SOLUTIONS

THE UNIVERSITY OF ZAMBIA
SCHOOL OF ENGINEERING
DEPARTMENT OF MECHANICAL ENGINEERING

UNIVERSITY EXAMINATIONS

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ME 232 - PROPERTIES OF ENGINEERING MATERIALS I

SOLUTIONS TO QUESTIONS

SECTION A - Answer at least two questions from this Section.

Q1.

(a) Assuming that metal crystals can be considered as hard spheres in contact, determine the co-ordination numbers and packing fractions for the following crystal structures:

(i) Body-centred cubic [4 marks]
(ii) Face-centred cubic [5 marks]
(iii) Hexagonal close-packed. [5 marks]
[Hint: Packing fraction = (volume of atoms in unit cell)/(volume of unit cell)]

Solution:

(i) Co-ordination numbers = near neighbours or atoms that any atom is in direct contact with.

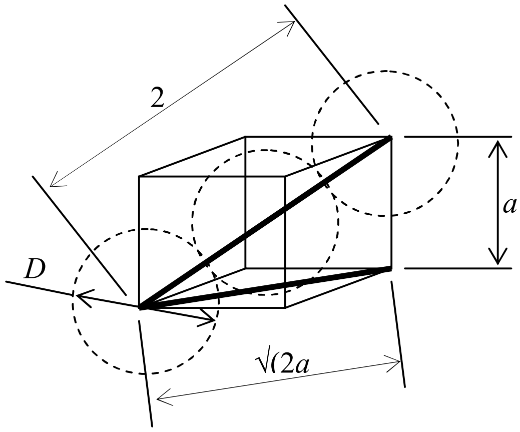
- For bcc, the atom at the centre of the unit cell is in direct contact with each of the eight corner atom. Therefore, the co-ordination number is 8 [1 mark]
- For fcc, the co-ordination number is 12. This can be shown by examining the most close packed planes, the (111) type. It will be seen that within such a plane any atom is in contact with six other atoms. An atom will also be in contact with three atoms in each of the planes of similar packing situated immediately above and below this plane. [1 mark]
- For hcp, the co-ordination number is also 12. The basal planes (0001) are the most closely packed and the atoms in these planes are arranged in the same manner as in the fcc (111) planes. [1 mark]

(ii) Packing fraction = (volume of atoms in unit cell)/(volume of unit cell)

- In the bcc, the diagonal length is also equivalent to two atomic diameters, $2D$.

Therefore, $2D = a\sqrt{3}$ or $a = 2D/\sqrt{3}$

The bcc cell contains two atoms.



The packing fraction is:

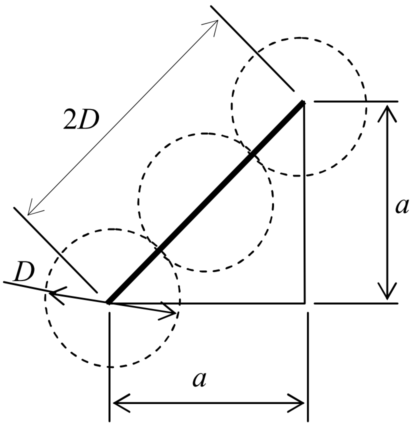
$$\frac{Volume\ of\ 2\ atoms}{Volume\ of\ unit\ cell} = \frac{\left(\frac{2x\pi D^3}{6}\right)}{\left(\frac{2D}{\sqrt{3}}\right)^3} = 0.68$$

[3 marks]

- In the fcc, the length of a diagonal of a square face in a cube of edge length *a*, is equal to $a\sqrt{2}$. In the fcc cell, this is the equivalent to the diameter of two atoms.

  So $2D = a\sqrt{2}$or $a = D/\sqrt{2}$

  An fcc cell has 4 atoms.



∴ Packing fraction is:

$$\frac{Volume\ of\ 4\ atoms}{Volume\ of\ unit\ cell} = \frac{\left(\frac{4x\pi D^3}{6}\right)}{\left(\frac{D}{\sqrt{2}}\right)^3} = 0.74$$

