# C-Fe-P (Carbon-Iron-Phosphorus)

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The previous review of this system by [1988Rag] presented a liquidus projection and a reaction scheme for both the stable and the metastable equilibria and two isothermal sections at 950 and 700 °C, mainly from the studies of [1929Vog], [1970Hof], [1970Lan], and [1984Sch]. Recently, [2000Shi] carried out a thermodynamic assessment of this system and compared the experimental results with the computed phase equilibria.
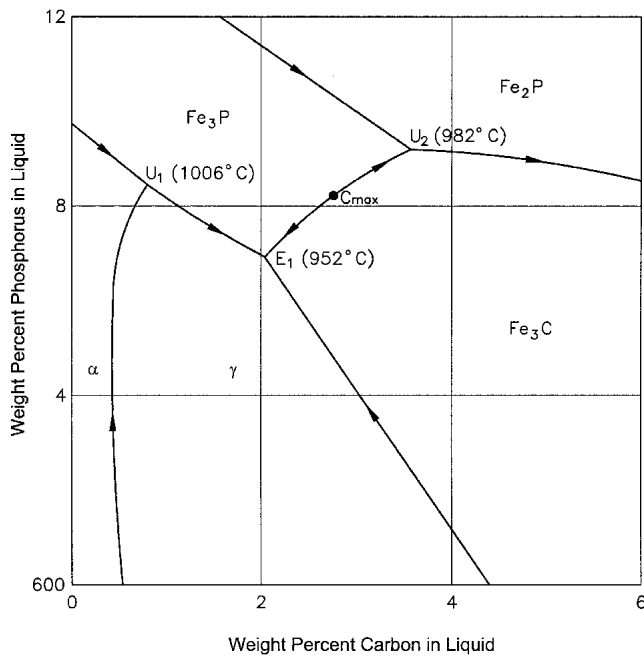


**Fig. 1**  C-Fe-P computed liquidus projection [2000Shi]

## Binary Systems

The Fe-C phase diagram [1985Gus] is in the form of a double diagram, corresponding to either the metastable equilibrium with cementite $Fe_3C$ ($D0_{11}$-type orthorhombic) or the stable equilibrium with graphite. Austenite $\gamma$ [face-centered cubic (fcc)] forms through a peritectic reaction at 1495 °C between body-centered-cubic (bcc) iron ($\delta$) and liquid. Around 1150 °C, the stable and the metastable eutectic reactions occur, yielding austenite and graphite (or cementite). Around 730 °C, austenite undergoes the eutectoidal transformation to bcc Fe ($\alpha$) and graphite (or cementite). The partial Fe-P phase diagram [1982Kub] depicts three intermediate phases: $Fe_3P$ ($Ni_3P$-type tetragonal), $Fe_2P$ ($C22$ type hexagonal), and FeP (MnP-type orthorhombic). At the Fe end, a gamma loop is present, with the maximum solubility of P of 0.55 at.% (0.30 wt.%) in fcc Fe. The solidification temperature of Fe is substantially lowered by P reaching 1048 °C, where a eutectic reaction yields $Fe_3P$ and bcc Fe ($\alpha$) containing 4.52 at.% (2.55 wt.%) P.

