

# HOMework 6.



## PROJECT WORK

By the end of this week, your team may have a pretty good idea of where the project is heading, and your materials processing and analysis should be underway. This week, try to translate your big-picture project questions into more specific questions, such as:

- What are your primary project goals? Which fundamental questions are you asking and attempting to answer? *What makes these questions significant?*
- What are your experimental controls and variables? How does your experimental plan look, in terms of scope and materials science connection building opportunities? Do you need to make some adjustments?
- What materials science data and analyses will appear in your final paper? How will you obtain the data? How will you communicate the data and analyses – tables, graphs, sketches, micrographs, photos?
- How will you connect relevant materials theory (e.g., phase diagrams, phase transformations, strengthening mechanisms, nucleation and growth, diffusion) to your processing variables, your experimental property data, and the broader performance context of your alloys?
- How will you connect environmental or societal impacts to your project? What data will you collect, and how will you present the data in your report and presentation?

Your materials science project work this week should be goal driven: if you run an experiment, do it because it will give you relevant data. Try analyzing your data and synthesizing your evidence as you go – build your paper as you proceed through your test plan.

## READINGS

### a. Research your phase diagram(s).

In Volume 4 of ASM Handbook, locate a binary phase diagram for the two primary constituents of the alloy system(s) you are studying. For example, if you are studying bronze, find the phase diagram for copper-tin alloys. If you know the composition of your alloy, try to locate it on the phase diagram and attempt to glean some information from the diagram (e.g., phases present at different temperatures, melting temperatures, solubility limits).

### b. Build your understanding of phase diagrams, either via textbook or videos.

#### Textbook reading options

- Ashby *Engineering Materials 2* Chapter 3 (Phase Diagrams 1) and Chapter 4 (Phase Diagrams 2)
- Callister 6th - 9th editions: Chapter 9 (Phase Diagrams)

### Video options

- David Dye, Imperial College videos. Check out videos 2.1, 2.2, 2.3, and 3.1:  
<http://dyedavid.com/mse104/>
- MIT Open Courseware videos, Check out videos 34 and 35 on Binary Phase Diagrams:  
<http://ocw.mit.edu/courses/materials-science-and-engineering/3-091sc-introduction-to-solid-state-chemistry-fall-2010/solid-solutions>

### Supplemental reading

- Ashby's "Teaching yourself phase diagrams" from older editions of the *Engineering Materials 2* textbook is sometimes helpful, if you are having difficulty understanding phase diagrams. This supplemental reading is posted on the Resources page of the course web site.

## STOLK'S TAKE ON THE MATSCI READINGS:

I love phase diagrams, almost as much as I love coffee. Actually, the two things are similar in many ways. "Coffee" can describe solid or liquid forms of the same substance. Phase diagrams often depict solid and liquid forms of the same substance. Coffee comes in a variety of flavors, some very simple and some quite complex. Phase diagrams can be very simple (e.g., Cu-Ni) or quite complex (e.g., Cu-Sn). Coffee smells delightful. Phase diagrams smell like oxidized metal mixed with puréed turnips (i.e., delightful). Coffee serves in a range of social, cultural, motivational, and cognitive roles. Phase diagrams bring people together, shape our beliefs and attitudes, spark our imagination and creative efforts, and further our understanding of the world. Coffee is delicious. Phase diagrams taste like Ground Ball Grape flavored Big League Chew (i.e., delicious). Need I go on?

There are many types of phase diagrams. Chances are you've seen a few unary (one chemical component) temperature-pressure diagrams in your chemistry or physics classes. You know what I'm talking about – the water phase diagram, with the liquid, solid, and vapor phases, and the triple point. Yeah, I bet you've seen that. Unary diagrams are nice and all, but they've served their purpose for now, so we're going to leave them in the dust right now. Yes, indeed, it's time to double our pleasure, double our fun, with binary diagrams. For our materials phase diagrams, we'll hang onto that temperature axis from the unary diagrams, as we frequently heat and cool materials during processing operations. But since we usually deal with materials at ambient pressures, we can treat pressure as constant, and get rid of that pesky pressure variable. This frees up the pressure axis to be used for something else. What variable would you like to put on the x-axis? I'm thinking that composition would make a great choice, as it will enable us to see what happens when we mix two materials together. Guess what, you just arrived in binary land (or "B-land", as the big wave surfers and antique stamp collectors like to call it). Welcome. Take off your shoes, hang your hat, and stay a while.

