# COE-C2004 - Materials Science and Engineering

## 2022-2023 Autumn II Final Exam – Written part

**05.12.2022 08:45-10:45**

**General rules:**

- **Keep your microphone and video camera open during the whole exam.**
- The written exam is an open book exam so you can utilize all materials.
- **Discussion is strictly prohibited during both written and oral exams.**
- Zoom chat is used for any possible announcements and students' questions during the exam.
- You are suggested to turn off your speaker from 08:45 to 10:45 and only pay attention to the ZOOM chat.
- When required, always show the step-by-step derivation or calculation processes, without which hinting the number does not qualify for grades.
- When required, always give a brief and concise explanation or description, without which hinting the right choice or answer does not qualify for grades.
- There are 12 tasks in total in the written exam.

**Timeline:**

08:30-08:45 Preparation for the exam
08:45-10:45 Written exam
10:45-11:00 Create one PDF file and submit
**No more extended submission after 11:00!**
11:00-13:00 Oral exam (~15 mins for each group)
The grouping and exact oral exam time for each group will be announced at 10:55-11:00 via ZOOM.

**Values of physical constants:**

| Quantity | Symbol | Value |
|---|---|---|
| Permittivity of a vacuum | $\epsilon_0$ | $8.85 \times 10^{-12}$ F/m |
| Electron charge | $e$ | $1.602 \times 10^{-19}$ C |
| Avogadro's number | $N_A$ | $6.022 \times 10^{23}$ atoms/mol |
| Boltzmann's constant | $k$ | $1.38 \times 10^{-23}$ J/atom · K<br>$8.62 \times 10^{-5}$ eV/atom · K |
| Gas constant | $R$ | 8.31 J/mol·K |
| Planck's constant | $h$ | $6.63 \times 10^{-34}$ J · s |

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**Task 1. (5 points)** (Derivation or calculation steps are necessary)

The atomic radii of $Li^{+}$ and $O^{2-}$ ions are 0.068 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?

**Task 2. (10 points)** (Derivation or calculation steps are necessary)

(a) Using Figure 1, calculate the percent ionic character of the interatomic bonds for the intermetallic compound $TiAl_3$.

(b) On the basis of this result what type of interatomic bonding would you expect to be found in $TiAl_3$? And why?

| IA | IIA | IIIB | IVB | VB | VIB | VIIB | VIII | VIII | VIII | IB | IIB | IIIA | IVA | VA | VIA | VIIA | 0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 H 2.1 | | | | | | | | | | | | | | | | | 2 He – |
| 3 Li 1.0 | 4 Be 1.5 | | | | | | | | | | | 5 B 2.0 | 6 C 2.5 | 7 N 3.0 | 8 O 3.5 | 9 F 4.0 | 10 Ne – |
| 11 Na 0.9 | 12 Mg 1.2 | | | | | | | | | | | 13 Al 1.5 | 14 Si 1.8 | 15 P 2.1 | 16 S 2.5 | 17 Cl 3.0 | 18 Ar – |
| 19 K 0.8 | 20 Ca 1.0 | 21 Sc 1.3 | 22 Ti 1.5 | 23 V 1.6 | 24 Cr 1.6 | 25 Mn 1.5 | 26 Fe 1.8 | 27 Co 1.8 | 28 Ni 1.8 | 29 Cu 1.9 | 30 Zn 1.6 | 31 Ga 1.6 | 32 Ge 1.8 | 33 As 2.0 | 34 Se 2.4 | 35 Br 2.8 | 36 Kr – |
| 37 Rb 0.8 | 38 Sr 1.0 | 39 Y 1.2 | 40 Zr 1.4 | 41 Nb 1.6 | 42 Mo 1.8 | 43 Tc 1.9 | 44 Ru 2.2 | 45 Rh 2.2 | 46 Pd 2.2 | 47 Ag 1.9 | 48 Cd 1.7 | 49 In 1.7 | 50 Sn 1.8 | 51 Sb 1.9 | 52 Te 2.1 | 53 I 2.5 | 54 Xe – |
| 55 Cs 0.7 | 56 Ba 0.9 | 57–71 La–Lu 1.1–1.2 | 72 Hf 1.3 | 73 Ta 1.5 | 74 W 1.7 | 75 Re 1.9 | 76 Os 2.2 | 77 Ir 2.2 | 78 Pt 2.2 | 79 Au 2.4 | 80 Hg 1.9 | 81 Tl 1.8 | 82 Pb 1.8 | 83 Bi 1.9 | 84 Po 2.0 | 85 At 2.2 | 86 Rn – |
| 87 Fr 0.7 | 88 Ra 0.9 | 89–102 Ac–No 1.1–1.7 | | | | | | | | | | | | | | | |

Figure 1 The electronegativity values for elements.

