Glossary

Here is a **Glossary** of some of the more important iron steel and sword related words and terms that come up a lot in the Hyperscript and are either not necessarily known to all and sundry or possibly known but open to misinterpretation.
Far more keywords with links to their appearance in the text can be found in the index
Words given in *red italics* here are words you also find in this glossary.

Basics

Atom
My heartfelt commiseration if you had to look that one up! Here you'll find first help - but you should definitely go and see a professional.

Alloy
A mixture of two or more metals with "sliding" concentrations in contrast to a *compound* with a fixed concentration.
Iron plus carbon in any concentration below about 4 % is an *alloy* called steel or *cast iron*.
If you mix 25 at% carbon with iron (about 6.7 wt%), you have the fixed values needed to form only Fe_3C and that is a compound called cementite and not an alloy. *Cementite* relates to iron just like water relates to oxygen or hydrogen or the IRS to service: not at all!
An alloy is typically called after the element that dominates. On occasion some alloys have a name of their own. Iron alloys are also known as "*steel*" or "*cast iron*".

Austenite
The name for face-centered cubic crystal *phase* of iron or steel, quite different from the body-centered cubic crystal *phase* called *ferrite*, the stuff you typically have at room temperature.
Austenite is named after the eminent scientist William Roberts-Austen. For pure iron and most simple steels it can only exist at high temperatures. Austenite at room temperature is only found in high-alloy "austenitic" steels containing large amounts of e.g. nickel.

Beer
You do know what that is. What you don't know is how important it was and is for the development of iron, steel and swords.

Blast furnace
An iron *smelter* that produces liquid *(cast) iron* or *pig iron* in contrast to a *bloomery* that produces solid iron / steel.
There is no basic difference between bloomeries and blast furnaces except that the latter can be huge and run continuously since there is no need to remove anything from the inside. Everything comes out as liquid.

Bloomery
An iron *smelter*, always small, that produced a *bloom*, i.e. a piece of solid iron / steel, in contast to a *blast furnace* that produced liquid iron.
There is no basic difference between bloomeries and blast furnaces except that the necessity if removing the solid bloom and compacting it by banging it with a hammer necessitated to keep bloomeries small.

Bloom
The more or less spongy mixture of iron / steel with inclusions of *slag*, *charcoals* and other dirt produced in a "*bloomery*", an old-fashioned smelting furnace.
The distinctive feature of a bloom is that its iron / steel was never liquid.

Brass
An *alloy* of copper and predominantly zinc. All other copper alloys are called *bronze*.

Bronze
The generic name for all copper *alloys* beside *brass*. Typically distinguished by prefixes like "phosphorous-bronze". Without prefix it is usually tin bronze.

Brittleness
The opposite of *ductility*. A brittle material cannot be given a new shape by deforming it, e.g. with a hammer. It breaks or fractures if deformation exceeds a certain typically small limit.
Look here for details.

Carbide
A somewhat imprecise name for simple carbon *compounds* like Fe_3C (cementite) SiC (silicon carbide) or many metal carbides like Mo_2C; W_2C, and VC. Carbides tend to be very hard and are part of many steels.

Carbon steel — In principle, you can alloy iron with all the elements of the periodic table. Modern steel does incorporate many elements, indeed.
Carbon as alloying element is very special. For millennia it was the major alloying element (with phosphorous coming second), and even today carbon steel is very prominent because the sum total of the resulting properties often provides for the best compromise between performance and price.
However, the modern term *carbon steel* always "forgets" that there are always sizeable concentrations of manganese and silicon in your carbon steel too.

Cast Iron — The name of all iron-carbon *alloys* with a carbon concentration larger than about 2%.

Casting — Producing a certain shape of some material by pouring the liquid material in a suitable form. Extremely simple in principle, one of the most complex Materials Science and Engineering process in reality. Here is a first entrance into the "why".

Cementite — The stuff that turns iron into carbon steel. Cementite is the name for the chemical *compound* Fe_3C; it is an and iron *carbide*. It forms as a new *phase* all by itself inside your *carbon steel* as soon as the mix gets colder than some specific temperature specified by the *phase diagram*

Charcoal — Rather clean and pure carbon produced by pyrolysis (= heating in an oxygen free / lean environment) of wood. The one and only *reducing* agent available for *smelting* for several millennia.
All about that here.

Coke — Rather clean and pure carbon produced by pyrolysis of (always very dirty) coal.
Used for smelting after charcoal became scarce because most available trees were already cut down.
All about that here.

