UNIVERSITY OF TORONTO

FACULTY OF APPLIED SCIENCE AND ENGINEERING

FINAL EXAMINATION, DECEMBER 2001

JVM 209F

EXAMINER: Prof. Harry E. Ruda

STUDENT NAME: ______________________

STUDENT NUMBER: ______________________

Answer all questions using the space provided in this booklet.

QUESTION #	MARK
Q1 (15)	
Q2 (18)	
Q3 (35)	
Q4 (32)	
Total (100)	

Question 1: Question on Pair-Potentials (15%)

Assume that a solid is composed of A-atoms that are pair bonded in A-A bonds described by a so-called Lennard-Jones potential. Further, assume that when the atoms are separated by a distance of 1 nm, the total interaction energy is exactly zero, while the interaction energy is 2.24×10^{-20} J when the atoms are separated by their equilibrium separation – in both cases a temperature of 0 K is assumed.

Determine:

(i) The binding energy **(2%)**

(ii) The range parameter **(2%)**

(iii) The equilibrium separation between atoms **(3%)**

Given that heat energy $k_B T_m$ is applied, where $k_B = 1.38 \times 10^{-23}$ J/K is Plank's Constant, and T_m is the melting point of this material, it is found that the separation between atoms in the pair extends to 2 nm apart.

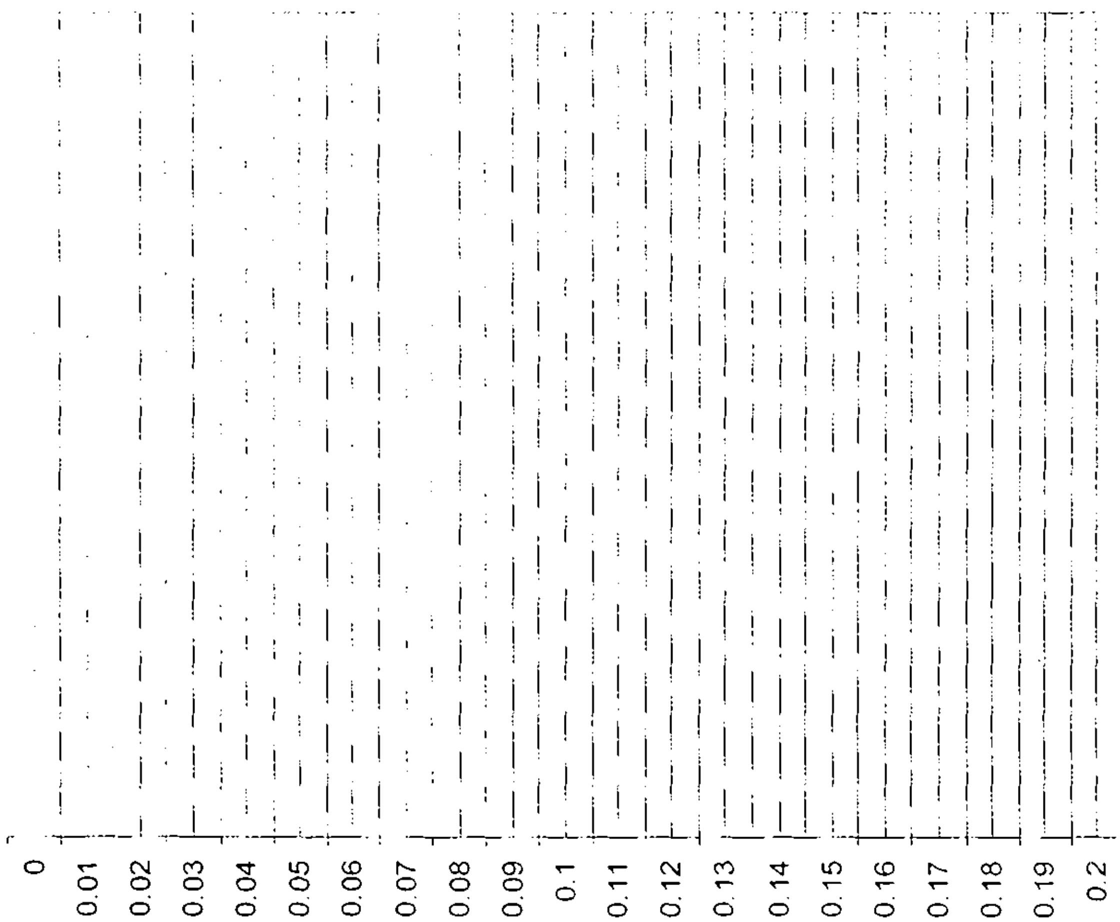
Determine:

(iv) The melting temperature of the material, T_m **(5%)**

Assume that B atoms can substitute for A atoms in the case of a solid solution α, principally composed of A atoms. Assume that the weight fraction of B atoms in the solid solution is x, and the binding energy of the solid solution is $E_\alpha(x) = E_A + x\,(E_B - E_A)$ where E_A and E_B are the binding energies of A-A and B-B pairs, respectively, assuming that the equilibrium pair separation is constant for all alloy compositions (i.e., with the same value as for A-A pairs).

If $E_B = 7.59\text{x}10^{-20}$ J,

(v) Draw a graph of Young's Modulus (in units of GPa) on x for $0 \le x \le 0.2$, where $G = 10^9$ and $Pa = N/m^2$. **(3%)**



Question 2: Question on Crystallography (18%)

(i) What is the $(11\bar{2}0)$ planar density in terms of the HCP lattice parameters a and c? (3%)

(ii) Provide two directions that define the plane given in part (i) above (3%)

(iii) Assuming an ideal geometry for the unit cell (i.e. $c/a = 2\sqrt{\frac{2}{3}}$) and given that atoms have an atomic radius of 2×10^{-10} m in the cell, provide a quantitative answer for part (a) in units of number of atoms per cm^2 **(4%)**

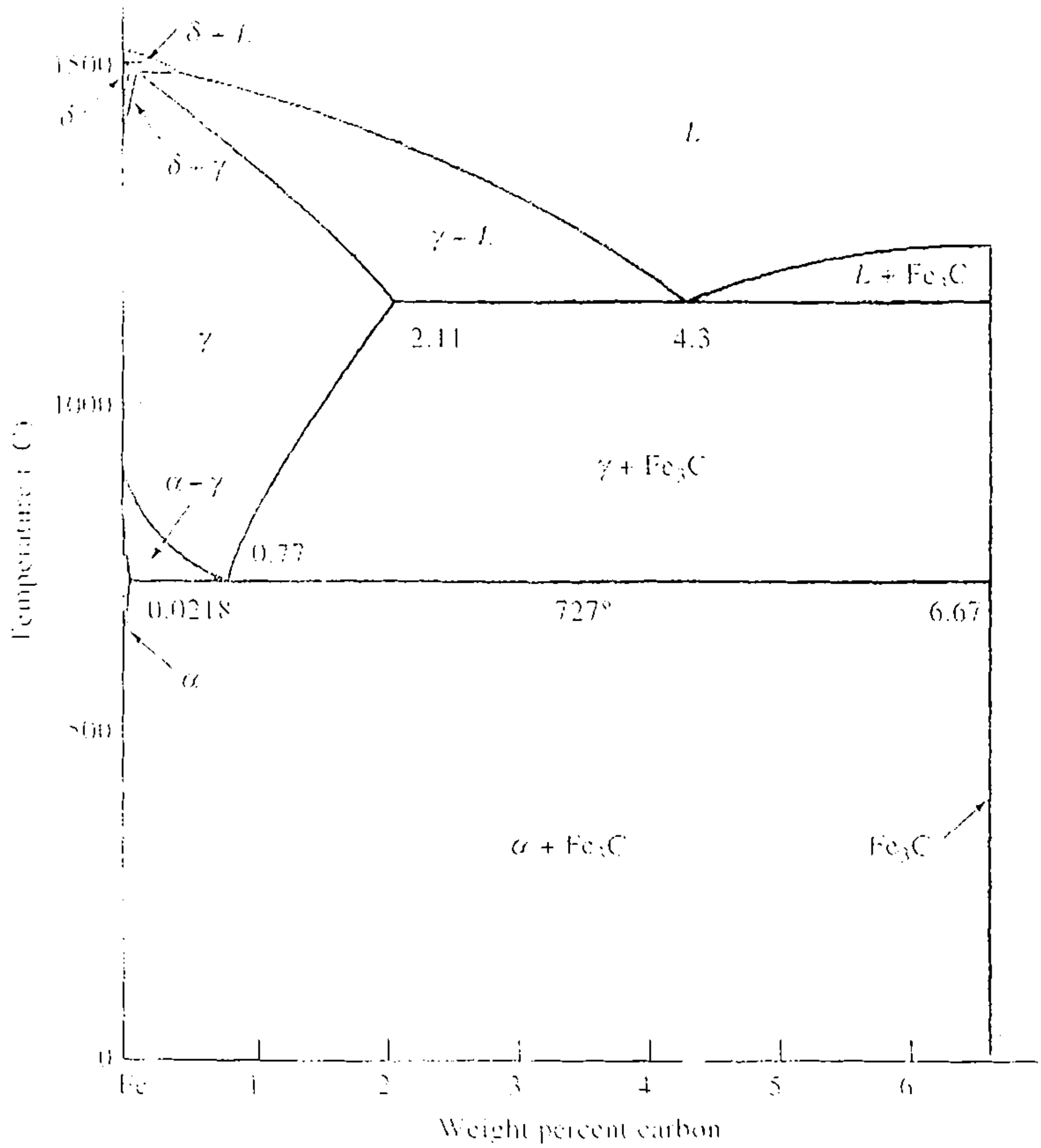
(iv) Why do real HCP metals display c/a ratios varying from 1.58 (for Be) to 1.89 (for Cd) number of atoms per cm^2? **(3%)**