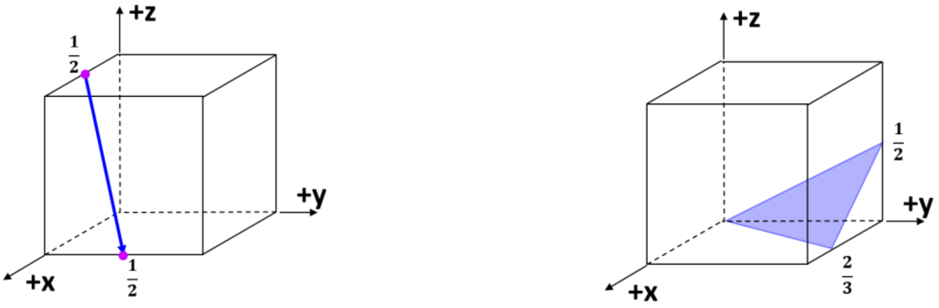
**Task 3. (8 points)** (Derivation or calculation steps are necessary)

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%".

**Task 4. (4 points)** (Derivation or calculation steps are necessary)

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 2.




(a) (b)

Figure 2 Drawings for Task 4.

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**Task 5. (6 points)** (Derivation or calculation steps are necessary)

Consider a single crystal of some hypothetical metal that has the FCC crystal structure and is oriented such that a tensile stress is applied along a $[\bar{1}02]$ direction. If slip occurs on a (111) plane and in a $[\bar{1}01]$ direction, compute the stress at which the crystal yields if its critical resolved shear stress is 3.42 MPa.

**Task 6. (8 points)**

Consider the schematic nanostructure depicted in Figure 3. Name the structure defects in eight black circle regions. The black regions are marked with IDs 1, 2, 3, 4, 5, 6, 7, 8 (The region IDs are indicated close to their black circles). The three kinds of solid balls with different colors/sizes represent three kinds of atoms.

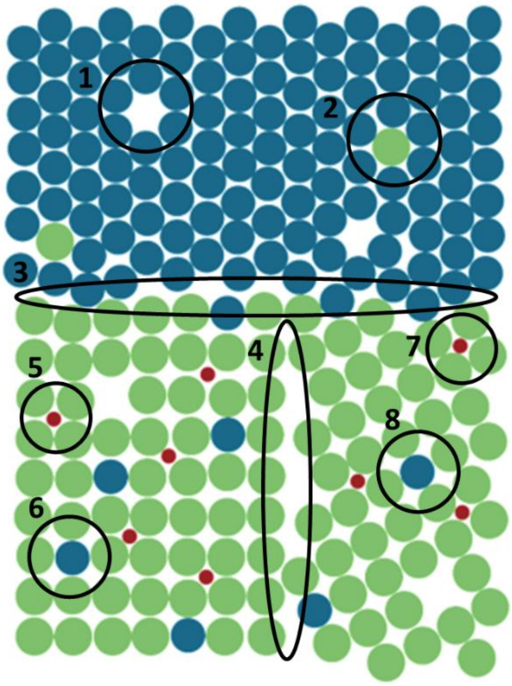


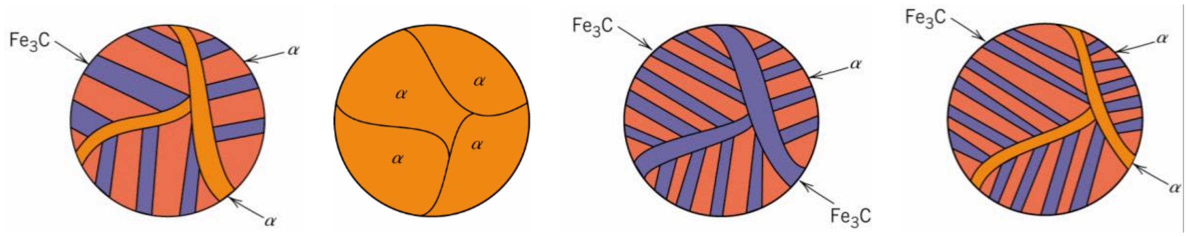

Figure 3 Drawing for Task 6.

