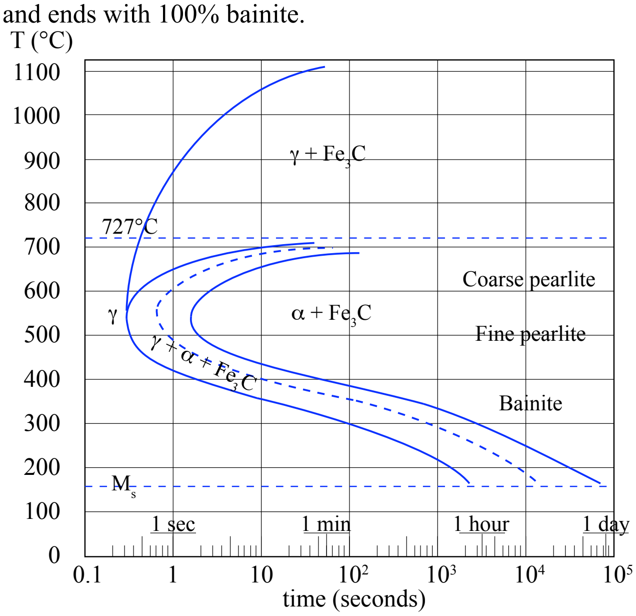
(b) (**5 points**) The eutectoid composition at 558°C is 74.1 wt % Zn. Sketch the microstructure resulting when an alloy of this composition, showing a δ phase morphology at 560°C as shown below, is cooled slowly to room temperature. Label all phases.



5. Kinetics (10 points)
The following phase diagram is from the *ASM Metals Handbook*, 8th edition, Vol. 8, (1973).



(**a**) (**5 points**) The following TTT diagram describes the isothermal kinetics of a 1020 steel. Show directly on the plot a thermal treatment that begins with 100% austenite, and ends with 100% bainite.



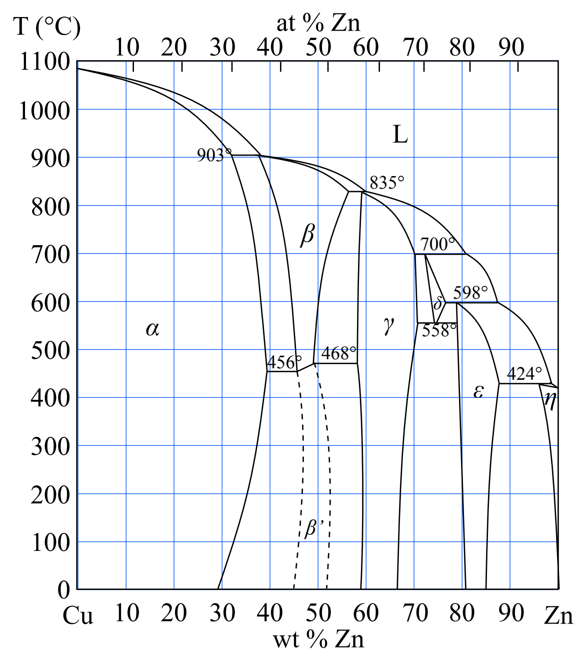
(**b**) (**5 points**) Will a quench rate of 1000°C/sec convert a sample with 100% austenite to 100% martensite? Show why or why not on the same TTT diagram above.

6. Kinetics (10 points)
Mark ☒ the ballot box corresponding to the best answer.
Two (**+2**) points for correct answers, **-1** if wrong, **0** if blank.

(**a**) The temperature at which a heavily cold worked Cu alloy recrystallizes
☐ decreases as the amount of cold work increases
☐ decreases as grain size increases
☐ both

(**b**) The driving force for grain growth during annealing is
☐ reduction in strain energy
☐ reduction in surface energy
☐ both

(**c**) When metallic alloys are quenched following a homogenization treatment in a single phase region of the phase diagram
☐ a supersaturated solution solution results
☐ the alloy is ready for aging
☐ both



(**d**) Brass can be precipitation hardened if it has the following composition
☐ 35 wt% Zn
☐ 70 wt% Zn
☐ both

(**e**) Glass ceramics are aged to
☐ relieve internal stress in the glass
☐ precipitate a crystalline phase
☐ both

7. Metallic Alloys (10 points)

Temper	Definition
H1	Strain-hardened
H2	Strain-hardened, partially annealed
T3	Solution-treated, cold-worked, naturally aged
T6	Solution-treated, artificially aged
T9	Solution-treated, artificially-aged, cold worked

The above table is a partial list of the "temper designations" for aluminum alloys specified by the Aluminum Association and published in the *ASM Metals Handbook*, 9th edition, Volume 2 (1979). Recognizing that the specified treatments appearing in the "definition" column occur *in sequence*, and *in the order given*, rank the various temper treatments in order of highest strength to lowest strength.

