COMPLETE METALSMITH

Tim McCreight

Brynmorgen Press

Acknowledgments

So many people contributed to this book that it is impossible to mention them all. The students I've worked with in college classes and at workshops have helped clarify many of the descriptions. I owe a huge debt to the generous authors whose books have been so valuable in my professional life. With each new edition of this book I have been privileged to call upon a wider circle of colleagues, too many, in fact, to name.

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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. The 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

Materials

Metallurgy

Metallurgy is a complex, highly technical field that is worthy of our attention. It is helpful for a metalsmith to understand the structure and behavior of metals because this can help explain events in the studio.

Crystals

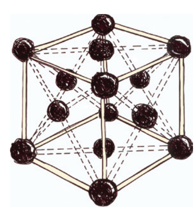
Metals exist at room temperature as crystals, regularly shaped units arranged in an ordered recurring pattern called a space lattice. There are 7 crystal systems and 14 lattice configurations. Here are the three lattice arrangements most relevant to metalsmiths.

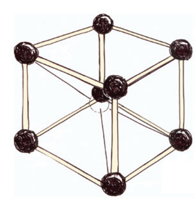
It is not a coincidence that easily worked metals share the same crystal structures. Crystal shape is one factor that determines malleability.

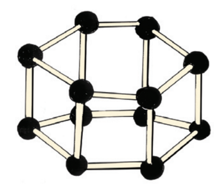
Face-Centered Cubic
lead
copper
aluminum
gold
silver
nickel
iron (at high temps)

Body-Centered Cubic
chromium
lithium
molybdenum
potassium
sodium
vanadium
iron (at room temp)

Hexagonal Close-Packed
beryllium
cadmium
cobalt
magnesium
titanium
zinc

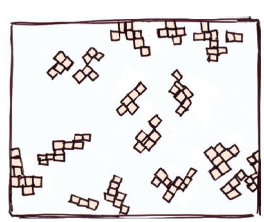




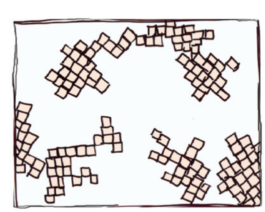


Recrystallization

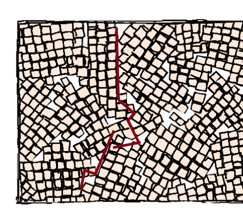
When a metal is heated to its melting point it loses its crystalline organization and becomes fluid. When the heat source is removed and the metal cools, it re-establishes its crystal pattern, starting with the first areas to cool. Many clusters of crystals start to form simultaneously, all having the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



Crystals start to form as the metal cools.



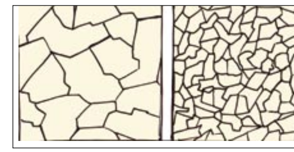
As they grow, crystals bump into one another, forming irregular grains.



Solid metal; the red line traces grain boundaries.

Metallurgy

Crystals



annealed *work-hardened*

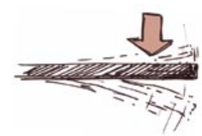
Crystals move most easily within a semi-ordered structure. Crystals at a grain boundary are caught in a "logjam" with the result that the metal is tough and difficult to work.

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.

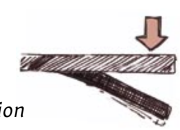
In time, even at room temperature, crystals will realign themselves into an organized lattice. By heating the metal we accelerate the movement of atoms and the subsequent recrystallization. This process is called annealing.

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.



elastic deformation



plastic deformation

I am trying to check my habits of seeing, to counter them for the sake of greater freshness. I am trying to be unfamiliar with what I am doing.

John Cage

Annealing

Annealing is the process of reducing stress within metal by heating it to a prescribed temperature. This can be done with a torch or kiln. Temperatures are usually gauged by watching the heat colors change, something best seen in a dimly lit area. Alternatively, paste flux can be painted onto metal to serve as a temperature indicator: it is clear at 1100° F (593° C). 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.