**Task 7. (5 points)** (Derivation or calculation steps are necessary)

A cylindrical specimen of an alloy with a diameter of 8.2 mm is stressed elastically in tension. A force of 15,700 N produces a reduction in specimen diameter of $5.5 \times 10^{-3}$ mm. Calculate the Poisson's ratio for this material if its modulus of elasticity is 140 GPa.

**Task 8. (6 points)** (Explanation or description is necessary)

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)

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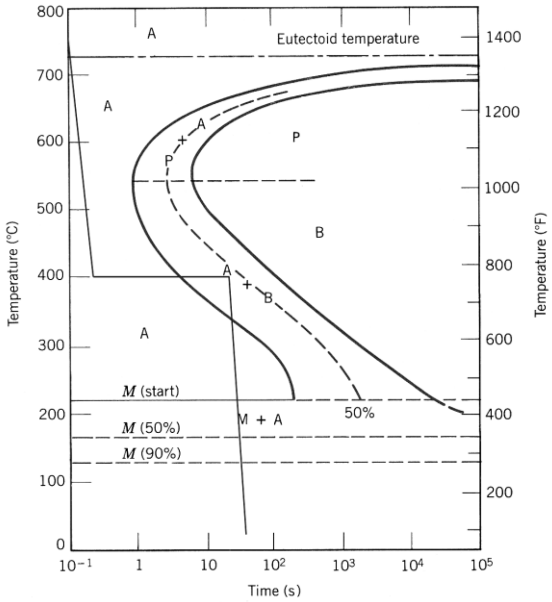
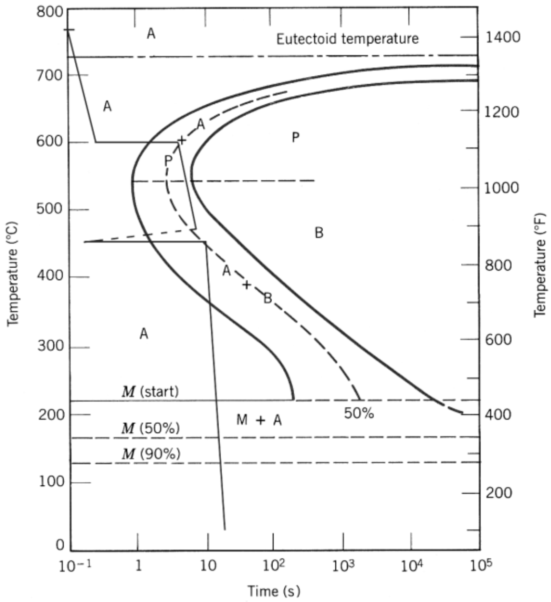
**Task 9. (12 points)** (Explanation or description is necessary)

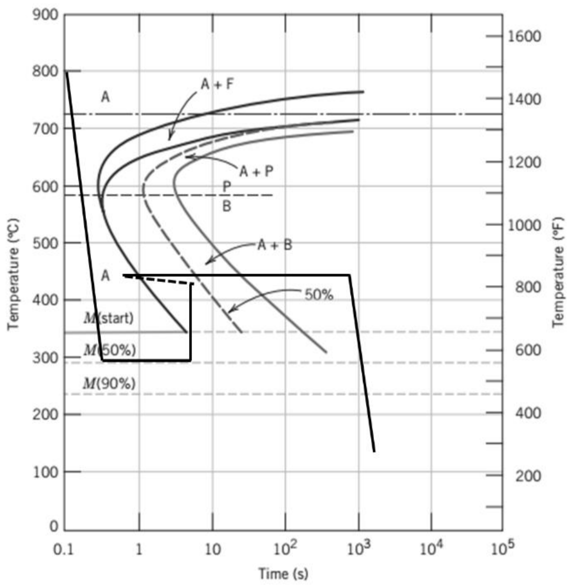
Figure 4 shows different isothermal transformation diagrams for iron–carbon alloys of eutectoid composition. List the microconstituent(s) present for the time–temperature paths indicated in figures (a-d) and briefly explain the reasons.