Will a binary phase diagram serve you well during your Part Two project? Maybe. The silver teams are set, since Revere usually dealt with sterling silver (Ag-Cu). And the iron teams will be okay, since pig iron is basically Fe and C, with minor amounts of impurities. The copper teams don't really need a phase diagram, since they're dealing with a single chemical component. But what about those bronze teams? Were Revere's bronze alloys limited to two chemical components? Not really, but perhaps we should make our lives a little easier by assuming that the bronzes were *primarily* composed of two elements. Sound okay to you? If not, take a few minutes to explore ternary phase diagrams, which are pretty cool but a bit more difficult to interpret.

I encourage you to think about binary phase diagrams as a tool that can help you understand how two different components interact with each other as a function of temperature and/or composition. Believe it or

not, this understanding can help you predict the microstructure and properties of the material. But let's not get ahead of ourselves. Take a moment to consider what, exactly, the phase diagram can tell you. What information is available from a binary temperature-composition diagram? Your textbook and the Ashby supplemental reading do a nice job of introducing phase diagrams concepts, so I'm not going to waste document real estate for that, but I will provide a few questions for you to think about as you read:

1. Can you label the phases present in all the unlabeled regions of a phase diagram? This is often a necessary first step before you begin to gather more detailed information on phase compositions and relative amounts (weight percentages) of the phases.
2. Can you say anything in general about how well your two chemical components like each other? For example, binary isomorphous phase diagrams have a single solid phase (isomorph = "one form"), which means that at no point do the two different components (e.g., Cu and Ni) reach a point where they have this sort of discussion:
  - Cu: Nickel, you are really cramping my style.
  - Ni: Me?! I'm so sick of your freakin' face centered cubic structure that I'm about ready to pack up my valence atoms and walk out the door.
  - Cu: My fcc structure is beautiful, and you know it. Your atomic radius and electronegativity, on the other hand, leave much to be desired. You think you can go around pushing and pulling me and my electrons without any consequences?
  - Ni: Okay, that's it. I'm leaving, and I'm taking all my nickel friends with me. We're going to start a new community, based entirely on our preferred social structure and ways of interacting.
  - Cu: Fine, go! But I suspect you'll be back when the temperature starts to rise in your utopian nickel dream-world!

Nope, nickel and copper would *never* have that conversation. Silver and copper, on the other hand, is a different story. You'll notice on the silver-copper phase diagram that this system has two **terminal solid solutions**, meaning that there is a point at which silver is no longer miscible in copper, and vice versa. Other binary systems, like the Cu-Sn bronze system, show a number of **intermediate phases or intermetallic phases** in the middle of the diagram, which appear when the two elements join forces to create an entirely new phase with a different structure and properties.

3. What type(s) of three-phase equilibria appear on your phase diagram? These are the horizontal lines within the diagram, and they indicate that some sort of reaction (e.g., eutectic, eutectoid, peritectic) is taking place. Can you interpret what this reaction means in terms of microstructural and property changes?
4. Given a particular binary phase diagram and composition, could you sketch the appearance of the microstructure as a function of temperature (moving vertically through the diagram)? Given an isotherm, could you sketch the structural changes that occur as a function of composition (moving horizontally through the phase diagram)?
5. The binary phase diagrams you're studying now usually show conditions of **thermodynamic equilibrium**. What isn't shown on the phase diagrams is how much time it may take for the binary system to get to a state of thermodynamic equilibrium. Does it take a millisecond for a reaction to proceed? An hour? A year? Which reactions would you expect to occur more quickly? What effect(s) would fast cooling of an alloy have on its microstructure and properties?

