Department of Mechanical Engineering
University of Saskatchewan

ME324.3 Engineering Materials

Mid-Term Examination (Closed Book)

Student #: ________________________________

Instructor: **I. Oguocha**
Time Allowed: **2 h** **Friday, 29 October 2004.**

Section A: Multiple Choice Questions (50% of the Total Midterm Mark)
Answer ALL questions. There is NO penalty for guessing.

WARNING: This is a very busy exam. Do not waste your time on irrelevancies and verbose statements. Wherever applicable, go straight to the point (s).

In **Questions 1-7** indicate whether a statement is **true** (***T***) or **false** (***F***).

1. __________ A *crystalline* material is a 3-D array of points in space, each of which is indistinguishable from other points and has identical surroundings.

2. __________ A *basis* is an object or a combination of objects that sits at a lattice point.

3. __________ An *edge dislocation* is characterized by its burgers vector, which is parallel to the dislocation line vector.

4. __________ FeS inclusions in steels are planar defects.

5. __________ An alloy of *eutectic composition* does not solidify over a temperature range but completely solidifies at the *eutectic temperature*.

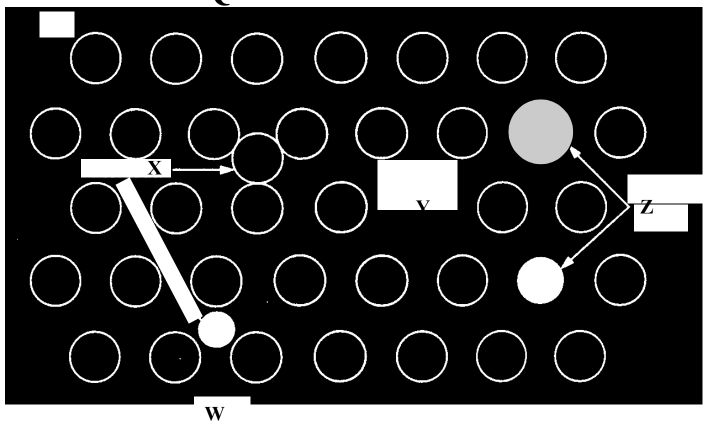
6. __________ A *homogeneous nucleation* occurs when nuclei form without the benefit of of interaction with the mold wall.

7. __________ An alloy of *peritectic composition* does not solidify over a temperature range but completely solidifies at the *peritectic temperature*.

In the following questions, circle the correct answer where required.

8. A unit cell is
   (A) The smallest group of atoms which when regularly repeated forms the crystal
   (B) A group of atoms which form a cubic arrangement
   (C) A unit cube containing the smallest number of atoms
   (D) The smallest group of atoms which will diffract X-rays.

Use the Figure below to answer Questions 9 to 12.



9. The defect labelled ***W*** is
   (A) Substitutional atom (B) Vacancy (C) Interstitial atom

10. The defect labelled ***X*** is
    (A) Vacancy (C) Substitutional atom
    (B) Self interstitial (D) Interstitial atom

11. The defect labelled ***Y*** is
    (A) Self-interstitial (C) Substitutional atom
    (B) Interstitial atom (D) Vacancy

12. The defect labelled ***Z*** is
    (A) Self-interstitial (C) Substitutional atom
    (B) Interstitial atom (D) Frenkel defect

13. Regions within a metal that are high energy and form a result of cooling into a polycrystalline solid
    (A) Voids (C) Lattice
    (B) Interstices (D) Grain boundaries

14. Which of the following statements is **false**?
    (A) Doping of silicon with phosphorus is made possible by diffusion
    (B) Formation of pearlite from austenite is brought about by diffusion
    (C) Diffusion makes it possible for a bottle of perfume uncapped in one part of a room to be felt in a distant corner of the room.
    (D) Martensite forms by a diffusional process.

15. A combination of two or more metals, one of which is *intentionally added* to the base metal, is called a(n):
    (A) Mixture (C) Solution
    (B) Compound (D) Alloy

16. The furnace for converting iron ore into *pig iron* is called the
    (A) DR furnace (C) Open hearth furnace
    (B) Basic oxygen furnace (D) Blast furnace

17. The raw material used in iron-making process that acts as a *reducing agent* for iron ore
(A) Hematite (C) Coke
(B) Dolomite (D) Hot air

18. The raw material used in iron-making process that combines with the ash and iron ore impurities to form *slag*
(A) Hematite (C) Coke
(B) Dolomite (D) Scrap

19. The type of iron made by using a *direct reduction (DR)* furnace
(A) Pig iron (C) Sponge iron
(B) Wrought iron (D) Cast iron

20. The type of furnace used by the IPSCO plant in Regina for its steel making
(A) DR furnace (C) Electric arc furnace
(C)Basic oxygen furnace (D) Blast furnace

