COMPLETE METALSMITH

Tim McCreight

Brynmorgen Press

I hear and I forget.
I see and I remember.
I do and I understand.

—

Chinese proverb

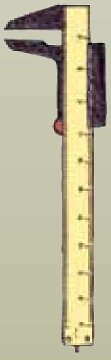
Contents

Introduction

This book represents years of intensive research and experimentation. Information from hundreds of sources has been collected, distilled, and illustrated. It is intended to be both a text and a tool, a blend of instruction and reference. Like other tools, its value increases as you bring to it your own perceptions and skills. It is designed to make the information easily accessible, and built to stand up to years of benchside use.

This book was originally published in 1980, then revised and enlarged in 1991. With the coming of a new century, plans were made to revise it again. The challenge we faced was to deal with two elements that were important to the book's success—thoroughness and ease of use. The question became, "How can we make it basic and advanced at the same time?" The solution was to create three editions, each with its own virtues. This Student Edition gives solid, must-have information that is appropriate for entry level students, hobbyists, and casual metalsmiths. The Professional Edition covers the same material, but goes into greater depth. The ProPlus Edition is a package that includes the Professional print edition plus a CD with the full text rendered as an electronic file. It also includes calculation software, video clips, and two additional books by the same author, *Practical Jewelry Rendering* and *Design Language*.

Metalsmithing involves some chemicals and procedures that are potentially dangerous. Great care has been taken to omit hazards where possible, and to give clear warnings wherever they apply. These will be only as effective as you make them. So, be wise.

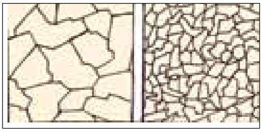


Chapter 1

Metals

Metallurgy

Crystals

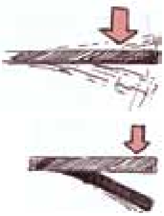


Crystals move most easily within a semi-ordered structure. Crystals at a grain boundary are caught in a logjam with the result that the metal is tough and difficult to work.

When metal is worked, large crystals are broken into smaller ones, which creates more grain boundaries. We refer to such metal as work-hardened. A similar condition is created when metal is rapidly cooled. Because crystals do not have time to grow into an organized structure, the metal recrystallizes into many small grains.

Eventually crystals will realign themselves into an organized lattice. By heating metal we accelerate the movement of atoms and the subsequent recrystallization. This process is called annealing.

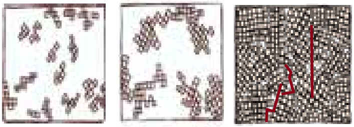
Deformation



When force is applied to a metal, it yields in a process called *elastic deformation.* If only limited stress is applied, the metal will bounce back. There will come a point, though, when the force is enough to permanently bend the metal, a process called *plastic deformation*. Each alloy has unique limits of elastic and plastic deformation.

Recrystallization

When a metal is heated to its melting point it loses its crystalline organization and becomes fluid. When the heat source is removed and the metal cools, it reestablishes its crystal pattern, starting with the first areas to cool. Many clusters of crystals start to form simultaneously, all having the same order but not necessarily the same orientation.



As crystals form, they bump into one another, forming irregular grains. The red line traces grain boundaries.

Annealing

Annealing is the process of reducing stress within metal by heating it to a prescribed temperature with a torch or kiln. Quench a piece in water to cool, then slide it into pickle to dissolve surface oxides. In its annealed state, the crystal arrangement contains irregularities called vacancies. These facilitate crystal movement and so contribute to malleability.

For most jewelry metals, heat to a dull red and quench as soon as the redness disappears.

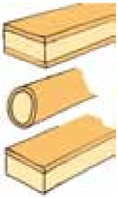
Gold

- Gold was probably the second metal to be worked by early humans, being discovered after copper. Quality gold work can be found from as early as 3000 B.C.
- If all the gold ever found (about 20,000 tons) were cast into a single ingot, it would make only a 20-yard cube.
- One ounce of gold can be flattened to a sheet that will cover 100 square feet, or drawn to a wire almost a mile long.
- Gold can be made into a foil that is less than five millionths of an inch thick. At this point it is semi-transparent.