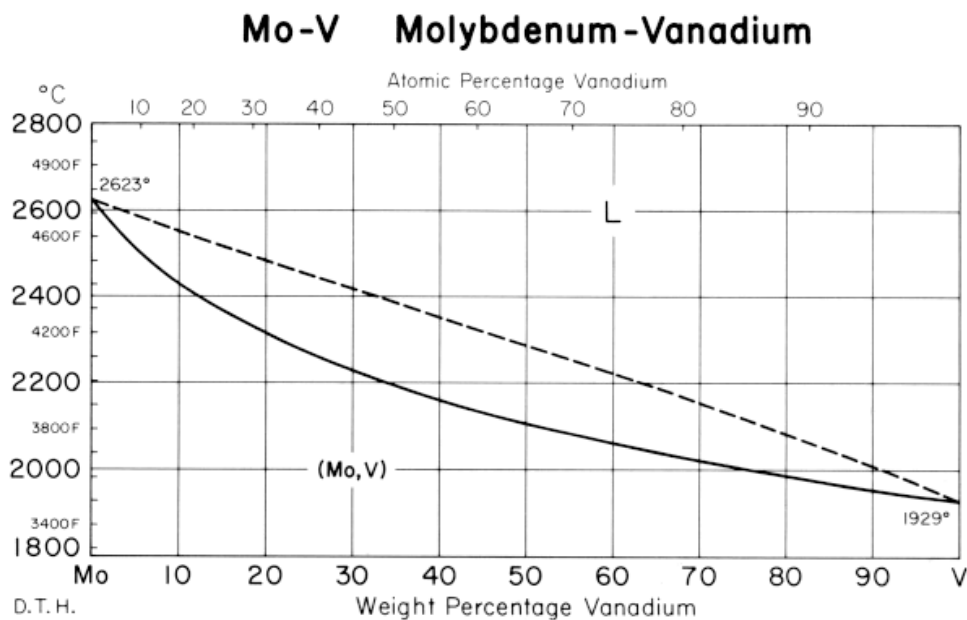
Finally, there's a lot of new terminology in the phase diagrams reading, e.g., eutectic, solvus and liquidus and solidus lines, three phase equilibria, solubility limits, etc. Don't try to memorize all of these at once; rather, do your best to integrate these terms into your language as you discuss your Part Two materials and processes.

Enjoy your phase diagrams. Sip them like a fine cup of espresso. Ride them like a North Shore wave.

## PROBLEMS

When you work through the practice problems, consider how the concepts apply to your project topic. Will your materials have one phase, two phases, or multiple phases in the solid state? If you are dealing with a two-component or multi-component alloy, what are the solubility limits of each component in the other components? How do the solubility limits change as a function of temperature? How will your microstructure appear? Does your alloy system form two distinct microstructural regions, or “microconstituents”? How might the presence of different phases affect the properties? Wow, I’m starting to sound like a broken record.

**Use the binary, isomorphous, molybdenum-vanadium phase diagram for Problems 1-3.** Note: the dashed curve in the phase diagram indicates that there is some error or uncertainty in the location of the liquidus line; the uncertainty in the liquidus line should not affect your calculations.



