1.1.2 The "Why" Questions

- In this Hyperscript I will focus on "**why questions**". I need to take you to the very roots of Materials Science so you can understand the answers. We need to talk about atoms, *why* they stick together to form iron or steel in the structure of a crystal, and *how* defects in this crystal determine some of the important properties of iron. Things like the *second law of thermodynamics*, *phase diagrams*, *precipitates* and *dislocations* will come up.
  - Some of you may not have encountered these fancy words before; some of you might see them as synonymous for "boring" or "things I will never understand". Don't worry, be happy! I will introduce those things patiently, slowly and—**promise!** —*without math*. You will understand to the extent you should, and I will do my best not to make it boring.
    So do not worry about fancy words coming up that you do not (yet) understand. What you should worry about is that you probably don't know the exact meaning of some everyday words like *temperature* or *hardness*.
  - Funny enough, it appears that going to the very roots of those simple *"why" questions* has never been done before for a general, non-specialist readership. Nobody thought it worthwhile to tell you in sufficient detail about swords, metals and steel. There are good reasons for this.

    1. It is not something *easily* done.
    2. There is not much to be gained in terms of *scientific recognition*. My peers in the science community will hardly take notice of what I'm doing here.
    3. Lack of scientific recognition can always be compensated by large amounts of money. But there isn't much money in a hyperscript (or paper book) about iron, steel and swords either.
    4. Some years ago, interest in swords and sword lore was not keen, and active smiths were almost extinct. So why bother?
    5. It's a lot of work and takes a lot of time out of doing science or drinking beer, whatever comes first.

    Item 4 has changed in recent years, about the others I'm not so sure. But it looks to me that the time might have come, when an in-depth hyperscript about iron, steel and swords might be appreciated by enough people to make writing it worthwhile.
  - I do acknowledge some valiant efforts to address the general matter by some scientists. Take, for example, the books of **Rolf Hummel** or **Steve Sass**, two authors I know and esteem. However, they did not go deeply enough into the matter I want to pursue here. This link gives some information about some books I have read and that might benefit you too.
    It also gives a few of the major Internet sources that I used and that are of interest for the whole Hyperscript.

    Science Module

    Books
  - The science behind many everyday topics was never properly explained to a general readership. But interestingly enough, a lot of effort has been made to educate you, the average reader, about far-out stuff like *black holes*, *time travel* through *worm holes*, exotic elementary particles like the *naked bottom quark* (one of my daughters was quite stricken with it), *string theories* in 11 dimensions, or the *big bang* at the beginning of the universe.
    Take "*The Grand Design*", the newest book of **Stephen Hawking**. It is actually frowned upon in the physics community—so why did Steven write it? I don't know but can think of several good reasons:

    - Because it was fun to do.
    - Because being the physics celebrity in polite (but ignorant) society feels good (even if your colleagues give you those looks).
    - Because you feel that it's your duty to educate as many as possible about the subject dearest to you.
    - And, perhaps, because there is a lot of money in any book you write—if you are Steven Hawkings.
  - I let you guess at my reasons for writing this book. Drink (lots of) your favored beverage while you guess, and you may get closer to the truth.
- The "*what is* " questions around iron, steel and swords have been discussed in many *good* books and publications for quite some time, in contrast to the "*why* " questions. A lot of more or less superficial answers have been supplied as well.
  - The emphasize here is on "*good*". I most certainly don't want to imply that a book is automatically bad if it does not address the deepest layers of knowledge about its topic. Just before 1900, for example, **Ludwig Beck** wrote "Die Geschichte des Eisens" (The history of iron). The 5 ponderous volumes still provide for good reading (provided you're fluent in German) even so the author never answers any of the "why" questions from above. He wasn't stupid or lazy; he simply couldn't—the answers weren't in around 1900.

    In the 1962 book of **T. A. Wertime**, entitled "The Coming of the Age of Steel", you will *not* find key words like "*dislocations* ", "*precipitates*" or "*phase diagram"*. The importance of whatever those terms mean for really understanding steel (or just about any metal) was known by then—but only by some scientists, and not yet by the engineers. Nevertheless, Wertime's book still provides for good reading.

- I could go on enumerating and discussing books and articles forever, but I won't. I have made my point. Also, to be honest, I haven't read most of the books about iron, steel and swords that are out there. Nobody has; there are simply too many. I will, however, refer to some of the literature that was relevant for me in footnotes.
  - So please note that I'm not even remotely saying that books dealing on an empirical level with iron, steel and the art of sword making are worthless, outdated, unscientific or wrong, and that it's me, and only me, who gives you the good stuff. Quite the opposite. Some of the people who wrote these books actually might be able to make steel or to forge a sword—in pronounced contrast to me. Many authors certainly know far more about some science issue than I do, for example about the thermodynamics or mechanics of steel. Then there are people who can wield a sword in a fight and thus are far better judges of the fighting quality of a sword than I am.

