SUPPLEMENTAL MATERIALS

Writing-to-Learn in introductory Materials Science and Engineering

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We present the instructions and scoring rubrics for each of the WTL prompts included in this study. We also include the full conceptual assessment implemented in this study to gauge conceptual knowledge attained throughout the course. Finally, we provide an elaboration on the assessment results included in the main paper by breaking down results to a question-by-question basis.

WTL Assignments

The assignment instructions for each WTL assignment are provided below. Each assignment was designed to provide students with an authentic scenario conducive to materials science analysis and problem-solving. Instructions receive minor edits annually in order to enhance clarity, although its requirements have stayed the same in each iteration. The versions included were last updated in May 2020.

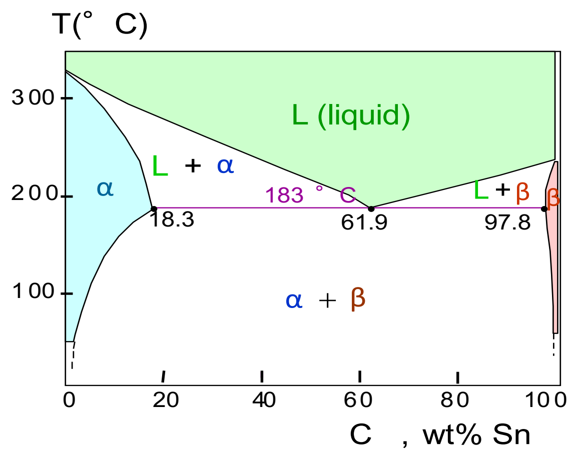
Initial Draft

Objective:

You have been hired as a consultant for GM to determine why a Lead-Tin alloy solder failed. A solder is an alloy that has a low melting point and is used to join two components (please see http://www.globalspec.com/learnmore/manufacturing_process_equipment/welding_equipment_supplies/solder). This solder was chosen because it has a eutectic point at a temperature of 183 °C, which is lower than the melting point of either pure lead or pure tin. However, when GM uses the Lead-Tin alloy as solder they find that they do not achieve total melting even at a temperature of 200 °C. Upon analyzing the solder, you determine that the wt% Sn in the Lead-Tin alloy is 50%.

Assignment:

Using discipline specific terminology to describe the names of the important points, lines, and phases denoted in the phase diagram, write a memo explaining to one of the division managers why the Pb-Sn alloy solder didn't melt at the expected temperature. In your discussion, explain how to use the lever rule to determine the percent α phase and percent L phase of the solder at 200˚C, and how to use the liquidus to determine the temperature needed for complete melting of the solder. Use these strategies to find the melting temperature for the solder and its phase fractions of α and L at 200˚C. Additionally, include a discussion about how the microconstituents, i.e. portions of the Pb-Sn alloy with distinct microstructures, will affect its performance as solder.



Items to keep in mind:

- When we read your memo, we will play the role a manager with minimal materials science background who is trying to understand the science behind why the solder failed.
- If external references are used, they should be cited using MLA citation style format. Make sure to cite all of your sources, including our textbook and the references listed above.
- Since you are trying to persuade the division manager of your credibility as a consultant, you should carefully edit and proofread your memo.
- The memo should be 350-500 words in length, excluding references.
- For initial draft **please replace your name in the document with your UMID**.

Peer Review

Peer Review Guidelines:

- *Print* and read over your peer's memo to quickly get an overview of the piece.
- Then read over the rubric for the phase diagrams solder prompt.
- Read the memo again more slowly keeping the rubric in mind.
- Highlight the pieces of texts that let you directly address the rubric prompts for the peer review online tool.
- For your online responses, focus on larger issues (higher order concerns) of content and argument rather than lower order concerns like grammar and spelling.
- Be ***specific*** in your responses, referring to your peer's actual language, mentioning terms and concepts that are either present or missing, and following the directions in the rubric.
- Use respectful language whether you are suggesting improvements to or commenting on your peer's work.

Rubric Prompts:

1. This memo should be understandable to someone with minimal scientific background. For a reader with minimal scientific background, which parts are difficult to understand? Which parts are easy to understand?
2. The memo should include discipline-specific terminology to name the important points, lines, and phases on the phase diagram. What is explained well? Are there any terms or features missing in the phase diagram explanation? How could the phase diagram explanation be improved?
3. The memo should also describe using the lever rule to determine the percent of α and L phases of the Pb-Sn alloy. Is there anything missing in the description? Which parts are difficult to understand? Which parts are easy to understand?
4. The memo should also describe using the liquidus to determine the temperature needed for complete melting of the Pb-Sn alloy. What is covered well? What was confusing? How could the description of the temperature needed for complete melting be improved?
5. The memo should include a discussion of the why the micro-constituents (i.e. portions of the Pb-Sn alloy with distinct microstructures) of the Pb-Sn alloy are important for its performance as solder. Is the discussion thorough and clear? What could be added to make the discussion more complete?

Revision

Revision Prompt:

Revising writing means re-seeing it, and the process of reading and commenting on the writing of others as well as receiving feedback from your peers gives you a way of seeing your own writing differently. Meaningful revision means changes at the sentence and paragraph level, usually involving a minimum of three sentences. ***In order to receive full credit for revision, meaningful revisions are required.***

Revision Guidelines:

- Re-read the prompt.
- Re-read the rubric and consider what a complete and effective response would include, noting what you do not fully address.
- Make a list of the content that you thought was effective while reviewing the drafts of your peers.
- Read and summarize the feedback you received from your peers.
- With these items in mind, re-read your draft and mark places where you can improve the content.
- Revise and submit your response.

Checklist from Phase Diagram Peer Review Rubric:

1. This memo should be understandable to a person with minimal scientific background.
2. The memo should include discipline-specific terminology to name the important points, lines, and phases on the phase diagram.
3. The memo should also describe using the lever rule to determine the percent of α and L phases of the Pb-Sn alloy.
4. The memo should also describe using the liquidus to determine the temperature needed for complete melting of the Pb-Sn alloy.
5. The memo should include a discussion of the why the micro-constituents (i.e. portions of the Pb-Sn alloy with distinct microstructures) of the Pb-Sn alloy are important for its performance as solder.

Initial Draft

Objective:

Over the summer you begin volunteering for a South Africa based social service organization (http://www.rethakafoundation.org), which is working to improve living conditions in impoverished rural areas using an environmentally conscious approach. In the area where you are working, waste management is a particularly low priority and the organization is hoping to design school bags for local children using high-density polyethylene (HDPE) recycled from milk bottles. This strategy should mitigate waste management, while also providing a much-needed resource for children who travel a long way each day to school. Although your supervisor has a lot of experience with community service, they do not have a science background.

To help your supervisor convince potential donors from chemical companies that recycling HDPE for use in the school bag is a viable idea, you need to read and summarize an article about the properties of recycled HDPE (Pattanakul, 1991) in the form of a memo. Your memo should teach the donors about HDPE and the extent to which its mechanical properties will change after it is recycled so that they can decide whether it will be a serviceable material to use as the rigid frame of the bag. Estimate the stresses experienced by a typical backpack and use this estimate to decide whether the change in mechanical properties caused by recycling will significantly impact the performance of the backpacks. In in your discussion include a drawing of a proposed stress-strain curve that depicts HDPE before and after it is recycled. **Be sure to describe both what is happening to the local polymer structure and how this influences the macroscopic mechanical behavior when external forces are applied.**

References:

Pattanakul, C.; Selke, S.; Lai, C.; Miltz, J. Properties of Recycled High Density Polyethylene from Milk Bottles. J. Appl. Poly. Sci. (1991) 43, 2147-2150

Items to keep in mind:

- When we read your memo, we will play the role of donors from chemical companies with minimal scientific background who is trying to understand why recycled plastics have different mechanical properties.
- Your memo should summarize all important points from the paper but should focus on the data contained in **Table II** in the paper by Pattanakul et al. (including a discussion of the yield strength, tensile strength, ductility, and modulus of elasticity and how these relate to the local microstructure).
- If external references are used, they should be cited using MLA citation style format.
- Since you are aiming to persuade potential donors of the viability of this idea, make sure to carefully edit and proofread your memo.
- The memo should be 350-500 words in length, excluding references.

Peer Review

Peer Review Guidelines:

- *Print* and read over your peer's essay to quickly get an overview of the piece.
- Then read over the rubric for the recycled polymer prompt.
- Read the memo again more slowly, keeping the rubric in mind.
- Highlight the pieces of texts that let you directly address the rubric prompts for the peer review online tool.
- Be ***specific*** in your responses, referring to your peer's actual language, mentioning terms and concepts that are either present or missing, and following the directions in the rubric.
- Use respectful language whether you are suggesting improvements to or commenting on your peer's work.