21. The commercially pure iron used in making chains and hooks
(A) Pig iron (C) Sponge iron
(B) Wrought iron (D) White cast iron

22. The main raw material that the IPSCO steelmaking plant in Regina uses is
(A) Iron ore (C) Scrap
(B) Pig iron (D) Sponge iron

23. Metal alloys that cannot be mechanically deformed at ambient and elevated temperatures are
(A) Cast alloys (C) Deformed alloys
(B) Wrought alloys (D) Plastic alloys

24. *Malleable iron* is made from which of the following irons
(A) Pig iron (C) Gray cast iron
(B) White cast iron (D) Wrought iron

25. Another name for **nodular** cast iron is
(A) Malleable (C) Gray
(B) Ductile (D) Pearlitic

26. From thermodynamic viewpoint, the **driving force** for a phase transformation is
(A) Dislocations (C) Change in enthalpy (ΔH)
(B) Change in entropy (ΔS) (D) Change in free energy (ΔG)

27. Which of the following statements is **false** about the change in free energy of a reaction:
(A) ΔG determines the rate of a spontaneous reaction
(B) If $\Delta G = 0$, the reaction is at equilibrium
(C) If $\Delta G < 0$, the reaction is spontaneous in the specified direction
(D) If $\Delta G > 0$, the reaction is not spontaneous in the specified direction.

28. A *metastable* phase is
    A. Fully stable against all perturbations
    B. Unstable to any disturbance
    C. Stable only against small disturbances
    D. None of the above.

29. The <u>first digit</u> of the AISI-SAE steel designation system indicates
    (A) The percentage of the main alloying metal
    (B) The percentage of carbon
    (C) The basic type of steel
    (D) Whether the metal is ferrous or non-ferrous

30. The <u>second digit</u> of the AISI-SAE steel designation system is often used to indicate
    (A) The percentage of the main alloying metal
    (B) The percentage of carbon
    (C) The basic type of steel
    (D) The approximate amount of the main alloying metal

31. The <u>last two</u> or <u>three digits</u> of an AISI-SAE steel number are used to indicate
    (A) The percentage of the main alloying metal
    (B) The percentage of carbon
    (C) The basic type of steel
    (D) A variation of the basic type of steel

32. Which of the following is **true** about the ASTM designation system for steels?
    (A) The first digit indicates the type of steel
    (B) The last two digits indicates the iron content
    (C) The number is carefully chosen to indicate chemical composition and mechanical properties of the steel
    (D) The number is an arbitrarily chosen number pre-fixed by the letter "A", which is designated for ferrous materials.

33. A steel numbered 1055 in the AISI-SAE numbering system has how much carbon in it?
    (A) 55 %　　　(C) 5.5%
    (B) 0.055%　　(D) 0.55%

Use the Figures Q34-36 to answer Questions 34-36.

The eutectic system A-B in **Figure Q34-36** includes four alloys represented by the vertical lines labelled 1-4. On the right hand side of this figure, cooling curves corresponding to the four alloys have been lablled A-D.

34. The cooling curve for alloy 3 is ____________

35. The cooling curve for alloy 1 is ____________

36. The cooling curve for alloy 4 is ____________

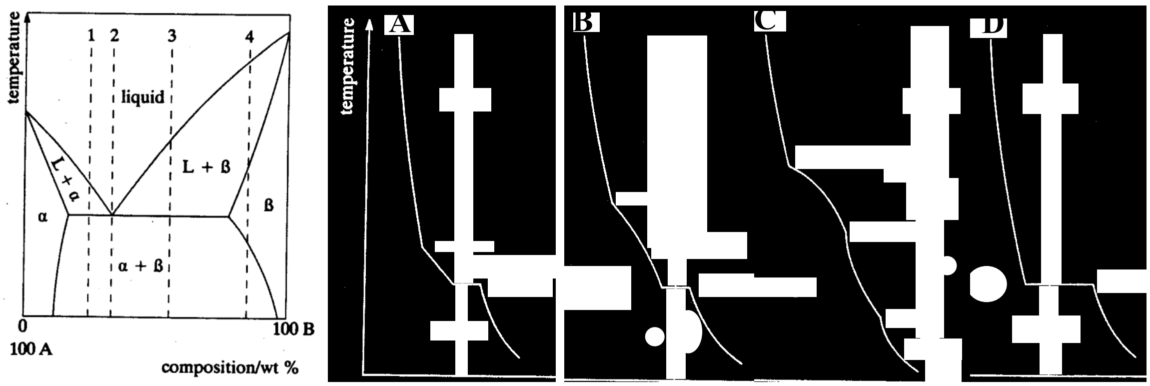


Figure Q34-36.