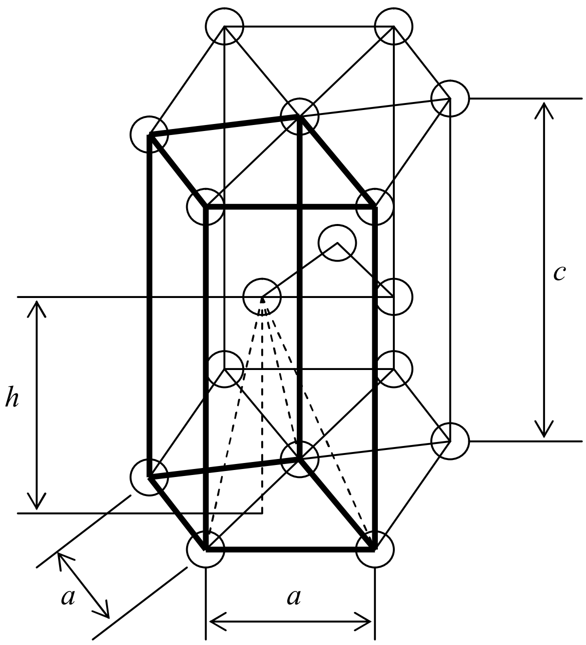
[4 marks]

- In the hcp, there are two lattice parameter, a and c. from the figure, it will be seen that parameter a is equal to one atom diameter, D, and that the parameter c is equal to $2h$, where h is the height of a regular tetrahedron of edge length a.

$$h = \frac{a\sqrt{2}}{\sqrt{3}}$$

Therefore,

$$2h = \frac{2a\sqrt{2}}{\sqrt{3}} = c$$



The area of a regular hexagon of side equal to a is $a^3 3\sqrt{3} / 2$

So the volume of a hexagonal prism is $\frac{1}{2} a^3 3\sqrt{3} \times 2\sqrt{2} / \sqrt{3} = 3 a^3\sqrt{2}$

$= 3 D^3\sqrt{2}$, as $a = D$.

A Miller-Bravis hcp cell contains six atoms.

The packing fraction, therefore is:

$$\frac{Volume\ of\ 6\ atoms}{Volume\ of\ unit\ cell} = \frac{\left(\frac{6x\pi D^3}{6}\right)}{3D^3\sqrt{2}} = 0.74$$

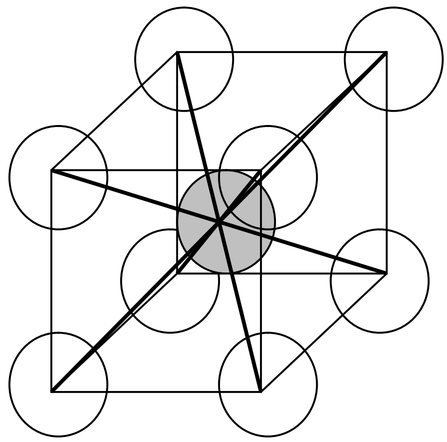
[4 marks]

(b) Draw sketches showing the near neighbours of the atoms in these crystal structures.
- **(i) Body-centred cubic** **[2 marks]**
- **(ii) Face-centred cubic** **[2 marks]**
- **(iii) Hexagonal close-packed.** **[3 marks]**

Solution:

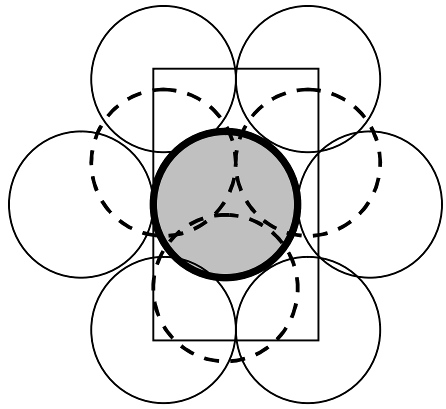
(i) bcc:

Each centre atom is in contact with the 8 corner atoms, which are its near neighbours. [2 marks]



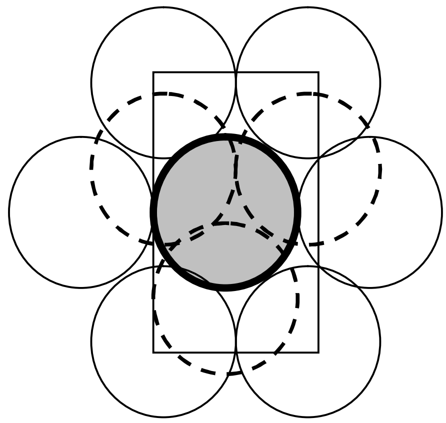
(ii) fcc:

Each face atom is in contact with the 4 corner atoms, 2 others from its two lateral neighbouring cell, and 3 each from the neighbouring cells (on either side) in the plane of the paper. This brings the total to 12 near neighbours. [2 marks]



(iii) hcp:

