BRASS INSTRUMENT METALWORKING TECHNIQUES: THE BRONZE AGE TO THE INDUSTRIAL REVOLUTION

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In this article I will describe historical and current metalworking techniques used in brass instrument making. I will discuss the development of each of these techniques in chronological fashion, independently from the development of the instruments themselves. Of several important studies in this area, I wish to draw particular attention to the article of Robert Barclay in *Studia Organologica,* in which the author describes very succinctly the techniques used in the making of Nuremberg trumpets in the seventeenth and eighteenth centuries.

To investigate the metalworking techniques of past ages, we may draw upon several sources. From the earliest times, we have more than just artifacts and excavations to examine. Descriptions and illustrations in hieroglyphs and on antique Greek painted vases can help to give us insight into the development of metallurgy (Figs. 1, 2a, 2b).

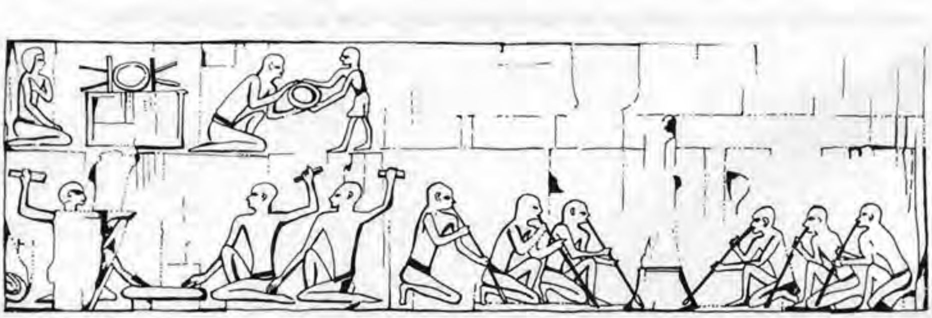

Fig. 1
Goldsmiths in a picture in the grave of Ebe (Schech abd el Gurna, no. 36, after N.D. Davies, *The Rock Tombs of Deir el Gabrawi,* I/24, cited in Lietzman, 1984). In the upper part of the picture, a writer gives a laborer a ring of gold to work on. In the lower part, six men are blowing in a fire, with pipes of fire-resistant clay. Three other workers strike on a metal disc, using hammers without handles.

Fig. 2a
Picture of a Greek smith on an Attic amphora from about 550 BC. One of the oldest and most informative Greek pictures of a smith's workshop. The master smith holds the workpiece with a pair of tongs as his apprentice strikes it with a large hammer. Two important visitors look at the work of the smith (Lietzman, 1984).

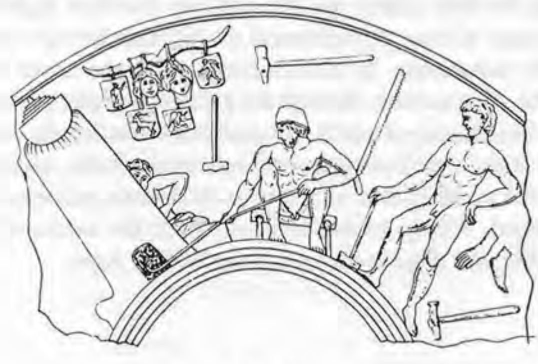

Fig. 2b
Decoration on a Trojan bowl. In a smelting workshop two enormous figures arise. They are being shaped with various tools, such as a forging hammer and a shaving and burnishing tool (Lietzman, 1984).

From the point at which written sources on the subject begin to appear, the picture becomes progressively clearer. Some Egyptian texts, the Bible, and the Shu King (in which copper is mentioned for the first time) give some insight into the matter as it existed until about 1000 BC. The more numerous Greek texts from around the fifth to third centuries BC, together with the remnants of Greek and Roman mines, give a much better idea of developments in those times. Still more information can be obtained through an examination of early Roman literature. None of these texts, however, was written with the purpose of discussing metallurgy or metalworking in particular.

In the Middle Ages, however, the situation improves, with the appearance of the writings of the monk Theophilus (*Schedula Deversarium Artium*, ca. 1100) and the alchemists. At the end of the fifteenth and the beginning of the sixteenth centuries, we see for the first time writings and books devoted principally to metallurgy and metalworking. These include *De re metallica*, written by Georg Agricola (1546), and *Pirotechnica* , by Vittorio Biringuccio (1540) (Johannsen, 1925), both of which deal with the mining and smelting of ores in great detail (see fig. 3). Metalworking techniques are further clarified by studying the illustrations in *Das Hausbuch der Mendelsche Zwölfbrüderstiftung*, and the *Landauerstiftung*, both from Nuremberg (Goldman, 1965). As can be seen in the list of references, technical information increases significantly in quantity in later times.

THE METALS

In addition to organic materials such as wood, cane, and horn, only three metals or alloys are used to make lip-vibrating wind instruments: silver, bronze, and brass. We may assume that the very first metal deposits found were of gold and silver. These two are rather striking for their glossy surface and are therefore highly visible in most surroundings. Because of their properties and the fact that they are rare, they were (and are) very desirable substances. In earliest times, gold and silver (and copper soon thereafter) could be obtained only through the gathering of pieces of the metals in their native state. Later on in history it was discovered that when fireplaces and hearths made of certain types of stones were heated to very high temperatures, small deposits of metal would be found in the ashes. How or why the first deliberate gathering of ores took place cannot be determined. We do know, however, from the works of Biringuccio and Agricola how mining was done at the end of the Middle Ages.

Silver

Silver can be found in the earth in its pure, native form, sometimes abundantly and in large pieces. Usually it was found fairly deep, and in 1477 a block measuring 2 x 2 x 1 meters was discovered in the Erzgebirge, in the neighborhood of Dresden. (Lietzman, 1984)

The processes by which silver is extracted from ore must have been known prior to 2000 BC, because the amount of metal in use would appear to have been more than that which could have been found in native form. There are two means by which silver can be extracted from ore: chemical and metallurigcal. The former process involves acids or mercury; the latter, fire, smelting, and reduction with lead. Since mercury was not discovered until around 440 BC (Agricola, 1546) smelting or reduction with lead must

A—Furnace of the Carni. B—Low wall. C—Wood. D—Ore dripping lead. E—Large crucible. F—Moulds. G—Ladle. H—Slabs of lead. I—Rectangular hole at the back of the furnace. K—Saxon furnace. L—Opening in the back of the furnace. M—Wood. N—Upper crucible. O—Dipping-pot. P—Westphalian method of melting. Q—Heaps of charcoal. R—Straw. S—Wide slabs. T—Crucibles. V—Polish hearth.

