EUTECTOID DIAGRAM

The transformation of eutectic liquid to a relatively fine-grained microstructure of two solid phases upon cooling can be described as a special type of chemical reaction. This **eutectic reaction** can be written as

$$\text{L (eutectic)} \xrightarrow{\text{cooling}} \alpha + \beta, \tag{9.3}$$

where the notation corresponds to the phase labels from Figure 9.14. Some binary systems contain a solid-state analog of the eutectic reaction. Figure 9.17 illustrates such a case. The *eutectoid reaction* is

$$\gamma\text{(eutectoid)} \xrightarrow{\text{cooling}} \alpha + \beta, \tag{9.4}$$

where *eutectoid* means "eutectic-like." Some representative microstructures are shown in the **eutectoid diagram** of Figure 9.18. The different morphologies of the eutectic and eutectoid microstructures emphasize our previous point that although the specific nature of these diffusion-limited structures will vary, they will generally be relatively fine grained. A eutectoid reaction plays a fundamental role in the technology of steelmaking.

The Fe$-$Fe$_3$C system (Figure 9.19) is, by far, the most important commercial phase diagram we shall encounter. It provides the major scientific basis for the iron and steel industries. In Chapter 11, the boundary between irons and steels will be identified as a carbon content of 2.0 wt %. This point roughly corresponds to the carbon solubility limit in the **austenite*** (γ) phase of Figure 9.19.

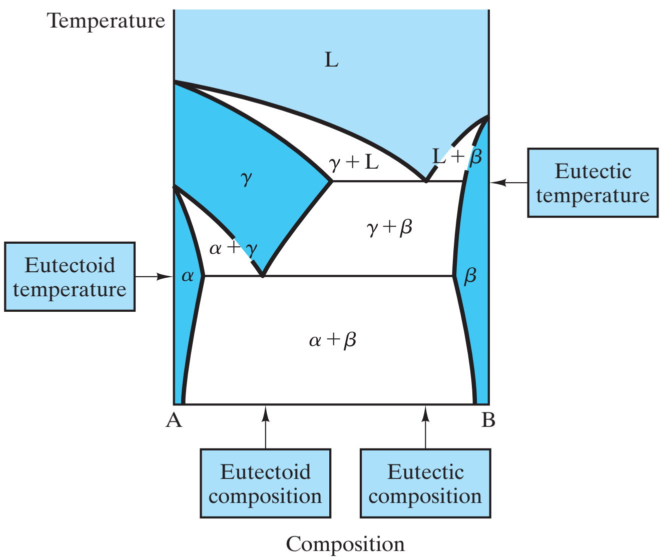

FIGURE 9.17 *This eutectoid phase diagram contains both a eutectic reaction (Equation 9.3) and its solid-state analog, a eutectoid reaction (Equation 9.4).*

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*William Chandler Roberts-Austen (1843–1902), English metallurgist. Young William Roberts set out to be a mining engineer, but his opportunities led to an appointment in 1882 as "chemist and assayer of the mint," a position he held until his death. His varied studies of the technology of coin making led to his appointment as a professor of metallurgy at the Royal School of Mines. He was a great success in both his government and academic posts. His textbook, *Introduction to the Study of Metallurgy*, was published in six editions between 1891 and 1908. In 1885, he adopted the additional surname in honor of his uncle (Nathaniel Austen).

Micrometer scale structures such as these developed during the slow cooling of commercial alloys play a central role in contemporary industries. Among the most important examples are Figures 9.19 and 9.20 relative to the iron and steel industries. More detailed examples are illustrated in Section 9.4.

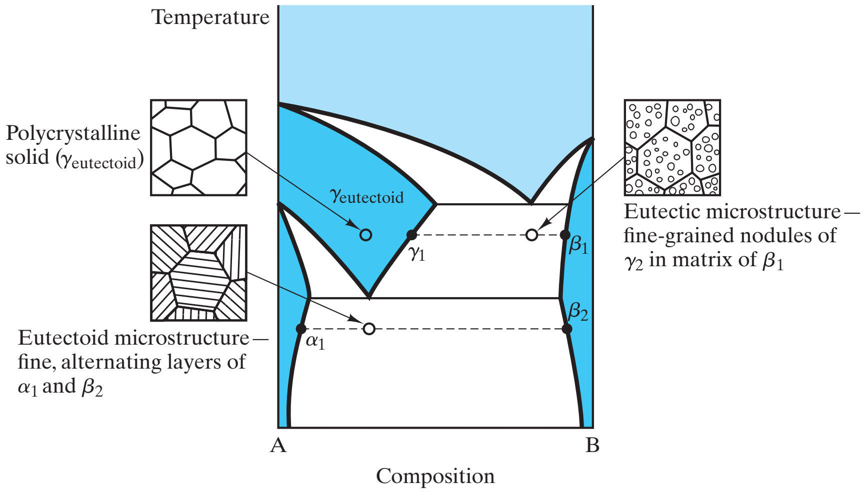

FIGURE 9.18 *Representative microstructures for the eutectoid diagram of Figure 9.17.*

In addition, this diagram is representative of microstructural development in many related systems with three or more components (e.g., some stainless steels that include large amounts of chromium). Although Fe_3C, and not carbon, is a component in this system, the composition axis is customarily given in weight percent carbon. The important areas of interest on this diagram are around the eutectic and the eutectoid reactions. The reaction near 1,500°C is of no practical consequence.

A final note of some irony is that the Fe–Fe_3C diagram is not a true equilibrium diagram. The Fe–C system (Figure 9.20) represents true equilibrium. Although graphite (C) is a more stable precipitate than Fe_3C, the rate of graphite precipitation is enormously slower than that of Fe_3C. The result is that in common steels (and many cast irons) the Fe_3C phase is **metastable**; that is, for all practical purposes it is stable with time and conforms to the Gibbs phase rule.

As just noted, the Fe–C system (Figure 9.20) is fundamentally more stable, but less common than the Fe–Fe_3C system because of slow *kinetics* (the subject of Chapter 10). Extremely slow cooling rates can produce the results indicated on the Fe–C diagram. The more practical method is to promote graphite precipitation by a small addition of a third component, such as silicon. Typically, silicon additions of 2 to 3 wt % are used to stabilize the graphite precipitation. This third component is not acknowledged in Figure 9.20. The result, however, is that the figure does describe microstructural development for some practical systems. An example will be given in Section 9.4.