

American University of Beirut
Faculty of Engineering & Architecture

MECG045: Engineering Materials

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Date: 06/02/2002

Final Exam

Duration: 3 hours

Open Book Open Notes

Write clearly all derivations and answers on this Final Exam booklet

Name:

ID#:

True or False [10 Points]

Answer with T(ue) or F(alse) to the following questions (1 point each)

	A cored microstructure can develop in an alloy cooled from the melt if the diffusion rate of the constituent atoms are too low
	Brittle fracture is preceded by necking
	Annealing is performed to increase the hardness of martensitic alloys.
	Martensite is a metastable phase of steel
	Pearlite is only formed when the overall composition of austenite lies directly in line with the eutectoid invariant point.
	In solid state reactions, the initial slow period of reaction is attributed to the time required for nucleation.
	Proeutectoid ferrite forms before pearlite in hypereutectoid steel
	Dislocations move most easily in a crystal along the highest density planes along the lowest density direction.
	Phase diagrams give only equilibrium information about the stability of phases
	The interstitial diffusion coefficient for a small atom diffusing in a metal is usually larger than its diffusion coefficient via a vacancy mechanism

Multiple Choice [2 Points for each question]

Circle the appropriate answer for these questions

- Which of the following statements is NOT true
 - The [100], [010] & [001] are equivalent in the cubic system
 - The [100] & [001] are equivalent in the cubic system
 - The [100], [010] & [001] are equivalent in the tetragonal system
 - The [100] & [010] are equivalent in the tetragonal system
- The pearlite microstructure is formed
 - in hypereutectoid steels

- (b) in hypoeutectoid steels
- (c) in eutectoid steels
- (d) all of the above
- (e) none of the above

3. Within the elastic limit

- (a) Strain is produced by bond breaking and reforming
- (b) Stress is proportional to strain
- (c) Complete recovery of strain is not possible
- (d) Strain is produced by bond stretching
- (e) b and d, are correct
- (f) a and b, are correct

4. A ceramic is likely to fail under which condition (consider the crack tip radius to be equal in all cases).

- (a) There is a surface flaw 2 μm in length with its long axis perpendicular to the stress.
- (b) There is an internal flaw 1 μm in length with its long axis parallel to the stress.
- (c) There is an internal flaw 4 μm in length with its long axis parallel to the stress
- (d) There is a surface flaw 2 μm in length with its long axis parallel to the stress
- (e) There is an internal flaw 1 μm in length with its long axis perpendicular to the stress.

5. Aluminum-lithium alloys are hardened by

- (a) forming precipitates of a lithium-rich phase
- (b) decreasing the number of grains in the material
- (c) a purification process
- (d) increasing dislocation content

Problem 2 [5 Points for each question]

1. An FCC crystal is subjected to a tensile stress, σ , of 140 MPa along the $[\bar{1}\bar{1}2]$ direction. Calculate the force per unit length on dislocations that lie on the $(\bar{1}\bar{1}1)$ plane and have the following Burgers vectors: $\frac{a}{2}[\bar{1}10]$ and $\frac{a}{2}[101]$. Let $a = 2.5 \times 10^{-10}$ m.

solution

(problem 5.8)

2. Given the fact that platinum is FCC with atomic weight 195, calculate the mass of one unit cell. Then, given the density = 21.5 g/cm³, calculate the size of the unit cell and the diameter of a Pt atom. Finally, calculate the areal density of packing of Pt atoms on a close-packed (111) plane. (Consider the plane to pass through the centers of the atoms.)

4.2 There are four atoms per unit cell. The mass of four atoms would be

$$4 \times \frac{195.1}{6.022 \times 10^{23}} = 1.3 \times 10^{-21} \text{g}$$

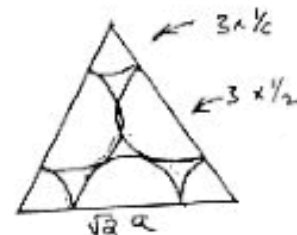
The volume of a unit cell would be its mass divided by its density:

$$\frac{1.3 \times 10^{-21} \text{g}}{21.5 \text{g/cm}^3} = 6.0 \times 10^{-23} \text{cm}^3$$

