

PHASE DIAGRAMS

THE
IRON-CARBON
SYSTEM

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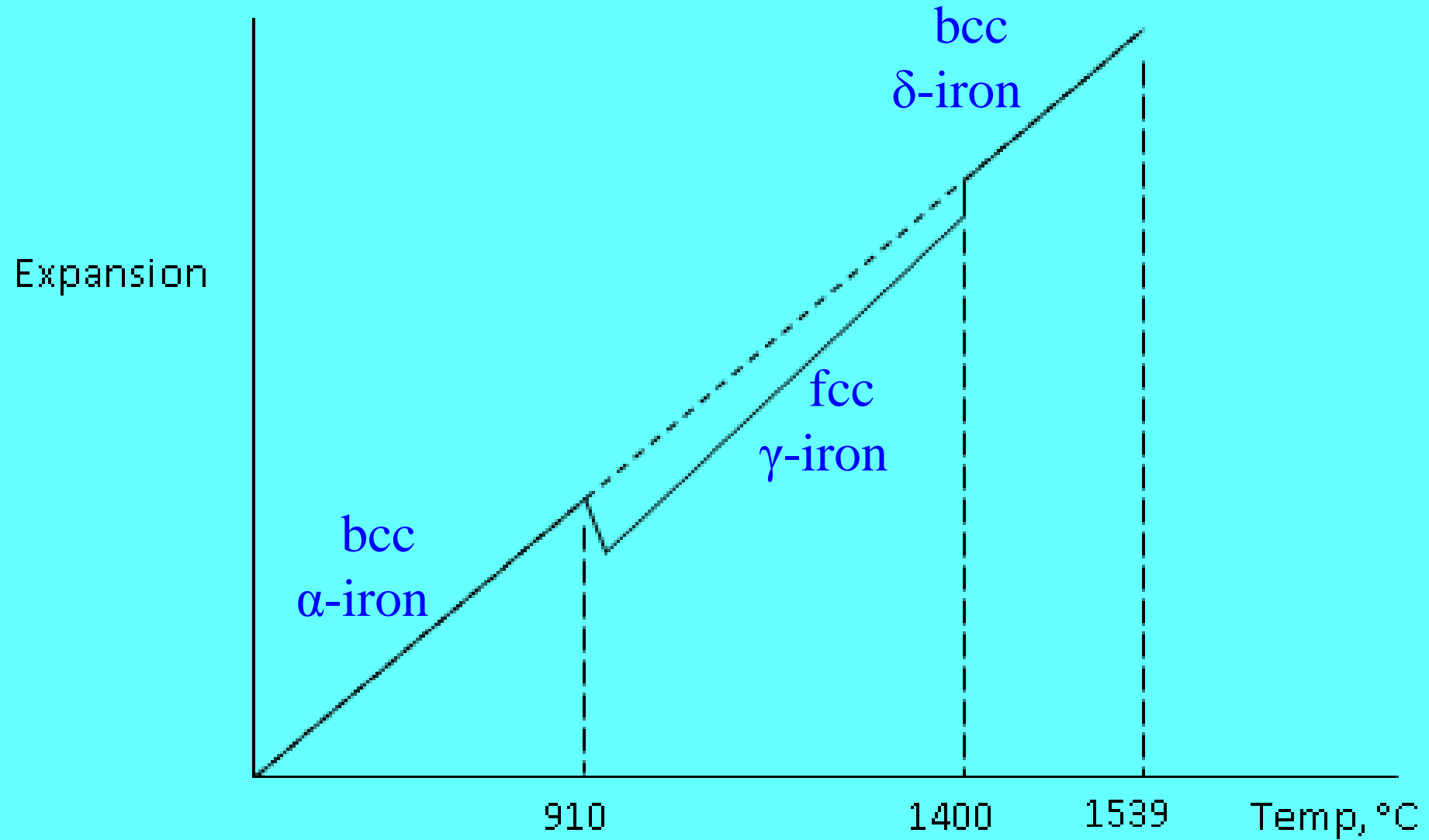
- Most important of the phase diagrams.
- Gives the various grades of steel and irons.
- Steel still the most important construction and engineering material.
- Important to see where various grades of steel belong in the diagram.
- Important to know how to draw it and show its most important features.

So then, here we go!!!!!!!!!!!!!!!

Allotropic forms of Pure Iron

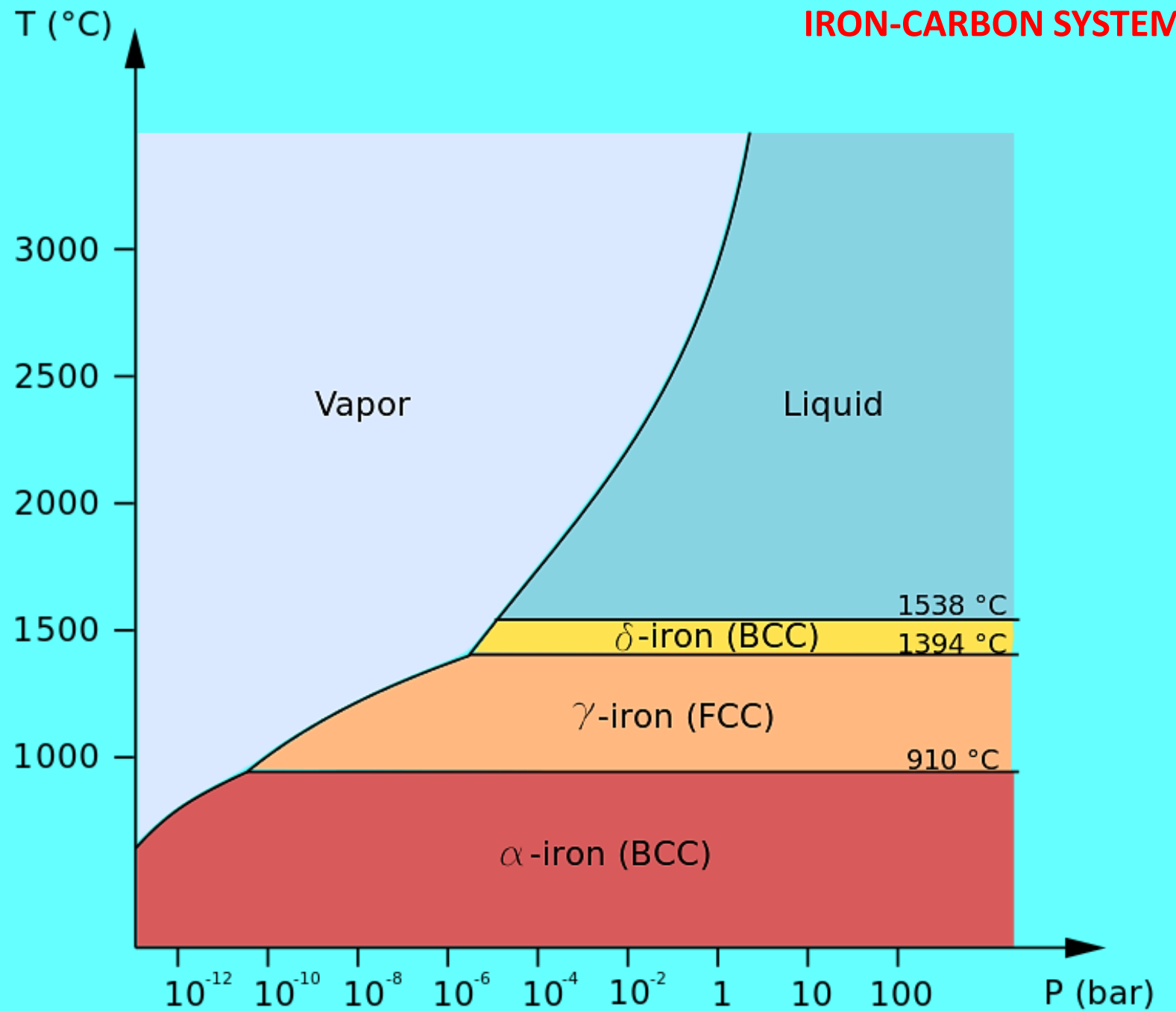
- On cooling pure iron solidifies at 1538 or 1539°C into bcc, **δ -iron**
- Further cooling – changes to fcc at 1394 to 1400°C, **γ -iron**
- Further cooling – back to bcc again at 910°C, **α -iron**
- These are called ***allotropic*** changes or transformations

Allotropic Transformations of pure iron.



IRON-CARBON SYSTEM

Allotropic Transformations of pure iron.



