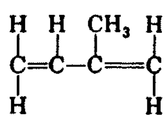
January 25, 1993 | I MAKE-UP : FINAL EXAMINATION | Time: Two hrs.

ENG. 170A

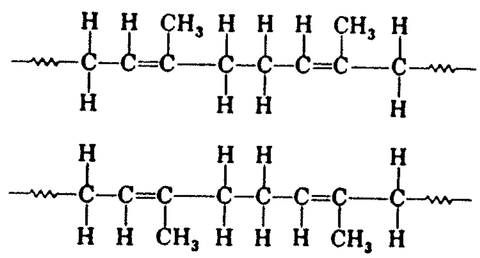
1(a). Using the attached iron-carbon phase diagram, distinguish between the three following types of plain-carbon steels : (i) eutectoid (ii) hypoeutectoid and (iii) hypereutectoid.
1(b). Describe the structural changes that take place when a plain-carbon eutectoid steel is slow-cooled from the austenitic region (950°C) to just below the eutectoid temperature. Calculate the amounts of the two phases present in a 8-kg steel body.
1(c). A 0.35%C hypo-eutectoid plain-carbon steel is slow-cooled from 950°C to a temperature just slightly below 727°C. Calculate the weight percent of proeutectoid ferrite in the steel.

2. Using the attached TTT-diagram, draw schematic time-temperature cooling paths for a 1080 steel which will produce the following microstructures: Start with the steels in the austenitic condition at t = 0 sec and T = 850°C. (i) 100% martensite (ii) 50% martensite + 50% coarse pearlite (iii) 100% fine pearlite (iv) 50% martensite + 50% upper bainite (v) 100% upper bainite and (vi) 100% lower bainite.

3. The structures of an isoprene monomer and isoprene polymer are shown in the figures, (a) and (b), below.



(a)



(b)

Calculate the percentage of sulfur (by weight) if all the possible cross-links in the isoprene molecule are filled. Atomic weights : C 12.011, H 1.008, S 32.064.

4(a). At what temperature will the conductivity of silicon be one-half the value at 22°C? The band gap is 1.1 eV and the Boltzmann constant $k = 8.61 \times 10^{-5}$ eV/°K.
4(b). An extrinsic semiconductor is made by adding boron to silicon to give an electrical resistivity of 1.80 ohm.meter. What type of semiconduction prevails in this material? Calculate the concentration of charge-carriers per cubic meter in the doped-silicon. Assume $\mu_n = 0.08\ m^2/V.s$ and $\mu_p = 0.048\ m^2/V.s$.

5. Calculate a theoretical value for the saturation magnetization and saturation induction for nickel, assuming all unpaired 3d electrons contribute to the magnetization. Nickel is FCC and a = 0.352 nm. One Bohr magneton = $9.27 \times 10^{-24}\ A.m^2$ and the permeability in vacuum (μ_o) is $4\pi \times 10^{-7}$ T.m/A, respectively.

6. A unidirectional carbon-fiber-epoxy-resin composite contains 62% by volume of carbon-fiber and 38vol% epoxy-resin. The densities are 1.75 g/cm^3 and 1.20 g/cm^3, repectively. (i) What are the weight percentages of the carbon and resin fractions of the composite? (ii) What is the average density of the composite?

