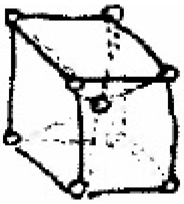
Heat Treating

One-Page heat treating chart (PDF Format)

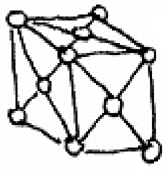
I’m the type of person that needs to really understand something in order to work with it. I don’t like “black boxes.”

When I first started blacksmithing, I had a very difficult time tempering metal – mainly because I didn’t have a clue what I was doing. I knew you had to heat the metal up, then cool it down, then heat it back up again. What’s up with that? It sounds like my wife making fun of the way I make iced tea. First you boil the water to make it hot, then you add ice to make it cold. Then you add sugar to make it sweet, then lemon to make it sour… Like making iced tea, the steps you go through to heat treat metal seem to make no sense.

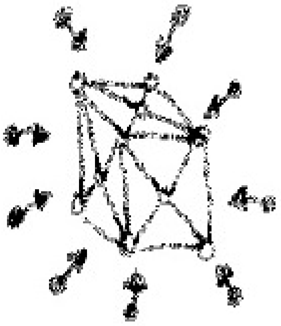
So, with the help of some metallurgy textbooks, some friendly physicists, and some words from Bob Patrick – Master Blacksmith Extraordinaire, I think I’ve finally figured out what’s going on, and it seems to have really helped my tempering skills. Maybe you’re one of those lucky people who can perfect an art without understanding the science. But if you are more like me, maybe you can benefit from my journey. The following is not intended to provide complete safety instructions for tempering metal. It is intended ONLY to provide some information about what is happening inside the metal during this process. Please research and follow all the safety instructions for your equipment and the particular metal alloy you are working with. Some have very unique properties – please be careful!



When pure, molten iron cools into a solid, it wants to form a structure that mineralogists call a “body-centered cubic lattice.” Imagine a bunch of square-sided blocks packed face-to-face, side-to-side, and top-to-bottom. Now imagine that there is a iron atom at each corner where the blocks meet, and another iron atom in the exact center of each block, inside the cube. That’s the body-centered cubic lattice. This structure puts the iron atoms pretty close together, not leaving much room for other atoms to hang out inside the cubes. These stacks of cubic structures seldom run from one end of the metal piece to the other in one unending row. If you could see them, there would be areas where these cubes are all aligned in the same direction, then other areas where the cubes align in different directions, with a jagged borders in between them all where nothing fits together very well. The areas where these cubes run in the same direction is known as a “crystal.” Your work piece will have many crystals – areas where the cubes align in different directions. This is a good thing. If your work was all one big crystal, it would have too much “grain”, and could split very easily.



When you heat iron up to about 1400 degree Fahrenheit (the temperature varies slightly for different alloys, but is about 1360 degrees for the most common high carbon steels), it reaches a “critical temperature” where something really strange happens. All of these body-centered cubic structures suddenly realign to what is know as a “face-centered cubic lattice.” Imagine that same bunch of square-sided blocks packed face-to-face, side-to-side, and top-to=-bottom. As the iron heats up, the cubes grow larger and larger, increasing the distance between each of the iron atoms. At the critical temperature, the atoms in the middle of the cubes suddenly “flop” over to the sides of the cubes, leaving larges areas of open space in the middle of the cubes. That’s the face-centered cubic lattice. When the iron cools back down below the critical temperature, the structure flops back to the body-centric alignment.



If the iron is pure, containing no impurities like carbon, this change in structure is an interesting, but not very useful process. If, however, the metal is mostly iron, but contains between 0.4 and 2.0 percent carbon, something very useful indeed happens. When the metal is heated past the critical temperature and the interior of the cubic structure is opened up, the carbon atoms flow into those voids. Mineralologists call this open cube structure with internal carbon “Austinite”. If the metal cools very slowly, the carbon atoms will squeeze back out of the iron cubes before they revert to the smaller, body-centric structure resulting in what mineralogists call “Martinsite”. If the carbon-saturated cubes cool very quickly, however, the carbon is trapped inside the cubes. This imbedded carbon makes the structure much stiffer. These little iron cubes are crammed full of carbon that really doesn’t fit, but can’t escape. One person I spoke to called this “pregnant iron,” and warned that pregnant iron, like pregnant women, had to be treated with even more than usual care.