Rubric Prompts:

1. This memo should be understandable to a person with minimal scientific background. For a reader with minimal scientific background, which parts are difficult to understand? Which parts are easy to understand?
2. The memo should describe the influence of recycling on the mechanical properties of high-density polyethylene (HDPE), including schematic stress-strain curves before and after recycling. Is the description thorough and are the stress-strain curves clear? Does the description include relevant discipline-specific terminology? Do the stress-strain curves include all relevant features? How could the description and/or stress-strain curves be improved?
3. The memo should describe what is happening to the HDPE both macroscopically and microscopically when external forces are applied. Are explicit relationships between the atomic to macroscopic structure and the mechanical properties of the polymer included? This should be described in terms of a summary using the data from **Table II** in the paper by Pattanakul et al. How could the description be improved?
4. The memo should include an estimate of the stresses experienced by a typical backpack during use. Is the estimate reasonable and explained well? Is anything missing from the estimate?

Revision

Revision Prompt:

Revising writing means re-seeing it, and the process of reading and commenting on the writing of others as well as receiving feedback from your peers gives you a way of seeing your own writing differently. Meaningful revision means changes at the sentence and paragraph level, usually involving a minimum of three sentences. ***In order to receive full credit for revision, meaningful revisions are required.***

Revision Guidelines:

- Re-read the prompt.
- Re-read the rubric and consider what a complete and effective response would include, noting what you do not fully address.
- Make a list of the content that you thought was effective while reviewing the drafts from your peers.
- Read and summarize the feedback you received from your peers.
- With these items in mind, re-read your draft and mark places where you can improve the content.
- Revise and submit your response.

Checklist from Recycled Polymer Peer Review Rubric:

1. This memo should be understandable to a person with minimal scientific background.
2. The memo should describe the influence of recycling on the mechanical properties of high-density polyethylene (HDPE), including schematic stress-strain curves before and after recycling.
3. The memo should describe what is happening to the HDPE both macroscopically and microscopically when external forces are applied. This should be described in terms of a summary using the data from **Table II** in the paper by Pattanakul et al.
4. The memo should include an estimate of the stresses experienced by a typical backpack during use.
5. The memo should include a coherent argument for why or why not recycled HDPE could be used for the rigid frame of the backpack.

Initial Draft

Objective:

The city of Flint needs to replace several pipes due to the recent Flint water crisis. You have been hired as a consultant by the city to advise them on the type of piping to use. Based upon your knowledge of corrosion and considering the galvanic series, write a memo to the government officials suggesting which metal or metal alloy they should use and why. Include a discussion of the relative reactivity of your chosen metal/alloy, the types of corrosion that are most likely to occur in this system, the relevant chemical reactions that could lead to such corrosion, and any preventative techniques the city should apply. In your memo, make sure to discuss the relative cost of the potential pipe materials.

References:

http://cen.acs.org/articles/94/i7/Lead-Ended-Flints-Tap-Water.html

https://www.scientificamerican.com/article/zapping-lead-pipes-with-electricity-could-make-them-safer-for-drinking-water/

https://players.brightcove.net/1399189305/370f2eae-5572-4746-8886-72790b360bff_default/index.html?videoId=4774241533001

Items to keep in mind:

- When we read your memo, we will play the role a government official with minimal scientific background who is trying to understand the materials science behind corrosion.
- Keep in mind that the pipes in Flint are currently made out of iron, lead, and copper.
- Consider environmental aspects that could damage the pipes, i.e. tree roots, freeze-thaw cycle.
- If external references are used, they should be cited using MLA citation style format.
- Since you are aiming to persuade potential donors of the viability of this idea, make sure to carefully edit and proofread your memo.
- Since you are aiming to persuade officials, while demonstrating your credibility as a consultant, make sure to carefully edit and proofread your memo.
- The memo should be 350-500 words in length, excluding references.

Peer Review

Peer Review Guidelines:

- *Print* and read over your peer's memo to quickly get an overview of the piece.
- Then read over the rubric for the corrosion prompt.
- Read the memo again more slowly, keeping the rubric in mind.
- Highlight the pieces of texts that let you directly address the rubric prompts for the peer review online tool.
- For your online responses, focus on larger issues (higher order concerns) of content and argument rather than lower order concerns like grammar and spelling.
- Be ***specific*** in your responses, referring to your peer's actual language, mentioning terms and concepts that are either present or missing, and following the directions in the rubric.
- Use respectful language whether you are suggesting improvements to or commenting on your peer's work.

Rubric Prompts:

6. This memo should be understandable to someone with minimal scientific background. For a reader with minimal scientific background, which parts are difficult to understand? Which parts are easy to understand?
7. The memo should explain the chemical origins of corrosion, including the anticipated compatibility of metal/alloy joints based upon their relative placement in the galvanic series. Is the explanation of corrosion origins complete and explained well? Is the role of the galvanic series in corrosion prevention discussed? Is there anything missing in the discussion of the galvanic series? How could these descriptions be improved?
8. The memo should detail the types of corrosion that are most likely to occur in the water system. For each type of corrosion, the relevant chemical reactions should be mentioned. Are the most likely corrosion mechanisms and their corresponding chemical reactions clearly described? How could these descriptions be improved?
9. The memo should provide a coherent argument for upgrades to the water system, including the specific metal/alloy to use for new pipes, and any additional preventative measures to be employed. The argument should be based upon both scientific reasoning and materials costs. Is the argument comprehensive, concise, and/or persuasive? How could the argument be more convincing?

Revision

Revision Prompt:

Revising writing means re-seeing it, and the process of reading and commenting on the writing of others as well as receiving feedback from your peers gives you a way of seeing your own writing differently. Meaningful revision means changes at the sentence and paragraph level, usually involving a minimum of three sentences. ***In order to receive full credit for revision, meaningful revisions are required.***

Revision Guidelines:

- Re-read the prompt.
- Re-read the rubric and consider what a complete and effective response would include, noting what you do not fully address.
- Make a list of the content that you thought was effective while reviewing the drafts from your peers.
- Read and summarize the feedback you received from your peers.
- With these things in mind, re-read your draft and mark places where you can improve the content.
- Revise and submit your response.

Checklist from Corrosion Peer Review Rubric:

1. This memo should be understandable to someone with minimal scientific background.
2. The memo should explain the chemical origins of corrosion, including the anticipated compatibility of metal/alloy joints based upon their relative placement in the galvanic series.
3. The memo should detail the types of corrosion that are most likely to occur in the water system. For each type of corrosion, the relevant chemical reactions should be mentioned.
4. The memo should provide a coherent argument for upgrades to the water system, including the specific metal/alloy to use for new pipes, and any additional preventative measures to be employed. The argument should be based upon both scientific reasoning and materials costs.

Initial Draft

Thomas Hales, associate professor of mathematics, demonstrates his solution to the Kepler conjecture, a problem that mathematicians have been wrestling with since 1611. Tennis balls courtesy of the Varsity Tennis Club. Photo by Bob Kalmbach

Objective:

One day you are talking with a friend who works at a grocery store, who relates the following request to you:

“To make efficient use of space, our produce manager asked me to come up with the most efficient way to pack oranges as tightly as possible within a finite space. I heard that the most efficient sphere packing is to arrange the spheres in layers with each sphere resting in the small hollow between the three spheres beneath it like the pyramid arrangement of Thomas Hales’s tennis balls! What do you think?”

The task now falls to you to help out your friend. Write a formal letter to the produce manager explaining whether your friend’s proposed way of stacking oranges is a good or bad idea, and why. Keeping your audience in mind, construct a response that combines writing, calculations, and/or images to describe the most efficient/tightest orange packing method put into a finite space (think about all the cubic crystal structures we have learned in class). In your response, compare the volume-filling efficiency or packing fraction of your suggested orange stacking method to other possible orange stacking methods (such as stacking oranges like a SC, FCC, BCC, or HCP structure). In addition, discuss in the letter which orange stacking method is favored for mechanical stability in the context of susceptibility to slipping along different planes.

Items to keep in mind:

- When we read your response, we will play the role of a grocery store manager with a high school-level scientific background who is trying to pack oranges as tightly as possible in a finite space.
- Be sure to consider both APF and mechanical stability in order to provide a holistic proposal for how to optimize orange stacking.
- External references are not required, but if used, they should be cited using MLA format.
- You should carefully edit and proofread your memo.
- This memo should be 350-500 words in length, excluding references.
- For initial draft **please replace your name in the document with your UMID**. This is to help ensure anonymity during the Peer Review process. You may use your name in the revision if you so wish.

Peer Review

Peer Review Guidelines:

- Print and read over your peer's letter to quickly get an overview of the piece.
- Then read over the rubric for the Crystal Structures Oranges prompt.
- Read the letter again more slowly keeping the rubric in mind.
- Highlight the pieces of texts that let you directly address the rubric prompts for the peer review online tool.
- In your online responses, focus on larger issues (higher order concerns) of content and argument rather than lower order concerns such as grammar and spelling.
- Be *specific* in your responses, referring to your peer's actual language, mentioning terms and concepts that are either present or missing, and following the directions in the rubric.
- Use respectful language whether you are suggesting improvements to or praising your peer.

