Hand tool

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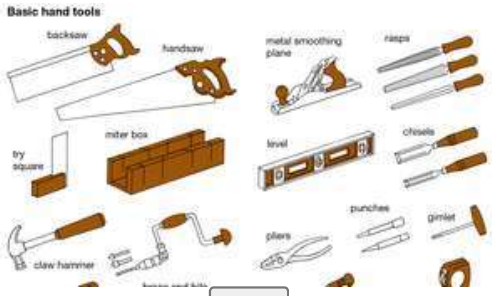
Hand tool, any of the implements used by craftspersons in manual operations, such as chopping, chiseling, sawing, filing, or forging. Complementary tools, often needed as auxiliaries to shaping tools, include such implements as the hammer for nailing and the vise for holding. A craftsperson may also use instruments that facilitate accurate measurements: the rule, divider, square, and others. Power tools—usually handheld motor-powered implements such as an electric drill or electric saw—perform many of the old manual operations and as such may be considered hand tools.



hand tools

Basic hand tools used in carpentry.
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A tool is an implement or device used directly upon a piece of material to shape it into a desired form. The earliest known tools, found in 2011 and 2012 in a dry riverbed near Kenya's Lake Turkana, have been dated to 3.3 million years ago. The present array of tools has as common ancestors the sharpened stones that were the keys to early human survival. Rudely fractured stones, first found and later "made" by hunters who needed a general-purpose tool, were a "knife" of sorts that could also be used to hack, to pound, and to grub. In the course of a vast interval of time, a variety of single-purpose tools came into being. With the twin developments of agriculture and animal domestication, roughly 10,000 years ago, the many demands of a settled way of life led to a higher degree of tool specialization; the identities of the ax, adz, chisel, and saw were clearly established more than 4,000 years ago.

The common denominator of these tools is removal of material from a workpiece, usually by some form of cutting. The presence of a cutting edge is therefore characteristic of most tools, and the principal concern of toolmakers has been the pursuit and creation of improved cutting edges. Tool effectiveness was enhanced enormously by hafting—the fitting of a handle to a piece of sharp stone, which endowed the tool with better control, more energy, or both.

Early history of hand tools

Geological and archaeological aspects

The oldest known tools date from 3.3 million years ago; geologically, this is the middle of the Pliocene Epoch (about 5.3 million to 2.6 million years ago). The Pliocene was succeeded by the Pleistocene Epoch (2.6 million to 11,700 years ago), which terminated with the recession of the last glaciers, when it was supplanted by the Holocene Epoch (11,700 years ago to the present). The Pleistocene and Stone Age are in rough correspondence, for, until the first use of metal, about 5,000 years ago, rock was the principal material of tools and implements.

At first, humans were casual tool users, employing convenient sticks or stones to achieve a purpose and then discarding them. Although humans may have shared this characteristic with some other animals, their differentiation from other animals may have begun with the deliberate making of tools to a plan and for a purpose. A cutting instrument was especially valuable, for, of all carnivorous animals, humans are the only ones not equipped with tearing claws or canine teeth long enough to pierce and rend skin: humans need sharp tools to get through the skin to the meat. Naturally fractured pieces of rock with sharp edges that could cut were the first tools; they were followed by intentionally chipped stones. For archaeologists, the finding of primitive, intentionally made cutting tools indicates and confirms the early presence of humans at a site. Once understood, fire helped shape wooden implements before adequate rock tools were available for the purpose.

Fire was also the basis of metallurgy. When in historic time the powers of water and wind were applied to the daily tasks of grinding grain and raising water, the way to industrialization was opened.

The idea of relating human history to the material from which tools were made dates from 1836 when Christian Jürgensen Thomsen, a Danish archaeologist, was faced with the task of exhibiting an undocumented collection of clearly ancient tools and implements. Thomsen used three categories of materials—stone, bronze, and iron—to represent what he felt had been the ordered succession of technological development. The idea has since been formalized in the designation of a Stone Age, Bronze Age, and Iron Age.

The three-age system does not apply to the Americas, many Pacific Islands, or Australia, places in which no Bronze Age existed before the native inhabitants were introduced to the products of the Iron Age by European explorers. The Stone Age is still quite real in some remote regions of Australia and South America, and it existed in the New World at the time of Columbus's first visit. Despite these qualifications, the Stone–Bronze–Iron sequence is of value as a concept in the early history of tools.

The Stone Age was of great duration, having occupied practically all of the Pleistocene Epoch. Copper and bronze appeared more than 5,000 years ago; iron followed in the next millennium or so and as an age includes the present.

The apparently abrupt transition from rock to bronze tends to mask the critical discovery of native metals and their utilitarian use and fails to indicate the significant discoveries of melting and casting. From bronze one can infer the crucial discovery of smelting, the process by which most of the common metals can be recovered from their ores. Smelted copper necessarily preceded bronze, a mixture of copper and tin, the first alloy. Iron came later, when technique, experience, and equipment were able to provide higher temperatures and cope with problems involved with its use.

Stone as a material

The Stone Age is divided into two contrasting periods: the Old Stone Age, a long era of stagnation; and the New Stone Age, a brief period of swift progress.

The Paleolithic Period, or Old Stone Age, endured until about 10,000 years ago and was characterized by tools of chipped stone, cutting tools with rough and pock-marked surfaces

and generally serrated cutting edges. The later Paleolithic was also an era of wood, horn (antler), and bone. These three materials, all softer than rock but nevertheless intractable, could not be worked successfully without the aid of harder rock tools, such as serrated blades and gravers, or burins, small scrapers with either pointed or narrow, chisel-like ends. Bone was a particularly useful material, for its toughness made feasible barbed fishhooks, eyed needles, and small leatherworking awls.

The term Neolithic Period, or New Stone Age, defines the second period, at the beginning of which ground and usually polished rock tools, notably axes, came into widespread use after the adoption of a new technique of stoneworking. The beginning of the Neolithic, the retreat of the last glaciers, and the invention of food crops, involving agriculture and animal domestication, were more or less contemporary events. The period terminated with the discovery of metals.

The revolutionary art that created the definitive ground and polished tools of Neolithic man was essentially a finishing operation that slicked a chipped tool by rubbing it on or with an abrasive rock to remove the scars of the chipping process that had produced the rough tool. Not only was the edge keener than ever before, but the smooth sides of the edge also promoted deeper penetration and, hence, greater effectiveness, with the added advantage of easier tool extraction from a deep and wedging cut.

As a tool material, the term *rock* covers a wide variety of rocks, ranging from the dense and grainless flint and obsidian to coarse-grained granite and quartzite. Each kind of rock has certain unique properties that are further influenced by temperature and humidity. Stone of any kind is difficult to manipulate. It has been noted, for example, that the indigenous peoples of Australia reject as unsuitable a great many of the flints they have worked on, sometimes in the ratio of 300 rejects to one accepted tool. This high discard rate may help explain the thousands upon thousands of rock artifacts that have been found.

Flint, homogeneous and isotropic (having equal properties in all directions), is the rock of first choice for toolmaking. Reasonably well distributed over much of the world, it is an impure quartz, a form of silica, usually opaque and commonly of gray or smoky-brown colour. It is

harder than most steels, having no cleavage planes, but displaying the conchoidal, or shell-like, fracture of a brittle material that leaves a sharp edge when flakes are detached. (Glass, which may be considered an artificial quartz, also exhibits the conchoidal fracture.) Obsidian, a volcanic glass of rather limited distribution, is usually black or very dark and, because of its conchoidal fracture, was used like flint. Most edged rock tools, however, were of flint. Flint was once an object of trade, and flint mines were in Neolithic time what iron mines became at a later age.

Types of stone tools

Three principal types of tools appeared in the long Paleolithic Period, with substantial variations occurring within each type. The types are distinguished principally by workmanship but also vary in size and appearance and are known as core, flake, and blade tools. The core tools are the largest; the earliest and most primitive were made by working on a fist-sized piece of rock (core) with a similar rock (hammerstone) and knocking off several large flakes on one side to produce a jagged but sharp crest. This was a general-purpose implement for the roughest work, such as hacking, pounding, or cutting. The angle of the cutting edge was rather large because of the sphericity of the stone. In time, thinner, sharper, and more versatile core tools were developed.

Although large flakes with sharp edges of small angle were a by-product of core tool manufacture and were well suited for slitting and scraping, they were not flake tools in the proper sense. True flake tools derived from an advanced technique practiced more than 2 million years later that sought the flake and discarded the core from which it had been detached; flake tools were made deliberately to serve a certain function and were not the casual spin-off of another operation. Finally, there were blade tools, longish slivers of rock with keen unserrated edges, directly useful as knives or as stock from which other pieces might be skillfully broken to serve numerous purposes. While flake and blade tools were developing, core tools were refined by overall chipping to create thinner and more efficient forms.

Techniques for making stone tools

Archaeologists have noted three different techniques for working rock to successive stages of refinement in the Paleolithic Period. The first and always basic method employed the hammerrock to fashion either a large and rude core tool such as the chopper, whose form persisted for perhaps 2 million years, or to rough out (block in) large tool blanks that would be brought to final form by removing small flakes. The hammerrock technique produced short and deep flake scars. A variation employed the anvil stone, a large stationary rock against which the workpiece was swung to batter off large flakes.

The second method was the soft-hammer, or baton, technique, based on a discovery of perhaps 500,000 years ago that hard rock (flint in particular) could be chipped by striking it with a softer material. The baton was a light “hammer,” an almost foot-long piece of bone, antler, or even wood, whose gentler blows detached only quite small flakes that left smooth, shallow scars. Such small flakes, when removed from the large scars left by the hammerstone, reduced the coarse and jagged edge to many small serrations, giving a straighter and more uniform cutting edge whose angle was also more acute than formerly and, hence, sharper.

Pressure flaking was the third technique. In this, a short pointed instrument of bone, antler, or wood was used to pry, not strike, off tiny flakes in order to leave the smallest scars. As the least violent and most advanced of the methods of working stone, it gave the craftsperson the ultimate in control for the removal of materials in the shaping of an implement.

To judge from the few remaining hand-tool-making societies, it is likely that every early human was adept at making new tools quickly and easily and on the spot, as fast as the old ones were blunted or broken. The earliest simple tools, made by taking convenient hand-sized stones and giving them sharp crests by a few well-placed blows, were evidently discarded after use, for their widespread dispersal suggests that they were made at the place of use and abandoned after serving their purpose. Tens of thousands of prehistoric rock tools survive, compared with only very few bits and pieces of the skeletal remains of the makers. Stone, of course, is imperishable, whereas bone is not, and one individual might have made several hundred tools.

Limitations of stone tools

The possibilities in the design of rock tools were limited by the inflexibility and brittleness of the material. The design effort was constrained to the sizing of the tool to the intended task and the development of sharper, longer, and more usefully shaped cutting edges that always required backing to support them. In use, the bending and twisting of long knifelike tools had to be avoided lest the action destroy them; this would also have been true of chisels and gouges. Similarly, even the much later heavier tools, such as the ax and adz, required care in use.

The effectiveness of rock tools has been demonstrated from time to time by both archaeologists and modern workers unaccustomed to such tools. An experienced operator using a rock knife can skin a small animal about as quickly and deftly as he can using steel. When the rock tool is subjected to substantial forces, however, the worker must use caution, intelligence, and control. Care is required to avoid twisting or prying with a rock blade (knife or ax); a thin blade may snap, and a thick one may collect local nicks.

Paleolithic tools

Early tools are classified by their industry, or type of workmanship. Such tool traditions are identified by a name derived from the site at which the type first drew archaeological attention. For example, the primitive chopping tools that persisted for nearly 2 million years, first identified in Olduvai Gorge, east of Lake Victoria, Tanzania, constitute the so-called Oldowan industry, regardless of the part of the world in which implements of similar workmanship happen to be found.

The sequence of traditions shows growth and development; it does not imply abrupt transitions at certain times or the disappearance of an old industry with the advent of another. A new technique simply meant that something better or different could be accomplished, from the refinement of the cutting edge or the upgrading of old tool forms to the manufacture of a completely new tool. Innovation sometimes was possible only by drawing upon previously unworkable materials.

An overview of the products of the successive toolmaking industries shows that much effort went into cutting edges in the longitudinal direction of the pieces of flint. Knifelike instruments predominated and thus defined the nature of the fundamental need—namely, that of a cutting tool which could slit and sever.

With the passage of time and the acquisition of skills, the average size of the tool decreased; there was more cutting edge per pound of material, an important factor when flint had to be imported to a region. This trend was reversed in the Neolithic Period, when the heavy woodsman's ax and adz became essential elements for clearing forests for agriculture and timber. The world was then changing from an economy based on gathering and hunting food to a way of life founded on raising food.

