ANCIENT MINE

THE SONS OF VULCAN

THE STORY OF METALS

By

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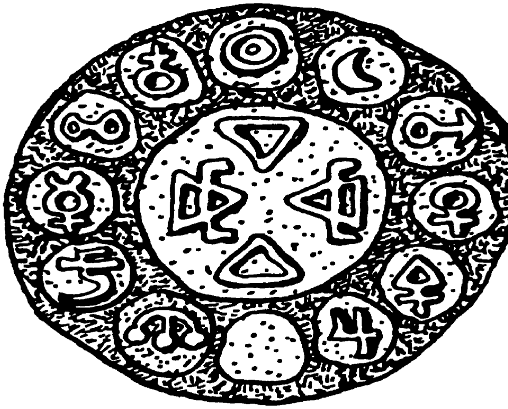
Illustrated by the Author

LOND

T. WERNER LAURIE, LTD.

24 & 26 BLACK FRIARS LANE, E.C.4



FOR

RODERICK, CONRAD AND BILLY

First Published . 1944
Printed in Great Britain by
Butler and Tanner Ltd.,
Frome and London

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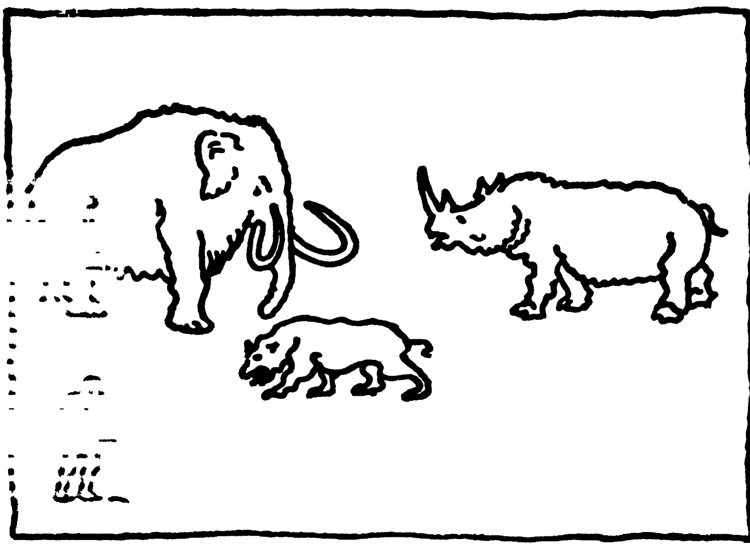
I. The Beginning of Tools

OF all things made by man, tools are by far the oldest, older indeed than any other fact we yet have learned of ancient man himself. Tools were used before food was cooked by fire, before the crudest pottery was made, before caves, or trees, or tents of hide, or huts of earth served man for shelter from the rain and wind. Tools have been found in gravel banks, in beds of streams or buried under the earth; tools that we know were made nearly a million years ago. Yet of the life of man as a being who walks erect, who thinks, who works and has some kind of organized life, all that we know is covered by a scant fifty thousand years.

The most ancient tools were not even made, they were found; smooth, flat, water-worn pebbles that fit the hand, bits of shell, or splinters of flint whose jagged edges served as blades to scrape the flesh from hide and bone. But even before this, there must have been a time when there were no tools at all, not a fishhook, knife blade, spearhead or axe. What was the world like without tools? We do not know how it was in the beginning for we have not yet been able to clear away the mists of a million years. Yet only two hundred years ago a toolless people still lived upon the earth, the Tasmanians. They knew neither fire nor any kind of shelter. They squatted on their heels by night and their only food was shellfish, or small animals eaten raw.

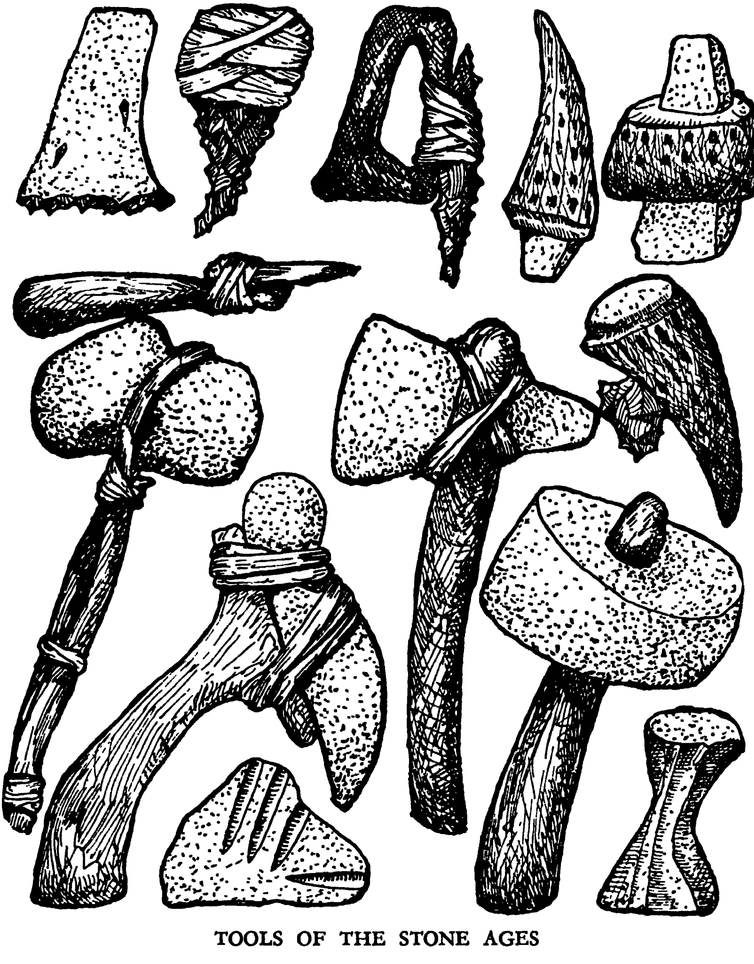
Diodorus of Sicily, who lived two thousand years ago, tells of a people of his own time who existed in a toolless world. He calls them "the fisheaters" and says that their country lay along one of the coasts of Arabia. They had no homes, nor even any families; all slept on the ground, herded together like animals. Their food was fish, and these they caught by building low stone walls along the shore, at such places where the sea ran into narrow bays. When the tide came in it would flow over these low walls carrying with it many kinds of fish. But as the tide began to ebb, seeping back through the crevices among the stones, it left the larger fish stranded on the sand. The fish-eaters then would laugh and shout, darting here and there catching the fish with their bare hands. They split them open, removing the bones which they threw aside on a pile. Then they mixed the meat with buckthorn, to flavour it, and made



PREHISTORIC MAN AND THE ANIMALS HE HAD TO FIGHT WITH STONE WEAPONS

fish-cakes on which they gorged themselves for four days at a time, stopping only to sleep before beginning the feast again. In all that time they had no water—there was none there to drink. At last, driven by thirst, they would climb into the neighbouring mountains, where there were fresh-water springs. From these they would drink until, swollen with food and water, they would fall into a stupor from which they would wake only to start the same round of life again.

But if the tide held high, or the wind made the sea too rough for the fish to come near the shore, these folk would first take the fishbones from the piles where they had heaped them and

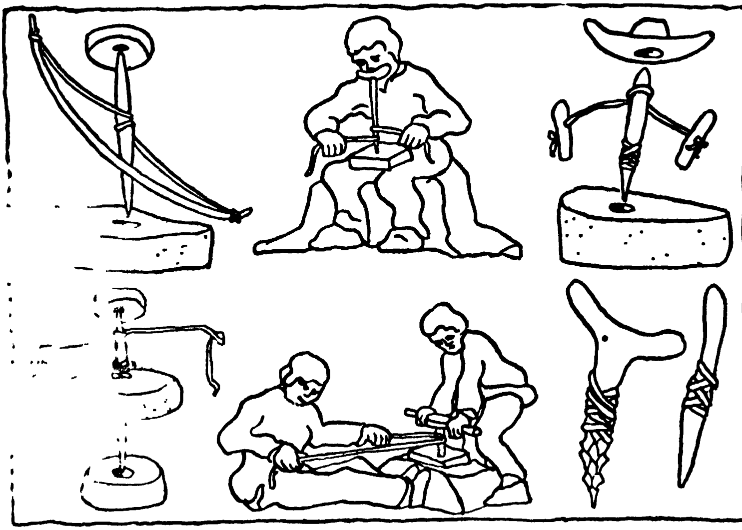


TOOLS OF THE STONE AGES

suck what meat and juices might remain. These gone, they would live on the large mussels they found in the sand. But should the wind hold and the mussels give out, they starved.

Not many people, even in the time of Diodorus, lived as these fisheaters did, but some hundreds of thousands of years earlier it was the common way of life for a great many of our ancestors who lived in a world without tools.

But not all the toolless people, even in ancient times, lived along the seashore. Some ate seeds, or fruits, even insects and the green shoots of trees, but most of them were hunters who



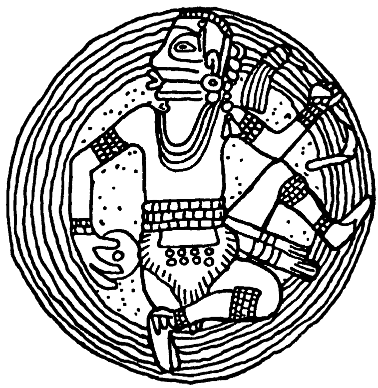
PREHISTORIC DRILLING TOOLS

lived on the flesh of animals. And it is probably these hunting folk who first made tools, for the fishhook and the harpoon do not seem to have come into the world so early as the axe and spear.

The most ancient hunters caught their animals barehanded, as they slept—you may imagine what skill, courage and patience that took. Later they learned to throw stones. That needed but little intelligence, for even an ape will throw stones, but it led to things that were intelligent—the invention of the spear and, eventually, of the bow and arrow.

We do not know which was the first tool invented—it may have been the spear point, which would serve both as a throwing weapon and a flesh knife. It may have been the axe-head which could be used as a scraper for hides, a cutting tool for wood and a very dangerous and accurate weapon when thrown. Whatever it was, once the idea of using tools got started, it spread throughout the whole of the ancient world.

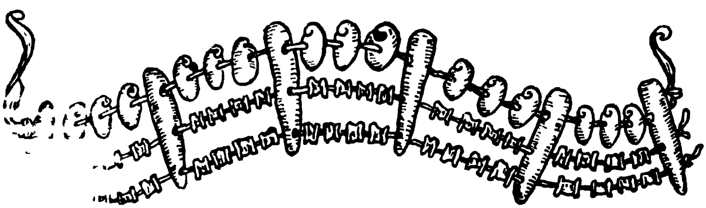
It is amazing how much early mankind seems to have moved about, not only on land but on sea as well. Far up in Stone Age France we find shells that could only have come from India, and the taro plant was taken from the South Sea Islands to Africa in the days of stone tools.



PREHISTORIC SHELL ORNAMENT

The first tools were usually made of flint, although some were made of chert and a few of black natural glass. In time there grew up regular factories for making tools where flint or chert was plentiful. The skill of these early tool-makers was extraordinary. They made axes and saws, drill points and spearheads that are things of wonder in their beauty and workmanship to us to-day.

When we think of these ancient people, we picture them as having flat heads, heavy jaws, a slouching walk, hairy bodies with long arms and clawlike hands. And that is how they probably were. Yet those powerful hands were wonderfully skilled, as you will find if you try to split off tiny flakes from a piece of flint as they did. That little brain and great body had the patience to bore a hole through the hardest kind of stone with nothing but a reed or a sharpened stick, twirled between the palms, for a drill. Nor were they content with only simple tools. Besides the axe, the adze and the spear, they invented fishhooks and the harpoon and a number of types of drill, one of which, the pump drill, we still use to-day. Their throwing machine, the bow and arrow, was not improved upon, in principle, until the invention of gunpowder about five hundred years ago. So skilful were some of these early craftsmen that no better needles than theirs, of polished bone, were to be made until as late as the time of Columbus.



ORIC NECKLACE OF TOOTH, BONE AND SHELL

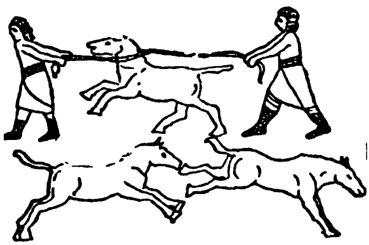
ve you here the history of these early stone tools keep us too long from the history of metal tools, wish to follow their invention, change and improvement down through the ages, you will find it told in *The Carpenter's Tool Chest.*

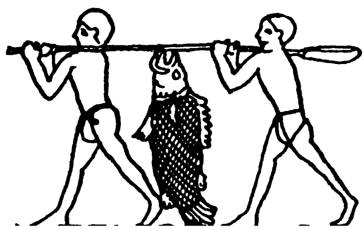
The life of the early hunter was probably a good deal better than that of the fisheater, but it still was no easy life to live. Before he invented the bow and arrow he had only the axe, the spear, the knife and possibly the boomerang and sling. Yet, with no better arms than these, the hunting folk killed the sabre-toothed tiger, probably more fierce than any animal we now know. The invention of the bow and arrow made a tremendous difference, but even with this, life must have been bitterly hard. The hunter must ever keep close to moving animal herds, for if the hunt failed he faced starvation.

After the hunter came the shepherd, when man had learned to tame the cow, the horse, the sheep, the goat, the camel and the ass. Now, instead of hunting his food, he followed his flocks

ANCIENT MAN AND HIS WEAPONS

and herds from pasture land to pasture land, living on the flesh and milk, butter and cheese which the beasts made possible. It sounds like an easy life and a pleasant one—under the sun and the stars, with plenty to eat and little work to do. Poets have always sung the golden age of the shepherd's life. But I doubt if it was really so.

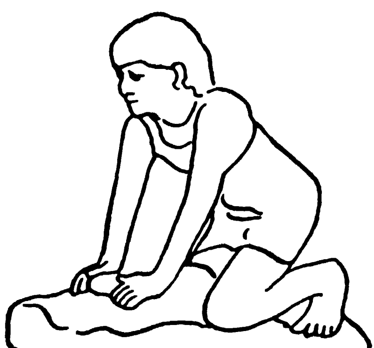




..RING WILD ANIMALS IN · ANCIENT WORLD

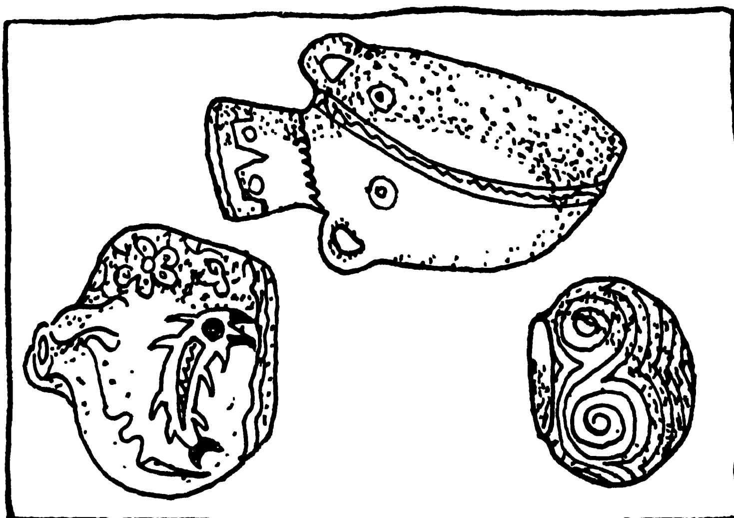
ANCIENT FISHERMEN

..s a description of shepherd life that has come down to Roman times. This tribe, so goes the ancient record, ..s of a sort, spears and round leather shields, bows and



ANCIENT BREAD MAKING

arrows, throwing rocks and knob-headed clubs. They followed their flocks from place to place, for ever seeking water and grass. Drought was always a danger, and wild animals raided their beasts by night. Tribe fought with tribe for possession of the pasture lands. They were always on the march. You must keep your place with the moving flocks, for if you fall out along the way, no one will wait for you. There was no place in this world for the old, or the sick, or the lame. "Such people," the ancient writer says, "were given the chance to hang themselves by tying the tail of an ox around their necks,"



PREHISTORIC, GREEK AND TROJAN POTTERY

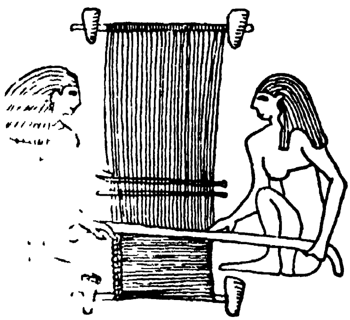
and, he goes on, "should they fail to do this, anyone in the tribe has the authority to do it for them."

It was only when man came to settle down to the farmer's life, to grow his food instead of seeking it, that the fear of hunger was no longer so ever-present and terrible. For now he eould store up his grain against his time of need, and while crops might fail, as no doubt they did, he now had, for the first time, a little breathing spell in which to look at the world about him and plan a better kind of life.

Weaving and spinning, pottery and basketwork had come.

Houses were built of sun-dried brick, or of withes woven together and plastered over with clay. A family could now live in some security. There was a place in this new world for the old, the sick and the lame. It was the beginning of life as we know it, and it was in this farmer's world that the use of metals came.

If you will think of all the time that has passed, from the beginning of tools down to now, as being but a day and a night of twenty-four hours—then twenty-three hours and forty-eight minutes of that time would have been taken up with the world of the fisheater, the hunter, the shepherd and the first farmer—only twelve minutes of it would stand for the time that has passed since the coming of metal tools.



ANCIENT WEAVERS

[illegible] look back on the age-long, dim and misty world of the stone tool users and see how bitter and terrible life must have been, behind each upward step on that long and sometimes wavering climb certain shadowy figures begin to take form, to stand out beyond the rest—for behind the axe, the adze, the spear, behind the bow and arrow and the drill, behind the weaver and the carpenter, we feel the presence of those men who made all these things possible. And as the world changes with the coming of metal tools, on down through the ages of copper, bronze, iron and steel, these shadowy figures become more and more distinct until at last we see them clearly—the toolmakers, the sons of Vulcan who made the world we know.

II. *The Sons of Vulcan*

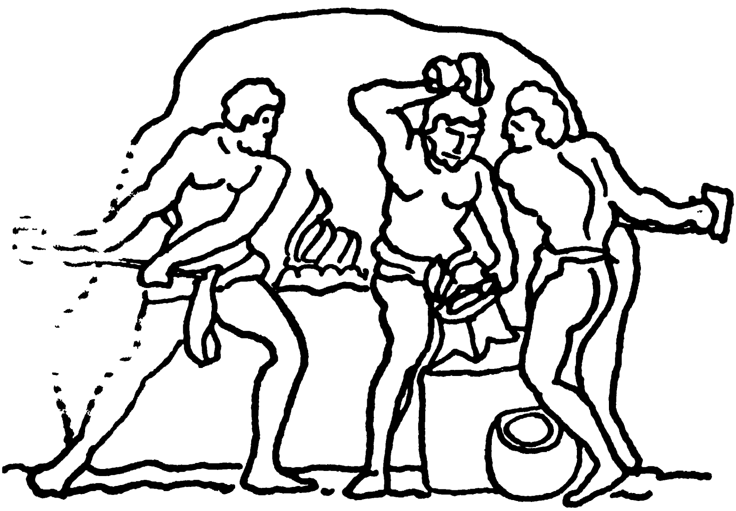
YOU would think that these, who gave so much to the world, would always have been held in high esteem by other men. But all too rarely has this been true. For the artisan, and especially the metalworker, has been looked upon in many ages with a curious combination of awe and disfavour, respect and fear. We see this all through the ancient legends, the folk tales that have grown up in every part of the world to tell the stories of the coming of tools and the invention of the crafts.

Vulcan was the son of Jupiter and Juno, king and queen of the Roman gods. Among the Greeks he was called Hephastus, son of Zeus and Hera, their eldest son, brother of Athena, Ares, Apollo, Aphrodite, Artemis, and Hermes. Yet his life was not spent, like theirs, in the pleasant fields of Olympus. When he was but a boy, his father, in anger, hurled him from heaven to earth. He was crippled by the fall, and when he returned, limping through the golden halls, the other gods roared with laughter to see that he was lame.

Though this is but a legend, it is none the less a true picture of the Greek world and the way the Greeks looked on work and craftsmen. For Vulcan during his stay on earth had learned to work. He became, in fact, the first of all the world's craftsmen to the Greeks and Romans. In his shop "imperishable and shining as the stars" he had an anvil and twenty bellows that blew up the fires at his command. There, with the cross-eyed giants, Brontes, Steropes, and Pyracmon, he worked as a smith and the world rang to his mighty hammering.

If there was cruelty in that laughter of the gods, there was also fear. For Vulcan had power no other god possessed, and though he remained a stranger among his brothers, yet at some time or other every one of them sought his aid or received from him some priceless gift. It was Vulcan who made Achilles' shield, the gates of dawn, and the axle of the chariot of the sun. He wrought the helmet of Pluto, the trident of Poseidon, and even the very thunderbolts that gave to Zeus his power over gods and men.