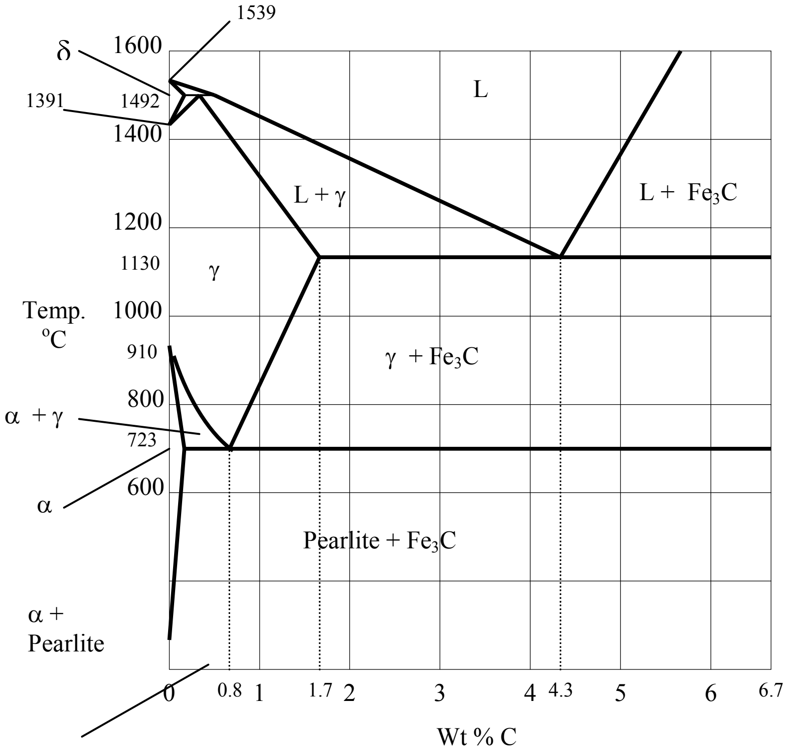
This is the same as in the fcc. Each face atom is in contact with the 4 corner atoms, 2 others from its two lateral neighbouring cell, and 3 each from the neighbouring cells (on either side) in the plane of the paper. This brings the total to 12 near neighbours. [2 marks]



Q2.

(a) Draw a fully labelled Fe-C phase diagram up to 6.7% Carbon. [12 marks]

Solution:



0.8 %C = Eutectoid
4.3 %C = Eutectic

0.03 %C = limit of C in α at 723°C
1.7 %C = limit of C in γ at 1130°C
0.01 %C = limit of C in δ at 1492°C
6.7 %C = useful limit of C in iron

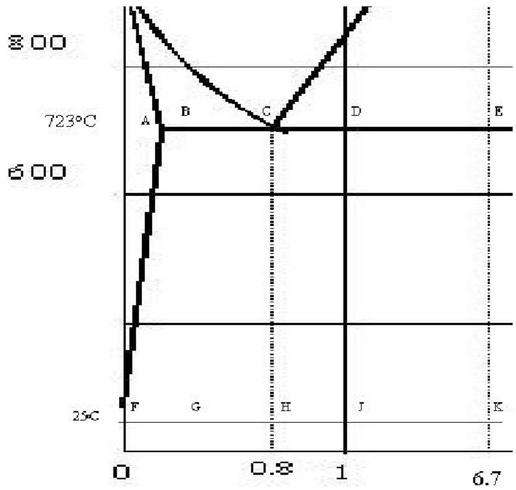
α = ferrite
γ = austenite

Equilibrium Diagram of the Iron-Carbon System

(b) With reference to your Fe-C phase diagram, for two plain carbon steels of 0.4% and 1.0% Carbon;

- **(i) Calculate the amount of austenite present in each of these steels at 723°C, assuming the transformation is complete. [2 marks]**
- **(ii) Calculate the amount of pearlite present in each of these steels at 25°C, assuming slow cooling. [2 marks]**
- **(iii) Suggest a typical application for each steel in its fully hardened and tempered conditions, and justify your choice. [4 marks]**

Solution:



(i) At 723°, assuming the transformation is complete, the austenite content is:

- 0.4%C ⇒ (AB/AC)x100 = ((0.4 - 0.03)/(0.87 - 0.03)x100 = 44%
- 1.0%C ⇒ (DE/CE)x100 = ((6.7 - 1.0)/(6.7 - 0.87))x100 = 98% [2 marks]

(ii) At 25°C, the pearlite content is:

- 0.4%C ⇒ (FG/FH)x100 = ((0.4 - 0.0)/(0.87 - 0.0))x100 = 46%
- 1.0%C ⇒ (JK/HK)x100 = ((6.7 - 1.0)/(6.7 - 0.87))x100 = 98% [2 marks]

(iii) Suggested uses:

- 0.4%C steel is suitable for the manufacture of shafts. Correctly heat-treated, it will have a high surface hardness to withstand wear and possess good strength and toughness to transmit power. [2 marks]
- 1.0%C steel is a tool steel. The high surface hardness obtainable would make it suitable for use as, for example, a milling cutter. [2 marks]

Q3.