37. The following *invariant reactions* occur in low-carbon steels (i.e., wt% C ≤ 0.25):
    (A) Eutectic, peritectic and monotectic
    (B) Eutectic and eutectoid
    (C) Monotectic, eutectoid, and peritectic
    (D) Euectoid and peritectoid
    (E) Eutectoid and peritectic

38. A *two-phase mixture* of ferrite and cementite is called
    (A) Austenite (C) Steel
    (B) Pearlite (D) Ledeburite

39. One of the following phases/microconstituents is best described by the following:
    - *Low yield strength, very ductile, low carbon solubility*

    (A) Cementite (C) Pearlite
    (B) Austenite (D) Ferrite

40. One of the following phases/microconstituents is best described by the following:
    - *Medium yield strength, medium ductility, fixed carbon content*

    (A) Cementite (C) Pearlite
    (B) Austenite (D) Ferrite

41. One of the following phases/microconstituents is best described by the following:
    - *High yield strength, low ductility, Fe:C ratio of 3:1*

    (A) Cementite (C) Pearlite
    (B) Austenite (D) Ferrite

42. In the Iron-Fe_3C system, the maximum solubility of carbon in α-iron is approximately
    (A) 0.008 wt.% (C) 0.77 wt.%
    (B) 0.022 wt.% (D) 2.11 wt.%

43. The amount of pearlite in unhardened plain-carbon steels increases as the carbon content is increased up to what percentage?
    A. 0.022 wt.% C. 0.77 wt.%
    B. 2.1 wt.% D. 6.69 wt.%

44. Carbon content of cast iron ranges roughly from
(A) 0.022 to 0.77 wt.% (C) 0.6 to 1.0 wt.%
(B) 2 to 4.5 wt.% (D) 4 to 6 wt.%

45. In the $Fe-Fe_3C$ diagram, the *eutectic mixture* of austenite and cementite is
(A) Austenite (C) Cast iron
(B) Pearlite (D) Ledeburite

46. Two major types of bainite form in steels, depending on the quenchant temperature
(A) Upper bainite and lower bainite
(B) Upper bainte and nodular bainite
(C) Plate bainite and ferritic bainite
(D) Upper bainite and pearlitic bainite
(E) Long bainite and short bainite

47. The element that is most important for promoting graphitization in gray cast irons is
(A) Silicon (C) Cerium
(B) Magnesium (D) Copper

The following questions require careful examination of the figure before answering.

Use Figure Q48-50 to answer Questions 48-50.

48. Figure Q48-50 **(a)** is the
A. TTT diagram of a hypoeutectoid steel
B. TTT diagram of a hypereutectoid steel
C. TTT diagram of an alloy steel
D. TTT diagram of a eutectoid steel

49. Figure Q48-50 **(b)** is the
A. TTT diagram of a hypoeutectoid steel
B. TTT diagram of a hypereutectoid steel
C. TTT diagram of a eutectoid steel
D. TTT diagram of an alloy steel

50. Figure Q48-50 **(c)** is the
A. TTT diagram of a hypoeutectoid steel
B. TTT diagram of a hypereutectoid steel
C. TTT diagram of an alloy steel
D. TTT diagram of a eutectoid steel

