Depending on pressure and temperature, many metals can exist in more than one crystalline form, a phenomenon known as allotropy. For example, iron undergoes a series of allotropic transformations during heating and cooling as shown in the diagram. Note that an allotropic transformation is a solid state phase transformation, and as such, occurs at a constant temperature during either heating or cooling.

Under equilibrium cooling conditions, pure iron solidifies from the molten state at 1540°C (2800°F) and forms what is called delta iron ($\delta$Fe), which has a body-centered cubic (BCC) structure.

Delta iron is then stable on further cooling until it reaches 1395°C (2541°F), where it undergoes a transformation to a face-centered cubic (FCC) structure called gamma iron ($\gamma$Fe). On still further cooling to 900°C (1648°F), it undergoes yet another phase transformation, transforming from the FCC structure back to the BCC structure. This BCC structure is called alpha iron ($\alpha$Fe) to distinguish it from the higher-temperature delta iron.

This last transformation, $\gamma$Fe $\rightarrow$ $\alpha$Fe, is extremely important, as it forms the basis for the hardening of steel. Note that the $\gamma$Fe $\rightarrow$ $\alpha$Fe transformation occurs at 900°C (1648°F) on cooling, somewhat lower than the 910°C (1673°F) transformation temperature on heating.

This temperature differential is known as the temperature hysteresis of allotropic phase transformation, and its magnitude increases with faster cooling rates. The temperatures (designated $A$) associated with heating contain the subscript c, which is French for chauffage, meaning heating. Cooling temperatures have the subscript r for the French refroidissement, meaning re-cooling.

Many other metals, as well as some nonmetals, also exhibit allotropic transformations. For example, titanium, zirconium, and hafnium all exhibit a transition from a hexagonal close-packed (HCP) structure to BCC on heating. Note that in each case, a close-packed structure is stable at room temperature while a looser packing is stable at elevated temperatures. Although this is not always the case, it is typical of many metals.

This information is from Elements of Metallurgy and Engineering Alloys, a new book by F.C. Campbell. Visit www.asminternational.org and click on “Materials Information” to read a sample chapter and view the table of contents.