All the stories that the Greeks wove about their gods and heroes were but the reflection of their own daily lives and thoughts. To them Vulcan could not be like the other gods, because he worked, and the Greeks despised any kind of work. Among the Athenians it was an insult to be called a craftsman,



VULCAN

and in Sparta it was forbidden for any citizen to engage in any form of work or trade. To make quite sure no Spartan broke this law, their rulers every year went through the solemn mummery of declaring war against all those who worked in the Spartan state, "that they might be outlawed and beyond the pale of any rights and privileges as citizens."

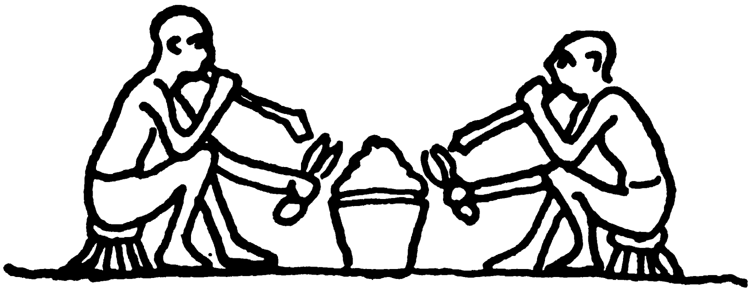
The stories that have come down to us from Homer all praise the glory of war, battle and adventure. Hesiod sings of the farmer's life, but has little to say of craftsmen. In all the old Greek tales and plays, the craftsmen, where mentioned at all, are looked upon more often with disdain than honour. "Then they came to the country of the Chalybes who take no thought of ploughing the earth with oxen or for the harvest of sweet fruits from the orchard, nor do they pasture flocks, but instead, they burn the iron from the heavy earth and all they earn they barter for their daily bread. No day dawns but sees them at their heavy labour in a world filled with fire and soot and smoke."

GREEK SMITH

Nor was it only among the Greeks that we find something of this same attitude. It comes up again and again in the legends of other folk and from other times. Loki, the god of the Norsemen, was, like Vulcan, a metalworker. He, too, made companions of giants and dwarfs and all manner of outlanders. It was he who secured the aid of the dwarfs in forging Mjollnir, the homing hammer of Thor, as Vulcan helpers had made Zeus's thunderbolts. Yet in many folktales of the North, Loki, like Vulcan, is always a little different from the other gods.

EGYPTIAN SCRIBE

Tubal-cain, the Phœnician, Hiawatha of the American Indians, Quetzalcoatl of Mexico, each was the bringer of the crafts to his people, yet each remained, in some strange way, an outsider to those who owed him most.

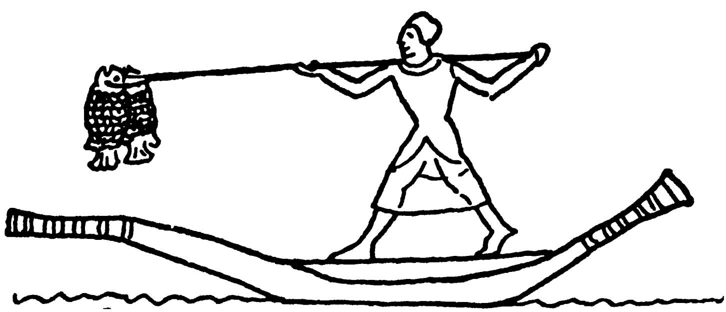


EGYPTIAN METALWORKERS

..sed this setting apart of those who worked from
' It does not always seem to have been so. You have

THE EGYPTIANS HUNTED WILD FOWL WITH THE BOOMERANG AND FISHED WITH THE DOUBLE-POINTED SPEAR only to look at the thousands of pictures of craftsmen drawn or carved on the ancient Egyptian temples to see that the artisan was once highly honoured among his fellows. Was not the king of the Egyptians the chief workman of many crafts? So his titles show. Did he not, each spring, plough the first furrow that started the farmer's year?

Yet, in later times, even among the Egyptians the life of the craftsman came to be looked upon with scorn. Here is a letter



EGYPTIAN FISHERMAN

written by an Egyptian father to persuade his son to become a clerk rather than to enter one of the crafts.

"I have seen the metalworker at his task at the mouth of the furnace, his fingers burned and scarred like a crocodile's skin, he stank worse than fish spawn. Every workman who holds a chisel suffers more labour than a man who hacks the earth, for him wood is the field and his chisel the mattock. At night, when he should be free he must still work on until his task is done, sometimes longer than his strength can stand. The stonecutter seeks out the hardest kind of stone to work and before he has finished his task his arms are worn out. The barber shaves until late at night, he goes from street to street to seek men to shave. He wears his arms out to fill his belly like a bee who eats his work. The boatman, who carries goods down the river to the delta, to get their price, does more work than his strength can bear, and, in the end, the mosquitoes kill him.

"The farmer has always bills to pay, and these go on to all eternity.

He cries out louder than the Abu bird. The weaver in his workshop is worse off than a woman. He squats all day on his knees and his belly does not taste clean air. The courier, starting off for foreign lands, leaves his goods to his children, fearing he will be killed on the way by lions or Asiatics. The cobbler is wretched. He is for ever begging. The bleacher whitens linen on the quay—he is the companion of crocodiles . . .

"On the other hand," the letter goes on, "there is no office which has not a superior except that of the scribe—It is he who commands. Does he not make the written record? That is what makes

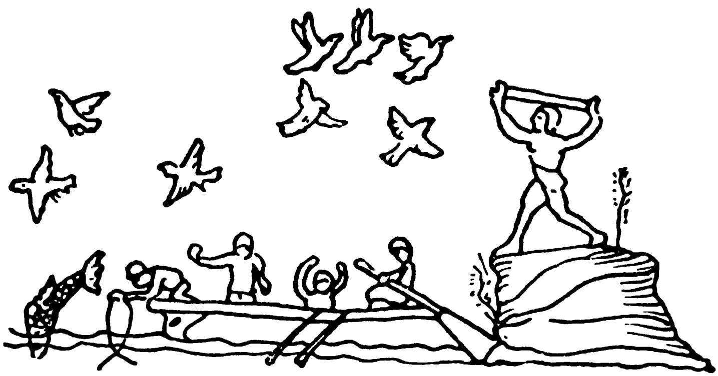
EGYPTIAN SCRIBES

the difference between him and the man who handles an oar. The scribe comes to sit among the great ones of the assembly and no scribe fails to eat of the victuals from the king's house."

Four thousand years ago that was written, yet you can still find those in our world who will tell you it is more honourable to seek such scraps as may fall from the tables of the rich and powerful than to make a clean, free world for yourself by the labour of your own two hands.

Very few think that way to-day and it would not now matter much that men held such notions in the past, had not this feeling been so widespread in the ancient world, and especially, had it not so deeply coloured all the history that has come down to us.

In the beginning, I think, the craftsmen must have been looked upon with a good deal of wonder and awe, particularly the metalworker. Have you ever seen a billet of white-hot steel lifted from the furnace by the iron fingers of a crane and set down on the rolling line of a mill? At once the rollers pick the glowing billet up; turning and twisting, it seems a living thing

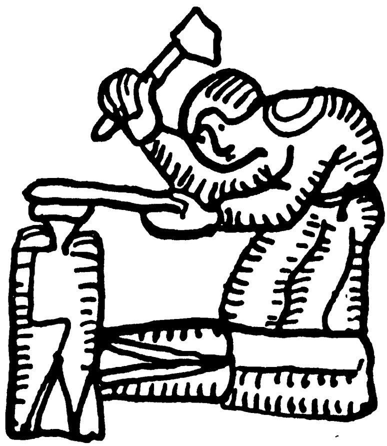


ETRUSCAN HUNTER AND FISHERMAN

as it starts through the mill. You have to run to keep abreast of it as the rollers squeeze and press the block into shapes. Great clouds of steam shoot up as it is chilled, and then, all in a moment, it comes off the end of the line flattened into sheets or rolled into bars already cut to length and cool enough to be lifted in your hand. Not even to-day, with all we know, can anyone watch a change so suddenly made without a feeling of awe and wonder.

How then must it have seemed to the ancient folk to watch a smith in the darkness of his shop blow up his fire, snatch the hot iron, all glowing and spitting sparks, set it on his anvil, where, under his hammer, he shaped a tool faster than eye could follow the blows? All done in a moment of intense and godlike energy. Was there not in those who watched some memory of the tens of thousands of years when their fathers had made their tools by the infinite labour of chipping and grinding stone? Certainly the smith was honoured for his work in the beginning, but at some time there came a change.

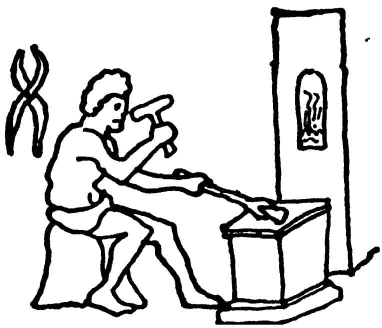
The smiths themselves, I think, were responsible for a good deal of the myth and superstition that grew up around their



NINTH-CENTURY ANGLO-SAXON SMITH

craft. For they actually did come to draw away from other men. In part, this was because they needed ore and charcoal in their work, and they set up their shops near where these could be found. But that was not the whole reason. They seem to have wished to work alone even where ore and charcoal had to be brought to them.

In ancient France and Spain there were whole towns where only smiths lived. Here they worked in solitude, allowing no other people to come near their shops. They built walls of timber and earth around their towns and their shops were tunnel-like and partly underground. In these they would work for months on end, producing their marvellous metalwork—tools and implements, swords and spears, helmets and armour, bits and harness ornaments. Sometimes they coloured their wrought iron with bright enamels, an art we think they invented. They also knew how to coat one metal with another—iron with copper, bronze or tin, an art we know they invented. They made steel and even are said to have cast iron in moulds, which is the most difficult way of working with iron. The fur-



ROMAN SMITH

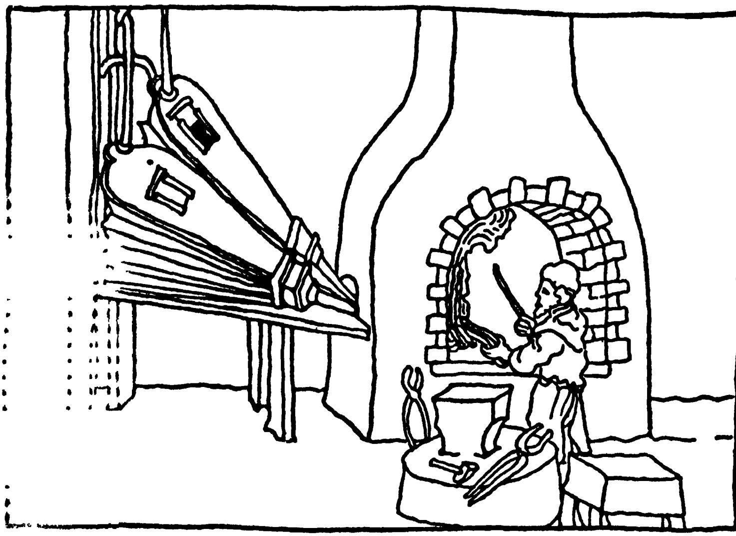
nace which they invented for smelting ores came in later years to be used all over the world, from the wealds of Sussex to Japan.

At certain times of the year, we believe, they closed their shops, put out their fires, threw open the gates of their villages and held great fairs to which men came to buy the beautiful things they had made.

They were proud of their craft, these ancient Gauls and Spanish folk. When any smith among them died he was buried under the anvil in his shop with his tools beside him, as a soldier is buried with his arms. Yet of the lives of these people we know almost nothing, for they shut themselves off from the rest of the world.

We do not need to go back two thousand years to find the smith a little mysterious in his work. The tale of Weyland Smith, outside whose cave horses were shod by unseen hands, is the legend of a man who was both swift and skilful and who lived apart from his fellows.

Biscornet, who made the hinges for Notre Dame of Paris, is said, in the old tales, to have sold his soul to the devil—how



MEDIÆVAL SMITH

else, thought the mediæval Frenchman, could mortal man do work so marvellous? And well they might think so, for even to-day, and covered with the many coats of paint that are needed to protect them from rust, these wrought-iron bands of Biscornet make patterns of such beauty against the crimson cathedral doors that your heart will leap in wonder at the craftsmanship they show. But Biscornet must have worked alone, or if he had helpers they took with them to their graves the secrets which he taught them. For the method by which Biscornet made these hinges, joining together so many thousands of small and delicate pieces, was lost for many centuries —it became known again less than fifty years ago.

But if this sense of mystery with which the smith so often surrounded his work had something to do with the attitude of his fellows towards him, it was not its only cause. For in the work of the carpenter, the potter and the weaver, the butcher

FRENCH BLACKSMITH'S SHOP—SEVENTEENTH CENTURY

and the baker, there was nothing mysterious—they all worked in open shops in the heart of the town where any who passed could watch. Yet they were set apart from their fellows, and even in some periods looked upon with scorn by those who wrote the records of their times. Certainly we can find little enough in the old accounts and histories to tell us how they lived and worked or even what they made. We read, instead, over and again the glory of battle, war and conquest.

The scribes who made these records but echoed the thoughts and feelings of their own times. The soldier had come to be the hero of all stories in a military world over which he and his kind ruled by force. The ring of the hammer on the anvil was drowned in the beating of drums. There was no one to speak for the craftsman and he did not speak for himself.

Yet if the written record is scant, the tools the craftsmen used remain, and many of the things they made exist to tell the story of those men who worked on and built, even in times of neglect and cruelty, slavery and war, the real foundation of the world we know to-day.

We have come, now, to realize that the history of man is more than the mere record of wars and conquest, more than the rise and fall of kings and governments, for it must include the simple account of the daily lives of those who have created things, the farmers, weavers, potters, smiths, artists and craftsmen, mechanics and discoverers—all the inventors and users [illegible] and machines.

[illegible]e have thrown aside the false pride and ignorance [illegible] made Vulcan a stranger among his fellows, and we are rid [illegible]perstition that could only see, in the craftsmanship of [illegible], the work of the devil. We are just beginning to [illegible] life could be in a world of craftsmen, makers and [illegible] things. Let us, then, look at the story of one of the [illegible], that of the metalworkers. Perhaps if we can come [illegible]stand what they have already done, how and why, we may see more clearly what there is yet to do.

III. *Ancient Mines*

BEFORE there could be any metal tools, there had to be metal from which to make them, and this need brought into being two ancient crafts, that of the miner and that of the ore smelter. Actually mines were known before metals, as long ago, in fact, as the early Stone Age, but they were by no means common. At that time the usual method of getting flint was to dig for it in open pits, but in northern France some flint mines have been found that go down into the earth more than thirty feet, and that have regular galleries extending from their shafts.

Mining, however, in the sense of digging into the earth, did not become common even with the first use of metal, for gold was long known before it was mined. The most ancient gold workings were the beds of streams, where the metal was found, as a dust or in nuggets, in the sand and gravel from which it was separated by washing. The simplest way of washing gold is to place the sand and gravel, scooped from the stream bed, in a flat pan, which is held level and swung slowly around in circles until all the contents have started to swirl. The swirling is a spiral motion and its movement is much faster towards the outer rim than in the centre. Gradually the lighter particles of earth, sand and rock debris move outward towards the lip where they can be slopped over from time to time by a slight tilt of the pan; while the heavier gold moves towards the centre where it can be lifted from among the larger pebbles that remain. This is called, by miners, "placer mining," and the gold so recovered is called "colour."

Placer mining is still practised to-day. A man can work alone or with a partner. It takes but little equipment and the rewards are great to those who succeed in finding gold. But for one such miner who makes a strike a score of others spend their lives combing the deserts and the mountains of the earth, labouring in the heat of Australia and Africa, or freezing through the winters of the Klondike and the Yukon, and finding in a lifetime only enough gold to lure them on to further search.

In some places placer mining of a sort is done with the aid of machinery. Here great streams of water are shot with tremendous force against a mountainside so that the rock is shattered and torn away. This debris is swept into troughs as the water rushes down the cliffside, and there it is gathered on moving belts where the gold is shaken free.

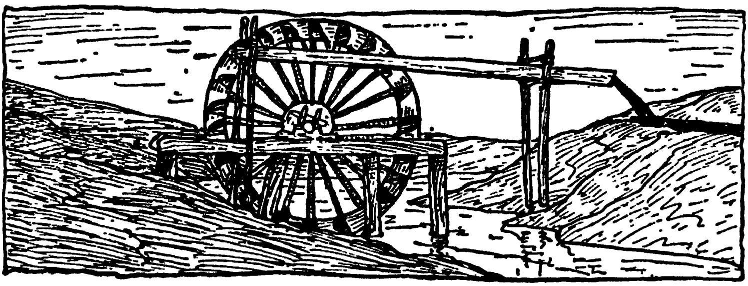
WASHING FOR GOLD—CALIFORNIA—1848

We are apt to think that this is quite a modern method, but the Roman writer, Pliny, tells us of a mine in Spain where gold washing was done over two thousand years ago in almost this same way.

"There," he says, "the workman would bring rivers of water from far away, as far as a hundred miles, carrying them along the ground in large wooden pipes. Where valleys occurred they built great stone aqueducts over which streams could be made to flow, from one mountainside to another. In some places it was necessary to cut channels right across the faces of cliffs, so steep that the workmen had to be hung in the air on ropes and let down from above. Here, some took the levels and laid out the course of the channel while other workmen cut into the rock."

These men, swinging on their ropes high against the sky, seemed to Pliny more like birds than human beings, yet so able were they that "for all the difficulty of their task they made water flow in places where, before their labour, no man might find so much as a spot on which to set his foot."

With great labour and skill they brought the streams to the place where the washing was done, and there they built reservoirs with gates which might be opened when the reservoirs



ROMAN PUMP: THE ROMAN PUMP WAS A WATER-WHEEL HAVING BUCKETS ON THE SIDE OF THE RIM WHICH SCOOPED UP WATER AS THE WHEEL TURNED AND DROPPED IT IN A TROUGH

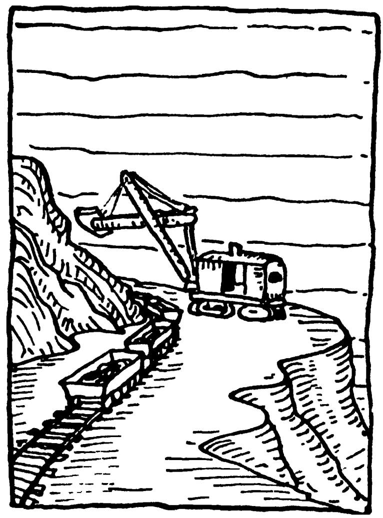
were filled and the water let fall with great force upon the gold-bearing rock below. This rock, broken and ground to small pieces, was swept along in trenches, tumbling and rolling with the flow of the stream. The bottoms of these trenches were covered with prickly rosemary so that, as the gold dropped from the broken ore, it could be caught and held while the waste debris was carried on outward towards the sea. From time to time these rosemary linings were taken from the trenches and burned until only gold and light ash were left. Then gentle washing removed the ash and left only pure gold. "So great was the amount of broken rock, washed out to sea, that the whole of the coast of Spain was extended at this place."

Five hundred years earlier than this the Greeks had, at Mount Laurens, a vast silver mine where the metal was washed from the ore. This mine, like almost all Greek mines, belonged to the state, but was rented out for short periods to private operators who worked it with slaves. Greek writers have called it a place of dread and terror, where men died like flies, and this we may

GREEK MINERS

well believe, for the galleries from which the ore was dug were so shallow that a man must work either kneeling or lying on his belly. No one, however strong, could live for long at such labour, working cramped in a little space, without rest, and choked by the foul air which settled there.

The ore was crushed under stone mill-wheels turned by hand. Nearby there was a terrace built of flat stones, cemented together. Water was brought to this terrace in a canal and the wet, crushed ore was swept back and forth on the stone floor with brooms until the silver had dropped out and could be gathered. All this work was done by hand, slow and bitter labour, digging, crushing, washing and picking over piece by piece the broken rock. Seven million tons of debris lie there to-day, below the mine, the awful testament of five hundred years of cruelty and greed. When, some day, you may see the temple of the Parthenon rise glorious above the city of Athens, give a thought to the miners of Mount Laurens who paid for it.



OPEN-PIT MINE

Open-pit mining, especially for copper and iron, was known in the ancient world, and we still mine this way. In Utah, U.S.A., there is such a mine where the three sides of a mountain valley have been cut into vast terraces, one above the other, like huge nested horseshoes. Railroad tracks placed on these carry trains of ore cars, and powerful shovels rip away and load them with enough ore to make two hundred thousand tons of copper every year. I do not think that that much copper was mined in all the world in the thousand years that Greece and Rome endured.

