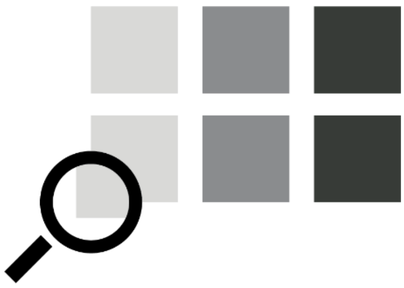
GRANTA EduPack MicroProjects with Solutions:
Phase Diagrams and Phase Transformations



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These ***MicroProjects*** are short investigations of an aspect of Materials Science and Engineering that can be completed in less than an hour. Each poses a set of questions that can be answered using the GRANTA EduPack Material Science and Engineering (MS&E) database. All start at a level that is readily accessible, using the SEARCH function to find records, creating charts using the CHART/SELECT function, and extracting relevant data from a Record and its linked SCIENCE NOTES. Hints in gray help with any difficult step.

Each MicroProject has an attached ***Discussion Point*** – a challenge to go further – highlighted in red and separated from the MicroProject by this separator:

The Discussion Point poses a question linked to or arising from the MicroProject. Responding to the Discussion point requires independent thought and research, takes longer, but is rewarding if followed. It is an add-on for more advanced study.

Each MicroProject and its Discussion point has a fully worked ***Sample Response***, available to the instructor. The charts shown in the responses are reproduced here exactly as produced by GRANTA EduPack.

Example Use: In-class activities, homework assignments, activity to introduce students to functionalities of GRANTA EduPack

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Phase Diagram Teaching Package Files:

- Lecture PowerPoint
- Student Lecture Notes
- Exercises
- Quiz Questions (Word and GIFT Format)
- Concept Maps
- Misc.

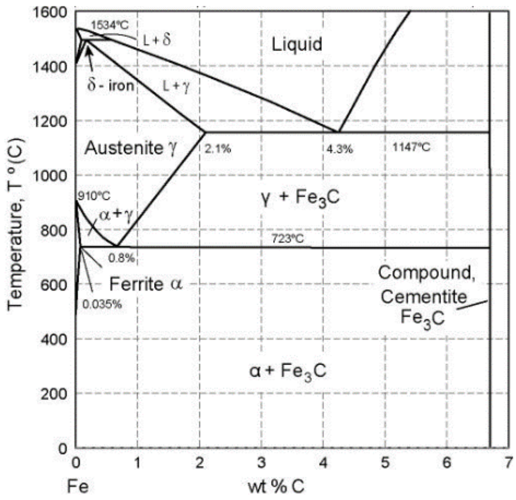
GRANTA EduPack Introductory MSE Teaching Package Topics:

- Bonding and Material Families
- Crystallography and Crystal Defects
- Mechanical Properties
- Phase Diagrams

Phase Diagrams and transformation MicroProject 1

Exploring the Iron-Carbon Phase diagram Part 1

A Phase diagram is a map, in Temperature-Composition space, of the phases that co-exist in equilibrium in a binary or ternary alloy. Among metal systems, the Iron-Carbon diagram is perhaps the most important. But what does it *actually* tell us? How does it help engineers?



- Open the MATERIALS node on the Home page. Open Metals and Alloys – Ferrous alloys and make a list of the carbon contents of

  Low carbon steel
  Medium carbon steel
  High carbon steel
  Cast iron

  Mark these ranges onto the Iron-Carbon diagram shown here.

- Three of the phases on the iron-carbon diagram are Ferrite (α), Austenite (γ) and Cementite. What are they? To find out, open the PHASE DIAGRAM node on the Home page, select the Phases tool and the Fe-C (steels) tab. Hover the mouse over the Phase name to get a schematic and a description.

- Open the Cooling Path tool and select the Fe-C (steels) tab. Explore the way the microstructure changes as the mouse is dragged down one of the three marked cooling paths. Now sketch the microstructures that should appear in the four separate phase fields when a Fe - 2wt% C alloy is cooled from the liquid (phase-field 1) to room temperature. (Hint: Use the microstructures shown in the Cooling path tool as a reference.)