If the carbon content is high enough, and the metal is cooled fast enough, the crystal structure can become so stressed that it actually shatters. This is why we cool high carbon steel in oil, rather than water – Oil cools iron slower than water does. This process of using a liquid to cool the iron is called “quenching.” If the metal has very little carbon in it (less than 0.4%, also known as “mild steel”), it can be safely quenched in water, because there isn’t enough carbon in it to cause these structural stresses. Railroad spike labeled HC, for “high carbon”, contain higher than normal carbon content for railroad spikes, but are actually only about 0.43% carbon – just barely heat treatable, and perfectly safe to water-quench. I am told that the railroad uses these spikes in the curves of the tracks, because they are stronger.

Some steels have other trace elements besides carbon in them that can alter the recommended quenching method. I’m ignoring that here because you are unlikely to be purchasing those steels unless you know this stuff in much more detail that is covered by this article. For most beginning and intermediate blacksmiths, our “high carbon tool steel” comes from leaf springs, coil springs, lawn mower blades and the like. Air hardening tool steel is expensive and uncommon. If you are dealing with these alloys, make sure you alter your quenching process accordingly. This article is not intended as an instruction on how to quench. Rather, it is an explanation of what is happening within the metal when these processes occur.

Unless you have some reason to produce easily shattered steel, the brittle structure resulting from oil quenching high-carbon steel isn’t really very useful to you. What you want is something that has enough carbon in it to be very hard and stiff, but not so much carbon that it becomes brittle.

Different applications call for different amounts of carbon within the iron cubic structure. Cutting and engraving tools need to be extremely hard, and have a very high amount of carbon trapped in their cubes. Springs need to be more flexible. You can control the balance of hardness and flexibility by controlling the amount of carbon that gets trapped within the cubic structure. You can also affect this balance by adding trace amounts of other metals, but that is a little beyond the scope of this amateur explanation. I'm only discussing hardness and flexibility, but there are several other properties affected by heat treating such as durability (the resistance to being scratched) tensile strength (the resistance to being stretched), etc.

In theory, you could heat the metal up and control how fast it cooled, allowing just enough carbon to ooze back out of the cubes to achieve the characteristics in the metal that you need. In practice, this is, for all practical purposes, impossible. For one reason, when metal cools very slowly, the interior of the metal remains hot much longer than the surface. In order to get a consistent cooling throughout the metal without going so slowly that you lose all that trapped carbon, you have to cool the metal very quickly.

So, in practice, it is far easier to first cool the metal very rapidly, trapping far too much carbon inside, making it much too brittle to use, then gradually raise the heat again until the iron cubes grow large enough to allow a little of the carbon to escape the cubes. This happens far below the critical temperature. In fact, a controlled heat of around 430 degrees Fahrenheit will allow enough carbon to escape to make a sharp blade hold it's edge(assuming your steel had enough carbon in it in the first place – mild steel has very little carbon and will not harden). A temperature closer to 600 degrees Fahrenheit will allow carbon steel to be very "springy". This re-heating process is known as "tempering." "Heat treating" steel is the process of heating high carbon steel above the critical temperature, quenching it rapidly to trap carbon in the structure, then tempering it to release just enough carbon to create the properties you are looking for.

Modern bladesmiths often use special high-temperature ovens to produce these temperatures, but blacksmiths have been heat treating metal for millennia. They do this by taking advantage of a few unique properties of iron. These tricks were once secrets passed from master blacksmith to apprentice. Thankfully, these secrets are now public domain.

