Materials Science and Engineering Final Exam

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Task 1:

The atomic radii of Na^{+} and O^{2-} ions are 0.1 nm and 0.140 nm, respectively.

(a) Calculate the force of attraction between these two ions at their equilibrium interionic separation, i.e., when the ions just touch one another.

(b) What is the force of repulsion at this same separation distance?

a) Force of attraction between these two ions

$$F_{attract} = \frac{A}{r^2} = \frac{1}{4\pi\epsilon_0 r^2}(|Z_1 e||Z_2 e|)$$

$$= \frac{1}{4\pi \times 8.85\times10^{-12}\times(0.1\times10^{-9}+0.14\times10^{-9})^2}(|+1||1.602\times10^{-19}| \, |-2||1.602\times10^{-19}|)$$

$$= 8.0127\times10^{-9} N$$

b) Force of repulsion at this distance

Task 2:

(a) What types of interatomic and/or intermolecular bonding (if any) would you expect to be found in (1) pure HF, (2) pure HCl, (3) pure Al?

(1) for pure HF, it is covalent bond since it is bond between hydrogen and high valence atom fluorine

(2) for pure HCl, it is ionic bond since it is bond between an anion and a cation, where H gives one electron to Cl

(3) for pure Al, it is metallic bond since it is bond between pure metallic element that shares delocalized sea of electrons

(b) Please give an order on the boiling temperatures of these three substances in task 2 (a). And explain the reason.

Order of boiling temperature from high to low: pure Al > HF > HCl. Since covalent compounds do not exhibit electrical conductivity while ionic compounds exist in stable crystalline structures, ionic bonds have higher boiling temperature than covalent compounds. Metallic bond share delocalized electrons, increasing their attractive force and tends to have higher boiling point than ionic bonds

Task 3:

Iron (Fe) undergoes an allotropic transformation at 912 C: upon heating from a BCC (α-phase) to an FCC (γ-phase). Accompanying this transformation is a change in the atomic radius of Fe: from r_{BCC} = 0.12584 nm to r_{FCC} = 0.12894 nm, resulting in a change in density. Compute the percentage of density change associated with this reaction. The atom weight of iron is A_{Fe} = 55.85 g/mol.

Hint: Percentage of density change is defined as “change of density/density of BCC iron × 100%”.

In FCC, we have $a = 2\sqrt{2}r$ $\Rightarrow$ volume of one atom : $\frac{a^3}{4}$

$\Rightarrow V_{Fe} = 0.012127\ nm^3$

In BCC, we have $a = \frac{4r}{\sqrt{3}}$ $\Rightarrow$ volume of one atom : $\frac{a^3}{2}$

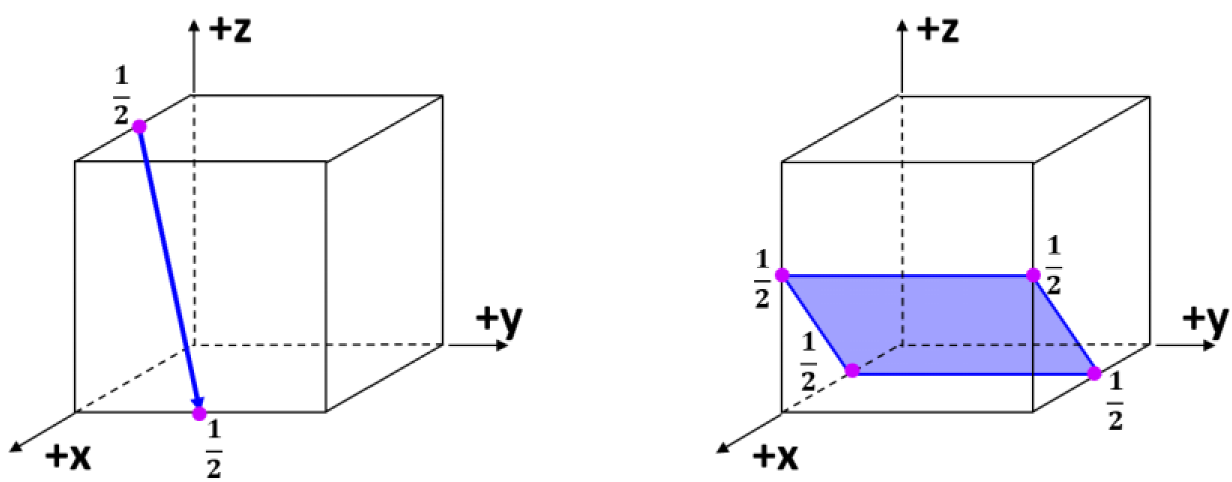
$\Rightarrow V_{Fe} = 0.0122172\ nm^3$

$\Rightarrow$ Volume decreases from BCC to FCC

% of decrease $= \frac{V_{Fe\,BCC} - V_{Fe\,FCC}}{V_{Fe\,BCC}}$ = 1.18% decrease (answer)