Rubric Prompts:

10. This letter should be understandable to someone with minimal scientific background. For a reader with minimal scientific background, which parts are difficult to understand? Which parts are easy to understand?
11. The letter should describe the relationship between tightly-packed spheres and the suggested crystal structure(s). What is explained well? Is there anything missing in the description? How could the description be improved?
12. The letter should include a comparison of the volume-filling efficiency of the suggested orange-packing structure(s) to that of a simple cubic structure. Is the comparison thorough and clear? Is there anything missing in the comparison? How could the explanation be improved?
13. The letter should provide a discussion of the mechanical stability of these structures in terms of their susceptibility to slipping along different planes. Is the discussion straightforward and complete? Is there anything missing in the discussion? How could the discussion be improved?

Revision

Revision Prompt:
Revising writing means re-seeing it, and the process of reading and commenting on the writing of others as well as receiving feedback from your peers gives you a way of seeing your own writing differently. Meaningful revision means changes at the sentence and paragraph level, usually involving a minimum of three sentences. *In order to receive full credit for revision, meaningful revisions are required.*

Revision Guidelines:

- Re-read the prompt.
- Re-read the rubric and consider what a complete and effective response would include, noting what you do not fully address.
- Make a list of the content that you thought was effective while reviewing the drafts from your peers.
- Read and summarize the feedback you received from your peers.
- With these items in-mind, re-read your draft and mark places where you can improve the content.
- Revise and submit your response.

Checklist from Crystal Structure Oranges Peer Review Rubric:

1. This memo should be understandable to someone with minimal scientific background.
2. The memo should describe the relationship between tightly-packed spheres and typical crystal structure(s).
3. The memo should include a comparison of the volume-filling efficiency of the suggested orange-packing structure(s) to that of a simple cubic structure.
4. The memo should include a discussion of the relative mechanical stabilities of these structures in terms of their susceptibility to slipping along different planes.

WTL Rubrics

To quantify the effect of WTL on student learning between the draft and revision, we developed rubrics to numerically score WTL submissions on a 0-4 scale. At least two example submission excerpts were included per rubric criterion in order to provide a reference for scoring.

1. Would this memo be understandable to a person with a minimal scientific background.

Score	Description
0	No translation into their own words.
1	Translating into their own words or more accessible language.
2	Translating into their own words or more accessible language and attempt to explain terminologies in their own words.
3	Make connections between phase diagram and the problem, translating into their own words or more accessible language, provide an interpretation of the phase diagram or an accessible explanation of the use of the lever rule.
4	Make connections between phase diagram presented and the problem, include an accessible explanation of the use of lever rule, translating into their own words or more accessible language, provide an interpretation of the phase diagram.

Exemplars:

0— To use the lever rule to determine the %α phase, a tie line can be constructed across the 2-phase region, and the following formula can be applied:
Wα = (C0-CL)/(Cα-CL)

4— Each region within the phase diagram corresponds to a different state of the material. For example, you may know that water exists as solid, liquid, or gas depending on the temperature. For alloys, the same concept applies. However, with alloys, there is a twist. The α phase corresponds to solid phase in which both Tin and Lead are soluble within each other, which the L phase is when a liquid state is present. In figure 1, the α state is high in Lead %weight. Intermediate states such as L + α have both solid solution and liquid characteristics. Finally, β state corresponds to another solid solution in which Tin is high in %weight.

2. The memo should include discipline-specific terminology to name the important points, lines, and phases on the phase diagram.

Score	Description
0	No mentioning of the discipline - specific terminologies on the phase diagram.
1	Mentioning only some of the terminology on the phase diagram
2	The mentioning of the terminology is complete, but failed to provide accessible explanations to those terminology.
3	The mentioning of the terminology is complete, and provided accessible explanations to those terminology.
4	The mentioning of the terminology is complete, provided accessible explanations to those terminology, and applying the terms in their interpretation or using their definitions.

Exemplars:

1— Looking at the phase diagram, the different letters are representative of the phase that the material is in at different temperatures and compositions: L denotes liquid phase, alpha and beta denote the solid phases. According to the diagram, the lead-tin alloy has a melting point at 183 degrees...

4— The vertical axis is temperature and the horizontal axis is percent by weight Tin. The very left of the graph represents pure lead while the very right represents pure tin. Alpha phase is solid lead with substitutional tin and beta phase is solid tin with substitutional lead. Then there is the liquid phase denoted by “L”. There are regions where there is both liquid and solids present. The barrier between all liquid and liquid plus solid is termed the liquidus line, while the barrier between liquid plus solid and all solid is termed the solidus line. The phase diagram of Lead-Tin alloy is shown below with red lines indicating temperatures and concentrations of interest.

3. The memo should also describe using the lever rule to determine the percent of α and L phases of the Pb - Sn alloy.

Score	Description
0	No explanation to lever rule.
1	Mentioned only the equation of the lever rule.
2	Mentioned the equation form of the lever rule with some interpretation.
3	Explained the lever rule using their own words, not just referring to equations and relate lever rule to the problem with soldering.
4	Explained the lever rule using their own words, related lever rule to the problem with soldering, correctly used lever rule to determine the percentage of α and L phases.

Exemplars:

2— By using the lever rule, we can look into the percent alpha phase and percent L phase of the solder at 200°C. The formula is as follows, where the percent of liquid content can be determined.

$$w^l = \frac{w_B^s - w_B}{w_B^s - w_B^l}$$

Using this equation, it can be estimated that the percent L phase of the solder at 200°C is around 73% and the percent alpha phase of the solder is roughly 27%.

4— There is a method known as the lever rule which can determine based on the phase diagram how much of the alloy belongs to the individual phases while in a two-phase region. The lever rule works by comparing proportionally how close the current concentration is to being purely one phase or the other. In the case of the 50 wt% solder at 200 °C, it is split between being liquid and alpha phase. The distance wt% difference between being pure liquid and the actual wt% is found by drawing a line horizontally across at the temperature. Where the line intersects the liquidus line determines what wt% would give a pure liquid, in this case it is at 60 wt%. Taking the difference is 60 – 50 = 10 wt%. This is then divided by the whole possible range from solidus line, which intersects at 18 wt%, to the liquidus line. This gives 10/(60-18) = 23.8 wt% alpha phase. The reason this gives alpha phase is because the amount that is alpha phase is the difference between the current alloy and being pure liquid. Doing this again from the opposite side will give (50-18)/(60-18) = 76.2 wt% liquid phase. This answer makes sense intuitively because 50 wt% is much closer horizontally to the pure liquid phase than pure alpha phase.

4. The memo should also describe using the liquidus to determine the temperature needed for complete melting of the Pb - Sn alloy.

Score	Description
0	No explanation of liquidus line.
1	Mentioned liquidus line, but failed to use this for determining the temperature.
2	Mentioned liquidus line, and used this for determining the temperature.
3	Mentioned liquidus line, used this for determining the temperature, and provide a solution to the solder problem.
4	Mentioned liquidus line, used this for determining the temperature, explained why this is important for solving the issue at hand, provide a solution to the solder problem.

Exemplars:

0— To completely melt a lead-tin alloy solder with wt% Sn of 50%, the phase diagram indicates that a temperature of ~220 degrees is necessary.

4— The solder you are currently using was thought to be a eutectic alloy that has the lowest melting temperature, which on the phase diagram is shown to be at 61.9 wt% (percent by weight) tin. However, after analyzing the solder, it was determined to actually be 50 wt%, and by following the line drawn at 50 wt%, it intersects the liquidus line at approximately 215 – 220 °C. That is the temperature that your current solder will become fully liquid at.

5. The memo should include a discussion of why the micro-constituents (i.e. portions of the Pb - Sn alloy with distinct microstructures) of the Pb - Sn alloy are important for its performance as solder.

Score	**Description**
0	No mentioning of micro-constituents.
1	Touched on micro-constituents but did not (or very vaguely) relate the microstructures to the performance as solder.
2	Explained micro-constituents well with either their own words or diagrams, but failed to make connections between microstructures and the performance as solder.
3	Explained micro-constituents well with either their own words or diagrams, and made connections between microstructures and the performance as solder.
4	Explained micro-constituents well with either their own words or diagrams, made connections between microstructures and the performance as solder, and relates to the composition of the solder.

Exemplars:

1— In terms of the microstructure of the alloy, different phases can affect the behavior.

4— The term microconstituent is an element of this microstructure that has a characteristic structure. For example, in figure 1, right at the 50% wt% Sn, below 1830C, both the primary α and the eutectic structure are present. The varied microconstituents can reflect on the melting property of the alloy. A greater amount of eutectic structure would allow melting to occur more easily than a primary α structure.