Gold	**Au**
Melting point	1945° F 1063° C
Hardness	2–2.5
Specific gravity:	
Cast	19.23
Worked	19.29–19.34
Atomic weight	197.2

Gold-filled

This term refers to a material on which a layer of gold has been bonded by fusing. The resulting ingot is rolled or drawn to make sheet and wire. A standard practice is to clad the base with 10% (weight) 12K gold. Since 12K is half pure, this means that the final result, if it were melted down and assayed, would equal 1/20 or 5% pure gold. This is marked as 1/20 GF. This technique has two advantages over plating: a thicker layer of gold can be achieved, and the gold is denser because it has been worked. The term rolled gold refers to a similar material that has only half as thick a gold layer: 1/40.



What karat is it?

Determining karat requires a testing kit:

- nitric acid and aqua regia
- metal samples of known karat
- touchstone (slate or ceramic)

Rub the object to be tested on the stone (called "touching") to leave a streak. Make a parallel line on the stone with one of the test needles. Flood both marks with acid and observe the reactions. When the two streaks change color at the same rate, a match has been made. Nitric acid is used for low-karat golds and aqua regia is used for high karats.

Silver

Silver	**Ag**
Melting point	1763° F
	961.7° C
Hardness	2.5
Specific gravity	10.5
Atomic weight	107.88

Sterling.925	
Melting point	1640° F
	893° C
Specific gravity	10.41

Sterling

Sterling is the alloy most commonly used in jewelrymaking and silversmithing. It was adopted as a standard alloy in England in the 12th century when King Henry II imported refiners from an area of Germany known as the Easterling. Coin silver, an alloy once used in currency, contains more copper (10% to 20%) than sterling. It melts at a lower temperature than sterling and is more likely to tarnish. A 90% alloy was used in U.S. coins until 1966 but now no silver is used in any U.S. coin. An alloy popular in the Far East uses 90–93% silver and the balance zinc, producing a metal with a low melting point and a bright, white shine.

In recent years a number of alternate sterling alloys have been patented. Most replace a small amount of the copper with a metal that is less likely to oxidize such as tin, germanium, zinc, or platinum. These alloys are commonly used in casting but have not become widely available as sheet and wire.

Argyria

Argyria, a condition caused by ingesting silver, is evidenced by a blue or blue-gray skin color. Until the 1950s silver was used in several medicines, and it is still sold as a miracle cure for such ailments as leprosy, plague, and anthrax. In 1999 the Food and Drug Administration prohibited sellers of colloidal silver preparations from making claims about health benefits.

Electrolytic Cleaning

This kitchen version of electrostripping is especially useful for removing tarnish from flatware. Line a pot with aluminum foil and stir in ¼ cup of baking soda, salt, and liquid soap with enough water to cover the objects. Set the sterling in the pot, bring the mix to a simmer and allow it to stand for at least 20 minutes. The oxides will be transferred to the aluminum, which you'll see is darkened. Throw that away and wash the silver before using it.

Copper

History

Copper was probably the first metal to be put to use by our ancestors and remains important to us today. It conducts heat and electricity very well, can be formed and joined, and combines with many elements to form a broad range of alloys.

8000 BC	Copper was discovered.
6000 BC	Egyptians used copper weapons.
5000 BC	Beginning of the Bronze Age.
3800 BC	Evidence of controlled bronze alloying.
2750 BC	Egyptians made copper pipes.

Copper	**Cu**
Melting point	1981° F 1083° C
Hardness	3
Specific gravity	8.96
Atomic weight	63.5

Copper is available in more than 100 alloys. Comprehensive data is available from:

Copper Development Association
260 Madison Avenue
New York, NY 10016
212–251–7200
www.copper.org

Commercial Copper

- Copper is sold in standard sheets 36"x 96" (3' x 8') and in coils 12 and 18 inches wide. When ordering, specify Hard, Half-hard, or Annealed.
- When copper is hot-rolled it develops a slightly rough surface. For this reason most craftspeople prefer cold-rolled material. Copper alloy #110 is a common choice.
- Copper cannot be heat-hardened, but responds to work-hardening.

Japanese Alloys

Shaku-do 0.5% to 4% gold, balance copper.
Melting point 1968–1980° F (1070–1082° C).

This alloy is valued for the deep purple color achieved through oxidation.

Shibu-ichi 75% copper, 25% silver.
Melting point 1775° F (968° C).

This is a silvery pink alloy that darkens and reticulates easily.