The size of the unit cell, a , would be the cube root of the volume, and the diameter of a Pt atom would be $\sqrt{2}a/2$:

$$a = (6.0 \times 10^{-23})^{1/3} = 3.9 \times 10^{-8} \text{cm}; \quad \text{atom diam} = 2r = 2.76 \times 10^{-8} \text{cm}$$

The areal density of packing of Pt atoms on a (111) plane is found by dividing the total area occupied by atoms by the area of the plane. In a unit cell, the (111) plane subtends an equilateral triangle with a side of length $\sqrt{2}a$, and it contains a total of 2 atoms, as shown. Using the fact that $4r = \sqrt{2}a$, and that the area of the plane is $1/2$ base \times height, or $1/2 \sqrt{2}a \sqrt{3}a/\sqrt{2}$,



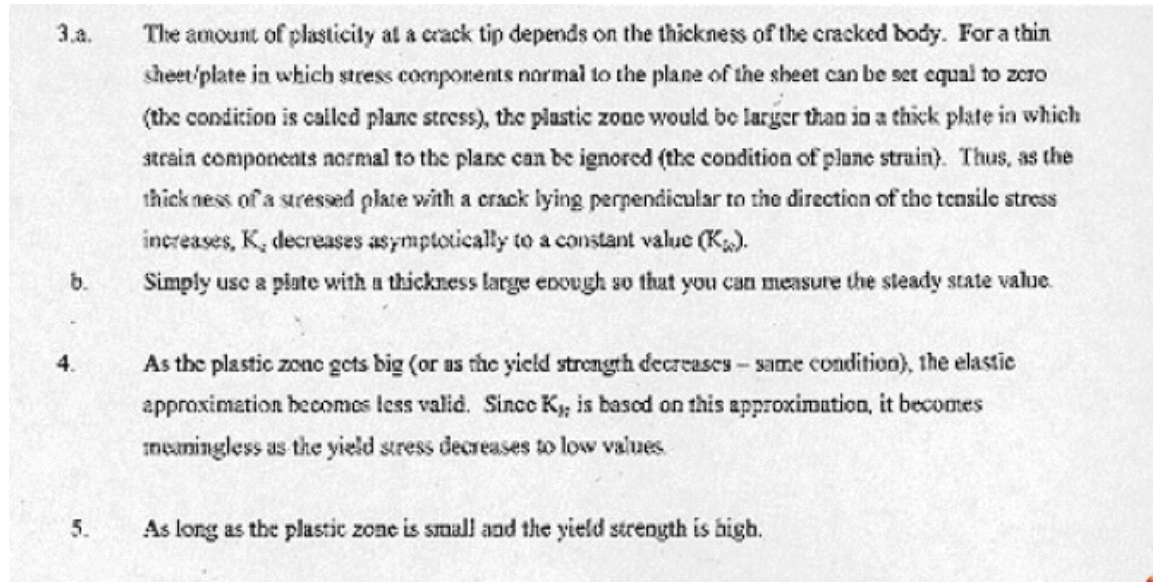
$$\text{packing density} = \frac{2\pi (2a/4)^2/16}{\sqrt{3}a^2/2} = 0.91$$

3. If you were to plot the value of K_{IC} for a stressed plate with a crack lying perpendicular to the direction of the tensile stress vs. the thickness of the plate, the curve would descend asymptotically to a constant value.

(a) Rationalize this behavior.

(b) How would you use this fact to specify a test that would produce a value of K_{IC} that could be used as a material constant?

(c) Why is it that the value of K_{IC} becomes meaningless as the yield strength is decreased to relatively low values?



4. A sheet of steel 1.5×10^{-3} m thick having different pressures of nitrogen on both sides at 1200°C , is permitted to achieve steady-state diffusion conditions. The diffusion coefficients for nitrogen in steel at this temperature is 6×10^{-11} m^2/sec and the diffusion flux is found to be 1.2×10^{-7} $\text{kg}/\text{m}^2\text{-sec}$. The surface concentration of nitrogen in the steel at the high-pressure side is $4 \text{ kg}/\text{m}^3$. How far into the sheet will the concentration of nitrogen be $2 \text{ kg}/\text{m}^3$. Assume a linear profile.