1. Would this memo be understandable to a person with a minimal scientific background.

Score	Description
0	No translation into their own words.
1	Translating into their own words or more accessible language
2	Translating into their own words or more accessible language and A: provide an interpretation of implications of recycling OR B: provide a graph that they do not interpret.
3	Make connections between the application and scientific context, translating into their own words or more accessible language, provide an interpretation of the graph.
4	Make connections between the application and scientific context, include the implications of recycling the polymer, translating into their own words or more accessible language, provide an interpretation of the graph.

Exemplars:

0— While incineration and pyrolysis are viable options, the most environmentally conscience solution is repurposing plastic waste. […] Its microstructure contains little branching, resulting in strong intermolecular bonds and a high tensile strength on the macroscopic level. One study comparing the properties of virgin and recycled HDPE concluded that a greater percentage of recycled material resulted in an increased elastic modulus and lower percent elongation. However, material composition (% recycled) showed no significant effect on tensile strength.

4— There was no change in tensile strength, which determines how much a material can withstand as it is pulled. This is indicated by the highest stress peak in stress-strain curve right before failure. There was, however, a slight an increase in the modulus of elasticity (a steeper initial linear segment in stress-strain curve), which determines how much a material stretches when it is loaded. […] During the recycling process, it was found that there was an increase in crosslinking (chains forming bonds with adjacent chains).

2. Does the summary accurately summarize the paper?

Score	Description
0	Did not include any summary.
1	Three or more items are missing and/or incorrect, particularly a missing item from Table II of Pattanakul, et al.
2	A: said something incorrect, but the list is not complete (i.e. missing 1-2 items). However, the three elements of Table II (modulus, tensile strength, elongation) of Pattanakul must be present. OR B: everything is correct, but only include items from Table II and no others.
3	Everything they said is correct, but the list is not complete (i.e. missing 1-2 items). However, the three elements of Table II (modulus, tensile strength, elongation) of Pattanakul must be present.
4	Included all 6 material properties [1) chain length/molecular weight 2) melt flow index 3) impact resistance (izod) 4) tensile strength 5) modulus of elasticity 6) percent elongation/ductility and described a general trend correctly.

Exemplars:

1— The results demonstrated negligible difference in tensile strength for different percentages of recycled HDPE in recycled bottles versus virgin bottles. This means the material from recycled milk bottles is as strong as virgin plastic and can withstand as much weight. In addition, there is a slight increase in the modulus of elasticity with increased recycled HDPE compositions, which means the recycled HDPE has a higher resistance to being deformed. In other words, it is stiffer.

4— By comparing various types of mechanical tests on virgin HDPE and on recycled HDPE from milk bottle, it is found that even 100% recycled HDPE shows quite similar Melt Flow Index (MFI) with virgin resin which indicate no change of flow properties occurred. Also, weight average molecular weight and its distribution which is essential for determining mechanical properties shows no significant change for recycled HPDE. Specifically, there is only a slight increase in the weight average molecular weight indicating that there is minor increase of chain scission and cross-linking in terms of the micro-structure of recycled HDPE. However, even with the slight change of micro-structure, test results proves that the elastic modulus, tensile strength almost remain the same if 100% recycle HDPE is compared with virgin one. As for impact strength, a decrease of 10-15% is observed. However, as much as 50% decrease of elongation is found for recycled HDPE, suggesting that it ductility has decreased quite a lot.

3. Does the writing make a coherent argument for why or why not recycled HPDE could be used to make backpacks?

Score	Description
0	No argument presented.
1	They take a stance as to if the recycled polymer will work to make backpacks.
2	They take a stance as to if the recycled polymer will work to make backpacks and discuss how the mechanical properties change due to recycling (include either prior or post recycling).
3	They take a stance as to if the recycled polymer will work to make backpacks and either A: discuss how the mechanical properties change due to recycling (including the properties both prior to and post recycling) OR B: provide an estimate of the stresses a backpack will undergo and discuss mechanical properties prior to or post recycling.
4	They take a stance as to if the recycled polymer will work to make backpacks, discuss how the mechanical properties change due to recycling (include prior to and post recycling), and provide an estimate of the stresses a backpack will undergo.

Exemplars:

1— In short, it would be a great idea and would work well. […] All this means is that the material becomes more brittle when it is recycled. The reason being that the recycling process wears the material slightly.

4— There was no significant difference in strength for the different HDPE compositions. The elasticity is larger for recycled HDPE and this is due to weathering of polyethylene degradation, not reprocessing. The percent elongation is smaller for recycled HDPE. The impact strength of different mixtures was also measured and it was found that there was no decrease in impact strength up until 50% recycled HDPE. For mixtures with a greater percentage of recycled HDPE, the material stiffened, became brittle, and cracked easily. Generally, the properties of recycled HDPE are not very different from those of virgin HDPE and recycled HDPE could be used for similar applications of virgin HDPE and would provide a use for a material that would otherwise be wasted. The weight a backpack carries is around 20lb over 72in2 of area (stress of 1.9Pa). Based on the strength and elasticity data, the recycled backpacks can sustain stresses much greater than 1.9Pa.

4. Is a stress strain curve of the HDPE before and after it is recycle included? Are the graphs scientifically sound and the key features present?

Score	Description
0	Did not include graph or it was not a stress-strain curve.
1	There is either a single curve OR there are two curves but all of the comparisons are wrong OR they provide metal curves and modulus of elasticity and tensile strength are incorrect.
2	There are two curves, but either modulus or tensile strength is wrong OR they provide metal curves and percent elongation is wrong.
3	A: all elements are present (see 4) and between curve comparisons are all correct, but it is a metal curve (not a polymer) OR B: all elements are present and it is a polymer curve, but the elongation/rupture point is wrong.
4	The curve includes both recycled and virgin HDPE correctly mapped to Table II of Pattanakul, et al. as it 1) includes linear portion and the slope is steeper for recycled HDPE 2) a local maximum should be present, which is higher for recycled HDPE 3) rupture points with point further right for virgin HDPE. Curve includes axis labels and virgin/recycled labeled. Curve represents a polymer (not a metal).

5. Does the summary describe what is happening both macroscopically and microscopically when external forces are applied?

Score	Description
0	No discussion of polymer response to applied load.
1	Fails to compare recycled and virgin HDPE and is incomplete in that it only includes a very limited discussion of macroscopic or microscopic phenomena OR does not discuss properties under external forces. Too incomplete to evaluate accuracy.
2	As with rubric point three (criterion 5), but with includes incorrect content.
3	A: They completely address both macroscopic and microscopic, but do not compare recycled vs. virgin OR B: they completely compare recycled to virgin but do not discuss macroscopic or microscopic phenomenon (missing one) OR C: they partially address both macroscopic and microscopic and compare recycled to virgin. Must be correct.
4	Contains relevant descriptions of both macroscopic and microscopic phenomena. For macroscopic this means inclusion of elastic and plastic regimes (plastic will deform elastically on moderate load and then deform plastically on greater load)/effects of degradation. Microscopic includes both discussion of the greater crosslinking in recycled polymer leading to differences in properties and the "uncoiling" and "ordering" of chains that occurs with stress.

Exemplars:

1— HDPE is a linear polymer that is flexible and has van der Waals and hydrogen bonding between chains to hold them together. The linear molecular structure of HDPE would allow the backpack to remain flexible and would allow students to store objects of different shapes.

3— At a microscopic level when HDPE is recycled the polymer will experience both degradation and branching or crosslinking reactions that occur simultaneously. This means that some of the molecules will degrade while others while increase in molecular weight. Overall, this makes the material more brittle and stiff. At a macroscopic level, this means that both polymers will begin to elongate, but the recycled polymer will break before the virgin polymer will.

1. Would this memo be understandable to a person with a minimal scientific background.

Score	Description
0	No translation into their own words.
1	Translates into their own words or more accessible language.
2	Translates into their own words or more accessible language and attempts to explain the chemical principles behind corrosion. This must include reference to the galvanic series or chemical reactions, but with little background provided.
3	Translates problem into accessible and original language, providing a thorough and correct explanation of how metallic reactivity dictates corrosive behavior. Does not provide an in-depth or consistent solution to abating corrosion in Flint.
4	Translates problem into accessible and original language by providing a thorough explanation of how metallic reactivity dictates corrosive behavior. Relates this knowledge through a coherent and thoughtful plan for abating corrosion in Flint.

Exemplars:

1— The 316/304 Stainless steel is not very reactive. With this type of stainless steel it is considered “passive”, all this means is that it has undergone a process where a protective film is added to the inward and outward facing steel piping.

2— The pipes used in Flint at the moment are made out of lead (Pb), copper (Cu), and galvanized steel. The pipes that are causing the most issues with water quality are lead pipes. Lead is a corrosive material. This means it undergoes a chemical reaction when it comes into contact with the dissolved oxygen (O_2) found in water and as a result breaks down.