Composite — Something made from at least two different materials / *phases* on a macroscopic scale (visible without microscope). Examples.
pattern welded swords (2 kinds of steel).
Concrete (stones and cement).
Steel enforced concrete (concrete and steel).
Carbon or glass fiber enforced epoxy (CFC, GFC)

Composition — The quantitative listing of what is inside
Example: Some high-speed steel with a composition of 1 % C, 0.4 % Si, 0.4 % Mn, 4 % Cr, 6 % Mo, 6 % W, 2 % V, and 5 % Co.
This describes an *alloy* since percentages are "sliding", i.e could have other values, and there can be no compound with that exact composition.

Compound — Anything that can be also described as a molecule with a fixed *composition.* H_2O is a compound of 2 hydrogen and 1 oxygen atom called "water", C_2H_4OH is a compound of 2 carbon, 5 hydrogens and 1 oxygen atom called (ethyl) alcohol, and a mixture of water (51%) and alcohol (49 %) is an *alloy* called wodka.

Concentration — How much of something is contained in something else. There are many ways to attach numbers to concentrations, and that leads to a certain amount of confusion. Prominent are

- Percent [%]. If not qualified it always means weight percent [wt%].
- Atom percent [at%].
- Parts per million [ppm]. Always relative to atoms or molecules.
  1 ppm = 0.0001 %

Crucible — A typically small ceramic container that allows to melt metals or to smelt metal *ores* inside it without dissolving, melting or breaking.
Normal ceramics do not make good crucibles; "refractory" materials had to be developed for serious melting / smelting of iron and many other materials.

Crucible steel — Steel produced in ancient times (maybe 400 AD - 1800 AD) in the "East" (India, Sri Lanka, Iran, ...) by processing bloomery iron together with a carbon source in a small *crucible* that could resist very high temperatures. If all goes well the product is a ultra-high carbon steel that was liquid once and thus is free from solid inclusion, in contrast to *bloomery* steel.

Crystal — Any regular arrangement of atoms or molecules in space.

Damascene Technology — A highly confusing misnomer that should not be used. Its usual meaning (especially in German) is the forging of a steel *composite*.

Defects

Any locally occurring deviation from the regular arrangement of atoms / molecules in a *crystal*.

Diffusion

The random movement of atoms inside some ensemble of many atoms. Easy to conceive for a gas, inconceivable inside a solid for centuries.
Diffusion in solids like iron nevertheless occurs, helped by *defects* like *vacancies* and *interstitials*, and provides the key to most if not all of material processing and technology.
I give you a science super link for this

Dislocations

Defects inside the otherwise perfectly periodic arrangement of atoms called *crystal*. The deviation from perfection happens along a (virtual) line that runs throught the crystal.
Dislocations are responsible for much of the material properties that are important for swords (or just about all metal products), in particular *hardness* and *ductility*.

Ductility

The opposite of *brittleness*. A ductile material can be formed into a new shape with a hammer before it finally will crack or break. It will undergo *plastic deformation*
Look here for details

Elastic deformation

Any deformation induced by applying forces (a better word is *stress*) to some objects that is reversible, meaning that the object assumes its initial shape again after the forces / stress is released.
Plastic deformation, on contrast is irreversible; there is a permanent shape change after the deforming stress is released

Elasticity

A dangerous word since it typically mixes up two different things:
1Young's modulus, a measure of how much force is needed to elastically elongate a **standard** sized piece of material a certain amount, and
2. how much force is needed to bend something like a sword blade a certain amount.
In the second case what you get depends on Young's modulus **and** the exact size and geometry of the blade. Materials with a large Young's modulus we call *stiff*; the opposite is *resilient*.
Look here for details

Etching

Generally the dissolution of something in a corrosive liquid.
Here the conditioning of a polished surface by dissolving a little bit in a structure sensitive way ("defect etching"), revealing the *structure*

Ferrite

The body-centered cubic crystal *phase* of iron or steel found at room temperature, quite different from the face-centered cubic crystal phase of *austenite*, the stuff you have at high temperature.

Fire welding

See "*Forge welding*"

Forge welding

Joining two pieces of iron / steel in the forge so it becomes one piece with a hardly noticeable boundary and with both pieces always being solid. This is in pronounced contrast to *liquid welding*, the "usual" type of welding today.
This is one of the many ways of *welding*, also known as "*hammer*" or "*fire" welding*.
Essential are rather high temperatures and a kind of "flux", sprinkled on the hot surfaces before they are welded together by banging with the hammer. Every decent smith can do it; science has not yet quite understood how it works.