Archaeologists have named the early tools by guessing at their presumed use, often in the light of other known facts about the culture in which the tradition appeared. As the tools move closer to the present, and specialized forms are seen in the creation of a wider variety of products, the descriptive name is on firmer ground.

Eoliths

The first act of the drama of tools is hazy. There are what have been called eoliths, "tools from the dawn of the Stone Age." Such stones with sharp fractures, found in great quantities in layers from the geological epochs before the Pleistocene, were once assumed to be tokens of human presence in the preceding Pliocene and even earlier Miocene epochs. These rocks, fractured by glacier pressure, wave action, or temperature change, are no longer taken as indexes of humans, although primitive peoples undoubtedly used them as ready-made objects before they deliberately started to fracture similar rocks in the late Pliocene. There are detailed criteria by which human-flaked and nature-flaked stones can be almost unerringly distinguished. Human origin is also evidenced by association with detached flakes and the stones that served as hammers.

The oldest known tools—consisting of primitive hammers, anvils, and cutting tools and dating to 3.3 million years ago—were discovered in 2011 and 2012 at the Lomekwi 3 site near

Kenya's Lake Turkana (Lake Rudolf). Tools found in 1969 at the Koobi Fora site, near Lake Turkana, consisted of five choppers, a number of flakes, and a couple of battered stones. The tools lay on the surface; the flakes were found three feet below them in tuff (volcanic rock) datable to about 2.6 million years ago. Artifacts known from Olduvai Gorge, Tanzania, included tools, as well as the jaw and teeth of a human who may have been the toolmaker. These items were found in the 1950s under tuff having a potassium-argon date of about 1.8 million years, a Lower Pleistocene age.

All of these tools are of a single type, a general-purpose implement that changed little in form during the next 2 million years. It is variously known as a pebble tool, pebble chopper, chopping tool, or simply as a chopper. Waterworn and hence rounded, up to about the size of a fist, the pebble, preferably flattish rather than spherical, was given a few violent but skillfully applied blows by a hammerstone. Several large flakes or chips were knocked off the rock to create on it a sharp and roughly serrated crest, or ridge, yielding an implement that was edged at one end and could be gripped at the opposite end. Rudimentary yet versatile, the chopper could be used to hack, mash, cut, grub roots, scrape, and break bones for their marrow.

Although the large sharp-edged flakes struck from the pebble were themselves useful for light cutting and scraping, it was not until perhaps 40,000 years ago that there was a development of flake tool industries in which preshaped flakes were purposefully detached from a core that was then discarded. But the Oldowan chopper and the struck-off flakes—the earliest generalized primitive tools—between them solved the problems of how to get through the skin of a slain animal, dismember it, and divide the meat.

The Acheulean industry

As the Pleistocene Epoch progressed, humans slowly developed the primitive chopper into a better instrument. About half a million years ago a superior implement finally appeared after nearly 2 million years of effort. The industry, or style, is known as the Acheulean, and the typical implement was the flint hand ax (sometimes called a fist hatchet). Throughout the ages the plump chopper and its bluntly angled crest had been streamlined by starting with a longer piece of rock and flaking the entire surface to produce an almond-shaped (amygdaloid)

implement 20–25 cm (8–10 inches) long. This stone, much thinner than the chopper, was also sharper and more effective because the cutting edges were formed from the intersection of two curved and flaked surfaces (bifacial working).

This Acheulean hand ax was the product of evolution; certain of the intermediate stages, clearly leading to the typical and standardized form, have been identified as Chellean and Abbevillian. Despite the term *ax*, the tool was not hafted but was simply held in the hand. One end was tapered, the other rounded. The tapered end might be rather pointed or have a small straight edge. The tool was sharp for most of its periphery and seems to have been primarily a hunter's knife but probably very useful, too, for other purposes, such as chopping, scraping, grubbing, and even piercing. Sharp, thin and symmetrical, light and elegant, it was quite different from the heavy chopper, with its rather blunt edge.

Another biface, the Acheulean cleaver, assumed prominence about 250,000 years later. A variant of the hand ax, it had a wide cutting edge across the end instead of a point and was better suited than the hand ax for hunting or hacking wood.

Neanderthals, excellent hunters and toolmakers, appeared on the scene at least 200,000 years ago, just ahead of the last glaciation but well within the Acheulean. Their tool kit was impressive for the wide variety of hand axes, borers, knives, and choppers it contained. The kit was novel for its scrapers and heavily serrated blades having a sawlike appearance, implements that were essential to the working of wood, bone, and horn into tools and weapons. The Neanderthals regularly used fire, and it is presumed that they could make it, although the direct evidence is missing. Fire was useful in tool manufacture, for charring the end of a stick not only helped shape the point by making it easier to scrape but also hardened it, as for a spear point. This fire hardening was probably the first human-manufactured modification of a natural property. Thoroughly wet wood, bent to shape and brought to dryness over the heat of a fire, would retain its bent form, a most useful property.

The Mousterian flake tools

The Mousterian and related flake industries followed the Acheulean. A refinement of the prepared-core technique, termed Levallois, was developed during the middle to upper Acheulean. In this method, a core was craftily trimmed in such a manner that a skillfully applied last blow would detach a large preshaped flake directly usable as an implement; the core was discarded. Such a flake tool, with one flat surface, is known as a unifacial tool because a single bevel forms the working edge. There are two principal kinds of flakes, points and scrapers. The former are roughly triangular, with two trimmed or sharp edges meeting in a point, the base or butt of the triangle being thick and blunt. The side scrapers have a sharp edge in the long direction of the flake, with an opposite, thicker butt section. The scraper could function as a knife, although it is speculated that it was used for working wood and skins, a supposition leading to the idea that skins were being used for clothing.

Late Paleolithic toolmaking

The fourth phase of Paleolithic toolmaking was introduced perhaps 40,000 years ago by the Aurignacian industry, a forerunner of the last and most brilliant achievements of the Old Stone Age. Extraordinary inventiveness was characteristic of the Aurignacian tradition and its several short-term successors. They can be lumped into a unit of development that spans the next 25,000 years.

Fully modern humans—whose first representative is the Cro-Magnon—emerged within this period, perhaps 35,000 years ago, during the time of the development and elaboration of rock technology, which, by providing a variety of specialized tools, mostly of the flake and blade types, at last brought materials other than rock into extensive use. It was also a time when the great plains in northern and eastern Europe carried such a heavy reindeer population, in addition to wild horses and mammoths, that it has been called the Reindeer Age. This produced a hunting economy providing food and great quantities of bone, horn, skin, sinews, and, while the mammoth lasted, ivory; with it grew new technologies exploiting the unique properties of materials hitherto unworkable because of their hardness. This technological diversification was made possible by new techniques and rock tools, whose specialization and complexity fit them to the fresh tasks. The most significant tool was the burin, or graver, a stout, narrow-bladed flint able to scrape narrow grooves in bone; two parallel grooves, for

example, would allow a sliver of bone to be detached as stock for a needle, pin, awl, or other small object. Larger pieces of bone were worked into hooks with one or more barbs or points. Sections of antler were carved into splitting wedges to work out long pieces of bone to form the dartlike projectiles of the spear-thrower. Sandrock polishers were added to the tool kit to sharpen and shape tips, needles, and other articles.

A spectacular item that developed by the end of the Paleolithic was the spear-thrower, a hand-held stick, of wood or antler, notched at one end. Functioning as an extension of the arm, it added considerable kinetic energy, and therefore range, to a short spear tipped with flint or bone. The tipped projectile represented still another innovation, for it was the first hafted implement.

Hafting, or the fitting of a handle to a cutting edge, was a momentous and far-reaching invention of about 35,000 years ago. It was a critical step toward the creation of new tools and improved models of old ones. In its simplest form, the haft may have been no more than a grass or leaf bundle whose limited function was to protect the hand when a fractured rock was used as a knife. Mechanically, the handle became a force-transmitting intermediary between the source of the force and the toolhead. An extension of the arms, the handle provided an increased radius of swing. This moved the toolhead faster to give it more kinetic energy for a harder and more telling blow than the arms alone could provide. A man using a hand-held axhead could cut only small trees, whereas with a hafted ax he could fell a tree of almost any size.

The prepared-core technique that provided preshaped flakes was refined and extended to provide preshaped blades, long, slender pieces of flint of trapezoidal cross section, each corner having a straight cutting edge without the serrations of a chipped tool. This is known as the blade tool industry, a final complement to the core and flake tool technologies. Such blades made thin and splendid knives of great variety; many of these knives were backed; that is, the back of the blade was blunted for safer handling. Thin blades were further reduced to smaller pieces, often having a geometric form such as triangular, square, or trapezoidal, called microliths. These small bits of sharp flint were cemented (using resin) into a groove in a piece

of wood to form a tool with a cutting edge longer than it was feasible to produce in a single piece of brittle flint; examples are a spear with a long cutting edge or the farmer's sickle of later date.

The second major mechanical invention of the Upper Paleolithic was the bow, a device even more effective than the spear-thrower for increasing the distance between the hunter and the hunted. It is difficult to date precisely, for the only evidence of its use is found in cave paintings. Mere finds of rock points without bows prove nothing because such tips were used on the projectiles of spear-throwers. The earliest representations of the bow come from North Africa from 30,000 to 15,000 BCE. Once the bow had been devised, it spread with astonishing rapidity, its effectiveness making it the weapon par excellence. When the bow was pulled, it stored the gradually expended energy of the archer's muscles; this energy was suddenly released to give the projectile a "muzzle velocity" far higher than that possible from a spear-thrower and of superior accuracy. It was a principal weapon through the 15th century CE and was ousted then only by gunpowder.

Neolithic tools

The Neolithic Period, or New Stone Age, the age of the ground tool, is defined by the advent around 7000 BCE of ground and polished celts (ax and adz heads) as well as similarly treated chisels and gouges, often made of such stones as jadeite, diorite, or schist, all harder than flint. A ground tool is one that was chipped to rough shape in the old manner and then rubbed on or with a coarse abrasive rock to remove the chip scars either from the entire surface or around the working edge. Polishing was a last step, a final grinding with fine abrasive. That such a tool is pleasing to the eye is incidental; the real worth of the smoothing lay in the even cutting edge, superior strength, and better handling. The new ax would sink deeper for a given blow while delivering a clean and broad cut; its smooth bit, more shock resistant than the former flaked edge, had less tendency to wedge in a cut.

Although the polished rock tool is the index to the Neolithic Period, it may be noted that the ice sheets were receding and climatic conditions were assisting the conversion of hunters into herdsmen. The new, relatively sedentary life spawned further inventions, such as pottery.

From the standpoint of tools, the potter's kiln and art were necessary steps to metals, for a modification of the kiln probably provided the high temperatures and equipment needed for metalworking, first for melting native metals and later for the smelting process that gave rise to a wealth of metals, several of which proved to be superior materials for tools.

The polished Neolithic ax, a heavy implement, was in sharp contrast to the delicate small-rock work of the last stages of the Paleolithic Period and was a reversal of the traditions of products that had yielded ever more lineal feet of cutting edge per pound of stone. The ax and its companion adz met the need to clear land as agriculture developed. An efficient tree-cutting tool was indispensable for the slash-and-burn agriculture then devised. Trees were either cut down or killed by ringing them with an ax; the debris was burned over, with the ashes conferring a slight enrichment of the stump-filled field. The soil was next scarified with sticks or stone-headed hoes resembling the adz to prepare it for seeding among the stumps. Without manuring or other treatment, the land was exhausted after a few years, necessitating a repetition of the clearing process elsewhere. The consequence was a shifting settlement pattern, with a good ax needed not only for felling trees but also for working timber for settlement.

Wood began its broad role in human life with the ground and polished tools of the Neolithic. Home and fire, furniture and utensils, cradle and coffin were products of the ax, adz, and chisel, which could fashion wood intricately and with precision. This kit of tools turned wood into an almost universal building material, for a host of new things was now possible, such as dugout canoes of oak, paddles and framing for hide-covered boats, sledges, skis, wooden platters and ladles, as well as other household gear. Mortise and tenon joints were invented for the structural framing of substantial habitations. Some of the gabled houses were up to 30 metres (100 feet) long and 20 metres (66 feet) wide and are believed to have served as both granaries and living quarters for perhaps 20 people comprising several families.

