1. The wear resistance of a steel shaft is to be improved by hardening its surface. This is to be accomplished by increasing the nitrogen content within an outer surface layer as a result of nitrogen diffusion into the steel; the nitrogen is to be supplied from an external nitrogen-rich gas at an elevated and constant temperature. The initial nitrogen content of the steel is 0.0025 wt%, whereas the surface concentration is to be maintained at 0.45 wt%. For the treatment to be effective, a nitrogen content of 0.12 wt% must be established at a position 0.45mm below the surface. Specify an appropriate heat treatment in terms of time for the temperature of 500 and 600℃. The preexponential and activation energy for the diffusion of nitrogen in iron are 3×10^{-7} m^2/s and 76,150 J/mol, respectively over the temperature range. (20%)

Table Tabulation of Error Function Values

Z	erf(Z)	Z	erf(Z)	Z	erf(Z)
0	0	0.55	0.5633	1.3	0.9340
0.025	0.0282	0.60	0.6039	1.4	0.9523
0.05	0.0564	0.65	0.6420	1.5	0.9661
0.10	0.1125	0.70	0.6778	1.6	0.9763
0.15	0.1680	0.75	0.7112	1.7	0.9838
0.20	0.2227	0.80	0.7421	1.8	0.9891
0.25	0.2763	0.85	0.7707	1.9	0.9928
0.30	0.3286	0.90	0.7970	2.0	0.9953
0.35	0.3794	0.95	0.8209	2.2	0.9981
0.40	0.4284	1.0	0.8427	2.4	0.9993
0.45	0.4755	1.1	0.8802	2.6	0.9998
0.50	0.5205	1.2	0.9103	2.8	0.9999

2. (A) The Scheil equation is normally derived using an idealized eutectic phase diagram, such as that in the following diagram. Derive the equation of solute concentration in the solid $C_s = k\,C_0\,(1-f_s)^{(k-1)}$ where k is the equilibrium redistribution coefficient and C_s and C_l are the solute concentrations by weight in the solid and liquid respectively, f_s represents the fraction by weight of the solid in the alloy. (6%)

(B) Consider the face-centered cubic crystal structure and the planes (100), (110), and (111). On the basis of the degree of close-packing associated with each plane, rank these planes in order of their growth velocity during freezing. Also rank the (100), (110), and (111) planes for the body-centered cubic lattice. Which plane is finally developed during crystal growth in both crystal structures? Explain why? (7%)

(C) It is desirable to produce castings with a very fine grain size. Give two basic ways of increasing the number of grains. (7%)

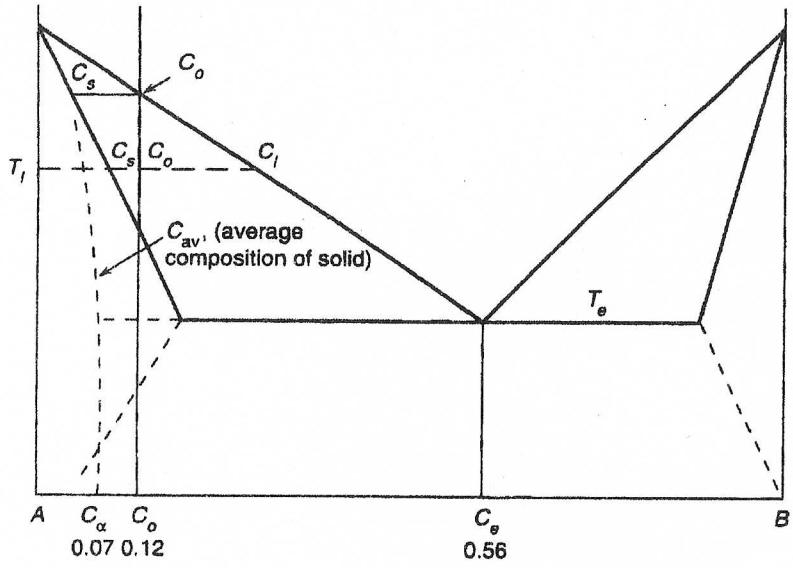
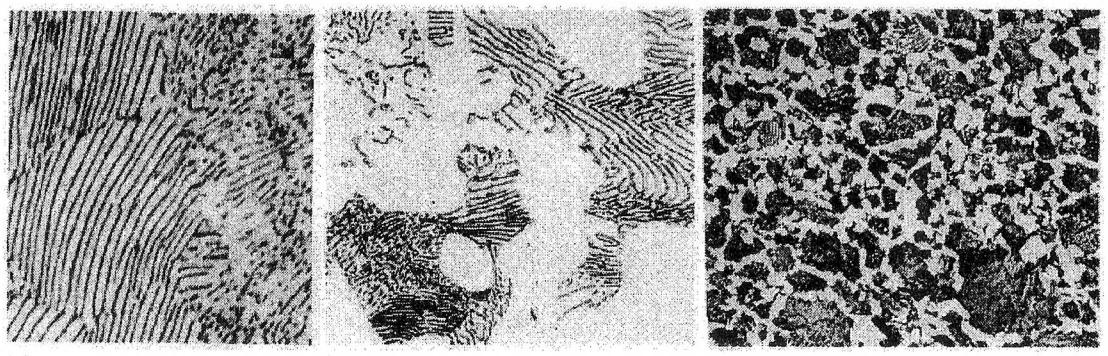


Fig. 14.26 Idealized eutectic phase diagram with the liquidus and solidus drawn as straight lines.