Problem 3 [5 points each]

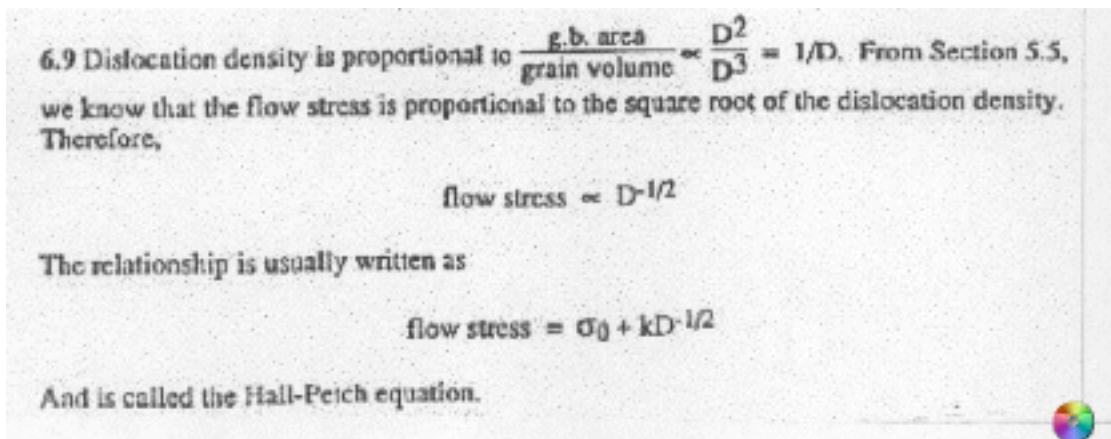
1. Suppose that the activation energy for the growth stage of recrystallization of a stainless steel spoke were 180kJ/mole. Calculate the annealing temperature needed to triple the rate of growth that you would find at 700°C. The gas constant R is 8.31J/K·Mole.

$$\begin{aligned} \textcircled{1} \quad \frac{\text{Rate 1}}{\text{Rate 2}} &= 3 = \frac{\exp\left[-\left(\frac{180 \times 10^3}{8.31 \cdot T_2}\right)\right]}{\exp\left[-\left(\frac{180 \times 10^3}{8.31 \cdot T_1}\right)\right]} \\ &= \frac{\exp\left[-\left(\frac{180 \times 10^3}{8.31 \cdot T_2}\right)\right]}{\exp\left[-\left(\frac{180 \times 10^3}{8.31 \cdot 973}\right)\right]} \\ 3 \exp\left[-\left(\frac{180 \times 10^3}{8.31 \cdot 973}\right)\right] &= 6.4414 \times 10^{-10} = \exp\left[-\left(\frac{180 \times 10^3}{8.31 \cdot T_2}\right)\right] \\ \ln(6.4414 \times 10^{-10}) &= -\left(\frac{180 \times 10^3}{8.31 \cdot T_2}\right) = -21.1631 \\ \rightarrow \boxed{T = 1,023.5 \text{ K}} \end{aligned}$$

2. If grain boundaries are assumed to be the major sources of dislocations in a material, and if dislocation sources are uniformly distributed on grain boundaries, then the dislocation density, ρ , must be proportional to the grain boundary area per unit volume. Relate ρ to grain size d , and use this idea to show that the flow stress should vary with grain size according to

$$\sigma_{\text{flow}} = \sigma_0 + k d^{-1/2}$$

where σ_0 is the stress needed to overcome the effects of lattice friction, solute atoms, etc.; d is the average grain diameter, and k is a constant.



3. We would like to produce a 2in thick steel wear plate for a rock-crushing unit. To avoid frequent replacement of the wear plate, the hardness should exceed HRC 38 within 0.25 in of the steel surface. However, the center of the plate should have a hardness of no more than HRC 32 to assure some toughness. We have only a water quench available to us. Design the plate, assuming that we only have the steels given in Figure 11.5 of your book.

