

6.3 Surprise?

6.3.1 Nirvana once more

Did you get what I did in the preceding chapters? Did you notice that I quietly and unobtrusively *changed the topic*? I moved from *nirvana* considerations to *real* life where nirvana is rarely achieved.

Let's recall: *Nirvana* for all materials, including iron and steel, is this best-of-all states, the best way to arrange your atoms. Or, if you want to read the more *fancy definition* again: the state with the absolute minimum of the "free enthalpy" or simply "thermodynamic equilibrium".

For a piece of *pure* iron, nirvana would imply an infinitely large perfect single crystal containing only the required number of *vacancies* if it has some temperature.

For a piece of carbon steel, i.e. iron plus about 1 wt% carbon in the iron, nirvana would be the basic structure as outlined in the phase diagram. It would consist of a perfect ferrite single crystal with just *one* and then necessarily *big* iron carbide (Fe_3C , called cementite) precipitate in it. No grain boundaries, no dislocations, no nothing—except the required vacancies according to temperature and a very few atomically dissolved carbon atoms according to the phase diagram.

Let's CAPITALIZE this:

**Phase diagrams outline
only the nirvana structure.**

In other words: From the phase diagram we know what (structure-wise) the steel *should* be.

We also know what you *should* be and a lot of people have told me what I *should* be. Worse, some people never tire to tell me this *every day* (Daddy, don't drink so much beer!). The problem is: I'm just *not* what I should be, and I never will be. I suspect the same is true for you.

I do try do improve, however. At least that's what I tell others. But despite strong or feeble efforts, we never seem to quite get there.

The problem is that in order to get more perfect, we must *change* something. This requires some effort and some time. Even if I seriously start dieting, I will not lose excess material over night. It takes time and energy to get results. If you need to lose a lot of surplus you, it takes more time and energy.

How hard we try to get better depends on the magnitude of the "*driving forces*" we experience. If you cough a lot and your doctor tells you that you are developing lung cancer, the driving force for quitting smoking is a lot stronger than when you feel in top conditions.

The grand total of this little consideration is:

- The *path to nirvana* is the interesting part of your existence. It is a *process* that requires change.
- All changes start with a *first step*, and that is often the most difficult part of the process. A little help from the outside can be very valuable.
- Where you will find yourself on the way to nirvana depends on:
 - *How far* from nirvana you presently are.
 - How large the **driving force** is that pushes you there.
 - The *help* or the *obstacles* you might encounter.

I'm not sure if Buddhists would agree with my point of view here as far as *people* are concerned. As far as *materials* are concerned: this is it!

Crystals are no smarter than most humans and behave as outlined above. The big differences to humans are:

- All crystals are equal (really!) under the (second) law.
- All crystals in identical circumstances do exactly the same thing.
- We (meaning a few humans) can calculate precisely what they are going to do. At least in principle, if not (yet) in reality.

Take your average steel crystal. It's a poly crystal for reasons [already discussed](#), and it is full of dislocations for many possible reasons. Maybe because you, the smith, beat it up.

Its surplus carbon may have precipitated. If so, it's certainly not just one big lump but many smaller ones.

In other words: our average *real* steel crystal is not enjoying nirvana at all—just like you and me. It is trying to achieve nirvana, however—just like you and me. It will never quite reach it—just... OK. you get the point. To drive that point home, let's reconfigure the list from above:

- The *way to nirvana* is the interesting part in *processing* steel. The *structure* must change on going there, and for this atoms must *move*.
- All *structural* changes start with initiating or *nucleating* the required structure (e.g. a new lattice type) in some small region. This first step is often the most difficult part of the process. A little help from the outside can be very valuable. I have covered that [here](#).
- Where you will find your steel on its way to nirvana depends on:
 - *How far away* from nirvana is it? (In scientese: How much higher is the "free enthalpy" compared to what it would be at nirvana?)
 - How large is the *driving force* for inducing changes. This is similar to the point above and roughly given by the "distance" to nirvana.
 - Do you have some *help* like vacancies that make the atoms mobile or are there *obstacles* like slag inclusion?

All in all, the pathway of a material to nirvana is a process, too. Things need to change and for a crystal that means that its structure needs to change. This can only happen if the distribution of its atoms changes and that involves that *atoms move*.

[Here we go again](#). But now we know a thing or two and can give the *kinetics* of sword making a closer look.

**The way things change on the way
to nirvana is called *kinetics***

In the preceding chapters I have inched more and more away from just looking at nirvana and moved closer and closer to processes and their *kinetics*. For the rest of this book that will be our main topic. There is a simple reason:

Nirvana is boring!

Did you ever notice that in all medieval paintings depicting heaven and hell, it is always far more lively down in the pit? OK, it's hot and doesn't smell so good but at least there is some action. How long can you take it to sit on a cloud in a white night gown, singing hosanna, and not doing much else? In particular not doing a bit of sinning along the time-honored wine, women and song line? Right. Me neither.

And let's not forget that members of the other sex, who are very pious and close to God / nirvana, are usually boring if not outright useless already in this life for what you may have in mind.

It's the same thing for steel. Nirvana steel is bad steel as far as sword making is concerned. However, steel far off the nirvana state is not necessarily good sword steel either. While there is only *one* proper nirvana state, there are zillions of non-nirvana states and some are better than others for what we have in mind.

It is a little bit like women. Most are not perfect (fortunately) but what kind of non-perfection is best for you depends on what you want to do. Conceive and raise a true-blooded heir? Have an intellectual discussion about gender mainstreaming? Getting your laundry done? Engage into you-know-what, possibly repeatedly, without generating heirs of any kind? That's why in the [good old times](#) the sword bearers often had several ladies in attendance. Nowadays we have at least several kinds of steel.

So what the *modern smiths* Materials Scientist and Engineers need to do, after they figured out the properties that their *women* steel needs to have, is:

1. Figure out what kind of state the steel you want needs to *be* in.
2. Figure out what kind of state the steel you have *is* in.
3. Figure out how to get from here to there,
4. and, being practical, figure out how one gets from here to there *cheaply*. That might mean to compromise a bit, maybe, and getting only *almost* there.

● Unfortunately, this didn't help you, the ancient smith, very much. Mostly because you didn't even know what steel is. What *you*, the ancient smith, needed to do is:

1. Learn and practice for many years, following the time honored "learning by doing and getting kicked in the rear by the master" concept.
2. Do everything *exactly* as taught by your master. Give him gifts. Find a better master if you want to make better swords. Give him more gifts.
3. Hope that the quality of the iron / steel you buy or make is not going down for unknown reasons. Pray a lot. Live a quiet life.
4. If you are the enterprising type, try small variations of the process as you learned it from your master, and then hope for the best. Pray to your God to collect your customers if the swords you made for them proved to be inferior, keeping them from getting back at you. Pray a lot more and bribe somebody
5. If your swords break frequently and your customers survive, run and hide. Pray a hell of a lot, make sacrifices, bribe important people. If you still have money, have a (fitted) sarcophagus made.

▀ What I am are going to do now, schlepping you along if you like, is to look a bit more closely into the *kinetics* of steel making.