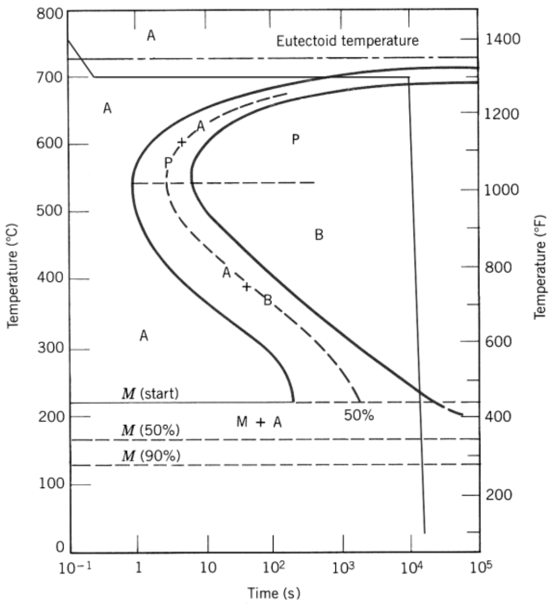

(a)




(b)




(c)




(d)

Figure 4 Isothermal transformation diagrams for iron–carbon alloys of eutectoid composition.

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**Task 10. (9 points)**

Indicate all the eutectic, eutectoid, and peritectic reaction points (if any) with their temperatures in Figure 5 (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.

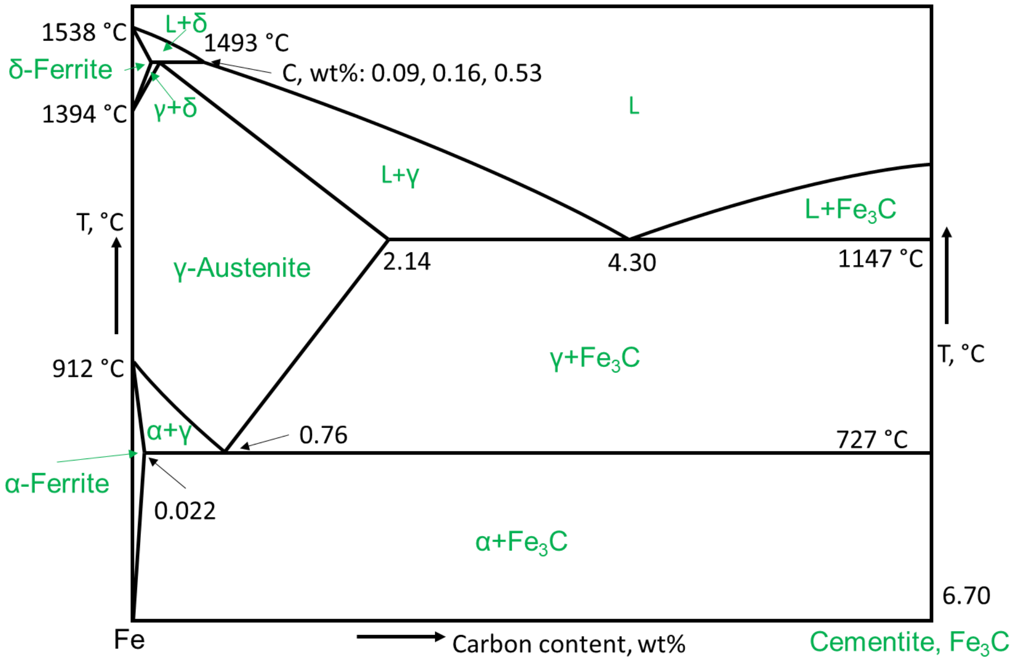


Figure 5 Fe-$Fe_3C$ phase diagram.

**Task 11. (9 points)** (Derivation or calculation steps are necessary)

Consider 1.0 kg of austenite containing 1.15 wt% C, cooled down below 727 °C. Please use the data from the Fe-$Fe_3C$ phase diagram in Figure 5.

(a) What is the proeutectoid phase?

(b) How many kilograms of pearlite and the proeutectoid phase form?

(c) How many kilograms of total ferrite and cementite form?

(d) Schematically sketch and label the resulting microstructure.

**Task 12. (18 points)** (Derivation or calculation steps are necessary)

When a metal is heated up, its density ρ decreases (without phase transformation). For the specific metal here, there are two sources that give rise to this decrease of ρ: (1) the thermal expansion of the solid, and (2) the formation of vacancies. Consider a specimen of FCC-copper at room temperature (20 °C) that has a density of 8.940 g/cm$^3$.

(a) Determine its density upon heating to 1000 °C when only thermal expansion is considered.

(b) Determine its density when the introduction of vacancies is also taken into account.

(The energy of vacancy formation $Q_v$ is 0.90 eV/atom, the volume coefficient of thermal expansion $\alpha_v$ is $5.1\times10^{-5}$ 1/°C, atom weight $A_{Cu} = 63.55$ g/mol)

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