> Heat to a dull red; quench as soon as the redness disappears.
- 14K gold
- 10K gold
- red golds
- sterling
- fine silver
- copper

> Heat to medium red; quench as soon as the redness disappears.
- bronze

> Heat to bright red; air cool.
- white gold (nickel-based)
- brass

Gold

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

- 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.
- Pickles for gold include Sparex #2 or a mixture of 1 part nitric acid (reagent grade) with 8 parts water.
- Gold dissolves in aqua regia and solutions of chlorine with potassium cyanide or sodium cyanide.

Purity of Karats

Fine (pure) gold is too soft for most uses so it is alloyed with other metals to achieve a desired hardness. During this process the color, malleability, and melting point can also be altered. Silver and copper are the two most common additives but many other metals can be used.

The relative amount of gold in an alloy is called the karat. This word signifies proportion and should not be confused with carat, which is a unit of weight (except in the UK, where both words are spelled with a “c”). Think of karat as a fraction with 24 as the denominator, e.g., 18K—eighteen-twenty-fourths, or ¾. This tells us that the alloy is 75% gold. By law, a metal described as 18K must be at least 75% gold. The remainder of the alloy is not restricted by law, which only specifies the proportion of precious metal.

Fluxes

When pouring gold ingots, sprinkle an even mixture of powdered charcoal and ammonium chloride (sal ammoniac) on the metal while melting. This will yield a bright, tough ingot that will withstand rolling. Dangerous fumes are produced, so ventilation is required.

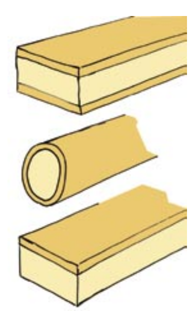
If iron or steel is present (for instance as a result of file wear), purify the scraps by melting with a flux of 1 part potassium nitrate (saltpeter) and 2 parts potassium carbonate. After cooling, remelt with the sal ammoniac flux and pour the metal into a mold.

Voluntary Product Standard 70–76

This US law has set legal tolerances for gold since 1976. It allows variation of 3 parts per thousand (.072K) on unsoldered goods and 7 parts per thousand (.168K) on soldered objects. This is called plumb (i.e., accurate) gold. Manufacturers were given until 1981 to dispose of their old merchandise made at lower standards.

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 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.



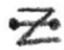
Scientific Notation

An alternative system describes the precious content in parts per thousand (ppt), typically written as a decimal. An alloy containing ¾ gold becomes 750/1000 or .750 or Au 750. Here are some common decimal equivalents.

Au 950	22 ¾ karat	95% gold
Au 900	21 ¾ karat	90% gold
Au 800	19 ¼ karat	80% gold
Au 750	18 karat	75% gold
Au 650	15 ¾ karat	65% gold
Au 583	14 karat	58.3% gold
Au 417	10 karat	41.7% gold

Gold

Alloys



Electrum

- A mixture of roughly equal parts of gold and silver is called electrum. Maximum hardness of this alloy is at a 50/50 mix.
- The hardest alloy of gold, silver, and copper is reached at 50/25/25. This will be 12 karat yellow.
- An increase of the copper content in a gold alloy up to 18% will lower its melting point. To continue lowering, as when making solder, add silver.
- Many kinds and colors of gold solder are commercially available, but in a pinch, a lower karat gold may be used.
- White gold usually has 10% to 20% nickel and can contain zinc, copper, or manganese. It has no silver.