## Computed Ternary Phase Equilibria

Shim et al. [2000Shi] made a thermodynamic assessment of this ternary system, using their own description of the Fe-P system and that of [1985Gus] for the Fe-C system. The liquid phase was described as a regular substitutional solution. The two-sublattice model was used for the fcc and bcc solid solutions. Fe and P substitute for each other on the substitutional sites. Vacancies (Va) and C reside in the interstitial sublattice. New results on the solubility of P in Fe-C melts [1992Yan] were included in the optimization. A ternary interaction parameter was derived for the liquid phase.
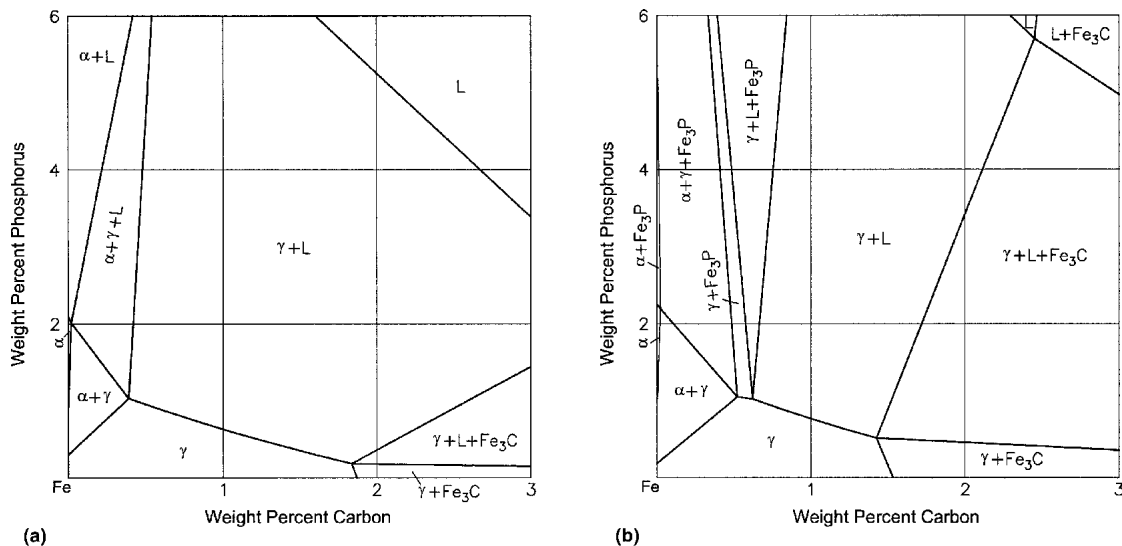


**Fig. 2**  C-Fe-P computed isothermal sections at **(a)** 1100 °C and **(b)** 1000 °C [2000Shi]
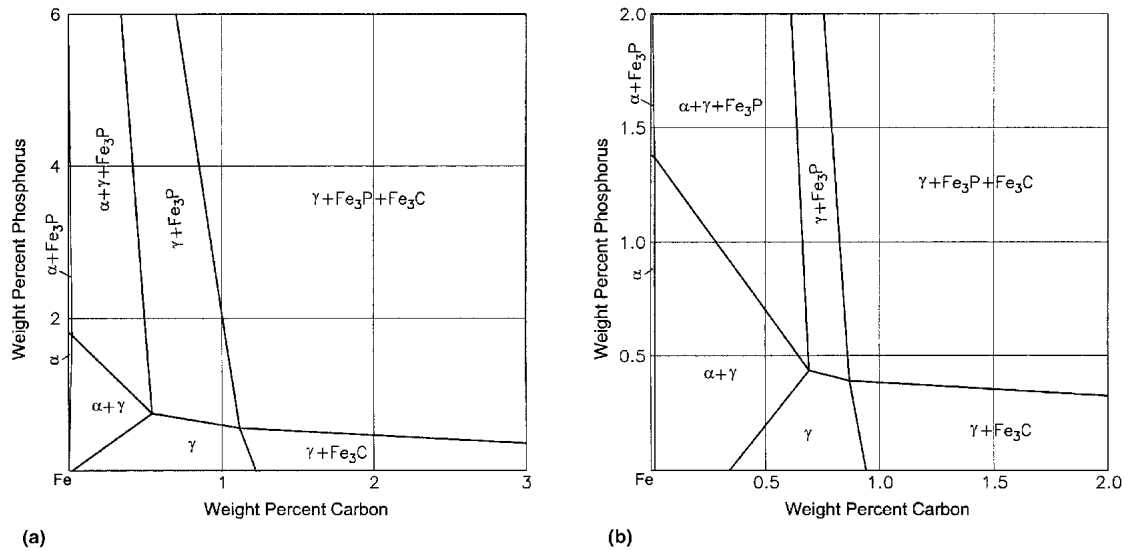
**Fig. 3** C-Fe-P computed isothermal sections at **(a)** 900 °C and **(b)** 800 °C [2000Shi]
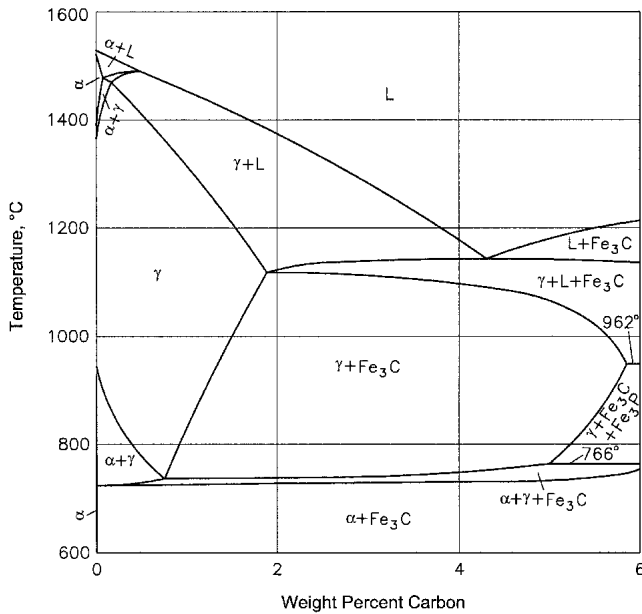