In a revealing experiment, 4,000-year-old polished rock axes, furnished by the Danish National Museum and carrying the sharpness left after their last use 4,000 years ago, were fitted with ash handles modeled after that of a Neolithic hafted ax preserved in a bog, giving

the ax an overall length of nearly 63 cm (25 inches). (A modern steel felling ax has a 91-cm [36-inch] handle.) When these were used in a Danish forest, it was soon found that the violent action of the modern technique of swinging a steel ax and putting shoulder and weight behind the blade to give long and powerful blows was disastrous, either ruining the edge or breaking the blade. Proper handling meant short quick strokes that chipped at the tree, the body action being constrained to mainly elbow and wrist motion. After getting into form, the men found it possible to fell an oak tree more than 0.3 metre (1 foot) in diameter in half an hour or a pine 61 cm (2 feet) in diameter in less than 20 minutes. One-eighth acre (600 square yards, or 0.05 hectare) of silver birch forest were cleared by three men in four hours. One axhead cut down more than 100 trees on its original (old) sharpening. It was concluded that Neolithic people and their ground flint axes had no great difficulties in making large clearings in the forest for the purposes of cultivation. It may also be remarked that it was less trouble to clear the forest than to break the age-old and tough sod of the plains.

The Neolithic farmers of northern Europe, with their practice of deforestation for agriculture, were completely dependent upon polished axes. This created a heavy demand for good rock that depleted local sources and resulted in flint mining in well-endowed locations in what are now England, Belgium, the Netherlands, France, Denmark, Sweden, Poland, Portugal, Sicily, and Egypt. Often more than just mining, these operations were ax factories where flints were shaped into rough form by chipping at the pithead and then traded. Grinding and polishing were done by the consumer.

An idea of the magnitude of such a mining enterprise is offered by the well-explored workings known as Grimes Graves, about 130 km (80 miles) northeast of London. The site covers about 34 acres (14 hectares) and includes both opencast workings and 12.2-metre- (40-foot) deep shafts with radiating galleries that exploited the flint deposit laid down as a floor under chalk beds. Excavation was probably by wooden shovel (a product of the polished ax and chisel) or possibly the shoulder blades of oxen. It is estimated that 50,000 picks made of red-deer antlers were used during the 600 years of activity in the mine, which began about 2300 BCE.

A last innovation of the Neolithic was the augmentation of the two older techniques of working stone, chipping (or flaking) and grinding, by a third, the pecking, or crumbling, method. In this procedure a point of the rock being worked was bruised by a hard hammerstone, the struck points crumbling into powder under relatively light but rapidly delivered blows. This technique allowed the manufacture of tools from numerous varieties of appropriate but nonflaking rock and the production of hollow ware, such as querns for grinding grain, mortars, and bowls. It also could be applied to flakable stone; such a stone, after having been roughed out by flaking, was pecked to level the ridges between flake scars before grinding and polishing.

Stone tools maintained themselves during the Metal Age, yielding only slowly to the new material, which was expensive and the product of special skills. The copper and bronze tools and weapons for hunting, warfare, husbandry, and domestic use that constitute impressive displays in museums were rare luxuries. Even the much more abundant iron, which overtook and replaced copper and bronze articles, was available only sparingly for many centuries.

Early metals and smelting

The discovery that certain heavy “stones” did not respond to hammerblows by flaking or fracturing but were instead soft and remained intact as their shapes changed marked the end of the long Stone Age. Of the pure, or native, metals, gold and silver seem to have attracted attention at an early date, but both were too soft for tools. The first metals of value for toolmaking were natural copper and meteoric iron. Although they were scarce, they were tough and potentially versatile materials that were suited for new purposes, as well as many of the old. They also introduced a new problem, corrosion.

Metalworking

Copper occurs in native state in many parts of the world, sometimes in nuggets or lumps of convenient size. It is malleable; that is, it can be shaped by hammering while cold. This also hardens copper and allows it to carry a sharp edge, the hammered edge being capable of further improvement on an abrasive stone. After a certain amount of hammering (cold-working), copper becomes brittle, a condition that can be removed as often as necessary by

heating the material and plunging it into cold water (quenching). The softening operation is known as annealing, and repeated annealings are necessary if much hammering is required for shaping.

Among early toolmakers, nuggets of copper were hammered into sheets, divided into strips, and then separated into pieces to be worked into arrowheads, knives, awls, choppers, and the like. Copper was also shaped by beating pieces of the soft metal into appropriately shaped rock cavities (molds).

Meteoric iron, widely distributed but not in heavy deposits, was a highly prized material more difficult to fabricate than the softer copper. Its celestial origin was recognized by the ancients: the ancient Egyptians called it black copper from heaven, and the Sumerians denoted it by two characters representing heaven and fire.

Like copper, iron hardens under the hammer and will then take a superior edge. Iron can be annealed, but the process is quite different from that of copper because, with iron, slow cooling from a high temperature is necessary. Meteoric iron is practically carbonless and, hence, cannot be hardened in the manner of steel; a high nickel content of about 8 percent makes it relatively corrosion resistant.

For early toolmakers, small meteorites were the most convenient sources of iron, but larger bodies were hacked at with copper and rock tools to yield tool-sized pieces for knives, spear points, arrowpoints, axheads, and other implements. Meteoric iron was beaten into tools in much the same way as copper, although it could not be forced into a mold in the manner of the softer metal. Much rarer than copper, meteoric iron also was often used for jewelry, attested to by burial finds of necklaces of iron and gold beads, iron rings along with gold rings, and ornaments in sheet form.

Casting

In casting, a liquid metal is poured into a cavity or a mold, where it takes the shape of the mold when it congeals; casting shapes the metal to essentially final form once a proper cavity

has been prepared. Some touch-up work may be needed; for an edged copper tool, such as an ax or knife for example, hammering the cutting side gives a keen edge.

A great step forward was made with the discovery that gold, silver, and copper could be melted and cast with many advantages. Casting meant that the size of the tool was no longer dependent on the size of a chunk of available copper. Old tools could be added to a melt instead of being thrown out. This reuse of old metal accounts in part for the scarcity of virgin-copper implements.

To make the procedures of melting and casting possible, several innovations were required. Pottery making, already well established, provided the knowledge of heat-based processes. Clay vessels were essential to working with fluid metal, for, in all but the most primitive operations, it was necessary to convey the melt from furnace to mold. Aside from providing crucibles, pottery making taught how to restructure a fire with a deep bed of prepared charcoal to provide a heat superior to that of a simple campfire. Tongs of some sort had to be devised to carry the hot crucible; it is surmised that green branches were bent around the pot and replaced as needed.

A number of forms of molds were developed. The most primitive was simply an impression of a rock tool in clay or sand to give a cavity of the desired form. A more durable mold resulted when the cavity was worked into stone. Cavities of uniform depth allowed flat but profiled pieces to be cast. For example, some ax blade castings were roughly T-shaped, the arms of the T being afterward bent around to clasp a handle of some sort, with the bottom of the T becoming the cutting edge. A one-piece mold, prepared for a dagger, could have a groove for most of the length of the cavity to provide a stiffening rib on one side. With experience, closed but longitudinally split and, hence, two-piece molds were devised, each side having a groove down the middle to furnish a strengthening rib on both sides of the blade.

Split molds for copper were not desirable because pure copper is a poor metal for casting. It contracts a good deal on cooling and has a tendency to absorb gases and thereby become porous, blistered, and weak. Also, molten copper exposed to atmospheric oxygen contains embrittling cuprous oxide.

Smelting

Perhaps 1,000 years after humans learned about melting virgin copper, they found that still another stone, a brittle one directly useless for tools, would produce liquid copper if sufficiently heated while in contact with charcoal. This step was epoch making, for it was the discovery of smelting, or the separation of a metal from a chemical compound called ore. Smelting, as differentiated from melting, was the first metallurgical operation and is still the principal method of gaining metals from their ores. Copper was the first metal to be smelted; it was another 1,000 years before iron was reduced from its ores.

Mycenaean dagger, bronze with gold, silver, and niello, 16th century BC. In the National Archaeological Museum, Athens. Length 16.3 cm.
Hirmer Fotoarchiv, Munich

As mined, raw ore is a nonchemical mixture of ore proper (heavy) and earthy matter, or gangue (light); the two may be largely separated by crushing the raw ore and washing away the lighter gangue. The ore proper is a chemical compound of oxides, sulfides, carbonates, hydrates, silicates, and small amounts of impurities such as arsenic and other elements. Smelting frees the metal from the various combinations with which it is bound into the compound form. A preparatory step is to heat the washed ore (roasting, or dressing) not only to dry it but also to burn off sulfides and organic matter. Early practice involved heating the ore in intimate contact with charcoal to provide the essential reducing atmosphere, producing a metallic sponge made up of metal and slag. For chemical as well as practical reasons, the iron of tools, wrought iron, continued to be worked out of the spongy mass until the Middle Ages.

Originally copper smelting was terminated at the spongy stage. Early smelters soon discovered that better results were obtained when the metallic sponge was left in the furnace and subjected to draft-induced high temperatures. The metal became liquid and seeped down to the hearth, as did the slag, which, being lighter than the metal, floated over it, permitting recovery of the copper.

At some time during the copper period, a new kind of “copper” happened to be made by smelting together two separate ores, one bearing copper, the other tin. The resulting metal was

recognized as being far more useful than copper alone, and the short period of copper tools came to an end. The new metal, a copper–tin alloy of mostly copper, was bronze. It was produced in the fluid state at a temperature less than that needed for copper, could be formed economically by casting, and could be hammer-hardened more than copper. The tin noticeably increased the liquidity of the melt, checked the absorption of oxygen and other gases, and suppressed the formation of cuprous oxide, all features that facilitated the casting operation. A two-piece, or split, mold, impracticable for copper, worked very well with bronze. Furthermore, it was found that bronze expanded just a bit before solidifying and thus picked up the detail of a mold before it contracted in cooling.

The earliest bronzes were of uneven composition. Later, the tin content was controlled at about 10 percent, a little less for hammered goods, a little more for ornamental castings. The edges of hammered bronze tools of this composition were more than twice as hard as those obtained from copper.

The Bronze Age of tools and implements began about 3000 BCE. In the course of the following 2,000 years the much more abundant iron supplanted bronze for tools, but bronze continued to be used in the arts.

All of the early metals were expensive commodities in antiquity and were monopolized by kings, priests, and officials. Most metal was diverted to the manufacture of weapons for professional soldiers. Industrial use was severely limited. The metal chisel was used on rock for buildings of state or for fashioning furniture for the wealthy; the common people living in a mud or reed hut had no reason to own such a tool.

Generally speaking, molds for copper and bronze were of baked clay, although soft rock was sometimes carved; metal molds are known from about 1000 BCE. Sectional molds of three and four pieces, permitting more complex castings, are known from about 2600 BCE. The earliest metal tools and implements were simply copies of existing rock models. It was only slowly that the plasticity of the new medium and especially the possibilities inherent in casting were appreciated. The rock dagger, for example, was necessarily short because of its extreme brittleness. With copper and then bronze, it became longer and was adapted to slashing as well

as to stabbing. Casting allowed forms that were impossible to execute in flaked stone, such as deeply concave surfaces. Holes could be cast in, rather than worked out of, the solid.

Sometimes the process was reversed. There were, for example, pottery imitations of bronze vessels for the poorer classes, with such necessary adjustments as a heavier lip for the pottery jug. The lines of bronze daggers have been noted in rock daggers of a later date, despite the difficulty of imitating a metal object in stone. Bronze axheads were copied in stone, even to the shaft hole, which was difficult to produce and impractical for a rock tool; it is possible that some of the rock replicas of bronze daggers and axes were used for ceremonial rather than utilitarian purposes.

Malleable metal had several advantages over a brittle material, such as rock or bone or antler. It could be severely deformed without breaking and, if badly bent, could probably be returned to service after straightening. It was shock resistant and chip-proof, good qualities for use in the ax, adz, and chisel, and the edges could be kept keen by hammering or abrasion; its sharpness was, however, inferior to that of good stone. In particular, metal allowed the fashioning of many small items, articles of a size awkward to make of bone or horn, such as pins, fishhooks, and awls. Copper pins were stronger, tidier, and more attractive than the fish bones and thorns they replaced for securing clothing; even in the 3rd century BC there were shapes resembling the modern safety pin. Tweezers were invented, but whether for depilatory or surgical purpose is unknown; there are artifacts presumed to be scalpels. Plates, nails, and rivets also developed early.

The most common tools were awls and pointed instruments suitable only for wood and leather. Woodworking was facilitated by the invention of the toothed copper saw, made of smelted metal and cast to shape. Edged tools—the ax, adz, and chisel, at first similar to rock models—became predominant, and, although not nearly as sharp as the tools they replaced, they had the advantage of toughness and could easily be resharpened. In particular, the chisel made it possible to use cut rock for construction purposes, principally in temples and monuments. Abrasive sand under metal “saw blades” allowed rock to be cut neatly, just as the

sand under tubes (made from rolled-up strips) that were turned provided a boring device for larger holes.