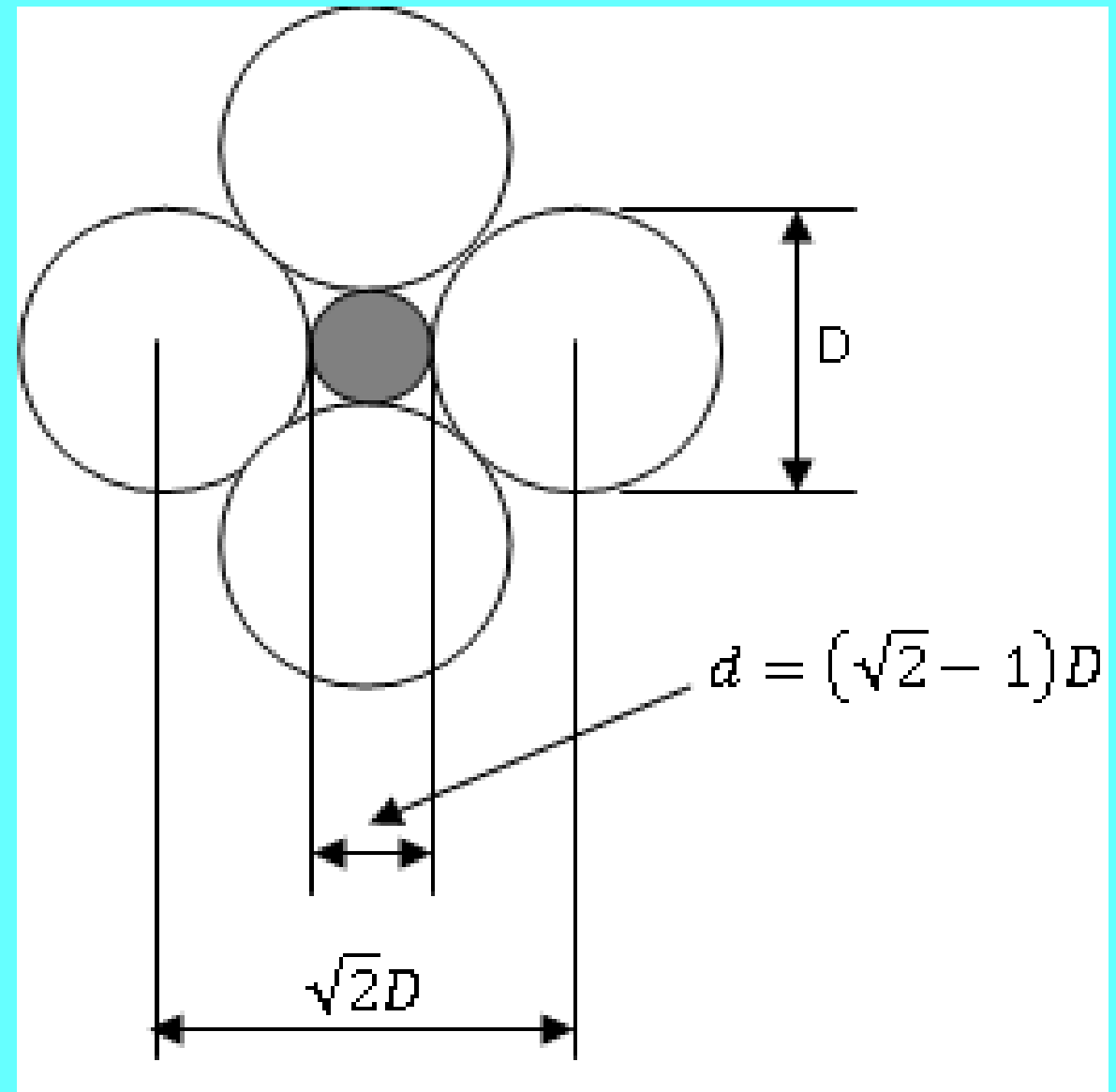
- α -iron loses ferromagnetism at 770°C → the **Curie temperature**.
- γ -iron is the structure of closest packing while α -iron and δ -iron are not.
- Transitions $\alpha \rightarrow \gamma$ and $\gamma \rightarrow \delta$ are abrupt
- Changes in dimensions called **dilatation** occur.
 - **Volume dilatation** = change of volume per unit volume
 - **Linear dilatation** = change in length per unit length.

Solubility of Carbon in Iron

- Diameters: C = 0.154 nm, Fe = 0.256 nm
- Solubility in fcc γ -iron is maximum at 1.7% at 1130°C → ***austenite***.
- Solubility in bcc phases are much smaller:
 - = 0.1% at 1492°C in bcc δ -iron → ***δ -ferrite***.
 - = 0.03% at 723°C in bcc α -iron → ***α -ferrite*** (generally just termed ***ferrite***).

- In fcc, interatomic space is bound by six atoms - octahedral space.
 - Expressed as coordinates of the unit cell: the centres of these spaces are at
 - $(0, 0, \frac{1}{2})$ and
 - $(\frac{1}{2}, \frac{1}{2}, \frac{1}{2})$

- Octahedral space in the fcc structure,
- $d = 0.106 \text{ nm}$
- Thus C (0.154 nm dia), will cause local distortion and stresses in the material lattice.



- Thus for 1.7% w/w, the maximum number of C atoms that can go into interstitial solid solution in the γ -iron is about 1 atom to about every 12 spaces available.

(Let the student prove this at home.)

- In the bcc, spaces are not cubical, but have one smaller and two larger dimensions.
- The sphere could be fitted into a space that has coordinates $(\frac{1}{2}, \frac{1}{4}, 0)$.

- And a sphere of diameter of

$$d = \left(\sqrt{\frac{5}{3}} - 1 \right) D = 0.074 \text{ nm}$$

can be fitted into the space of the α -iron.

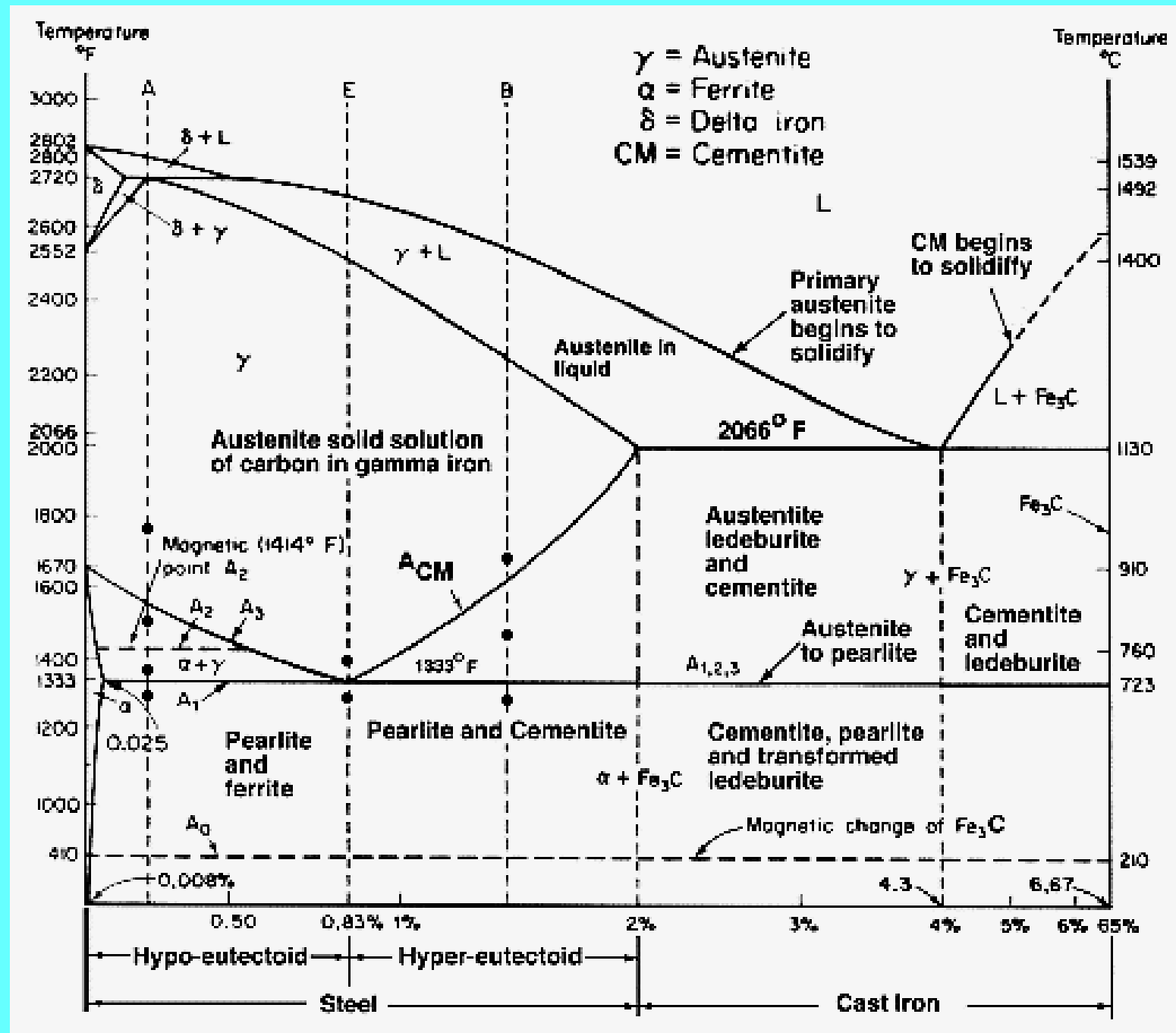
(Let the student prove this at home.)