But by far the most interesting and usual method of mining is to burrow into the earth with tunnels, shafts, and galleries, following the veins and reefs of ore wherever they may lead. We do not know when the first mines were dug. They have been known from the earliest times in Egypt, India and Spain. Spain was especially the treasure-house of metals in the ancient world. There copper and gold, silver, lead, iron, tin and mercury were found. We hear of a Roman mine there that descended over a mile and a half into the earth, where the miners broke the ore from the gallery walls with sledges and picks, and other men standing in line passed the broken rock from hand to hand until it reached the pit-mouth. They worked by the light of torches, and only those whose station was near the entrance saw the light of day for months on end. But long before the coming of the Romans, the Carthaginians had opened and worked many mines in Spain. One of these, the Rio Tinto, was so rich that, although it was old in the days of Hannibal, it is still being worked to-day. How much metal the Carthaginians took from Spain we do not know. They paid eight hundred thousand pounds of silver in annual tribute to the city of Rome, after their defeat, yet this could have been as nothing to the whole amount of metal they must have mined in the centuries that had gone before.

GOLD WINNOWED FROM CRUSHED ORE BY SHAKING IT IN A CLOTH

We have an account of a mine in Egypt that was even older than those of Carthage, Greece and Rome. The story of this mine comes to us from a writer who lived two thousand years ago. Yet he himself is repeating a tale that came to him from even earlier times: "The kings of Egypt gather together and condemn to mining such men as have been guilty of some crime. They also send captives of war and even those who have been unjustly accused by evil persons. Not only is the guilty man sent, but all his family and relatives as well, for great profit is to be gained by the king from their labour."

Those condemned must work both night and day, enjoying no rest and cut off from escape. None of these persons was given any chance to take care of his body. The sick, the lame, the weary and the aged, women as well as men, were compelled to work in chains under the blows of the overseer. The guards of these prisoners were chosen from among foreign soldiers who could not speak the language of the condemned workers, and this was done so that no guard might be moved to pity through the pleading of his prisoners.

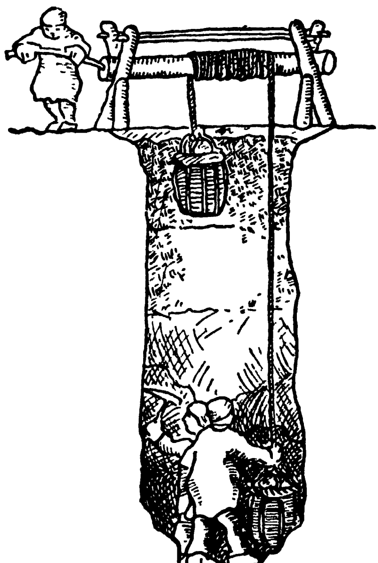
The whole mine was in charge of an overseer who pointed

EGYPTIAN PUMP

out where the work was to be done. The strongest prisoners plied heavy hammers, bringing no skill to their task, only force, and they cut tunnels through the rock to follow the vein of gold. Within the mines, men worked in darkness except for such light as was given by their lamps. They threw to the ground the blocks of ore which they had broken away, and boys, not yet grown, crawled through the galleries gathering these pieces which they carried out of the mine.

Those older and weaker than the heavy workers broke up the quarried ore with hammers or under grinding stones until it was about the size of peas. The women and the old men received this ore and cast it into other mills which stood near by, in a row, and ground it under mill-wheels until it was like a fine powder.

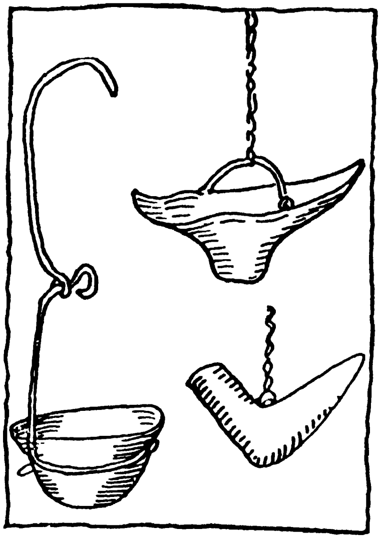
This ore dust was then placed on a sloping board where water was passed over it until all the earth was washed away, leaving the heavy rock. What was left was picked up and rubbed between the hands and then lightly sponged until only pure gold remained. Skilled workmen took this gold dust and put a measure of it, mixed with a lump of lead, some salt, a little tin and some barley bran, into a clay pot on which they fastened



CHINESE MINE

a lid with mud. These pots were then baked for five days and five nights, and when cool were broken open, and in each of them there was found a cake of pure gold. For all this sounds a little like a witch's brew, it actually was, in principle, good smelting.

Probably all the mines of Egypt, Carthage, Greece and Rome were not so terrible and cruel for those who worked as these we have just heard about, but very likely most of them were, for these are the only accounts of ancient mining that have come down to us. Small mines of the ancient world worked by a few men were probably something like the small mines in China of to-day. The shaft of one of these mines is about five feet across, and the sides are protected by wicker work. Over the shaft is a crude windlass which is turned by wooden cranks with one man on each end of the beam. On the beam there is a



ROMAN AND CHINESE MINER'S LAMPS

rope, so coiled that an empty basket goes down each time a full one is pulled up. The miners themselves go down in the basket, one at a time, holding on to the rope. They have lamps made of porcelain in which vegetable oil and a rush wick furnish the flame. The men stay underground three hours at a stretch and they tell this length of time by an incense stick which they light and which will burn exactly that long. In each shift there are two men and a boy.

Even in the great mines in the ancient world the owners learned in time to take better care of their workmen. After all, a slave cost ten pounds in Athens and a mine superintendent three hundred, which is just three times as much as was paid for the great Greek teacher, Plato, when he was sold as a slave. They learned to shore and timber their tunnels and shafts to prevent slides and cave-ins, and they invented ways of bringing fresh air to the miners working deep in the earth. They knew that, quite often, dangerous gases are found in mines, so they used to let down lighted lamps into their mine shafts as a test for poisonous gases before the miners would enter them. If

[illegible] AIR IN AN ANCIENT MINE BY SHAKING A CLOTH

[illegible] gas was present the lamp would go out. But even [illegible] there was no poisonous gas the still air in a mine is soon made foul and exhausted where men are working. To overcome this the Romans used to build a fire at the bottom of one of their shafts so that the heated air when rising from this shaft would draw fresh air down through other shafts into the mine. What is even more extraordinary, they also knew that you could keep air fairly fresh by stirring it, and this they did by shaking linen cloths. It has been but a few years since we, ourselves, relearned that air could be made fresh, even in a closed room, by stirring.

It was really water more than gases, however, that made ancient mining so difficult. A vast amount of water is constantly flowing under the surface of the earth, and when mine shafts and tunnels have been dug this water will sometimes seep through their walls so fast that it will fill them. In some of the Roman mines the water was bailed out in buckets passed from hand to hand along lines of slaves stationed from the farthest interior to the pit-mouth. But more often some sort of pump was used.

The Egyptians had long ago learned to make a number of kinds of pump. These they used to lift water from canals to

FRENCH MINE—SEVENTEENTH CENTURY

turn it on to their fields. Some of these were sweeps and others were continuous belts which carried small scoops, each of which could lift a little water and carry it to a higher level where it was dumped. Archimedes, the Greek, invented a pump, made like a screw, which turned inside a cylinder and in so turning lifted water from one level to another. But none of these pumps could raise water very high. To do that you must have a whole series of them in line in order to lift the water from the inside of the mine to the pit head. The Romans used water-wheels, one of which, about fifteen feet in diameter, has been found in a Roman mine in Spain. Vitruvius, a Roman engineer, tells of a pump worked in his day by men and animals. From his description it would appear to have been a reversed paddle wheel. It was not, however, until late in the Middle Ages that good pumps were made. Before that time the depth of all mines was limited by the kind of pumps that could be used.

IV. Mediæval and Modern Mines

THAT we know as much as we do about the mines and metals of the Middle Ages is due to the work of a man named Georgius Agricola. Agricola was born in Germany late in the fifteenth century and died there in 1555. He was interested in everything that happened in the world in which he lived, but above all he was most interested in mining, and he set down in a book, which he called *De Re Metallica*, all the great knowledge and experience he had gained through a long and busy life.

Here he tells the story of mining as he has heard it from the folk tales and traditions of his country and here he shows all the methods and processes used in his own day—how mines were found, how surveyed, what tools were used, how water was pumped and air changed in the mines. He tells of the crushing, washing, smelting and assaying of ores and metals. All this is done with great care and exactness, yet there is nothing dry or dull in Agricola's book. All through it you feel again and again that his real concern is with the man who does the work.

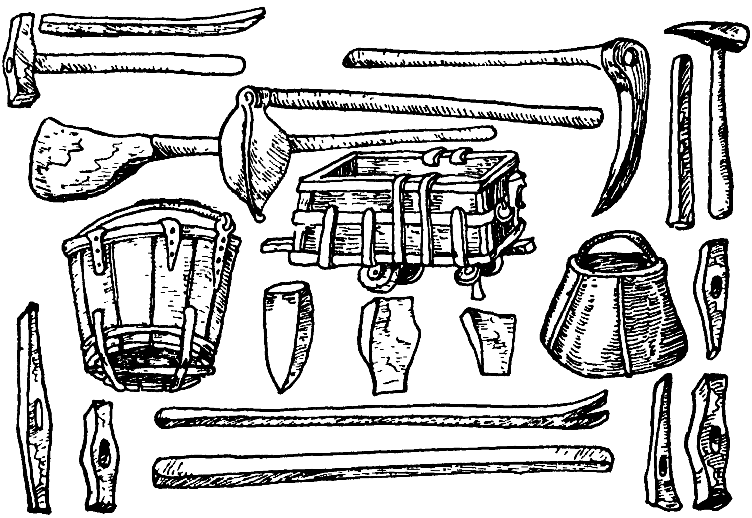
Miner, metalworker, smelter, inventor, scholar, man of affairs that he was, Agricola never forgot that he himself was a miner first and last. He was proud of his craft and he cared deeply for the simple folk among whom he worked and spent his life. He wrote his book, I think, as a lesson and a guide to other miners and mineowners, pointing out to them the need of better mining methods, and above all that mines must be made safe and miners treated with fairness and decency.

He had very clear ideas about gases, dust and timbering. He showed the need of proper ventilation, and he described a score of ways with which to improve it—ducts to lead air through the mines, bellows and fans to move it along.

He studied pumps and described many of them—piston pumps with metal or leather valves, chain of buckets turned on

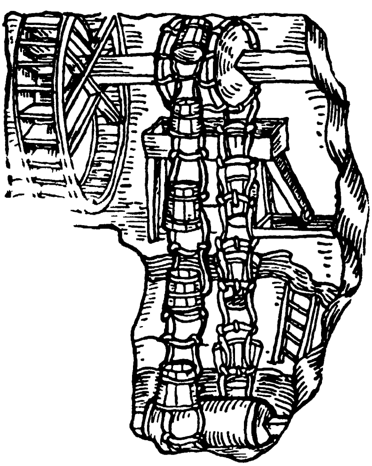
MEDIÆVAL MINERS WASHING ORE

drums that were operated by machines. He showed how water, wind, animals or men could be used to furnish power to work the pumps or to raise the ore to the surface. These were machines, crude enough it is true, but none the less true machines. They led the way to the machine world of to-day. It was, indeed, the need of better mine pumps that brought about the invention of the steam-engine some one hundred and fifty years after Agricola's time.



In his book Agricola tells about the small mines in the mountain country of his day where the ore was taken out and stored until winter came, and then placed on sleds which were guided down the mountainside by the miners. In some places the ore was put into sacks made of pigskin, which the men dragged down the mountain, by hand, in places where it was too steep for horses or mules. In winter weather they would sometimes slide down the mountain slope, sitting on their sacks, and guiding these with sticks—"Not," says Agricola, "without risk!"

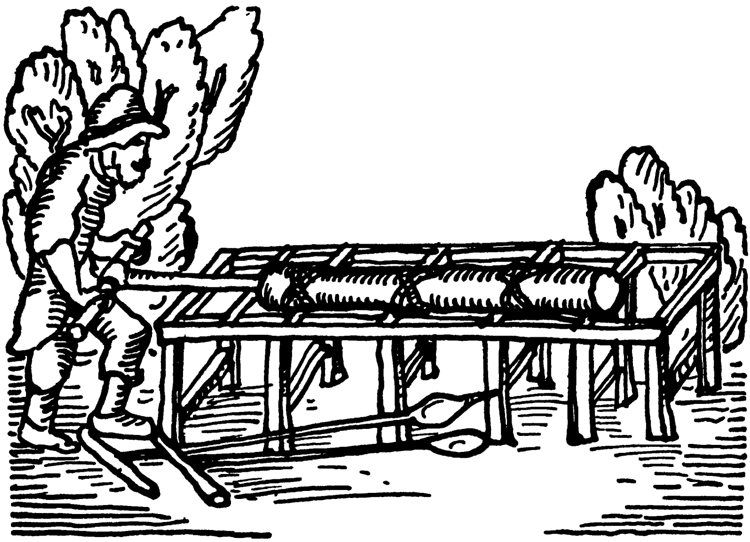
In deep mines they brought their ore out on little carts and barrows that ran on wooden rails. The mines in those days in Germany were privately owned. When a man found a prospect of metal he went to the burgomaster to establish his claim. The burgomaster would then stake out the mine-head and measure off nine parcels of land in each direction. Three of these each side of the mine head went to the discoverer, one to the king, one to the king's consort, one to his master of horse, one to his cupbearer, one to the groom of the king's chamber and one to the burgomaster.



MEDIÆVAL BUCKET-CHAIN PUMP

In England, in Anglo-Saxon times, the mines were originally owned by the king and worked under lease by miners. Then there was a long period of struggle between the king and the landlords as to who owned the mines. Under the Normans this was settled—the state retaining ownership of mines regardless of who owned the land. But the struggle went on and one result of the victory of the barons at Runnymede was to break the claim of the crown to mine ownership. Thereafter, the crown still received a royalty from the mines, but the landlords owned the mineral. As late as the seventeenth century any miner who wanted to could prospect the "common land" in England. But this was stopped when all the "common land" was usurped by the great landlords.

In Agricola's day the miners worked in three shifts of from three to seven hours each, and they were not expected to work longer than that, "except in times of great necessity." "Then," says Agricola, "whether they draw water from the shafts or mine the ore, they keep their vigil by the light of lamps. To prevent themselves from falling asleep, through the late hours or from fatigue, they lighten their long and heavy labours by singing—which is neither wholly untrained nor unpleasing." Agricola also says that "in some places a miner is not allowed to work two shifts in succession because it often happens that he either falls asleep in the mine, overcome by exhaustion from



BORING A PIPE FOR A PUMP

too much labour, or he arrives too late for his shift or he leaves sooner than he ought. But elsewhere he is allowed to do so because he cannot subsist on the pay earned in one shift, especially if provisions grow dearer."

A bell in the mines was rung to signal to the miners to come to the mine for their shift, and those inside were warned that relief was near when the overseer stamped on the pithead. They, in turn, passed the word along by signal taps of their hammers, but in any case they would have known when seven hours had passed, for their lamps were made to carry only enough oil for that length of time.

The workmen in these mines were divided into crews. There were miners, shovellers, windlass men, carriers, sorters, washers and smelters. To get the ore out they used picks and sledges, and sometimes they drove wedges into the cracks to break away large blocks. Where the rock was very hard, fire was sometimes used, but this custom is very old.

MEDIÆVAL MINE

Pliny tells about the use of fire in mines in Roman days, saying, "occasionally a very hard rock was met with which must be broken with fire and vinegar." And Livy speaks of this, too, adding that, "the fire must be lit only when the wind is right." Just why they used vinegar we do not know. There is an old tale that when Hannibal was crossing the Alps he cut passages through which his elephants could march, and these were said to have been made by pouring vinegar into crevices to eat away the rock. Vinegar is an acid, and it might possibly have a little effect upon a rock, but it most certainly is not strong enough to eat a rock away. Fire was used because rock, when heated, has a tendency to crumble; in fact some of it will explode. In these Roman mines, however, it was much more common to use battering rams to break loose the mass of rock. These were huge beams, slung on ropes, which could be made to strike the mine wall with great force. Fire was dangerous in a mine, for the galleries might become filled with suffocating smoke and fumes. In late mediæval times, when fire was used, all mining workmen were required to stay out of the mine, and no permission was given any mine to use fire if there was any chance that the smoke might seep into neighbouring galleries. This method of mining was still in use in England in the seventeenth

PREPARING BILLETS TO BE USED TO BURN AGAINST MINE WALLS–NOTE THE SMOKE COMING FROM THE PIT-HEAD

century and in Norway and Sweden up to about a hundred years ago. In 1627 gunpowder was first used for blasting in Germany, where many inventions and improvements in mining were first made.

The oldest map of a mining region comes from the Egyptians of over three thousand years ago. In the Middle Ages when the survey of a mine had been made the whole map was laid out again in full size on a level field in the neighbourhood, and this field was called the "surveyor's field."

One of the curious superstitions of mining that has lasted from the most ancient times to our own day is that mines can be found by the use of a "divining rod." This was a fork, cut from a tree, that had two handholds and a long projecting point which turned upwards slightly. It was believed that if you held such a stick in your hands, with the clenched fingers upwards, and walked over land, then the point of the stick would turn downwards when you came to a place where metals could be found. Hazel twig was thought to be best for silver, ash for copper, pitch pine for lead and tin, iron rods for gold. These were sometimes called "witching sticks," and even so intelligent a man as Robert Boyle, founder of the Royal Society,

BREAKING HARD STONE IN A MINE BY BUILDING A FIRE AGAINST THE WALL

believed in them. They were also used to find water as well as metals. I have known, in our own day, very able miners and well-drillers who would not think of prospecting a mine or digging a well without having first used a witching stick to find it. Certain men were thought to have unusual powers with the divining rod, and these diviners were always in demand by miners seeking metal or well-drillers seeking water. Of course, there may be no truth in this superstition, but mining is a dangerous and difficult labour—it brings sudden and great rewards as well as quick and terrible disasters. It is not surprising, then, that a good many superstitions grew up about mining.

One of these tells of a race of little people called gnomes who lived in the mines but were rarely seen. They really did nothing, although they made a pretence of being very busy. Sometimes they threw pebbles, in play, at the miners, for they were full of fun and liked to play practical jokes, but they never injured any-one unless severely provoked. Almost all the German miners of the Middle Ages believed in gnomes, and I have seen Mexicans of our own time set out little cups of wine and bread for the tiny folk who live in the earth.

SEARCHING FOR GOLD WITH DIVINING ROD

Mining methods improved quite rapidly after the days of Agricola; better pumps were invented, and a great variety of ventilators and hoists were tried out. The invention of gunpowder and its use for blasting must have made a tremendous difference in the work of miners. But it was not really until quite modern times that mining became the vast and important industry that it is to-day. Two things, it seems to me, brought this about. One of them was the beginning of the use of coal for fuel, and the other the invention of the steam-engine. The use of coal began about the time of Queen Elizabeth, but it did not come into its own as the great modern fuel until the age of machinery began.

Machinery had long been in use before the invention of the steam-engine. The Egyptians and Babylonians had used machines for pumping water and the Romans had used grinding mills and water-wheels. We hear of windmills in ancient Persia and treadmills worked by men or animals in almost all the ancient countries. But after the fall of Rome the use of mills died out and it was not until about the fifteenth century that they came back into favour again. The earliest of these seem to have been in Spain, and shortly after there was a mill in France. We hear of an old mill in England about the time of King John. "There was a windmill standing near the nunnery

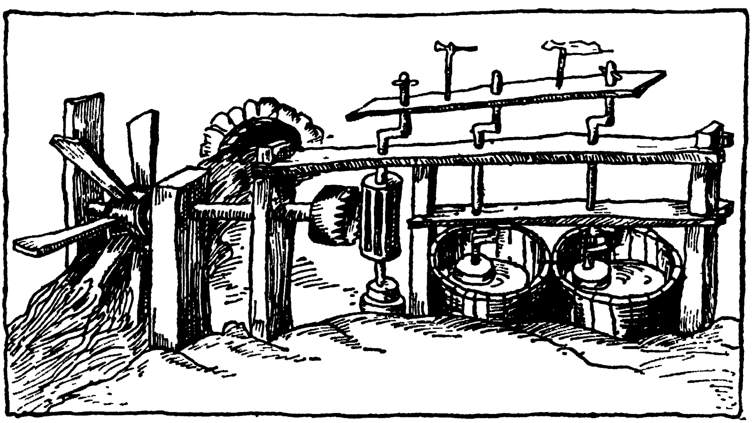
OMAN WORKER AT THE SAME TASKS AS MEN IN MEDIÆVAL GERMANY

without Ridingate, which the hospital held by grant of the nuns there. The condition mutually agreed upon at the time of this grant was: that the nuns, bearing the fourth part of the charge of the mill, should reap the fourth part of the profit of it and have their own corn ground there for them, when they would, gratis and free of cost." The hospital side of the bargain seems to have been to build a road from the highway to the mill.