Iron and steel tools

Iron technology was derived from the known art of reducing copper and bronze. The principal requirement was a furnace capable of maintaining a reducing atmosphere—i.e., one in which a high temperature could be maintained from a good draft of air. The furnace had to be tall enough to allow the iron to drop from the smelting zone and form a slaggy lump, usually called a bloom.

After aluminum, iron is the most abundant metal, constituting about 5 percent of Earth's crust. Copper is in short supply, having a presence of only 0.01 percent. Iron ore suitable for simple smelting was widely distributed in the form of surface deposits that could be scraped up without elaborate mining procedures.

The limitations imposed by the dearth of metals in the Bronze Age were now lifted; new tools and implements became possible, and their numbers could increase until even the poorer classes would have access to metal tools. The iron of antiquity was wrought iron, a malleable and weldable material whose toughness was enhanced by forging. Brittle cast iron, versatile and widely used in modern industry, was unknown to the ancients, and it would have been of no value for their edged tools and implements. The earliest history of smelted iron is obscure, with the first scanty evidence of man-made iron dating from about 2500 BCE in the Middle East. A thousand years later the abundance of ores led to the displacement of copper and bronze by iron in the Hittite empire.

During most of its history, iron was not recovered in a molten state but was reduced to a spongy aggregate of iron and slag formed at a temperature well below the melting point of pure iron (1,535 °C, or 2,795 °F). This plastic metallic sponge was consolidated by hammering to squeeze out slag and weld the iron particles into a compact and ductile mass; thus it was called wrought iron, essentially pure iron with remnants of unexpelled slag coating the iron particles. Wrought iron contains so little carbon that it does not harden usefully when

cooled rapidly (quenched). When iron containing 0.4 to 1.25 percent carbon is heated to 950 °C (1,740 °F) and then plunged into water or oil, it is hardened.

By about 1200 BCE, when iron had become important in the Middle East, humans had learned how to create on wrought iron a steel surface, or case, that could be hardened by heating and quenching. This case was produced by the prolonged heating of wrought iron packed in a deep bed of glowing charcoal. The procedure worked because a surface of red-hot carbonless iron readily absorbs carbon from the carbon monoxide generated in the enveloping charcoal fire.

Knowledge of casting gathered from working with smelted copper and bronze did not apply to a metal whose shape could be changed only by hammering. Moreover, the malleability of iron is less than that of copper for the same temperatures, which means that the smith has to work harder to change the shape of the metal. Stone hammers gave way to hafted bronze hammers, iron itself coming into use later. The first anvils—for copper and bronze—were convenient flat stones; they were followed by increasingly larger cast-bronze models that in turn were superseded by rudimentary forms of the modern type, in which several pieces of iron are welded together. The earliest iron artifacts are of ruder appearance than the bronze articles that came before them.

A valuable property of wrought iron is the ease with which two or more pieces may be united by hammering while the metal is at a high temperature. Even at the production stage, small pieces of spongy iron were united into larger blooms. Hammer welding had been practiced before by goldsmiths and, in spite of the difficulties due to gassing, was even used for joining copper to make, for example, tape by welding together strips cut from plate. Welding became an essential production procedure. When iron tools had reached the end of a useful life, they could be reused by welding the scrap into a blank and starting over, a process akin to the melting of copper and bronze scrap to cast new tools.

Iron ordinarily has twice the flexibility of bronze and is much tougher, for a bar of iron can be bent back upon itself without fracturing, whereas a bronze bar (such as a sword blade) breaks after only a light bend (bronze blades repaired by casting new metals into the fractured sections are known). Bronze, in other words, is brittle when compared to iron, although copper

is not. As the tin content of bronze rises, hardness increases, but ductility is lost. Most of the malleability is missing from cold bronze with 5 percent tin, and ductility becomes practically nil at a 20 percent tin content. The cutting edge of a hammered bronze tool is superior to that of a similarly treated iron tool, and it is corrosion resistant.

In the Early Iron Age, when the metal was still in scarce supply, local armament makers were the chief consumers of the new metal. Agricultural tools, needed for clearing forests and for cultivation, were the next iron tools to develop. Axes, picks, and hoes also were needed. Iron was smelted in the Middle East before 2500 BCE, but the Iron Age proper was 1,000 or more years in maturing. Its full development came with the discovery of hardening by carburization (addition of carbon) and heat treating, which led to superior edged tools of great toughness.

Toward increasing hand tool specialization

During the evolution of tools over more than 3.3 million years, using as principal materials, successively, stone, bronze, and iron, humans developed a number of particular tools. Taken together, these specialized tools form an inverted pyramid resting upon the first general-purpose tool, the nearly formless chopper. With the discovery of metals and the support of numerous inventions allowing their exploitation, the first approximations to the modern forms of the basic tools of the craftsperson established themselves, with the main thrust of further development directed at improving the cutting edges.

The earliest tools were multipurpose; specialized tools were latecomers. A multipurpose tool, although able to do a number of things, does none of them as well as a tool designed or proportioned for one job and one material. How a handle is added to a tool (hafting) provides the primary distinction between the knife, ax, saw, and plane. An application or craft is best served by a further specialization or form within a category: the knives of the butcher, woodcarver, and barber reflect their particular tasks. When confronted with the unusual, a skilled craftsperson develops a special tool to cope with the situation. In the early 19th century, for example, joiners had dozens of planes in their kits to deal with the many moldings, rabbets, and jointings they had to produce before the day of machine-made stock and mill-planed lumber.

Percussive tools

Several tools involve a violent propulsion to deliver a telling blow. These have been named percussive tools, and their principal representatives are the ax and hammer. Under these two names are found an immense number of variations. The percussive group may also be called dynamic because of the swift motion and the large short-term forces they develop. This means that mass and velocity and, hence, kinetic energy and momentum are factors related to the force generated or transmitted. The distribution of weight between the head and handle and the mechanical properties of the head (i.e., its suitability for a cutting edge or its lack of elasticity) must also be recognized in the design of a percussive tool. Obviously, these various influences were not formally considered during the agelong trial-and-error evolution of a now successful tool, but recognition of them aids in identifying the evolutionary stages of the tool.

hammer

Hammer.

Michael Jastremski

Percussive tools generally have handles that allow them to be swung; that is, their rapid motion endows them with kinetic energy. The attainable energy of a blow depends upon a number of factors, including the weight of the toolhead, the angle through which it is swung while gaining speed, the radius of the swing (handle length plus part or all of the arm length), and the muscle behind it all. There is a permissible energy level for a given task and tool, set by either the nature of the task or the material of the tool. Thus, a blacksmith flattening a 1-inch (2.54-cm) iron bar needs a heavy, fairly long-handled hammer, whereas a light and short-handled hammer, used with wrist action, is appropriate for forging a small soft gold wire. A hafted flint ax is an effective tool, but it may be destroyed if swung too hard or if twisted while in the cut. Bronze and steel axes can, and do, take longer handles than the stone ax and, being of tougher material, will not break under use that would fracture a stone head.

The physics of percussive tools takes into consideration the centre of gravity and what is technically called the centre of percussion—i.e., a unique point associated with a rotation, in this case the arc through which the tool is swung before delivering its blow and coming to rest. The tool’s centre of gravity is readily found because it is the balance point, or location along the handle at which the tool can be picked up loosely and still remain in the horizontal position. The centre of percussion is the ideal point at which striking should occur on the

toolhead to minimize the sting of the handle in the operator's hand as well as to deliver a blow with maximum force; this point is farther out than the centre of gravity and should be as close to the centre of the head as possible. This last condition is best met with a light handle and heavy toolhead, which places the centre of gravity close to the head and the centre of percussion in an optimum location in the cutting edge.

It is apparent that the sheer weight of the head is of paramount importance in promoting a proper balance, or hang, to the tool. On this basis alone, the shift from stone axheads to metal was a step in the proper direction because metal heads of the same size as those of stone are about three times as heavy. With the heavier head, the centre of gravity of the hafted tool is closer to the head, and the centre of percussion is more likely to be properly located.

With the mallet and chisel still other interrelations are involved. When working stone, a brittle material that responds to a sharp tool point by breaking into small chips, the sculptor strikes many light blows to remove material. As a consequence, mallets have short handles and the amplitude of swing is small, allowing a succession of rapid blows without undue fatigue. To provide energy and momentum, the mallet head is heavy. Being made of wood, it does not rebound in the manner of a metal head but stays on the chisel, which transmits the blow to the cutting edge and focuses it into a small area of stone to be chipped off. The net effect of the proper combination of all elements—the properties of wood, chisel, and stone, the weight of the head (perhaps even heightened by a lead-filled cavity), and the short handle—is to waste the least energy. The wooden head is of course expendable, particularly if it is of a one-piece clublike construction, for it becomes badly battered from contact with the metal chisel. A more refined mallet consists of a separate head and handle, the head having a working face of end-grain wood.

Working metal with a chisel requires that heavy blows be struck to enable the chisel to dig into the metal and lift out a chip. A steel hammer with a hardened face is used, and in this operation it is the soft end of the chisel that is battered and needs periodic dressing.

Hammers and hammerlike tools

Hammer is used here in a general sense to cover the wide variety of striking tools distinguished by other names, such as *pounder*, *beetle*, *mallet*, *maul*, *pestle*, *sledge*, and others. The best known of the tools that go by the name *hammer* is the carpenter's claw type, but there are many others, such as riveting, boilermaker's, bricklayer's, blacksmith's, machinist's ball peen and cross peen, stone (or spalling), prospecting, and tack hammers. Each has a particular reason for its form. Such specialization was evident under the Romans, and a craftsperson of the Middle Ages wrote in 1100 CE of hammers having "large, medium and small" weight, with further variations of "long and slender" being coupled with a variety of faces.

Since a pounder, or hammerstone, was the first tool to be used, it may also have been the first to be fitted with a handle to increase the blow. Although some craftspersons of the soft metals still favoured the handheld stone, presumably for its better "feel," hafting was an enormous technological advance. Yet it created a problem of major proportions that still persists—the joint between the handle and the head must carry shock loads of high intensity, a situation even more complicated with the ax than the hammer because the ax may be subjected to twisting on becoming wedged in a cut. The most satisfactory solution for metal heads is to create a shaft hole in the toolhead; it is a poor solution for a stone tool because it weakens the head, although it was tried, especially in stone imitations of bronze axheads.

In hammer hafting, it is possible to distinguish between long handles that allow tools to be swung to give them speed and those simpler handles by which a tool such as a pavement tamper may be picked up so that it can be dropped. A long handle, even if not needed for dynamic effect (as in a tool used only for light blows), makes the tool easier to control and generally reduces operator fatigue.

The oldest form of hafted hammer, probably the miner's maul of Neolithic date, had a conical or ovoid stone head with a circumferential groove at midheight; many such rilled stones have been found in flint, copper, and salt mines and elsewhere, though very few handles have survived. Such a stone could be bound to a short section of sapling with a branch coming off at an angle, twisted fibres or sinew serving as the ties. With such a side-mounted head it is likely that the handle's principal function was to lift and guide the head so that it might do its work

by simply dropping, the binding being too weak to carry much of the extra shock produced by swinging the tool. Better shock resistance could be attained by bending a long flexible branch around the groove in the stone and securing it with lashings.

Hammers and pounders of material other than stone were widely used; essentially clublike, they may be called self-handled. Clubs of hardwood might have one end thinned for grasping, or a mallet-like tool could be made from a short section of log with a projecting branch to serve as a handle. Similar mallets were made by piercing a short piece of wood and fitting a handle to it; this also gave an end-grain strike and made it more durable than a simple club. Antlers modified by trimming off tines are known from the Paleolithic Period. Such “soft” hammers were used for striking chisels of stone to prevent the destruction of the more valuable tool. Such tools, especially the wooden mallet, were used on metal chisels as well, particularly by stonecutters, because a very heavy blow on a light tool does not necessarily remove more stone than a moderate blow. There is a good deal of evidence that bone, antler, and flint wedges were used to split wood; here the use of a soft hammer would have been imperative.

The hammer as it is best known today—i.e., as a tool for nailing, riveting, and smithing—originated in the Metal Age with the inventions of nails, rivets, and jewelry. For beating lumps of metal into strips and sheet, heavy and compact hammers with flat faces were needed. These, in lighter form, were suited to riveting and driving nails and wooden pegs.

In the beginning, hafting of metal hammers followed the stone-tool tradition. The first step away from lashing came with casting a socket opposite the head into which the short end of an L-shaped wooden handle was fitted and further supported by lashings. Such a tool was necessarily light. Ultimately the idea of piercing the head with a shaft hole for a handle occurred to the Europeans in the Iron Age. This was several hundred years after it had become common practice among the bronze workers of the Middle East. The shaft hole, although posing fastening problems that still exist, allowed heavy hammers—mauls and sledges—to be made for smithing iron.