Fig. 3
Woodcut of the furnace of the Celts (Agricola, 1546).

have been used prior to this date. Therefore, lead and the process of extracting silver from ore were certainly known and in use at the same time. The first known leaden casting, a little Egyptian figure from about 3800 BC, was made earlier than the first known silver object from the same country—a necklace from about 2400 BC. This early appearance of lead, therefore, shows that it would have been possible at that time to refine silver by means of reduction with lead. In the tomb of King Tutankhamun (1343-1325 BC) two trumpets were found. One was made of bronze (or possibly copper) and the other of silver; both were made by means of flattening the metal with a hammer. These Pharaoh-trumpets are made of very thin material, and to protect them against damage, they were provided with two wooden inserts which fit into the bells when not in use.

Copper

As far as can be determined through archeological excavations and extant objects, copper is the first metal from which useful articles were made in great quantities. The so-called Copper Age was from ca. 8000 BC to ca. 3000 BC, when the Bronze Age began. Copper can be found in native form in pieces of rather large dimensions. The largest found to date had a weight of 420 tons. (Lietzman, 1984)

The melting point of copper is 1084°C, and such a temperature could be achieved in the sixth century BC, making it possible by that time to make copper castings. Many useful and decorative objects were made and sold. From the Gulgamesch epic we know that in about 2400 BC, blow-horns were in use, whose name, *si-im*, is related to the meaning of the word "copper."

Copper was later almost entirely replaced by brass for the making of metal musical instruments. Therefore it may be useful to trace the history of both metals. Soon after the discovery and identification of malachite, which was initially used by the Sumerians as a cosmetic (green eye shadow), it was found that this stone, when heated, leaves behind small pieces of copper in the ashes. For this reason the Romans began [malachite] mining operations in all the parts of their Empire where these particular stones could be found.

The monk Theophilus describes the extraction of pure copper from ores in his *Schedula* (ca. 1050). Pieces of stone are broken into smaller pieces after heating, then piled up with charcoal. After days of burning with the aid of bellows, a semi-refined copper substance remains. After being hammered on an anvil, the pieces are piled together with fresh charcoal again and the entire process is repeated.

Biringuccio and Agricola were more exact in their explanations of the methods used for the different types of ores. Most important was the process known as "pooling," which involves the repeated melting of copper, using fresh wood in the melt.

Brass was discovered prior to the Christian Era. It was found that when a particular mineral and copper were melted together, the volume of the metal increased by about 30% and took on a yellow color somewhat resembling gold. This mineral was calamine, a compound of zinc carbonate and zinc silicate. The fact that zinc was not only an element but also a metal was not discovered until the eighteenth century. The properties of brass are in no way inferior to those of copper, and for some purposes superior. It has almost no taste and was therefore considered useful for cooking utensils. Also, the sound produced by a brass instrument could not be surpassed by that of any other material.

Depending on where the ore was found, the refined copper would still contain greater or lesser amounts of other metals. These could include arsenic, silver, gold, iron, cadmium, lead, etc. Removal of the silver was attempted by adding extra lead and cupelling the mixture of lead and silver. (Cupelling is a method of refining gold and silver. Lead ores containing substantial amounts of silver are heated in shallow cups made of a porous material. With the application of large quantities of air, the lead oxidizes and is absorbed in the porous clay, leaving the "pure" silver behind.)

In order to make brass, calamine (also known at various times as *galmei, pomphilox*, etc.) was melted with copper. Two types of calamine exist, one from the earth, a true mineral; and *cadmia fornacis*, accretions from the chimneys of the smelting furnaces. Both are a mixture of zinc-oxides and -silicates. A certain quantity of melted scrap brass was added, and the most desirable resultant alloy consisted of about 28% zinc, 1% impurities, and the rest copper.

Bronze

Bronze is a mixture of copper and tin. Although the two metals can be found in their pure form in nature, the alloy cannot. Manufacture of this alloy requires a complete mastery of the technique of melting metal. This method employed a charcoal fire, made hotter by means of a more efficient furnace design and by directing more air into it. Eventually bellows worked by hand, and ultimately water power (ca. 1500 BC), were applied to this process. Around 2000 BC the crucible came into use for second and third meltings, and for melting metal for casting. (Derry, 1982)

It was probably through the use of tin-bearing stones in furnace building that the concept of alloying tin and copper together to make bronze was first discovered. It is impossible to say whether the alloying process was achieved by mixing together liquid copper and pure tin or by mixing the ores and then beginning the smelting process.

The melting point of bronze is lower than that of copper, and since bronze flows more freely in its liquid form, it therefore makes a better metal for casting than pure copper. It is also quite malleable, and in cold forging can be worked to a much greater hardness than had been previously possible with gold, silver, or copper. Around 3500 BC the first bronze castings appear, and by 200 BC bronze was known and used throughout Europe and a great part of Asia. Through trading and shipping the ores were available in large quantities, and so the amount of bronze objects increased enormously.

THE TECHNIQUES

Hammering, Forging, and Flattening

These metalworking techniques seem to be the first and perhaps the most important techniques, because they could be applied to all metals. Any metal which can be found in its native state could have been flattened between two stones, in a manner resembling the effect of a hammer and anvil (Fig. 4). By this means the metal becomes thinner, changes shape, and hardens at the same time. When annealed in fire, it becomes malleable again, and can be further hammered and flattened. Objects have been found which were made in about the eighth century BC, using these methods. Metalsmiths were thus able to make sheet 0.2 mm thin. Returning to the silver Egyptian trumpet, it is of particular interest, not only that the silver is hammered very thin (approx. 0.3 mm), but also that the cylindrical part (approx. 45 cm long) seems to be made without a seam (Fig. 5). The only method for making a seamless tube at that time was with the technique of raising, a brief description of which appears below. The mandrel for making such a thin and long tube had to be made of bronze or iron. At that time steel was unknown, but iron was mentioned for the first time by Hamurabi in his lawbook (ca. 1750 BC). (Hamurabi was king of Babylon, 1728-1686 BC. His "lawbook" is an inscription of Sumerian laws in 282 paragraphs, on an obelisk.) Iron daggers dating as early as the fourth century BC have been found in Egypt. The slightly conical shape of the tube lends plausibility to the idea that this piece might have been made by raising. Other theories propose that this tube does, indeed, have a seam. Soldering and perhaps brazing are certainly among the possibilities for making tubes in this way. The tubular part of the silver Egyptian trumpet has a longitudinal seam, made with the crenellation method. One side of the strip of hammered metal is provided with small square tabs, which resemble

Fig. 4
Egyptain goldleaf maker (Lietzman, 1984).