4— *WHAT IS CORROSION & THE CHEMISTRY BEHIND THE ISSUE*
In many cities, molecules called orthophosphate are continuously usually added to the water supply. When Flint switched to using their river as a water supply, the city never added this chemical. Orthophosphates bond to lead pipes, creating a protective coating between the metal and the water, therefore, blocking corrosive chemicals like oxygen from interacting with the lead.
If oxygen comes in contact with lead on the pipe, it will oxidize the lead molecule by taking electrons from it ($Pb = Pb^{+2} + 2e^-$). In this transfer of electrons, the oxygen is reduced because it gains electrons and the lead is oxidized because it loses those same electrons. The oxygen then uses these electrons to bond and eventually form water with two hydrogen molecules ($O_2 + 4H^+ + 2e^- = 2H_2O$). The oxidized lead can then dissolve into the water flowing past it in the pipe.

Overtime, as more and more lead breaks off into the water, the concentration of lead builds up in the drinking water and the pipes begin to corrode and thin. The type of corrosion that occurred in Flint is called erosion-corrosion. It is due to the combination of chemical reactions and abrasion during fluid motion. The reason this catastrophe happened so quickly was due to the high levels of chlorine in the Flint water. Through various chemical reactions, chlorine has the power to increase the rate of lead corrosion in these pipes.

THE SOLUTION

The galvanic series shows rankings of different metals reactivities in seawater. The metals at the top are unreactive while those at the bottom are most reactive. The more reactive a metal, the more likely it is to corrode.

From this table you can see that iron is the most reactive, followed by lead, and then followed by copper. I believe that a switch to all copper piping is the best solution to your water pollution issue. Unlike lead and iron, copper is corrosion resistant in many conditions. You may believe it corrodes easily due to the familiar characteristic of turning green after some time. In fact, this change in color is the metals own effort to protect its self from corrosion. The thin green layer, called patina, prevents oxygen and other corroding elements from touching the remaining copper making it an efficient water proofing material. This is why copper corrodes so slowly when compared to iron and lead.

Obviously, a huge aspect of this issue has been the cost of a solution. The range of prices of copper lies within that of 304 and 316 stainless steel. Since Flint already as copper pipes, those that are damaged beyond repair should be replaced with new copper piping along with all of the lead and iron pipes. This would reduce the price of this project because not every pipe would need to be changed.

2. The memo should explain the chemical origins of corrosion, including the anticipated compatibility of metal/alloy joints based upon their relative placement in the galvanic series. Is the explanation of corrosion origins complete and explained well? Is the role of the galvanic series in corrosion prevention discussed? Is there anything missing in the discussion of the galvanic series? How could these descriptions be improved?

Score	**Description**
0	No explanation to the chemical origins of corrosion, including the anticipated compatibility of metal/alloy joints based upon their relative placement in the galvanic series.
1	Briefly discusses the chemical origins of corrosion. Does not include the anticipated compatibility of metal/alloy joints based upon their relative placement in the galvanic series.
2	Discusses the chemical origins of corrosion **or** mentioned anticipated compatibility of metal/alloy joints based upon their relative placement in the galvanic series. The connection between the placement of the metal on galvanic series and the origin of corrosion is either incorrect or incomplete.
3	Discusses the chemical origins of corrosion **and** mentioned anticipated compatibility of metal/alloy joints based upon their relative placement in the galvanic series. The connection between the placement of the metal on galvanic series and the origin of corrosion is either incorrect or incomplete.
4	Discusses the chemical origins of corrosion. Mentions anticipated compatibility of metal/alloy joints based upon their relative placement in the galvanic series. The connection between the placement of the metal on galvanic series and the origin of corrosion is correct and complete.

Exemplars:

1— Overall, copper is incredibly resistant to corrosion from all materials it will come in contact with as it has a relatively low reactivity. Corrosion is defined as the failure or deterioration of a metal due to chemical reactions it undergoes. Although copper does react to water quite quickly, it is only a surface change and will not cause the metal to actually deteriorate as the layer formed does not dissolve into the water.

4— In solutions where two metals are present, the driving force that determines which metal will corrode is the electric potential (voltage) that exists between the cations and neutrally charged metals (Callister and Rethwisch 612). The electric potential, or voltage, can be thought of as the energy that is released when a reaction occurs. Since reactions that produce energy are more likely to occur than reactions that use energy, the overall reaction between the metals that produces a positive voltage will be favored. The relative reactivities of metals and commercial alloys in their ability to undergo oxidation is represented in the galvanic series (Figure 1). The more reactive metals and alloys are placed at the bottom of the galvanic series, while the less reactive ones are at the top. Being more reactive means that the oxidation of those materials results in a more positive voltage, making corrosion more likely. Therefore, [the galvanic series] provides an estimation of how corrosive certain materials are...The proximity of metals and commercial alloys in the galvanic series with respect to each other represent the relative ability of the less reactive material to corrode the more reactive one.

3. The memo should detail the types of corrosion that are most likely to occur in the water system. For each type of corrosion, the relevant chemical reactions should be mentioned. Are the most likely corrosion mechanisms and their corresponding chemical reactions clearly described? How could these descriptions be improved?

Score	Description
0	No mentioning of corrosion mechanisms and their corresponding chemical reactions.
1	Describes the corrosion mechanisms and their corresponding chemical reactions, but is neither complete or correct.
2	Either (A.) describes all relevant correct corrosion mechanisms but does not provide the corresponding chemical reactions OR (B.) mentions some but not all contributing corrosion mechanisms and their corresponding chemical reactions. (reactions may be represented in words, diagrams, or equations)
3	Describes the correct corrosion mechanisms and corresponding chemical reactions with their own words. (reactions may be represented in words, diagrams, or equations)
4	Describes the correct corrosion mechanisms and corresponding chemical reactions with their own words and relates this to the main problem.

Exemplars:

1— The reason that Flint's water became contaminated was due to the corrosion of the iron, copper, and lead piping. Corrosion is the natural process of destroying a metal by chemical reactions.

3— The process by which corrosion occurs is an oxidation reduction reaction which produces hydroxides. These hydroxides combine with ferrous ions which become rust. Copper and iron are far enough apart on the galvanic series that when the two-different metals encounter corrosive water, they experience galvanic corrosion where the rate of corrosion will be increased. The metals have different affinities for electrons – the iron serving as the more anodic metal will attract electrons and the copper serving as the cathode will attract protons. This potential difference allows current to flow. This electrochemical cell can start the process of corrosion in pipes through the previously mentioned oxidation reduction reaction

4— Corrosion is an electrochemical attack on metal. On one end, oxidation occurs, which is when a metal loses an electron. For example:

$$M \rightarrow M^{n+} + ne^-$$

The place where oxidation happens is called the anode. On the flip side, whenever oxidation occurs, another reaction called reduction happens. This is when electrons are added to some chemical species. In the case of the flint water crisis, where neutral water with dissolved oxygen runs over the pipe[1], the following reaction occurs:

$$O_2 + 2H_2O + 4e^- \rightarrow 4(OH^-)$$

This galvanic component of reduction is known as the cathode. In the case of the flint water crisis, it is crucial to use a metal that is cathodic relative to the water. As a result, that metal will be less likely to oxidize and result in poisoning, because it will be less likely to release as a charged ion due to electron loss.

Such a ranking of reactivities is present when considering the galvanic series, which represents the relative reactivities of metals and commercial alloys in seawater. This series is shown in Figure 1.

4. The memo should provide a coherent argument for upgrades to the water system, Including the specific metal/alloy to use for new pipes, and any additional preventative measures to be employed. The argument should be based upon both scientific reasoning and materials costs. Is the argument comprehensive, concise, and/or persuasive? How could the argument be more convincing?

Score	Description
0	Does not propose an upgrade to the water system.
1	Proposes an upgrade to the water system, but lacks logical steps in reasoning.
2	Clearly proposes an upgrade to the water system based upon scientific reasoning. This solution is purely technical, lacking discussion of environmental and economic variables.
3	Clearly proposes a logical upgrade to the water system that demonstrates scientific reasoning as well as an awareness of environmental variables and materials costs. Considers making changes to either (A.) the pipe material OR (B.) water treatment.
4	Clearly proposes a logical upgrade to the water system. Provides a persuasive argument that combines scientific reasoning with an awareness of environmental variables and materials cost. Considers making changes to both pipe material **and** water treatment.

Exemplars:

1— Of the potential materials, the best long term choices would be aluminum, copper or stainless steel. An alloy such as brass would be the most, but the price makes this a less useful choice. Ultimately aluminum or an alloy of aluminum would be the best choice to maintain long term and is my recommendation to use in future piping endeavors.