The familiar claw hammer that can pull bent nails dates from Roman times in a well-proportioned form, for the expensive handmade nails of square or rectangular cross section did not drive easily. Aside from the claw hammer, other special forms of the peen—the end opposite the flat face—were developed. Hemispherical, round-edged, and wedgelike shapes helped the metalworker stretch and bend metal or the mason to chip or break stone or bricks. An especially important hammer was the filemaker's; equipped with two chisel-like heads, it was used to score flat pieces of iron (file blanks) that were subsequently hardened by heating and quenching.

Ax and adz

The ax and adz are similar enough to be considered together. This is especially the case with ancient tools that were small and ineffective because they were made of brittle stone or had unsatisfactory hafting. The difference between the tools lies in the relation of the cutting edge to the handle. In the ax the cutting edge and handle are parallel, whereas in the adz they stand at right angles. The ax and some adzes chop diagonally across the grain of the wood, but the developed adz, with its long handle, cuts with the grain, and the nature of the chips is quite different. The ax is used for felling or cutting through, whereas the adz is used for smoothing and leveling, although some forms were developed to scoop out gutters or to dig out logs to make canoes. The adz was often shorter handled than the ax and, because of this, was essentially a chipping tool rather than the shaving tool it became when the handle was lengthened. The great problem of both tools is satisfactory hafting; the shock impact between the toolhead and handle threatens any type of connection, however ingenious.

The celt, a smooth chisel-shaped toolhead that formed either an ax or adz, dates from the invention of agriculture and the domestication of animals. The earliest true axheads, made of fine-grained rock with ground edges, are of Swedish provenance and date from about 6000 BCE. Even earlier, self-handled axes, made of reindeer antler, were used. The brow tine, an antler branch running nearly at right angles to the main stem (beam), was sharpened, giving a small ax with a haft of about 20 cm (8 inches). By sharpening the tine the other way, a tiny adz was created. Some of these small bone implements have survived as the Lyngby tools, named from a Danish site of perhaps 8000 BCE.

A subsequent design socketed a stone blade in a short length of antler that was perforated for a handle. This Maglemosian style, from a Danish site of about 6000 BCE, was a popular model for several thousand years despite its narrow cutting edge and length of about 50 cm (20 inches).

The desire for a better feel or a longer cutting edge, or perhaps the shortage of antlers, led to a great variety of haftings. A common arrangement involved lashing heavy celts to knee-shaft handles made from branched tree sections. To permit the use of larger celts, the stone was sometimes fitted into a wooden handle, but this created the danger that the handle would fail due to the weakening hole. Heavy clublike handles with ample strength at the hole gave the tool an unfavourable balance.

Surviving examples of celts of soft stone are believed to have been restricted to nonwoodworking axes, used for killing game or perhaps for certain ritual purposes. Hard-stone axes with shaft holes, often obvious imitations of bronze axes, are associated with the Bronze Age. They are among the supreme examples of stoneworking and are products of the pecking technique. From their delicacy it may be inferred that these axes were not for the working of wood.

Early metal designs

An Egyptian relief of about 2500 BCE, the time at which the pyramids were being built, shows a metal ax (copper or bronze) of curious shape, almost semicircular, lashed to a wooden handle along its diameter. The same picture shows a knee-shaft adz whose metal blade makes an angle of about 30° with the handle. If the number of pictures and artifacts of the adz is a guide, the adz was more widely used than the ax. Generally speaking, the adz had a short handle, with angles of the order of 60° between blade and handle. Although the ancient Egyptians became skilled metalworkers, this was not reflected in their tools, the designs of which hardly changed over 2,000 years.

On the other hand, bronze axes and adzes from Mesopotamia of even the period 2700 BCE are shaft-hole types, the hole for the handle being formed in the mold. Aside from eliminating the

nuisance of lashing the blades, these castings permitted a heavier head than the thin-bladed Egyptian models and had better dynamic characteristics.

Shaft-hole axes and adzes were also being cast in Crete about 2000 BCE. At the same time, a new tool was created there. The double-bit (two-bladed) ax, classically associated with the Minoans, was first known in 2500 BCE as a votive ax, a piece of tomb furniture made of riveted bronze plates. It became a working tool when it was cast in bronze with a shaft hole about 500 years later. Double-bit adzes also date from this time, as do ax–adz combinations. The succeeding Mycenaean, Greek, and Roman civilizations carried these designs forward. According to Homer, Odysseus used a double-bit ax of a type that disappeared with the use of bronze. Illustrations or artifacts from the Middle Ages reveal only iron single-bit types, although in a bewildering variety of profiles. By mid-19th century the double-bit was again in use, principally in the United States as a lumberman's ax. The ax was also used in Canada and Australia, where it is still marketed.

European usage

In western Europe the advent of metal was about 500 years later than in the Middle East. In making the transition from stone to metal, Europeans continued the tradition of the knee-shaft handle. Another type of metal head was given a wide slot, by either forging or casting, into which a cleft knee-shaft was fitted and lashed. This was the palstave. To minimize splitting of the shaft, a stop was later cast at the bottom of the slot. Subsequently, one or two eyes, or loops, were furnished in the casting to allow firmer lashing.

The socketed head, perhaps carried over from the spearhead, was an improvement because the knee-shaft stub sat in a socket with greater security, although it still required lashing. Like its predecessors, this tool was small, almost toylike; the cutting edges of about 3.8 cm (1.5 inches) and short handles suggested a one-handed operation. Adzes were similarly proportioned, as were hammers.

The Bronze Age smiths of Europe were slow in inventing the shaft hole that those of the Middle East had developed in an earlier millennium. The knee-shaft tradition, with its

socketed head, entered even the Iron Age before shaft-hole tools appeared in Europe. To forge a socket is a difficult enough operation with even modern equipment. A shaft hole, however, is fairly simple to make, but such tools appeared in northern Europe well after the Iron Age was underway, perhaps after 500 BCE. By this time, expensive bronze had been supplanted by plentiful iron for use in tools.

Bronze tools had been relatively delicate in design; their iron successors soon gained size and developed in character and effectiveness to display specialized forms. Of these, two are especially important. First, there was the felling ax of the woodcutter, the blade beveled on both sides for symmetry and often fitted with a flat end suited to driving splitting wedges. There were numerous variations of this form as the tool evolved toward its finely balanced modern conformation.

The iron ax had little advantage over its bronze forerunners until smiths discovered carburization and could produce a temperable steel along the cutting edge. This must have occurred early, for repeated heatings of the edge in forging would draw in small quantities of carbon from the charcoal of the fire. A number of Roman axes subjected to analysis have been found to contain steel.

Steeling, or the welding of strips of steel to the iron head, was invented in the Middle Ages. The head was first rough-forged by bending a properly shaped piece of flat iron stock around an iron handle pattern to form the eye. Steeling could take one of two forms. In the first, a strip of steel was inserted between the overlapping ends and the whole welded into a unit (inserted steeling). For the second, the overlapping ends were welded together and drawn to a V-shape over which a V-shaped piece of steel was then welded (overcoat, or overlaid, steeling). Inserted steeling was regarded as superior because it furnished about three times as much steel to resist loss of metal by repeated grinding and sharpening. The manufacture of steeled, or two-piece, axes ended in the early 20th century. Thereafter heads were made of a single piece of high-carbon steel whose properly tempered edge was backed by a tough body.

To convert felled timber into squared timber, special tools were required. As the log lay on the ground or on low blocking, vertical sides were produced by using a broadax, or side ax.

Somewhat shorter handled than the felling ax, it had a flat face, the single bevel being on the opposite or right side; it sliced diagonally downward as the carpenter moved backward along the log. The head was heavy, about twice that of a felling ax, and, although it was a two-handed tool, the broadax was never swung in the manner of a felling ax but, instead, was raised to waist height and allowed to fall with minimum added pressure. The handle was bent, or offset to the right, to give finger clearance when “hewing to the line” on a debarked log. A felling ax was used to score a line, after which the broadax was used to split off the wood along the score line. Hewn timber found in old buildings often carries the faint marks of the scoring.

If the timber was to be presented to view it was smoothed by an adz that removed the last of the score marks and left a type of ripple finish. For this purpose a long-handled adz was used, the radius of its gentle swing originating in the carpenter’s shoulder. The blade was beveled on the inside and removed material in the same manner as does a plane.

The adz was once an indispensable tool of general utility. In addition to surfacing, it was particularly useful for trueing and otherwise leveling framework such as posts, beams, and rafters, in setting up the frames of wooden ships, and in dressing ships’ planking. For special purposes the blade was round instead of flat, allowing the adz to cut hollows such as gutters. Dugout canoes, log coffins, and stock watering troughs, all cut from a whole log, were products of the adz. Short-handled adzes were used by coopers and makers of wooden bowls.

Cutting, drilling, and abrading tools

Knife

The same jagged crest on the Paleolithic chopper that developed into the ax also developed into another broad tool category, the knife, which combined a uniquely shaped sharp blade with a handle that optimized the position of the cutting edge. In contrast to the blades of the ax, adz, chisel, or plane, the motion of a knife is a slicing action made in the direction of its edge.

Damascus steel
Knife blade made of Damascus steel.
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The first hafting of stone knives may have taken the form of a protective pad of leaves or grass. Next, pieces of flint were set into grooves of wooden handles and cemented with resin or bitumen to leave the sharp cutting edges exposed. The Metal Age produced a longer and tougher blade that could be set into a handle, or riveted to a handgrip. Some knives, such as surgical knives and razors, were cast with a handle (self-handled). Copper, bronze, and iron blades were hammered to produce a locally hard edge.

Aside from the utilitarian use of the knife in the field, kitchen, and workshop, variations giving it the status of a weapon appeared in the form of daggers and short and long swords. The stabbing dagger probably had its origin in the Neolithic Period, although an effectively thin and adequately strong blade did not appear until the Iron Age.

Hunting knives, equally useful as fighting knives, developed an overall style, proportion, and balance that changed little over the centuries after the introduction of iron. The first known folding knife is a Roman model of the 1st century CE. Beginning in the late Middle Ages, many improvements in detail were introduced. These included fancy handles and springs and locks for the blade.

As individual crafts emerged, an impressive number of convenient but single-purpose knives were fashioned to suit the specialized tasks of various craftspersons, including goldbeaters, farriers, shoemakers, and farmers.

Drilling and boring tools

A varied terminology is related to making holes with revolving tools. A hole may be drilled or bored; awls, gimlets, and augers also produce holes. An awl is the simplest hole maker, for, like a needle, it simply pushes material to one side without removing it. Drills, gimlets, and augers, however, have cutting edges that detach material to leave a hole. A drilled hole is ordinarily small and usually made in metal; a bored hole is large and in wood or, if in metal, is usually made by enlarging a small hole. Drilling usually requires high speed and low torque (turning force), with little material being removed during each revolution of the tool. Low

speed but high torque are characteristic of boring because the boring tool has a larger radius than a drill.

The Upper Paleolithic Period furnished the first perforated objects of shell, ivory, antler, bone, and tooth, although softer, perishable materials, such as leather and wood, were undoubtedly given holes by the use of bone or antler splinters. How holes were made in harder materials is subject to speculation; it has been suggested that flint blades were trimmed to sharp points by bilateral flaking and that these points were turned by hand, a very slow process. Another scheme involved the use of an abrasive sand under the end of a stick that was twirled back and forth between the palms. At some unknown time, more efficient rotation was attained by wrapping a thong around the stick or shaft and pulling on the ends of the thong. Such a strap, or thong, drill could be applied to drilling either with an abrasive or with a tool point hafted onto the end of the stick. The upper end of the shaft required a pad or socket (drill pad) in which it could rotate freely.

After the invention of the bow, sometime in the Upper Paleolithic Period, the ends of the thong were fastened to a bow, or a slack bowstring was wrapped around the shaft to create the bow drill. Because of its simplicity, it maintained itself in Europe in small shops until the 20th century and is still used in other parts of the world. Abrasive drilling in stone was well suited to the high-speed bow drill. For larger holes the amount of material that had to be reduced to powder led to the idea of using a tube, such as a rolled copper strip, instead of a solid cylinder. This is called a core drill because the abrasive trapped between rotating tube and stone grinds out a ring containing a core that can be removed.

A new and more complicated tool, the pump drill, was developed in Roman times. A crosspiece that could slide up and down the spindle was attached by cords that wound and unwound about it. Thus, a downward push on the crosspiece imparted a rotation to the spindle. A flywheel on the spindle kept the motion going, so that the cords rewound in reverse to raise the crosspiece as the drill slowed, and the next downward push brought the spindle into rotation in the opposite direction.

The earliest (perhaps Bronze Age) drill points had sharp edges that ultimately developed into arrow shapes with two distinct cutting edges. This shape was effective, especially when made of iron or steel, and remained popular until the end of the 19th century, when factory-made, spiral-fluted drills became available at reasonable cost to displace the blacksmith-made articles.