Forging

The mechanical shaping of something into the desired form by *plastically deforming* it with a hammer (or modern stuff like roller mills). Forging includes techniques like "*hammer*" or "*fire" welding*.
Until about 1850 the only way to process iron and steel since the stuff could not be *cast* (in contrast to most other metals in use by then).

Fracture

You know the general meaning of the term "fracture". What you may not know is that fracture occurs right after (always small) *elastic deformation* for *brittle* materials and after a more or less pronounced regime of *plastic deformation* for *ductile* materials.
Fracture is sensitive to very small defects in the material.

Fracture Toughness

Simplified, this is just a measure of how much energy is needed to fracture a standard size piece of something. It is easy to measure.
Not simplified, trying to understand fracture toughness is a nightmare.

Hammer welding

See "*Forge welding*"

Hardness

Simplified, hardness is defined (and measured) as the extent to which a given force can press a very hard object (like a pointy diamond) into the material to be characterized.
Not simplified, it measures at what level of mechanical *stress* (the *yield stress*) *plastic deformation* will occur in metals. Rather complex but well understood.

Interstitial

An atom of any kind that is located in the interstices of a crystal structure, i.e. wedged in between the regular atoms. Interstitials are comparatively mobile inside a crystal i.e.. the can *diffuse* easily.
Carbon atoms are interstitials in an iron crystal and that goes a long way for understanding the properties of carbon steel.

Liquid Welding

The "normal" welding where the two pieces to be welded are turned liquid at the seams and the gap filled with liquid metal, too.
In sharp contrast to all solid-state welding (also known as sintering or bonding) and in particular *hammer welding*
One of the most complex processes in Material Science and Engineering; here is why.

Malleability

A material that allows to change its shape with a *mallet* or hammer (= malleus in Latin) is malleable or has a high malleability.
Same thing as *ductility*.

Martensite

One of the several possible manifestations (or "*phases*") of crystalline iron with a little bit of carbon in it (= steel). "Manifestation" means the specific way the atoms are arranged in space.
Martensite is not a particularly "good" way to arrange iron atoms; it only occurs if the steel is not capable to produce its preferred arrangement because you do not give it enough time by cooling it very rapidly ("*quenching*"). Martensite is much harder than the other phases of iron but also quite brittle.

Melting

The simple *phase change* from solid to liquid for a material with just one atom / molecule, e.g. iron. Always occurs at a fixed and sharply defined temperature, the melting point.
Not so simple if you have more than one atom / molecule, e.g. the binary system iron / carbon. That's what *phase diagrams* are about.
Don't confuse with *smelting*.

Nucleation

What needs to happen at the very beginning of a *phase change*. Things don't melt (or freeze) all over all of a sudden, but the new *phase* spreads from tiny nuclei that must "somehow" form first.
Nucleation is typically difficult, helped by defects, responsible for much that goes wrong, and a powerful tool in the tool box for making superior steel and other materials - if you know what you are doing.
I give you a science super link for clarifying the "somehow" above.

Ore

Any compound you find in nature that contains the element wanted, typically as oxide (e.g. hematite; Fe_2O_3) but also as carbonates (e.g. siderite Fe_2CO_3) or sulfides (e.g. pyrite, FeS_2). Ores are rarely pure compounds, but mixes of all kinds of stuff plus "dirt", called gangue.
Unfortunately, rocks that contain traces of **pure** gold or platinum and not their compounds are also called ore

Pattern Welding

Forge welding (also known as hammer or fire welding) at least two different grades of iron / steel in such a way as to produce a pleasing pattern on the *etched* blade. It is such an especially complex way of *piling*.
Often (and wrongly) referred to as "damascening", in particular in Germany.

Periodic table

A way of arranging all 92 or so elements that brings out similarities and relations between the elements.
Elements with similar behavior are always found in the columns of the periodic table; elements with just one proton more or less in the nucleus are next to each other in the rows of the table.
Here it is.

Phase

A word with many meanings. Here it means exclusively a region of space where all physical properties of a material (e.g. density, hardness, chemical *composition*) are essentially uniform.
A clearly defined piece of some specific material in other words.
Graphite and diamond are just two different phases of the material carbon (C), as are water and ice relative to H_2O.