(v) Iron is well known to exhibit a polymorphic transformation from BCC to a close packed structure (either HCP or FCC structures) on cooling. On further cooling the material may again transform its crystal structure back to BCC. Using a hard sphere model for the atoms, and assuming that the atomic radius of iron remains constant, calculate the percentage volume change for the transformation from BCC to HCP. **(3%)**

(vi) What is the term used to describe materials that exhibit polymorphic transitions such as those described in part (vi) above? **(2%)**

Question 3: Question on Phase Equilibria (35%)

Refer to the phase diagram below when answering this question.



(i) Describe all of the invariant reactions shown in the diagram using equations in terms of composition, relevant phases and temperature, as appropriate (3%)

Consider an alloy containing 3 weight % carbon:

(ii) Determine all of the phases present (i.e., if a given phase exists in more than one form, identify this) and their amounts (i.e., for all forms if there is more than one form of a given phase) at equilibrium on cooling from 1500°C to 500°C for the following 6 temperatures: 1500°C, 1160°C, 1140°C, 1000°C, 750°C and 500°C **(12%)**

(iii) Apply the Gibbs Phase Rule for each of the temperatures identified in part (ii) above **(4%)**

(iv) Draw the microstructure for a 3wt%C alloy, equilibrium cooled from 1500°C to 1000°C, labeling all phases present and their compositions, making reference to their amounts **(3%)**

(v) Draw the microstructure for a 3wt%C alloy, equilibrium cooled from 1500°C to 500°C, labeling all phases present and their compositions, making reference to their amounts **(3%)**

(vi) Draw the microstructure for a a 3wt%C alloy, non-equilibrium cooled from 1500°C to 500°C, labeling all phases present and their compositions, making reference to their amounts **(3%)**

(vii) Draw schematically a TTT-diagram for a 1.5 weight % carbon alloy, identifying phases and key temperatures as appropriate **(4%)**

(viii) Comment on the shape of the TTT-diagram drawn in part (vii) in terms of the two controlling factors **(3%)**

Question 4: Question on Mechanical Properties (32%)

For each of the following multiple choice questions, please fill in as many of the open circles to the right of the question as appropriate that correspond to the correct response. Marks will be subtracted for every response that fills in more or less than the correct number of responses.