Task 4:

Give the Miller indices for the direction represented by the blue vector and the plane filled by the blue area that have been drawn within a unit cell in Figure 1



- Miller indices for direction of blue vector

  Vector tail : $(x_1, y_1, z_1) = (1/2, 0, 1) \cdot (a, b, c)$

  Vector head: $(x_2, y_2, z_2) = (1, 1/2, 0) \cdot (a, b, c)$

  $\Rightarrow$ Vector normalized: $\dfrac{(1-1/2)a}{a}, \dfrac{(1/2-0)b}{b}, \dfrac{(0-1)c}{c} \Rightarrow \left(\dfrac{1}{2}, \dfrac{1}{2}, -1\right)$

  Reduced to smallest integer: $(1, 1, -2)$ (scale by 2)

  $\Rightarrow$ Miller indices : $[1 1 \bar{2}]$ (answer)

- Miller indices for plane of blue area

  Theres no need to relocate origin

	x	y	z
Intercept	$1/2$	∞	$-1/2$
Reciprocal	2	0	-2
Reduction	1	0	-1

$\Rightarrow$ Miller indices : $(1 0 \bar{1})$ (answer)

Task 5:

(a) Which types of interstitial sites will the Mg^{2+} and Si^{4+} ions occupy?

According to the coordination number table, since the ratio of Mg/O radius falls between 0.414 and 0.732 and Si/O radius falls between 0.225 and 0.414, Mg^{2+} is expected to occupy at octahedral sites and Si4+ is expected to occupy tetrahedral sites

(b) What fraction of the total tetrahedral sites will be occupied?

From the formula, we know that there is one Si4+ for each O2, and since there are four O2 or eight oxygen atom

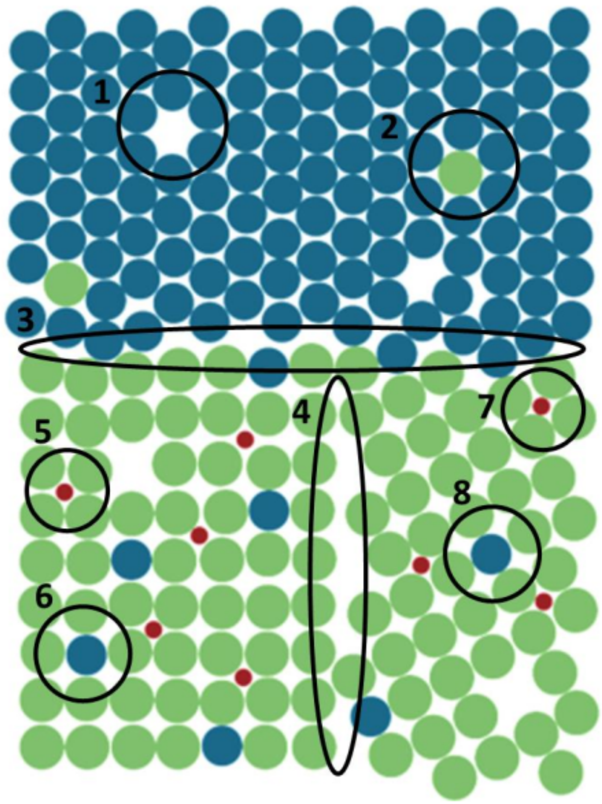
=> 1/8 of the tetrahedral sites will be occupied.

(c) What fraction of the total octahedral sites will be occupied?

From the formula, we know that there is one Mg2+ for each O2, and since there are 2 oxygen atoms

=> 1/2 of the octahedral sites will be occupied

Task 6:



Defects in
Region 1: Vacancy defect
Region 2: Substitutional foreign atom
Region 3: Grain boundary
Region 4: Edge dislocation
Region 5: Interstitial impurity atom
Region 6: Substitutional foreign atom
Region 7: Interstitial impurity atom
Region 8: Substitutional foreign atom

Task 7:

A cylindrical specimen of an alloy with a diameter of 8 mm is stressed elastically in tension. A force of 15,700 N produces a reduction in specimen diameter of 5×10^-3 mm. Calculate the Poisson's ratio for this material if its modulus of elasticity is 140 GPa.