Brass & Bronze

Yellow Brass	**26 0**
Melting point	1750° F 954° C
Specific gravity	8. 5

Jeweler's Bronze	**226**
Melting point	1886° F 1030° C
Specific gravity	8.7

Brass Facts

- Brass is an alloy of copper and zinc and it can achieve a wide range of properties and colors.
- The practical limit of zinc in a copper alloy is 42%. Beyond this, the alloy becomes too brittle for most uses.
- Low zinc brasses that contain up to 20% zinc are grouped under the term "gilding metals."
- Brass is mildly antibacterial.
- The bronze of antiquity was a mix of 10–20% tin with the balance being copper. Today the term bronze refers to any tin-bearing brass or golden-colored brass.
- To distinguish brass from bronze, dissolve a small sample in a 50/50 solution of nitric acid and water. Tin is indicated by the white precipitate, metastannic acid.

Common Alloys

Gun Metal	Historically an alloy of 88% copper, 10% tin, and 2% zinc, it was used to cast cannons and large industrial products.
Pinchbeck	An alloy of about 83% copper and 17% zinc invented by the English watchmaker Christopher Pinchbeck in England around 1700. It resembles gold and was used to make costume jewelry and inexpensive accessories. By extension, the word has come to mean "cheap imitation."
Nordic Gold	Alloy of 89% copper, 5% aluminum, 5% zinc, and 1% tin that is used for euro coins.
Bell Metal	An alloy of roughly 80% copper and 20% tin, used for, you guessed it, bells. It makes a rich tone when allowed to vibrate but is notoriously brittle when the blows are confined. For proof, visit Independence Hall in Philadelphia.

Nickel & Aluminum

Nickel	**Ni**
Melting point	2651° F
	1445° C
Specific gravity	8.9
Atomic weight	58.69

Nickel Silver

Copper	60%
Nickel	20%
Zinc	20%

The term "nickel silver" refers to several alloys with roughly the proportions shown above. The alloy was originally developed in the Far East and came to be known as Paktong (a.k.a. Pakton, Pakfong, Paitun, Baitong, Baitung, and other derivations). Other names include Alpacca, Argentium, Electrum, Stainless NS, and Nevada Silver. Nickel silver gained in popularity after 1840 when electroplating created a need for an inexpensive silver-colored substrate. This origin can still be seen in the abbreviation EPNS which stands for electro-plated nickel silver.

This metal is used in jewelry because of its low cost and generally favorable working properties. It can be forged, stamped, soldered, and polished. Though it can be cast, its high melting point and tendency to oxidize make casting difficult.

Common Alloys

Other alloys that contain nickel are Monel Metal, Nichrome, and Nickel Alloy #752.

Aluminum	**Al**
Melting point	1220° F
	660° C
Specific gravity	2.7
Atomic weight	26.97

Properties

Aluminum is the most abundant metallic element on the planet, making up 8% of the earth's crust. Because of its light weight, resistance to corrosion and ability to alloy well, it is used structurally (buildings, aircraft, cars), as architectural trim (siding), and in functional objects like cookware. It is the second most malleable and sixth most ductile metal. It is usually found in bauxite as an oxide called alumina: Al_2O_3.

Joining

Aluminum can be soldered and joined only with special solders, many of which are sold with their own flux. Welding can be done with 43S or #717 wire used with #33 flux. Check with your supplier for detailed information. Welding is made easier with a TIG (tungsten inert gas) welder, but can be achieved with gas/oxygen systems.

Anodizing

This is a process of electrically causing the formation of a resistant oxide film on the surface of aluminum. This porous, nonconductive layer can be colored with dyes.

White Metals

Britannia Metal	
Melting point	563° F
	295° C
Specific gravity	7.4

Health & Safety
The fumes produced by these metals are potentially unhealthy. Lead can be absorbed through the skin. Wash after handling any lead-bearing alloy.

White Metals

The term "white metals" refers to several malleable, gray-colored metals and alloys with low melting points. These are also called *easily fusible alloys, pot metal,* and *type metal*, the latter coming from the use of these alloys in making printers' type.

Because of their low melting points, white metals can be melted with almost any torch or on a kitchen stove. Melting is best done in a small-necked crucible or ladle to help reduce oxidation. Protect the metal from oxygen during melting with a coating of olive oil, linseed oil, or lard. These float on the surface of the melt and will slide out from underneath when the metal is poured.

Pewter
Pewter, as used in antiquity and associated with colonial America, was an alloy of lead and tin. In the late 1700s a substitute alloy was developed in England and named Britannia Metal. Today the words pewter and Britannia are used interchangeably and usually refer to an alloy of 91% tin, 7.5% antimony, and 1.5% copper.