Decimal Equivalents

1 K	.0417
2 K	.0833
3 K	.1250
4 K	.1667
5 K	.2083
6 K	.2500
7 K	.2917
8 K	.3333
9 K	.3750
10 K	.4167
11 K	.4583
12 K	.5000
13 K	.5417
14 K	.5833
15 K	.6250
16 K	.6667
17 K	.7083
18 K	.7500
19 K	.7917
20 K	.8333
21 K	.8750
22 K	.9167
23 K	.9583
24 K	1.0000

Testing

With a small file, make a scratch in an inconspicuous spot. Wearing rubber gloves, use a wood, glass, or plastic stick to apply a drop of nitric acid to this spot. Observe the reaction. When done, rinse everything well in running water.

› no reaction	gold
› bright green bubbling all over	base metal
› green only in scratch	gold layer over base metal
› milky in scratch	gold over silver

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.

Formulas

Alloying Down (to lower karat)

1. Multiply the amount to be lowered by its karat.
2. Multiply the same amount by the desired karat.
3. Subtract the amount you found in Step 2 from the amount in Step 1.
4. Divide the difference (Step 3) by the desired karat.

Alloying Up (to raise karat)

1. Multiply the amount to be changed by its karat.
2. Multiply the same amount by the desired karat.
3. Subtract the amount in Step 1 from the amount in Step 2.
4. Subtract the desired karat from 24.
5. Divide the answer to Step 3 by the answer to Step 4.

Silver

Silver	Ag
Melting point	1761° F 960.5° C
Hardness	2.5
Specific gravity	10.5
Atomic weight	107.88
Sterling	**.925**
Melting point	1640° F 893° C
Specific gravity	10.41

Silver

Silver, known in the ancient world as argentum, was at one time thought to be more precious than gold because it appeared less commonly in nature. Pure silver, like pure gold, is soft and is therefore often alloyed. Though many metals may be used, copper is preferred because it greatly toughens the alloy without detracting from the bright shine of silver.

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. The product they made was of a consistent quality and was used as currency by 1300, when it was known as Easterling silver.

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 US coins until 1966 but now no silver is used in any US 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.

Britannia Silver

Britannia silver (958.3 parts per 1000) was the legal alloy in England from 1697 to 1719. It was contrived to discourage the melting of coins and is still a legal alloy there. Don't confuse this with Britannia Metal, which is a form of pewter.

Silver resists aqua regia because hydrochloric acid forms a dense chloride film that resists corrosion.

Strength

Annealed fine silver has a hardness of Vickers 26 (tensile strength of 9 tons per square inch). Cold working increases the hardness to Vickers 95–100 (tensile strength of 20–22 tons per square inch).

Silver

Heat Hardening

In conventional work-hardening, metal is made rigid by upsetting the orderly arrangement of grains. A lesser degree of toughness can be achieved by reducing the number of dislocations and vacancies, that is, by creating extreme regularity. This is achieved by warming the metal sufficiently to begin recrystallization and holding it at this temperature long enough to allow gradual ordered crystal growth.

To harden sterling, heat a finished piece to 575° F (300° C) and hold it at that temperature for at least one hour. Air cool. Pure metals like copper and fine silver cannot be heat hardened because it is the arrangement of alloy ingredients that contributes to the hardness. Though there is validity to the theory of heat-hardening, in practice, tumbling with steel shot is more commonly used to harden jewelry items. It is faster and significantly more effective.

The inner life of a human being is a vast and varied realm and does not concern itself alone with stimulating arrangements of color, form, and design.

—

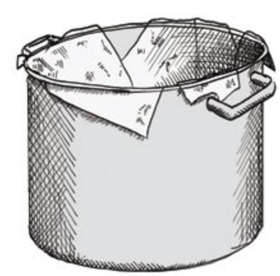
Edward Hopper

Argyria

Argyria, a condition caused by ingestion of 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 safe and easy. It's especially useful for removing tarnish from flatware and hollowware. In a pot lined with aluminum foil, mix a dilute solution of equal parts of baking soda, salt, and liquid soap. A quarter cup of each to a gallon of water is a typical mixture. Set the sterling in the pot; bring the mix to a simmer and allow it to stand for 10–20 minutes as the oxides are transferred to the aluminum, which you'll see is darkened. Throw that away and wash the silver before using it.