4.1 Point defects have atomic dimensions in all directions **(1.5%)**:

A) true o
B) false o

4.2 Substitutional atoms occupy interstices in the parent lattice **(1.5%)**:

A) true o
B) false o

4.3 Many different point defects exist in crystals, for example **(1.5%)**:

A) excited electrons o
B) self-interstitials o
C) slip lines o
D) vacancies o
E) precipitate particles o
F) substitutional atoms o

4.4 The Burgers vector of an edge dislocation is perpendicular to the dislocation **(1.5%)**:

A) true o
B) false o

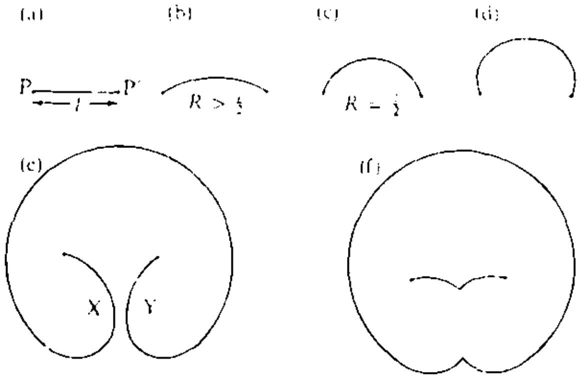
4.5 To obtain the Burgers vector of a dislocation, Burgers circuits are drawn **(1.5%)**:

A) first around the dislocation, and then, with the same number of jumps, in the perfect crystal o
B) first around the dislocation and then, with one fewer jump, in the perfect crystal o
C) first in the perfect crystal, and then with the same number of jumps, around the dislocation o
D) first in the perfect crystal, and then with one fewer jump, around the dislocation o
E) in an anti-clockwise direction o
F) in a clockwise direction o

4.6 Edge dislocations can climb **(1.5%)**:

A) true o
B) false o

4.7 The sequence of events in the operation of a Frank-Read source is shown in a, b, c, d, e, and f **(1.5%)**.



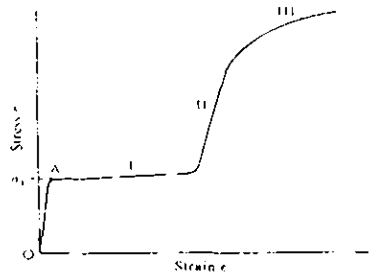
The maximum stress to operate the source:

A) corresponds to event b o
B) corresponds to event c o
C) corresponds to event d o
D) corresponds to event e o

4.8 The critical resolved shear stress is independent of orientation **(1.5%)**:

A) true o
B) false o

4.9 This is a generalized stress-strain curve fo a single crystal. During stage II **(1.5%)**:



A) only the primary slip system operates o
B) the primary slip system operates o
C) slip occurs on more than one slip system o
D) the work-hardening rate is less than in stage III o
E) the work-hardening rate is greater than in stage I o

4.10 The stress-strain curves of polycrystalline materials do not exhibit stages I and II shown by single crystals **(1.5%)**:

A) true o
B) false o

4.11 Work-hardening is a useful strengthening mechanism but it has the following disadvantages **(1.5%)**:

A) only useful for two phase materials o
B) decreases the ductility of the material o
C) not suitable if the material is to be used at elevated temperature o
D) only applicable to single crystals o

4.12 The presence of a dispersion of small particles increases the strength of a material by an amount that depends on **(1.5%)**:

A) the volume fraction of the particles o
B) the valency of the solute atoms o
C) the size of the particles o
D) the viscoelastic deformation rate of the particles o

4.13 Explain the difference between the critical resolved shear stress, τ_c and resolved shear stress **(3%)**

4.14 Explain why pure FCC metals such as Ag and Cu have low values of τ_c **(3 %)**

4.15 List all the primary the slip systems for an HCP crystal **(4%)**

4.16 If a tensile stress of 80 Mpa is applied to the [210] direction of a BCC crystal, calculate the resolved stresses acting on the (110) $[\bar{1}11]$ and $(10\bar{1})$ [111] slip systems. If only these two systems are able to operate, which one is the primary system? **(4%)**