Pewter can be sawn, soldered, fused, formed, and cast. Keep separate tools for pewter and don't let filings accidentally mix with silver or gold. Finishing can be done with fine steel wool and a mix of lampblack (soot) and kerosene blended to a paste. Fine steel wool (4/0) also leaves a pleasant finish.

Contamination
When heated above their melting points, white metals will burn pits into gold, platinum, silver, copper, and brass. Use separate files and soldering tools to keep these metals away from each other.

Removal
To remove white metal that is fused onto sterling or gold, file, scrape, and sand to remove as much of the white metal as possible, then allow the work to soak in this solution overnight.

3 oz. glacial acetic acid
1 oz. hydrogen peroxide

Iron & Steel

Mild Steel
Melting point 2759° F
1515° C
Specific gravity 7.86

Iron **Fe**
Melting point 1535° F
2793° C
Specific gravity 7.9
Atomic weight 55.85

Hardening Steel

Not all steel alloys can be hardened; only steels with 1.5% to 3.0% carbon will work. Hardening is a two-step process. First, heat the object to a bright red (called the critical temperature) and quench it in the appropriate media, most commonly oil. This leaves the steel in a hard but brittle condition. In the second step, called tempering, heat the steel to temperatures between 400–600° F (200–300° C), depending on the desired balance between hardness and flexibility. An alternate method, called case-hardening, diffuses carbon into the outer layers of mild steel to create a thin shell that can be hardened.

0.15–0.3% carbon	mild (low) carbon steel	cannot be hardened
0.3–0.5% carbon	medium carbon steel	used for tools
0.5–1.6% carbon	high carbon steel	specialty tools
> 2.5% carbon	malleable iron	for cast and machined parts

Properties

Iron is the world's most widely used metal. It can be alloyed with a wide range of elements to produce many diverse properties. Iron ore usually contains sulfur, phosphorus, silicon, and carbon. When all but 3–4% carbon has been smelted out, the resulting metal is poured into ingots and called cast iron or pig iron. Further refining is necessary to make a steel of good working qualities.

Metals Used for Steel Alloys

- Chromium increases corrosion resistance; 10–20% is used in stainless steel.
- Manganese increases hardenability and tensile strength.
- Molybdenum increases corrosion resistance; high temperature strength.
- Tungsten forms hard abrasion-resistant particles called tungsten carbide. It is used for cutting edges.

Reactive Metals

Titanium	**Ti**
Melting point	3047° F 1675° C
Specific gravity	4.5
Atomic weight	47.9

Niobium	**Nb**
Melting point	4474° F 2468° C
Specific gravity	8.57
Atomic weight	92.91

Reactive Metals

This term refers to a group of six tough, gray metals that are lightweight, have a high melting point, and are resistant to corrosion. In order of importance, they are titanium, niobium, tantalum, zirconium, tungsten, and hafnium. The first two are of interest to jewelers principally because of the colors produced by their oxidation films. The others are included in this group by scientists but are not important to jewelers.

Working Properties

Titanium and niobium cannot be soldered or annealed in the jeweler's studio but both metals lend themselves to all other traditional processes. They can be drilled, filed, drawn stamped, or raised, with conventional tools. Pure titanium is ductile and shows low thermal and electrical conductivity. It is twice as dense as aluminum and half as dense as iron. Its resistance to corrosion, combined with light weight and toughness, make it well-suited to use in prosthetics. It is added to steel to reduce grain size, to stainless to reduce carbon content, to aluminum to refine grain development, and to copper to harden it.

Titanium

Titanium is the ninth most abundant element in the earth's crust and can be found in most rocks, clay, and sand. It was first identified in 1791 but has been commercially viable only since 1947 when the Kroll refining process was invented. Titanium dioxide is a white powder used in paints and enamels.

Niobium

Pure niobium is soft and ductile and polishes to look like platinum. It is more plentiful than lead and less common than copper. Niobium is extremely ductile. This property can be a drawback for applications where strength is required.

When this metal was first discovered in 1801 it was called *columbium*, but it was rediscovered and renamed in 1844.

Chapter 2

Tools

Handtools

Anyone reading this book already knows about tools, knows about the timeless and universal appeal of the Right Tool. The handtools of our field impart a wisdom that traces its roots not to brilliant thought but to a genius of touch.

Value in handtools falls into several categories: design, quality, and spirit. The first two are somewhat objective, while the last is clearly up to you. Duke Ellington said about music, “If it sounds good, it is good,” and the same thing applies here. If it feels good and works well, it’s the right tool for the job.