The basic auger originated in the Iron Age as a tool for enlarging existing holes. It had a crossbar so that it might be turned with two hands, and it resembled a pipe split lengthwise. The auger was sharpened in several ways: on the inside of the semicircular end, along the length, or on both. The end might be forged into a spoon shape and the edges sharpened so that cutting could take place at the bottom of the hole in addition to the sides. To clear the hole of parings it was necessary to pull the auger from its hole and turn the workpiece over. Augers with spiral or helical stems that brought the shavings or chips to the surface were an invention of the Middle Ages, although one example dates from Roman Britain.

The familiar and common brace, a crank with a breast swivel at one end and a drill point at the other, is first seen in a painting of about 1425 that shows the biblical Joseph at his bench. This brace and other early examples are shown fitted with a bit of small diameter. It has been suggested that the function of the new tool was to make a small, or pilot, hole for the larger auger bit. This is a reasonable assumption, for the crank, fashioned from a wide board, had insufficient strength (because of its cross grain) to drive a large bit. This weakness was later counteracted by reinforcing the two weak sections with metal plates, a practice that continued until about 1900 despite the commercial introduction of iron sweeps (cranks) in about 1860. This invention permitted the boring of holes of up to one inch in diameter with one-handed operation; larger holes still required two-handed augers. An iron sweep is noted in a German manuscript of 1505, and an English book of 1683 has a metal brace as part of a blacksmith’s kit.

Early wooden braces were equipped with a large socket into which bits with appropriate shanks could be fitted interchangeably. When the sweep came to be made of iron, bits were given square shanks that fit into simple split chucks (holders) and were secured with a

thumbscrew. Soon the screwed shell chuck and ratchet was devised to set the standard for the modern tool. By 1900 the swivel turned on ball bearings instead of a leather washer, and the metal parts were nickel-plated.

The bow and pump drills, suitable only to small work, required two hands, one to steady the tool, the other to operate it. One-hand drills began to appear in about 1825. Their essential elements were a steeply pitched screw and a nut that mated with it; when the latter was pushed down, the screw and attached bit turned. Many variations of the principle were offered before the modern push drill assumed its present, convenient form. It is still suitable for only light work in wood.

Both the bow and pump drills remained the metalworker's prime tool for drilling small holes until the first geared hand drill was invented in 1805. Like every other tool, it underwent many improvements before acquiring its present rugged simplicity. Its great advantage lies in its unidirectional motion and the gearing that rotates the drill faster than the rate at which the crank is turned. The one-directional motion allowed better drills to be designed, and, with their greater mechanical efficiency in chip production, it was not long (1822) before drills with spiral flutes were proposed. A manufacturing problem—the flutes had to be hand filed—was not solved until the 1860s when the invention of a milling machine made possible the now universal twist drills.

Augers were used for boring both across the grain of wood and along the grain. The latter operation produced wooden pipes and pump casings or wheel hubs; special bits of many forms were designed for these purposes. The more common use of the auger or bit was in the cross-grain direction to make holes for wooden pins (treenails, or trunnels) or bolts for connections. The modern auger bit has a screw ahead of the cutting edges that pulls the auger into the workpiece. This screw provides an automatic feed and relieves the worker of the necessity of pushing the tool. Although the idea appeared in the mid-16th century, application of the principle was limited until the advent of screw-making machinery in the mid-19th century.

Saw

The chipped flint knife, with its irregular edge, was not a saw in the proper sense, for though it could sever wood fibres and gash bone or horn, it could not remove small pieces of material in the manner of a saw. Furthermore, the necessarily broad V-shaped profile of the flint saw severely limited its penetration into the workpiece; the nature of its cut was limited to making an encircling groove on a branch or a notch on something flat.

The true saw, a blade with teeth, one of the first great innovations of the Metal Age, was a completely new tool, able to cut through wood instead of merely gashing the surface. It developed with smelted copper, from which a blade could be cast. Many of the early copper saws have the general appearance of large meat-carving knives, with bone or wooden handles riveted to a tang at one end. Egyptian illustrations from about 1500 BCE onward show the saw being used to rip boards, the timber being lashed to a vertical post set into the ground.

The use of relatively narrow, thin, and not quite flat blades made of a metal having a tendency to buckle, coupled with poorly shaped teeth that created high friction, required that the cutting take place on the pull stroke. In this stroke the sawyer could exert the most force without peril of buckling the saw. Furthermore, a pull saw could be thinner than a push saw and would waste less of the material being sawed.

The familiar modern handsaw, with its thin but wide steel blade, cuts on the push stroke; this permits downhand sawing on wood laid across the knee or on a stool, and the sawing pressure helps to hold the wood still. Operator control is superior, and, because the line being sawed is not obscured by the fuzz of undetached wood fibres or sawdust, greater accuracy is possible. Some tree-pruning saws have teeth raked to cut on the pull stroke to draw the branch toward the operator. Blades that are thin and narrow, as in the coping saw (fretsaw or scroll saw), are pulled through the workpiece by a frame holding the blade. Electric reciprocating and sabre saws, which have narrow blades that are supported at only one end, pull the blade when cutting to prevent buckling. The carpenter’s pull saw for wood requires sitting on the floor and using one’s feet to stabilize the wood while sawing. Long forgotten by the Western world, it has been kept alive in China and Japan, where some craftspersons still favour it.

Although there is no positive evidence of either the type of saw or the method used, the Egyptians were able to saw hard stone with copper and bronze implements. The blade, probably toothless, rode on an abrasive material such as moistened quartz sand. The 2-metre (7.5-foot) granite coffer still in the Great Pyramid carries saw marks.

During the Bronze Age the use of saws for woodworking was greatly extended, and the modern form began to evolve. Some saws with narrow blades looked very much like hacksaw blades, even to the holes at either end. They might have been held in a frame or pinned into a springy bow of wood.

Iron saws resembling those of copper or bronze date from the middle of the 7th century BCE. A major contribution to saw design was noted in the 1st century CE by Pliny the Elder, whose works are one of the major sources on the technology of the ancients. Pliny observed that setting the teeth—that is, bending the teeth slightly away from the plane of the blade alternately to one side and the other, so creating a kerf, or saw slot, wider than the thickness of the blade—helps discharge the sawdust. He seems to have missed the more practical point that the saw also runs with less friction in the now wider slot. The Romans, always ingenious mechanics, added numerous improvements to both simply handled saws and frame saws but did not make push saws despite the advantage of the kerf that made the saw easier to work with and less liable to buckle. Roman saw sets and files have been found in substantial numbers. The small handsaws were sometimes backed with a stiffening rib to prevent the buckling of thin blades; today’s backsaw still carries the rib. Frame saws, in which a narrow blade is held in tension by a wooden frame, were exploited in many sizes, from the small carpenter’s saws to two-person crosscut saws and ripsaws used for making boards.

The time and provenance of the push saw are uncertain, although it appears that it may date from the end of Roman times, well before the Middle Ages. Nevertheless, after the decline of the Roman Empire in the West, the use of the saw seems to have declined as well. The ax again became the principal tool on the return to the more primitive state of technology. Saw artifacts are very few in number, and even the Bayeux Tapestry of about 1100 shows no saw in

the fairly detailed panels dealing with the construction of William the Conqueror's invasion fleet; only ax, adz, hammer, and breast auger are among the woodworking tools.

With the Middle Ages came the search for a nonclogging tooth to be used when crosscutting green and wet wood. The new saws were long, with handles at both ends, so that two men might each pull, adjacent teeth being raked in opposite directions. To provide space for the cuttings, M-shaped teeth with gaps (gullets) between them were developed; this tooth conformation, first noted in the mid-15th century, is still used in modern crosscut saws manufactured for coarse work and for cutting heavy timber.

Perhaps even more important than crosscutting was the need to rip a log lengthwise to produce boards. Saws for this purpose were generally called pit saws because they were operated in the vertical plane by two people, one of whom, the pitman, sometimes stood in a pit below the timber or under a trestle supporting the timber being sawed. The other stood on the timber above, pulling the saw up; the pitman and gravity did the work of cutting on the downstroke, for which the teeth were raked. A pit saw occasionally was nothing more than a long blade with two handles (a whipsaw), but more often it was constructed as a frame saw, which used less steel and put the blade under tension.

The fretsaw was a mid-16th century invention that resulted from innovations in spring-driven clocks. It consisted of a U-shaped metal frame, on which was stretched a narrow blade made from a clock spring, the best and most uniform steel available, for it was not forged but rolled in small, hand-powered mills. These relatively thin blades had fine teeth that were well suited to cutting veneer stock from decorative wood for furniture of all kinds.

By the middle of the 17th century, large waterpowered rolling mills in England and some parts of the Continent were able to furnish broad strips of steel from which wide saws could be fashioned in many varieties. In particular, the awkwardly framed pit saw was largely replaced by a long, two-handled blade of increased stiffness. Smaller general-purpose saws were developed from this rolling-mill stock into the broad-blade saws of today. The modern broad-blade handsaw is taper ground, that is, the blade is not of uniform thickness but is several thousandths of an inch thinner at the back than at the toothed edge. This makes possible no-

bind cutting, and such saws require little set for fast and easy cutting. Continental craftspersons still use the frame saw for benchwork. Since the only purchased part is the blade itself, workers often make their own wooden frame, which is tightened by twisting a cord with a short stick.

File

The file's many tiny chisel-like teeth point in the direction in which it must be pushed in order to be effective. Because little material is removed with each stroke, the tool is well suited to smoothing a rough workpiece or altering its details. The file was unknown in early antiquity, during which time smoothing was done with abrasive stone or powder or with sharkskin, the granular surface of which approximates sandpaper.

Files of copper are unknown, but bronze was shaped into flat files in Egypt in 1500 BCE. A combined round and flat file of bronze was produced in Europe by 400 BCE. The file became popular in the Iron Age and a number of specimens survive from Roman times. The longest is flat, one inch wide, about 38 cm (15 inches) long including the handle, and has about 20 cm (8 inches) of working length. A number of shorter files of about 10-cm (4-inch) working length are particularly interesting because of the notch they carry near the handle. The V-shaped cross section (called knife-shaped today) indicates that these files were intended for dressing sawteeth. The notch enabled the worker to set the teeth—i.e., bend successive teeth to alternate sides to gain a free-running saw. These files had straight-across and coarse toothing, but the advantages of obliquely cut teeth and of double-cut (intersecting) teeth were appreciated early.

A treatise written in 1100 mentions files of square, round, triangular, and other shapes. At this time files were made of carburized steel that was hardened after the files were cut by either a sharp, chisel-like hammer or a chisel and hammer. An illustrated manuscript of 1405 that was copied by a succession of later authors shows a polygonal file; the screeching of the filing operation is commented upon too, with the curious suggestion that files be made hollow and filled with lead to eliminate the noise. In 1578 a writer asserted that the only way in which threads could be cut in screws was with the file.

Although Leonardo da Vinci had sketched a file-making machine, the first working machine was not produced until 1750, and it was a century later before machine-cut files substantially replaced those cut by hand. Power-driven, hand-cut rotary files are still used on dense metals because hand-formed, discontinuous teeth dissipate the heat well.

The ordinary file, in terms of its material and cut, is primarily used on cast iron and soft steel. Other materials—various nonferrous alloys, stainless steels, and plastics—are better accommodated with files of special composition and tooth formation (cut). A wide selection is manufactured.

Rasps, or, more correctly, rasp-cut files, have a series of individual teeth produced by a sharp, narrow, punchlike chisel. Their very rough cut is suited to the fast removal of material from soft substances, such as wood, hooves, leather, aluminum, and lead.

Chisel

The remote origin of the chisel may lie with the stone hand ax, the almond-shaped tool that was sharp at one end. Although long rectangular chisel-shaped flints appeared about 8000 BCE, the later Neolithic Period evinced a version that was finished by grinding. With care, flint and obsidian chisels can be used on soft stone, as shown by intricate sculptures in pre-Columbian South and Central America. Gouges—i.e., chisels with concave instead of flat sections, able to scoop hollows or form holes with curved instead of flat walls—were also used during this period. Chisels and gouges of very hard stone were used to rough out both the exteriors and interiors of bowls of softer stone such as alabaster, gypsum, soapstone, and volcanic rock. The final finish was produced by abrasion and polishing.

The earliest copper chisels were long, in the manner of their flint forebears. Such so-called solid chisels of copper (and later of bronze) were used not only for working wood but soft rock as well, as many magnificent Egyptian monuments of limestone and sandstone testify.