Phase Change
Phase Transition

What happens at certain temperatures for materials. One phase of the same material then changes into one or more different phases.
Example 1: ice (solid H_2O) melts and becomes water (liquid H_2O),
Example 2: water evaporates and becomes steam (H_2O gas)
Example 3: *ferrite* (solid pure iron) changes to *austenite* (solid pure iron).
Example 4: *Austenite* plus 0,5 % carbon (one phase) changes into *ferrite* plus 0.01 % carbon and cementite (mix of two phases called steel).

Phase diagrams

Maps in temperature - *composition* "space" that tell you exactly what you will find at some composition (e.g. iron with 1 % carbon) and some temperature (e.g. room temperature).
The phase diagram also tells you what happens if you go from one point (e.g. iron with 1 % carbon, room temperature) to another one (e.g. iron with 2 % carbon, 1000 ^{o}C). i.e. what kind of phase changes will occur at which temperature.

Photon

The "particle of light whenever light is represented by the particle avatar

Pig iron

The stuff produced by old *blast furnaces*. It is essentially *cast iron* with plenty of dirt.

Piling

Making a large piece of iron / steel by *forge welding* some single pieces with defined *composition* and geometry but without the goal to make a pattern as in *pattern welding*.
Details here

Plastic deformation

A permanent change of shape possible without cracking or *fracture* for *ductile* materials after sufficiently large forces (or better *stresses*) have acted on the object.
What a metal does after being struck by a hammer.
By definition impossible for brittle materials

Precipitates

Small particles of one substance or *phase* (like iron carbides; Fe_3C or silicon dioxide, Si_2O) embedded in a matrix of something else (like iron (Fe) or silicon (Si), respectively).

Quenching

Rapidly cooling something, e.g. by throwing red-hot steel in cold water. How fast the cooling occurs depends on size. Throwing a hot potato in cold water will cool down the skin within seconds but the inside of a large potato is still quite hot after minutes. There is *nothing* you can do about that.

Reduction

Here the opposite of oxidation. Oxidizing a metal produces a metal oxide ("MeO") or some kind of *ore*. Reducing the oxide, typically by the gas carbon monoxide (CO) produced be burning carbon (in the form of *charcoal* or *coke*), produces the metal and something else now oxidized, typically carbon dioxide (CO_2)
MO + CO --> Me + CO_2 in chemical shorthand.

Resilience

A vague term that is the opposite of *stiff*. A steel wire or a rubber band with the same cross section both deform *elastically* for forces not too large. But the steel is rather stiff compared to the resilient rubber; it gives far less than the rubber for the same applied force.
Stiff = large Young's modulus,
Resilient = small Young's modulus.

Second Law

Basic law of physics, subdivision thermodynamics, that states what kind of ("equilibrium") structure a large bunch of atoms present in some given form (for example a piece of steel, a beer, a cubic meter water, you) would assume at some temperature if given enough time.
It's a law that comes in equations so it gives you precise and unambiguous answers (provided you know what the question is and how to do the math).
Your equilibrium structure, by the way, consists primarily of water, some simple gases, and compost.

Segregation

There are many meanings, here I mean exclusively the separation of *defects* or impurities in a solid or during freezing by *diffusion*.
Segregation is what makes casting or any freezing process for something a bit "dirty" incredibly complex. Good for much fun and nightmares in Material 'Science and Engineering.
I give you a science super link for this.

Slag

Liquefied by-products of *smelting*, typically mixtures of oxides, that are not only almost unavoidable but absolutely essential to the smelting of metals.
Here is why.

Smelter

Any contraption that produces carbon monoxide by burning carbon that *reduces* the *ore* it is fed with (typically metal oxides, sulfides or carbonates) to metal and carbon dioxide (or other oxides).
Running a smelter - a *bloomery* or *blast furnace*, for example - involves to feed it (more or less continuously) with the *ore*, carbon (*coke* or *charcoal*) plus stuff for forming good *slag* at the top, to blow in a precisely determined and always large amount of air at the right position around the bottom, and setting the whole thing on fire.
What is going on inside a smelter is rather complicated.

Smelting

The process of *reducing* metal ore to the metal; typically done in a *smelter*.
Don't confuse with *melting*.