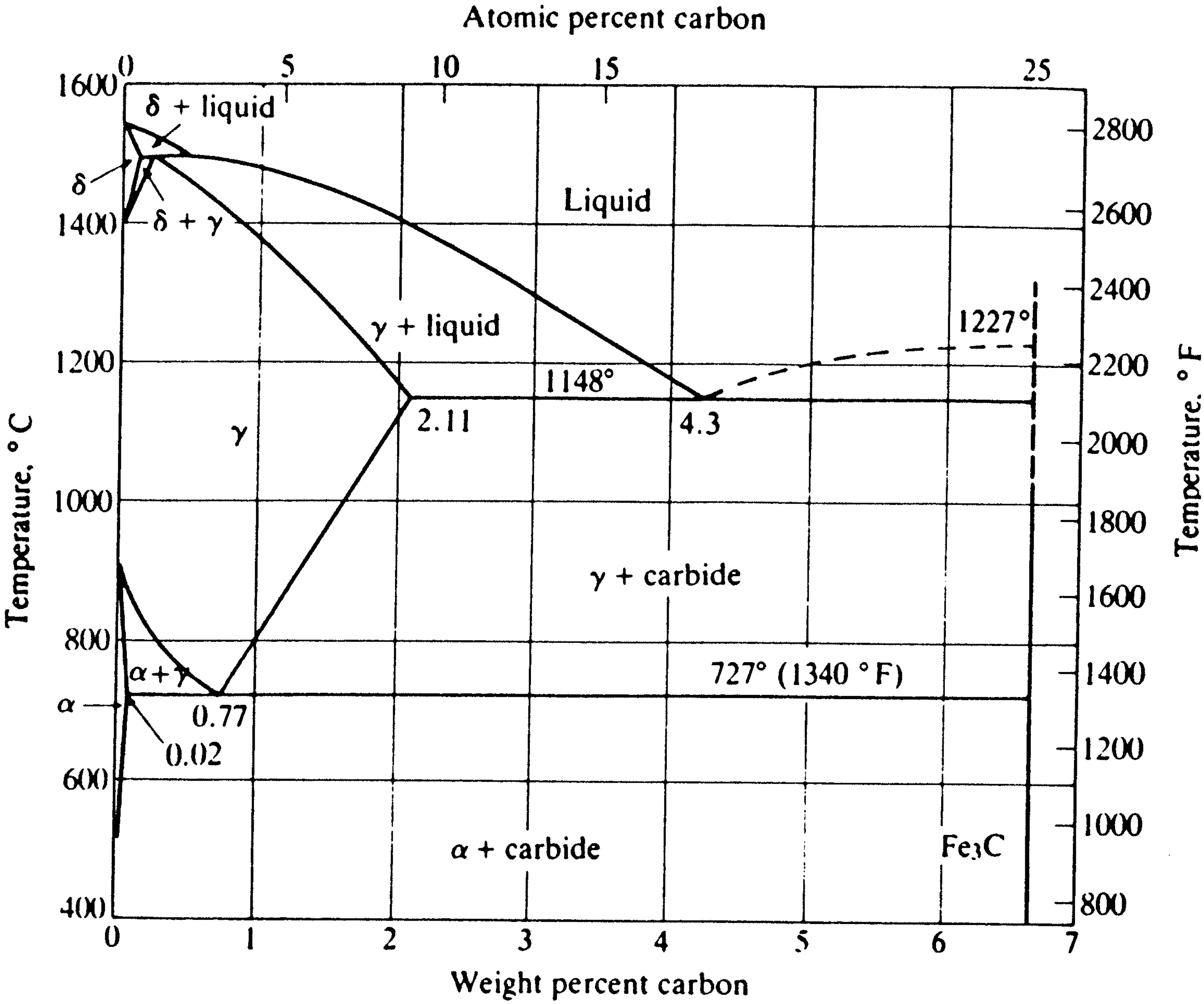


FIG. 5-5.1

Fe-Fe$_3$C Phase Diagram. The lower-left corner receives prime attention in heat-treating of steels (Fig. 7-3.1). (In calculations, 0.77 percent is commonly rounded to 0.8 percent.)