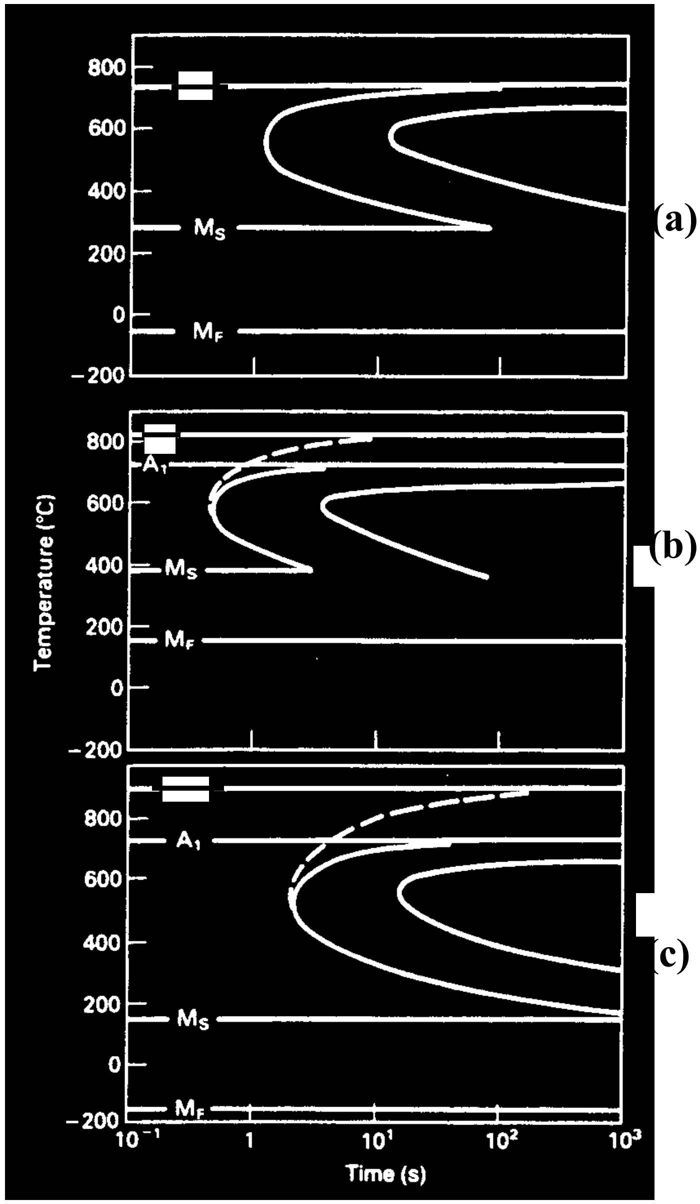


Figure Q48-50.

SECTION B: ANSWER ALL QUESTIONS

This Section Carries 50% of the Midterm Mark

Question 1: (69 Points)
Use the phase diagram for copper-antimony (Cu-Sb) system shown in **Figure Q1** (next page) to answer the following questions:

	Points
(a) How many *phases* are present?	**2**
(b) How many *three-phase equilibria* are present?	**2**
(c) Locate and circle the location of all the *three-phase* equilibria present.	**10**
(d) State the *terminal solid solutions* present.	**4**
(e) How many *intermediate phases* are present?	**2**
(f) How many of the intermediate phases named in (e) are *stoichiometric*?	**2**
(g) State any *stoichiometric intermetallic* compound(s) present.	**2**
(h) State any *congruent intermediate* compound(s) present.	**2**
(i) State any *incongruent melting* intermediate compound(s) present.	**2**
(j) Locate and draw a square around all *congruent equilibria*.	**6**
(*k*) Label all the phase fields.	**15**
(l) Determine the number of *degrees of freedom* at the location marked • in the diagram?	**4**

(m) Figure Q1 contains two *eutectic* reactions, one *eutectoid reaction* and one *peritectoid reaction*. Name and completely specify these *invariant reactions* by providing the following information.