Platinum

Platinum	Pt
Melting point	3225° F
	1774° C
Hardness	2 – 2.5
Specific gravity	21.4
Atomic weight	195.09
Palladium	
Melting point	2820° F
	1552° C
Specific gravity	12.2
Atomic weight	106.4

Platinum

Platinum is a dense white metal that has a high resistance to corrosion. It was discovered by Spaniards in South America in 1538. They called it *platina* because of its similarity to silver, *plata*. Today we refer collectively to six related metals as the platinum group: platinum, palladium, rhodium, ruthenium, iridium, and osmium.

Rhodium

Rhodium was separated from platinum in 1803 and takes its name from the Greek word *rodon* (rose) because of the colors of the metallic salts. Rhodium is often plated over sterling articles to provide a bright, tarnish-resistant outer layer. Its reflectivity index (85% of the visible spectrum) is slightly lower than sterling's but this lack of shine is generally imperceptible. Worked rhodium has a Vickers hardness of 100 but electroplated rhodium has a Vickers of 775–820, indicating that it is extremely wear-resistant.

Platinum group metals dissolve slowly in aqua regia.

Working with Platinum

Platinum group metals can be cast but because of their high melting points, a special investment must be used. When you buy this, request a data sheet and follow the mixing directions carefully. No flux is needed when melting.

Cleanliness is very important when heating metals of the platinum group. An oxidizing flame is recommended. Contamination by silver, aluminum, iron, or lead will cause intercrystalline cracking at the grain boundaries. If contamination occurs there is no way to correct the problem metallurgically. The damaged area must be cut out and replaced with a patch.

Platinum group metals require an oxygen torch for soldering or casting because of their high melting points. These metals are well suited to settings for precious stones because of their toughness and great resistance to tarnish.

Uses

More than half of all platinum metals mined are used by the jewelry industry. Other uses include:

- medical implants
- architectural decoration, as leaf
- plating on the tips of fountain pens for durability (especially osmium)

Is it platinum?

To determine whether a piece is platinum, heat a sample to bright red and air cool. Metals of the platinum group will remain bright and shiny. Because of this resistance to oxidation, no flux is needed when soldering.

Copper

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

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 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.

> When exposed to moist air, copper forms poisonous acetates, sulfates, and chlorides known collectively as verdigris. The name comes from *vert-de-grice*, Old French for "Green of Greece," a reference to metal sculptures of antiquity. Because of these compounds, you should always wash your hands after handling copper. Copper cookware and serving pieces should either be plated with a noncorrosive metal such as tin or washed before each use.

> Most copper is electrolytically refined, i.e., electrically deposited on an anode. This product is pure but contains oxygen atoms scattered throughout the metal. When heated, this forms CuO_2, which breaks down the bond between crystals and can weaken the metal as much as 60%. To alleviate this problem, most copper is alloyed with a deoxidizer such as phosphorus.

> Copper cannot be heat hardened, but responds to work-hardening.

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

Japanese Alloys

Shaku-do 0.5% to 4% gold, with the 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 260
Melting point 1750° F
954° C
Specific gravity 8.5

Jewelers Bronze 226
Melting point 1886° F
1030° C
Specific gravity 8.7

Brass

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.

Alpha brasses	less than 36% zinc	good for cold working; have a rich yellow color
Beta brasses	more than 36% zinc	good for hot working; have a pale color

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 that was 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.

The afternoon knows what the morning never suspected.

Swedish Proverb

Nickel

Nickel	**Ni**
Melting point	2651° F 1455° C
Specific gravity	8.9
Atomic weight	58.69

Nickel

The word nickel means “deceiver” in German, and was given to the ore (niccolite) because it was easily mistaken for copper ore. Nickel is a hard white metal used primarily as an alloying ingredient. It increases hardness and resistance to corrosion without impairing ductility.