3— Through some research, we have concluded that Schedule 10 stainless steel would be an ideal material to replace the current lead pipes. The materials used for pipes can range anywhere from metals to plastics. Given the high chloride levels in the current Flint water supply, the rate of corrosion of the pipes are accelerated. It is imperative to choose a material that is able to withstand this corrosion while staying cost effective. Plastic polymers are an adequate candidate for the pipes given their durability and low cost. Unfortunately, the harsh winters of Flint will lead to increased stress from freeze-thaw cycles. Most of these plastics are unable to handle this drastic change in temperature and will split when frozen. Copper is another common material with high durability and resistance to corrosion. However, copper, similar to polymers, is prone to splitting under low temperatures, and the cost of installation can be very high. Galvanized steel is also an option, but the corrosion/health risks and difficulty of implementation do not make it an ideal candidate. On the other hand, Schedule 10 stainless has the durable characteristics of copper and the ability resist temperature changes similar to galvanized steel (Chen). In addition, the cost of implementation are lower than both copper and galvanized steel, making it a good choice for the replacement process.

4— The preferred pipe material should have the following characteristic:
Relatively corrosion resistant (this is the main focus, and the choices are located at the upper section of the galvanic series)
Affordable for township level pipe replacement (this rules out expensive and rare materials such as Gold and Platinum, even if they have excellent corrosion resistance)
High material strength or hardness (the pipe must be able to withstand large water pressure, and stresses from the environment. For example if the pipes are buried underground, they must be able to support pressure from the ground and potential earth quakes. This rules out "soft" materials such as Gold, Graphite and copper.)
Upon consideration the aforementioned criterions, stainless steel is the recommendation of candidate. It has excellent corrosion resistance, because Iron Oxide layer is formed on the materials surface that insulates oxygen from further corrosion. Stainless steel is also economically feasible ($280 per 10 ft. of pipe). It also has demanded material strength, as it has already been commonly used for architecture.

*Preventive measures for corrosion

Extra preventive measures can also greatly assist in the pipe safety and durability. To counter-act "erosion-corrosion", pipe elbow could be reinforced with metal oxide or Tin/Nickel coating. New pipes can also be built underground for cooler temperature, which slows down corrosion reaction. Lastly, monitor the pH level of water. Chlorine Ion creates acidic environment that speeds up corrosion. Monitoring and maintaining pH level at pH 7 helps control corrosion.

1. Would this memo be understandable to a person with a minimal scientific background.

Score	Description
0	No translation of the problem and solution into their own words.
1	Translates the problem and solution into their own words or more accessible language. Only explains concepts in crystallography.
2	Translates the problem and solution into their own words or more accessible language, and attempts to relate the orange stacking problem to crystallography knowledge.
3	Translates the problem and solution into their own words or more accessible language, makes one or more correct connections between orange stacking and atom stacking, but fails to acknowledge the differences between atoms and oranges and/or limitations of the model.
4	Translates the problem and solution into their own words or more accessible language, makes correct connections between orange stacking and atom stacking, and successfully acknowledges the differences between atoms and oranges and/or limitations of the model.

Exemplars:

1— In the field of material science engineering, a characteristic called atomic packing factor (APF) is commonly used to determine how packed a structure is. Arranging spheres in layers with each sphere resting in the small hollow region between the three spheres beneath is structurally identical to a face-centered cubic crystal structure, which is found for many metals. APF is calculated by dividing the volume of atoms in a unit cell by the total unit cell volume, and a higher APF indicates more tight packing. A face-centered cubic structure provides an APF of 0.74, which happens to be the maximum packing possible for uniform spheres. Hexagonal close-packed structures also have a high APF of 0.74, and can also be achieved by having each sphere resting in the region between three spheres beneath. In contrast, a body-centered cubic crystal structure has a lower packing factor of 0.68 and is not optimal for this situation. A simple cubic structure would not be ideal either, as it has the lowest APF of 0.52.

4— When packing oranges, we can use simple cubic structure or hexagonal close-packed structure (HCP), which is the traditional way to stack oranges. Here we'll compare their efficiencies. To demonstrate, we'll simplify oranges into solid spheres with diameter a and subdivide structures into small repeat entities called unit cells. In the unit cell of a simple cubic structure like in salt crystal, atoms are located at each corner of a cube (figure 1). In HCP (figure

2), the top and bottom layers are the exact same. They both contain seven spheres forming a hexagon. Then there is a middle layer of three spheres in a triangle.

2. The letter should describe the relationship between tightly-packed spheres and typical crystal structure(s).

Score	Description
0	Does not describe the relationship between tightly-packed spheres and typical crystal structures.
1	Explains some typical crystal structures but does not identify which ones are tightly-packed structures and why.
2	Explains some typical crystal structures and APF. Identifies and explains which of these structures are most tightly-packed and why.
3	Explains some typical crystal structures and APF. Identifies and explains which of these structures are most tightly-packed and why. Explains how this is related to the orange stacking problem.
4	Explains some typical crystal structures and APF. Identifies and explains which of these structures are most tightly-packed and why. Explains how this is related to the orange stacking problem and relates this to a valid suggestion to the manager based on the discussion.

Exemplars:

2— In the unit cell of a simple cubic structure like in salt crystal, atoms are located at each corner of a cube (figure 1). In HCP (figure 2), the top and bottom layers are the exact same… It's easy to see that 0.74 is much larger than 0.52, meaning HCP is much more efficient in space filling than the simple cubic structure.

4— The most commons methods consist of creating a square base pyramid. The simple cubic (SC) structure contains unstable successive layers of atoms each positioned on the one underneath. A more stable structure, called body centred cubic (BCC), consists of layers of atoms arranged as in Figure 1 have to be stacked one on top of each other, making sure that each atom of a new layer seats on 4 atoms. This arrangement is not the most space efficient as it lives many empty spaces. Indeed, the fraction of volume of atoms to the total volume used, known as packing fraction (PF), is approximately 0.68. To interpret this result, 68% of the available space is used. A more efficient method is to stack each atom on top of three other atoms underneath. This structure is called face centred cubic (FCC) and the layers of atoms are meant to optimize the space by moving the atoms closer together, as shown in Figure 2. When stacking the layers, each atom will seat on three atoms and, due to how the atoms are more densely packed together, the chance of atoms slipping along these horizontal planes is lower than in BCC. Also, the PF of this structure is higher and can be calculated at 0.74.

3. The letter should provide a discussion of the mechanical stability of these structures in terms of their susceptibility to slipping along different planes.

Score	Description
0	Does not provide discussions of the mechanical stability of crystal structures or orange stacks.
1	Provides some discussion of the mechanical stability of crystal structures and/or orange stacks but the discussion is vague or incorrect.
2	Provides correct discussion of the mechanical stability of crystal structures. The discussion is only technical without linking to the problem of orange stacking.
3	Provides discussions of the mechanical stability of crystal structures. Links the discussion of the mechanical stability of crystal structure to the problem of orange stacking.
4	Provides discussions of the mechanical stability of crystal structures. Gives a complete discussion of the mechanical stability of crystal structure and relates this to the proposed solution to the orange stacking problem.

Exemplars:

1— If it is assumed that the density of the structure is correlated to its mechanical stability, we can conclude that my friend's proposed stacking method will provide the most stable structure. This is because density increases as packing increases, so the structure with the highest APF of 0.74 will be the most dense.

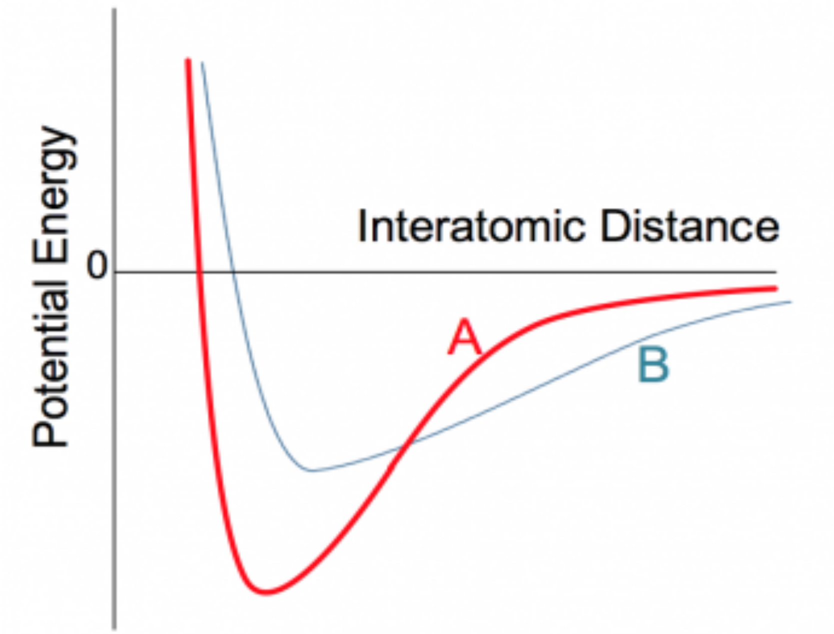
4— Next, we are going to examine their mechanical stability. As we can see in figure 1, top spheres in the cubic structure sit right on top of the bottom ones. If a box of oranges is arranged in this manner, the upper oranges will have a tendency to slide and lie in the gaps of the oranges in the layer beneath. As a result, the cubic structure is susceptible to slip along layers. On the other hand, the oranges in each plane in HCP are already filling in the gaps formed by the plane of oranges underneath them. Thus, HCP is more mechanically stable… After comparing two characteristics of the two possible structures, we can conclude that the hexagonal close-packed structure is more ideal for orange stacking. The reason is that it's more efficient in space-filling and more stable mechanically than the simple cubic structure.