Steel

Before very roughly 1800+ steel was the word for an iron alloy with a carbon (or phosphorous) content between about 0.2% and 2.1% by weight.
In our modern world steel is a generic word for a wide range of *alloys* that always contain iron as the main component and many other elements (typically Mn, Si, Ni, Cr, V, ...); sometimes in in relatively large concentrations.
Steel is always a micro *composite*, consisting of different materials just on a microscopic scale.
I gave you a super module for the various kinds of modern steel

Stiffness

Another word besides *elasticity* that needs to be considered with care. Stiff is the opposite of *resilient* and means "had to deform elastically". That may denote a specific material property expressed by *Young's modulus* as a number (stiff then means a "large" number), or the property of an object like a sword blade that can also be expressed as a mix (in a rather complex way) of Young's modulus *and* the precise dimensions / geometry of the object. A "thick" blade is always stfifer than a thin one made from the same steel, for example
So beware!

Strain

What is caused by *stress*. In one dimension strain is simply the elongation of a an object expressed in fractions of the total length and therefore without a formal dimension. A strain of 1 is a length change of 0.01 %.
Look here for details.

Stress

What causes *strain*. It is simply the force applied to a surface divided by the surface area. The (stupid) unit is Newton per square meter called 1 Pascal (Pa)
If you hang me from a rope with 1 cm^2 cross-sections, you have a stress of about **10 MPa**.
Equal stresses cause equal strain in the same material - no matter what its dimensions.
Look here for details.

Structure

The arrangement of the various building blocks of a piece of material. For a simple crystal the structure describes the kind of periodic arrangement of the one kind of atoms encountered (*austenite* or *ferrite*?) plus the kind, distribution and concentration of the defects that live in that arrangement.
In a slightly more complex material like carbon steel it is all of that but separately for the different phases encountered plus the geometry and distribution of these phases
If you want it simple: The structure is what you "see" in a microscope after *etching*.
Here is an example. Now describe it in words.

Tempering

Nowadays it only means to keep some material at some elevated temperature for a while, typically to render the structure a bit less complicated by "annealing" some defects.
Tempered steel was and is steel that has been first quenched, producing extreme hardness coupled with brittleness and then is tempered, decreasing hardness somewhat but brittleness a lot.
In ancient times it meant predominantly the opposite, i.e. more or less rapid cooling by immersion into more less effective and disgusting liquids.

Temperature

You think you know what that is. You are most likely wrong.
Here is why.

True damascene

Describes the pattern on *wootz swords* as opposed to *patten welded* or *piled* swords.
Not a useful term; here is why.

Vacancy

A missing atom in a crystal, easy to conceive. Not easy to conceive is that the *second law* forces all crystals in the universe to produce a precisely determined amount of vancancies under all conditions; with rapidly increasing concentration if the temperature goes up. Even more difficult to conceive is that all material technology depends on these vacancies.
Start to find out why here.

Weldability

The ability to joing two metal pieces by *liquird welding* without suffering intolerable degradation of key properties.

Welding

The term welding without a prefix (e.g. hammer welding) always refers to *liquid welding*.
Weldabiltiy is a key property for many applications and at the same time an extremely complex property wth regard to *composition* and *structure*.

Wootz

There is no unambiguous definition of "wootz" or wootz" steel". Here I use the name "wootz" for ancient *crucible steel* that allows to produce swords with a "nice" *water pattern* consisting of bands of carbide (Fe_3C) precipitates.

Wootz swords — Swords showing a "nice" *watered silk pattern*. Here are details, including the meaning of "*nice*".

Watered (silk) pattern; **Watered steel** — *Wootz swords* with a specific pattern reminiscent of a water surface. Sometimes called "*true damascene*".
Always associated with wootz steel as the material used for making the sword.

Wrought iron — Originally meant as "worked iron", the stuff you get after consolidating a (carbon-lean) *bloom*.
Later the term describes iron rather low in carbon and not yet quite a steel that is easy to work with.

Yield stress; **Yield strength** — The particular *stress* (or the *strain* caused by it) that marks the onset of *plastic deformation*. A rule of thumb is: Stress below the yield stress produces only *elastic deformation*.
For metals the yield stress is the same as *hardness*, just given in different units.

Young's modulus — A simple number that relates stress and strain in the elastic region of deformation.
A material with a large Young's modulus (like diamond, tungsten or steel) is sometimes called *stiff*, a material with a small Young's modulus (like rubber or styrofoam) is sometimes called *resilient*.
Young's modulus has nothing to do with hardness.
Young's modulus of composite materials is essentially a (weighted) average of the two individual numbers.
Iron and all low alloy steels have pretty much the same Young's modulus. *Piling* or *pattern welding* thus does not change the elastic behavior of a blade.