5. Inside Real Crystals

5.1 A Close Look at Real Iron

5.1.1 Nobody is Perfect

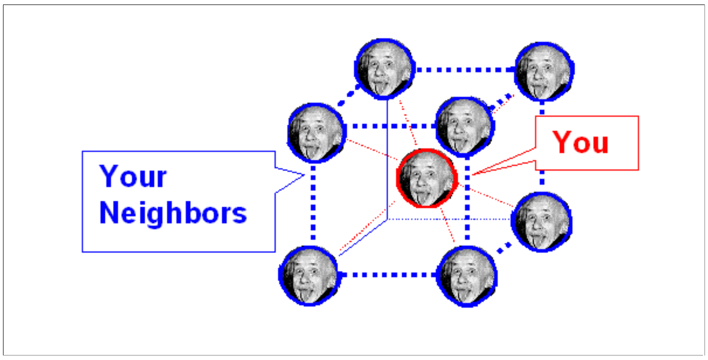
- Get a piece of real iron. Any iron or even "mild steel" (with just a little bit of carbon) will do. Cut off a piece of your car body, or take a regular nail, etc., etc. Let's look at our piece of real iron *once more*.
  - Except that this time we do not crank up our brain microscope to the high magnification level where we see the iron atoms. Here we make do with magnifying just a few thousand to a few hundred-thousand times.
    At that low magnification we will *not* see the atoms. The truth is that looking at atoms is only fun when you do it for the first time, after that it tends to get a bit boring. All iron atoms not only look the same, they are exactly the same. If you have seen one you have seen them all. Worse, most of the time they aren't doing anything exciting either.
    You simply won't notice a tree, not to mention a forest, if you only look closely at leaves. Watching *only* atoms in your sample you may miss the action somewhere else in your specimen since you only watch an *extremely tiny* part of it.
    The total amount of material investigated at atomic resolution so far is less than one cubic millimeter (1 mm^3) of material, and electron microscopists started watching atoms around 1975. That's around the volume of a pinhead. You agree, I hope, that they might have missed something.
- What they tend to miss are lots of wonderful **defects** (more properly called **crystal lattice defects**) contained in their crystals, because on an atomic scale they are so far apart that most of the time you miss them.
  - If you have one gold nugget per square meter (1 m^2 equals about 10 sqf) in your claim, you will have to search a long time if you comb the ground with a high-power microscope, seeing about (100 × 100) μm^2 at one go. Covering one 1 m^2 means you have to search 100.000.000 of those patches, and that will take a while.
- Electron microscopists are no fools, however. I used to be one, after all. They know that they are going to miss something if they *only* work a high magnification. That's why they invented many other ways to look at a sample, and that's what we are going to do now.
  - So crank *down* your magnification and look again. What are you going to see?
  - Not all that much that will excite *you*. There are two reasons for this:

    1. *First,* most of the defects we are after are invisible. You need to use some little tricks to make them visible.
    2. *Second* , even the ones you happen to see by accident don't have little labels attached saying, for example, "I'm a grain boundary", or "I'm an iron-carbide particle", so changes are that you don't recognize what you see.
  - Without some background knowledge you might not notice that the grayish smear you see is actually something exciting. I did not exaggerate when I mentioned that it takes at least 5 years of training (studying Materials Science an Engineering, for example) before you can start using an electron microscope and related equipment in a sensible way.
- So with a little help from me you are going to see *defects* now. Since the defects in the iron crystal turn iron into steel, and since those defects determine almost all the properties of steel, we now must delve into the systematics of defects in crystals.
  - It's actually not that difficult, just a bit mind-boggling. Boggling the mind can be fun, for the boggler and the bogglee. I suspect you do it routinely with a bottle of the good stuff, movies, soccer, football or other sports, not to mention women. Now let's do it with defects.
- Let's start by **defining defects**:

A defect is anything in the crystal that destroys the ideal perfection of the crystal locally

- That sounds a bit pompous in theory but is easy in reality. Just imagine that *you* are one of the atoms in a perfect iron crystal. Have a glass or two of your good stuff and you should have no problem imagining to be an iron atom.

- Now look around you. What you see in a perfect crystal are your next neighbors, eight other iron atoms in precisely determined (average) positions. Those next neighbors are also you, by the way, since all iron atoms are exactly alike. You and your neighbors flit back and forth at high speed because you vibrate if you feel warm so you only see each other as a fuzzy blur.



Being an iron atom

- Now if you see *anything different* from that, it can only mean that a defect is present.
It's clear from that analogy that atoms find defects quite exciting. Defects break the monotony of hanging around all the time with people exactly like yourself. It's the best possible company of course but it gets a bit boring at times.