Discussion point. Martensite

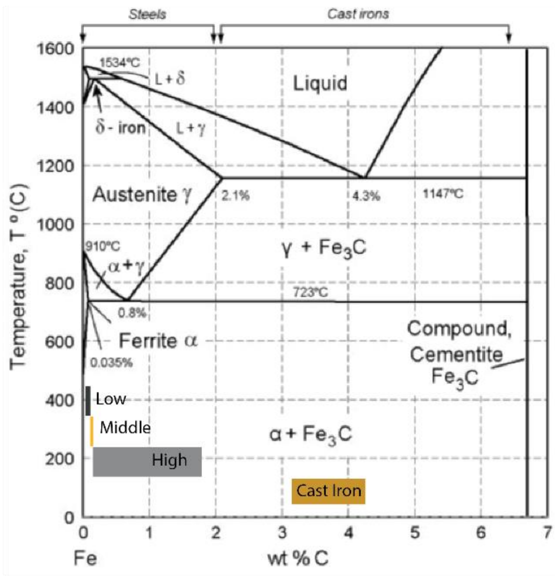
Martensite is another steel phase that is commonly used in industry. But it is not found on the equilibrium phase diagram. Why not? Research martensite and find out how it is formed, its beneficial properties, and why you won't find it on the phase diagram.

Answers and Sample Responses

The carbon content of steels and cast iron.

The records list the composition. The carbon contents are

Low carbon steel	0.02-0.3%C
Medium carbon steel	0.3-0.7% C
High carbon steel	0.7-1.7%C
Cast irons	3.2 – 4.1%C



Ferrite, Austenite and Cementite

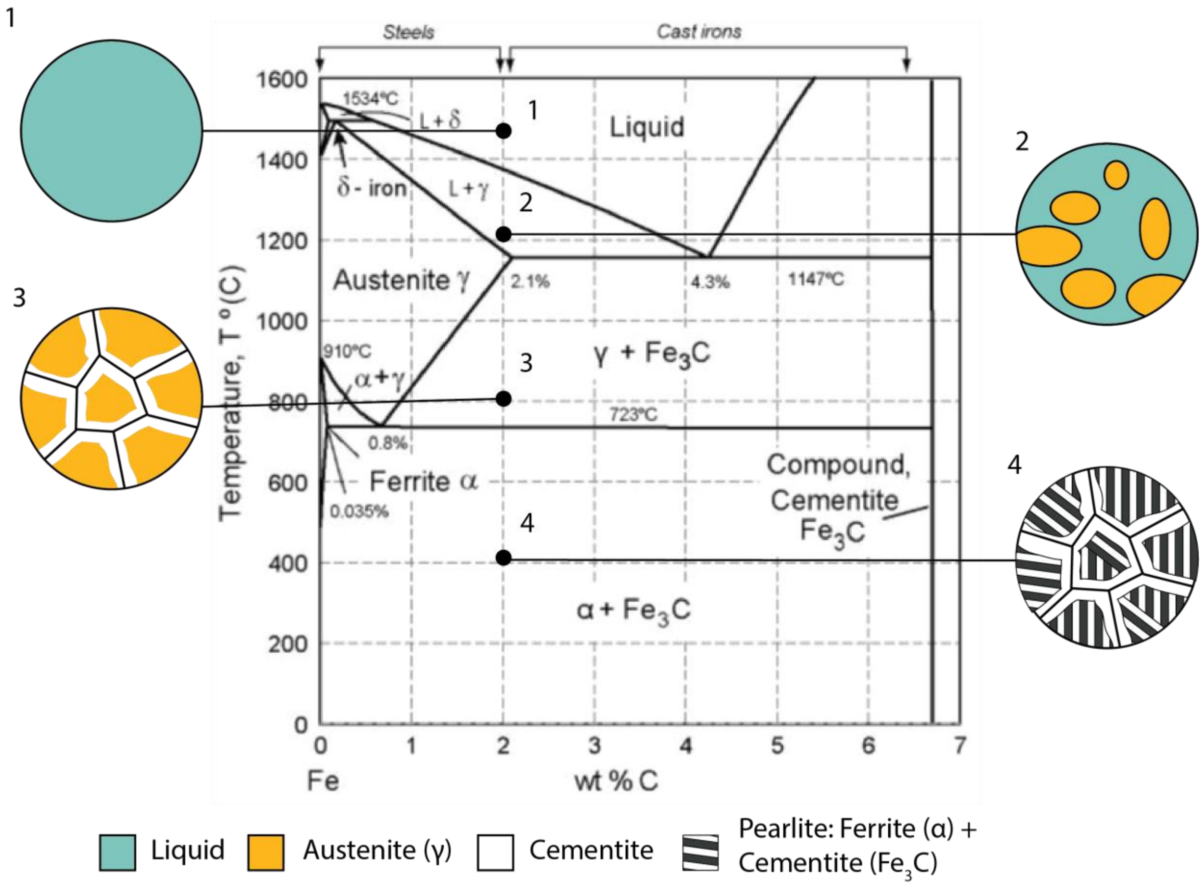
Ferrite is body-centered cubic (BCC) α-iron with up to 0.035 wt% carbon.