    On the other hand, many engineers and scientists involved in actually making steel probably know less about the basic principles behind steel properties than I do. The reason is simple. You don't need to know all the fundamental stuff for producing all kinds of steel and to make the most amazing things with steel. Scientific knowledge about iron, steel and just about all other materials emerged in the 19th century and was consolidated no earlier than around 1960. Yet more than 2000 year before that time some artisan-artists already made most amazing steel product: swords.
- Looking at steel before about 1960, one looked at the *empirical* knowledge gained during the last 2000 years or so, plus some insights from classical physics disciplines like mechanics and thermodynamics that emerged in the 17th century. Before (roughly) 1960 only a few theoretical Materials Science specialists (who could not have forged a sword if their live depended on it) knew the fundamental answers to the "why" questions raised above. These guys had some ideas about our topic because they actually discovered the scientific principles that allow us to answers the "why" questions now. Of course, you have never heard their names. You wouldn't even connect scientists whose names you have heard to steel and sword making. **Galileo Galilei** and steel? **Albert Einstein** and steel? Well, we shall see (provided you keep reading).
  - Let me emphasize again that there are still scientists and engineers out there that work with steel but do not know much more about steel then what I'm going to tell you here. They simply don't need to know that for doing their jobs. Understanding iron and steel on the level I will pursue here is not yet going to help you very much in making thousands of tons of steel every day, fine objects like swords or sewing needles, or the landing gear of a Jumbo jet. For making a baby you don't need to know the working of nature on the deepest level either. It might even distract you from your enterprise if you think too much about what the DNA of your sperm (or egg; I'm certainly not writing this only for the males of the species) is going to do in the near future.
- Nevertheless, if you want to get the ultimate answers to the "why" questions, you must go to rock bottom—and down there you find the **atoms**. All properties of steel derive from the way its atoms hang together.
  - So nothing helps. You first need to know a bit about atoms—that they really and truly exist, for example—and some of the tricks involved in making solids by sticking a lot of atoms together. If you don't know about the breakthroughs in science made in the first half of the 20th century, let's say *Albert Einstein* (here he is again!) proving once and forever the reality of atoms, you simply cannot understand the answers to the "why" questions.
    I grant you that it is more fun making a baby than understanding exactly how it comes into being. I don't want to keep you from making babies or just practising it, nor from forging your sword. But it won't hurt to read up a bit on the "theory" of whatever you are doing, whenever you take a break. It actually might be entertaining or just plain old *fun*. Try me.
  - Considering that it takes a while before discoveries in basic physics trickle down to engineering (especially if a world war provides for some distraction), the year 1960 may be seen as a fuzzy starting point for the emergence of Materials Science, the science that investigates and understands properties of all materials (including steel) on the deepest possible level.
- You got it by now. Only by looking at the very atoms that constitute a piece of steel (and anything else) we will be empowered to understand the properties of steel (and everything else) on the deepest and most fundamental level. So what I'm going to do in this book is to look at the atoms. And if I say "look", I mean it.
  - I will ask and answer the "why" and "how" questions that come up as soon as we look at steel from the viewpoint of the atoms in the steel. Going into the depth of this matter, far more "why" questions of a more general type will come up than you would have imagined in your wildest dreams. Why do things melt?, for example. I'm also going to address these deceptively simple questions in some detail.
- Dear reader, I assume that you are not overly familiar with quantum theory, statistical thermodynamics, chemistry, crystallography, metallography, electron microscopy, and all the other topics that are at the heart of "**Materials Science and Technology**", the discipline that deals with topics like steel forging or semiconductor technology. Taking you to the very roots of steel technology without cutting corners thus will not be a quick and easy undertaking.
  - I strongly believe that it can be done, however, and what follows is my first shot at this issue. If you will come with me I will take you on a long and (I hope) fascinating journey to the very roots of our civilization. Because that's what Materials Science and Technology is! Without "technical" materials like wood, fur, leather, flintstone, bronze, iron, and combinations like pianos, Mercedeses, microchips, (I skipped a few development stages), there is no civilization.
    I'll try to make it easy reading. But let's not fool ourselves: it will be an arduous journey with pitfalls and strenuous uphill walks.

- If you make it to the end, you will be wiser but also a bit exhausted. That is only natural. The rewards for your perseverance will include a much better appreciation of the beauty of swords and of the artistry that went onto their making. You will also have a better understanding and appreciation of *all* the many metal things that you use every day (I hope this doesn't include a sword), and of some other key materials like silicon. In short:

You will have a better understanding of your culture.