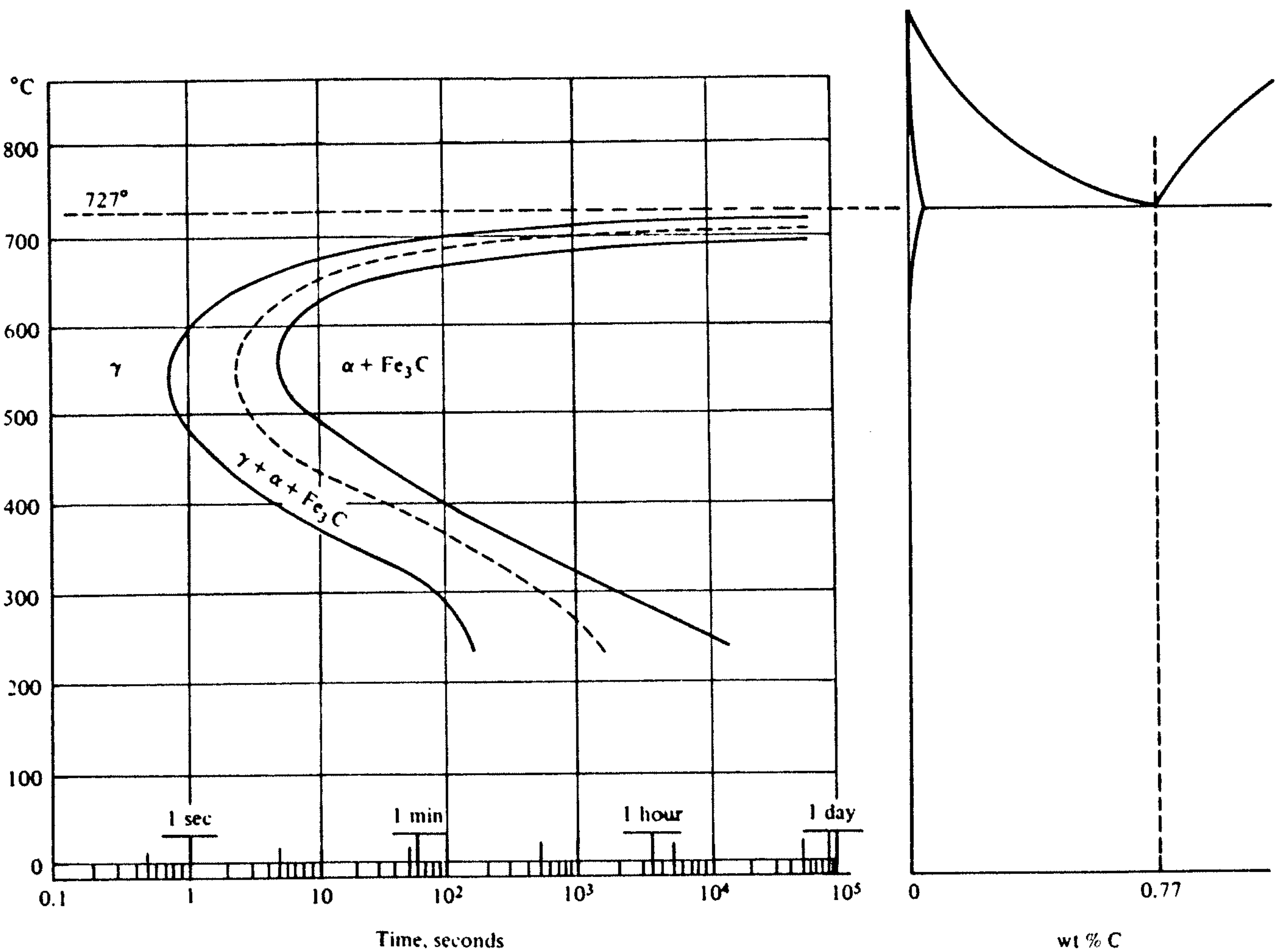


FIGURE 6.2-2 TTT diagram for eutectoid steel shown in relation to the Fe–Fe_3C phase diagram

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1(a). Eutectoid : Steels with 0.77 w/o (or 0.8 w/o) carbon

Hypoeutectoid : Steels with carbon content less than the eutectoid composition : < 0.77 w/o C.

Hypereutectoid : Steels with carbon content greater than the eutectoid composition : > 0.77 w/o C.

1(b). The plain-carbon eutectoid steel at 950°C is austenitic in structure. On slow-cooling it to a temperature just below the eutectoid temperature ($< 727°C$), austenite decomposes to yield pearlite :

$$\gamma\text{(austenite)} \rightarrow \underbrace{\alpha\text{-ferrite} + \text{cementite}}_{\text{Pearlite}}$$

The phases α-ferrite (0.02 w/o C) and cementite (6.67 w/o C; Fe_3C) form a lamellar structure.