Austenite is face-centered cubic (FCC) γ-iron with up to 2.1 wt% carbon.

Cementite is the compound iron-carbide, Fe_3C.

Cooling Path Sketches

The Fe 2% C passes through four phase fields as it cools. The high carbon content will give more Fe_3C than the lower-carbon alloys shown in the Cooling-path tool.



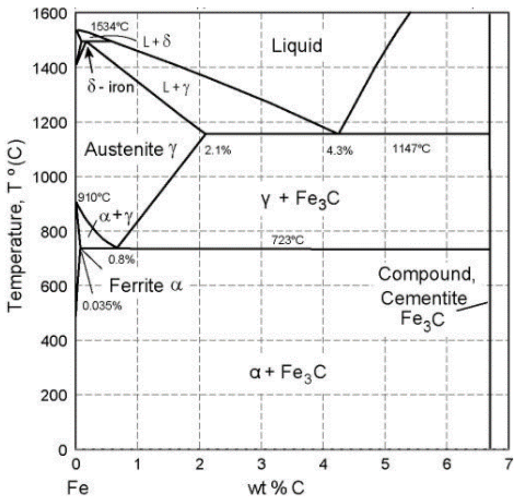
***Discussion point.* Martensite** *(Paraphrased from the sources below.)*

Martensite is formed by rapidly cooling austenite by quenching in water or oil. There is not enough time for the atoms to diffuse to new atomic positions. Instead, the austenite-to-martensite transformation involves a near-instantaneous rearrangement of atoms, a *diffusionless transformation*. Martensite is a *metastable phase*; it exists only because the rapid cooling gives no time for the transformation to the equilibrium phase-structure (ferrite plus Fe_3C) so it does not appear on the equilibrium phase diagram. Martensite is extremely hard but almost as brittle as glass. If tempered (held at temperature between 200 C and 650 C for between 1 and 2 hours), it evolves into a structure with an exceptionally good combination of strength and toughness.

Sources: Structure and Properties of Engineering Alloys by William F. Smith
https://study.com/academy/lesson/martensite-definition-transformation-microstructure.html

Phase Diagrams and transformation MicroProject 2

Exploring the Iron-Carbon Phase diagram Part 2



A Phase diagram is a map, in Temperature-Composition space, of the phases that co-exist in equilibrium in a binary or ternary alloy. Among metal systems, the Iron-Carbon diagram is perhaps the most important. But what does it *actually* tell us? How does it help engineers?

- There are three Phase reactions (when one phase transforms into two others or two react to form one) on the Fe-C phase diagram: the Eutectic reaction, the Eutectoid reaction and the Peritectic reaction. What are they? (Hint: Select the Phase Diagram glossary tool and the Fe-C (steels) tab for guidance.)

  Mark these reactions onto the Iron-Carbon diagram shown here.

- Use your marked-up diagram to answer the questions:

  What is the sequence of phase-changes when a low carbon steel is heated from room temperature to 1000 C?

  What is the sequence when a cast iron containing 4.3% carbon is heated from room temperature to 1200 C?