Assessment

The conceptual questions of the concept inventory-style assessment delivered as a pre- and post-assessment in an introductory materials science course is included below. Assessment questions were designed to fall into one of six topics, four of which were covered in WTL assignments (binary phase diagrams, stress-strain, corrosion, and crystal structures), and two which were not (bonding and the water phase diagram). Students were prompted to report confidence in their answer on a 1-5 scale after each question.

The following section contains questions about content that you will be learning in MSE 250 this term. Therefore, some topics may be unfamiliar to you. *It's OK if you don't know the answer to something.* All answers will be de-identified prior to analysis. Credit for participating will not rely on "correct" answers but rather to provide your current understanding at this time. It's very important that we obtain natural responses from each student. This means that you should complete the questions on your own without discussing it with others or using outside information.

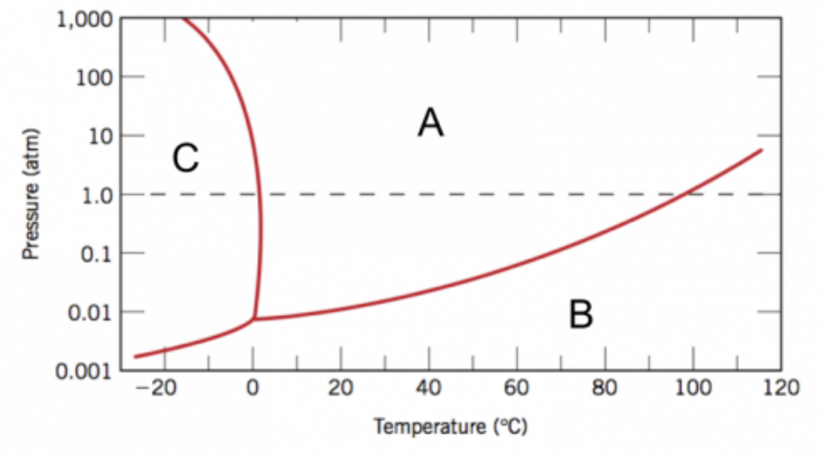
The following question refers to the below potential energy curves.



Q1. **Select the material which has the higher value for each of the following properties.**

	A	B
Lattice parameter (a)	○	○
Modulus of elasticity (b)	○	○
Melting point (c)	○	○
Coefficient of thermal expansion (d)	○	○

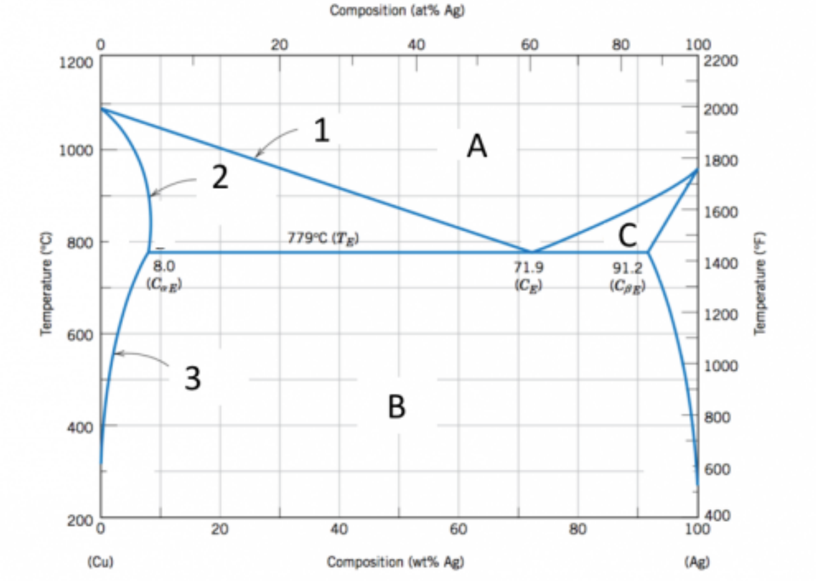
The following question refers to the below phase diagram of water.



Q2. **At 100 atm and a temperature of -5 ˚C water would undergo what phase transition moving from phase A to C?**

- ◯ Melting
- ◯ Freezing
- ◯ Deposition
- ◯ Sublimation
- ◯ Condensation
- ◯ Evaporation

The following two questions refer to the copper-silver binary phase diagram shown below.



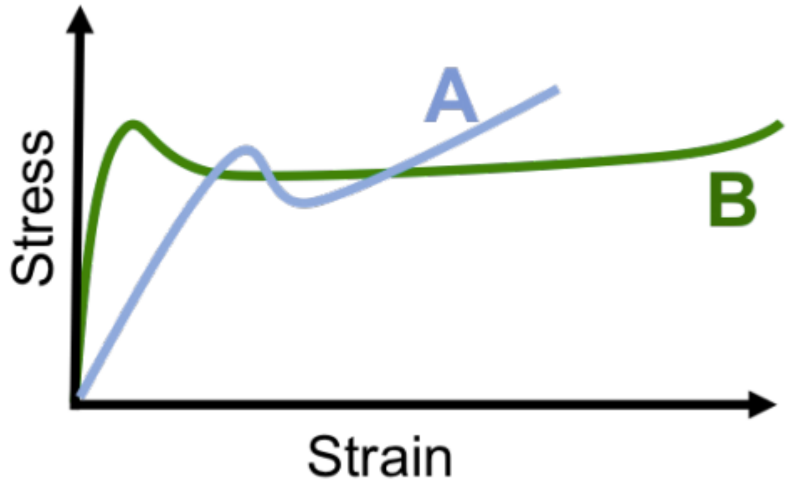
Q3. **In order, what are the phases of portions A - C?**

- ◯ A) alpha + beta , B) Liquid C) beta + Liquid
- ◯ A) Liquid, B) alpha + beta, C) alpha + Liquid
- ◯ A) Liquid, B) alpha + beta , C) beta + Liquid
- ◯ A) beta, B) alpha, C) alpha + beta

Q4. **At composition 20% Ag, the melting temperature is?**

- ◯ 780 ˚C
- ◯ 1000 ˚C
- ◯ 820 ˚C
- ◯ 1090 ˚C

The following question refers to the below stress-strain curves.



Q5. **From the stress-strain curves of polymers A and B shown in the diagram, which has the larger tensile strength and which undergoes a greater % elongation?**

- ◯ Tensile strength: A > B, % Elongation: A > B
- ◯ Tensile strength: A > B, % Elongation: B > A
- ◯ Tensile strength: B > A, % Elongation: B > A
- ◯ Tensile strength: B > A, % Elongation: A > B

Q6. **Which of the following reactions will most likely lead to corrosion?**

- ◯ $Fe^{3+} + e^- \rightarrow Fe^{2+}$ $V^0 = 0.771$ V
- ◯ $Fe^{2+} + 2e^- \rightarrow Fe$ $V^0 = -0.440$ V
- ◯ $Ni^{2+} + 2e^- \rightarrow Ni$ $V^0 = -0.250$ V
- ◯ $Au^{3+} + 3e^- \rightarrow Au$ $V^0 = 1.420$ V

Q7. **Which of the following can be used to minimize galvanic corrosion? Select all that apply.**

- ◯ Include a 'sacrificial' anodic metal.
- ◯ Use a large anode area.
- ◯ Insulate dissimilar metals from one another.
- ◯ Add an inhibitor to your system.

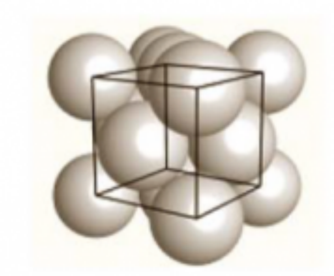
Q8. **Two pieces of metal, A and B, are the same size and shape but Metal A has a greater yield strength than Metal B. Which of the following statements is true?**

- ◯ Metal A will permanently deform at a greater stress than Metal B.
- ◯ Metal A will have a greater tensile strength than Metal B.
- ◯ Metal A will have a greater young's modulus of elasticity than Metal B.
- ◯ Both a and b.
- ◯ a, b, and c are all true.