By using bronze, a better casting metal than copper, and molds, it was possible to economize on metal by hafting a short chisel to a wooden handle. This also resulted in less damage to the mallet. The round handle was either impaled on a tang with a cast-on stop (tanged) or set into

a socket (socketed); both forms of hafting presaged modern forms. The Egyptians used the chisel and clublike mallet with great skill and imagination to make joints in the construction of small drawers, paneled boxes, furniture, caskets, and chests.

The use of iron meant that tools had to be forged; no longer were the flowing lines and easily made cavities of casting available to the toolmaker. Consequently, early iron chisels were rude and solid. Tanged chisels were easier to make than socketed chisels, for which the socket had to be bent from a T-shaped forging. Hardened steel edges (first developed by accident) were created by repeatedly placing the iron in contact with carbon from the charcoal of the forge fire.

Chisels and gouges were made in great variety in later centuries as generally increasing wealth created a demand for more decoration and luxury in both religious and secular trappings and furniture. The rough and heavy tools of the carpenter were refined into more delicate models suited to woodcarvers, to joiners who did wall paneling and made stairs, doors, and windows, and to cabinetmakers. In the 18th century a woodcarver’s kit may have contained more than 70 chisels and gouges.

Plane

The plane is a cleverly hafted cutting edge, the function of which is to skin or shave the surface of wood. Used to finish and true a surface by removing the marks of a previous tool (adz, ax, or saw), a plane leaves the surface smooth, flat, and straight. The plane and the related spokeshave are unique tools because both depend upon a constant depth of cut that is given by the slight projection of the blade beyond the sole, or base, of the instrument.

The plane is an anomaly for which no line of descent has been identified. Pliny the Elder ascribes its invention to Daedalus, the mythical Greek representative of all handiwork.

It has been suggested that the Paleolithic unifacial (flat) scraper is the remote ancestor of the plane. While it is true that localized planing of a very poor sort, such as removing high spots, can be done with such a scraper, the difference in design and action between the two is too great to proclaim the scraper the forerunner of the plane. The adz seems a more likely

progenitor. Early adzes were beveled (sloped) on the outside, although later, with better hafting and longer handles, the bevel was moved to the inside. The blade and handle of an outside-beveled adz could be used in a plane-like fashion to lift a shaving; however, the control of the blade projection, or depth of cut (or thickness of shaving), is critical to the concept of the plane and is met in only one other tool, the spokeshave.

The earliest illustrations of wood finishing, the surfacing of pieces of furniture, are Egyptian and show the surfaces being scrubbed with flat objects that appear to be abrasive stones or blocks riding on abrasive sand. Presumably, the surfaces had been dressed by an adz, and the marks of this tool needed to be erased. Stone scrapers are not in evidence, and, although the adz is shown, it is being used as an adz, not as an improvised plane.

The Romans were the first known users of the plane, the earliest examples coming from Pompeii. In a manner of speaking, these planes are full-blown, without a prehistory and without even vague antecedents. The modern plane differs in details but not in principle or in general appearance.

These Pompeian planes were of comfortable size, about 20 cm (8 inches) long and 5.7 cm (2.3 inches) wide. The blade was relatively narrow, about 3.8 cm (1.5 inches) as opposed to the modern width of about 5 cm (2 inches). The sole was made of iron, one-quarter-inch thick, that was bent to form a shallow box filled with a wooden core; it was cut away at the back to form a handgrip, while the mouth was cut out about one-third of the way from the front. The cutting blade, or plane iron, was held in position by a wooden wedge tapped under an iron bar placed across the mouth. Frontier posts in Great Britain and Germany have yielded nearly a dozen Roman planes, ranging in length from 33 to 43.2 cm (13 to 17 inches). Three constructions are represented: iron sole with a wooden core, all wood, and wood reinforced with iron plates at the sides of the mouth.

Planes can be divided into two main categories: the first, typified by the common bench plane, consists of a straight iron and a flat sole and is used for working flat surfaces; the second includes a variety of planes defined by the profile of the iron and sole. If the iron has a concavity, a projection or molding is created in the workpiece; if the iron has a projection, a

groove is dug. Generally speaking, planes with profiled irons and correspondingly fluted soles are molding planes. Some of the Roman planes had irons for cutting rectangular grooves.

After the decline of the Roman Empire, the plane apparently fell into disuse. Practically no planes, and only a few other tools, have survived from the period of 800–1600 CE. Secondary sources, such as illuminated manuscripts, legal documents, carvings, and stained-glass windows, do provide some information, but they lack details.

By the late 17th century the plane was firmly reestablished in the craftsperson's tool kit. Bench planes, or common planes, were used for surfacing panels or for creating straight edges on boards so that two or more might be joined into a wide panel. Boards were sawed or split (riven) from the log and were, consequently, quite rough. The first planing operation was done with the roughing, or fore, plane, which was of medium length, possibly 40.6 to 45.7 cm (16–18 inches). This fore plane had a slightly convex iron that removed saw and adz marks but left hollows that needed to be leveled by straight-iron planing. If the workpiece was long, a long-bodied trying, or jointing, plane having a length of about 76 cm (30 inches) was needed to remove large curves in the wood. Short planes—a common length was about 23 cm (9 inches)—were called smoothing planes for the final finish they produced.

Planes with straight irons and flat soles could easily be made by the craftsperson. Taste and fashion in 17th-century wood carving, however, prized decorative features such as moldings and beadings, which led to a proliferation of plane types and established plane making as an industry.

The indispensable common (straight iron) plane was improved in a number of details throughout the years. In Roman planes the wedge holding the iron was jammed against a cross bar in the mouth of the plane. This feature, awkward because it impaired the free escape of the shaving, was eliminated in the 16th century by seating the wedge in tapered grooves.

Another improvement was the invention of the top iron, apparently an English innovation of the late 18th century. This top iron, or chip breaker, used an inverted plane iron placed over the

cutting iron to limit the thickness of the shaving and help it to curl out of the mouth. Now called the double iron, it is a feature of all but the smallest of modern planes.

As advanced metallurgy and machine tools allowed good castings to be accurately mass-produced, wooden planes were gradually displaced in Britain and the United States by cast-iron bodies with wooden handles.

The 19th century saw much effort in Britain and the United States aimed at eliminating the wedge, which required the use of a hammer to adjust the iron. Various methods for the easy removal and accurate setting of the iron culminated in the screw and lever adjustor for the iron and the cam-actuated cap. This final evolution was completed about 1890, and changes since that time have been trivial. Despite their advantages, continental Europe has not been partial to iron-bodied planes with screw and lever adjustments, and such tools cost much more than the still common wooden plane with wedge and hammer adjustment.

The spokeshave, which may be likened to a short-bodied plane with a handle on either side allowing the tool to be pulled toward the operator, has left little in the way of a record. The term was first used about 1510, but the earliest known example seems to be only half as old. Both the English word and the German *Speichenhobel* suggest that it was originally the specialized tool of a wheelwright that became generalized for use on convex surfaces. As with the plane, the cutting blade (iron) projects only slightly from the short sole to regulate the depth of cut.

The drawknife is a handled blade that is pulled toward the operator. It is a rather questionable relative of the plane, for, though it lifts shavings in a similar manner, it lacks the positive thickness control of the plane. The tangs at the ends of the modern knife are bent at right angles in the plane of the blade. While it is used in much the manner of a spokeshave, the drawknife is actually a roughing tool for the quick removal of stock. Skill is required in its use because the depth of cut is regulated by the tilt of the blade, and the grain of the wood tends to assert itself. The drawknife appears to be an older tool than the spokeshave and has undergone a change since the Viking times when it was first used. Under the Vikings the handles were

bent at right angles to the plane of the blade, and the tool seems to have been used for smoothing axed or adzed timber in medieval Scandinavia, Russia, and elsewhere.

Tool auxiliaries and screw-based tools

Workbench and vise

The workbench and vise form an organic unit, for the vise is a fixture that is either part of the carpenter's bench or is attached to the machinist's bench.

Screws and screw heads

Screws and screw heads (A) Cap screw, (B) machine screw with oval head, (C) setscrew with hollow head, (D) self-tapping screw, (E) flat-head wood screw, (F) machine screw with Phillips head, (G) lag screw.
Encyclopædia Britannica, Inc.

Neither a bench nor a mechanical fixture would have offered an advantage in the early chipping or flaking of stone. On the contrary, complete freedom in the positioning of the workpiece and hammer was essential to permit the many small, yet discretely placed and directed, blows that were the crux of fashioning stone tools. When large and unidirectional forces needed to be applied, as in woodworking, in many phases of metalworking, or even in the manipulation of bone and horn, the advantage of a bench or a fixed rest became apparent.

Wood assumed its important role in structures, furniture, and fittings with the development of polished stone tools (ax and chisel) in the Neolithic Period and was skillfully exploited for finer work with the advent of copper and bronze tools. Most of the furniture of ancient times no longer exists, but much visual evidence, provided largely by sculptures, representations on vases, mosaics, and wall frescoes, depicts all manner of furniture, such as thrones, stools, benches, footstools, couches, cupboards, tables, chests, and beds.

Oddly enough, a stout table or workbench is missing from the renderings of busy Egyptian shops. The workpieces are on the floor, and the craftspersons are kneeling or bending over their work or sitting on low stools, even in those scenes in which tables are being finished. Perhaps the craftspersons used their feet to position the work on the floor while using a chisel and mallet to effect joinery work, a practice still known in some areas.

Evidence in Europe suggests that woodworkers made use of a table or workbench as long ago as the Neolithic Period. The simplest form of table bench was a short length of heavy board split from a trunk and supported on four legs made of saplings set into bored holes. This style of bench, with its four legs somewhat splayed for greater stability, became common in Roman times. As the first users of the plane, the Romans found that a stout workbench was a necessity; trueing a surface without a bench on which to lay and secure the wood was nearly impossible.

Two early methods, still in use, were devised for holding the workpiece. The simplest procedure was to use wooden pegs set into holes in the bench top; the other was to use what are variously known as bench stops, holdfasts, or dogs. The stems of these T-shaped iron fittings were set into holes in the workbench, and a sharp end of the horizontal part of the T was turned to engage the wood.

Other arrangements came into use, including trestles for supporting wood to be sawed and specialized benches—horses—on which the leatherworker or coppersmith sat while facing a raised workpiece. A small workpiece was often held by a strap that was tightened when the craftsperson placed a foot in a loop that formed the free end and dangled beneath the table. Such horses proliferated from medieval times onward as new specialties developed.

A frequent accessory of the metalworker’s bench was the anvil, which is still informally present on many machinist’s vises in a rudimentary form suited to light work. Aside from making castings, metalworking was largely concerned with forging. The earliest anvils were convenient flat stones, usable for only the simplest kind of flat work. Anvils with the characteristic overhang, or horn, were first cast in bronze and, later, welded from short lengths of iron. Bench anvils were necessarily small, and the large free-standing specimens of the smith had to await the development of cast iron. Only then were larger masses of metal conveniently available.

Blacksmith's anvil
Encyclopædia Britannica, Inc.

The medieval carpenter’s bench was still very much like the Roman’s, with pegs serving as end fixtures. The metalworker, especially when using a file to shape and clean small forgings and

castings (harness gear, buckles, and so on), used a simple rest, essentially a notched post driven into the ground in front of the bench, to support the workpiece.

Within a century, according to the pictorial record, the metalworker's rest was replaced by a screw vise, at first quite small. This vise was like a hinge; one leaf or jaw was fastened to the bench, and the other was pulled up to clamp the workpiece and was tightened by the use of a nut and bolt passing through the middle of the hinge. Portable clamp-on vises that can be attached to a plank, tabletop, or bench top date from 1570.

Closing the vise by turning the tightening nut with a wrench was a slow and awkward process. At the end of the 16th century the screw was inverted so that it could be turned from the front by means of the T-handle that is part of every modern vise. This form of vise would remain an integral element of the workbench of every smithy.

The modern machinist's vise has jaws that run parallel, and some vises pivot as a unit on a vertical axis (swivel-base vise). Both of these features were in use before the end of the 18th century.

The carpenter's bench developed more slowly. For a woodworker, workpieces could be firmly fixed only with a screw arrangement of some sort. Although all of the necessary elements were known as early as 1505, for centuries nothing came of the idea of bench vises using the screw.

The woodworker needs two types of vises. One holds (clamps) the board into place so that its long edges may be trued and planed; custom places this vise at the left front of the bench, a convenient location for the right-handed worker. The second vise is at the right side of the table; its moving jaw has an adjustable bench stop that permits long pieces of wood to be held between it and a fixed stop in the bench top. Both types of vises were developed and made part of the same bench by the early 19th century.