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 electroplated 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

Nickel silver (German silver)	Cu 60% Ni 20% Zn 20%	This is the alloy most commonly used for jewelrymaking. In strength, cost, malleability, and ductility, it is similar to brass.
Monel Metal	Ni 67% Cu 30% Balance: Fe, Mn, C, Si, S	This tough, oxide-resistant metal has many uses in industry but is rarely used in the crafts. It melts at 2370° F (1300° C).
Nichrome	Ni 80% Cr 20%	Because of its ability to resist oxidation and its high melting point (2550° F, 1400° C), this metal is used in wire for the heating element of electric kilns.
Nickel Alloy #752	Cu 65% Ni 18% Zn 17%	This alloy will “swell” when heated above 1800° F (980° C). When its reticulated oxide skin is removed in a nitric acid pickle, the metal will be found to be dramatically perforated. It can be soldered and polished.

Aluminum

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.

History

Though the existence of aluminum was theorized in the 1700s it was not isolated until 1825. When the Washington Monument was completed in 1884, a 100 oz. pyramid of aluminum was made to crown it. At the time, this was the largest mass of aluminum ever made—before placement, it was displayed in Tiffany's window in New York City. Commercial production was devised in 1886 and many alloys have been developed since then.

Alloys

As is the case with many metals, industry organizations have developed a universal system to identify components of an aluminum alloy. The first digit of a 4-digit number designates the principal ingredient, with the remaining numbers specifying their proportions.

1xxx	pure or almost pure aluminum
2xxx	copper alloys
3xxx	manganese
4xxx	silicon
5xxx	magnesium
6xxx	magnesium & silicon
7xxx	zinc
8xxx	other elements

The 1000, 5000, and 6000 series are commonly preferred for anodizing, but many other alloys will work.

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.

Popular Alloys

2S — pure aluminum
3S — Al + 1.25% Mn
4S — Al + 1.2% Mn and 1% Mg
17S — Al + 4% Cu, 0.5 Mn, 0.5 Mg
24 — SAl + 4.5 Cu, 0.5 Mn, 1.5 Mg

Anodizing

This is a process of electrically causing the formation of a resistant oxide film on the surface of aluminum. The film may be colored with dyes which can give finished aluminum products a wide range of color possibilities. For more information, see Chapter 6.

Reactive Metals

Titanium	**Ti**	
Melting point	3020° F 1660° 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

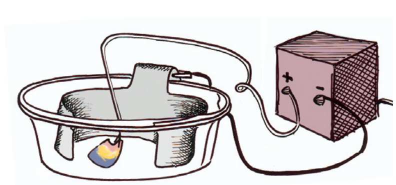
This term refers to a group of six tough gray metals that are lightweight, have a high melting point, and are resistant to corrosion. In order of importance, they are titanium, niobium, tantalum, zirconium, tungsten, and hafnium. The first two are of interest to jewelers principally because of the colors 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

In its pure form, niobium is soft and ductile and polishes to look like platinum. There is a good bit of niobium on the planet; it is more plentiful than lead and less common than copper. Niobium is extremely ductile. In drawing wire, for instance, the cross section can be reduced by as much as 90% before annealing. This property can of course be a drawback for applications where strength is required.

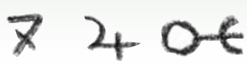
When this metal was first discovered in 1801 it was called columbium, but it was rediscovered and renamed in 1844. After years of confusion the scientific community formally adopted the name niobium, but the older name is still sometimes encountered.

See Chapter 6 for information on anodizing reactive metals.

White Metals

Britannia Metal

Melting point	563° F 295° C
Specific gravity	7.4



tin

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.

Health & Safety

The fumes produced by these metals are potentially unhealthy. Heat under a ventilating hood or arrange a fan over your shoulder to move fumes away from you. Lead can be absorbed through the skin. Wash well after handling any lead-bearing alloy. It is especially unwise to eat, drink, or smoke in an area where white metal is being worked.