$$\text{weight fraction of } \alpha\text{-ferrite} = \frac{(6.67 - 0.77)}{(6.67 - 0.02)} = 0.8872$$

$$\text{weight fraction of cementite} = 1.0 - 0.8872 = 0.1128$$

In an 8-kg steel body :

amount of α-ferrite $= 8(0.8872) = 7.0977$ kg

amount of cementite $= 8(0.1128) = 0.9023$ kg

1(c). A 0.35 w/o C steel is slow-cooled from 950°C to a temperature just below 727°C: at about 782°C, ferrite begins to precipitate out of the austenitic-phase making the lattice richer in carbon. As the temperature 727°C is approached, the equilibrium structure is seen to be α-ferrite (0.02 w/o) and austenite (0.77 w/o C).

$$\text{weight fraction of ferrite} = \frac{0.77 - 0.35}{0.77 - 0.02} = 0.56$$

Thus, the pro-eutectoid α-ferrite constitutes 56% by weight of the carbon steel at slightly below 727°C.

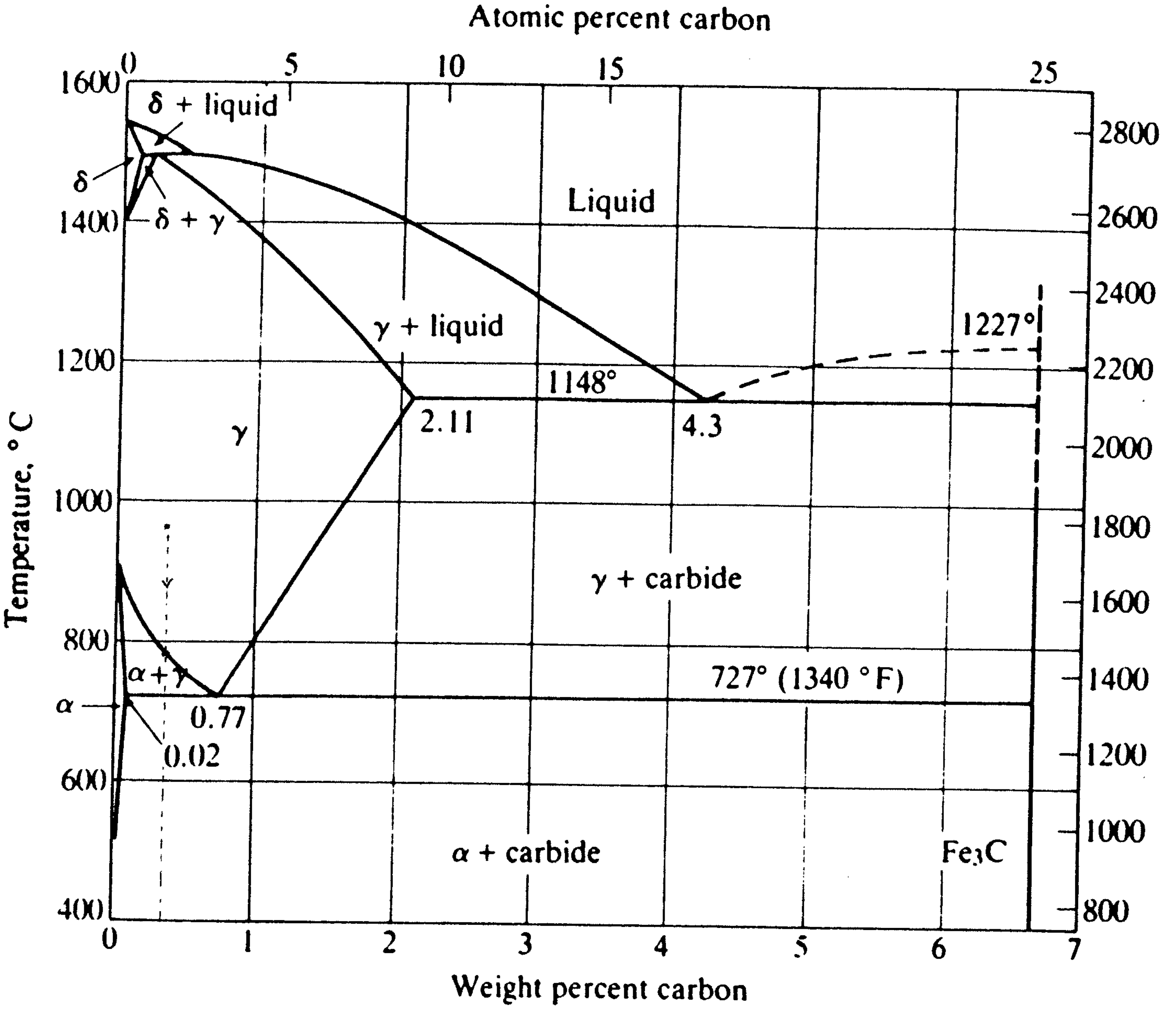


FIG. 5-5.1

$Fe-Fe_3C$ Phase Diagram. The lower-left corner receives prime attention in heat-treating of steels (Fig. 7-3.1). (In calculations, 0.77 percent is commonly rounded to 0.8 percent.)

2.

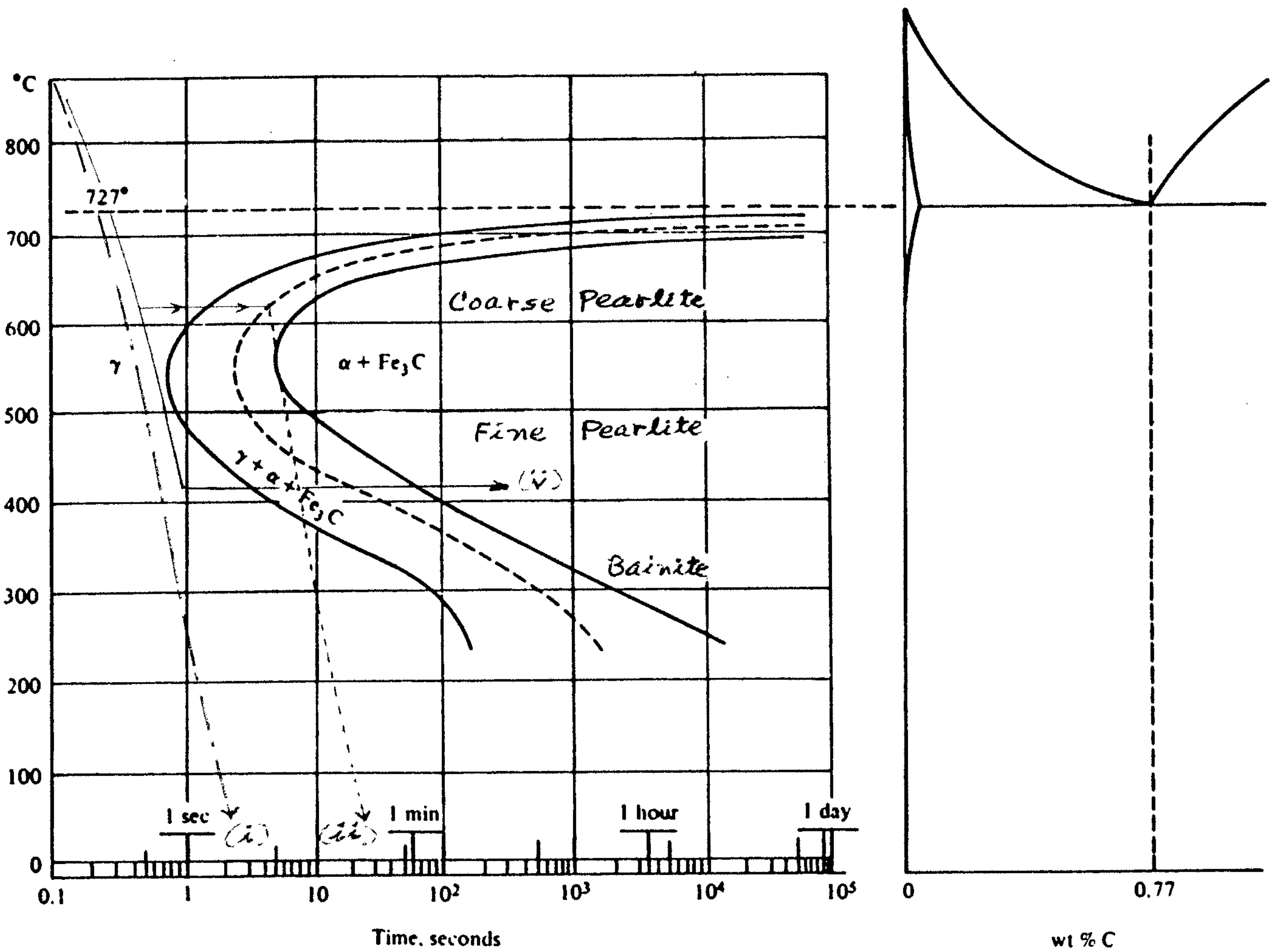


FIGURE 6.2-2 TTT diagram for eutectoid steel shown in relation to the Fe–Fe_3C phase diagram

2. (contd.)