- Thus, ferrite takes only about 1 carbon atom per 700 spaces at maximum solubility!

Cementite and Ludeburite

- **Cementite** = intermediate compound of iron and carbon at 6.67% C w/w, the formula Fe_3C .
- Between iron (austenite) and Cementite, is a **eutectic** at 4.3% C and 1130°C.
- The eutectic is between austenite and cementite and is called **ledeburite** - commercially called **pig iron**.

The Iron-Carbon System



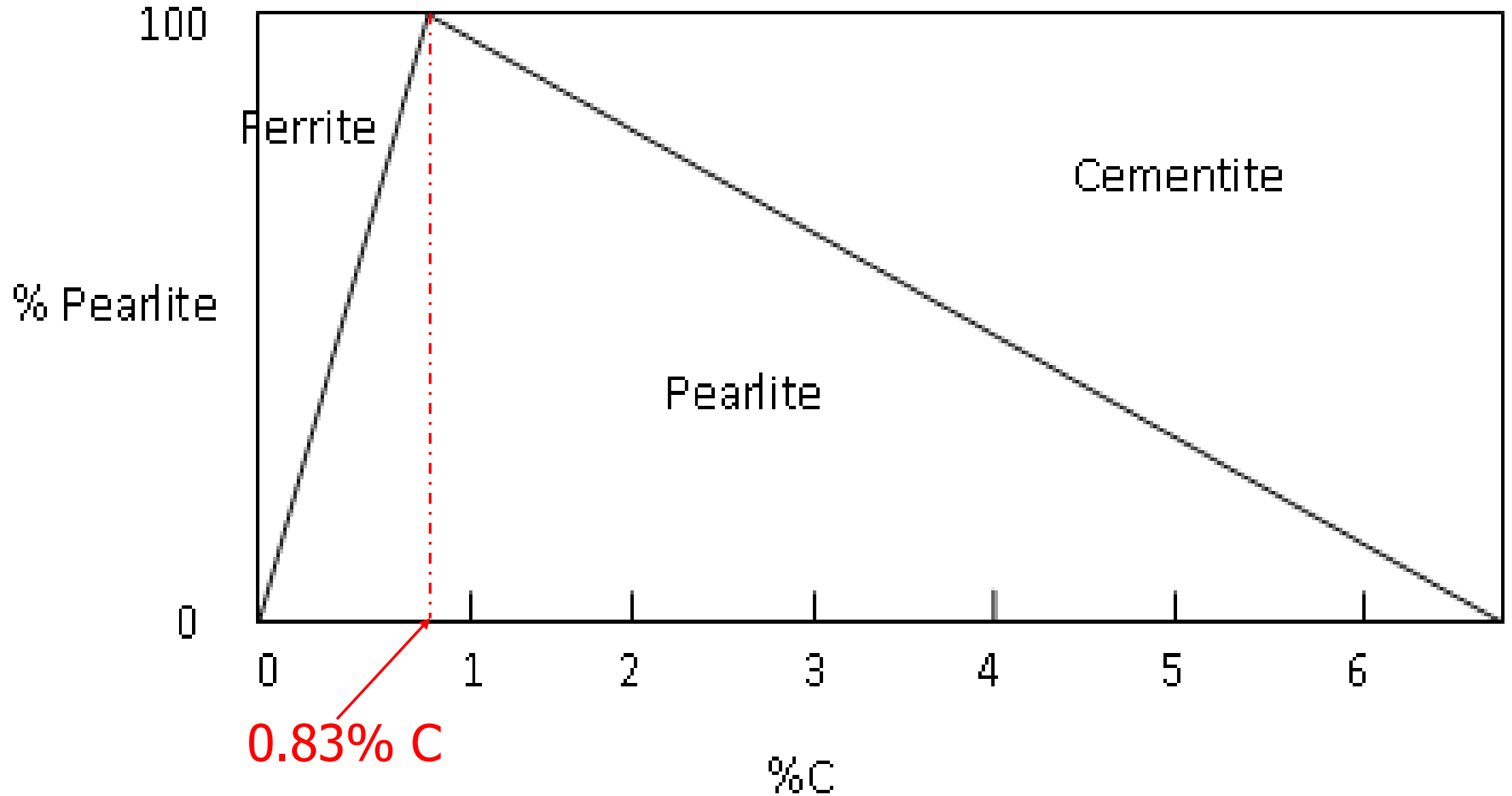
- Greatest solubility of C in austenite is 1.7% at the eutectic temperature (1130°C)
- Above and below this temperature, solubility decreases.
- Above 0.2% C, on heating, limit of solubility is reached, at the solidus → two-phase (austenite + liquid) region.
- Above 0.83% C, on cooling, cementite precipitates when limit of solubility is reached.

Modification of Allotropic Change Temperatures

- Austenite - higher solubility for C than either ferrite or δ -iron.
 - Result: presence of C raises the temperature of the $\gamma \rightarrow \delta$ change and lowers that of the $\gamma \rightarrow \alpha$ change – increasing austenite temperature range with increase in C content.
- On cooling, say, 0.3% C alloy from austenite: change to ferrite begins at about 850°C - ferrite crystals nucleate on austenite grain boundary.

- Lower boundary of austenite region is formed by two lines:
 - One from 910 °C at pure iron – **the ferrite separation line.**
 - The other from 1130°C (taken up to 1147°C) at 1.7% (up to 2%) C – **the cementite separation line.**
 - The lines intersect, showing a ***eutectoid*** reaction at 723°C (up to 727°C) between 0.80 and 0.83% C. (sometimes up to 0.90% C).
 - The ***eutectoid*** formed is called ***pearlite***.

- The eutectoid, **pearlite**, forms as precipitation of **ferrite and cementite** (laminated flakes of cementite and ferrite).
- Pearlite = $(0.83/6.67) \times 100 = 12.4\%$ cementite and 87.6% ferrite.
- Structure of any alloy at room temperature would be:
 - part ferrite and part pearlite for $0.83\% < C$
 - part pearlite and part cementite for $C > 0.83\%$



- Upper boundary of austenite region is formed by two lines:
 - One from 1400°C at pure iron – the δ -ferrite separation line.
 - The other from 1130°C at 1.7% C – the cementite separation line.
 - The lines intersect, showing a **peritectic** reaction at 1492°C (up to 1493°C) at about 0.18% C. (sometimes taken as much as 0.20% C).

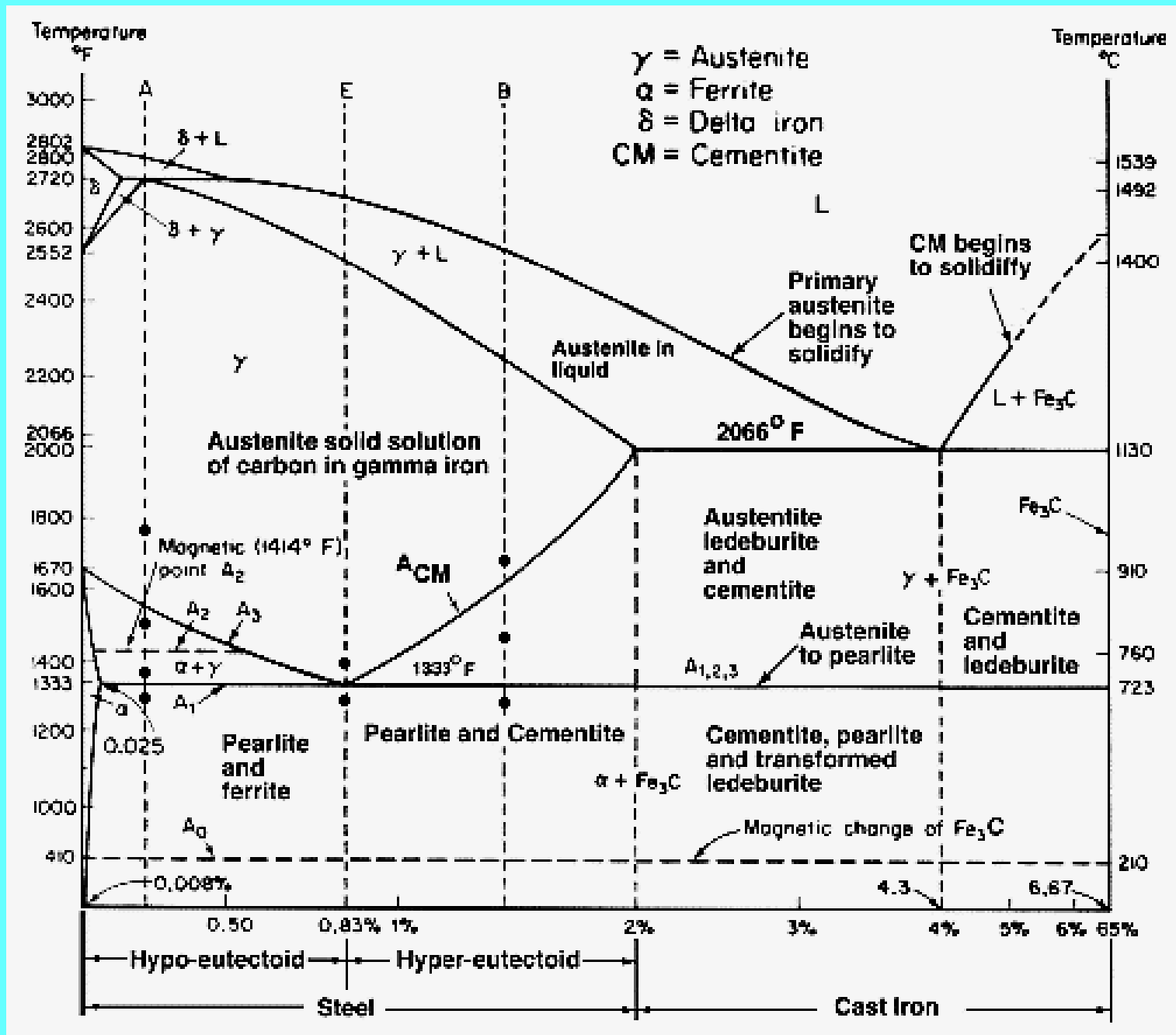
Thus:

- The upper part of ***austenite*** region terminates in a ***peritectic*** reaction at 1492°C at 0.18% C;

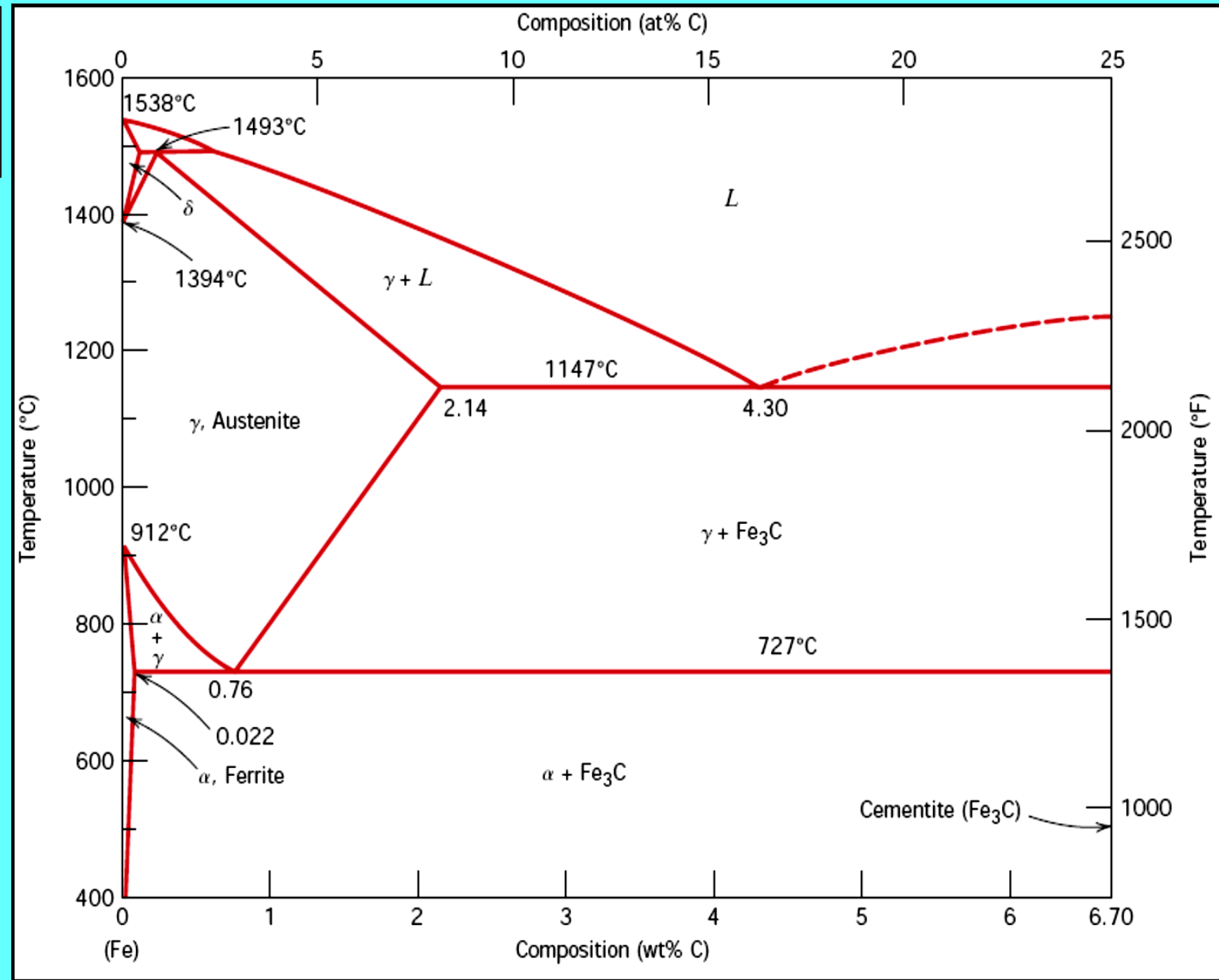
while

- The Lower part of ***austenite*** region terminates in a ***eutectoid*** reaction at 723°C at 0.83% C.