Almost all of this early machinery was entirely made of wood —wooden gears, cogs, beams, bearings and wheels. Those parts which bore most of the wear were made of oak, ash, hickory, or best of orange wood. Mills in America as late as the

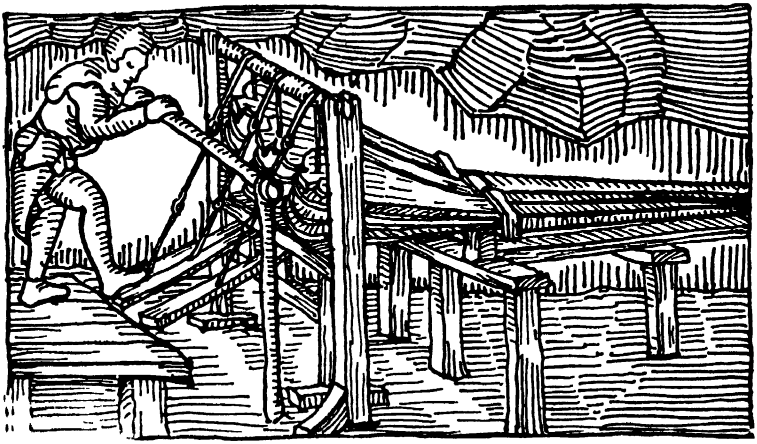
TREADMILL

MEDIÆVAL ORE-STAMPING MILL WORKED BY WATER POWER

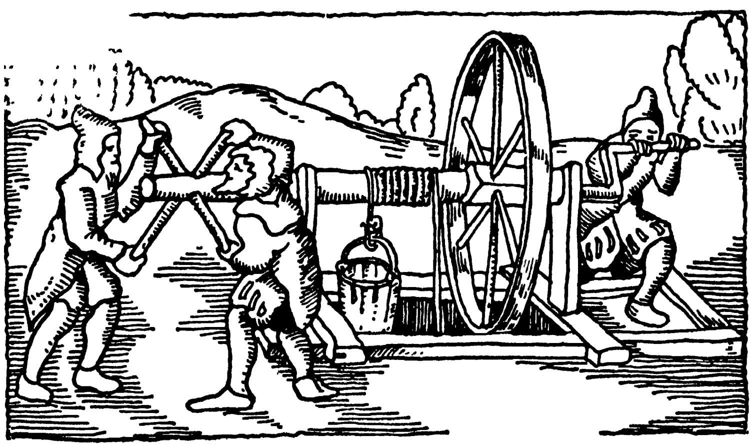


WATER POWER

ITALIAN COLOUR-GRINDING MILL OF THE SIXTEENTH CENTURY, SHOWING THE USE OF WATER POWER. THE DRAWING IS TAKEN FROM AN OLD PRINT. WHOEVER MADE THE ORIGINAL, AS SHOWN, IT WOULD NOT HAVE WORKED AT ALL

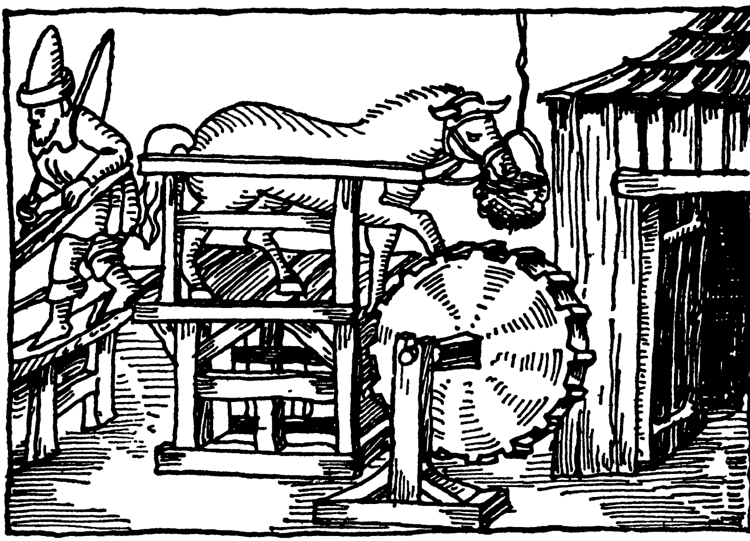


AIR INTO A MINE BY BELLOWS WORKED BY FOOT PEDALS



RAISING ORE FROM THE MINE BY WINDLASS

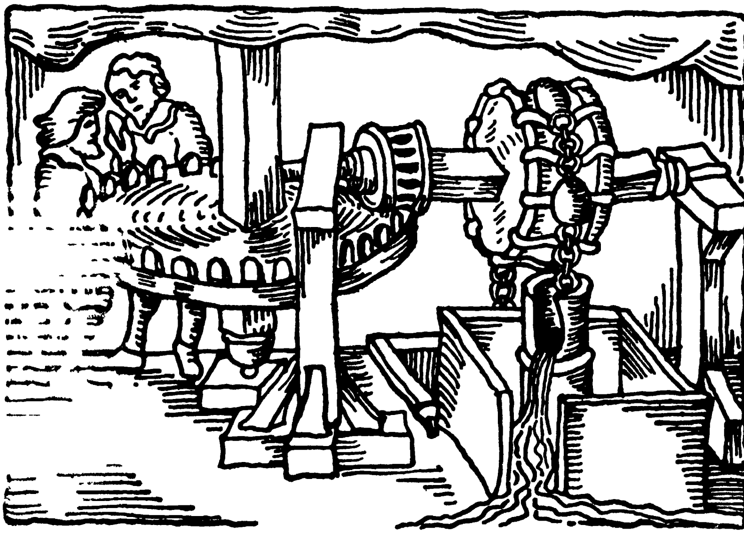
Revolutionary War were made of wood; some of these are still working, having been rebuilt and repaired. But about the beginning of the nineteenth century, when so much machinery was coming into use—looms for weavers, jennies for spinners, sawmills, corn-grinding mills and a world of small machines—metal then began to be used for mill parts. With the invention



MEDIÆVAL TREADMILL. THE HORSE STANDING ON THE PLATFORM TURNS THE WHEEL WITH HIS FORE FEET WHILE EATING FROM THE BASKET SUSPENDED IN FRONT OF HIS NOSE

of the steam-engine, the steamboat, and the railroad, the demand for steel grew enormously. All of this greatly increased the employment of the miner. Mines were driven farther and farther into the earth, and ore was sought in every part of the world.

According to a report published in 1769, the deepest mine in England was at Ecton Hill in Staffordshire—being four hundred yards from the hilltop to the mine floor. Access, however, could be gained to the shaft at a much lower level, so that the actual descent was but one hundred and sixty yards. It was a copper mine. "In descending from the principal lodgment," so goes the account, "you pass thirty ladders, some half broken, others not half staved; in some places there were but half-cut steps in the rock; in others you must almost slide on your



MEDIÆVAL MACHINERY—COGS AND TRUNDLE

breeches, and often in imminent danger of tumbling topsy-turvy into the mine."

Sixty men worked below in this mine in six-hour shifts receiving twopence the hour. The ore was drawn to the platform at the shaft-head by a man working a winch and then taken along the traverse to the pit-head in waggons which carried one and a half tons of ore. These waggons had cast brass wheels which ran in grooves cut in the traverse floor. They were pushed by boys of twelve and fourteen years of age.

The ore was then broken up by men and carried to the sorting sheds by little boys using handbarrows. In the sorting sheds the broken ore was sorted by little girls and then further broken or buckled by women who used small hammers for this work. Finally the ore was washed and taken to the smelter where it brought from nine to eighteen pounds per ton.

When smelted and cast in bars the metal sold for from ninety to one hundred and fifteen pounds a ton.

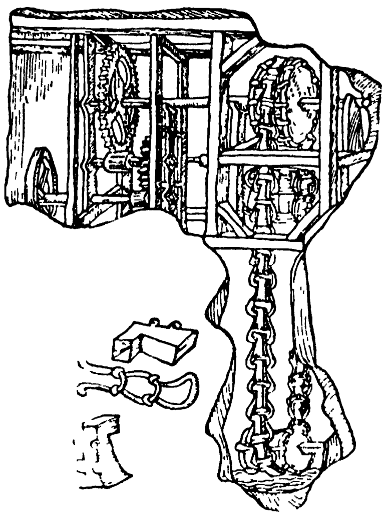
Men, women and children worked in this mine; the women earning from fivepence to tenpence a day, while the children

BELLOWS PUMPING AIR INTO A MEDIÆVAL GERMAN MINE

received from twopence-halfpenny to five pence for the same time.

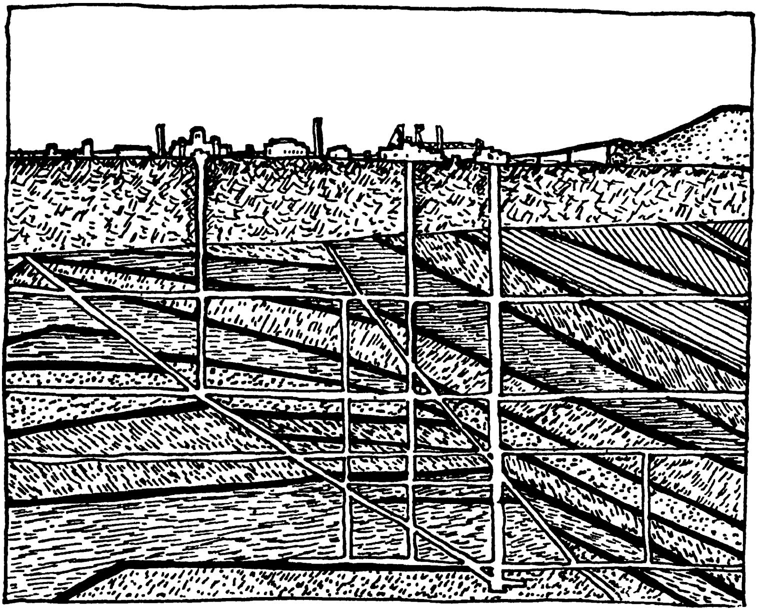
The writer of the report says that the mine gave employment to all the labouring poor in the near-by parishes assuring steady work to both sexes and all ages from five to sixty years. There seemed nothing wrong to this writer in the ages of these workers, their wages, and their working conditions. The author of the report points with pride to the fact that the Duke of Devonshire, who was the owner of this mine, made a clear profit of between £10,000 and £12,500 each year from this enterprise.

In our own day mining is one of the very great industries of the world. Each day over six million men go down into the earth to seek the ores that make our metals and the fuel that smelts these ores, runs our factories and heats our homes. A drawing is given of a modern mine, showing the shafts and tunnels, galleries and stopes that make up a network of streets and avenues for these cities underground. Railroad tracks are laid along these passages to the furthest workings in the mine, and on these ore cars pass to and fro, carrying the ore to the hoists which lift it to the surface at the pit-head. Electric plants furnish light and power. No longer is the miner's life so often endangered by the explosion of underground gases set on fire by a miner's light, for since the time of Faraday and Davy, when the modern miner's lamp was invented, this dreaded danger has been much reduced. Power is now used to operate drills and borers, channelling machines and air hammers that rip away the rock or strip the ore from face and wall, doing the work in a moment that in an older age required the heavy labour of many men. Dynamite and nitroglycerine blast great masses of rock or open the seams of ore or coal.



[illegible]VAL TIMES MOST OF THE [illegible] MILL MACHINERY WAS MADE OF WOOD, BUT IN THIS BUCKET-CHAIN PUMP BOTH THE GEAR AND ITS SUPPORT ARE MADE OF METAL

Shores and timbering of wood, steel and concrete support the walls and ceilings and protect the men from cave-in and falling rock. Clean, fresh air is pumped throughout the mine while other pumps draw out the foul air and any gases that might collect. Enormous water-pumps, capable of lifting millions of gallons of water a day, keep dry the interior of even the deepest mine. At the pit-head there are showers and

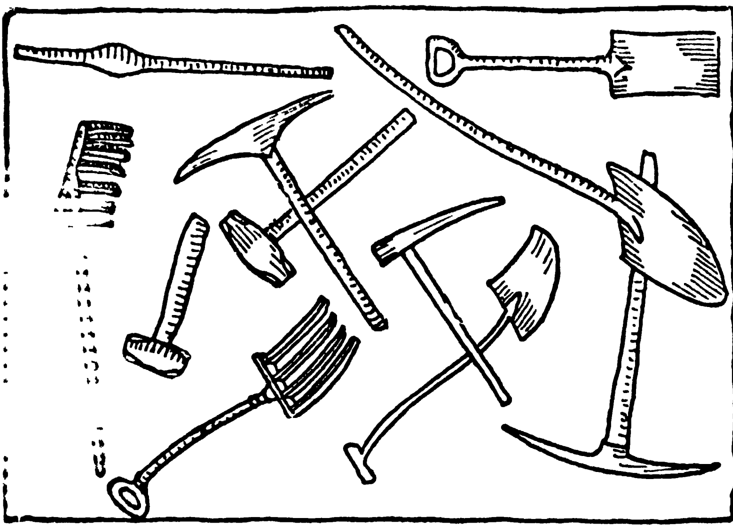


MODERN MINE

At the surface of the earth are the ventilating pumps, the power plant which furnishes power to the water-pumps in the mine; power also to operate hoists and cars and to furnish light. Ore lies in the earth in layers sandwiched between larger layers of rock. The vent, pump and main shafts pierce down through these layers. Spreading off at different levels and in different directions are the galleries which tap the ore

locker rooms where every miner coming up may wash away his weariness and soil and leave his working clothes behind. In many countries now every task, every machine, every change made in a modern mine is controlled by law and watched over by inspectors to see that the rigid regulations laid down by governments are obeyed. But this is not true everywhere. In South Africa, South America and in Asia there are still mines to-day that are almost as terrible as the mines of ancient Egypt and Greece. Even in Europe and in the United States there are mines to-day that have no place in a world that knows what we know.

There are accidents even in the modern mines and sometimes terrible disasters, where hundreds of men are buried and



MINER'S TOOLS

crushed under the fall of rock. These disasters grow less each year, and the time should come when there would be none of them at all. For we are at last beginning to learn that the labour of all men must be made safe for them, and that no gain is worth the price of any workman's life.

What a far cry the clean, efficient, modern mines are from those of Greece and Rome, Egypt and ancient Spain. In those older mines men worked as slaves, spending the brief span of their lives in darkness and eternal danger. Yet these ancient

OPEN-PIT MINING—FRANCE—SEVENTEENTH CENTURY folk sought almost all the ores we seek to-day, and they knew almost as much about mining as we do—ventilation, timbering, the pumping of water, the hoisting of ore, the need of safety—but they did very little to develop and improve these things.

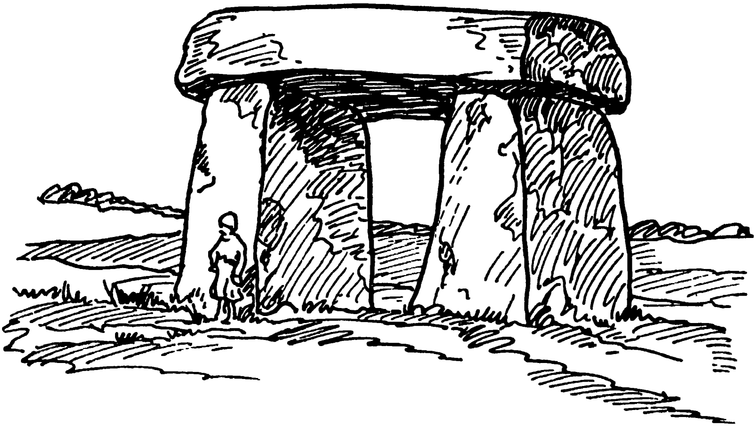
Theirs was a slave world and slaves were plentiful. Such labour, they thought, was cheaper than building and using machines. Actually this was not so, quite the opposite—it was terribly wasteful of life and energy. Despite all the thousands of mines that were worked, some of them for centuries, and the millions of miners who laboured in them, I doubt very much if as much ore was taken from the earth throughout the whole of ancient history as is produced to-day in a single year by modern workmen—free men who are trained to their jobs, who are equipped with proper tools and machines, who work [illegible] and are paid a fair wage. Not only was the amount of [illegible] and metal smelted so much less in the ancient world [illegible] ours, but their metals were far more costly than are [illegible] day. You and I can buy copper or bronze implements, [illegible] steel tools that would have been beyond the means of [illegible] few in the ancient world.

[illegible] changes that have made this possible—changes in [illegible] work and in the work life of the workmen, improvements in wages and hours, safety, tools and training—these did not come quickly or easily. On the contrary, they were fought for step by step down through the centuries.

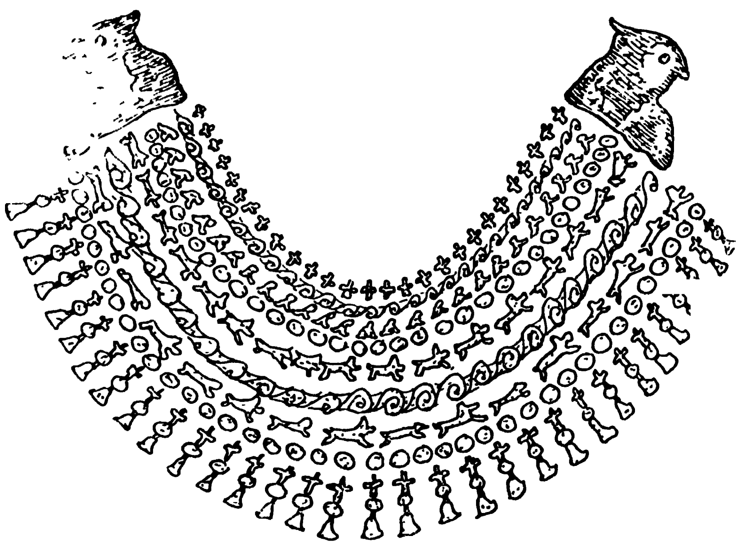
V. Metals

THE first of all the metals used by man was gold, and this seems to have been true everywhere in the ancient world. Rings and bracelets, collar and breast ornaments, beautiful in design and workmanship, have been found in the ancient tombs and buried towns of such widely separated places as Sumeria and Ireland, Egypt and Peru. Most, if not all, of this early gold came from stream beds rather than from mines, and, as we have seen, it is not difficult to pan the dust or nuggets of gold from the gravel and sands of gold-bearing streams. Then, too, free raw gold was quite probably much more common then than now. But even so, it is hard to understand just why these ancient folk wanted gold at all. It certainly was of no use to them for making tools, being both far too soft and scarce. Yet, from a time altogether lost in the mists of the past, men have sought for gold as we seek it to-day, risking their lives, undergoing terrible hardships and travelling immense distances to get it. It does not seem to have been because it represented money to them then as it does to us now, for among both ancient folk and peoples of much later times other things served for money long before gold was so used; shells and beads in Stone Age Europe, pearls and copper among the American Indians, iron treated with vinegar in Spartan Greece, copper rings in Gaul, even stone mill wheels in the South Sea Islands. Yet at a time somewhat after the beginning of farming, there began a great moving about over the earth of the early food-raising folk; and from the traces they have left behind it appears that, whatever else they did, they all of them hunted gold.

These first farming folk raised their crops by irrigation—that is, they built dams or dug trenches that could turn the water from a stream to flood their fields. While this was quite necessary in rainless countries like the Nile and Mesopotamian



[illegible] MONUMENTS WERE BUILT BY PREHISTORIC PEOPLE USING [illegible]LS SET ERECT WITH A STONE LINTEL OVER THEM. A [illegible] THESE WOULD BE SET IN A CIRCLE. IT IS STILL A [illegible] OF WONDER HOW THEY RAISED THESE HUGE WEIGHTS



PREHISTORIC GOLD ORNAMENT

valleys, where farming seems to have begun, it was not at all needed in other parts of the world to which some of these first farmers moved. But they did it none the less, and so to-day we can follow these ancient irrigating folk through western Asia, India and China by the trenches that they dug. And wherever we find these old irrigation works, they are located almost without exception along the banks of a stream that once bore gold.

Later farming folk left even more permanent marks behind. For it became their custom to build, wherever they went, either pyramids of earth, stone, or brick, or to construct great circles of rock set on end. Just as we can follow the earlier peoples, so can we trace these later stone-circle and pyramid builders all over the world by the monuments they left behind. You will find pyramids or the traces of them in Egypt, Mesopotamia, India, China, and across the South Seas to Central America, Mexico and Peru, while stone circles appear all about the Mediterranean Sea and northward through France to the British Isles. And all through this great belt around the earth we find evidence of the use of gold. In some places other metals came, in time, to be mined—copper, tin, silver, lead and iron, but in only a few places were all of these produced, even when they were near at hand and easier to be had than gold.

You might say the ancient folk wanted gold for ornaments, and people have certainly liked to wear ornaments from the earliest times—animal teeth and ivory, amber, jet, pearls and jade, even coloured shells. But while men have gone great distances to get these bits of jewellery, they made no such tremendous journeys, nor did they face such dangers, as were faced in the search for gold.