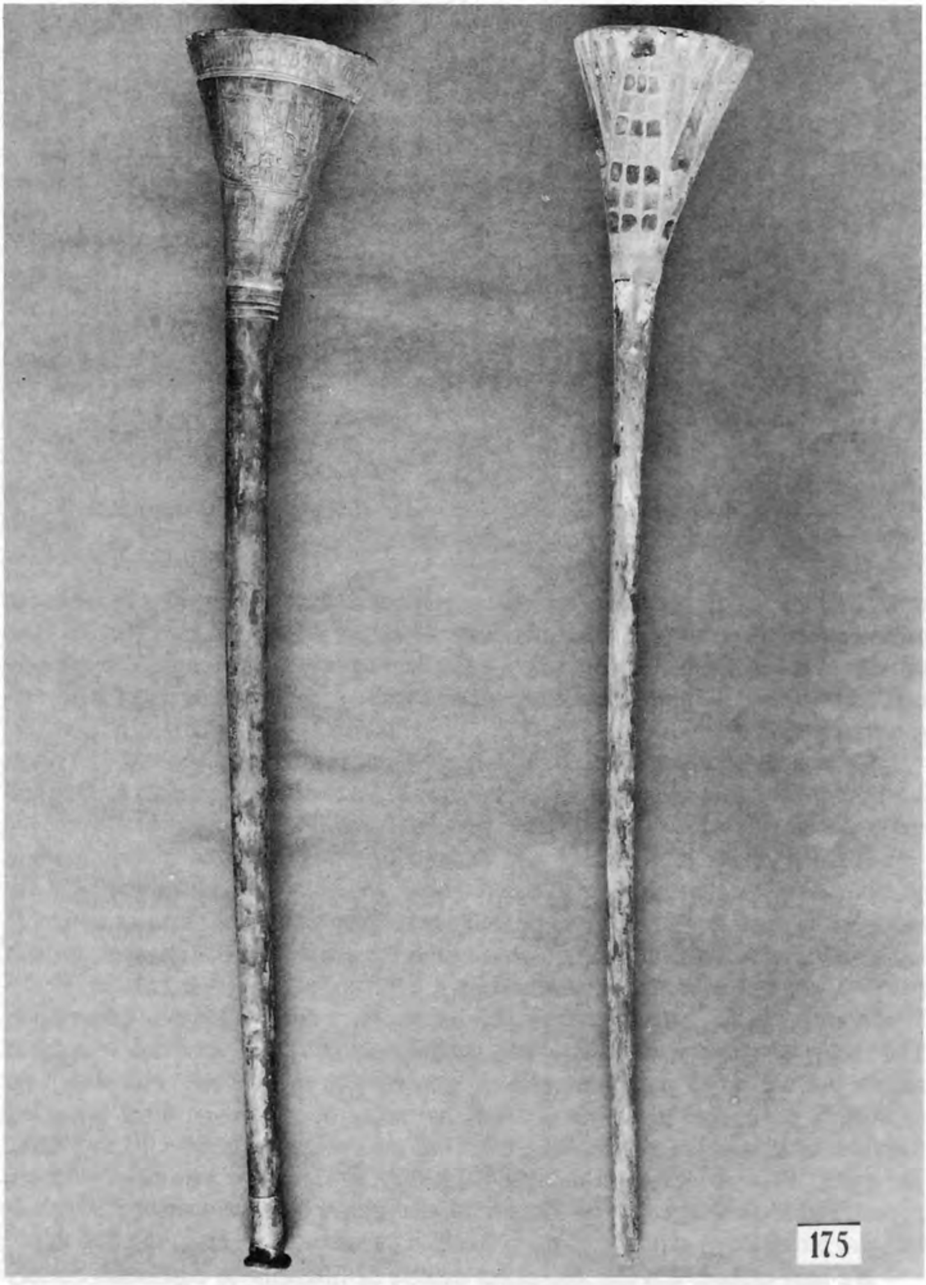

Fig. 5
Silver trumpet from the tomb of Tutankhamun. Cairo Museum (Fischer, 1989).

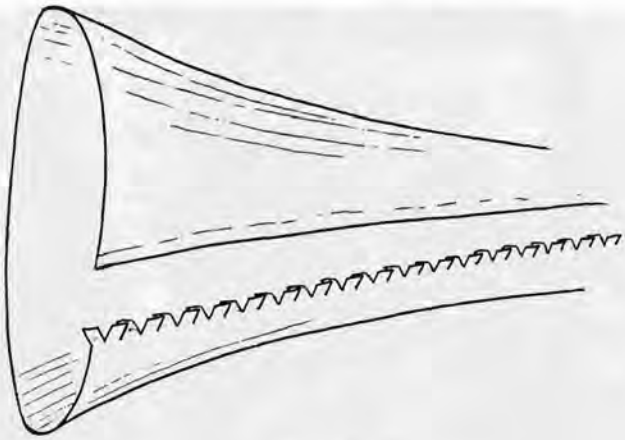

Fig. 6
Bell seam with crenellation. Notching and overlapping are clearly visible (Barclay, 1987).

dovetail joints. The other side of the oblong piece of thin metal is inserted between the tabs and then flattened with a hammer, after which the seam is soldered (Fig. 6). The outside of the instrument is very smooth, but the inside is rather rough. The strongly conical bell is richly embellished, and engraved with a scene depicting the pharaoh and three gods.

The most beautiful hammered and forged objects in gold are those of the Skythes, a tribe living from the seventh to the third century BC between the Russian river Don and the Danube.

These methods of flattening and hammering brass were the most important techniques used in the making of trumpets, horns , and trombones until about 1820. By using the appropriate hammers, anvils, and working procedures, the makers were able to form the desired bell shape. It is interesting that the shape of the bell changes through the ages from a rather funnel-shaped cone to a hyperbolic curve (Worthmüller, 1954). With this change the actual forming process became more difficult and time-consuming. The hammering became more laborious, but this extra work was necessary in order to satisfy the wishes of musicians and composers. The sheet metal with which an instrument maker had to work was made by means of a water-powered flattening hammer, which would forge the brass ingot into a sheet approximately 0.5 mm thick. The watermill came into use in about 80 BC (Derry, 1982) and became more and more popular in the following centuries. The twelfth century saw the development of large tail-hammer installations, with which many kinds of metals were forged (Figs. 7 & 8).

We may assume that the instrument makers of fifteenth- to eighteenth-century Nuremberg had at their disposal brass sheet of good quality. Economically, the smelters' two principal objectives were to make as much metal as they could, and with the highest

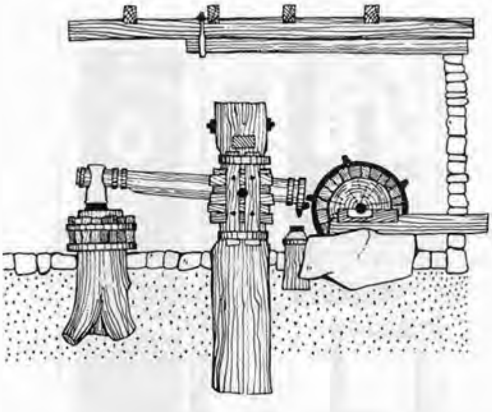

Fig. 7
The oldest type of water-driven tail-hammer (Lietzman, 1984).