The first trick is how to know when you've passed the critical temperature. You don't need to go very much past it, or to remain at that temperature very long. Doing either of those would risk burning the metal or letting very large crystals grow. By a useful coincidence, there is a relatively easy, low-tech way to tell when you've passed the critical temperature. You see, iron has another useful property you are no doubt well aware of – it's magnetic! If you touch a magnet to it, the magnet will stick. What you may not know is that at 1414 degrees Fahrenheit, iron passes what is know as the Curie Point, and becomes non-magnetic. The Curie Point is totally unrelated to the Critical temperature, but it just happens to be very, very close to it. See the IRON-STEEL TEMP CHART in our reference area. If you take a piece of metal up to where it is no longer magnetic, and you can be pretty sure you've passed the critical point. Most blacksmiths keep a magnet or two stuck to the side of their anvil to help reduce the anvil's bell-like "ring". This same magnet can be used to test for critical temperature. Of course, don't hold the magnet on the hot metal too long, or it could melt, crack, and/or lose it's magnetism.

Another, less accurate way to tell if you’ve reached the critical temperature is to check the color. Critical temperature varies by alloy and carbon content, but is somewhere between bright red and dull orange. this method is not especially accurate, because different people have trouble agreeing on what color something is, and because these colors are hard to see very well unless your forge area is very dark.

The other temperature you need to be able to find is the correct tempering temperature. This temperature depends on the characteristics you want in your work piece. Fortunately for those of us without specialized tempering ovens, iron has another useful property that can assist with this. When hot iron cools, it naturally develops a layer of black oxidation. See our post on oxidation. In many cases, you would want to leave this black coating on the iron, as it helps protect the piece from red rust. If, however, you do remove the black coating after the piece is cool (with a wire brush, grinder, flap wheel, file, etc.), the result will be a pewter-colored shiny surface. If you heat the piece back up, this shiny surface will let you see the tempering colors. Have you ever tried to grind a sharp edge on a piece of metal, and an area turned brown or blue when it got a little too hot? These are tempering colors. They are different than the forging colors. Forging colors are incandescent – they glow in the dark. Tempering colors are iridescent – they look like the colors you see in a thin film of oil on glass.

If your piece has had the black coating removed, and you heat it up, it will do nothing at all until about 430 degrees Fahrenheit. At that point, the shiny surfaces on the piece will begin to turn pale yellow – a color blacksmiths traditionally called “straw”. At this point the piece has lost enough of the trapped carbon to still be very hard, but most of the brittleness is gone. If you keep heating it, it will turn gold, then brown, then blue. Blue occurs at about 600 degrees Fahrenheit, and is about as high as you would want to take it. Any higher and it will lose all it’s hardness (all the carbon has escaped from the cubes).

These colors are actually just a thin surface coating of oxidation. The interior metal has not changed color in any way. If you later polish off this color, you have not ruined the temper of your work.

The color, as we said, is actually caused by the buildup of a thin film of oxidation – the same thing as the black oxidation, only much, much thinner. When this layer is very thin, it will behave exactly like that thin film of oil on water. When light shines on the workpeice, some of the light will be reflected from the surface of the oxidation layer, and some will go through the oxidation and be reflected by the actual shiny metal underneath (this is why you have to create a shiny surface on your metal first in order to see the colors). So the light wavelengths shining on the metal will be reflected back twice, with the wavelengths slightly out of sync. If the layer is just the right thickness, certain wavelengths will be reflected back exactly out of phase – effectively cancelling each other out. This is called “interference”, and is responsible for the tempering colors you see. The thickness of the oxidation layer increases with temperature. At about 600 degrees Fahrenheit, the layer becomes thick enough that most of the colors in sunlight are suppressed to varying degrees by interference – all except the blue wavelength. Hence, you see the color blue on the metal surface. The same is true of the color yellow at 430 degrees, etc.

Most household ovens can reach 450 degrees, and can be used for some parts of the tempering process. After I have heated a work piece to critical temperature and quenched it in oil, I clean off the oil and take a wire brush to it to remove the black oxidation. You don’t have to remove it everywhere, but make sure and at least remove a patch on the areas you are most concerned about. Then I put the piece in an old cast iron skillet and pop it in the oven for about 20 minutes. The work piece doesn’t have to “cook” for any length of time. Once the temperature has been reached, you can remove it. The only reason I leave it in for 20 minutes is to make sure that the heat reaches all the way to the core of the work piece. I don’t want a nicely tempered surface over a very brittle core! If the correct temperature has been reached, your shiny areas should no longer look pewter – they will look slightly golden. If they have no color at all, crank the oven up another ten degrees and try again – household ovens aren’t really that accurate (I have learned that I have to set mine to 440 degrees). If your work turns a dark gold or brown, it got a little too hot for holding a really good edge.