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
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 as possible, then allow the work to soak in either of these solutions for several hours.

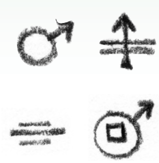
3 oz. glacial acetic acid
1 oz. hydrogen peroxide

8 oz. fluroboric acid
1.6 oz. 30% hydrogen peroxide
22 oz. water

Iron & Steel

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

Mild S teel	
Melting point	2759° F 1515° C
Specific gravity	7.86



In iron we possess a substance from which can be made the thick, heavy ribs of the vessel of war, the slender blade of the surgeon's knife, or the exquisitely artistic leaf work of the chancel screen.

Paul Hasluck,
Metalworking, 1907

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.

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

Steel Designation Nomenclature

This is one of several systems devised by the Society of Automotive Engineers (SAE) and the American Iron and Steel Industry (AISI).

- An initial letter indicates type of furnace used in smelting.
- The first two digits indicate major alloying material, in code.
- The last two digits indicate the percent of the material in this alloy.

Example: **B1065** *This is a plain carbon steel made in an acid Bessemer furnace that contains 0.65% carbon. It would be used for springs, tools, and blades.*

Code	Type of steel
1xxx	plain carbon (non alloy) steel
13xxx	manganese steel
2xxx	nickel alloy steels
23xxx	3.5% nickel
25xxx	5.0% nickel
3xxx	nickel/chrome steels
4xxx	molybdenum steels
40xx	carbon/molybdenum
41xxx	chrome/molybdenum
43xx	chrome/molybdenum/nickel
46/48xx	molybdenum/nickel
5xxx	chromium alloy steels
51xx	low chromium content
52xx	medium chromium content
53xx	high chromium content
6xxx	chromium/vanadium alloys
86/87xx	nickel/chromium/ molybdenum

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.

Other metals used for steel alloys are:

• chromium	for corrosion resistance; 10–20% used in stainless
• manganese	increases hardenability and tensile strength
• molybdenum	increases corrosion resistance; high temperature strength
• tungsten	forms hard abrasion-resistant particles called tungsten carbide; used for cutting edges

Organic Materials

Some organic materials may release unhealthy dust when they are sanded; ventilation and a respirator are recommended.

Organic Materials:

From its earliest beginnings jewelry has taken advantage of the diverse beauty of wood, bone, antler, and other organic materials. Each has special characteristics, but a few general ideas apply to all. Most organics:

- Burn easily.
- Have growth lines or grain that change the appearance and sometimes affect strength. In wood, for instance, it is important to consider grain direction when orienting the piece.
- Contain oils that will affect adhesives and may rub off on clothing.
- Are often porous and can be discolored by polishing compounds.

Wood

- Light-colored woods: maple, ash, holly
- Dense, close-grained woods like apple, cherry, pear, walnut, pecan
- Rain forest trees: cocobolo, paduck, rosewood
- Woods that are not recommended include soft woods like pine and fir, and woods that split easily like mahogany and oak.

Leather

In addition to its use as pendant cord, leather has a long history of use as hinges, as a backing for small ornaments, and for knife handles. Occasionally it is used as an inlay material. Cutting with a sharp blade is usually best, but leather can be sawn and filed. To train leather to a shape, wet a piece thoroughly in hot water and secure it around a form until completely dry. Vegetable-tanned leather is required for this process. Oil-tanned or chrome-tanned leathers will not mold when wet. Exotic leathers include skins from snakes, alligators, lizards, frogs, sharks and stingrays.

Antler

- › Antlers come from deer, elk, moose, and some goats; they are dropped and grow again each year (as opposed to horns, which grow additional layers each year).
- › Cut and file with jewelers' tools.
- › Protect against dust when machine grinding and sanding, which create an unpleasant odor.
- › No finish coat such as wax or varnish is needed. Polish with fine abrasive papers or by buffing.