Reaction	Temperature (°C)	Reaction Type	
			4
			4
			4
			4

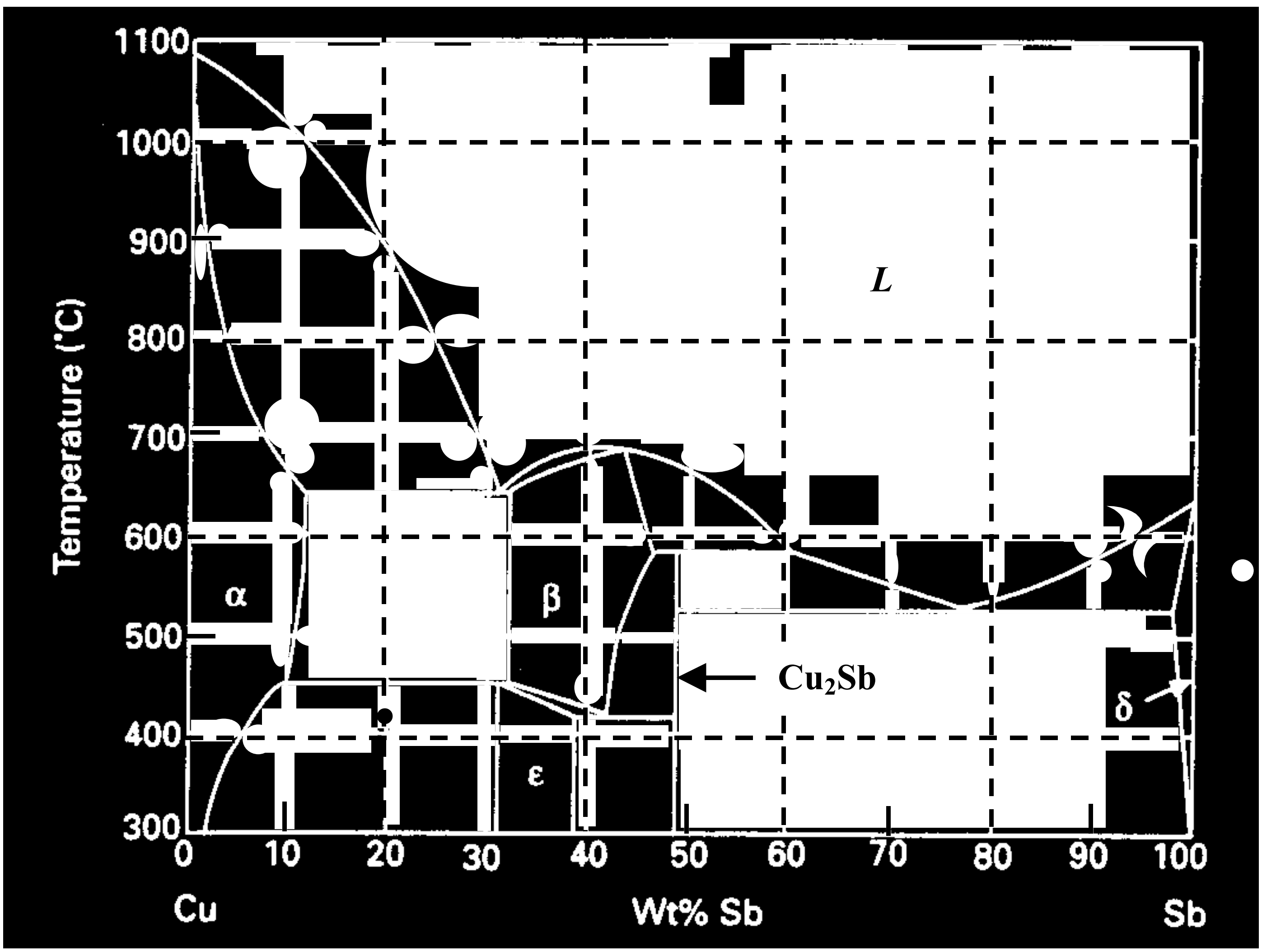


Figure Q1.

Question 2: (55 Points)

Figure Q2 shows the Fe-Fe_3C phase diagram. *Note that the temperature axis is in degree K.*

		Points
(a)	Label all the phase fields.	**22**
(b)	Label all the *critical temperatures* and *phases* indicated by the arrows.	**12**
(c)	Locate, <u>circle</u> and <u>name</u> all the *three-phase equlibria*.	**9**
(d)	Sketch the *cooling curve* for the steel alloy marked **X** in the figure.	**12**