Rulers

- Work in lighting that does not cast shadows.
- Do not take measurements from the end of a ruler. It could be worn and therefore inaccurate.
- The smallest division of any ruler is printed near one end.

Gauge Plate

This is a thick piece of steel cut with slots of specific size. It measures both sheet and wire in the Brown and Sharpe system (also called American Standard and American Wire Gauge, AWG). The other side often shows thousandths of an inch.

To use a gauge plate, find the slot that makes a snug fit, but don’t distort the metal by jamming it in. Be careful not to measure where the edge has been thinned by planishing, or thickened by shears.

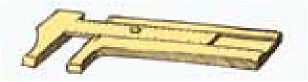
Degree Gauge

In this spring-activated tool, the size of the opening at the top is indicated by the scale at the bottom.

Dividers

In addition to making circles like a compass, the dividers can be used to hold a measurement for quick reference. Another use is to lay out parallel lines by dragging one leg of the tool along the edge of a piece of metal.

Sliding Calipers

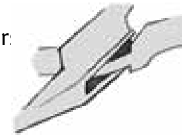


A casual tool like this brass model should not be used for extreme precision, but it is handy for quick reference. Other sliding calipers are equipped with digital readouts or precise gauges. These can be as accurate as a micrometer.

Pliers & Snips

Standard Pliers

Pliers come in several grades and a couple sizes. The word *watchmaker* indicates a smaller than average plier. Generally the higher the cost, the better the steel and manufacture. Box joints (which trap one piece inside the other) are preferred over the weaker lap joint.



Specialty Pliers

Pliers can be purchased or modified in the studio to deliver specific results. Here are a few possibilities.

- To make a large version of a round-nose pliers, solder short pieces of copper or brass pipe onto pliers. Some filing of the jaws might be needed to make a good fit. For softer work, epoxy short pieces of plastic pipe.
- Sometimes the width of pliers is not exactly the right width for a design. Solder a piece of steel, nickel silver, or brass into a notch cut in the pliers.

Ring-Forming Pliers

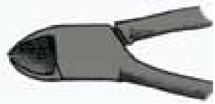
One of the most versatile and effective specialty pliers has one flat and one curved jaw. These have the advantage of a curved bending mandrel matched with a flat tangent face. Note how this differs from round-nose pliers, which focus energy at a single point, almost always making a dent on the convex side of a bend.

To make standard ring-forming pliers, file, then sand one jaw of a flat-nose pliers. To make a larger version, solder a curved piece of brass, nickel silver, or steel to one jaw of a large pair of pliers.

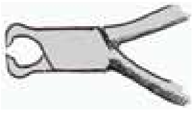
Snips

Snips cut by creating stress that breaks the molecular bonds of the material.

Side cutters: most familiar, all-purpose wire cutter.



End cutters: designed to reach into tight corners, usually more delicate, so not recommended for thick wires.

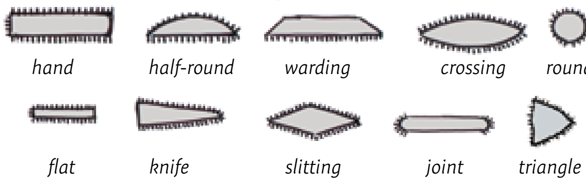


Sprue cutters: compound action device that provides increased leverage.

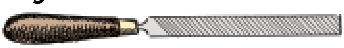
Saws & Files

Nomenclature

American-made files use the names rough, bastard, second cut, smooth, and super smooth. Foreign-made files (called "Swiss" files), are graded by number from 00 (coarsest) to 8. American-made files that emulate high quality files are called *Swiss Pattern* files.

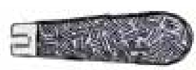


Length



Hand files are described by the length of the working area, usually 6, 8, or 10 inches. Needle files are described by their total length.

Handles



Files should be equipped with handles to provide increased leverage and to protect your hand from being poked by the tang.

Sawframes

The principal difference between frames is the distance from the blade to the back. Smaller frames (3–4") are easier to control, but you might need a larger frame for large-scale work. Cheap sawframes are false economy because they result in broken blades and wasted time. (This is also true of cheap sawblades.) To improve gripping comfort, slide a foam bicycle handgrip over the saw handle.

Blades

The teeth of a sawblade are angled outward alternately in a pattern called the set. This allows the corner of each tooth to engage and shear off a chip. The chip is then passed along the tooth and ejected out of the cut. When a sawblade is dull, it is usually because the set has worn away.