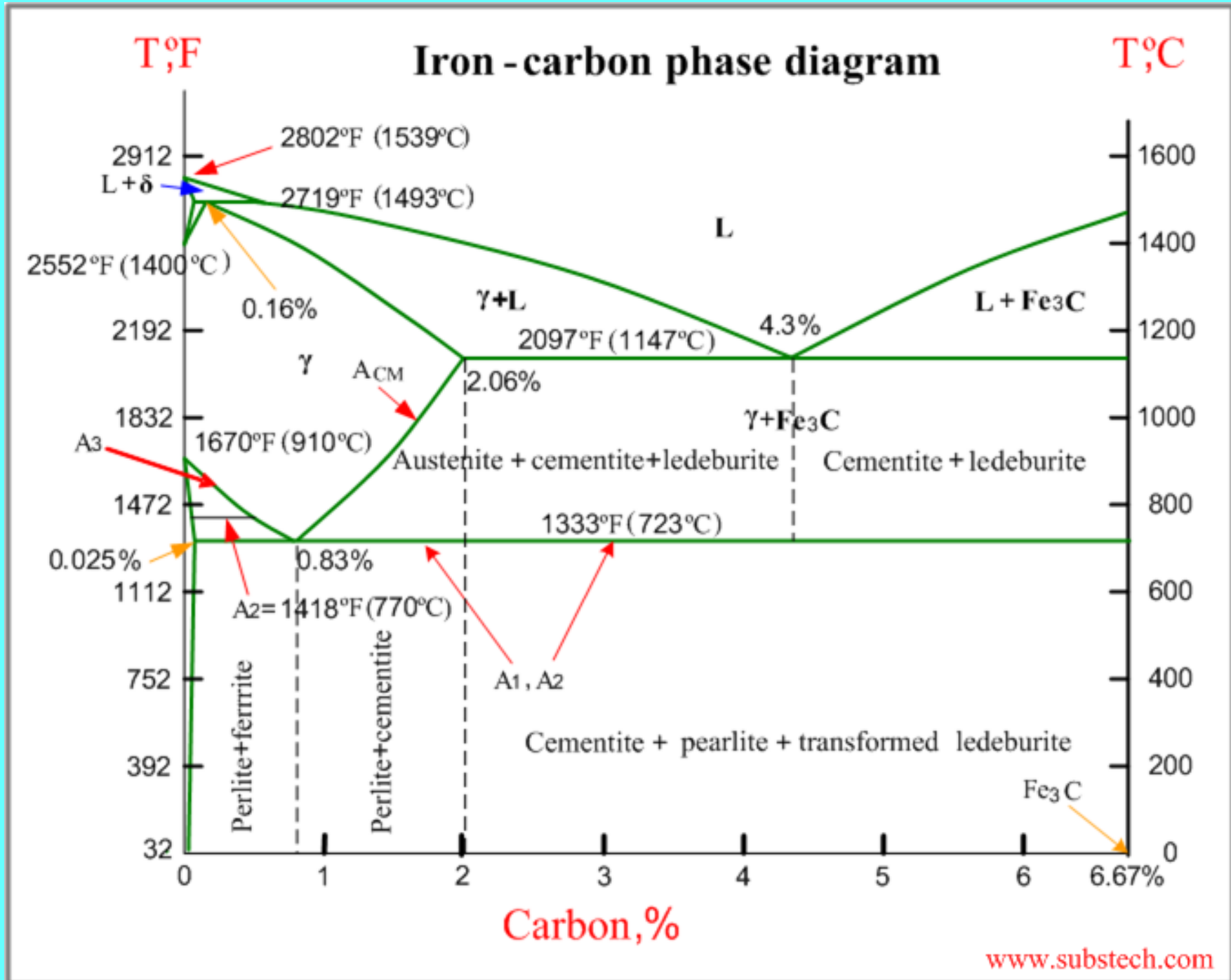
The Iron-Carbon System



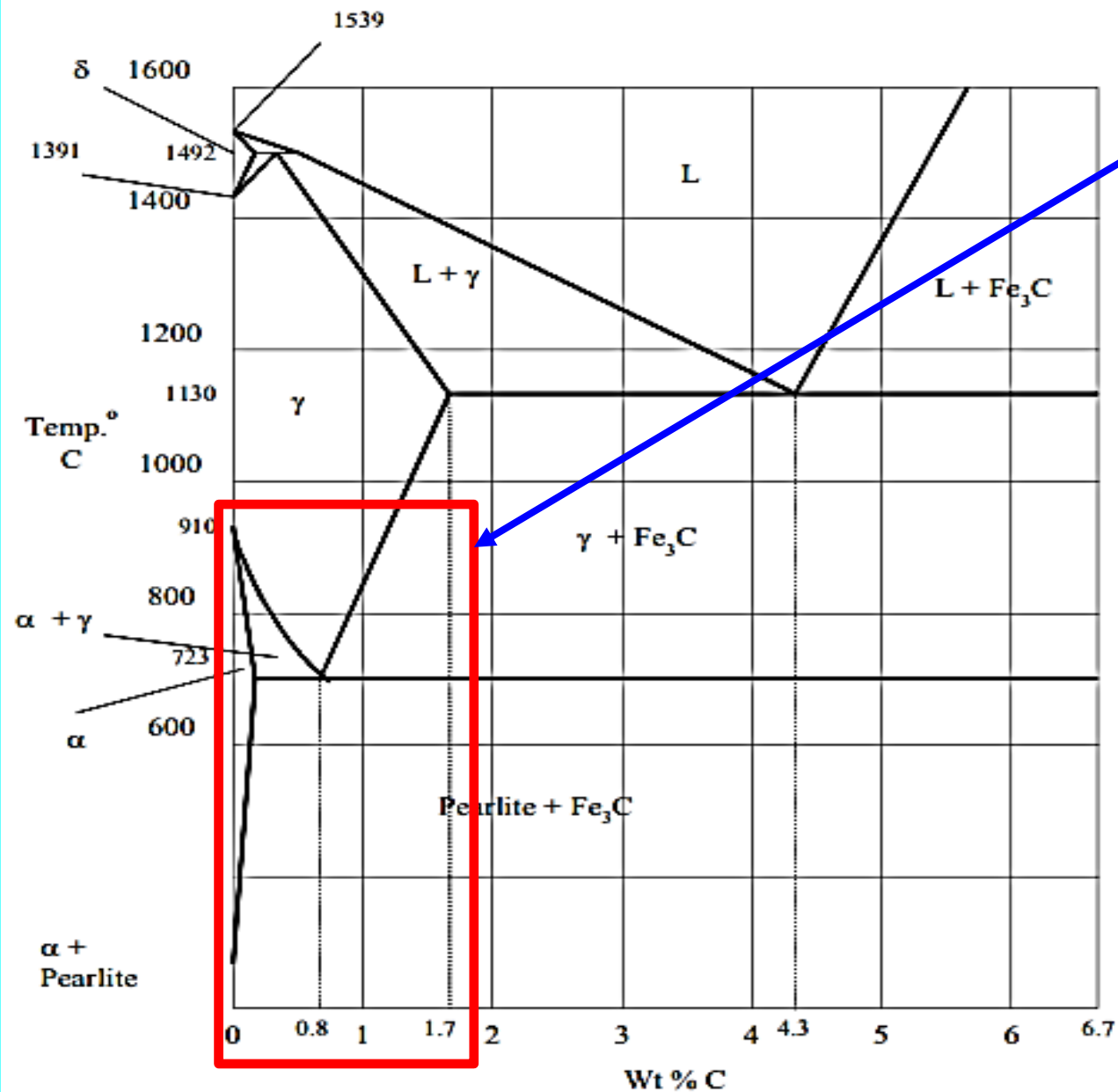
The Iron-Carbon System



The Iron-Carbon System



The Simplified Iron-Carbon System



The steel and most useful part of the Fe-C diagram

0.8 %C – Eutectoid
4.3 %C – Eutectic

0.03 %C – limit of C in α at 723°C
1.7 %C – limit of C in γ at 1130°C
0.01 %C – limit of C in δ at 1492°C
6.7 %C – useful limit of C in iron

α = ferrite
 γ = austenite

Equilibrium Diagram of the Iron-Carbon System

Relationship between Fahrenheit (°F) and Celsius (°C) Temperatures

$$^{\circ}\text{F} = ^{\circ}\text{C} \times \frac{9}{5} + 32$$

and

$$^{\circ}\text{C} = (^{\circ}\text{F} - 32) \times \frac{5}{9}$$

Some temperature comparisons:

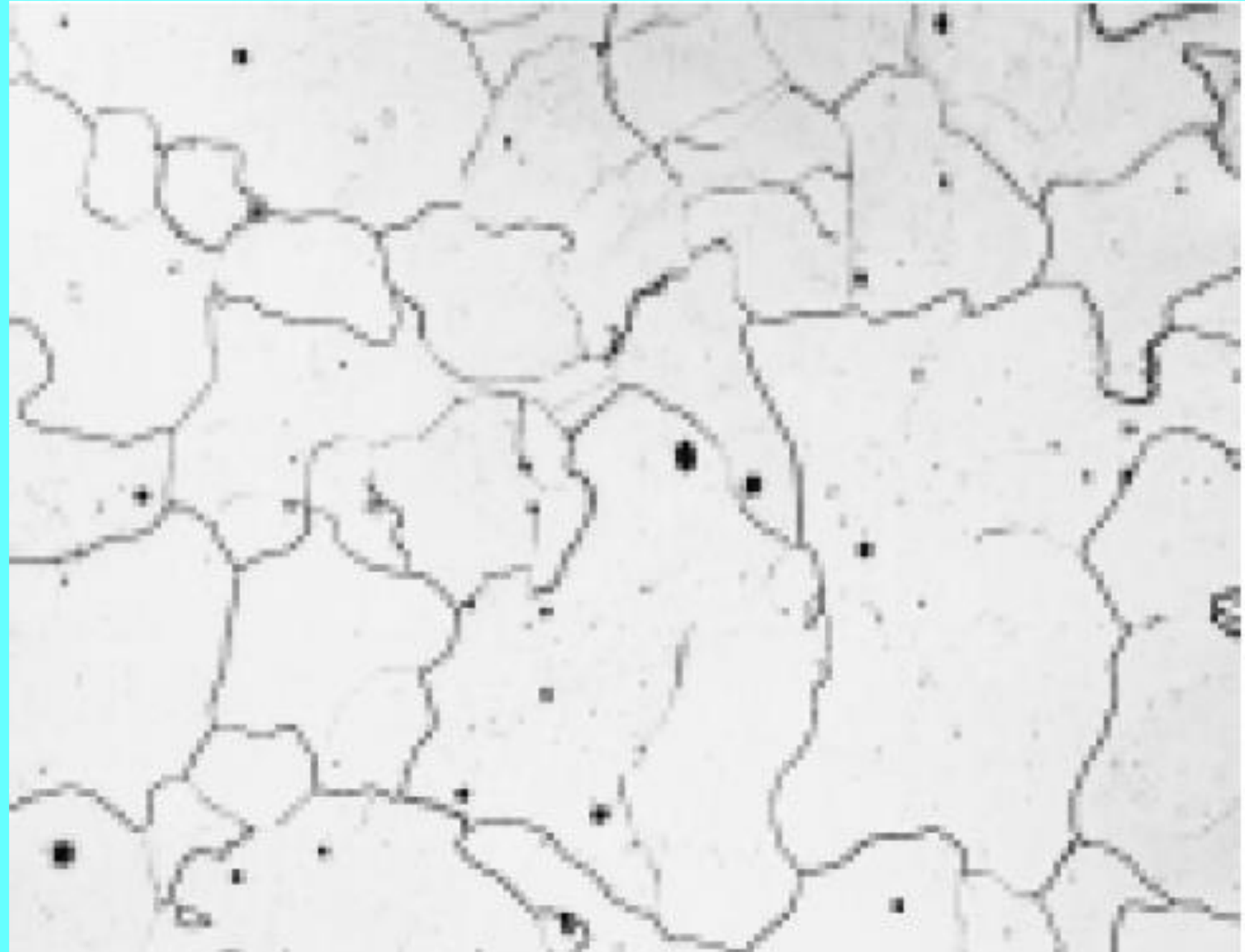
Freezing/melting point of water = $0^{\circ}\text{C} = 32^{\circ}\text{F}$