(add figure 11.5)

4. A manufacturer has for several years been making 16 mm diameter toggle pins, which in service are subjected to impact loadings, by machining a mild-steel bar and then case hardening the surface by carburizing. By mistake, the manufacturer was supplied with 0.5% carbon-steel bar which went through the same process

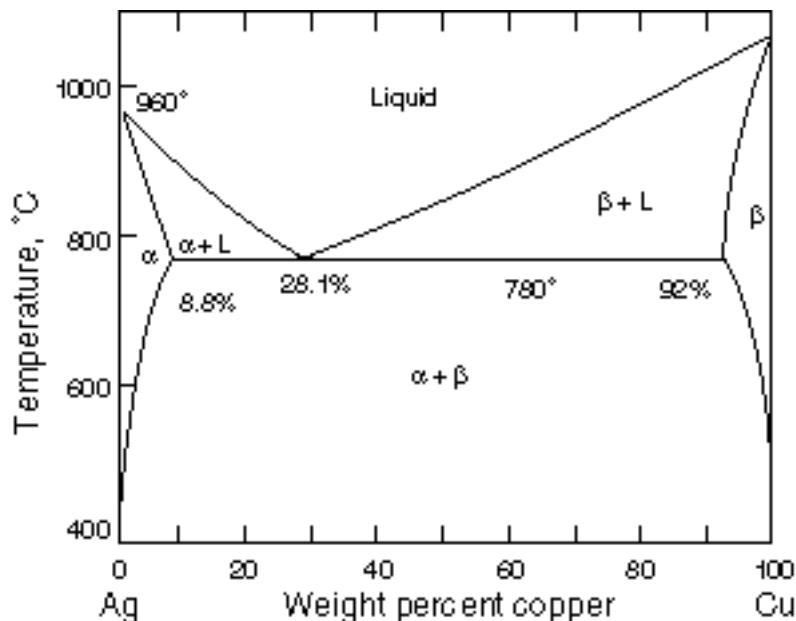
How would the properties of the pins be affected (toughness, ductility, strength). In view of these changes in properties would you recommend that they be allowed to go into service. Explain.

Problem 4 [5 points each]

1. Sterling silver is Ag-7.5%Cu. Using the phase diagram below, tell what the microstructure would look like if the alloy were melted and cooled slowly under equilibrium conditions to room temperature, and what it would look like if it were cooled too rapidly for equilibrium to be achieved. Make sketches to illustrate your answer.

6.4 Recrystallization involves the motion of boundaries of new grains as they grow to consume surrounding dislocated grains. These grain boundaries can be pinned by impurity particles, and their motion can be slowed down by segregated impurity atoms, both of which would be present in commercial purity aluminum.

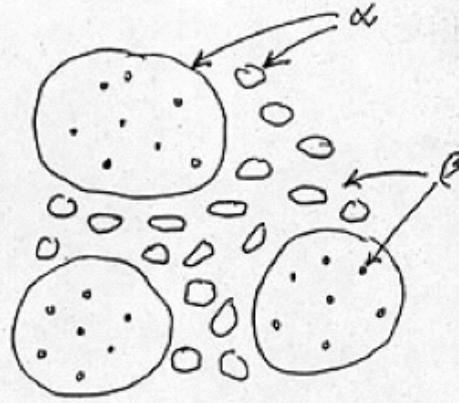
1.



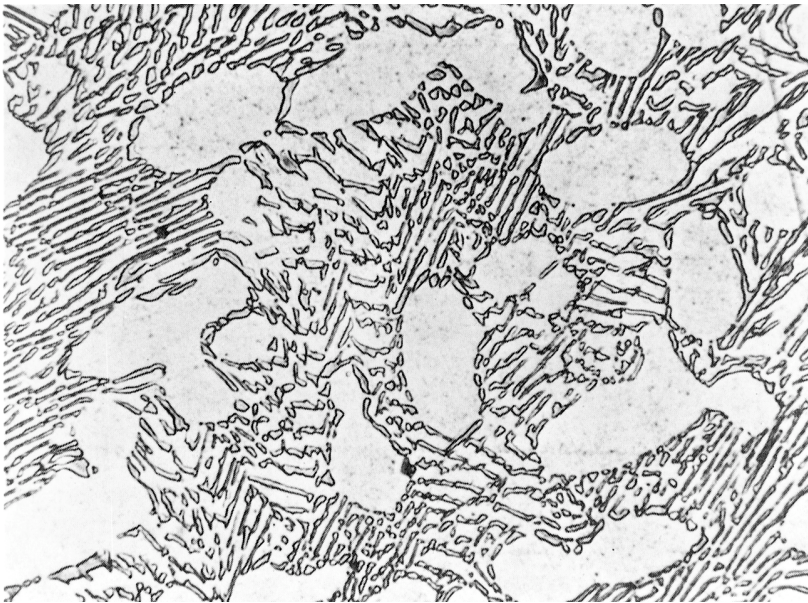
The Ag-7.5% Cu alloy when slowly cooled would have no eutectic constituent, because the eutectic line starts at 9%Cu. Therefore, the microstructure of a slowly cooled alloy would be polycrystalline (Ag-rich) α with precipitates of (Cu-rich) β , probably mostly at the α grain boundaries. If it were cooled too rapidly for equilibrium, then the α dendrites would be cored, and the non-equilibrium solidus line would lie below the equilibrium solidus, as explained in Fig. 8.18. The probable result would be the presence of a eutectic constituent, as found in the cast Pb-10%Sn alloy shown in Fig. 8.17.