Cylindrical specimen of an alloy, $E = 140$ GPa

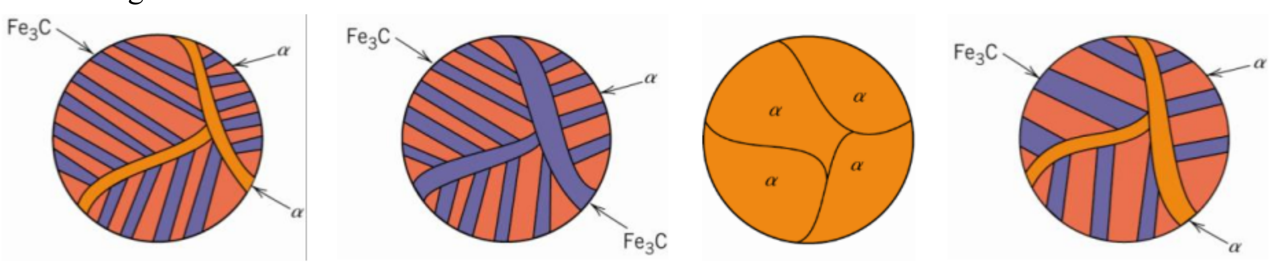
$d_0 = 8mm = 8 \times 10^{-3} m$ $\quad F = 15700N$ $\quad \Delta d = 5 \times 10^{-3} mm = 5 \times 10^{-6} m$

find Poisson's ratio ν

- Lateral strain: $\varepsilon_x = \dfrac{-\Delta d}{d_0} = \dfrac{-5 \times 10^{-3}}{8} = -6.25 \times 10^{-4}$
- Tensile stress: $\sigma = \dfrac{F}{A_0} = \dfrac{15700}{\pi (4 \times 10^{-3})^2} = 312341575.8$ Pa
- Tensile strain: $\varepsilon_z = \dfrac{\sigma}{E} = \dfrac{312341575.8}{140 \times 10^9} = 2.231 \times 10^{-3}$
- Poisson's ratio ν: $\nu = -\dfrac{\varepsilon_x}{\varepsilon_z} = -\dfrac{-6.25 \times 10^{-4}}{2.231 \times 10^{-3}} = 0.2801$ (answer)

Task 8:

Schematic room-temperature microstructures for four iron–carbon alloys are as follows. Rank these microstructures (by letter) from the hardest to the softest and briefly explain the reason for your ranking.



(A) (B) (C) (D)

Microstructure hardness from high to low: B>A>D>C

Reason: Matrix of overlapping ferrite and cementite is always harder than pure ferrite, which makes C the most soft. B has alpha ferrite within Fe3C matrix while A has Fe3C in alpha ferrite, so B is harder than A. D is similar to A but has longer width of grains, make it softer than A

Task 9:

a) After briefly cooling down to 400 degrees, there is nothing happening. Then kept at this temperature for about 50 seconds, nearly half of austenite is transformed into bainite. Then all of the austenite is quickly quenched to become martensite

=> microconstituents: nearly 50% is bainite, the rest is martensite

b) After briefly cooling down to 600 degrees, there is nothing happening. Then kept at this temperature for about 10 seconds, half of austenite is transformed into pearlite. Then cool down to around 450 degrees and restart timing. Keep at 450 degrees for about 10 seconds, half of the austenite transformed into bainite. Then all of the austenite is quickly quenched to become martensite.

=> microconstituents: 50% is pearlite, 25% is bainite, 25% is martensite

c) After briefly cooling down to 700 degrees, there is nothing happening. Then kept at this temperature for about 10000 seconds, half of austenite is transformed into pearlite. Then all of the austenite is quickly quenched to become martensite

=> microconstituents: 50% is pearlite, 50% is martensite

d) After briefly cooling down to 300 degrees, half of austenite is quenched into martensite. Then kept at this temperature for about 8 seconds and nothing happens. Reheat again to around 450 degrees and restart timing and kept for 1000 seconds, the martensite is tempered while all of the austenite is transformed into bainite. Finally, quenched to cool temperature around 150 degrees

=> microconstituents: bainite and tempered martensite

Task 10:

Indicate all the eutectic, eutectoid, and peritectic reaction points (if any) with their temperatures in Figure 4 (Indicate with the reaction names and corresponding temperature and carbon content values. No need to plot on figures). Also, for each one, write the reaction equations upon cooling.