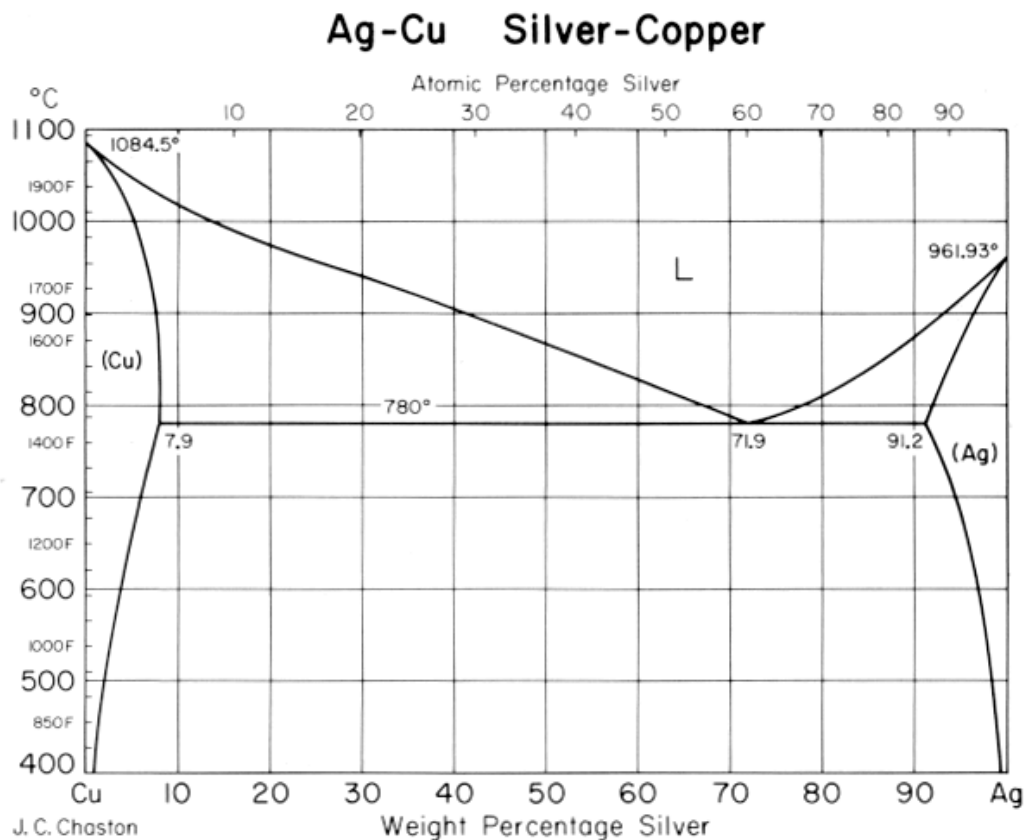
1. Sketch the expected trend in hardness as a function of composition for Mo-V alloys.
2. For a 50 wt% vanadium alloy at 2200 °C, determine the following:
  - a. Phases present
  - b. Compositions of the phases
  - c. Percent or fractions of the phases
3. What is the solubility limit of molybdenum in vanadium at 1900 °C?

**Use the silver-copper phase diagram shown on the next page for Problems 4-8.**

4. What are the solubility limits of Ag in (Cu) and Cu in (Ag)? The (Cu) and (Ag) phases are the same as  $\alpha$  and  $\beta$ , respectively (just different naming methods).
5. For equilibrium solidification of a Cu-Ag alloy containing 40 weight percent Ag,
  - a. State the temperature at which solidification begins.
  - b. State the temperature at which solidification is complete.

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6. For a Cu-Ag alloy of 50 wt.% Ag,
  - a. Determine the phases present, compositions of the phases, and relative amounts (weight fractions) of the phases at a temperature just **above** the eutectic temperature.
  - b. Determine the phases present, compositions of the phases, and relative amounts of the phases when solidification is just complete (at a temperature just **below** the eutectic temperature).
7. For a 50 wt.% Ag alloy, determine the fractional amounts of *microconstituents* when solidification is just complete.
8. Sketch the 50 wt.% silver alloy at a temperature just below the eutectic temperature. Label both the phases and the microconstituents.



9. The molybdenum-rhenium phase diagram is provided on the next page. Note that all the single-phase regions labeled.
  - a. Label all two-phase regions.
  - b. Specify the temperatures and compositions for all 3-phase equilibria in this system. For each 3-phase equilibrium, write the reaction upon cooling.
  - c. Assuming no phase transformations occur at lower temperatures, specify the strengthening mechanisms that are possible for an alloy of Mo with 18 wt. % Re.
  - d. BONUS: How would you form an alloy of Mo with 10 wt. % Re? Could you make it in one of our furnaces?

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# Mo-Re Molybdenum-Rhenium