Fig. 8
Brass and copper hammer workshop with annealing furnace, tail-hammers, and (flying-) shear. With a stretch hammer, the sheet is struck. With a doming hammer it is driven into the shape of a vessel (Schreber, 1766).

possible degree of purity. The first objective was obtained by applying as much calamine as possible to the liquid copper; and the second, by frequent pooling and re-melting. A very pure alloy has better working properties, and, due to the lower percentage of impurities, also fewer flaws (cracks, etc. due to metal fatigue). This means that more instruments can be made from the same quantity of brass.

In about 1500 the first rolling-machines—used for rolling the leading for glass windows—came into use (Fig. 9). By 1700 lead plates were being made in a rolling-mill (Fig. 10). However, the making of sheet metal continued to be done with hammer-mills until about 1800. Not until 1816 in Germany was the first cold rolling machine put into use. The making of seamless tubing was developed in 1820 by T. Burr (Lietzman, 1984), but the process was used only for lead tubes. In 1880 it finally became possible to make seamless tubes of a metal harder than lead by crossing the rolling wheels (Fig. 11). After

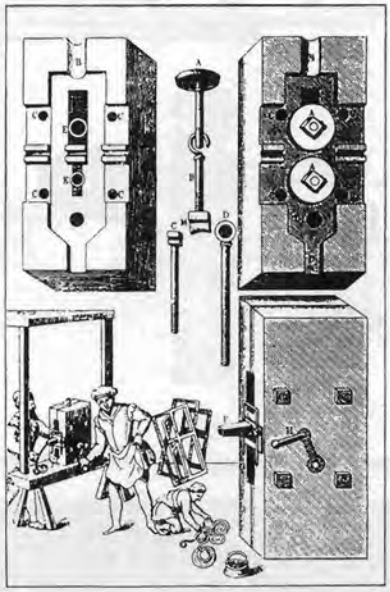

Fig. 9
Mill for making lead profiles driven by hand. Used for making strips for leaden glass windows. (Zonca, 1607).

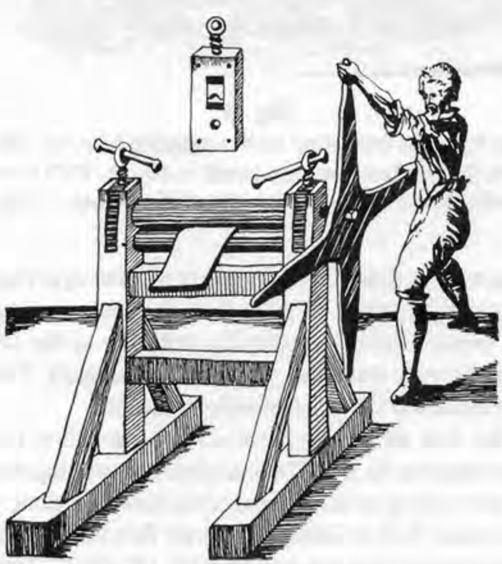

Fig. 10
Mill for making lead and tin sheet (Salomon de Caus).

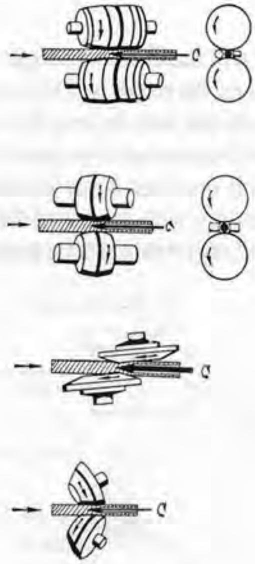

Fig. 11
Crossing the rollers (Lietzman, 1984).

the old methods were replaced by steam hammers and rolling-machines, the production of sheet metal for use in brass instrument making was altered to a point which is beyond the scope of this article. By rolling the pieces of brass instead of hammering them, the crystal structure of the metal changes into a length-oriented one. The use of electric furnaces made it possible to produce alloys almost without impurities.

Chasing

Chasing is a particular manner of forging in which a flat plate of metal is forced into a three-dimensional form by using a hammer. The plate or disc, while being supported by a piece of wood or iron, is then struck by hand with a doming hammer, and in this way it is possible to make alomst every desired shape. Well-known examples are the harnesses of the Greek and Roman soldiers, the bowls and dishes of the Celts, and other such objects.

Raising

In this technique, the metal becomes thicker—instead of thinner, as it does in chasing. When the rim of a metal disc is hammered over an iron stake to bend it, wrinkles will appear. After the wrinkles are hammered down, effectively compressing the metal, the rim will be a little thicker and will stand at some angle to the disc. If that process, after annealing, is repeated several times, the result will be a vessel shape (Fig. 12). It is even possible to make seamless tubes in this way as long as they are not too narrow. Perhaps this was the technique by which the pharoah trumpets were made.

The process of making a bell involves a combination of chasing, flattening, and forging. In making the desired pattern with the use of different hammers,the outer edge of the bell flare will be hammered rather thin. Some metals and alloys, such as iron and

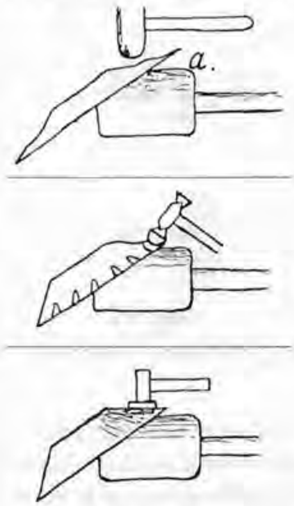

Fig. 12
Raising.

bronze, are forged and chased more successfully when red hot. Because of the constant recrystallization while in this condition,the metal does not work-harden. Hot forging was never an important process in the making of brass instruments, although it was essential in the production of tools of iron and steel.

Casting

After smelting, casting the metal is the next step. This technique had become very important by the bronze age, and smiths were able to make the desired alloy very accurately, having developed the skills needed to control the percentage of tin necessary to make the bronze suitable for special purposes. They were able to make a soft and tough alloy if hammering and forming were needed after casting, and a brittle and hard one if, for example, a knife or ax were to be cast. These different alloys have different melting points, of course, and that phenomenon was put to good use in the making of the Scandinavian lur.