Tusk

Tusk is an external tooth. Like our own teeth, tusks grow and (we hope) stay with their bearers for life. Some tusk material is called ivory, a term that should always include a descriptive term, as in "walrus ivory." Sale of tusks is carefully controlled to protect species.

Bone

The strength, density and beauty of bone will depend on the species and age of the animal and the bone's role in the body. A cow's leg bone, for instance, needs to be stronger than its shoulder blade.

To degrease bones

Fresh bones are preferred because as the marrow dries, it weakens the bone. Keep bones cold or frozen to delay the natural decay of the marrow. Start by scraping away as much tissue as possible, then boil the bones in a large container of water to remove the remaining gristle, then use any of these solutions:

- Soak for about three hours in a 50/50 solution of bleach and water. Note that prolonged exposure can weaken some bones.
- Soak overnight or longer in a 50/50 solution of ammonia and water. Though slower, this does not risk damaging the bones.
- Soak overnight or longer in hydrogen peroxide at full strength, as it comes from the drugstore.

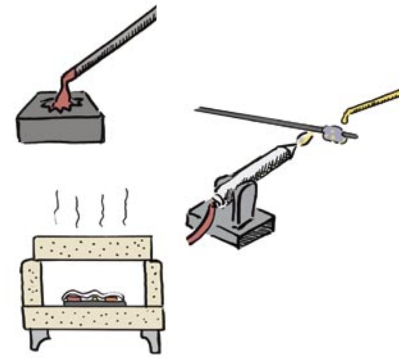
***Warning:** Never mix ammonia and bleach; the result is highly toxic.*

To color bones

- Polishing compounds like rouge will impregnate bones as they polish them. The choice of rouge (it is available in green, blue, black, and red) will give a subtle color to the bone.
- Dilute paints with the appropriate solvent (water for acrylics, turpentine for oils) and paint on generously. Wipe off to achieve the intended effect.
- Porous bones can be subtly darkened by boiling in strong tea.

Glass

Ways to Work with Glass



> **Casting**
Molten glass is dropped, blown or extruded into molds.

> **Lampworking**
Glass tubing and rod is manipulated and welded in the flame of a gas/oxygen torch.

> **Fusing**
Sheets of glass are melted together in a furnace, either flat or slumped over a form.

Expansion & Contraction

Not all glass products are compatable. Various chemistry, viscosity and expansion rates can create stresses in objects made of several pieces. The property of glass that makes a piece swell when heated and contract when cooled is described as a numerical value called the coefficient of expansion (COE). This is determined by each manufacturer according to a standardized test. The most popular glasses used by artists have a COE of 90 or 96. Viscosity is equally important but because there is no standard designation, it is mentioned less frequently. Mark all glass with relevant data and keep supplies clearly separated.

Annealing

Annealing removes the stresses and strains remaining in glass after shaping. If it is not annealed, glass may shatter from tension caused by uneven cooling. Annealing is done by reheating the glass and gradually cooling it according to a planned time-and-temperature schedule.

Tempering

In the tempering process, a finished glass article is reheated until almost soft. Under carefully controlled conditions, it is chilled suddenly by blasts of cold air or by plunging it in oil or certain liquid solutions. This tempering treatment makes the glass much stronger than ordinary glass.

It took more than a year to anneal the huge 200-inch (508-centimeter) telescope lens for the Palomar Observatory in California.

Dichroic

To make dichroic, or "two-color" glass, a layer of colored material is fused onto a layer of glass in a vacuum. The result transmits one color and reflects a different color, both of which can be vibrant. By manipulating the layers with construction and etching, manufacturers can create specific patterns.

Common Temps	Fusing Stage	Glass Stages
800° F – 1100° F	Brittle zone	Do not open the kiln in this range.
1325° F – 1425° F	Tack fuse	Edges become round; glass sticks together.
1425° F – 1600° F	Full fuse	Layers fuse together; flow to uniform thickness.