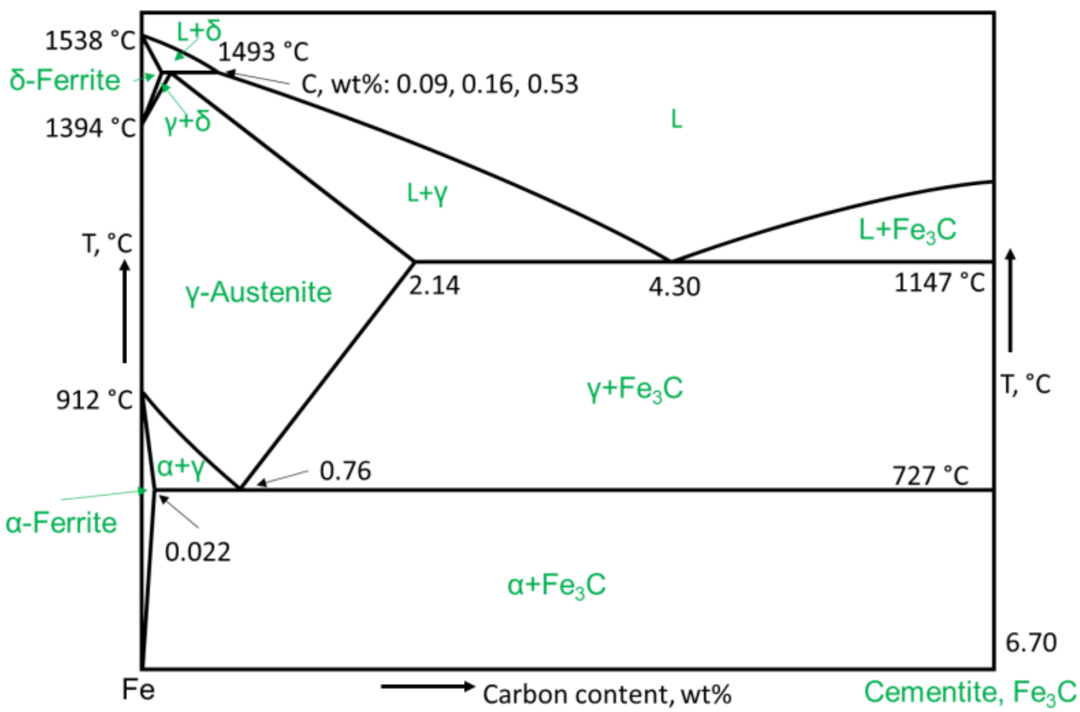


Figure 4 Fe-Fe₃C phase diagram.

- Eutectic reactions : $L \underset{}{\overset{\text{cooling}}{\rightleftharpoons}} \gamma + Fe_3C$. Temperature : 1147°C
  Carbon content value : Austenite γ : 2.14 %wt C , Liquid : 4.3% wt C
  Cementite Fe_3C : 6.7 % wt C
- Eutectoid reactions : $\gamma \underset{}{\overset{\text{cooling}}{\rightleftharpoons}} \alpha + Fe_3C$. Temperature : 727°C
  Carbon content value : Ferrite-α : 0.022 % wt C , Austenite γ : 0.76 % wt C
  Cementite Fe_3C : 6.7% wt C
- Peritectic reactions : $L + \delta \underset{}{\overset{\text{cooling}}{\rightleftharpoons}} \gamma$. Temperature : 1493°C
  Carbon content values : δ- Ferrite : 0.09 % wt C , Liquid : 0.53 % wt C
  γ - Austenite : 0.16 % wt C

Task 11:

Consider 1.0 kg of austenite containing 1.5 wt% C, cooled down below 727 C. Please use the data from the Fe-Fe_3C phase diagram in Figure 4.

(a) What is the proeutectoid phase?

The proeutectoid phase is expected to be only cementite Fe3C

(next page)

b) We have $C = 1.5$ wt% C

$\Rightarrow$ Proeutectoid phase (cementite) weight is

$$W_{Fe_3C} = \frac{1.5 - 0.76}{6.7 - 0.76} \times 1.0\ kg = 124g$$

Pearlite weight formed is : $1\ kg - W_{Fe_3C} = 876g$

c) Alpha ferrite formed weight is

$$W_{\alpha\text{-ferrite}} = \frac{6.7 - 1.5}{6.7 - 0.022} \times 1.0\ kg = 778g$$

Cementite weight is : $1\ kg - W_{\alpha\text{-ferrite}} = 222g$

d) The microstructure schematic sketch