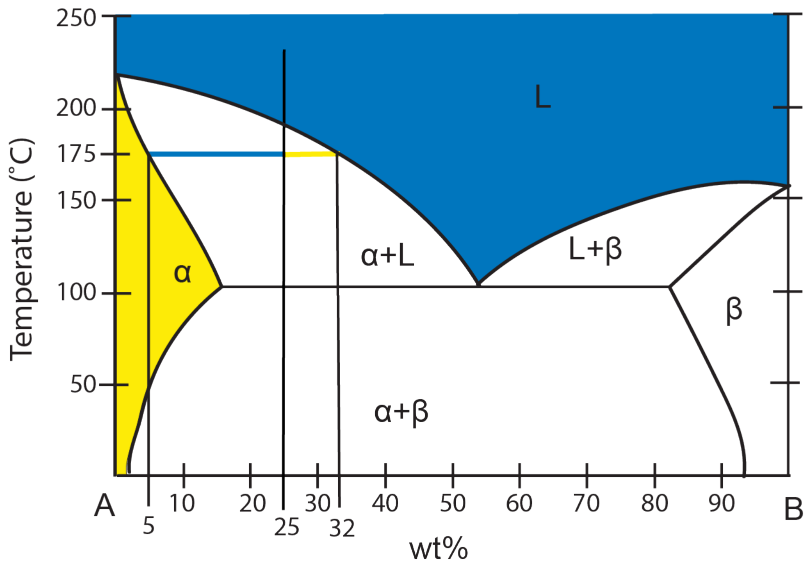
# GRANTA EduPack Exercises with Solutions
# Phase Diagrams





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GRANTA EDUPACK

This collection of Phase Diagram exercises and solutions has been put together to help you as an instructor choose or develop your own exercises for your students. You may simply want to browse through them for inspiration, or you may use them with your class. We are providing these in Word format so that you may pick and choose the questions you find suitable for your course this year.

Example uses: In-class lab activities (solo or in groups), supplemental questions for homework assignments

Most of the questions come from or are inspired by the exercises in the following books by Professor Mike Ashby of the University of Cambridge Engineering Department, co-founder of Granta Design. Some can also be found in other Ansys Granta resources (see here).

- **Materials Selection for Mechanical Design** by Michael F. Ashby (ISBN: 978-0-08-100599-6)
- **Materials: Engineering, Science, Processing and Design** by Michael F. Ashby, Hugh Shercliff, and David Cebon (ISBN-13**:** 978-0-08-097773-7)
- **Materials and the Environment** by Michael F. Ashby (ISBN-13: 978-0-12-385971-6)

This resource is part of the Ansys Granta Phase Diagram teaching package. The goal of this package is to provide a set of resources around introducing phase diagrams in the classroom. These resources were designed to be used separately or together, depending on the needs of the class and/or curriculum. Currently, the package contains the following resources:

- PowerPoint Lecture
- Student Note Sheet
- Exercise bank
- Quiz Question bank in Word, GIFT, and Blackboard LMS format
- Three MicroProjects
- Three concept map prompts

*Note: the exercises, quiz questions, MicroProjects, and concept maps all contain a "student-friendly" version for use in the classroom and a solution manual.*

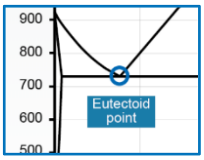
These resources easily integrate with the MS&E database from GRANTA EduPack and use many figures and definitions from said software. Our hope is this package, combined with GRANTA EduPack, supports teaching phase diagrams across a wide range of courses.

1. In the *Phase Diagram glossary*, there are three binary diagrams to explore. Explain the terms Liquidus and Solidus. Which important phase points only appear in the Fe-C diagram and what do they mean?

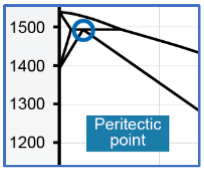
**Answer:** The Liquidus line shows the temperature at which solidification starts upon cooling. It is the boundary between the liquid region and the (Solid + Liquid) region.

The Solidus line shows the temperature at which solidification ends upon cooling. It is the boundary between the (Solid+ Liquid) region and the Solid region.

Two important phase points only appear on the Fe-C diagram: a peritectic and a eutectoid point.




A eutectoid point is the lower limit of a single-phase solid field formed by two falling phase boundaries intersecting in a 'V'. At the eutectoid point, a eutectoid reaction takes place upon cooling. A single-phase solid transforms into two different solid phases at constant temperature: Solid $\gamma \rightarrow$ Solid $\alpha$ + Solid $\beta$




A peritectic point is the upper limit of a single-phase solid field formed by two ascending phase boundaries intersecting in an inverted 'V'. At the peritectic point, a peritectic reaction takes place upon cooling. A liquid and a solid transform into a single-phase solid at constant temperature: Solid $\delta$ + Liquid L $\rightarrow$ Solid $\gamma$

2. In the *Phase Diagram glossary*, the Fe-C diagram has both a eutectic and eutectoid reaction. What is the difference between the two of them? How do they compare to the peritectic reaction?