This instrument, which was always made in pairs which curve in opposite directions, is a good example of the craftsmanship of bronzesmiths of about 1000 B. C. (Fig. 13). Several have been found in the moors of Denmark and the south of Sweden. The characteristic flat disc, often with eight bulbs, was held in place at the end of the instrument by bending the extreme end of the tube. The composition of the bronze in these instruments is in almost every case the same, i.e., 85% copper and 13.5% tin, with the rest being traces of other metals such as arsenic, lead, nickel,and silver. The ferrules, however, contain about 18% tin. (Becker, 1936). The casting technique used was the so-called "lost-wax" method. A model of beeswax was made and covered with a fire-resistant material. The wax was then heated, eventually melting and burning away, leaving behind a shape which could then be filled with molten metal. To cast the tubular parts of the lur, a core was prepared, following the inner measurements of the bore. The core was made of a mixture of loam, dung, and sand, and then covered with a thin layer of wax approximately 1 mm thick. The core was kept in place by a number of bronze rectangular pins of 1 x 6 x 10 mm, placed in a zig-zag pattern through the wax into the core. The wax model was provided with a spout into which the liquid bronze was poured, and little spouts or sprues (vents) to permit the wax and fumes to escape. A thin and smooth layer of loam was put around the wax model, and then the whole was packed in

Fig. 13

Lur from the early Bronze Age, ca. 900 BC. Instrument found in Brudevalte, Denmark. Now in National Museum, Copenhagen (Tarr, 1988).

the same mixture of sand, dung, and loam, as was used in the making of the core. Heating slowly, the wax melted out and the organic parts in the mould burned. While the mould was still hot the liquid bronze was poured in, and the loam, which had by then become porous, would absorb the fumes and gases. After casting and cooling, the core, which would already have crumbled, was then completely removed.

A lur usually consists of six conical sections. To connect these parts the makers used the so-called "ring-anchor" connection. First, at the ends of two parts which were to be joined together, three or four nicks parallel to the rim were made. After aligning the nicks, a wax ring was made in the form of the future connection ring. Then a loam mould

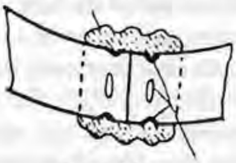

Fig. 14
Ring-anchor attachment (Dullat, 1989).

was made around this section and provided with spouts. The wax was melted out again and liquid bronze with a lower melting point (i.e., with 18% tin) was poured in (Fig. 14). The reason for using bronzes of different melting points to make the connection ring is clear: if the melting points were equal the tubes which were being connected would melt and collapse during the casting of the ring.

Sandcasting was also used at this time, and was almost certainly developed and used prior to the lost-wax method. By pushing a model into moist sand and pouring molten metal into the impression left behind, it became possible to cast rough and "losable" objects. "Losable" means that the model could be removed from the sand without destroying the impression. In later instrument making, casting was of some importance since it was used in the making of rough mouthpiece models. The rough model was then turned into its final dimensions on a lathe. The famous angel heads and balls of the Haas trumpets are also castings.

The surface on a sandcast object is often rough; it can be made smooth by sanding and polishing, although this often results in some loss of definition of details. For this reason, moulds were later made of fire-resistant plaster, which resulted in a casting which needed no additional finishing work, other than the removal of the spouts. To fill properly the space left behind in the plaster by the melted wax, the spout had to be large and wide. Initially, the weight of the metal itself was depended upon to ensure that the mould was completely filled throughout, leaving no air bubbles. Somewhat later, centrifugal force was used; immediately after the molten metal was poured in, the entire mould was swung around on a rope.

Drawing

It appears that the concept of pushing or drawing a thin, forged piece of metal through a die in order to give it smaller dimensions was known as early as 1900 BC. In cross-section the pieces were often round, or of other simple shapes. The first evidence of this is the use of drawn gold wire in jewelry from the second century BC. Because the drawing process work-hardens metal, the portion of the wire which has already been drawn through the die will retain its new shape and neither stretch nor break while drawing the remaining metal (which is still in its soft state) through the die. After annealing the drawn wire, the entire drawing process could be repeated, using a smaller die, and through repeated drawings and annealings, almost any desired size could be

Fig. 15
Swinging wire drawing, ca. 1418 (Lietzman, 1984).

Fig. 16
Leverage and water-driven drawbench (Weigel, 1698)

made. The technique of filigree work is entirely dependent upon the art of drawing wire.

Initially the force necessary for drawing was derived solely from the muscle power of the drawer, but later the energy was generated by swinging (Fig. 15). By applying leverage, pulleys, and other machinery, one could make thicker and/or longer wire (Fig. 16).

In the history of brass-instrument making, drawn wire came in use rather late and was not of great importance. Around 1650, the so-called *Sächsischer Rand* appeared, which involved strengthening the outer rim of the bell by means of a wire laid in the outer rim of the rather wide garland. Prior to that time, strengthening the bell was achieved by soldering an embellished wire (cast or rolled) on top of the outer edge of the garland, the so-called *Nürnberger Rand.*

In making tubes, however, drawing was and is indispensable. After rolling and soldering a long, narrow strip of copper, brass, bronze, or silver, a rod of a particular diameter is put into the rough tube. This is drawn as a whole through a die with a diameter

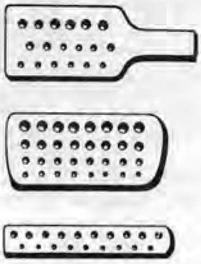

Fig. 17
Draw plates (Lietzman, 1984).

that makes the metal fit snugly onto the rod. By choosing the proper die it is also possible to diminish the thickness of the wall during the same process. The drawplate, made of steel with a variety of different sizes of holes (dies), is still indispensable in instrument making (Fig. 17).

Soldering and Brazing

The concept of soldering was developed when it was discovered that heating together two different metals would cause them to adhere to each other at a temperature lower than that of the melting point of either. Just as dry salt will thaw ice by giving the ice a lower melting point, something similar occurs with, for example, silver and bronze, silver and copper, etc. Copper melts at 1084° C, and silver at 961° C, but when put in contact with each other and heated, a liquid layer arises on the surfaces of both (called the *eutectic* point) at approximately 700° C, forming an alloy with a melting point lower than either metal, and effectively fusing the two together when cooled. An example of this phenomenon is a bronze ax with silver wire inlay of about 1800 B. C., found in the ruins of Ugarit, an important Phoenician harbor from ca. 2000 to 1200 BC. Grooves were made (cast?) in the bronze surface and silver wire was hammered in. After slow heating to the point of *eutecticum*, the silver became attached to the bronze.

Granulate work, in which very small pieces of metal were attached to an underlayer of the same metal, is possible only if one can use yet another metal as a soldering or brazing alloy. Several objects found in Mesopotamia and dating from ca. 2000 BC would indicate that this technique of soldering was in use at the time. Examples from the Skythes and Celts prove that soldering was commonly used in the making of gold and silver jewelry.