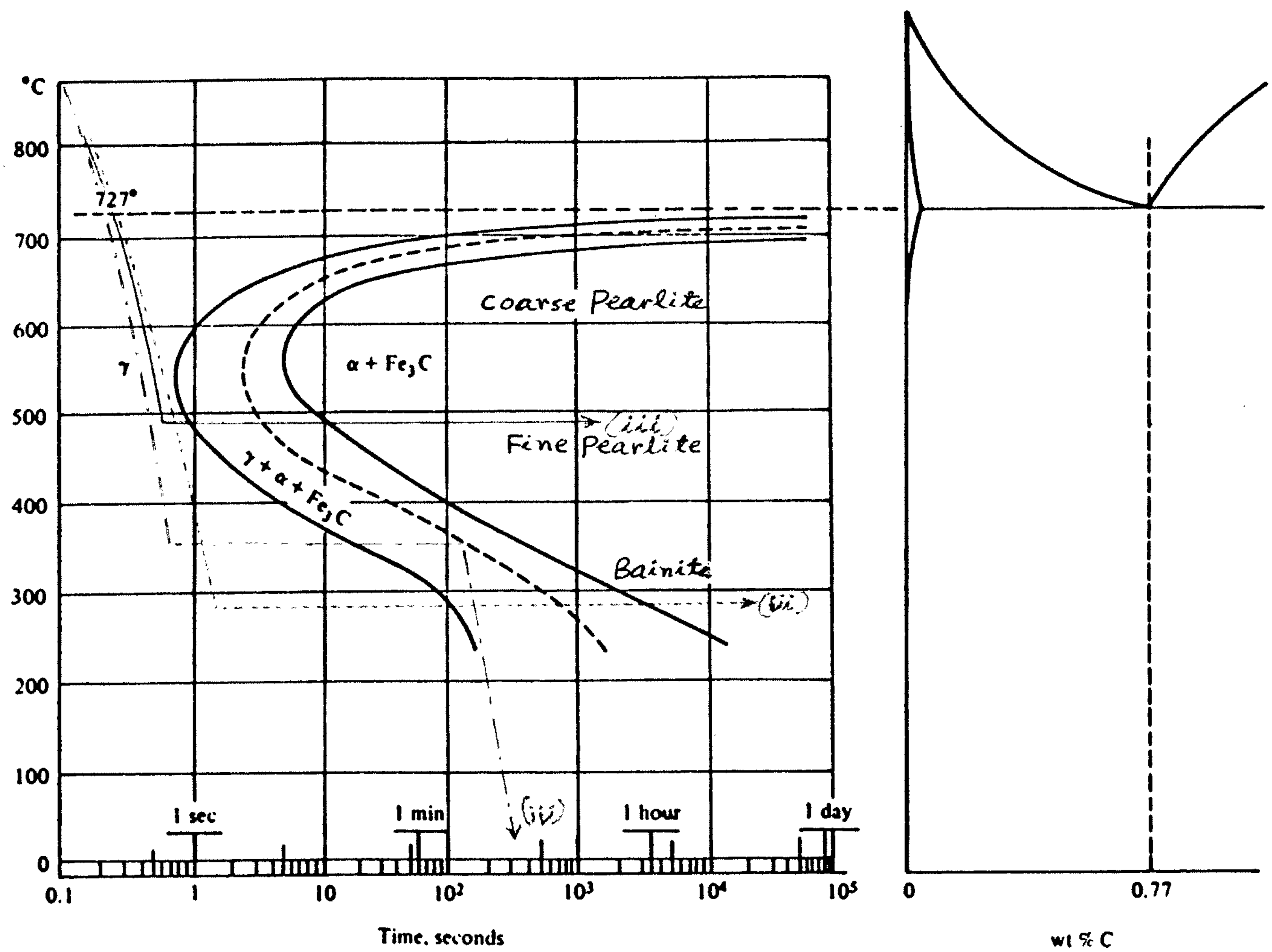
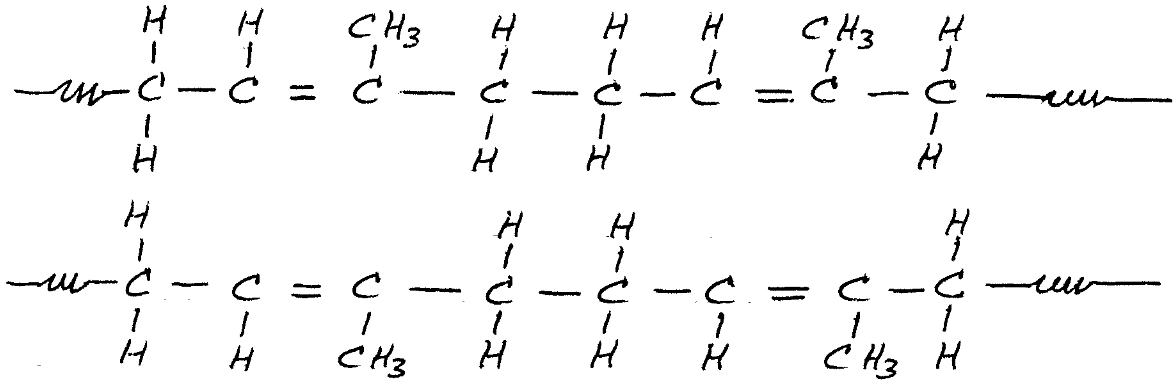