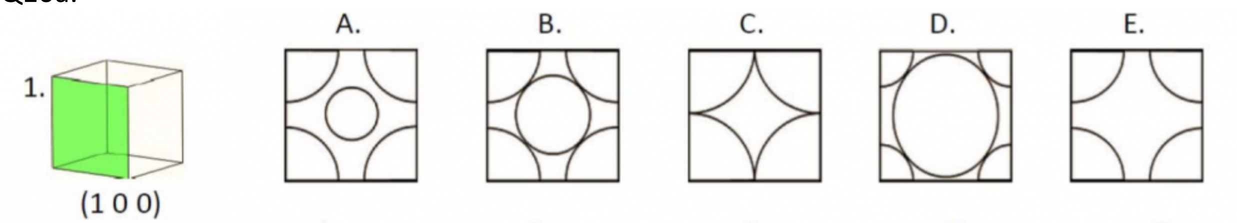
Q9. **Material A has a greater (average) atomic separation than Material B. Select the material which has the higher value for each of the following properties.**

	Material A	Material B
Mass Density (a)	◯	◯
Atomic Bond Strength (b)	◯	◯
Yield Strength (c)	◯	◯
Melting Temperature (d)	◯	◯

The following three questions refer to the face-centered cubic crystal structure shown below. For each, choose the correct illustration that corresponds to the specified plane.

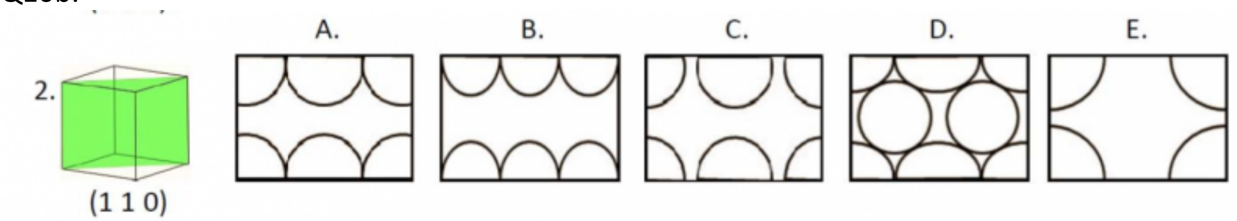


Q10a.



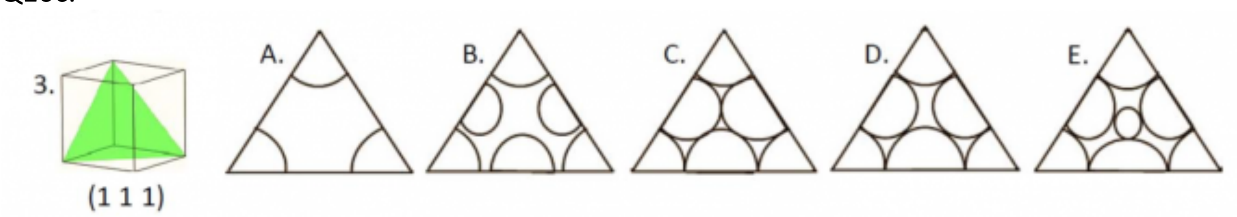
- A.
- B.
- C.
- D.
- E.

Q10b.



- A.
- B.
- C.
- D.
- E.

Q10c.



- A.
- B.
- C.
- D.
- E.

Q11. Which one of the following planed within its corresponding unit cell crystal structure is a close-packed plane?

- Face-centered Cubic (1 1 0)
- Face-centered Cubic (1 0 0)
- Body-centered Cubic (1 1 0)
- Face-centered Cubic (1 1 1)
- Body-centered Cubic (1 0 0)

Assessment Gains by Topic

The assessment results for each topic are shown in Table S1. Results were grouped by population (WTL group, non-WTL group, and WTL-free group) as described in the main paper.

Table S1. Assessment data by topic: averages are the mean fraction of correct answers on each topic from the pre- and post-assessments, χ^2 is the McNemar statistic, p is the p-value indicating statistical significance of changes from pre- to post-scores, and $\langle g \rangle$ is normalized gain from pre- to post-scores, and N is the number of participants in the assessment for each group.

Topic	Pre-av.	Post- av.	χ^2	P	$\langle g \rangle$	N
Topics covered in WTL assignments:						
WTL Group						
Binary Phase Diagrams	0.32	0.77	73.0	<0.01	0.66	
Stress-Strain	0.32	0.52	21.8	<0.01	0.29	
Corrosion	0.17	0.42	35.6	<0.01	0.30	
Crystal Structures	0.40	0.58	37.7	<0.01	0.30	
Non-WTL Group						
Binary Phase Diagrams	0.38	0.83	10.7	<0.01	0.71	
Stress-Strain	0.21	0.33	0.82	0.37	0.16	
Corrosion	0.24	0.26	0.11	0.74	0.04	
Topics not covered in WTL assignments:						
WTL-Free Group						
Bonding	0.63	0.73	23.8	<0.01	0.27	
Water	0.53	0.55	2.00	0.16	0.04	

Assessment Results by Question

The assessment results for each question are shown in Figure S1. Results were grouped by population (WTL group, non-WTL group, and WTL-free group) as described in the main paper.

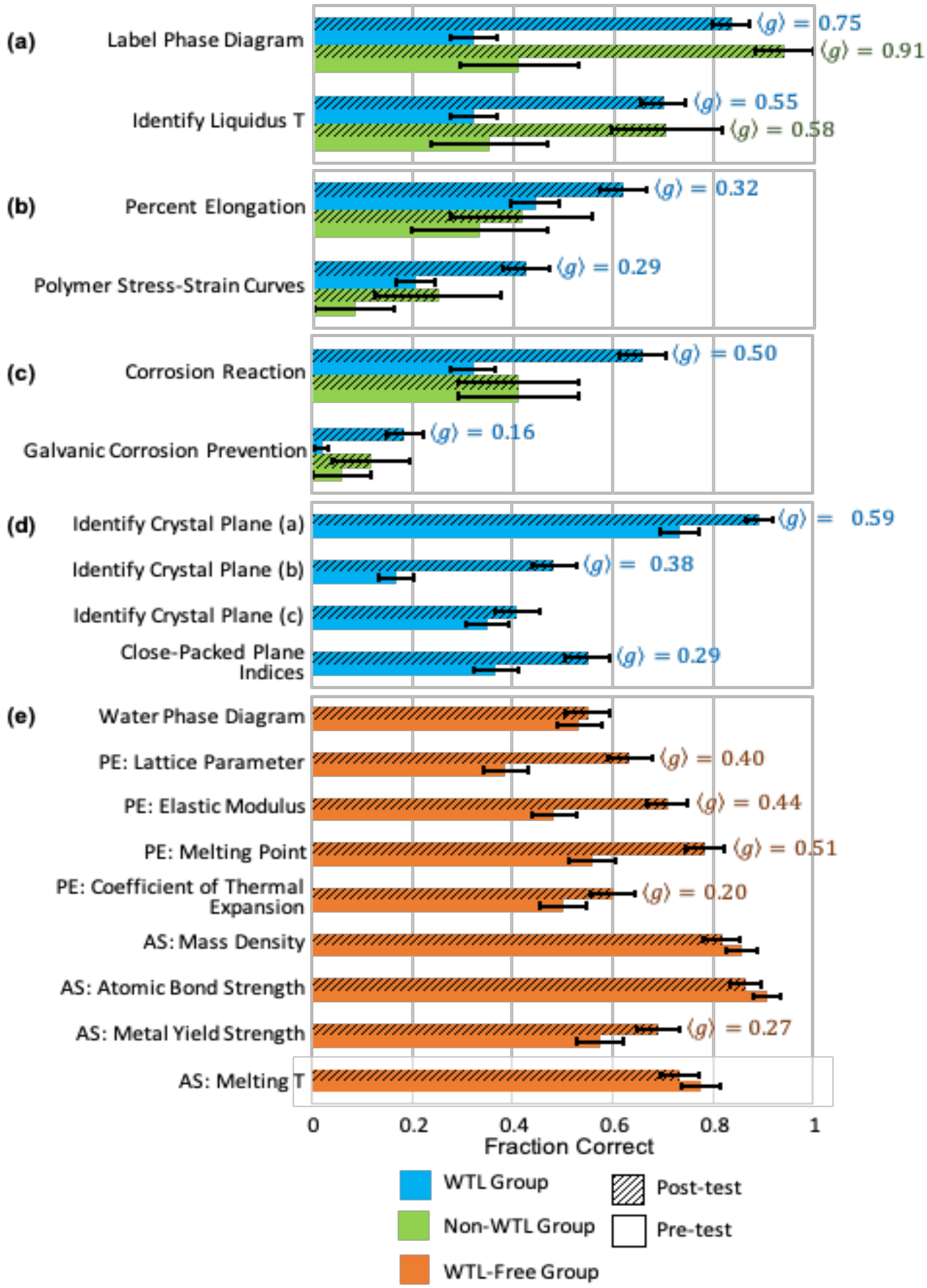


Figure S1. Pre- and post-assessment scores grouped by topic: (a) binary phase diagrams, (b) stress-strain, (c) corrosion, (d) crystal structures, (e) bonding and the water phase diagram. Note that in the WTL-free Group, AS refers to questions about atomic separation and PE refers to questions involving potential energy curves. Normalized gain values were indicated only if statistically significant ($p < 0.05$).