3.A graduate student dropped his steel specimens and can't remember which is which. He remembers that the three steel grades are 1030, 1045, and 1080, but that's all. With nothing at his disposal but optical metallography facilities and furnaces (and the Fe-C phase diagram attached to the test), he quickly devises a scheme to save his job. Vowing to carefully label the specimens next time, he puts all three in the oven to austenitize them for an hour.

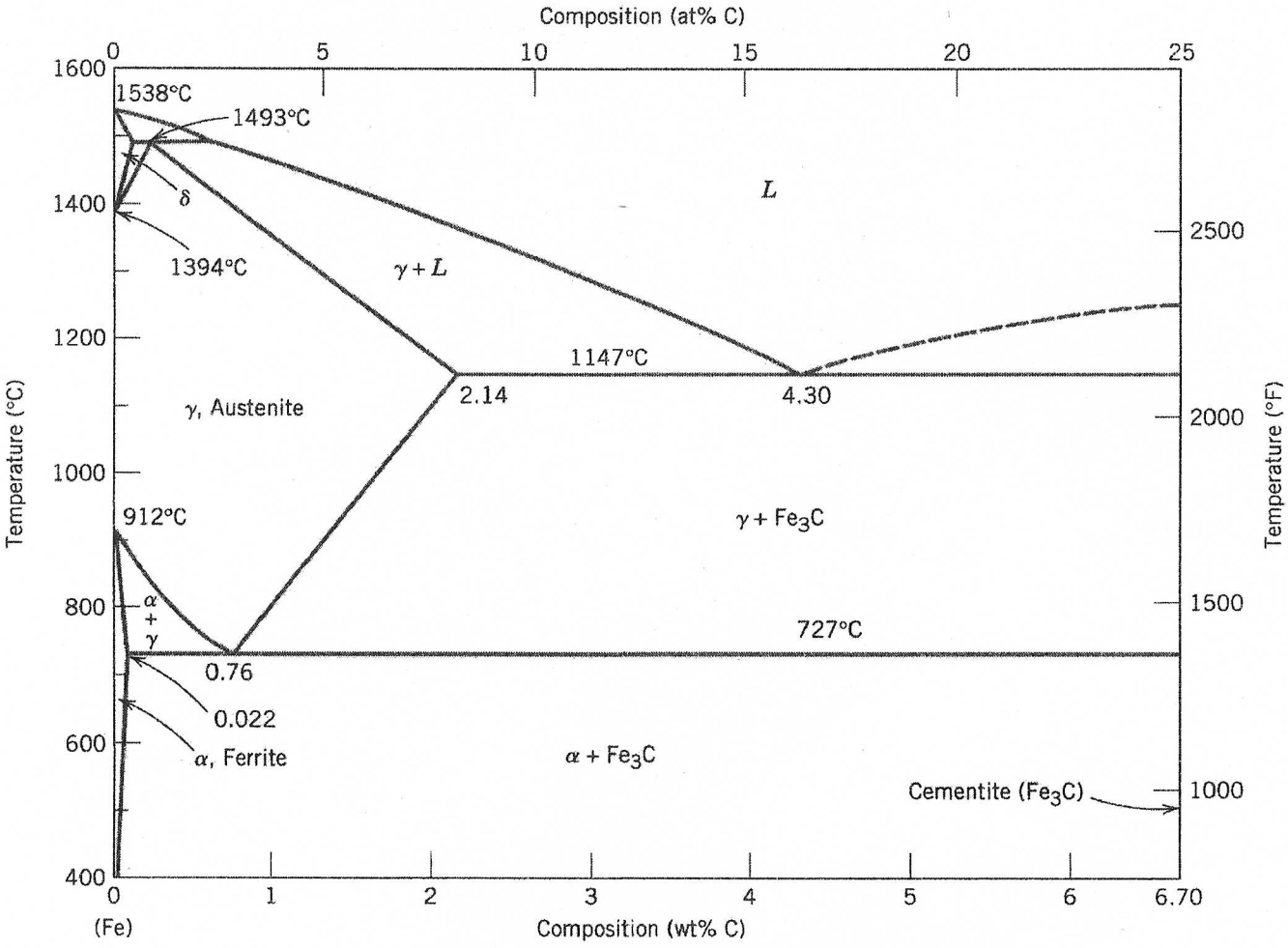
(A) What temperatures and times are acceptable for the austenitization and why? (10%)

After austenitizing he turns off the furnace and allow the specimens to cool very slowly. He obtains the following microstructures:



(a) (b) (c)

(B) You are supposed to help him identify which steel is which on the basis of the microstructures, and write the logic of your thought process that led to your conclusions. (10%)



The iron–iron carbide phase diagram.

4. The drag stress due to a dislocation atmosphere is one of the important components of the flow stress of a metal. Draw the figures to show the variation of the drag-stress with (A) the dislocation velocity, (B) the dislocation velocity at two different temperatures, (C) the strain rate, and (D) the temperature at constant strain rate. Give each figure a brief physical explanation. (20%)

5. (A) For the transformation that occurs on cooling, what are the effects of supercooling on the growth rate ? Why does the growth rate always increase with temperature in the reverse transformation (transformation on heating)? (10%)

(B) What is the critical radius of nucleation? Explain physically why this critical radius exists? (10%)