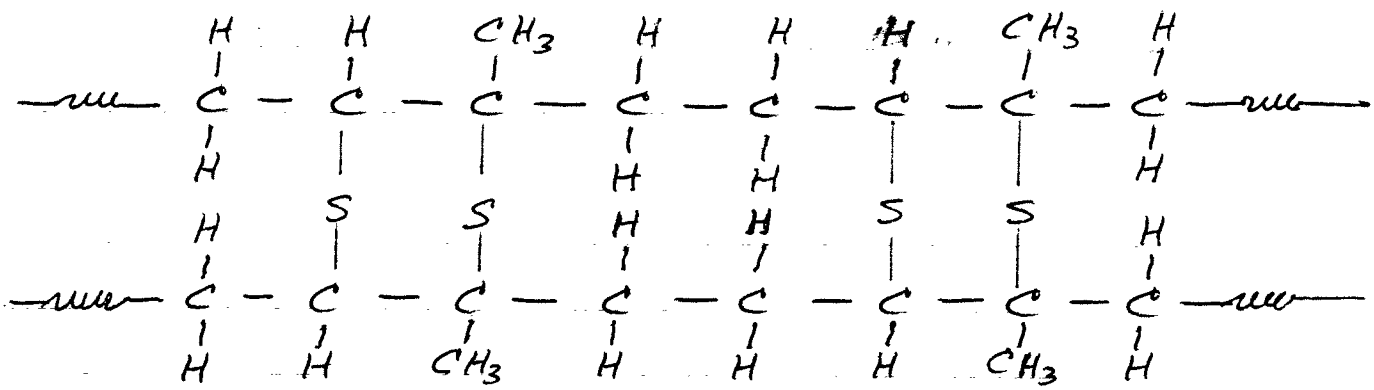