**Answer:**

- *Eutec-* means a normal 'V' meeting a horizontal line, whereas *peritec-* means an inverted 'V' meeting a horizontal line.
- *-tic* means a liquid phase is involved, whereas *-toid* means all phases are solid.

3. Read and understand the text that comes up when you click on *Lever rule* for the first time. Move on to the Lever rule diagram. There are two important concepts: weight fraction and composition. What's the difference between the two?

**Answer:** *Weight fraction* describes the percentage in terms of weight of a certain phase present. Because of mass conservation the sum of all weight fractions must be one. If we only have two phases (solid and liquid) we have:

$$W_S + W_L = 1$$

*Composition* is the percentage with respect to the weight of the component present (on the X-axis of binary phase diagrams). The mass of one of the components in one phase plus the mass of the same component in the other phase must be equal to the mass of the component in the total alloy. Expressed mathematically:

$$W_S C_S + W_L C_L = C_O$$

Combining these two equations and solving for the liquid and solid weight fraction, we obtain the lever rule:

$$W_S = \frac{C_O - C_L}{C_S - C_L} \; and \; W_L = \frac{C_S - C_O}{C_S - C_L}$$

4. The *Lever Rule* can be used at any composition. On the same diagram, what is the composition of the liquid and solid phases for a 60 wt% B alloy at 1300°C?

**Answer:** For a $C_O$=60 wt%B at 1300°C, $C_L$= 43wt%B and $C_S$=62wt%B (approximately). Using these numbers:

$$W_S = \frac{C_O - C_L}{C_S - C_L} = \frac{60 - 43}{62 - 43} = \frac{17}{19} = 0.89 \; or \; 89\%$$

And

$$W_L = \frac{C_S - C_O}{C_S - C_L} = \frac{62 - 60}{62 - 43} = \frac{2}{19} = 0.11 \; or \; 11\%$$

5. By looking at the Cu-Ni diagram in *Phases*, how are the copper and nickel atoms arranged in the solid phase? What does the term solid solution mean?

**Answer:** This means that the atoms randomly substitute for each other within the crystal structure. The solubility depends on the similarity between the crystal structures of the components and their atomic radii among other things.

6. Look at the eutectic phase in the Pb-Sn *Phases* phase diagram. What does it mean that the Sn atoms are found in the Pb solid phase and vice versa? Can this be predicted by the phase diagram itself?

**Answer:** For specific composition ranges, Pb is soluble in Sn and Sn is soluble in lead. That means that some Pb or Sn atoms will be found in the opposite solid phase. This is shown by the *solvus* line on the phase diagram.

7. In *Cooling paths,* looking at the eutectic phase diagram, which of the five cooling paths contains the eutectic transformation? This transformation is isothermal, what does that mean?

**Answer:** Path 3 contains the eutectic transformation. Isothermal means that the transformation takes place at one single temperature. It is enough to cool the alloy to the eutectic temperature for the structure to completely transform from liquid to eutectic.

8. Which of the three diagrams in *Cooling paths* contains a eutectoid point? When you cool eutectoid carbon steel (0.8 wt%) what's the final solid microstructure called? Is this, strictly speaking, a phase?

**Answer:** Only the Steel diagram contains a eutectoid point. The final solid microstructure of a eutectoid alloy is called Pearlite and it is <u>not</u> a phase. It's a mixture of two phases: ferrite and cementite.

9. In the *Phase diagram datatable*, which one is not a binary metal alloy diagram? What's special about the components int his diagram?

**Answer:** The only phase diagram that doesn't represent a binary metal alloy is the $SiO_2$-$Al_2O_3$ diagram. The components are ceramics and therefore compounds rather than pure elements.

10. In the *Phase diagram datatable*¸ how many of the binary diagrams have a eutectic reaction? How many have a eutectoid reaction?

**Answer:** Nine  phase diagrams have eutectic reactions:

1. Al-Cu
2. Al-Mg 40%
3. Al-Mg full
4. Al-Si
5. Al-Zn
6. Fe-C 7%
7. Ni-Cr
8. Pb-Sn
9. $SiO_2$-$Al_2O_3$

Five phase diagrams have eutectoid reactions:

1. Al-Zn
2. Cu-Sn
3. Cu-Zn
4. Fe-C 2%
5. Fe-C

**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.

**Ansys Granta Education Hub**

For more information on Ansys GRANTA EduPack software and related teaching resources, please visit https://www.ansys.com/products/materials/granta-edupack/

**Teaching Resources Website**

The Teaching Resources website aims to support teaching of materials-related courses in design, engineering and science. Resources come in various formats and are aimed primarily at undergraduate education. Visit grantadesign.com/education/teachingresources/ to learn more.

There are 350+ resources on the Ansys Granta Education Hub. The resources include:

- Lecture presentations with notes
- 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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