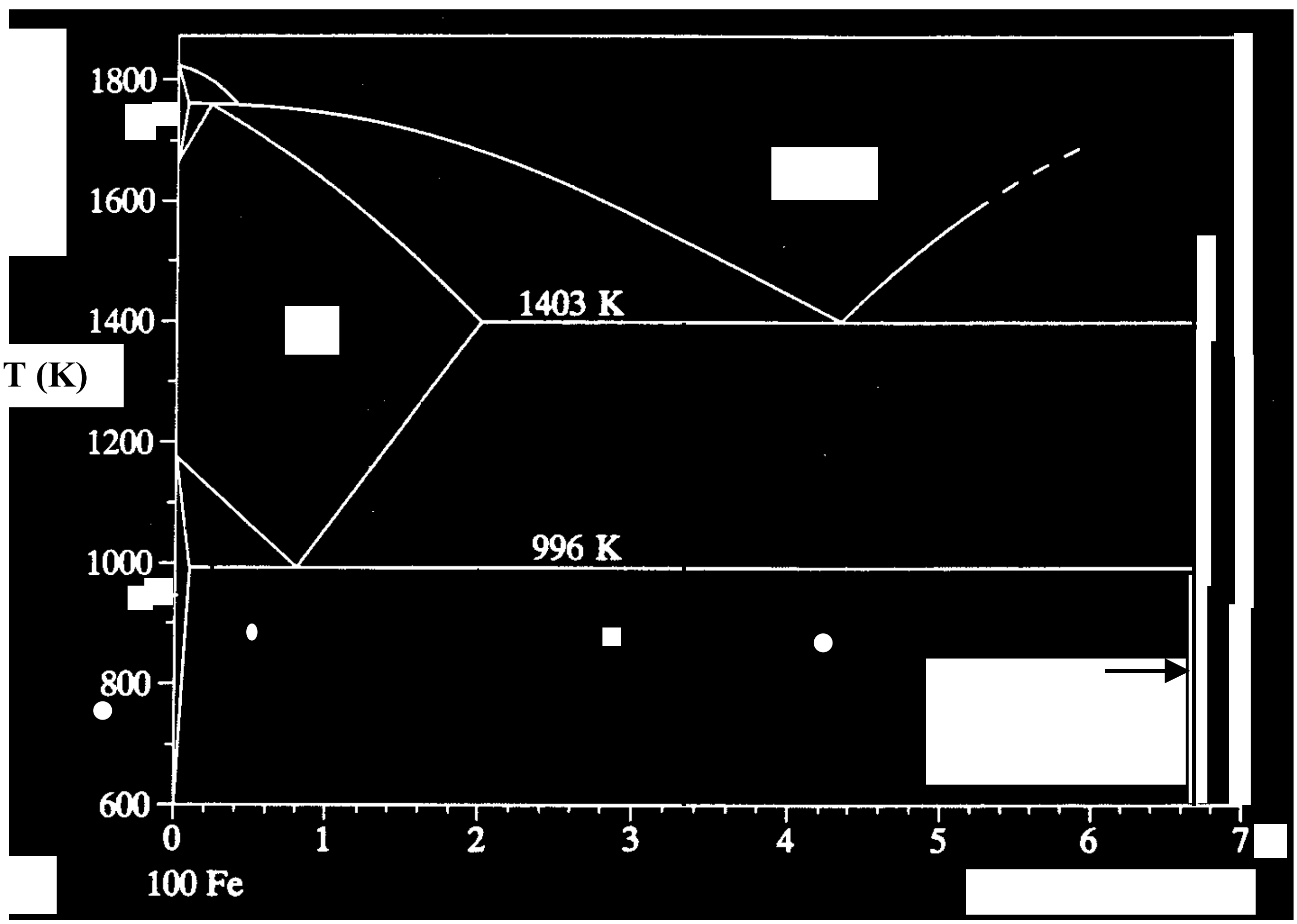


Figure Q2.

Question 3: (38 Points)

Marks

(a) What does the acronym **SEM** stand for? **4**

(b) What does the acronym **TEM** stand for? **4**

(c) Which of the two instruments above is most appropriate for viewing *dislocations* and *nano-structures* (i.e. *near-atomic structures*)? **2**

(d) Sate the TWO steps involved in a phase transformation. **6**

(e) The total change in free energy required for nucleation of a spherical solid precipitate from the matrix is given by:

$$\Delta G = \frac{4}{3}\pi r^3 \Delta G_v + 4\pi r^2 \gamma \ + \frac{4}{3}\pi r^3 \varepsilon$$

In this equation, state what the following stand for:

ΔG_v = **3**

γ = **3**

ε = **3**

r = **3**

(f) Re-write the above equation for the case of homogeneous nucleation of a spherical crystal from a pure liquid. Give reason(s) for your answer. **10**

Question 4: (37 Points)

		Marks
(a)	Why are *thin specimens* used for constructing TTT diagrams? Be very brief.	**4**
(b)	With respect to the Fe-Fe_3C alloy system, state TWO differences between a TTT diagram and an equilibrium phase diagram. Be very specific. Don't waste grammar.	**6**
(c)	Use **labelled sketches** ONLY (No description, no grammar!) to distinguish between the nucleation and growth of *pearlite* and *bainite* in steels.	**10**
(d)	With **well-labelled diagrams** ONLY (No description, no grammar), distinguish between a *phase boundary* and a *grain boundary*.	**8**
(e)	State THREE distinct reasons why alloying elements are added to plain-carbon steel bases to make alloy steels.	**9**

Question 5: (71 Points)

Points

Figure Q5 shows the TTT diagram for a commercial AISI-SAE 1080 plain-carbon steel.

(a) Label Figure Q5 using the following labels (the *shorthands* can save you time): **28**

γ_s = stable austenite, γ_u = unstable austenite, N = nose, CP = coarse pearlite, FP = fine pearlite, UB = upper bainite, LB = lower bainite, M = martensite, P_s = pearlite start, P_f = pearlite finish, B_s = bainite start, B_f = bainite finish, M_s = Martensite start temperature, A_1 = eutectoid temperature

(b) What is the approximate temperature (°C) at which the most rapid rate of transformation from austenite (γ-iron) to ferrite (α-iron) and Fe_3C occurs? **5**

(c) Small thin pieces of 0.25-mm-thick hot-rolled strips of AISI-SAE 1080 steel are heated for 1 h at 850 °C and given the heat treatments below. Using the TTT diagram of in Question 5(a) and other knowledge, determine the microstructures of the samples after each heat treatment. <u>Indicate the appropriate proportion of final microstructures in %</u>.

(i) Brine-quench to -20 °C **4**

(ii) Hot-quench in molten salt bath to 680°C and hold 3 h; brine quench to -20 °C. **4**

(iii) Hot-quench in molten salt to 600 °C in molten salt bath and hold 3 min; brine quench to -20 °C. **4**

(iv) Hot-quench in molten salt to 580 °C in molten salt bath and hold 4 s; brine quench to -20 °C. **8**

(v) Hot-quench in molten salt to 450 °C in molten salt bath and hold 1 h; brine quench to -20 °C. **4**

(vi) Hot-quench in molten salt to 300 °C in molten salt bath and hold 500 s; brine quench to -20 °C; re-heated to 350 °C for 1 h and cooled to room temperature. **10**