Odds are that you want at least part of your work to be a little less brittle, even if that sacrifices some of it’s hardness. If you are making a knife, only the edge should be super-hard – the core and spine should be much more flexible to keep it from snapping easily. A super sharp sword isn’t much good it it breaks the first time you hit something with it. If you’re making a chisel, you want the cutting edge hard, but the struck end softer. If you are making a spring, you want the whole thing flexible. Maybe it’s my lack of experience, but I find that I pretty much only use two tempering colors – gold for edges and blue for springs or struck ends. Unfortunately, most household ovens don’t go up to 600 degrees, so you have to do that differently.

I usually take the whole piece up to gold first, then, to temper some or all of it up to blue, I’ll grab it right out of that cast iron frying pan with a pair of pliers while it’s still hot, and hold it over the biggest gas burner on my stovetop, cranked all the way up. I’ll turn it and wave it and such to try to get the heat evenly distributed where I want it – keeping any edges that need to stay gold pointed down and away from the flame. The color will gradually darken to blue. Don’t go very fast, or the residual heat will keep creeping toward your gold edge. If the color starts getting away from you, you can quench the piece to cool it down quickly. In theory, this quenching can be done in water, since you are guaranteed not to have added any carbon back into the cubes unless you brought the piece all the way up to glowing red. I haven’t ever tried this, though. I just work slow enough that the color doesn’t spread. If it was that important, I would probably try to quench in oil. That, of course, would need to be done outside. Not only because of the fire danger, but because of the smell. Speaking of which, make sure you get all the oil off the piece before you stick it in the oven or your house will smell like some sort of smelting works.

That’s it! I’m sure the professional blacksmiths, bladesmiths, and metallurgists are groaning and rolling their eyes. I’m sure I’ll get lots of additions and corrections, but that’s fine. All I can say is that this little bit of imperfect and incomplete information about what is going on when you heat treat a piece of high carbon steel has really helped me understand and control what I am doing. I hope that it does the same for you!

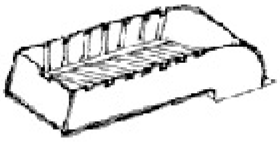
Make sure to check out our reference material on oxidation and our temperature chart while you’re here!

Iron Steel Temperature Chart

This IRON-STEEL TEMP CHART is not exactly a work of art, but it does bring together a wealth of information. Incandescent (glowing) and Iridescent (reflecting) heat colors and what they are good for, magnetic structures and temperatures, critical temperatures of carbon steel, and the various atomic structures of iron. All in one handy page!

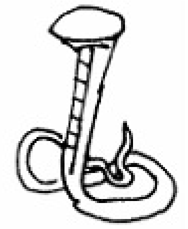
Leaf Veining Hardy Tool

How to make a hardy tool for stamping out leaf prints.



Railroad Spike Snake

Yet another thing you can make from a (legally obtained) railroad spike – a snake!



Rust - Black vs. Red

RUST – BLACK VS RED – LONG

This document describes the different types of iron oxides. It shows why black rust is considered very good and red rust is very, very bad.

CACBOA February 2014 Meeting

The February meeting of the Central Arkansas Chapter of the Blacksmiths Association of Arkansas (CACBOA) was held on February 15th at the forge of Larry Layne, in Sheridan Arkansas.

Larry Layne's Museum/Workshop

Larry's shop is a shrine to human-powered tools. In addition to the brick forge (laid by Larry's lovely wife Scooter), Larry has a couple of rivet forges, two really nice swage blocks, two anvils, three post vices, two post drills, an antique bellows, a spring-pole lathe, and a foot-pedal driven grindstone. There are crosscut saws, brace and bits, axes and tools of every description covering the walls.