1. _____

2. _____

3. _____

4. _____

5. _____

8. Metallic Alloys (10 points)

Strengthened by	Weakened by
	Porosity (casting)
Cold working	Annealing
Alloying	Welding
Phase Transformations	Phase Transformations

The above table lists some of the general effects of "processing" of metals and alloys on their mechanical strength. For example, an alloy used in the "as-cast" condition is generally weaker due to the porosity that occurs because of air entrapment during solidification from the liquid phase. Similarly, welding is listed as a cause of "weakening," due to the fact that the local application of heat needed to weld alloys causes significant atomic transport, including some in the liquid phase.

Explain why "phase transformations" is listed in both columns.

9. Ceramics and Glasses (10 points)

An important family of "magnetic" ceramics is based upon the spinel ($MgAl_2O_4$) structure. Spinel is formed from an fcc Bravais lattice and a basis of fourteen (14) ions per lattice point: 2 Mg^{2+}, 4 Al^{3+} and 8 O^{2-}. The magnesium ions are tetrahedrally coordinated by four oxygen ions, while the aluminum ions are octahedrally coordinated by six oxygen ions. Note that both the motif and the chemical formula preserve charge neutrality.

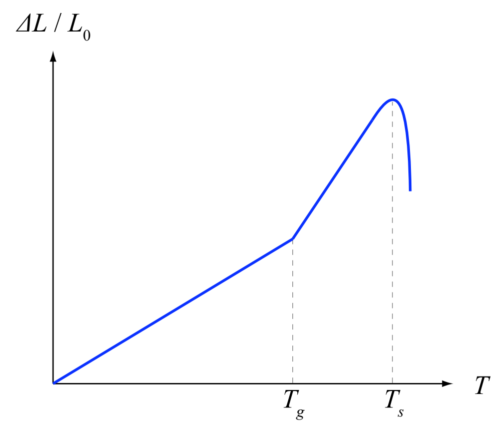
However, the magnetic (known as "ferrimagnetic") version of this structure is called an "inverse spinel," in which the octahedral sites are occupied by the divalent ions and one-half of the trivalent ions, while the remaining trivalent ions are in the tetrahedral sites.

One example of the ferrimagnetic ceramics is magnetite, the naturally occurring "lodestone" that was used to make the original compass. It is also found in meteorites. This could be the reason why, in Fox's hit series *The X-Files*, FBI investigators observed that magnetite could disrupt alien life forms, often causing their death or destruction (?).

Magnetite is an inverse spinel, yet its chemical formula is Fe_3O_4. Explain.

10. Ceramics and Glasses (10 points)

The following plot shows the thermal expansion behavior typical of a glass. Note that strain is plotted on the vertical axis, with temperature increasing to the right on the horizontal axis. At the softening temperature (T_s), the glass is unable to support its own weight and flows freely, invalidating the thermal expansion data.



During the processing of safety glass for windows, a treatment is used to place the surface of the glass in residual compression, so that it will not be as susceptible to fine surface cracks. In one of these treatments, the glass is first equilibrated above its glass transition temperature (T_g). Next it is subjected to cold air blast on both sides, a "surface quench," to form a rigid but thin "skin" on both surfaces. The skin is cool enough to remain below the glass transition temperature while the interior of the glass is still above T_g. The glass is then allowed to cool slowly and uniformly to room temperature.

Explain how this treatment causes residual surface compression.

Worksheet

No points will be given or deducted for work shown here. Please enter answers in the spaces provided.

DO NOT WRITE BELOW THIS LINE

Problem #	Possible Points	Your Score
1	10	
2	10	
3	10	
4	10	
5	10	
6	10	
7	10	
8	10	
9	10	
10	10	
Total	100	