FIGURE 6.2-2 TTT diagram for eutectoid steel shown in relation to the Fe–Fe_3C phase diagram

3. The structure of the isoprene polymer is shown below.



The cross-linking with the insertion of S involves the replacement of C = C double bonds with C – C single-bonds and formation of C – S bonds. These are depicted below.



In this structure, there are

20 C atoms	:	20 × 12.011
32 H atoms	:	32 × 1.008
4 S atoms	:	4 × 32.064
total	:	400.732

Thus, at complete cross-linking by sulfur,

$$\text{weight percent of S} = \frac{4 \times 32.064}{400.732} \times 100 = \underline{32\,\%}$$

The cross-linking of isoprene using S (Se or Te) is called vulcanization.

4(a). The dependence of electrical conductivity of Silicon on temperature can be expressed by

$$\sigma = \sigma_0 \exp(-E_g/2kT)$$

where σ_0 is a constant, E_g is band-gap energy, and k is the Boltzmann constant. At 22°C (295.15°K):

$$\ln \sigma_1 = \ln \sigma_0 - \frac{E_g}{2k(295.15)} \qquad (i)$$

At temperature T_2:

$$\ln \sigma_2 = \ln \sigma_0 - \frac{E_g}{2k\,T_2} \qquad (ii)$$

On subtracting equation (ii) from equation (i), we find

$$\ln \frac{\sigma_1}{\sigma_2} = \ln 2 = \frac{E_g}{2k}\left(\frac{1}{T_2} - \frac{1}{295.15}\right)$$

$$E_g = 1.1\ eV \quad \text{and} \quad k = 8.61 \times 10^{-5}\ eV/°K$$

Substituting and solving for T_2:

$$T_2 = 285.99°K \text{ or } 12.84°C$$

4(b). Boron is a trivalent element which when used as the dopant for Silicon produces excess electron-holes as charge carriers. Thus p-type semiconduction prevails in the B-doped Si. The contribution of electrons to the total conduction is small. Hence

$$\sigma \approx n_p \mu_p q$$

where n_p is the concentration of electron-holes (m^{-3}), μ_p is the mobility of electron-holes, and q is the charge per electron-hole.

$$\mu_p = 0.048\ m^2/\text{Volt.s.}$$

$$q = 1.6022 \times 10^{-19}\ \text{coulomb}$$

$$\sigma = (1.8)^{-1}\ \Omega^{-1}.m^{-1}$$

Substituting and solving for n_p:

$$n_p = \frac{(1.8)^{-1}\ \Omega^{-1}.m^{-1}}{0.048\ m^2.V^{-1}.s^{-1}\ 1.6022 \times 10^{-19} C} = 7.224 \times 10^{19}\ m^{-3}$$

5. Each Ni atom has $2\mu_B$ magnetic moment. As nickel is face centered cubic, there are 4 atoms per unit cell.

lattice parameter, $a = 0.352$ nm

volume of the unit cell $= a^3 = 4.3614 \times 10^{-29}$ m^3

μ_B, Bohr magneton $= 9.27 \times 10^{-24}$ A.m^2

The saturation magnetization, M_s, is computed per unit volume.

$$M_s = \frac{(4 \text{ Ni atoms})\ (2 \text{ Bohr magnetons})\ 9.27 \times 10^{-24} \text{ A.m}^2}{(4.3614 \times 10^{-29} \text{m}^3)(\text{atom})\quad (\text{Bohr magneton})}$$

$\underline{M_s = 1,700,371 \text{ A/m}}$

The saturation induction, B_s, is given by

$B_s = \mu_0 (H + M)_s \approx \mu_0 M_s$

$\mu_0 = 4\pi \times 10^{-7}$ T.m/A

Thus

$\underline{B_s = 2.1368 \text{ T}}$

6. Consider 100 cm^3 volume of the carbon/resin composite.

$V_c = 62$ cm^3 ; $V_r = 38$ cm^3

density of carbon-fiber, $\rho_c = 1.75$ g/cm^3

density of resin, $\rho_r = 1.20$ g/cm^3

mass of carbon-fiber $= V_c \rho_c = 108.5$ g

mass of epoxy-resin $= V_r \rho_r = 45.6$ g

weight percentage of carbon $= (108.5/154.1)100 = \underline{70.41\%}$

weight percentage of resin $= (45.6/154.1).100 = \underline{29.59\%}$

We have for the average density, $\bar{\rho}$:

$$\bar{\rho} = \frac{\text{mass}}{\text{volume}} = \frac{154.1}{100} = 1.541 \text{ g/cm}^3$$

If we use the linear additive relation,

$\bar{\rho}_a = (\rho_c V_c + \rho_r V_r)\, 10^{-2} = 1.541$ g/cm^3 $= \bar{\rho}$