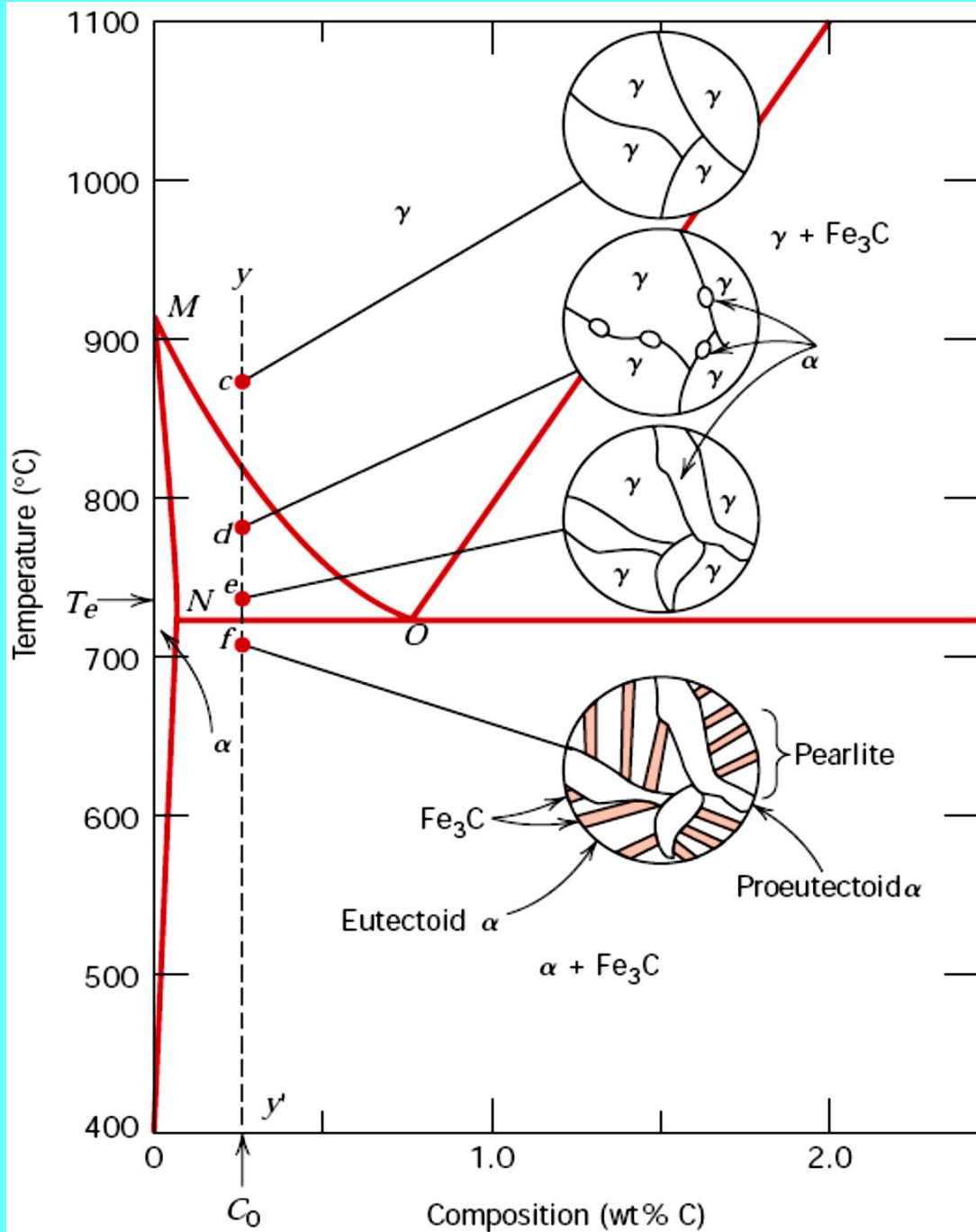
Boiling point of water = $100^{\circ}\text{C} = 212^{\circ}\text{F}$

Nomenclature of Iron-Carbon Alloys

- An alloy with less than 0.03% C (entirely ferrite at 723°C) → usually referred to as ***pure iron***.
- 0.03% C – 1.7% C (entirely austenite at 1130°C) → ***steels***, further divided as:
 - ***Hypoeutctoid steels*** (0.03 – 0.83% C) and
 - ***Hypereutctoid steels*** (above 0.83 – 1.7% C)
- 1.7% C – 6.67% C → ***cast irons***.

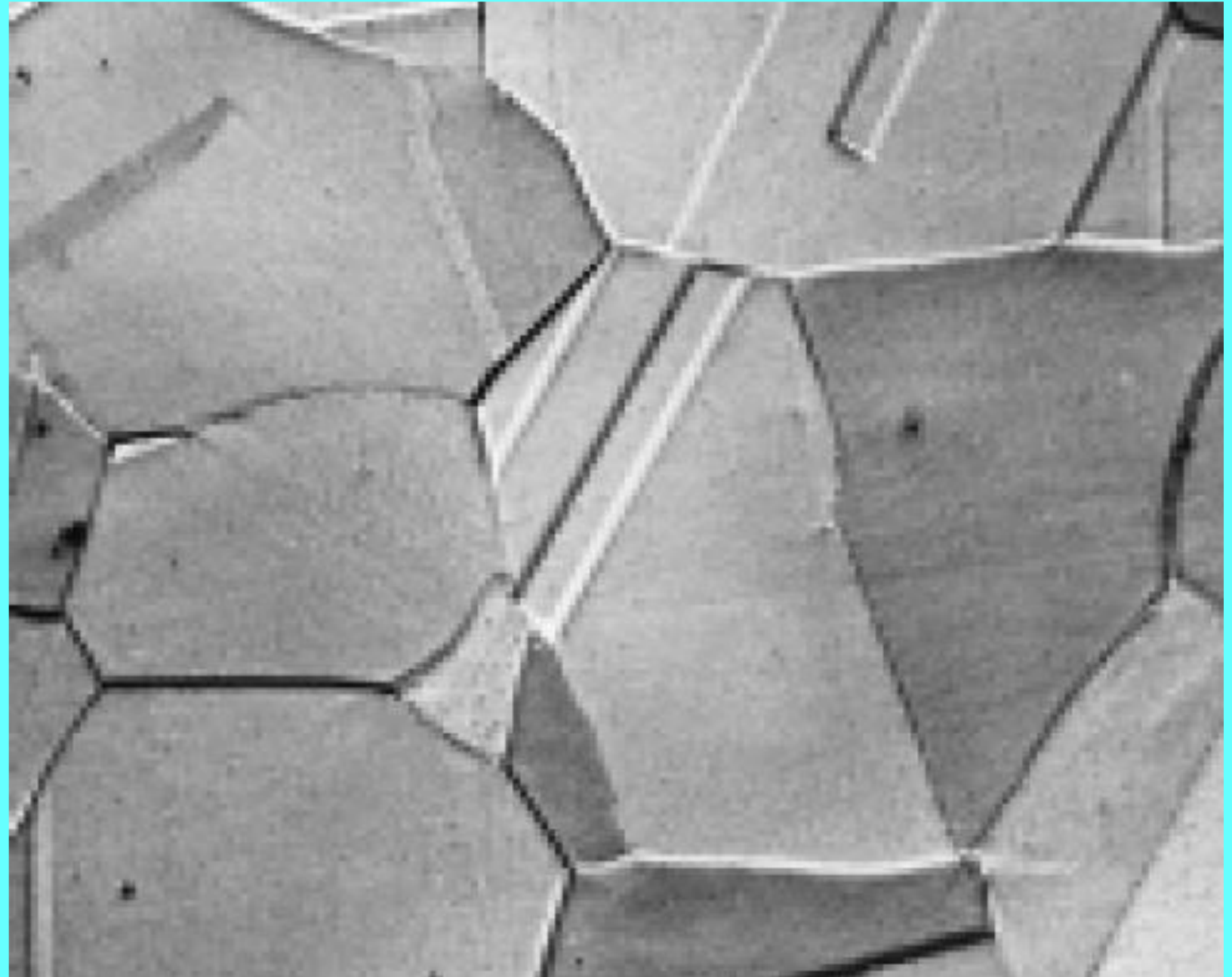
Pure irons (ferrite only) show sharp grain boundaries