Gold is an odd metal in many ways. It does not rust away like iron, nor tarnish as most other bright metals do. It is so easily worked that you can flatten a piece of it into sheets so thin that two hundred thousand of them will make a pile only one inch high. Or you can draw a single grain of gold into a wire over five hundred feet in length. And these ancient folk knew how to make both sheets and wire, although theirs were not so fine as this. Certainly with such a metal you could make quite delicate, beautiful and lasting ornaments. But is that enough to account for all the tremendous urge there seems to have been to seek it?

PROW ON GREEK COIN

Gold is a yellow metal, bright and shining when it is polished—the colour of the sun—and that, in itself, is perhaps the answer: for gold may have seemed to these simple folk to be a piece of the sun found on earth. And every one of these early gold-seeking peoples, whether the Mayas Incas of America, the South Sea Islanders or the farming folk of China, India, Mesopotamia, Egypt, ..ice, Spain and Britain, were all of them worshippers ..n.

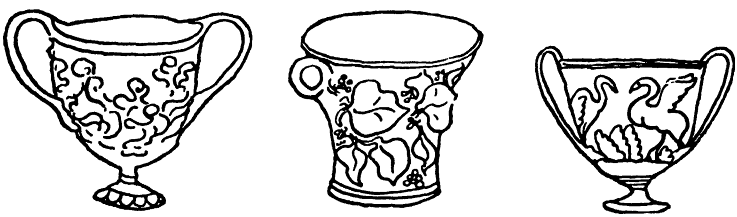
Whatever the reason for its beginning, this early search for gold was to become a matter of more importance to us than even gold itself has ever been. For it led to the use of the other metals; and that path, first traced around the earth by the gold seekers, was to be followed by the maker of copper, bronze, iron and steel tools. Once the age of metals had started, it spread through the world with such swiftness that the million-year-long

COPPER KNIVES FROM TROY AND AMERICA

twilight of the Stone Ages changed into the world we know to-day in what, by comparison, would seem but a moment of time.

Copper followed gold; then came tin, lead, silver and iron. Before the beginning of history almost every one of the base metals had been discovered and used, though some that are quite common now were rare in the early days.

How soon after the search for gold came the discovery and use of copper we do not know—certainly it was long before the beginning of history. Lucretius, a Roman writer of about two thousand years ago, thought that gold, silver, copper, iron and lead were all discovered at the same time as the result of a forest fire which had melted these metals from the earth,



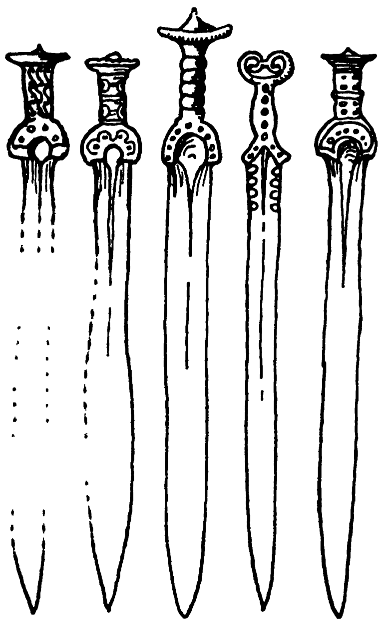
SILVER GOBLETS FROM POMPEII

"causing them to run from the earth in boiling veins." We know now, however, that copper and tin came into use some time before silver and lead and a long time before iron.

Copper is a fairly soft, reddish-brown metal. It was found quite plentifully all over the ancient world, especially in Cyprus, the Greek island from which it gets its name.

Tin is a heavy metal, silver white in colour, and scarce in the ancient world. It was sometimes found in stream beds as free nuggets, just as gold was found; and sometimes it was mined. Copper and tin when melted together make the alloy, bronze, and bronze was so important in the life and work of the metalworker that we shall tell of its use in a separate chapter. Meanwhile let us look at some of the other early metals which, while not so old as copper, gold and tin, had none the less their own places of importance in the early metalworker's shop.

Silver, like gold, is one of the precious metals first sought for ornament and later used for coins. In the early days silver seems to have been prized almost as much as gold itself. It is a white and shining metal which can be beaten into sheets or stretched into threads. It is harder than gold and will, in time, tarnish and lose its lustre.



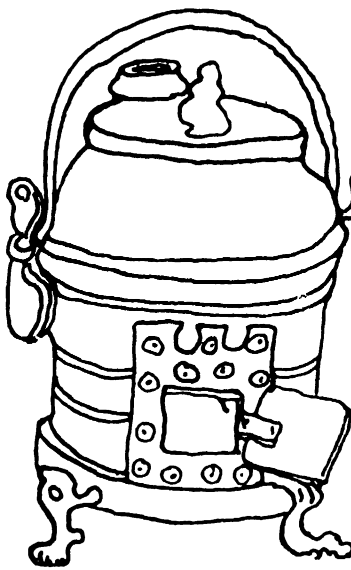
DANISH SWORDS

For some reason the Romans seem to have desired silver more than they did gold. When the armies of Carthage had been defeated and forced to pay tribute to Rome, the tribute demanded was in silver, not gold, although the Romans must have known that the Carthaginians had long worked some of the great gold mines of the ancient world.

The Romans made cloth woven of silver thread, and they are even said to have covered their war machines with silver. I am not sure just why they did this. A writer of their times said: "it made these engines bright so that they could be seen from afar," so it may have been the Romans' purpose to frighten their enemies with a show of flashing war machines.

Silver came early into use for ornaments, money, mirrors and tableware. The Egyptians and the Sumerians made silver beads, necklaces and bracelets almost as early as they made these things of gold.

The use of silver for coin seems to have begun in the country of Lydia in Asia Minor—a country noted for its wealth—and from there the custom seems to have spread throughout the ancient world. At all the great museums you may see collections of coins that have come down to us from ancient countries, many of them beautiful in design, showing arms and ships' prows, sacred animals, gods and kings on their faces. In fact the story of the coins of the world would be a fascinating one though it is too long to be told here.



ROMAN BRONZE STOVE

The rich and powerful, the kings and priests of the ancient world, used goblets, plates, bowls and dishes of silver on their tables and in their religious ceremonies. But it is doubtful if silver tableware was at all as common then as it is now. A Carthaginian embassy, which had been sent to Rome, returned to Carthage and complained that Rome must be a very poor city indeed, for although they had been entertained in all the great houses, "the same set of silver dinner dishes appeared on every table, having been loaned from household to household, wherever the ambassador was to dine."

The use of silver for mirrors seems to me even more interesting. The first metal mirrors were made of bronze, cast and polished. Later a mixture of lead, silver and copper was used. But polished bronze does not really reflect very well, and silver tarnishes easily. To avoid this, the Egyptians stained their mirrors black by rubbing them with the yolk of an egg. A black surface may not give quite as good a reflection as a silver one, but it does not tarnish either.

There do not seem to have been any glass mirrors, even in Roman times, for although they knew how to make glass and thin sheets of silver or tin they did not know how to apply these to glass. Polished metal mirrors of silver, bronze and sometimes steel, were in common use as late as the sixteenth century. About the thirteenth century, thin sheets of metal were set between glass plates for mirrors, and about two hundred years later a German inventor discovered a method of making mirrors by the use of tin and mercury. To do this the glass was first cleaned and polished and then an extremely thin sheet [illegible] applied to it. When this had been smoothed out evenly [illegible] whole surface it was covered with mercury which [illegible]ely stuck to the tin. All this had to be done with great [illegible] that no air bubbles or moisture should get between the [illegible] and the glass surface. Finally the glass was placed under [illegible] weight to squeeze out any excess mercury and the [illegible]as ready for use.

[illegible] made in this way were far better than the polished [illegible]rors that had gone before, but they were a good deal [illegible] difficult to make than it sounds. Sheet tin is very fragile and delicate to handle, and to get a perfect mirror it is necessary that the tin should cover the glass exactly and evenly. The most skilful mirror makers of this period were the Venetians, whose bull's-eye mirrors with delicately curved surfaces were once prized above all others. Even simple mirrors must have been difficult to make and quite probably too expensive for very common use.

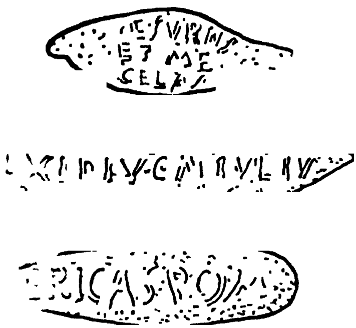
About one hundred years ago a new method of making mirrors was discovered in Germany and perfected in France. This discovery came by accident when Leibig, a German scientist, noticed that a certain salt of silver stuck to a glass vessel in which he had placed it. About thirty years later the process of applying silver to glass was perfected and, as it was quite simple, mirrors began to come more and more into common use. To-day you buy for sixpence a mirror that would have cost a small fortune in Roman or Egyptian days.

Although mercury was not used for mirrors in the ancient world, it was quite well known. Its most common use was in purifying gold and silver ores, for mercury has the curious property of being able to pick up gold or silver dust. A Roman writer, Vitruvius, tells how the fine clothing of rich Romans was burned when it became too old to wear, and the ashes were mixed with mercury. This was done because the Romans used to decorate their robes with gold embroidery, far too precious a metal to be thrown away. The mercury would separate the gold from the ash, then the mixture of mercury and gold would be put into a fine cloth bag and squeezed, much as is done in making cheese. When this was done, all the mercury would sweat out through the cloth, leaving behind pure gold.

The Greeks knew about mercury and used it in medicine, but they do not seem to have known exactly what it was. Aristotle called it "liquid silver." The Romans got their mercury by heating the ore until the metal became a gas which could be captured in vessels and chilled until it became a liquid. Pliny says that the making of mercury was very dangerous, sometimes causing the workmen to lose their teeth through breathing the fumes. To avoid this, they always worked with their backs to the wind, "so that any escaping fumes or gas might be blown away from them." They used forms of mercury in their colours, the rich Roman vermilion, for instance, but even in this form it was quite dangerous to work with, so the colour makers wore helmets of skin through which they could see well enough, and which protected their eyes as well as their lungs. These were quite probably the first gas-masks.

Although mercury had been known all through ancient history, no one actually knew what it really was until the days of the alchemists of the Middle Ages. It was one of these, Albert le Grand, who discovered pure, free mercury. These mediæval folk, however, for all their knowledge of metal, thought there was something magic about mercury, and they were a little afraid of it. This is not difficult to understand. It is a curious metal, almost like a thing alive. Its common name is quicksilver. We use mercury to-day in medicines, mirrors, colours, electric lights and thermometers.

Lead probably followed silver as a useful metal. Sometimes it was mixed with bronze, to which it gives a rich, dark colour. It also causes bronze to flow more easily into moulds. The more common use of lead, however, was for roofs, pipes and paints. In Babylon the roofs of the terraces that formed the Hanging Gardens were made of lead. In Rome it was very common for roofs, gutter and water pipes. The Romans got some of their lead from Britain, but probably most of it came from Spain.



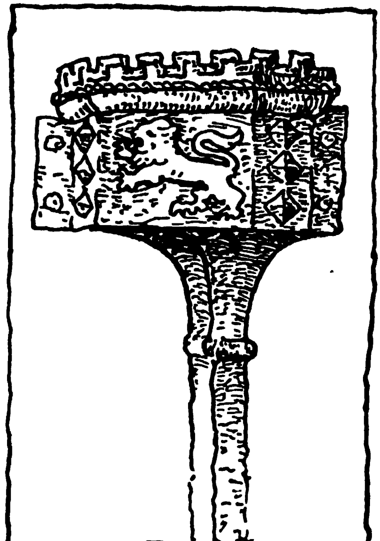
ROMAN LEAD PIGS

[illegible]nt lead smelters in both places made a practice of casting lead in lumps of convenient size for the plumbers. These were marked with their weight and sometimes with the date and the name of the founder. Many such lumps, called "pigs," have been found in England and Spain. In Rome itself water was piped to the houses just as we pipe it to our own to-day. Lead, in fact, is so much the plumber's metal that the name of his craft comes from the Latin word for lead "plumbum."

In the Middle Ages many of the roofs of the great cathedrals and castles were covered with sheet lead, and the glass in the windows was held in thin leaden strips. Drains and gutters, downspouts, tanks and cisterns were made of lead, and the plumber in his pride made of them things of great beauty, decorated with ornaments and scrolls.

Lead, curiously enough, has been used as a weapon in quite different ways in different times. It was the ancient practice to heat great kettles of lead until it was molten and pour it over castle walls upon the heads of climbing attackers. After the invention of gunpowder lead served for several centuries for the bullets used in rifles and small arms. The early pioneer made his own bullets in a small bullet mould and carried them in a pouch along with his powder horn.

We use lead in most of these ways to-day, but perhaps more important than any of these to us is its use in making glass and especially in making paint.

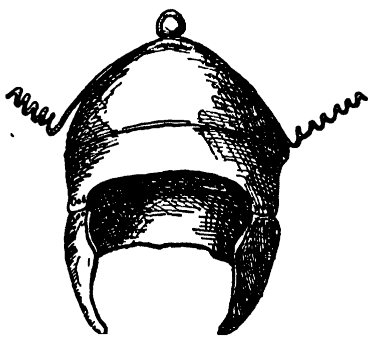


LEAD RAIN HOPPER HEAD

Just as thin sheets of lead protected the roofs of ancient buildings, so far thinner sheets of lead in the form of paint protect our wooden buildings from rot and our steel and iron structures from rust. It is really surprising how thin a coat of lead is needed to protect wood or steel—three coats, each a little more than one hundredth of an inch thick, will preserve wood for several years, while an even less thick layer protects the steel members of skyscrapers.

When you go down into the hold of a great liner, ploughing its way through the sea, you can lay your hand against the inside of the hull and feel the movement of the water on the outer side. When you see how thin are the plates that form this hull you get some sense of the great strength and toughness of the steel from which they are made. Yet for all its strength a ship of steel would make but few voyages were it not for the skin of lead that keeps this steel from rust.

Cobalt was also known, and it was used for making colours, but like mercury it was greatly feared. Even as late as the Middle Ages it was considered an evil metal, and its name means "black devil." When King Solomon, wishing to repay the King of Tyre for his help, offered the Phœnician king some gold and silver mines, Hiram, after inspecting them, declined the gift, because he had found these mines also contained cobalt ore, and he was afraid of the danger to his workmen.

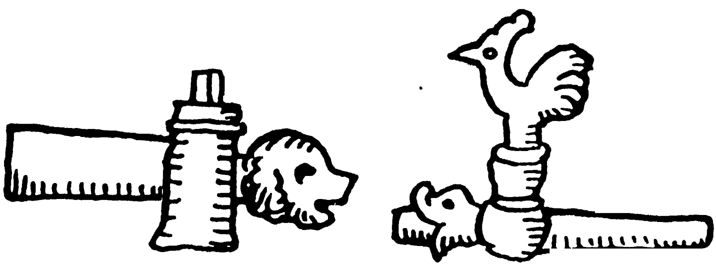


ETRUSCAN BRONZE HELMET

Nickel was known in Greece and India, but it was probably quite rare. It really did not come into general use until the sixteenth century, in Germany, where it got its name of nickel, which means "old nick," so called because it was so difficult to work.

Zinc, a metal which we use to-day in a hundred ways, was not known in its free state in the ancient world. It was not, indeed, until almost modern times that pure zinc was first made in Germany. But though the ancients had no pure free zinc they used the ore of zinc even when they could not separate the metal from its ore. Zinc and copper ores when smelted together form the alloy brass, and brass was used by the Greeks and Romans and perhaps by the more ancient Sumerians. I doubt, however, if it was at all common—certainly not as common as you may be led to think from the number of times brass and brazen things are mentioned in the tales of Homer or in the Bible. What is really meant is bronze, an altogether different metal. Bronze was the common metal of the ancient world, while brass was very rare.

We use zinc in making brass to-day, but perhaps even more important to us is the use of zinc to protect steel and iron. There are several ways in which this is done. It can be applied to metal as lead is in the form of paint or it can be made to



ROMAN WATER-COCKS

cover metal with a thin protecting coat. The oldest method for doing this is to heat the iron and then dip it in a bath of liquid zinc. This causes a thin coat of zinc to adhere to the iron, and since zinc does not rust this coating will protect the iron until the zinc skin is worn away or broken. This method goes back to the early Gaulish smiths who first learned how to coat one metal with another; and while I doubt if they ever actually used zinc in this way, they did so use copper, tin, bronze and silver.

Another method of covering iron with zinc is to put the iron into a bath of zinc salt solution and then pass an electric current through a block of pure zinc into the salt solution and then out of the solution again through the iron article which is to be plated. As the current flows along this path it takes pure zinc with it off the zinc block, drops this into the solution, picks up another zinc load from the solution, and leaves this stuck to the iron as it passes on out of the solution. Although these are quite different processes, we call the zinc-coated iron produced by either of them "galvanized iron."

There are two other ways in which zinc may be used to cover iron. One of these, called Sherardization, consists in coating the iron with a powder of zinc when the metal is at a temperature a little under what would be needed to melt it. This method gives a very even and thin coat and is used for small delicate articles or articles on which very perfect work is required.

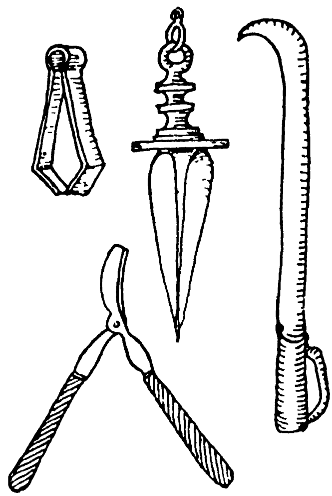
ENGLISH BRASS—ESCUTCHEON KEYHOLE

A crude method of applying zinc to iron, called "Schoop," consists in spraying the iron with molten zinc.

You will notice on any galvanized iron the delicate and frost-like patterns formed in the zinc. That is almost exactly what they are, for, just as water turns to crystals of ice on the window pane, so zinc sets in crystals on sheets of iron.

Zinc, lead, copper, tin, mercury, iron, nickel, cobalt, antimony, gold and silver—these were the metals known and used in the ancient world. At least three of them, copper, tin and iron, were of the greatest importance to the toolmaker, while gold and silver, even in ancient times, had already come to represent the wealth of the world. Yet for all the need and usefulness of these metals very little was actually known about any of them.

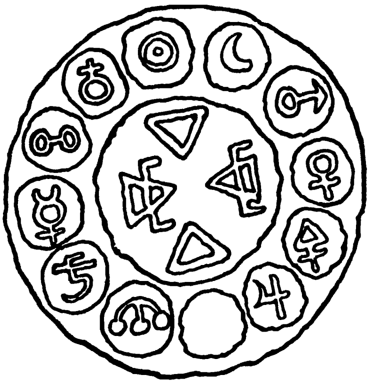
This fact is the more strange since the Sumerians, the Egyptians and the Greeks were all superb metalworkers. Their skill with metals and their knowledge of them, however, was limited to the practical side of metalwork. These ancient craftsmen knew *how* to work iron on the anvil under a hammer; they could make and cast bronze as well as we can to-day. They were the masters of every step in the metalworker's art from smelting the crude ores to finishing the finest tools and weapons, but they knew very little about *why* each step was taken.



SURGEON'S TOOLS FROM POMPEII. PINCERS FOR REMOVING HAIRS, KNIFE, SWEAT SCRAPER AND DENTIST'S PINCERS

It is the job of the scientist rather than the craftsman to know the "why" of things. But the scientists of the ancient world, at least so far as the records show, knew very little about metals. Aristotle, who was one of the great scientists of Greece, knew so little about iron that he wrote, "while iron is hard and has great strength yet there are mice in Cyprus able to gnaw through it." He also described the making of steel, but his description is not at all clear; it has been the source of a great deal of argument as to just what he meant. Daimachus, a fellow Greek, on the other hand, stated that there were different kinds of steel and that each kind should be used for particular tools and weapons—which is quite true. Pliny, the Roman, was a very intelligent man and a keen observer, yet he thought that iron must be tempered with the water from particular springs and that "human blood revenges itself upon iron: for the metal once touched by blood will easily rust."

All the metals seem to have been treated with a good deal of superstition and mystery, especially iron. And no one in Greek or Roman times seems to have studied the metals to find out what they really were and why they acted as they did.



THE SYMBOLS OF THE ALCHEMISTS

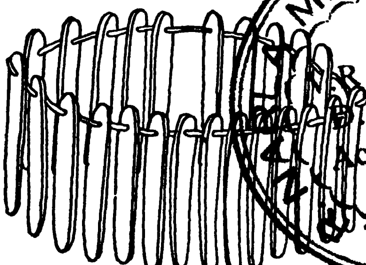
The alchemists in the fourteenth and fifteenth centuries used symbols to indicate the different metals. The circle enclosing twelve smaller circles was the sign of an alchemist's laboratory. If you read these symbols as you would the numbers on a clock face then: 12 o'clock is the symbol for gold; the moon at 1 o'clock stands for silver; the circle and arrow (thunderbolt) represents iron; 3 o'clock is copper; 4 o'clock is sulphur; 5 o'clock is tin; 6.0 was reserved for zinc but the symbol has been lost; 7.0 is carbon; 8.0 is lead; 9.0 is mercury, 10.0 is arsenic and 11.0 is antimony.