(vii) Hot-quench in molten salt to 300 °C in molten salt bath and hold 5 h; brine quench to -20 °C. **4**

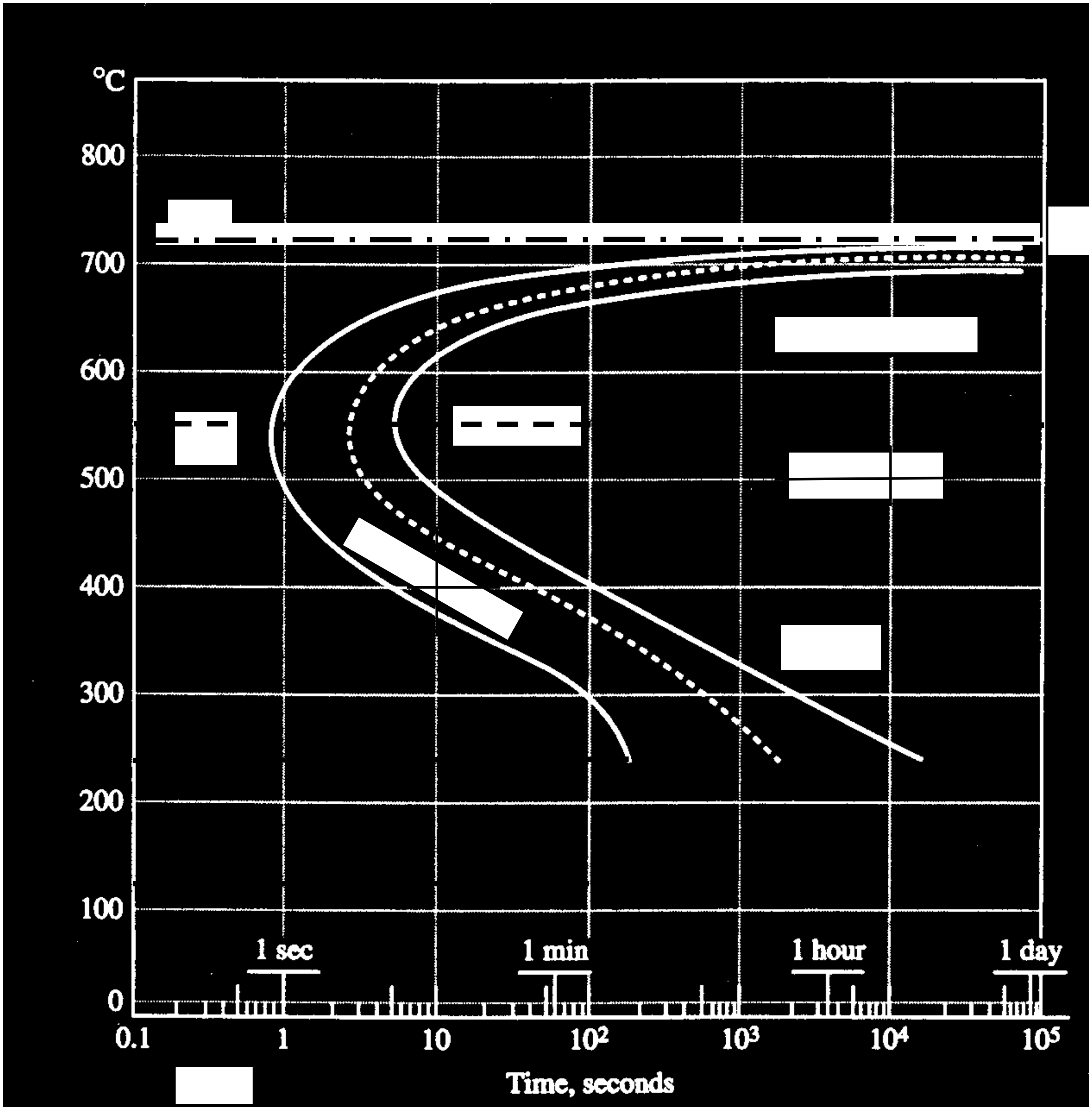

°C
800
700
600
500
400
300
200
100
0
1 sec
1 min
1 hour
1 day
0.1
1
10
10²
10³
10⁴
10⁵
Time, seconds

Figure Q5.

Question 6: (28 Points)

Marks

(a) Distinguish between a *low-carbon steel* and a *hypoeutectoid steel*. Be very brief. **4**

(b) Distinguish between a *high-carbon steel* and a *hypereutectoid steel*. Be very brief. **4**

(c) A commercial steel (1XXX steel) has the following composition (wt.%):
0.79 C, 0.76 Mn, 0.026 P, 0.03 S, and 0.21 Si.