(a) What is electrochemical corrosion? [4 marks]

Solution:

- Chemical or electrochemical reaction between a metal and its environment
- Involves removal of metal or its conversion to an oxide or other compound.
- In some cases, oxide forms protective layer - reduces/stops further corrosion
- In other cases, formation of layer does not stop further corrosion
- Results :

☞ high replacement costs

☞ high prevention costs – painting, plating [2 marks]

Types of Corrosion – Oxidation and Reduction:

- Most corrosion linked with oxidation (element combines with O_2) either directly or indirectly
  - ☞ In oxidation, metal is changed to a +ve ion and the electron passes onto the oxygen atom.
  - ☞ ∴Oxidation = Removal of electrons.

- On the other hand, reduction is the addition of electrons to the atom.
  - ☞ E.g. In an electrolytic extraction processes from CuO to pure Cu.
  - ☞ ∴Reduction = Addition of electrons. [2 marks]

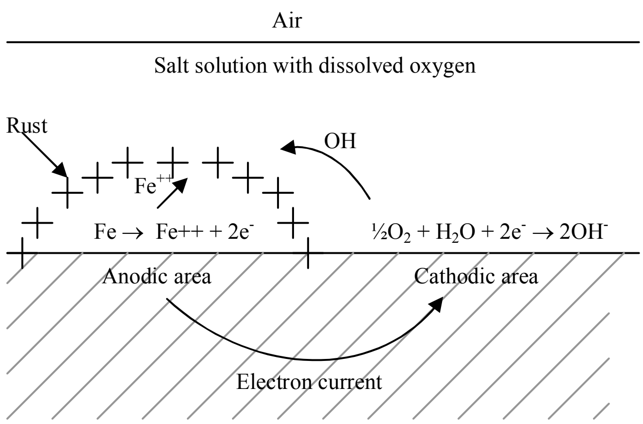
(b) Explain concisely each of the following forms of metallic corrosion

(i) Pitting **[6 marks]**
(ii) Corrosion fatigue **[3 marks]**
(iii) Stress corrosion **[3 marks]**
(iv) Fretting corrosion **[4 marks]**

Solution:

(i) ***Pitting***

- These are non-uniform and can proceed in otherwise undamaged material
- Pitting may start as a localised anodic area due to an inhomogeneity
  - ☞ e.g.: A drop of water on a steel surface has a higher concentration of dissolved O_2 near the outside than at the centre. An anodic area forms at the centre.



The Fe^{++} ions released react with OH^- ions to form ferrous hydroxide, thereby decreasing the OH^- concentration. These two effects increase the potential difference and hence the corrosion current. The ferrous hydroxide then reacts with atmospheric O_2 and more OH^- ions to form rust – a form of ferric hydroxide.

- Surface inhomogeneity causing localised anodic and cathodic areas:
  - ☞ Breaks in a protective layer
  - ☞ Deposits of foreign matter or loose corrosion products
  - ☞ Local inhomogeneities in the metal, e.g. oxide particles
  - ☞ Localised stressing of the metal, stress causing change in the electrochemical potential [6 marks]

(ii) Corrosion Fatigue

- Action of corrosion in the presence of repeated stresses
- Far more serious than either factor individually (corrosion or fatigue)

[3 marks]

(iii) ***Stress Corrosion***

- A form of intergranular corrosion
- More pronounced when the material is subjected to a tensile stress and becomes susceptible to corrosion attack due to the stress present.

[3 marks]

(iv) ***Fretting Corrosion***

- Particular form of corrosion fatigue
- May occur where there is slight relative movement of contacting surfaces due to the action of an alternating load
- May be found in bolted joints and other fitted assemblies
- Surface contact at high spots results in localised plastic flow and cold welding. The welds then rapture and loose metal particles oxidise with atmospheric oxygen.

[4 marks]

SECTION B: - Answer <u>at least two questions</u> from this Section.

END OF EXAMINATION
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