In the middle circle are the signs which represented Fire (bottom); Water (top); Earth (right); Air (left)

The first steps towards the real study of metals seem to have been taken by the alchemists of the mediæval age. The alchemists were curious people; we know very few of them by name and but little of what they did. Some say there were alchemists in ancient Egypt, and others say the art came into Europe with the Moors. Whatever the case, we know that during the twelfth and thirteenth centuries a good many alchemists lived and worked in England, France and Germany.

The alchemists surrounded themselves with all sorts of mysteries. They usually worked alone and were said to practise magic and the black arts. They pretended to have dealings with the devil and other evil spirits, and they made all kinds of weird experiments. Chiefly they sought two things—the elixir of life to gain immortality, and how to change base metal into gold.

For all their pretence and mummery they did some very valuable work. They appear to have been the first to understand what mercury is and to have smelted pure zinc and nickel. A few years ago it was common among scientists to make fun of the alchemists, but not all did. Sir Hans Sloane who suggested the British Museum believed base metal could be changed into gold, and to-day we now know it can. Actually the alchemists were the forefathers of the modern sciences. It



THE TOUCHSTONE WAS USED BY MEDIÆVAL ALCHEMISTS AND METALWORKERS TO TEST THE PURITY OF GOLD. TOUCHSTONES WERE MADE FROM EXTREMELY HARD FINE-GRAINED STONE. WHEN A PIECE OF GOLD WAS RUBBED AGAINST A TOUCHSTONE IT LEFT A MARK. THE ALCHEMISTS AND METALWORKERS COULD TELL FROM THE COLOUR OF THE MARK NOT ONLY IF THE ARTICLE WAS PURE BUT ALSO THE KIND AND AMOUNT OF ANY BASE METAL THAT HAD BEEN COMBINED WITH THE GOLD

was one of them, Roger Bacon, who had a great deal to do with the coming of the modern world.

Bacon lived in England sometime in the thirteenth century. He fought bitterly against the narrow superstitious world in which he lived. In Bacon's day men had come to believe that all that was ever to be learned had already been discovered and that the whole of knowledge was contained in the books of Aristotle. Bacon cried out that one had only to look at the world around him to see that there was much that Aristotle had not known. He believed that if men would only experiment, try new ideas, find out for themselves, then there would rise a world "in which ships would be moved over the rivers and seas by machines; that waggons and carriages would run without horses; that flying machines would be made wherein a man might sit and by turning a device beat the air with artificial wings." So far ahead of his times was Bacon that he was reviled and imprisoned and made to deny what he really believed. But the seed sown by this strange, far-seeing man fell on fertile ground—it started the modern world.

Scientists to-day say that the world is made up of ninety simple elements and that of these seventy-one are metals. Some of these are so rare they have not yet been found on our earth, and a few are so difficult to separate from their ores that they have not yet become useful to us. But such has been the progress of science since the mediæval world that where they knew but a few metals we know nearly fourscore; and what is more, we know a great deal about them: not only what they are but how to combine them into hundreds of alloys and combinations that serve us throughout the modern world.

Some alloys were known in the ancient world—bronze, brass, pewter, solder and electrum, for example. They knew, too, that iron and carbon combined to make steel, but it is very doubtful if they knew what actually happened when the metals were mixed.

An alloy is a mixture of two or more metals to form a single substance. This mixing is done in a number of ways, but it is usually accomplished by melting the metals together. Bronze, for example, is a mixture of copper and tin. Sometimes a little lead is added to give a dark colour and to make the alloy flow easily. Phosphorus added to bronze increases its hardness. Silver is sometimes added to bronze, particularly when casting bells, as it is believed to ensure a clear, mellow tone. Antimony, when added to bronze, forms the alloy called Babbitt metal which is much used for bearings.

Brass is an alloy of copper and zinc, while pewter is made from tin and antimony. Both brass and pewter were known in the ancient world but they were then quite rare. Brass is now one of our most useful metals, especially for pipe and fittings. Very beautiful brass castings of extraordinary thinness are made by the Javanese Islanders to-day exactly as they have made them for centuries.

Pewter is not used to-day as much as it was formerly. At one time a great deal of the tableware, particularly in England, was made of pewter. It is a white metal, fairly hard, that does not tarnish easily. Pewter may be cast in moulds or spun on a wheel. In spinning, a disk of metal is fastened to a wheel and then whirled rapidly while a tool is pressed against the metal to turn and bend it into simple round shapes such as bowls and plates, somewhat as you form a pot from clay on a potter's wheel. Brass, bronze and silver are also spun on wheels.

One common alloy of the ancient world is rarely made to-day. It was electrum, a mixture of gold and silver much used for ornaments and statues.

It would be impossible here to tell you of all the alloys that are made to-day. Probably the most important to us are the alloys of steel. Iron in its pure state is quite soft but when combined with a certain amount of carbon it becomes very hard and tough and is then called steel. Steel is alloyed with a great number of metals to produce special qualities. Chromium and copper steels, for example, resist rust as does Monel metal which contains steel, copper and nickel. Other alloys of steel are made by adding silicon molybdenum, vanadium, or any one of a number of other metals or compounds. In this way the modern metalworker can produce exactly the kind of steel he needs for any particular use—steel for tools so hard it will cut ordinary carbon steel like cheese—steel so tough that it may be used as armour-plate—steel so elastic that a thin sliver of it will serve for a lifetime on the mainspring of your watch.

All this is a far cry from the crude beginnings of metalwork, yet all of it has been accomplished in but a few thousand years. Let us look back now at the beginning of the metalworker's craft to see how this was done.

VI. *Copper and Bronze Tools*

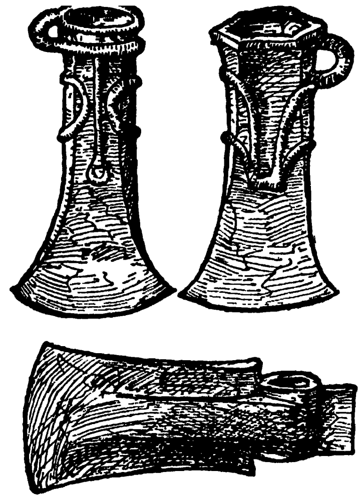
THE first metal to be sought after gold was copper, but copper, unlike gold, is rarely found free in nature. Certainly it was not so found in that part of the world where it first was put to use. There, the ore must be smelted—that is, pure metal must be separated by heat from the ore in which it is found.

The melting of a pure raw metal was already known, for gold had been melted from the earliest mining days. But while the heat that is needed to melt copper is almost exactly the same as that for gold, it was one thing to heat a little clay cup of gold dust to 2000° F., and quite another to raise that temperature and especially to keep it up long enough to drive off the impurities found in the ancient copper ores. That called for skill and the knowledge of fuels, fires and furnaces. It brought into the world the craft of the ore smelter.

We are not entirely sure where the use of copper began. Some think it was in Egypt, and others say it was among the Sumerians, in the Mesopotamian Valley. But wherever it started, we know that in both these places tools were made at a very early time by casting molten copper in moulds. The first copper tools were crudely made by beating the metal into shape, but almost at once the art of founding was discovered. This consists in melting a metal to a liquid state and then pouring it into a mould made to form the shape desired.

The first metal tools were chisels, and the moulds for them were shaped of clay mixed with ashes, or cut into stone. For such simple tools there need only be an open pattern cut in the surface of a smooth, flat stone or moulded in a block of clay. The metal could be poured into these much as you would pour batter into a muffin tin.

The cutting edge on such a tool would have to be made afterwards by grinding with hornblende, or by working the metal cold under the hammer. The first crude chisels were followed by larger and flatter ones, and the blade at the cutting edge was spread out fanwise, to give it more bite. Then these wide-bladed chisels were made to serve as adze and axe-blades by lashing them to handles. Not only were such tools made by open-mould casting, but so were knives, sickles, arrowheads, saws and spear points.

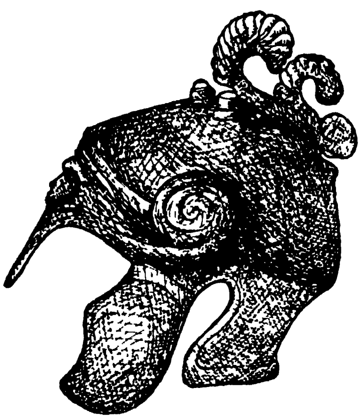


BRONZE AXE HEADS

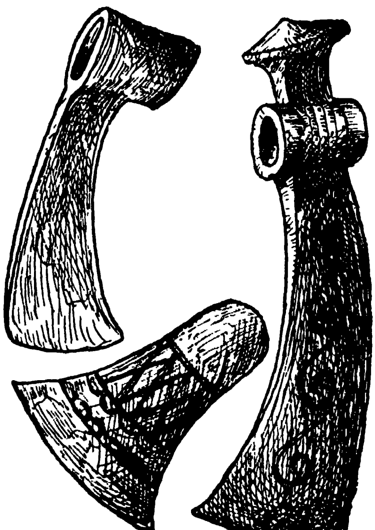
But at best the edges of these copper tools, whether you formed them by grinding or hammering, were not very sharp or hard. Any tales you may have heard of "an ancient lost art of hardening copper until it is like steel" are nonsense. Copper can be hardened a little by leaving in it slight impurities such as bismuth or arsenic, or it may be made tougher by repeated hammering, when hot, if this is followed by very slow cooling. But in neither way can it be made really hard, certainly nothing like bronze or iron. And should you try to temper copper, as iron is tempered, by plunging it when hot into a cold bath, you will actually soften it instead of making it harder.

As copper did not make very satisfactory tools, stone tools and weapons continued to be used for many centuries after the beginning of the use of metals. In some parts of the world they were still in use almost up to modern times. But you may be quite sure that once the toolmaker had started to use metal he was not going to turn back. Instead, he set about finding better methods and better metals with which to work. And this he did in a surprisingly short time.

The new metal was bronze, which is an alloy, a mixture of copper and tin. The discovery of bronze was one of the most extraordinary jumps in history, for it meant the mixing together of two metals, both of them soft, to make a third metal that is quite hard. What is more, the mixture had to be fairly exact, about one part tin to nine parts copper.



ETRUSCAN HELMET

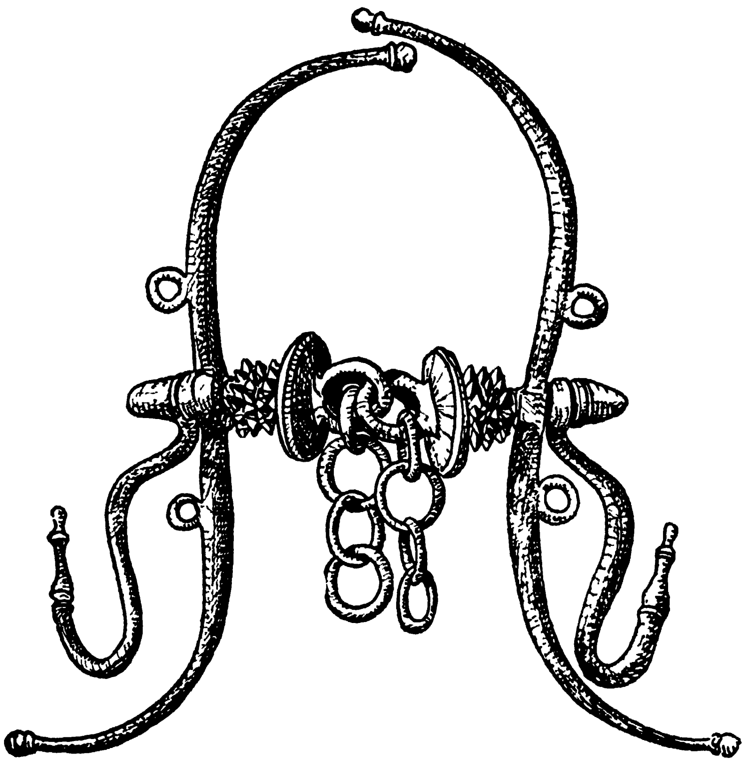


BRONZE AXE HEADS FROM SWEDEN

This might have happened first through the accidental smelting of a copper ore that contained a little tin. But, although such ores do exist in the world, they are not found near where bronze was first made.

You might think that the first bronze was no accident at all but made deliberately by mixing pure copper and pure tin. Tin is found free in nature, in stream beds, much the same as is gold. But there is no record of pure raw tin being found in any country near where bronze was invented.

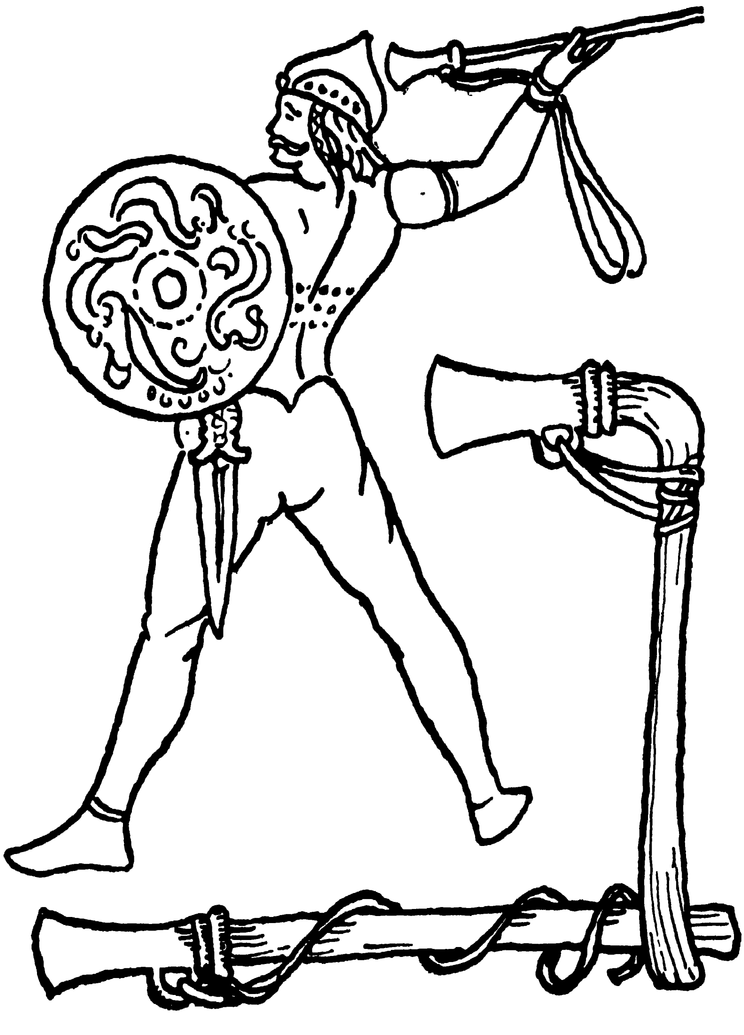
But in northern Persia there are places where both copper and tin ores are found in the same neighbourhood, separate, but lying close enough together to have been mixed by accident. Persia is not far from the country of the Sumerians, in



BRONZE BIT FROM POMPEII

the Mesopotamian Valley, who seem to have been the first users of bronze.

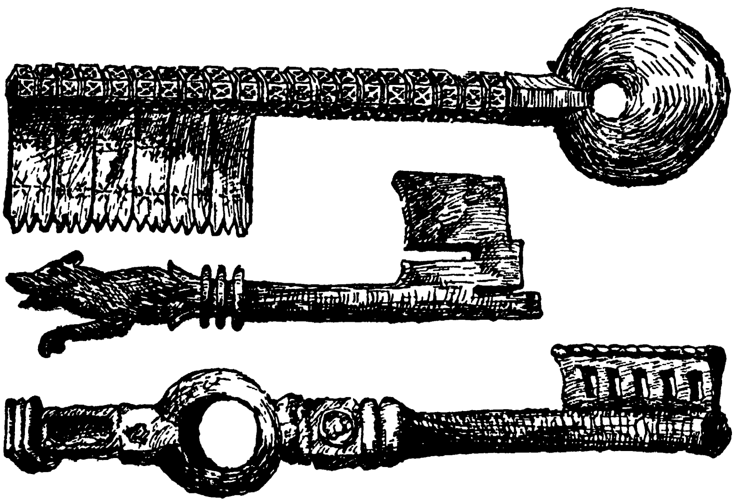
Whatever the beginning, these early bronze workers soon knew all that was to be known about bronze. They used the same mixture that we use to-day, and even added other metals to the alloy as we do, lead and silver, for example. Bronze was



BRONZE AGE WARRIOR—GAUL

so much better a metal for toolmaking than copper that it replaced copper almost at once—so quickly, in fact, that we do not speak of a copper age at all, as we do of the ages of stone, bronze and iron tools.

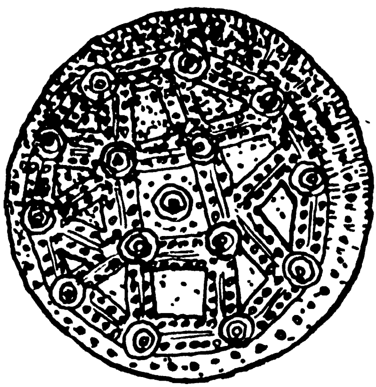
Even in the earlier copper-using days, the toolsmiths had improved their ways of casting, for they quite soon discarded open moulds and began to make their moulds in two parts,



ROMAN KEYS

cutting an impression of half the tool into each of two stones which when lashed together served to form the complete tool. This saved quite a bit of work in grinding and hammering, but it had one disadvantage—it would only form a solid casting. It did not leave any holes in the butt of an adze blade by which it could be lashed to a handle, nor did it leave sockets for the hafting of chisels and axe heads. Such holes and sockets had to be cut after the tool was cast—a long, hard job.

The Sumerians seem to have been the first to solve this problem by making cores of ashes and clay. These cores could be set in the mould where you wanted a hole; then, when the metal was poured, it would fill the mould except that part blocked out by the core. When the metal had cooled, the core could be tapped out, leaving the tool ready for hafting. In their core casting the Egyptians made it a practice to wire their cores in place, and this they did so skilfully that the cores in some Egyptian castings were moved less than one one-hundredth of an inch when the hot heavy metal rushed into the mould.

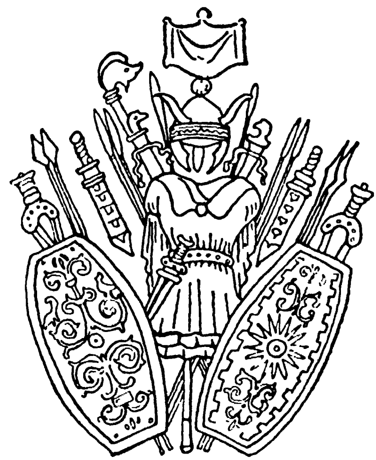


BRONZE AGE SHIELD FROM ENGLAND

In almost no time these early founders had become amazingly clever with their double moulds and cores, but even yet they were not satisfied. They went on to discover "lost-wax" casting, a method which we commonly use to-day. This was done by making a wax model of the tool to be cast. The model was then covered with layer after layer of clay mixed with ashes until a mould had been formed around it. An entrance channel was left for the metal and vents were provided for the outflow of wax and gases. As the metal was poured in, the wax would melt almost at once, being replaced by the metal in the mould. The process is called "lost-wax casting" because very little wax is recovered, most of it being lost in gas and smoke. This method of casting meant that the founder must make a new model for each tool he cast, and for this reason stone and clay double moulds continued to be used for all the simpler tools. But where the work required great delicacy or had irregular shape, especially if there was any undercutting, then the lost-wax method was by far the best. Clay cores could be used to form holes in wax casting just as they were used in the double moulds.

Just how extraordinarily able these ancient founders became you may believe when I tell you that quite large Egyptian castings have been found in which the metal is only one-fiftieth of an inch thick. When you work so close you must have your metal at exactly the right temperature when you pour, and your moulds and cores must be warm so that the whole mould will be filled, almost instantly. Otherwise you will be left with a patch to make or a warped, mis-shapen tool.

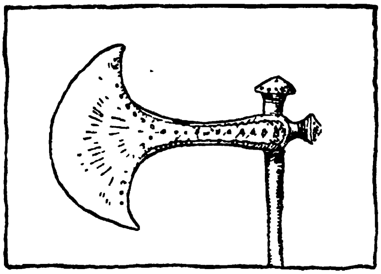
Almost immediately after bronze making began in Sumeria, we find bronze in use in Egypt, and from these two centres the craft spread outward in two directions around the world, just as gold seeking had done earlier; in fact, it followed the same path. Eastward we find bronze coming into use in India, China, Korea and Japan. Westward the bronze founder's art appears in Asia Minor, Cyprus, Crete, Greece, Italy, Spain and France. In France it passes up the river Rhone and on towards the north to Denmark and Scandinavia. About the same time bronze making began in the British Isles, especially in Ireland, where some of the most beautiful of all ancient tools were made.