2. Describe the changes that would occur in an alloy of Ag-70% Cu cooled from the liquid state to room temperature. Sketch the resulting microstructure and give the relative amount of each phase and each micro-structural constituent (i.e., primary phase and eutectic).

8.7 In a Ag-70%Cu alloy cooled slowly from the liquid phase, dendrites of β would begin to form at about 930°C , and the microstructure at 781°C would comprise about $2/3$ β and $1/3$ liquid of the eutectic composition. This last liquid would solidify into the eutectic constituent, comprising about $1/4$ β and $3/4$ α . Upon further cooling to room temperature, α would precipitate in the primary β dendrites (cf. Fig. 8.15), and some β would precipitate from the α in the eutectic, probably on the boundaries of the eutectic and primary β .



3. Given below is the microstructure of a Ag-Cu alloy of unknown composition. Deduce what the composition is and explain your reasoning. (Hint: Focus first on the eutectic constituent, and decide which phase is which, based on the phase diagram given in question 1 of this problem. Use area density to approximate fraction of each phase)

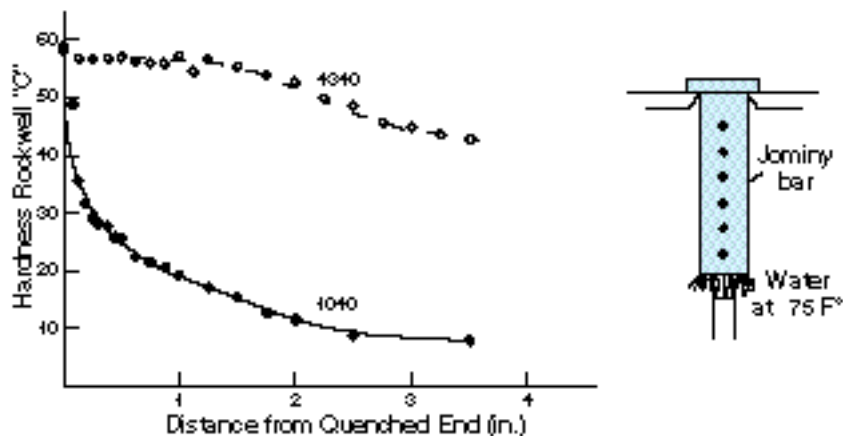


The figure shows a microstructure with about 1/4 primary phase and 3/4 eutectic constituent. The Ag-Cu phase diagram shown in Fig. 8.21(a) indicates the the majority phase in the eutectic would be the α phase. Thus, the matrix phase in the eutectic would be α . This is obviously the same as the primary phase; therefore, the latter is also α . Thus, the composition of the alloy is 3/4 of the way from 91%Ag to 72%Ag, if we assume that the alloy was cooled fairly rapidly from 780°C to room temperature and that the microstructure is not very different from what it was after solidification. Thus,

$$\frac{3}{4} (91 - 72) = 14$$

$$91 - 14 = 77\% \text{Ag}$$

4. The hardenability curves shown below both start at essentially the same hardness; explain why. Describe the expected microstructure at a distance of two inches from the quenched end in each steel.



10.3 Figure 10.7 shows the Jominy hardenability curves for a 1040 and a 4340 steel. Right at the quenched end, both steels are fully martensitic. Since they both have the same carbon content, they should both have the same hardness. (The hardness of martensite depends only on the carbon content.)

At 2 inches from the quenched end, the 4340 steel has a hardness of about 50Rc, down from about 59Rc at the quenched end. This is the result of formation of some ferrite, probably less than 10%; the rest of the microstructure would be martensite and bainite. The 1040 steel has a hardness of about 12Rc at this point, meaning that the microstructure is entirely ferrite and coarse pearlite.

