



## WHAT: Weekly Homework and Tasks

This is your second big WHAT and by now you know the drill. Yes, I know, you miss the first WHAT terribly, and you are wondering if the second WHAT can fill the gaping hole in your heart. I think it can.

Once again, the WHAT provides a comprehensive breakdown of each assignment for the week, including readings, upcoming MMA matches in T300, presentation guidelines, and questions to guide your product investigation.

The second week is extremely important. In it, you will learn what your material actually is and what, deep down, makes it special.

### Tasks

- Read Chapters 3 and 4 in Engineering Materials 1
- Tutorial: Please take a look at the “Bonding” tutorial [here](#). It does a great job summarizing bonding in materials.
- Make a visual representation of the atomic structure of your material.
- Find a video and/or description of the manufacturing process of your component.
  - Again, if this is not quick, then try to find something closely related. If you have questions about what to be looking for, ask me in class or by email.

### Homework

**As a team**, please answer the following questions about your **product**:

- What are the normal operating conditions of your product? Of the components?
- What temperature ranges do your components experience?
- What are the most extreme situations this product will be used in?

**Individually**, you should answer the following questions about **a component** of your product. Please remember to cite your sources and state your assumptions!

- What mechanical loading does it experience? Draw a free-body diagram and estimate the forces. What state of stress is it in? What does that imply for the stress tensor?
- How is your material held together? What bonds are there between atoms?
- What is the microstructure? Is it crystalline or amorphous? If crystalline, what is its crystal structure?



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- At what temperatures are the phase changes of your material? (melting, glass transition, crystallization, etc. as appropriate)
- What is the density of your material? How does that relate to its atomic structure?
- The visual representation of your material's microstructure.

Please remember to check out the HW Guidelines document for info on how to submit this work.

**As a team**, please prepare a  $2n$ -minute presentation for next Wednesday (16 Sept), where  $n$  is the size of your group in units of people. The goal of this presentation is for you to **teach the class** the following:

- a) **What is your product? What does it do? Why? What are the most important design factors of the design?**
- b) **For each component, what design factors are most important to the material selection?**

### Resources

- [interesting tutorials](#), including light alloys, polymers, and composites



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### A material scientist's take on the readings

In **chapter 3** we get the very basics of how we quantify mechanical properties. Note that, as materials scientists, we are rather fond of being able to compare material properties across materials. We do this by normalizing the mechanical response of materials by specimen geometry, and calling them stress and strain. **Stress** is a force normalized by the area on which it acts. **Strain** is a change in length normalized by initial length. The **elastic modulus** gives you a sense for how “stretchy” the material is at low strains; it is calculated from the slope of the stress-strain curve at very low strains (for which materials are linear elastic). From Table 3.1 and Figure 3.7 we see that the **stiffer** the material, the higher the Young's modulus ( $E = 1000$  GPa for diamond,  $\sim 200$  GPa for steel, 69 GPa for aluminum,  $\sim 17$  GPa for lead,  $\sim 3$  GPa for nylon, 0.2 GPa for low density polyethylene).

**Next, we're all about the building blocks of materials: atoms, the bonding between them, and their spatial arrangements.** The reading this week gets into the nitty-gritty details of materials at the atomic scale. Chapter 3 introduces and defines concepts of stress and strain. Chapter 4 should be a review for most of you (remember high school chemistry?).

So what is actually important? Again, the basics of bonding between atoms are covered very well by the tutorial. Again, not a pretty tutorial but the basic point gets across: the type of bonding and strength of bonding between atoms in a material affect properties like its stiffness, melting/softening temperature, and density. Depending on the type of atoms that are present in the material, different types of bonds will form.

In **chapter four** we are introduced to primary and secondary bonding in materials. There are several types of **primary bonds**: ionic, covalent and metallic; they are typically strong. There are also several types of **secondary bonds**: van der Waals and hydrogen; they are typically weak. Materials can exhibit multiple types of bonds. The types of bonds present depend on how the atoms in the material can share their electrons. We characterize bonds between two atoms/ions through **energy-distance curves** and **force-distance** curves. From these curves we can deduce the range of inter-ion/inter-atom distance that leads to stable bonds, the distance that leads to the most stable bond, and the stiffness of the bond for small stretching.

Note that ionic and metallic bonding **lack directionality**. Covalent bonding, on the other hand, is **directional**. This has a great effect on how atoms in a material can **pack**. The



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differences in bonding and packing will also have an effect on how materials react to an applied force. For example, let's compare a substance with strong ionic bonding, like NaCl (3.3 eV/atom), to a substance with about the same strength of metallic bond, such as aluminum (3.4 eV/atom). Do these materials behave similarly? No way, Jose. You can break the strong ionic bonds in salt pretty easily, right? Go ahead and try it. Pour out some salt on a tabletop and smash it with your spoon or fork. Note that what you're doing is breaking billions and billions of bonds. Now imagine doing this with aluminum. Sorry, but finely powdered aluminum has been known to spontaneously combust and start massive fires, so we don't tend to keep it in our salt shakers. It doesn't taste all that great on food, and it's not good for the brain, either. This ability of aluminum to react with air is related to its chemical properties, of course. Aluminum has an enormous affinity for oxygen, and it would much rather form covalent bonds with oxygen ( $\text{Al}_2\text{O}_3$ ) than hang out with its own kind. Back to our powder smashing, though. Think you can break millions of Al bonds in the same way you can break NaCl bonds? What would happen when you pound on Al powder, or any other metal for that matter, with your spoon or fork? Could you point to any evidence of broken bonds? What's going on here?

Something that is not covered in this chapter, but that is relevant to our course is how we can use the atomic/molecular arrangement of materials to **identify them in the lab**. One of the interesting aspects of atoms and molecules is that they all have characteristics that make them **identifiable**. That's right, they all have distinct "fingerprints" that we can see with our laboratory instruments, but we need to be clever enough to know which analytical technique to select, and how to analyze the data. For example, we know that different elements have electrons moving in orbitals of varying energy, and we know that through **absorption** and **emission** of energy, electrons can move from one orbital to another. Imagine we blast a solid sample with enough energy (with, say, an electron beam or some x-rays) to cause a bunch of electrons in the atoms in the material to get excited (absorption). Those excited electrons will want to quickly dump this excess energy and return to their equilibrium or lowest-energy state, and they can accomplish this energy dump by emitting the absorbed energy as x-rays. But here's the kicker: all those x-rays coming off the sample will have energy values that correspond exactly to certain transitions in the atoms from our material. If we use an x-ray detector to collect the x-rays and a computer system to sort the x-ray energies, as in our **energy dispersive x-ray spectrometer (EDS) and x-ray fluorescence (XRF)** systems, we can determine which elements are present, and in what amounts! Clever, eh?



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These techniques work great for detecting particular elements, but what about groups of molecules like those found in polymers and other **organic materials**? Molecules tend to absorb energy in the infrared range through vibration, and different types of bonds (e.g., C=O vs. C-H) require different amounts of energy to vibrate. A **Fourier transform infrared (FTIR) spectrometer** blasts samples with a range of IR wavelengths and shows which energies the material absorbs, and which simply pass through the material. With this absorption versus IR energy (or wavelength or wave number) spectrum, we can match our unknown organic material to spectra from known materials compiled in a database. Voila! We now have an analytical method that may help us determine why 3M™ Post-it® notes are stickier than off-brand post-it notes.