ROMAN ARMS OF BRONZE

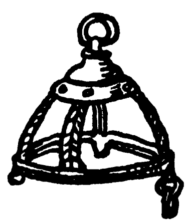
The path to central Europe passed up the Danube River valley, leaving behind two great bronze-making centres—one in Hungary and the other among the lake dwellers in Switzerland. From these centres it seems to have spread out fanwise through Germany and into Russia.

All this must have brought about an immense amount of trade, and we find places where these ancient bronze founders made and stored their tools all over Europe. This traffic, too, I think, had a good deal to do with the beginnings of many towns that in time were to grow into the great cities of Europe. Certainly it broke paths through the ancient forests and over wild mountain country which came to be roads, and, finally, under the Romans, were made into the great highways that bound the whole of the European world together.



BRONZE AGE BATTLE-AXE

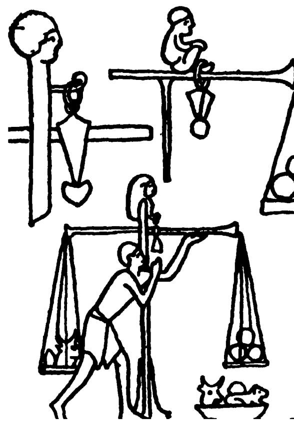
But the sea traffic that grew up in this age of bronze tools is perhaps even more interesting. It came into being because tin, which is necessary in the making of bronze, was not to be found either in Mesopotamia or Egypt, the two oldest bronze-using countries. The amount of tin that might have come from Persia was never enough to supply the demand, so tin had to be sought outside the ancient Eastern world, and the people who sought it were the Phœnicians. Their country lay at the easternmost end of the Mediterranean, where they had built two great cities, Tyre and Sidon. In time they set up many colonies—Carthage in Africa, Cadiz in Spain, Marseille in France—and with these connections they became, and remained for over a thousand years, one of the greatest nations of traders and sailors that ever existed. Just how able they



ANGLO-SAXON HELMET

GREEK WARRIOR WEARING BRONZE ARMOUR

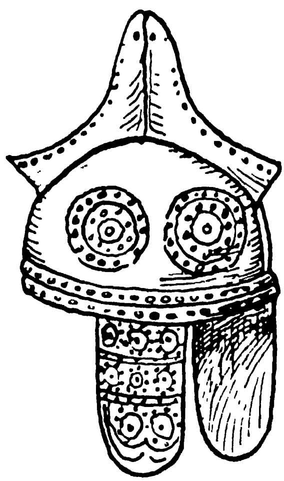
were you may believe when I tell you that twenty-one hundred years before Vasco da Gama sailed around the continent of Africa, these ancient Phœnicians took a fleet of triremes from the Gulf of Arabia and circled the African Continent, returning home through the Straits of Gibraltar. Triremes, mind you—vessels that were rowed with three banks of oars. It took them three years to complete the trip and they had to stop off on the way to plant, raise and harvest grain to keep themselves



EGYPTIAN STEELYARD

supplied with food for the voyage. Nor was this the only time this journey was made by Phœnicians. Hano of Carthage sometime later made it the other way around, going from Cadiz to Arabia.

The great sources of tin in the ancient world were Spain, in the west, and Malabar, across the Indian Ocean, both at tremendous distances for that time. But the Phœnicians made these trips regularly, and they even went to the British Isles to secure tin from the natives of Cornwall and Ireland. There is a story handed down to us from Roman times that explains why the Phœnicians were so successful, for it shows that they not only had courage as sailors, but that they dealt decently with the people with whom they traded. "They were wont to visit a people who lived beyond the Pillars of Hercules"—wc think that Cornwall is the place meant by this—"and when they had come to the shore they would set out the goods that they had brought for trade, and after building a great fire they would return to their boats again. The natives, seeing the smoke, would come out of the forests bringing with them gold, tin, hides or other goods, and would place, beside the

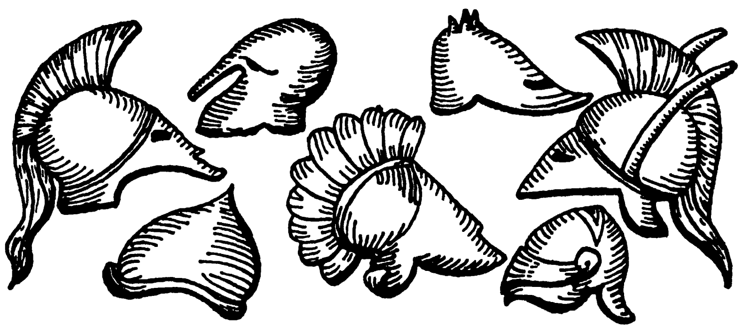


BRONZE AGE HELMET—DANUBE

Phœnician wares, as much of their own as they thought the cargo worth. This done they would retire again into the forest. The Phœnicians, then, would come ashore and, if satisfied, take the Cornish goods, leaving what they had first set out in trade. But if they were not satisfied they would withdraw and await a new offer." So the bargain, without words, would go on until both sides were pleased with what they got.

There is another Roman account of the tin trade that gives an idea of the distances travelled and the difficulties overcome to bring it to the ancient Eastern world.

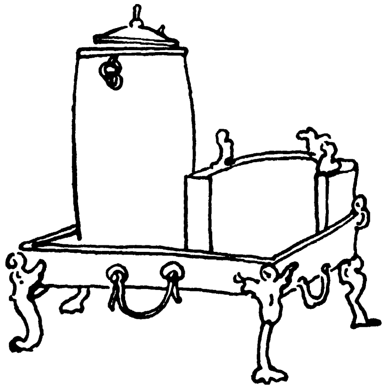
"The native people dig the tin and having melted it they carry it to a neighbouring island which they can only reach by going over the shoals when the tide is out. Then the foreign merchants, having bought the tin in the islands of Ictis, carry it by boat to Gaul where they put it on horses, after which it takes thirty days to bring the tin to the mouth of the Rhone." Here it was again put on shipboard and carried to Rome or to the eastern countries that needed it.



GREEK HELMETS

But besides the beginning of trade by road and ship, the age of bronze saw tremendous strides made in many other directions—the invention of writing, the beginning of law and government, the growth of cities and city-states. In this period almost every type of common carpenter's tool was made, with the exception of only the bubble level, the brace and bit and the plane. Many other things beside tools came to be made of bronze—weapons, armour, ship prows, chariots and even furniture.

The Bronze Age saw, too, the building of the pyramids of Egypt, for which millions of tons of stone were cut in the quarries of the upper Nile, shipped hundreds of miles down the river to the building site, shaped and set in place—every bit of that work was done with tools of stone and bronze. A task, Diodorus tells us, that required the labour of three hundred and sixty thousand people for more than twenty years in the raising of but one of these structures.



ROMAN HOT-WATER POT

The same age saw the building of Babylon, a city so vast that the later Greeks said it seemed more like a nation than a city. The wall around it, built of sand-clay bricks set in bitumen, was forty miles long, one hundred and fifty feet high and wide

BRONZE KNIFE FROM POMPEII

enough at the top for two chariots to drive abreast. Such a wall would require more than four hundred million tons of brick.

While it is impossible to list here all the other inventions and changes that came into the world during the Bronze Age, we shall see all those that are concerned with metalwork as we go on.

But of all that happened in this extraordinary age, perhaps the most surprising thing is that there ever should have been a Bronze Age at all. For, from a metalworker's point of view, iron should have come into use before bronze, and, had that occurred, bronze would never have become, as it did, the most important metal in the world for two thousand years.

VII. The Coming of Iron Tools

OF all the heavy metals in the world iron is by far the commonest. The very core of the earth is said to be made up of iron, and it seems to be present even in the outer universe, since every meteor that has been found is largely composed of iron. Not only is iron common, but it is much more easily prepared for working than are either copper or bronze. Before you can cast copper the ore must be smelted, whereas iron can be worked almost directly from the ore, without complete smelting, and at considerably less heat than is required for melting copper.

Let us set down side by side what we know of the first two great tool metals—iron and bronze. To make bronze, long and dangerous voyages had to be taken in search of tin, while iron ore was fairly plentiful everywhere. To cast bronze, moulds, cores and lost-wax models were required, and these took a great deal of skill in the making and handling. On the other hand, iron ore could be worked into a tool or a weapon by a method so simple and direct that even quite primitive and savage tribes have known how to do it. All this certainly makes one think that iron, rather than bronze, should have been the first important metal for making tools and weapons.

It has been said that iron actually was used much earlier than we now believe, and that the reason we do not find any traces of it in the ruins of Bronze Age temples, or buried in the dust of the ancient cities, is that it has rusted away, while the bronze tools have remained. It is quite true that iron, which is not protected, will rust away long before bronze begins to show any signs of great age. But although iron itself is not very permanent, iron rust is practically indestructible, and we do not find iron rust in the older Bronze Age towns and buildings.

We know definitely, too, of at least one great and highly developed people who were living in a copper-using age only a few centuries ago. These were the Mayas, of Mexico, who built marvellous pyramids and temples of the hardest kinds of stone, which they carved with beautiful and intricate designs, using only copper, stone and a few bronze tools. They were an amazing people; their masonry work was so accurate that you cannot slip a knife-blade between some of their joints, and they were such extraordinary builders that they raised stones weighing from ten to fifteen tons into place. They were a wise people, too, for their calendar was more accurate than that used by the Spaniards who conquered them. They were excellent miners, particularly for gold and silver, and some of their deep mines are still being worked to-day. Yet, though there were whole mountains of fine iron ore in Mexico, they made no use of it whatsoever until after the coming of the Spaniards under Cortez.

The oldest written record of iron is in a Chinese book called the *Shoo King*, written about four thousand years ago. In it were listed all the things that were paid in tribute to the Emperor Yu, and among them is an item of iron. But as iron is not mentioned again in any other Chinese record until nearly a thousand years later, we do not believe that these ancient Chinese knew very much about it, although later Chinese iron-workers came to be marvellous craftsmen.

In India we know that along the Ganges River there lived an ancient Hindu people who made a kind of steel. This steel was called "wootz," and it came to be greatly prized because of its strength and hardness. It was made from an ore that was mined from the surface of the ground. The smelter would take a little of this ore, about a pound or so, and after crushing it, put it into a small clay pot together with some finely chopped-up wood. He would then cover this over with a few leaves from the acacia tree, seal the pot with a lid of clay and then dry the sealed pot in the sun. When a number of these little crucibles were dry the smelter would build them into arches in groups of about twenty-four to a group, forming a small oven in which he would start a charcoal fire. This fire was blown up, slowly at first and then violently, with double bellows made of buffalo hide. When the pots had cooled they were broken open and in each of them would be found a little cake of metal. These cakes were reheated and then worked into sword blades or tools on an anvil under a hammer. So excellent was this steel that for many centuries it was considered the finest in the world. It is thought, in fact, that the famous Damascus blades of Roman times were made from Hindu wootz.

But even in far earlier times than these, we find bits of iron being used in Egypt and Mesopotamia for rings, ornaments and the like. One such bit, now in the British Museum, came from one of the pyramids and is thought to be over five thousand years old. These earliest pieces of iron, however, were not at all common. They are usually found together with gold and silver ornaments. From this we think that, at least in the beginning, iron was looked upon as a precious metal.

There are all sorts of legends about the discovery of iron. Most of them tell of some great fire that burned in a forest on a mountainside creating a heat so intense that the ore in the earth melted and ran out in streams. Some tales place the mountain in Crete, others say it was in Spain, and still others that it was somewhere in the Caucasus. The most interesting of these legends tells of a shepherd folk living in Spain who set fire to a forest in order to drive wild animals into the open and to clear the ground for grazing land for their cattle. The fire, according to the legend, became so hot that it melted the iron out of the earth. Whether we believe that iron was discovered in this way or not, this tale is important to us in itself, for it gives one more brief look into the life of Stone Age man—showing a terrible and cruel method of hunting and a quick if destructive way of clearing by burning over forest land. Curiously enough the records of American Colonial days show that this was done there, for a Virginia law of Revolutionary times prohibits the "driving of game into the open by burning its forest cover."

If you take all these old legends and make dots on a map to mark the places of which they tell, and then on the same map spot in the places where the earliest iron implements have been found, you will notice your dots getting more and more numerous in the neighbourhood of the Caucasus Mountains and along the south shore of the Black Sea. We do not yet know much about the ancient peoples of the Caucasus, but we do know that a people who dwelt along the shore of the Black Sea were famous for the iron they made. Their iron was called "barzel," and it was so fine that Alexander got his best weapons here when he marched against Persia. It is quite possible that it was among these people that iron making began. Wherever iron making actually began, we know that by the time of the Trojan War, a little over three thousand years ago, iron had come into fairly common use for tools.

Curiously enough, iron does not seem to have been welcomed into a bronze-using world. It was actually looked upon as a thing of evil for a very long time. The Greek poet Hesiod thought iron was evil and Herodotus said: "Iron came into the world to the hurt of man." As late as Roman times we hear the poet, Ovid, cry out: "The earth hid the metals and then iron came forth destructive and terrible." And Mahomet warned in the Koran: "Dire evil resideth in it, as well as advantage to mankind."

A great many superstitions grew up about iron. The Romans believed, for instance, that if you drew three circles in the air around anyone and three on the ground with a point of iron, that person could not be bewitched. They thought, too, that a nail taken from a grave and driven into a door-sill would keep off nightmare. But though they had some sort of fear of iron, they also used it in important ways—their wedding-rings were made of iron, and they used it in a great many medicines. They thought that you could cure diseases of the chest by pricking the skin with an iron point which had wounded a man. The Chinese still have the same belief, except that they do not require that the point come from a wound. But if most of these cures were ridiculous, some were quite intelligent—

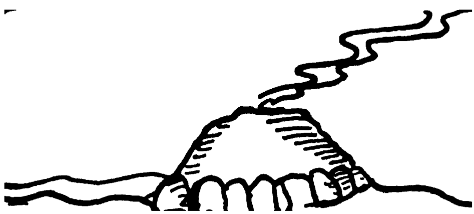
you can stop the flow of blood with iron filings, as they believed, although I do not recommend that you try it. We find the same kind of superstitions among the Greeks and the Egyptians, but we do not have to go back, even to Roman days, for such curious beliefs. Our own superstition about horseshoes bringing either good luck or bad comes from the fact that horseshoes are made of iron.

GREEK SMITH

However superstitious people may have been about iron, it was so much better a metal for making tools than bronze that, once its use had started, it soon drove out bronze tools altogether. The same thing, however, did not happen in the case of weapons, as we shall see, for bronze continued in use for arms and armour almost up to modern times.

We said a moment ago that the simplest way of working iron into tools did not require that the ore should be completely smelted. Here is the description of crude iron smelting that does not come down to us from ancient times but is taken from the account of what an explorer saw in Africa only a few years ago. Yet the process is probably very much like that used in the early iron-working days.

The native iron smelters, says Mungo Park, had furnaces about nine feet high and three feet in diameter, made of willow branches woven together and plastered over with clay. At the base there were seven draft inlets which were lined with clay and turf. At the top there was a vent. A layer of dry faggots was placed on the bottom of the furnace, and, on top of this,



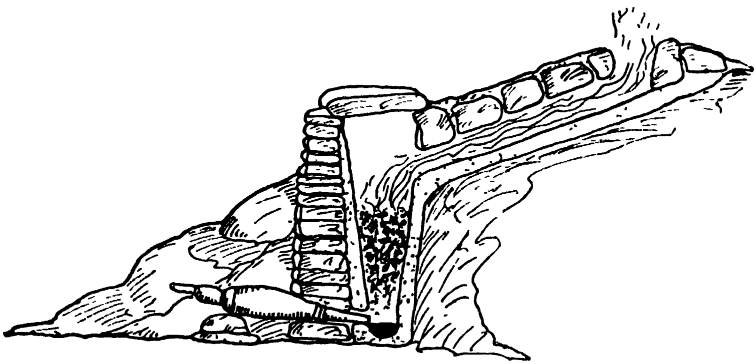
PRIMITIVE FURNACE

alternate layers of charcoal and egg-sized pieces of ore, until the interior was filled. The fire was then lit and blown upon with bellows, slowly at first and then more violently, but it was not until some hours had passed that flame began to pour from the vent at the top of the furnace. Then the whole mass burned intensely through the night until about dawn. When the fire began to pale the workmen would open wide all the inlets and let the air rush in to cool the furnace. This done, the furnace was broken open and all the debris removed, leaving a large lump of metal, encrusted with charcoal. Though much of this metal was worthless, the natives would get enough go od iron to pay for their labour. They would then break this mass into small pieces which would be reheated and then worked on an anvil with a hammer. The iron so made was fragile at the first working, but good enough for spears and knives. For tools, it must be worked a good deal longer.

Diodorus tells of iron making in Roman times: "In the island of Aethalie there is an ore that contains iron which is melted in batches to make metal. The workers first cut up a great quantity of it, and this they put into the furnace in a peculiar manner." (I believe he means in alternate layers with charcoal.) "When the heat has melted the ore, what is left is broken up into blocks and sold to the merchants who travel from village to village selling it again to the blacksmiths. Those who buy this iron make it into all sorts of figures, birds, beasts and the like, and also into tools."

The most famous of all the ancient furnaces were those used in Spain, which were called Catalan furnaces after the country where they were invented. The bottom of one of these furnaces was usually a large flat stone, slightly cupped. This stone was set in a pit dug into a hillside in such a way that the hill itself would form the back wall of the furnace, while the front was built up of stones. The inside was plastered with clay, and a little above the bottom there was an opening left for the tuyère, as the nozzle of the bellows is called. The oldest of these furnaces was fairly low—little more than three feet high. Later, in order to get more draught, the Catalans made a flue that ran off near the top of the furnace and extended along the ground for a little way up the hill. They covered these later furnaces with a capstone that could be removed when they wanted to charge the furnace with ore and charcoal. Crude as these Catalan furnaces were, they were used for many centuries, and the type in time became the standard furnace from England to Japan. The Chinese and Japanese practice was to throw burning charcoal into their furnaces until these were almost full; then they dumped the ore on top. They were such excellent smelters that they have been known to make in this way as much as six and eight tons of metal at a single heat.

You will remember that pure iron is very rarely found in nature. Iron usually comes combined with either oxygen or carbon, and with small amounts of other impurities such as arsenic or sulphur. What happened in these old furnaces was this: the ore, under the heat of the burning charcoal, would be freed of oxygen, sulphur and arsenic, and, in the case of those ores where carbon was present, a good deal of this, too, would be burnt out. The metal would partially melt and form into a stringy, spongy mass called a bloom. The bloom would be taken from the furnace, broken into pieces small enough to handle, reheated, and worked on the anvil under a hammer.



CATALAN FURNACE

The object of this heating and beating was to drive out nearly, but not quite, all of the carbon, and to knit the fibres of the iron into strong compact metal. Iron so made is called wrought iron. It was the earliest type of iron used, and it was almost the only kind used until nearly modern times.

There are three kinds of iron: wrought iron, cast iron and steel, and all of these are actually combinations of iron and carbon. Although the amount of carbon is never very large in any of them, it makes a great deal of difference in the kind of metal produced. Wrought iron, which has the least carbon of all, is strong, tough and elastic, but not very hard. Cast iron, which has the most carbon, is strong and may be extremely hard—in fact, fine, grey cast iron will scratch a diamond. But most cast irons unless especially treated are likely to be brittle —that is, they will shatter under sharp heavy blows. Steel has less carbon than cast iron and usually more than wrought iron. It is hard, strong, tough and somewhat elastic; but, more than this, steel can be combined with a great variety of other metals to form alloys each of which is the perfect metal for its particular use.

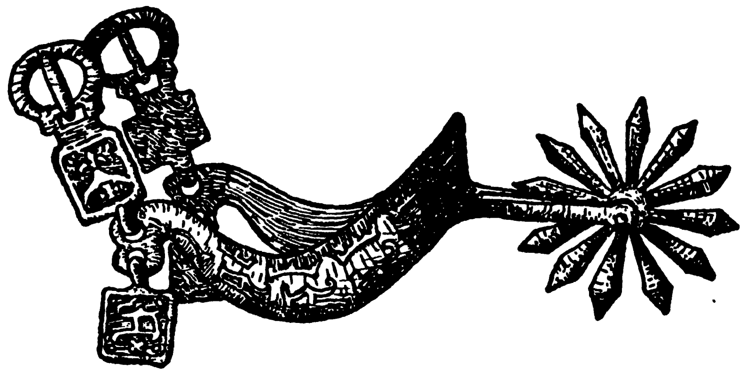
It would be an error to say that carbon alone brings about the differences among steel, cast iron and wrought iron. The amount of carbon that is combined with the iron is an important cause of these differences, but it is not the only cause, for, in part, these differences come about from the way in which the metal itself is made.