The first reference to the process of soldering appears in 97 A.D., as Sextus Julius Frontinus writes that lead tubes were made by rolling and soldering strips. It is possible to solder lead only with soft-solder, an alloy of lead and tin. Depending on the composition, the liquidus-solidus state is between 175^{o} and 275^{o} C. Working with soft-solder was almost always done with a soldering iron. Organ pipes are still made using the same process described by Sextus.

In twentieth-century brass-instrument making, soft-soldering is an important technique, as the instruments are now assembled totally with tin-lead solder. Before the nineteenth century the only parts of the trumpets and trombones that were soft-soldered were some braces and ferrules. (Jagdhorns, however, were soldered together between the coils with lead solder.) All the connections between tubes were made by means of a lap joint, in which usually each tube fits into the next tube, moving toward the bell.

Through the ages the techniques of hard-soldering and brazing became much more important in instrument making. The distinction between soft- and hard-soldering was not only the hardness of the solder alloy, but also the capability of a hard-soldered seam to withstand the force of the various forming processes involved in making bells and tubes. Hard-solder alloys are often made with a substantial silver content. Cadmium and zinc were added later, not only to make the alloy cheaper, but also to make it flow more easily.

All soldering processes require a flux, a chemical compound that pickles the seam, cleans it, and prevents it from oxidizing. The Egyptians used chrysocol, a green-colored, copper-based substance, mixed with sodium and other chemicals. Somewhat later, calamine mixed with alum was used. From about 1450, borax (sodium tetra-borate) became popular; it is still the most widely used flux. Ever since the guilds came into existence, every workshop had its own recipes for making fluxes and solders.

In Nuremberg it was standard practice to hall-mark instruments when they were completed. In order to receive the town's quality mark, a builder had to use *Gutes Lot* (i.e., "fine solder"). *Gutes Lot* was an alloy with silver (about 40%). *Schlechtes Lot* ("bad solder") was of copper and zinc, and was therefore actually a brazing alloy.

The *Handwerksordnung der Nürnberger Trompeten- und Posaunenmacher* ("Rules of the trumpet- and trombone-makers of Nuremberg") of 1625 states:

> Zum vierten, soll hinfuro ihrer keiner weder Rohr noch Hauptstück zu den Trompeten oder Posaunen gehörig mit schlechtem Loth löten, aus welchem nichts gut werden kann, bey Straffe van zweyer Gulden. ("Fourth, no tube or bell for trumpets and trombones will be soldered with bad solder, from which can come no good, with penalty of two guilders.")

Also of importance to the technique of soldering is the use of fire and torch. At first soldering was done, as in all other processes in which heat is required, in a charcoal fire, the heat of which was intensified with the use of bellows and/or a blow-pipe. The first step in this process is the careful preparation of the seam. If any severe forming processes were to be required of the newly soldered tube, it was necessary to form the seam with a relatively large overlap, resulting in more surface contact. If, however, the next processes could be done without much force, a butt joint was sufficient. To keep the seam closed in order to facilitate the capillary action of the solder, the tube was bound around with iron wire. To hold the seam closed when an overlapping joint was made, notches were cut into one side. These tabs were bent alternately up and down, and then the opposite side was inserted between. The tabs were then squeezed down to hold the joint fast. This technique was already in use, as was mentioned earlier, in the thirteenth century BC. The seam was then covered with a mixture of borax and pellets, or chips of solder. Sometimes a paste was made of borax, filings of solder, and water. The workpiece was put into a charcoal fire and the temperature was increased with a flow of air until the solder melted. After cooling, the iron binding wire was removed, the seam hammered flat and cleaned with a file.

In essence, soldering methods have not changed down to the present day, except that the charcoal fire has been replaced by torches which burn propane, butane, or some other type of gas. Sometimes in larger workpieces it is helpful to add oxygen to the gas, to further intensify the heat of a small torch flame.

Bending

In order to make instruments which could play more than the first one or two natural harmonics, and therefore be more useful musically, it is necessary to increase the total tube length. If the ratio of length to diameter becomes larger (i.e., the bore is made longer and smaller), more natural harmonics can be produced. The rate of taper is important as well, since overblowing becomes difficult if the rate of expansion is too rapid. Throughout history certain changes in this ratio can be observed, as in the progression from animal horn and shell to the long, slender, and mostly cylindrical trumpet of the fourteenth and fifteenth centuries. These later designs, longer and smaller in diameter, caused difficulties in handling and stability for the player, and also greatly reduced the potential lifetime of the instruments. The eventual solution was for them to be bent or folded in order to make them more compact.

In the process known as embossing, a decorative technique which will be discussed presently, a hollow object is filled with lead, or a special mixture of sand and pitch, or sand and bitumen. When the object is supported by such a filling material, it becomes possible to punch or hammer designs into the surface of the piece without misshaping the surrounding area. It was found that this principle could be used in the bending of tubes to prevent their collapse and preserve their round shape.

Almost certainly the Roman cornu was bent by filling the tube with some material. If the radius of the curve in which the bending was to be done were not too small, it could even have been done by filling the tube with dry sand and plugging both ends.

With bends of smaller radii, as are common in later centuries, sand does not provide enough support . Because of the fact that the metal on the inner side of the bend is compressed, small wrinkles often result. These must be removed during the bending process with a round-headed doming hammer. Sand or pitch will also not supply enough support for the hammering out of wrinkles, so liquid lead must be poured into the tubes for bending. Lead does work-harden somewhat, creating in effect a small anvil inside the tube, over which the wrinkles can be tapped flat. This work-hardens the brass at that spot, and as the bending process continues, new wrinkles can arise only at other points. This

Fig. 18
The so-called "Bendinelli" trumpet, made by Anton Schnitzer the Elder in 1585. Now in the Accademia Filarmonica, Verona.

skill was brought to its highest level in the sixteenth century, when instruments such as those by Schnitzer were made in the well-known Bendinelli pretzel shape (Fig. 18). Even in our time, bending is often done with a lead filling, but low-melting metals (such as cerrobend), hydraulic bending, etc., have come into use.

Stamping and Punching

About 700 BC the first coins were struck, and long before that it had been discovered that impressions could be stamped into metal with a harder object. Only after the invention of steel was it possible to transfer pictures onto metals such as gold, silver, or copper.

In the making of brass instruments, stamping and punching were important only in embellishing and signing the garlands and fittings. The shell-motifs in the Haas trumpets were struck into the metal with a steel die, while supported by a piece of lead. Many instruments in the seventeenth and eighteenth centuries were signed with letter or coat-of-arms dies.