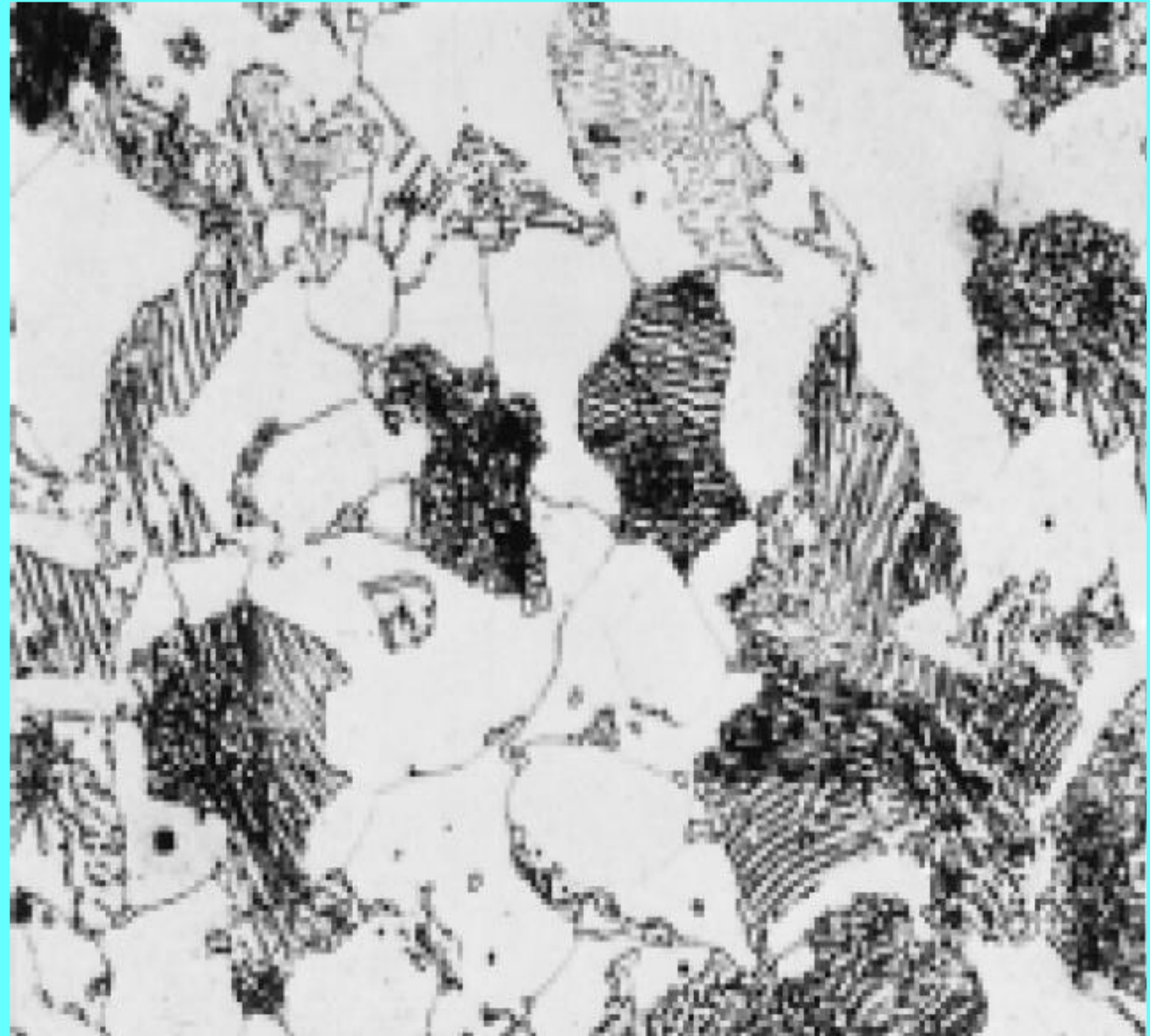


Hypoeutectoid composition
(0.76% C) as cooled from the
austenite region to below the
eutectoid temperature