(i) State the appropriate class for this steel using ONLY **one** of the following: *low-carbon steel*, *medium-carbon steel*, *high-carbon steel*, *low-alloy steel*, or *high-alloy steel*. **3**

(ii) Write the AISI-SAE number for this steel. **4**

(d) A commercial Nickel Steel (2XXX steel) has the following composition (wt.%):
0.39 C, 0.52 Mn, 0.007 P, 0.016 S, 0.28 Si, 5.00 Ni, 0.17 Cr, 0.15 Mo

(i) State the appropriate class for this steel using ONLY **one** of the following: *low-carbon steel*, *medium-carbon steel*, *high-carbon steel*, *low-alloy steel*, or *high-alloy steel*. **3**

(ii) Write the AISI-SAE number for this steel. **4**

(e) Why is manganese (Mn) usually intentionally added to steels? Be very brief. **6**

Question 7: (28 Points)

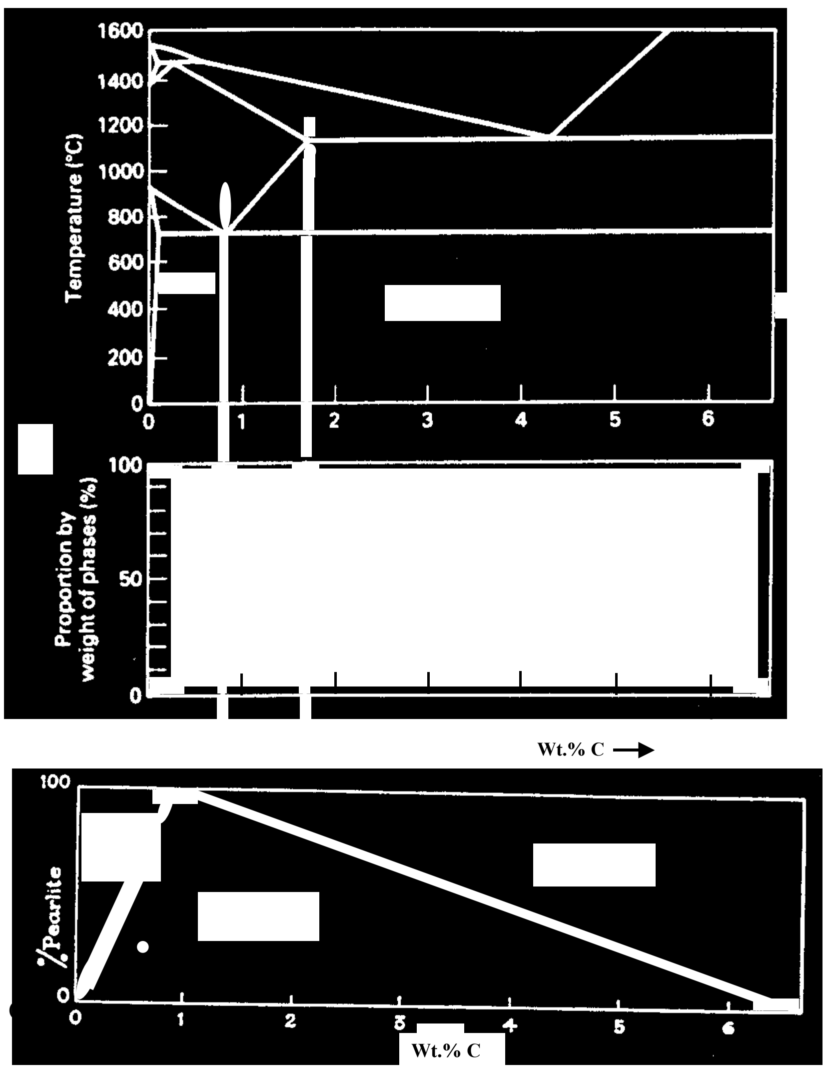
Points

The wt% of *ferrite*, *cementite* and *pearlite* formed in plain-carbon steels varies with carbon content. As wt% C varies from 0 to 6.67, the proportions of these microstructures change in a particular manner. Figure Q7(a) shows the equilibrium Fe-Fe_3C phase diagram. In Figures Q7(b) and (c) you are to plot how the proportions of these microstructures change with wt.% C (from 0 to 6.67 wt% C). Note that the diagrams are not drawn to scale. Consider room temperature structures in slowly cooled steel.

(a) Using Figure Q7(b), show how the proportion of ferrite formed in plain-carbon steel varies with wt.% C (from 0 to 6.67wt%). Clearly indicate the "start" and "end" of your plot. Use straight lines. **8**

(b) Using Figure Q7(b), as in (a), obtain a similar plot for cementite. **8**

(c) Using Figure Q7(c), show how the proportion (wt%) of pearlite formed in plain-carbon steels varies with carbon content (from 0 to 6.67wt% C). **12**



Figures Q7(a)-(c)