Blade Size

When three teeth engage the metal, the first one cuts on the left, the next tooth cuts on the right, and the third tooth keeps the blade running straight. If the blade is too small for the metal being cut, it is more likely to break. If the blade is too large, it will cut with a jerky motion.

Drills & Drilling

Safety

At the moment the cutting edge breaks through the underside of the piece being drilled, there is a tendency for the bit to snag. To avoid this, always start with a small bit and progress sequentially to larger bits. Even better, drill a small hole, then use a saw to enlarge it.

General Rules for Drilling

- Run the drill slowly.
- Avoid wiggling.
- Keep the bit at a constant angle.
- Let the bit do the work; don't push.
- Avoid creating friction heat; lubricate with beeswax, oil of wintergreen, or Bur-Life.

Drills

Pin Vise

For light use, grip a bit in a pin vise or glue it into a dowel. The tool will be more comfortable to use if it has a freely rotating knob on top, like the example shown here on the left.

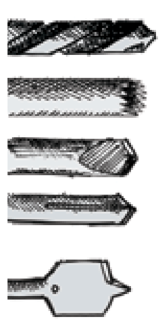
Electric

Many jewelers use electric and battery-pack drills or flexible shaft machines to drill holes. While these are hard to beat for ease, care must be taken not to run them too fast. Whenever possible, a drill press is preferred over a handheld model because it guarantees a perpendicular angle of attack.

Step Bit

A step bit is a single tool that accomplishes this without spending a lot of time changing bits. These can be purchased in several ranges, and while they are expensive, they can pay for themselves in saved time... and saved fingers.

Drill Bit Styles



Twist

Core

Pump

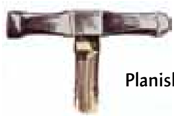
Pearl

Spade

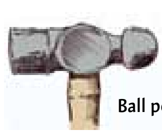
Hammers & Mallets

Hammers

The heart of the metalsmith's shop is in the hammers. In fact the word "smith" is derived from the verb "to smite" which means "to hit." While only a couple hammers are needed to get started, most smiths collect specialized hammers as their shops grow. Metalworking hammers can be bought new, but many smiths acquire and alter old hammerheads to suit their needs.


Planishing


Forging


Ball peen


Claw


Chasing


Riveting

Mallets

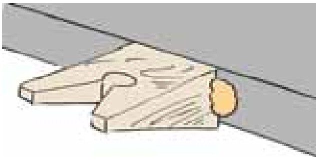
Tools in this family will bend metal without stretching or marring it. Probably the most popular material for mallets is treated rawhide. Other choices include wood, horn, fiber, plastic, and rubber. A popular material for raising mallets is Ultra High Molecular Weight (UHMW) plastic, which is rigid and inexpensive.

Deadblow Mallets

Most hammers bounce back, a phenomenon that makes the blow seem alive. This style of mallet is designed to kill the recoil, hence the name. A deadblow mallet has a hollow interior partially filled with sand or small pieces of a heavy metal like steel or lead. A split second after the blow is delivered, this mobile weight slams against the recoil and cancels it out.

Bench Accessories

Bench Pin

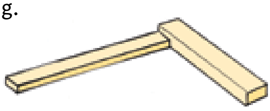


Any hardwood can be used to make a bench pin. This shape is a common starting place, but in practice the pin is filed, drilled, and carved to meet specific needs. You might find you want different interchangeable pins to meet a variety of specific needs.

Avoid drilling holes in the bench pin because they trap metal and eventually make the surface irregular. Keep a block of wood handy for drilling. An exception to this is a few well-placed holes that make it possible to work on objects with pinbacks and similar projections.

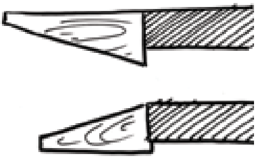
Squares

A small square can be made from steel or brass rod. One side is thicker than the other to allow the square to rest against the item being marked. File a notch and solder the pieces together carefully. Test against a commercial square, and if it is not right, reheat and adjust. Do not try to fix by filing.



Which Side Up?

Many people flip the pin over depending on the work being done—flat for sawing and sloped for filing. A variation on this is to create a sloped edge on the flat side.



Bench Knife

A knife can be improvised by grinding and resharpening a kitchen paring knife. These can often be bought at flea markets.

Scraper

A scraper can be made by breaking off an old triangular file and grinding a point. Faces should be ground smooth and polished.

Saw Blade Holders