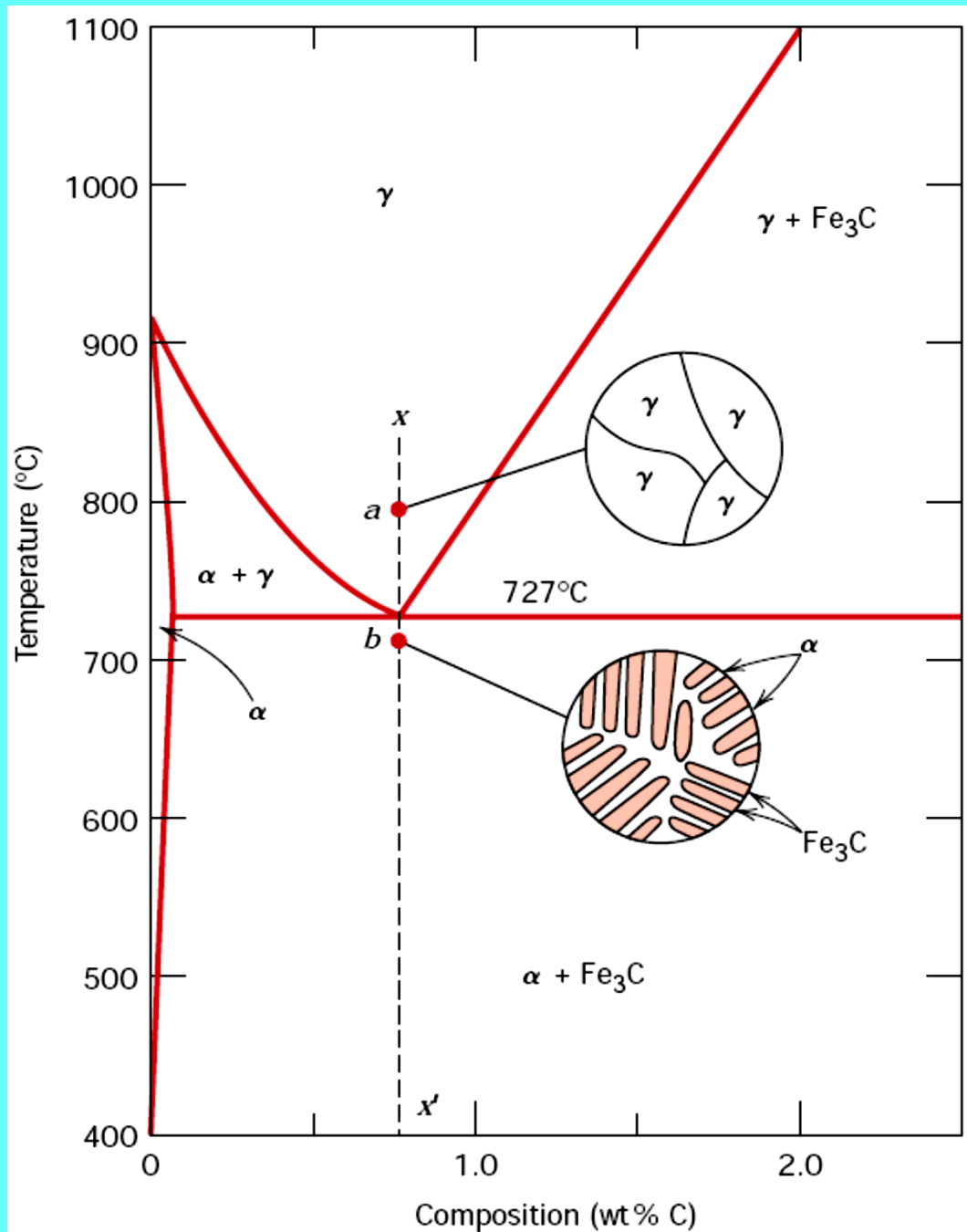
Austenite



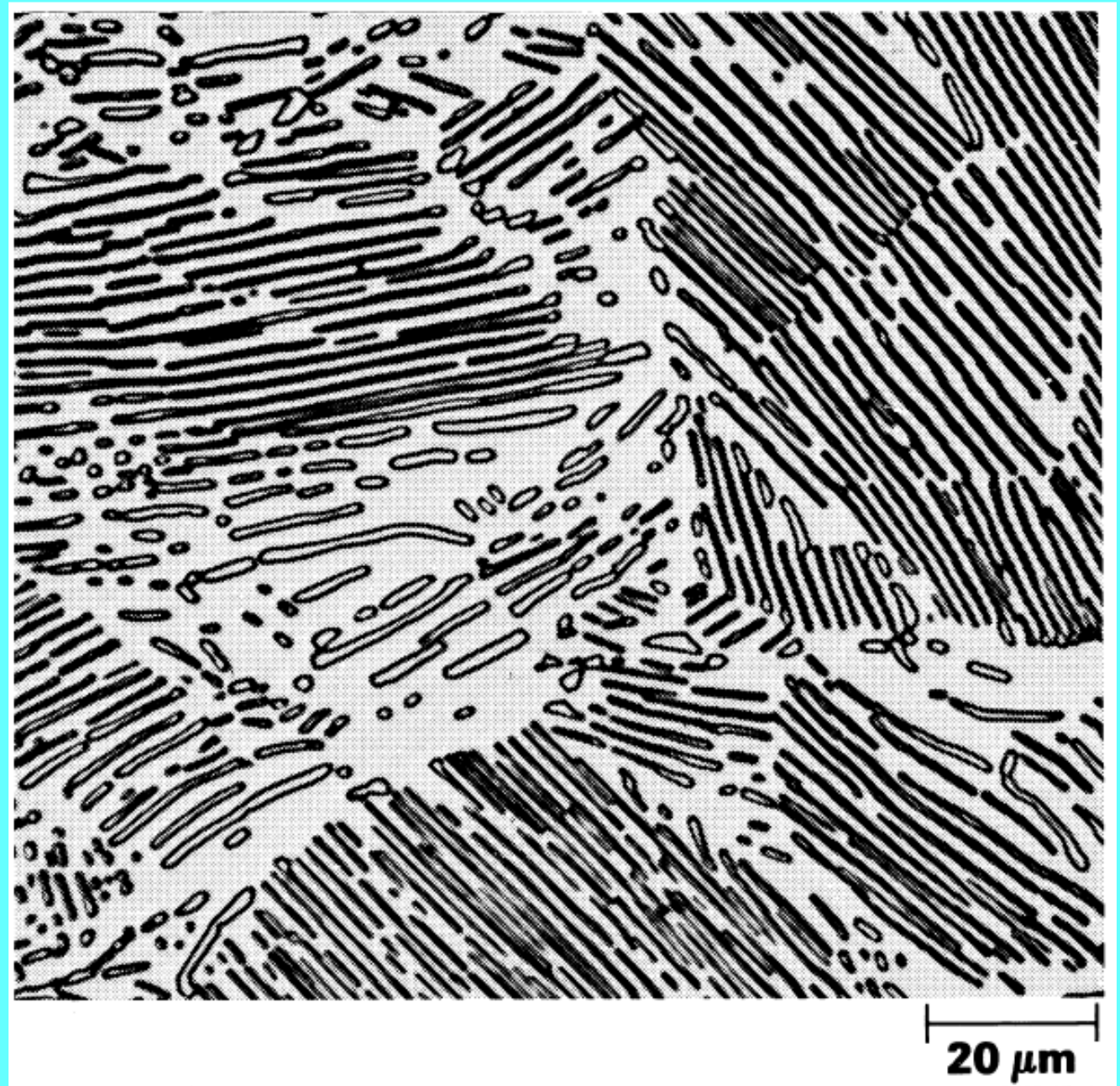
With increase in C content, (0.38% C) **pearlite** increases & appears dark or striped and can be distinguished clearly from the light ferrite



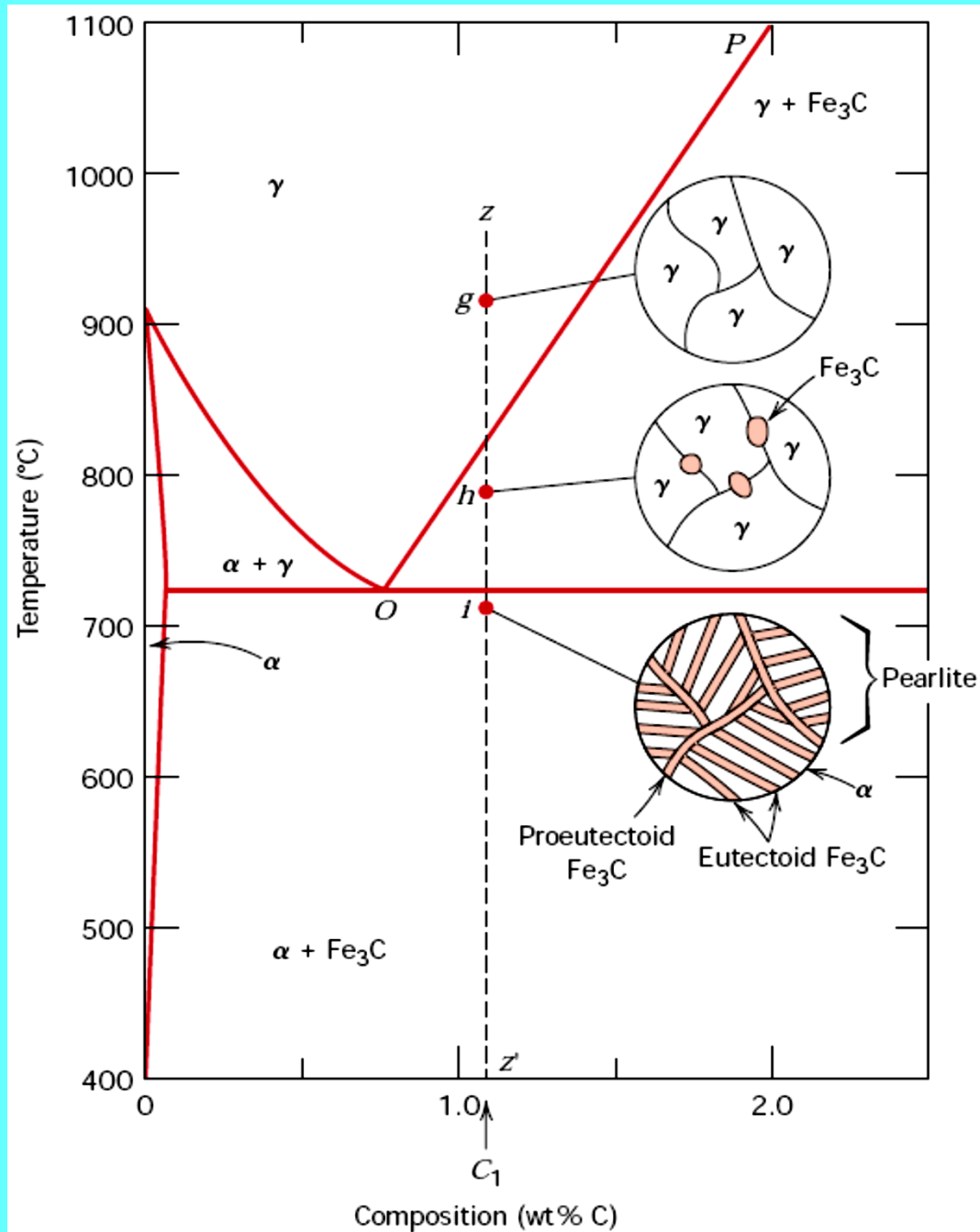
Eutectoid Composition – Above and below the eutectoid temperature



Eutectoid steel showing the pearlite microstructure consisting of alternating layers of ferrite (light phase) and cementite (dark phase).



Hypereutectoid Composition –
Above and below eutectoid
temperature



With increase in C content, pearlite increases in quantity appears dark or striped and may be distinguished clearly from the ferrite.



(1.4% C Steel - white hypoeutectoid cementite network surrounding the pearlite colonies.)

Cast Irons

- **Cast Irons** = all Fe-C alloys with $C > 1.7\%$ C.
- Never single-phase on first solidification – always contain some cementite.
- Changes on cooling are complex
- Final structure = **mixture of ferrite + cementite.**
- In hypereutectic alloys - some graphite forms from the liquid
- Cast iron containing cementite = **white cast iron.**

- Cast iron containing graphite (**graphitised cast iron**) = **grey cast iron**.
 - Graphitisation is favoured by slow cooling in the presence of silicon.
- **White cast iron** (owing to presence of cementite):
 - Extremely hard
 - Brittle
 - Excellent wear resistance properties to the surfaces of castings

- **Grey cast iron**
 - Graphite is distributed in flakes which break up the continuity of the metal matrix.
 - **Ferrite grey cast iron**
 - All the carbon is graphite

– **Pearlitic grey cast iron**

- There is some presence of pearlite
- Graphite flakes have no strength and act as internal cracks
- Therefore the material is weak and brittle.
- Extremely liable to fracture under shock loads

The End

But wait!!!

Assignment:

Refer to the Iron-Carbon Phase Diagram. Consider alloys containing 0.5% C, 0.83% C and 1% C, which have been slowly cooled from the austenite region (say 1100°C) to room temperature. Answer the following questions.

1. Why is slow cooling preferred to rapid cooling?
2. Describe the transformations that occur in the complete but slow cooling process of these alloys.
3. Calculate the relative amounts and compositions of the phases present at room temperature.
4. Draw the microstructure, which would result in each case.

This Assignment is Due in One Week's Time.

MEC 2309

***is the best course there can be
among courses at this engineering
foundation level.***

Simply enjoy yourself in it!!!

Now

The End

for real!!