- Knowing the fraction of each phase in a given alloy gives an insight into its properties. Use the Lever Rule tool as a guide to work out the weight-fraction of each phase in a Fe - 2wt% C alloy at both 400°C and 1000°C. Does the amount of Fe_3C change between the two temperatures? If it does, why? (Hint: Use the Lever rule, explained in the opening frame of the Lever-rule tool to calculation the weight fractions. Use the Lever Rule tool, Fe-C (steels) tab, as a guide.)

Discussion point. ***Pearlite and Banite***

Pearlite and Banite are phrases commonly used when discussing steel. But they are not phases listed on the phase diagram. What are these constituents and how are they formed?

Answers and Sample Responses

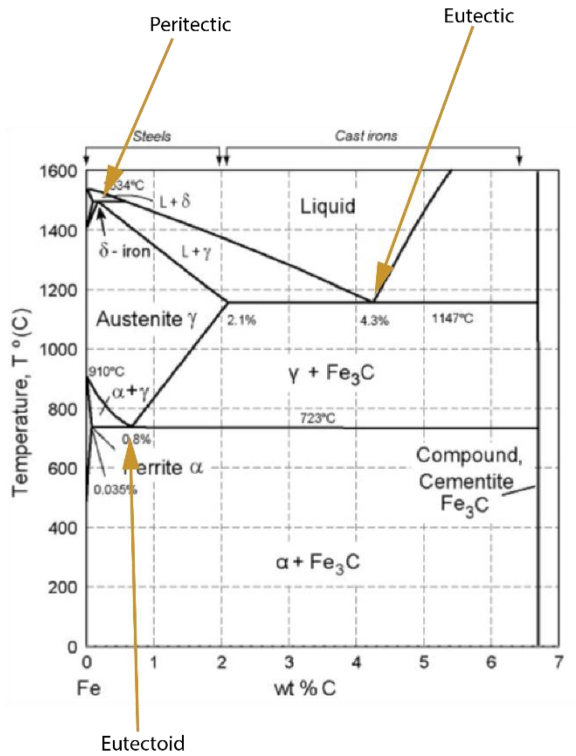
Phase Reactions on the Fe-C diagram

The Eutectic reaction at 1140 C: Liquid → γ+ Fe_3C
The Eutectoid reaction at 727 C: γ → α+ Fe_3C
The Peritectic reaction at 1534 C: L+δ→γ

Phase change sequences

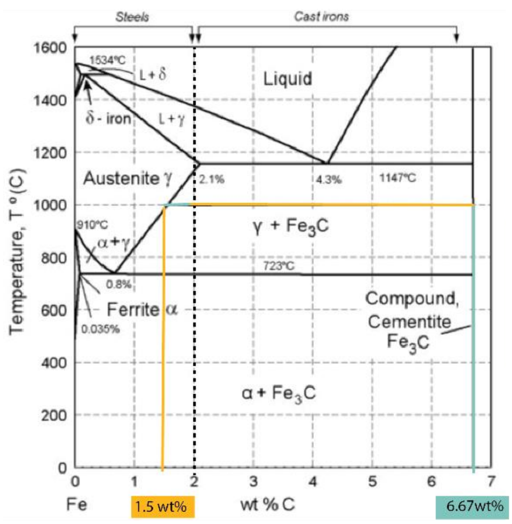
A low carbon steel, heated from room temperature to 1000C, first transforms from ferrite (α-iron) with a little Fe_3C to a mixture of ferrite (α) and austenite (γ) at 723C. Above about 800C it transforms into 100% austenite (γ) (see the line on the diagram opposite).

A cast iron with 4.3% carbon, heated from room temperature to 1200C, first transforms from ferrite (α-iron) plus Fe_3C to austenite (γ) plus Fe_3C at 723C. At 1147C it abruptly melts.