**Fig. 4** C-Fe-P computed vertical section at $P = 0.1$ wt.% [2000Shi]

The liquidus projection and five isothermal sections at 1100, 1000, 950, 900, and 800 °C were computed by [2000Shi] for the metastable equilibrium with Fe$_3$P. The liquidus projection is redrawn in Fig. 1. A comparison with the liquidus reviewed by [1988Rag] shows that an additional transition reaction U$_2$ is present in the computed projection in Fig. 1 near the Fe$_3$P-Fe$_3$C join. The computed isothermal sections at 1100, 1000, 900, and 800 °C are redrawn in Fig. 2 and 3, to supplement the data reviewed by [1988Rag].

Vertical sections along the 91Fe9P-95.5Fe4.5C, 92Fe8P-97Fe3C, 98Fe2P-98Fe2C, 98.4Fe1.6P-98.4Fe1.6C, and Fe-97Fe1.5P1.5C joins (all in weight percent) were calcu-

lated by [2000Shi] and compared with the experimental results of [1929Vog]. The computed Fe$_3$P-Fe$_3$C section was pseudobinary below 1000 °C, as was given in the earlier reports [1929Vog], [1984Sch], and [1988Rag]. Three more vertical sections were computed at constant weight percents of 2.4C, 0.1P, and 1P. The vertical section at 0.1 P is redrawn in Fig. 4. The invariant horizontal seen at 952 °C is the ternary eutectic reaction L ↔ γ + Fe$_3$C + Fe$_3$P, indicated at 955 °C in the reaction table of [1988Rag]. The horizontal at 766 °C corresponds to the transition reaction γ + Fe$_3$P ↔ α + Fe$_3$C, placed at ~750 °C by [1988Rag].

## References

**1929Vog:** R. Vogel, The Iron-Phosphorus-Carbon System, *Arch. Eisenhuttenwes.,* Vol 3 (No. 5), 1929, p 369-381 (in German)

**1970Hof:** H.P. Hofmann, K. Lohberg, and W. Reif, Solubility of Phosphorus in Fe and Fe-C Alloys below 1000 °C, *Arch. Eisenhuttenwes.,* Vol 41 (No. 10), 1970, p 975-982 (in German)

**1970Lan:** G. Langenscheid, H.A. Mathesius, and F.K. Naumann, Use of the Quantitative Television Microscope and of the Electron Beam Microprobe in the Study of the Fe-C-P System at 900-1000 °C, *Arch. Eisenhuttenwes.,* Vol 41 (No. 8), 1970, p 817-824 (in German)

**1982Kub:** O. Kubaschewski, Iron-Phosphorus, *Iron—Binary Phase Diagrams,* Springer-Verlag, Berlin, Germany, 1982, p 84-86

**1984Sch:** E. Schurmann, U. Hensgen, and J. Schweinichen, Melt Equilibrium of the Ternary Systems Fe-C-Si and Fe-C-P, *Geissereiforsch.,* Vol 36 (No. 4), 1984, p 121-129 (in German)

**1985Gus:** P. Gustafson, A Thermodynamic Evaluation of the Fe-C System, *Scand. J. Metall.,* Vol 14 (No. 5), 1985, p 259-267

**1988Rag:** V. Raghavan, The C-Fe-P (Carbon-Iron-Phosphorus) System, *Phase Diagrams of Ternary Iron Alloys, Part 3,* Indian Institute of Metals, Calcutta, 1988, p 33-44

**1992Yan:** Y.D. Yang, Interaction Coefficients in Fe-C-P Ternary and Fe-Cr-C-P Quaternary Solutions at 1400 °C, *Scand. J. Metall.,* Vol 21 (No. 5), 1992, p 194-201

**2000Shi:** J.H. Shim, C.S. Oh, and D.N. Lee, Thermodynamic Assessment of the Fe-C-P System, *Z. Metallkde.,* Vol 91 (No. 2), 2000, p 114-120