Spinning

The process known as metal spinning involves pressing a thin disc of metal with a large lever onto a form as it rotates on a lathe. In this way simple dishes, bowls, and cups can be made. This technique was often used in instrument making, at first only to smooth the surface of the already hammered bell and establish a perfectly round shape. Polishing and burnishing are done much more easily and quickly when the workpiece is turned on a lathe. Nowadays almost all bells for brass instruments are spun. It is understandable that a totally different crystal structure and wall thickness results when the metal is spun instead of hammered. After the Industrial Revolution, spinning became the main technique used in bell-making. Earlier, it was employed only in the last stages of finishing the bell.

Filing, Sawing, and Other Metal-Removing Techniques

In order to obtain a desired shape it was sometimes necessary to remove parts of the metal being used. When the shape is to be formed through flattening, raising, or some similar process, it is almost impossible to start with exactly the right amount of material for the finished pieces. In order to get rid of excess metal, parts could be bent over sharply and moved back and forth until they eventually broke off, but this could be done only with rather thin material. When the walls of the form of the object were heavier, extra metal was filed away and removed with a rough-surfaced stone. Cutting with a sharp rock was another method used to give the object its proper shape. After the develoment of methods of tempering iron and steel in about 1400 BC in Armenia and 500 BC in India (Lietzman, 1984), many of the tools used by metalsmiths of the past took on the shapes

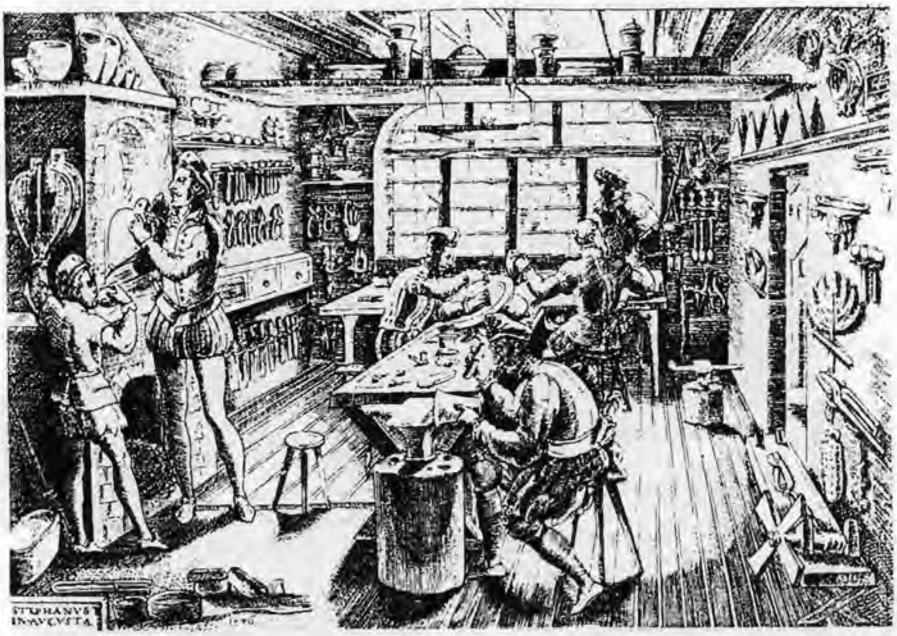

Fig. 19
Silversmith's workshop. Engraving of E. Delaume, ca. 1580 (Lietzman, 1984).

which are still familiar to us today—i.e., hammers, files, tongs, dies, punches, anvils, stakes, etc. (Fig. 19). The tools used in instrument making also remained the same until about 1820 (Fig. 20), after which time spinning lathes and other machinery entered the workshop. In the *Hausbuch der Mendelschen Zwölfbrüderstiftung*, some of the craftsmen's specialties are illustrated—for example, *Bruder Sebold Scharrd, Messingschlager* ("brass-flattener," Fig. 21). In these and other illustrations (Fig. 22) one can recognize all the familiar tools with which metal can be formed and shaped today. Pictures of a knife-maker, a candlestick-maker, and a file-maker are shown in the books of the *Landauerscher Stiftung*.

Though an exact date cannot be determined, the process of turning metal was done very early. Turning was done then, of course, on a treadle lathe, with human muscle power. In instrument building the most important turning was that employed in the making of mouthpieces. The first mouthpieces were nothing more than enlargements of the rim of the tube, as can be seen on the Egyptian trumpets. The lur had a mouthpiece which was cast in one piece as part of the first tube, resembling very much our modern trombone mouthpiece. The Roman tuba had a mouthpiece of horn or bone which was made separately from the instrument. The Saalberg lituus was cast in two halves, and the mouthpiece end, being cast as part of the instrument, was therefore not removable. In the

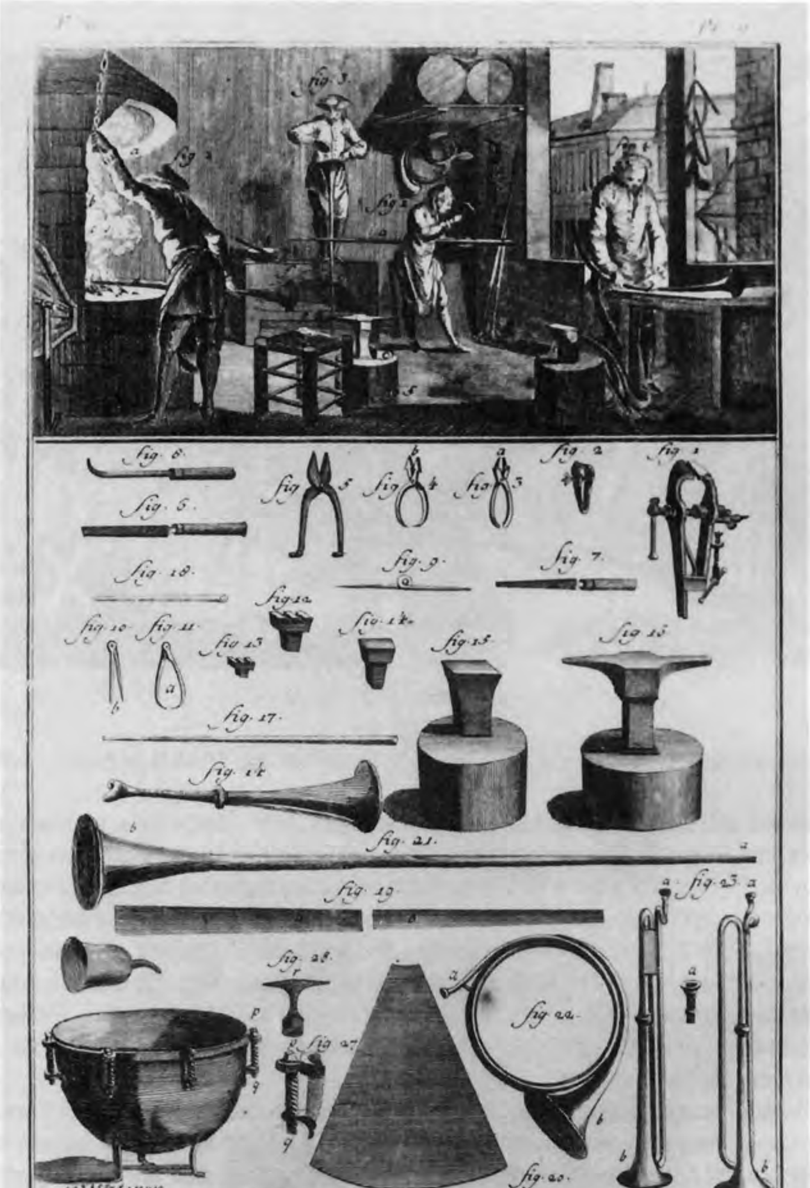

Fig. 20
Workshop of a brass instrument maker (Diderot and d'Alembert, 1751-80).