Lever Rule exercise

1000C



Fe_3C Phase

Composition: 6.67 wt%C
Weight Fraction:

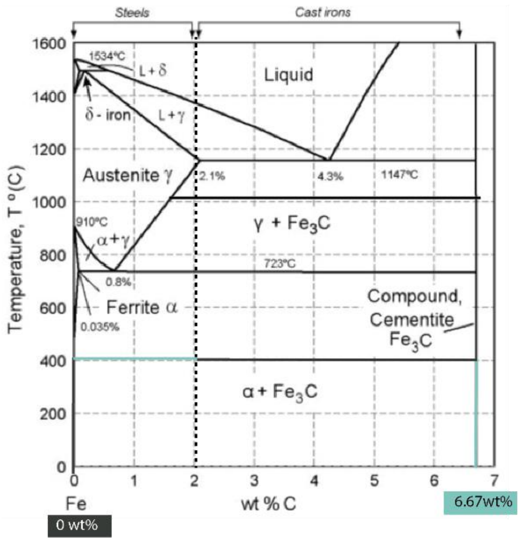
W_a=(2-1.5)/(6.67-1.5)=
0.5/5.17=0.1 or 10%

Austenite Phase

Composition: ~1.5 wt%C
Weight Fraction:

W_a=(6.67-2)/(6.67-1.5)=
4.67/5.17=0.9 or 90%

400C



Fe3C Phase

Composition: 6.67 wt%C
Weight Fraction:

W_a=(2-0)/(6.67-0)=
2/6.67=0.3 or 30%

Ferrite Phase

Composition: 0 wt%C
Weight Fraction:

W_f=(6.67-2)/(6.67-0)=
4.67/6.67=0.7 or 70%

Yes, the amount of Fe_3C changes due to the solubility change of C in Ferrite compared to Austenite.

Discussion point. ***Pearlite and Banite*** *(Paraphrased from the sources below.)*

A constituent is a microstructure that has a uniquely identifiable appearance via microscopy. It is not a phase, however. In this case, both pearlite and banite are formed through the eutectoid reaction and contain the phases Ferrite and Cementite. Pearlite is formed from slow cooling through the eutectoid isotherm with a distinct lamellar or spheroidal microstructure, while Banite is formed through faster cooling rates and can form plates or lathes. Both of these transformations involve diffusion, however, compared to the much faster diffusionless transformation to Martensite.

Sources: Physical Metallurgy Principles, 4th edition by R & L Abbaschian and R. Reed-Hill

Phase Diagrams and transformation MicroProject 3

Solder Alloys and their importance to Society

Soldering is a manufacturing process used in circuitry, from home projects to large scale electronic productions. But designing the alloys used for this process is no easy feat. What goes into choosing these seemingly simple materials?

- What is soldering? (Hint: Use the "Search" function to find more information about soldering)

- Why is the temperature of the soldering process so important? (Hint: Use the "Search" function to find more information about soldering and brazing)

- Historically, Lead Tin alloys were used for the majority of solder applications. Look at the phase diagram for this alloy—what about this alloy (and others like it) make it suitable for this low temperature manufacturing process? (Hint: Look up the Pb-Sn phase diagram in the "Phase Diagram Datatable" Segment of the Phase Diagram node)

- The composition of Pb-Sn solder alloys varied from roughly 5 to 60 wt% Sn. For a solder alloy with 30 wt%Sn, what is the total weight percentage of lead within the whole system, the primary Pd phase, and the eutectic phase just below the eutectic isotherm? (Hint: Use the Lever Rule tab for assistance in calculating these fractions)

Discussion point.* *Lead-free electronics

There was a large push to remove lead from electronic devices due to its toxicity. What are the alternative alloys currently being used and how did this impact manufacturing processes? Is lead solder still used anywhere?

Answers and Sample Responses

What is soldering? The record gives the following description:

Soldering is similar to low-temperature brazing, using alloys that melt below 450C. Soldered joints are less strong than brazed joints- more like an adhesive- but the equipment needed to make them is simpler and the temperatures reached by the component are much lower, an essential for the assembly of electronic equipment.

Why is the temperature of the soldering process so important?