Larry is retired, but works at the Grant County Museum in Sheridan as the resident blacksmith. His shop is quite literally a museum in itself. He is particularly interested in the processes and the tools which were used to make quality craftsmanship in the pre-industrial age.

After we insisted on the full tour, we cranked up Larry's forge and tried to use as many of Larry's tools as possible. We tested the new CACBOA chapter anvil stand, which held up just fine under our enthusiastic hammering. We also tested Herman's newly repaired rivet forge, and attempted to make a new handle for his blower – again using Larry's antique tools.

Scooter prepared a delicious lunch of barbeque, baked beans, cole slaw and potato salad back up at the house, which is also filled with antique collections such as powder horns and cast iron cookware.

In the business meeting, we had several people interested in the hammer-making class in April. There was some question regarding what kind of hammers would be made. Personally, I'm looking for a heavy rounding hammer. I don't see anything like that commercially available, and it would be difficult for me to do alone with a gas forge and no power hammer.

We discussed places where we could do demonstrations in order to increase interest and membership, and perhaps sell some items to raise money for some things the chapter needs (like a first aid kit). We discussed the museums in Pine Bluff, Sheridan, Conway, and Little Rock, as well as park events in Saline County (Saline River Bridge Rendezvous), Jacksonville (Reed's Bridge Civil

Ware Battlefield) and Scott (Connection).
February Trade Item – A Corkscrew or Bottle Opener

The trade item was a corkscrew or bottle opener, with several interesting variations. The March meeting place is TBD, with a trade item a forged tool for the forge (shovel, poker, etc.). The April meeting will be at the forge of Thurston Fox, in Mayflower.
– CACBOA Secretary, Robert Fox

February 2014 Meeting Notes - Northwest Chapter

BLACKSMITHS OF ARKANSAS

February 8th, 2014

This month's meeting was at Richard Ross' 'Elbow Holler Forge' in Flippin. We had a great turnout, especially considering the weather we've been having lately.

We had a few new members attending this meeting. Danny Blankenship was able to join us, after meeting several of us at James' shop back in December. Also, John and his son Eoin May both attended for the first time, and placed memberships with us. Eoin spent a good deal of time with Hardy at the forge.

This month's trade item was a pair of tongs. There were several comments made that this was one of the best trade item month's we've had. Every pair of tongs looked great. Bringing a trade item each month is one of the best parts of BOA meetings, and a great way to learn and share your process with other members. Once you see some of the collections of trade items owned by some of our long time members, it really makes you want to be a part of the monthly tradition.

At our business meeting, I was able to provide a few updates on upcoming events. I brought a rounding hammer made by Nathan Robertson, who will be teaching two classes for us the last Saturday and Sunday in April – the 26th and 27th. The first day will be a hand hammer class, which will cost around $75-80, and the second day will be a sledge hammer class, which will cost $100. You don't have to attend both days, but you do have to attend the hand hammer class in order to take the sledge hammer class. More details on this to come, including a location for the class. You will leave the class with a finished hammer, and the cost of the class is lower than the selling price of many of Nathan’s hammers, so it is a bargain!

Also, I was able to get in touch with the Ozark Folk Center in Mountain View. We do plan to have a meeting there later this year. I’m following up on questions related to possible costs to members or their families related to meeting there.

Joe Doster returned the medical kit to me. I plan to take it to future meetings either myself, or in the BOA trailer.

Richard Ross expressed an interest in a 100+lbs tire hammer class, hopefully we can pull together a class if there is enough commitment to it. I was committed to the class until Richard hid my new hammer from me after lunch, and waited until I was good and red faced before giving it back to me. He has now lost any support from me in the future. Ha!

One last note on Harold’s drawing in the last newsletter. My feelings on it… if someone as talented as Harold wants to draw your picture, you let them! And if they draw you with an exceptionally creepy smile, you just live with it. My wife’s only comment was, “Couldn’t he draw me just a little prettier?”

Justin Jones
BOA President

From Ball Peen to Top Set Tool

Instructions for making a top-set blacksmith tool from a ball-peen hammer. New top-sets can easily cost $80 to $120. This flea-market special is just as good, for about $2.