Tongs, pincers, and pliers

Tongs, pincers, tweezers, and pliers have the common task of holding or gripping objects so that they may be handled more easily. The early use of fire created a new problem, that of handling hot coals. Two sticks probably served as the first uncertain holders, but bronze bars may have replaced wooden tongs as early as 3000 BCE. An Egyptian wall painting of about 1450 BCE shows a crucible supported between two bow-shaped metal bars. The same painting shows a craftsperson, blowpipe in mouth, holding a small object over a fire with a tweezerlike instrument about 20 to 25 cm (8 to 10 inches) long. Bronze loops capable of handling large and heavy crucibles also appeared at this time.

Spring-back, or tweezerlike, tongs were the model used by the early ironsmith. The change to the mechanically more effective hinged tongs was slow, and it was not until 500 BCE that they became common in the Greek blacksmith's kit. Pivoted tongs, with short jaws and a long handle, have quite a mechanical advantage over tweezer-like tongs. A pair of 51-cm (20-inch) pivoted tongs is capable of exerting a gripping force of nearly 135 kg (300 pounds) with only a 18-kg (40-pound) squeeze from the smith's hand. Such tongs were constructed with one handle slightly shorter than the other so that an oval ring could be slipped over the two to help secure the grip.

Small tongs, often called pliers or forceps, were particularly valuable to the early craftsperson. who put them to many and varied uses. The Romans sharpened the jaws of tongs to create cutters and pincers. The pincers were useful for pulling bent nails because of the leverage they were capable of exerting. Although they were originally a carpenter's tool, pincers became a principal tool of the farrier because old nails had to be pulled from horses' hooves before new shoes could be fitted and nailed on.

Screw-based tools

Invention of the screw

Although Archimedes is credited with inventing the screw in the 3rd century BCE, his screw was not today's fastener but actually two other screw-type devices. One was a kind of water pump; still used today for large-volume low-lift industrial applications, the device is now called the inclined screw conveyor. The second was the "endless screw," actually the worm of

a worm and gear set, one of the ancients' five devices for raising heavy weights. With the state of the mechanical arts as it was then, Archimedes' concept of the screw was actually as a motion-transforming device and was more hypothetical than practical.

By the 1st century BCE, heavy wooden screws had become elements of presses for making wine and olive oil and for pressing clothes. The character of the screw took on a new dimension, for these screws were used to exert pressure; their modern counterparts are called power screws. These press screws were turned by means of hand spikes thrust into radial holes in the cylindrical end. The problem of making the internal thread of the nut prevented the use of small threaded fasteners in metal construction. The external thread, however, was readily, if tediously, made by filing.

Metal screws and nuts appeared in the 15th century. The square or hexagonal head or nut was turned with an appropriate box wrench; a T-handled socket wrench was developed in the 16th century. Some screws used in 16th-century armour have slots (nicks) in which a screwdriver may have been used, although this tool is not shown. Deep notches on the circumferences of the heads of other armour screws suggest that some type of pronged device was used to turn them. Slotted, roundheaded screws were used in the 16th century, but few screw-and-nut-fastened clocks are in evidence earlier than the 17th century. Metal screws were called machine, or machinery, screws since they were made of metal and mated with threaded holes.

The wood screw differs from the machine screw in that the wood into which it is turned is deformed into a nut. It must, however, be started in a hole made by awl or drill. Aside from a few and sometimes doubtful artifacts from Roman times, the wood screw is not mentioned until the mid-16th century, when it appears in a mining treatise. Here a screw tapered to a point, carrying a slotted head and looking very familiar except for its left-handed thread, is described so casually as to suggest that it was a common article. It is remarked that the screw is superior to the nail, which is also shown being driven by a claw hammer. There is no mention of a screwdriver.

Screwdrivers and wrenches

The simple screwdriver was preceded by a flat-bladed bit for the carpenter's brace (1744). The handled screwdriver is shown on the woodworker's bench after 1800 and appears in inventories of tool kits from that date. Screwdrivers did not become common tools until 1850 when automatic screw machines began the mass production of tapered, gimlet-pointed wood screws. In its early form, the screwdriver was made from flat stock; its sometimes scalloped edges contributed nothing to function. Being flat, the blade was easy to haft but weak when improperly used for prying. The present form of the screwdriver, round and flattened only at the end, was devised to strengthen the shaft and make use of readily available round-wire stock.

Early box and socket wrenches fit only a particular nut or screw with flat surfaces on the head. The open-end wrench may have rectangular slots on one or both ends. In their earliest forms, such wrenches, with straight, angled, or S-shaped handles, were made of wrought iron. Cast iron came into use around 1800. Modern wrenches are drop forgings and come in many formats.

The limitations of fixed-opening wrenches were addressed as early as the 18th century, when sliding-jaw types were developed to accommodate a range of flats. In these, the end of an L-shaped handle provided the fixed jaw, and the parallel jaw was arranged to slide along the handle until it engaged the flats. In the first models, the sliding jaw was fixed into position by a wedge that was hammered into place. By the early 19th century, patents for screw wrenches began to proliferate; in these the sliding jaw was positioned and held by means of a screw whose axis was parallel to the handle. The most common example is the monkey wrench, whose name appeared in tool catalogs in the 1840s but may have been in use before that time. A convenient variation of this type of wrench is the thin and angled Crescent wrench, a modern innovation.

The plumber's pipe wrench is a serrated-jaw variation of the monkey wrench, whose additional feature of a pivotable movable jaw enables it to engage round objects, such as rods and pipes.

Measuring and defining tools

Plumb line, level, and square

A plumb line is a light line with a weight (plumb bob) at one end that, when suspended next to a workpiece, defines a vertical line. *Plumb* comes from the Latin *plumbum*, or “lead,” the material that replaced stone as the weight for the bob or plummet.

bubble level
The spirit, or bubble, level, a sealed glass tube containing alcohol and an air bubble, was invented in 1661. It is used to find or create vertical and horizontal lines and surfaces.
© *mirkoni/Fotolia*

While an end-weighted string defines the vertical, its direct use for plumbing walls (making them vertical) is awkward. The Egyptians devised a tool resembling the letter E, from which a plumb line was suspended from the upper outboard part of the E. When the tool was placed against a wall, the wall was determined to be vertical when the string just touched the lower outboard part of the E. Oddly, this useful tool was apparently forgotten for many centuries and reappeared only in modern times.

The tool for determining horizontal direction is called a level. The Egyptians used an A-frame, on which a plumb line was suspended from the vertex of the A. When the feet of the A were set on the surface to be checked, if the plumb line bisected the crossbar of the A, the surface was horizontal. The A-frame level was used in Europe until the middle of the 19th century. Sometimes a variation is shown in which the frame is an inverted T with a plumb line suspended from the top of the vertical stem.

Because the surface of a body of water is always horizontal, a trough or channel filled with water can serve as a reference in some situations. The hose level, first described in 1629, consisted of a length of hose fitted with a glass tube at each end. Water was added until it rose in both vertically held tubes; when the surfaces of the water in each tube were at the same height, the object was level. This idea was impractical with only leather hose, but the development of vulcanized rubber hose in 1831 led to a resurgence of the device in 1849. Because the hose could be carried through holes in the wall, around partitions, and so on, the instrument enabled levels to be established in awkward circumstances.

The spirit, or bubble, level, a sealed glass tube containing alcohol and an air bubble, was invented in 1661. It was first used on telescopes and later on surveying instruments, but it did not become a carpenter's tool until the factory-made models were introduced in the mid-19th century. The circular level, in which a bubble floated under a circular glass to indicate level in all directions, was invented in 1777. It lacked the sensitivity of the conventional level.

The square appeared in the ancient Egyptian world as two perpendicular legs of wood braced with a diagonal member. In the following centuries many variations were designed for specific purposes, including a square with shoulders that allowed it also to cast a mitre of 45 degrees. Iron squares were rarely used before 1800, and factory-made metal squares did not appear until 1835. The adjustable, or bevel, square was used for angles other than 90 degrees beginning in the 17th century. In the earliest examples, the thin blade moved stiffly because it was riveted into a slot in the thick blade. Later models of the 19th century, however, were equipped with a thumbscrew that permitted the thin blade to be adjusted with respect to the thicker blade.

Compass, divider, and caliper

Compass, divider, and caliper are basically instruments that have two legs pivoted to each other at the top and are concerned with small-distance measurement or transfer. The compass and divider have straight legs; the caliper has curved legs.

The terms *compass* and *divider* are often interchanged, for each instrument can be used to draw circles, mark divisions (divide a given distance), or simply mark a distance. Technically, a compass is a drafting instrument that has one pen or pencil point and one sharp point that is positioned at the centre of the circle to be described, while a divider, on the other hand, has two sharp points, one for the centre and the other for scribing or marking. *Caliper* is a corruption of *calibre*, the diameter of a hole (as in a firearm) or of a cylindrical or spherical body. The outside caliper has inwardly curved legs that measure the diameters of solids created by rotating tools, such as lathe-turned objects, and the inside caliper has outwardly curved legs for measuring bores.

Dividers and calipers were known to both the Greeks and Romans, though the caliper was uncommon. A divider with a circular sector, or wing, connecting the two legs was sketched in 1245; its modern counterpart is the wing divider with a thumbscrew clamp and screw for fine adjustment. The caliper is mentioned in the Middle Ages, but the divider was the principal tool of the architect working on full-scale layouts of stonework, such as in the construction of a cathedral. Such dividers were large, often half as tall as a man. The divider underwent refinements that made it an important drafting instrument for Albrecht Dürer and Leonardo da Vinci; Leonardo suggested improvements that included the knuckle-joint hinge (to increase rigidity) and the adjustable proportional divider (Roman proportional dividers had a fixed pivot that gave only one ratio). Leonardo's notes also show the beam compass with a screw adjustment for large radii, as well as a compass that had interchangeable points, in which one leg had a clamp for different drawing media, such as graphite or chalk.

Chalk line

"Snapping a line," a technique familiar in ancient Egypt, is employed in modern building construction. The procedure uses a taut chalk-covered cord that is stretched between two points: the cord deposits a straight line of chalk when it is plucked and snapped onto the surface. After 5,000 years the only change in this technique is that, whereas the Egyptians used wet red or yellow ochre, the modern craftsperson follows the method of Greek masons who employed white and red chalks in addition to wet ochre.

Rules

The unit of linear measure in the ancient world, the cubit, was simply the length from the elbow to the extremity of the middle finger. Although the cubit gave an order of magnitude, it was hardly a standard, and it varied widely in different times and places.

One of many royal Egyptian cubits had a length of 52.43 cm (20.64 inches). It was divided into seven palms (measured across the fingers, not the knuckles), making a palm almost three inches. Each palm was, in turn, divided into four digits of about three-quarters of an inch apiece. Thus, 1 cubit = 7 palms = 28 digits. On occasion, digits were subdivided into 10ths, 14ths, or 16ths.

The common rule of Egyptian masons and carpenters was made of wood, had a narrow cross section, and had one beveled edge, with the two left-hand palms carrying the smaller divisions of digits. Some Egyptian rods were made of stone and used digits divided into 16ths. These may have been ceremonial rods or, perhaps, master gauges for calibration and comparison; their brittleness would make them unsuitable for the rough handling received by mason's tools.

The Romans introduced folding rules of bronze in 30- and 15-cm (12- and 6-inch) sizes. These were probably "pocket" instruments for officials—too expensive to be used by ordinary craftspersons, who probably used plain strip rules.

Only scanty evidence exists that graduated rules were used in the Middle Ages and the Renaissance; plain straightedges seem to have predominated. In 1683 an English writer described foot rules as having 1/8-inch (0.32-cm) subdivisions. The folding rule, now made of wood, reappeared at the end of the 17th century.

Measurement was long characterized by great national and regional differences. Because every large city in Europe and most towns had a different but locally standard "foot," rules with four different graduations (one on each face) were made.

Power tools

A power tool is technically a power-driven hand tool or portable power tool; these names distinguish it from the stationary power tool such as the drill press. While power tools are generally driven by electricity, the category also includes small pneumatic tools driven by compressed air, such as air impact wrenches and hammers. Gasoline-engine-driven tools (chain saws, gas-powered drills, and so on) are not included.

power saw
A worker using a power saw to cut through metal. Many power tools are driven by electricity.
© *lawcain/Fotolia*

The most popular power tools are the electric drill and the electric circular saw. Like its manual counterpart, the electric drill rotates a tool bit, but the circular saw has no manual prototype. Jigsaws, sabre, and reciprocating saws have familiar blades, as do electric screwdrivers, but

many power tools are contemporary creations built around the ubiquitous electric motor. Among modern power tools are polishers, several kinds of sanders (circular, belt, oscillating, and reciprocating), shears, and nibblers. Power tools, in limited commercial and industrial use before World War II, are now produced by the millions, largely for the home workshop.

Richard S. Hartenberg The Editors of Encyclopaedia Britannica

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