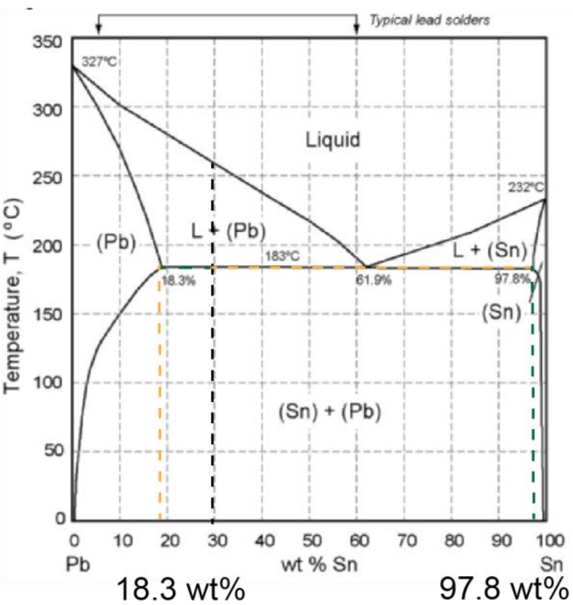
Components that are assembled using solder joints, mainly electronics, cannot withstand the temperatures used in other joining techniques like welding. These pieces are also quite delicate, so mechanical joining techniques like screws or nails will not work.

Pb-Sn as a Solder Alloy

Pb-Sn is a binary eutectic system, meaning two components are completely miscible in the liquid phase but phase separate into two solid phases upon cooling. At a specific composition (the eutectic composition) there is a eutectic phase reaction: L→ α+β . This causes a significantly depressed melting temperature compared to the two components individually. It is this depressed melting temperature that makes Pb-Sn and other low temperature eutectic alloys like it can be used to meet the temperature requirements of this joining processing technique.

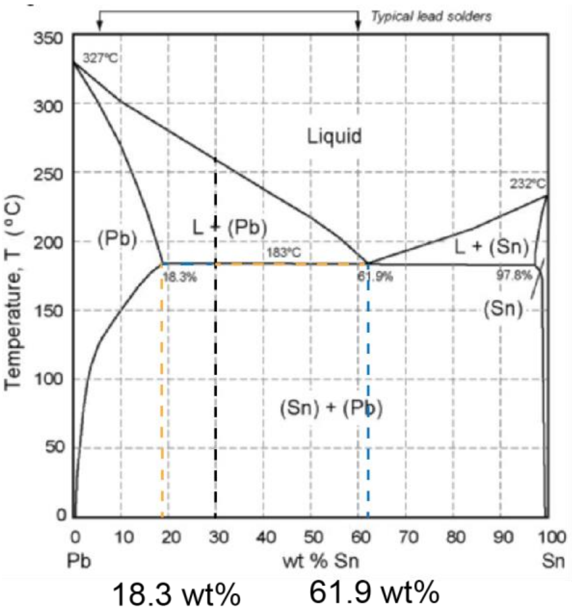
Lever Rule Calculation for Pro-Eutectic Phase

To calculate the total Pb content just after the eutectic reaction, use the tie line below



$$W_{Pb-Total} = \frac{97.8 - 30}{97.8 - 18.3} = \frac{67.8}{79.5}$$
$$= 0.85 \ or \ 85wt\%$$

To calculate the primary Pb weight fraction just after the eutectic reaction, use the tie line below



$$W_{Pb-Primary} = \frac{61.9 - 30}{61.9 - 18.3} = \frac{31.9}{43.6}$$

$$= 0.73 \; or \; 73wt\%$$

To calculate the eutectic Pb weight fraction, subtract the weight fraction of the total Pb amount from the primary Pb phase

$$W_{Pb-Eutectic} = (0.85 - 0.73) = 0.12 \; or \; 12wt\%$$

Discussion point. ***Lead-free electronics***

Lead is a heavy metal that can lead to heavy metal poisoning. Therefore, most electronics that are mass produced now do not contain lead. Now many ternary alloys are used, such as Sn-Ag-Cu. These alloys have higher melting points than Pb-Sn though.

Lead free solder can still be purchased and used for hand soldering

Source: CES EduPack 2019 Records for Soldering and Brazing

Document Information

This exercise unit is part of a set of teaching resources to help introduce students to materials, processes and rational selections.

Accuracy

The author(s) try hard to make sure that these resources are of a high quality. If you have any suggestions for improvements, please contact the author(s) by email. You may also write to the Ansys Granta Education Team with your suggestions at granta-education-team@ansys.com.

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- Case studies
- Exercises with worked solutions
- Microprojects
- Recorded webinars
- White papers
- Solution manuals
- Interactive exercises

Some of the resources are open access and students can access them. Others are only available to educators using GRANTA EduPack.

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