Problem 5 [5 Points each]

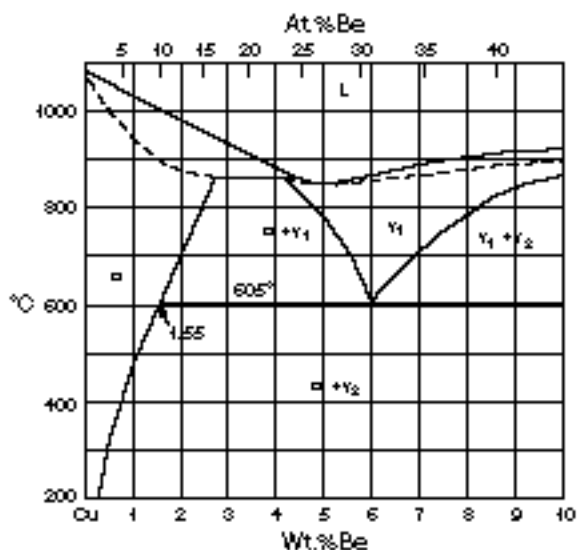
1. The skins of most commercial airplanes are fabricated from panels of precipitation-hardened aluminum-based alloys. However, these alloys cannot be used for many supersonic military aircraft; these require skins of stainless steel or titanium alloys, which results in a weight penalty. Explain why aluminum-based alloys cannot be used, considering the fact that supersonic flight entails aerodynamic heating by collisions of the aircraft with gas molecules in the air.

Also Explain why high-purity aluminum recrystallizes at a much lower temperature than commercial purity aluminum.

6.4 Recrystallization involves the motion of boundaries of new grains as they grow to consume surrounding dislocated grains. These grain boundaries can be pinned by impurity particles, and their motion can be slowed down by segregated impurity atoms, both of which would be present in commercial purity aluminum.

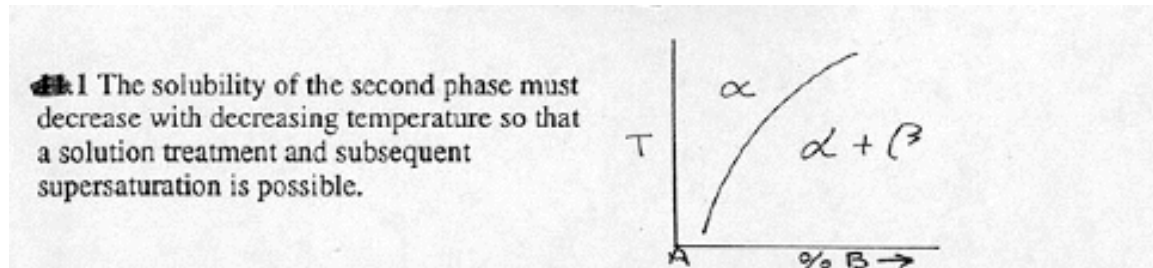
11.5 Aerodynamic heating of the airplane skin would lead to over-ageing, and thus softening of the skin, which is an important structural component of the airplane.

2. Copper with 2% beryllium is a precipitation-hardening alloy; the Cu-rich end of the phase diagram is given here. Describe the experiments you would do to devise the heat treatment that gives the maximum hardness in this alloy. (Keep it as simple as possible.)



11.6 For maximum possible hardening, pick an alloy near 2.5% Be; this will give the maximum volume fraction of precipitate. Solution treat at around 800°C; do not go above about 860°, because liquation could occur if there is some non-equilibrium γ_1 phase present. Age specimens at a series of low temperatures (e.g., 200 to 400°C) to see which gives the maximum hardness in an economically reasonable ageing time. 🌈

3. What kind of solvus line is needed for precipitation hardening? Explain your answer.



4. What other important characteristics must an alloy system have in order to exhibit precipitation hardening? Explain your answer.

11.2 An alloy system which is to exhibit precipitation hardening must be able to form a finely dispersed precipitate so that dislocations will be forced to cut through the second-phase particles, rather than loop around them. This requires a large ΔG_V (large undercooling) and a small interfacial energy. Thus, the system must be capable of forming a coherent, or semi-coherent, precipitate; this is often a metastable precursor to the equilibrium second phase. 🌈