Fig. 21
Sebold Scharrd, the 287th *Bruder* (1530). From *Das Hausbuch der Mendelschen Zwölfbrüderstiftung* .

Fig. 22
Ott Nagler, nail-smith, the 44th *Bruder* (1425). From *Das Hausbuch der Mendelschen Zwölfbrüderstiftung.*

late Middle Ages and early Renaissance, mouthpieces were made of sheet metal. This method was used for horns until about 1780, and even later. From about 1600 most mouthpieces were turned from rods of solid brass (sometimes known as "free-cutting" brass), using copying lathes.

Finishing the Surface

All of the above-mentioned techniques and procedures were used for the primary purpose of shaping the object. An important secondary goal, almost from the beginning, was to make the piece as beautiful as possible. In order to do so, metalworkers developed many other techniques.

An object could be made smooth and shiny by means of rubbing with very fine sand. There are many minerals which display very different grinding and sanding qualities. Pumice, for example, is a soft vulcanic rock which leaves small scratches on the metal, after which finer polishing can be done with rouge, a ferric oxide made in different grades of fineness. All this sanding and polishing was done by rubbing, sometimes with the aid of rotating on a lathe. Today, polishing wheels and buffs turning at high speeds are used on polishing machines. From the sixteenth to the eighteenth centuries the surfaces of brass instruments were not ground, but shaved with steel shaving tools.

Metal may be given a very high polish by smoothing it firmly in a deliberate and meticulous manner with a highly polished steel or hard mineral tool. Agate and haematite are very suitable minerals for this purpose when polished to a smooth, flawless surface. The combination of shaving or scraping and burnishing gives the old instruments their typical appearance: shiny, but with longitudinal small facets.

Embossing

Striking or stamping designs into walls of an article in such a way that motifs in relief result is called "embossing." An object made of thin sheet metal is filled with a mixture of pitch and sand, or sand and bitumen. It is also possible to push the object into or onto a mixture of pitch which has been softened by heating. This work can also be done on a flat surface of lead. The complementary techniques of chasing and *repousse* can provide surface decoration from the simplest linear patterns to elaborate ornaments in considerable relief. Embossing is done either on the inner or outer side of the object by the use of a variety of steel punches struck with a light hammer. Fine examples of these techniques are to be found on cups, bowls, guild-dishes and many other silver articles of the past.

In instrument making, embossing was of importance only in embellishing the garlands and bosses of the more expensive English trumpets and other highly decorated instruments.

Engraving

This is a very old technique. By scratching on the surface of the metal with some harder materials such as stone, a picture can be made. If this is done on metal which oxidizes easily, these scratches or lines are shiny at first and contrast very beautifully, but in time the lines will fill up with oxide and dirt and become decorative in a new way.

Engraving is, therefore, a method by which metal can be decorated by cutting away material from the surface in lines varying in width and section. The tools are made of small bars of steel, with the cutting edges chamfered to make oblique tips, and set in wooden, mushroom-shaped handles. With these gravers the pictures were "pushed" into the metal. Engraving reached its height in the seventeenth and eighteenth centuries, and was important in making printing plates. Engraving was also important in signing and embellishing trumpets, trombones, and horns. In the Golden Age of instrument making in Nuremberg, garlands were always beautifully decorated with letters (name, date, and place of the maker), master-marks, flowers, etc. Occasionally bells and sometimes even entire instruments were engraved with scenes, flowers, and other decorations.

Etching

Some acids will affect metals in such a way that the metal dissolves and disappears. This is how the characteristic rough and pitted surface is formed. The surface of an article can be covered with a protective coating, called a "resist," and after this has dried the design is scratched through it to expose the metal underneath, which will be affected by the acid or mordant. The depth of the lines depends on the length of time the object is immersed in the acid. By removing more of the resist again after a period of etching, the process can be repeated, and new parts of metal will dissolve. In this way it is possible to make a kind of relief in the metal surface. Sometimes this technique was used in signing instruments and in preparation for the *niello* or *emaille* technique. Etching was also an important process in printing.

Gilding and Silverplating

Pliny was aware of the fact that gold dissolves in mercury. When this gold-amalgam is heated the mercury evaporates and gold remains. This phenomenon made possible the process known as "fire-gilding." A thin layer of amalgam is spread over the object to be gilded. When this is heated slowly on a charcoal fire, the mercury evaporates and a small layer of gold adheres to the surface, which then needs only some polishing or burnishing. Because of the highly dangerous fumes given off in this process, gilding was done in Venice, during the time of Biringuccio, only on the beach, with an offshore wind. Today it is prohibited in most countries.

Silver can be applied by the same process. It is also possible to plate silver with silver nitrate. By immersing the object in a solution of this salt, a layer one molecule thick is formed on the surfaced. Many instruments had gilded and silver-plated parts.

Other embellishing techniques, such as *emaille* and *niello*, in which a colored or black glasslike material is burned on the metal, are not often used in instrument making. One of the trombones in the Accademia Filarmonica in Verona has ferrules with *niello* decoration.

The setting of gems is also rarely seen on instruments. In the Musée du Conservatoire in Brussels there is a Haas trumpet with this manner of decoration.

CONCLUSION

For ages human beings have had the ability to work metals into the shapes required for musical instruments. In the earliest times, control over the processes and the capability to handle the material were the limiting factors. Later—with the sixteenth century being the best example—production techniques were made subservient to the wishes of customers, musicians, and composers. Instruments were made which have never been equalled, neither musically, nor in terms of craftsmanship.

Whether accidental or not, the changes in musical ideas and the development of new technical possibilities came about at the same time. Around 1810 there arose a demand for new instrument designs, and by this time the technology was available to provide them. In every age, desires and possiblities come together on the highest possible level. In brass instrument making this occurred before the Industrial Revolution.

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