As wrought iron comes from the anvil after reheating and beating, it is a strong, tough and elastic metal, but it is not very hard. To make it hard enough for a sword blade or a tool point, it must be tempered. For a great many years it was thought that tempering was not known in the ancient world, but it most certainly was and quite generally. We read in Homer how, when Ulysses fire-hardened a timber of olive wood and drove it into the eye of the sleeping Cyclops, it hissed "just as does an axe or an adze when the smith plunges it into cold water that it may be tempered, for thence comes the great strength of iron."

Even if no ancient writer had ever mentioned tempering we still would know that iron was tempered from the early days of its use; for we see iron slowly replace bronze as the metal from which tools and weapons were made, and this would never have happened without tempering. An untempered wrought-iron sword blade would have been useless against a bronze shield or helmet. An untempered plough point would have bent and dulled in stony soil.

But while the ancient smiths did know tempering, most of them did it crudely and without any real understanding of what they did. Pliny, the Roman, thought that the temper in a sword blade or a tool depended on the kind of water into which it was plunged when hot. He said that the water from some springs was so much better for tempering that these places became famous among smiths. The kind of water used in tempering, as we shall see, has nothing whatever to do with the process.

That iron was so very slow in replacing bronze, particularly for weapons, was quite probably due to poor tempering. Polybius, a Roman writer, says that when the Gauls invaded



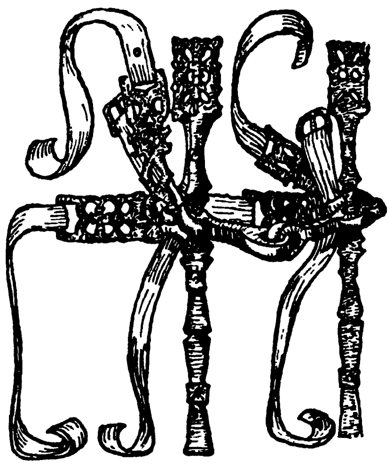
FOURTEENTH-CENTURY GERMAN SPUR—MEDIÆVAL SMITH'S WORK

Italy about two centuries B.C. they were defeated only because "their iron swords bent and the edges turned against the Roman armour so that after every stroke the Gaulish warrior must straighten his sword with his foot against the ground before he could strike a second blow."

Nearly a thousand years later than this we hear of the swords of the Vikings that bent in battle. "So then befell a great battle, and Steinthor was at the head of his own folk, and smote on either hand of him; but the fair-wrought sword bit not when as it smote armour, and oft he must straighten it under his foot."

The Norse legends are filled with these tales of good and bad swords. It is no wonder that the true and faithful swords were given names such as Thured's "Foot-biter" and Arthur's "Excalibur." It is not difficult to understand, too, why the Germans were slow to use iron for their weapons. But if the Germans did not know how to make the best iron in the early days, they learned rapidly, and before the end of the Roman day they had better arms than the Romans themselves.

Tempering is not quite as simple as just heating an iron tool and then plunging it into cold water. On many tools, for in-



ANCIENT SPANISH BIT

stance, only the point, or bit face, is tempered. In tempering, too, you must be careful not to harden your metal completely before you are quite through working on it, because, once tempered, it becomes much more difficult to change its form. There has always been a good deal of mystery and superstition among blacksmiths about tempering. Mathurin Jousse, who was a great ironworker in France about the middle of the seventeenth century, says of preparing the tempering bath: "The best water for tempering is May dew gathered at dawn from upland plants, for such plants have gained vigour from their exposure to the icy blasts of the north wind, and steel tempered from their dew has great strength because of this." Although dew is a very pure form of water, neither the purity of water nor where it comes from has anything to do with tempering. But after this lapse into age-old superstition the grand old craftsman goes on and really tells you how to temper steel. "Bring the steel to a cherry red, absolutely evenly all over, then plunge it into water where no air can get at it and afterwards rub it clean with fine dry sand."

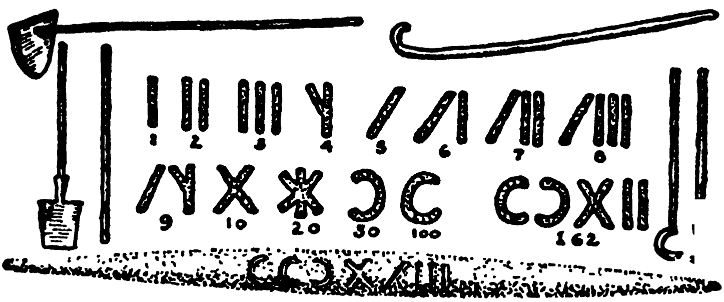
SEVENTEENTH-CENTURY FOUNDRY—FRANCE

Jousse then goes on to describe the colours through which a heated piece of steel passes as it cools. These colours are called the colours of temper. They are quite distinct and always occur in the same regular order—each colour representing a certain temperature and a definite degree of hardness.

When a piece of steel which has been heated to a bright cherry red is suddenly chilled it becomes extremely hard—the degree of hardness depending on the suddenness of the cooling.

Extreme hardness in steel, however, is likely to be accompanied by a tendency to brittleness. In light, delicate tools, such as razors, knife-blades, surgeons' tools, and the like, the quality of hardness is so much to be desired as to offset this tendency to brittleness. On the other hand, brittleness in heavy tools required for hand work would render them quite useless. A good example of this difference is shown in comparing a penknife blade with a screwdriver.

Almost everyone, at one time or another, has made the mistake of trying to turn a screw with a knife-blade only to see the point of the blade snapped off short. This is because the knife-blade is at once hard and brittle. It is made hard so that it may be brought to a sharp edge and retain its keenness for a



FRENCH FOUNDRY TOOLS—SEVENTEENTH CENTURY—THE MARKS SHOW THE WEIGHT OF THE PIG

long time. The screwdriver-blade on the other hand turns the screw without any trouble at all. It is not nearly so hard as the knife-blade but it is not brittle either. You could grind a screwdriver-blade to an edge, hone and strop it, but you could never make it as sharp as the knife-blade nor would it hold its edge for any length of time. It is better then, in making a screwdriver, to sacrifice a little of the quality of hardness in order to gain the toughness and strength required of the tool.

The smith uses the colours of temper as warning signals to tell him the exact moment at which a tool designed for a particular purpose should be plunged into cold oil or water to fix the degree of hardness at that point best suited to that tool.

Here is a list of the colours of temper with the temperature at each colour shown in degrees Fahrenheit. There is also shown the kind of tool which is usually made at this temperature.

430	Very pale yellow	Light wood-turning tools
440	Bright yellow	Razors
450	Pale straw	Milling tools
460	Straw yellow	Lathe tools
470	Deep yellow	Penknives
480	Dark straw	Iron drill points
490	Yellow brown	Taps and dies
500	Brown	Shears
510	Brown with red spots	Axes
520	Brown with purple spots	Wood chisels
530	Light purple	Pocket-knives
540	Full purple	Twist drills
550	Dark purple	Table-knives
560	Light blue	Wood saws
570	Blue	Stone chisels
600	Dark blue	Swords
630	Blue with green	Cold chisels

Just how long ago the smith learned to use the colours of temper we do not know. Jousse was the first to describe them, but we may be fairly sure that the makers of the Toledo and Damascus blades had known them much earlier and they may even have been known in the ancient world, but we have no record of this.

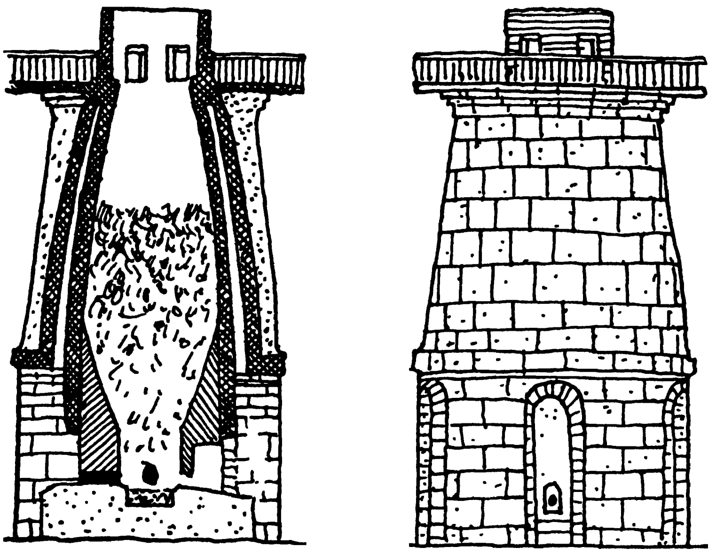
Another method of treating metal with heat is called annealing. A piece of steel is annealed by heating it to a cherry red and then allowing it to cool very slowly, burying it in sand or ashes so that it loses its heat gradually and over a long time. Steel so treated becomes soft and is quite easy to work.

As iron came more and more into use in the ancient world the smith learned a way by which the work of making blooms could be speeded up. This was done by roasting the ore over open fires before placing it in the furnace for smelting. This got rid of a good deal of the arsenic and sulphur. They also learned that they could make larger and better batches if their furnaces were higher. So we see the "low furnace" (from three to nine feet high) give way to the "middle furnace," which by the Middle Ages was from ten to sixteen feet high, and finally, in modern times, you may see great towering stacks at our mills that rise over a hundred feet above the ground.

Another improvement that made better iron and made it in less time was the use of lime or limestone as a flux. Fluxes had been known from very early times, particularly in the smelting of gold and silver. Their purpose is to gather to themselves the impurities of the ore and to keep the melting metal as free as possible of ash. Different kinds of fluxes are used for different metals. In the case of iron, dolomite or limestone, when put into the furnace with the ore and fuel, will collect a great part of the impurities and ash. These are formed into large grey-white clinkers known as slag which are taken from the furnace as the ore is smelted, leaving a much cleaner and better bloom. Lighter than the metal, slag floats upon the molten mass and is drawn off after the metal has been removed. For many years slag was thought to be quite useless; in fact, it was a great nuisance because, as there was no place to get rid of it, there grew up great waste heaps of slag around the iron and steel mills. But not long ago it was found that slag made an excellent road surface, and also, when combined with cement, a strong lightweight concrete, so these miniature mountains of slag are now fast disappearing.

Just when limestone was first used as a flux we do not know, but its use was quite common in Roman times and, in the form of limestone, it is always used to-day, especially in making steel.

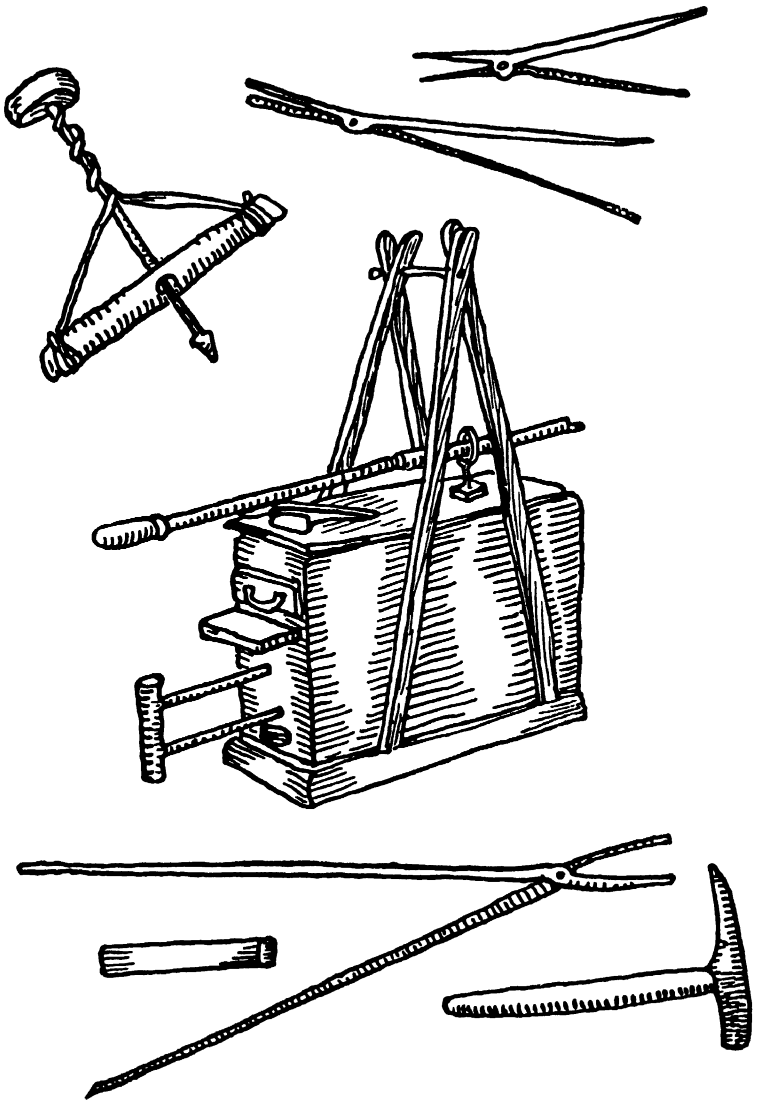
Furnaces did not begin to gain height until late in the Middle Ages, about Agricola's time, and the reason for this was the limited blast power of the bellows. The use of bellows to blow up a fire must have been known even in early copper-smelting days, as it is quite difficult to raise the heat required to melt copper without them. Who invented the bellows, we do not know. On an ancient Egyptian carving we see a group of metalworkers sitting around an open fire on which there is a small crucible. Each of the workers has a tube in his mouth with which he is blowing up the fire by lung power. Such a method could never have been satisfactory, even for melting small amounts of gold or bronze, and it wouldn't have done at all for copper or iron.



HIGH COLD BLAST FURNACE

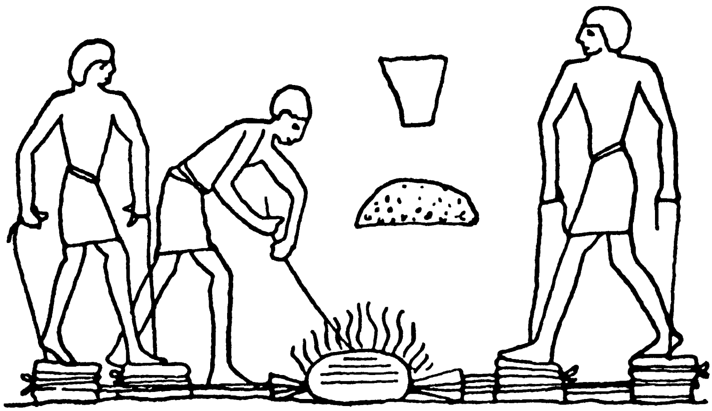
THE HIGH COLD BLAST FURNACE WAS ABOUT 50 FEET HIGH FROM HEARTH TO THE CHARGING FLOOR. THE EXTERIOR WALLS WERE BUILT OF STONE BOUND TOGETHER WITH IRON BANDS. THE INTERIOR WAS LINED WITH FIRECLAY BRICK. THE STEEPLY SLOPING BOSHES ABOVE THE HEARTH HELPED TO SUPPORT THE CHARGE AND KEPT IT FROM PRESSING DOWN ON THE HEARTH

We do not know it for a fact, but it is not too hard to believe that the Stone Age folk who were clever enough to invent such neat little fire-making machines as the pump and the bow drill could also have originated a simple form of bellows. For such a pair of bellows all that was needed was two paddles, connected



CHINESE PUMP BELLOWS AND SMITH'S TOOLS

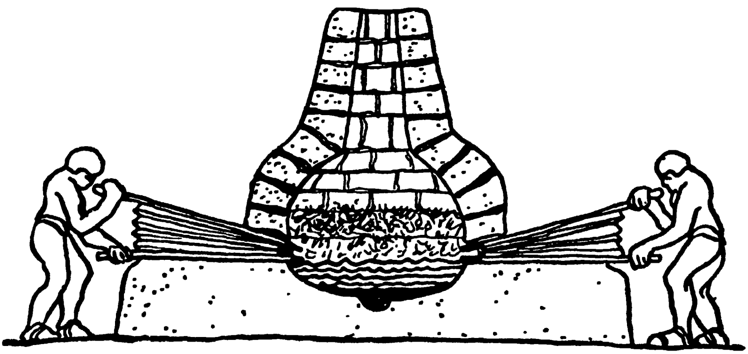
by a skin bag and having a nozzle at one end, out of which the air in the bag could be pushed by suddenly squeezing the paddles together. It wouldn't have been a very good bellows, because the nozzle would have to be drawn back out of the fire each time the paddles were opened to suck in a new supply of air. That problem was solved by the invention of the valve. A valve is a small door that can be opened, in one direction only, by pressure. The pressure may come from any source, your



EGYPTIAN DOUBLE BELLOWS

hand, a gear, or just flowing water or air. In a pair of bellows, the valve is a small flap of leather that is fastened on one side and is free on the other. One such valve is placed in the nozzle and another set in one of the paddles. These work in exactly reversed directions, so that one of them opens only when the other is closed. The nozzle valve opens when the bellows are squeezed together, thus allowing the air to spurt out. When the bellows are spread apart again, to draw in a new supply of air, the nozzle valve closes and the inlet valve in the paddle face opens. Such a bellows will work quite well to blow up a fire, even though it does furnish the draught in a series of puffs, with a wait between, while the bellows are refilled. If you want to get a steady forced draught you need two such bellows, so that they can be worked alternately.

In an ancient Egyptian drawing we see a clever set of double bellows. The picture shows two workers, each of whom is standing on a pair of sacks that appear to be made of leather. With one foot on each sack the workman can throw his weight to the right or left foot and so squeeze each sack in turn. In each hand he has a string that is connected with one of the sacks. As



ROMAN FURNACE

he shifts his weight to his right foot, for instance, to force the air out of that sack, he can draw air into the sack under his left foot by pulling upward on the string in his left hand. With good rhythm he can keep up a steady and strong blast without very much effort.

As heavier and heavier blasts came to be needed to supply the larger and higher furnaces, the bellows were built larger and larger until it took all the strength of a powerful crew of men to work them. Yet even in Roman days these bellows seem to have been worked only by hand. This was not because the Romans did not know how to harness power; they did that sometimes in their grain mills, ore crushers and pumps, using treadmills operated by men or animals. They knew water power but rarely used it. The Romans did not want labour-saving devices, because there were millions of slaves in the Roman state. They went to a good deal of trouble to keep these slaves steadily at work. For centuries the Romans were not nearly as fearful of invading enemies from outside the Empire as they were of the hordes of slaves within the state, who might at some time rise and overwhelm them. They worked vast numbers of slaves, in gangs, at dull and wasting tasks, that these slaves might not have either the strength or the heart left to fight for their freedom.

It was useless then for the Romans to build higher furnaces as long as they used hand-worked bellows. It was not, indeed, until towards the end of the Middle Ages, when water power came into common use, that stronger and better bellows were made. But when they did come, they brought great changes to the ironworker's craft.

The first forge in which the bellows were worked by water power was built early in the fourteenth century near the town of Moyeuvre in what was then the Duchy of Burgundy. Other mills followed in Germany, France and Spain. Forges were now built beside streams where there was a natural fall of water or where water could be led to the wheel through flumes. Such a wheel might be so made that the water would fall upon the paddles from above and so drive the wheel forward or the wheel could be so made that the flow of water could be sent rushing under the wheel to turn it in reverse. In either case the long, heavy, timber axle of the wheel turned as the wheel revolved. This axle was extended into the shop through an opening in the wall. At its inner end there was set a series of lugs or cams so spaced that each cam, in turn, would lift the upper leaf of a great bellows and then let this leaf fall as the cam passed on with the turning of the wheel. This upper bellows leaf was heavily weighted so that when it fell it did so suddenly and with great force, thus driving a strong blast from the nozzle. Two such bellows set side by side and operated alternately by two sets of cams could keep up a strong continuous blast as long as the mill-wheel turned.

WATER-WHEEL

With the forced draught that could now be developed iron making began to improve rapidly. The Catalan furnace of Roman times could make only about one hundred and fifty pounds of iron in a day. Metalworkers have estimated that if iron had to be made in a Catalan furnace to-day it would cost about two hundred and fifty pounds a ton or over ten times the cost of finished steel shapes to-day. The German furnaces of the Middle Ages could make about one hundred and fifty tons of metal in a year. By 1756, in England, Abraham Darby was able to make over one thousand tons a year. To-day the average American furnace produces 210,000 tons a year.

The coming of the blast furnace and the growing demand for iron caused forges and furnaces to be built everywhere that ore and fuel could be found. The older low Catalan furnace could only produce iron from fairly rich ore. The high furnace opened up ore fields, especially in Germany and France, which before were too lean to pay.

The low furnace had not only required richer ore but it was able to free only a part of the iron from the ore. When the furnaces were cleaned and the bloom removed there was always a great mass of cinders encrusted with partly smelted iron. This waste is called the scoriæ, and around all the old forges huge piles of scoriæ grew up through centuries of iron making. The hot blast of the high furnace, however, could not only smelt leaner ores, it could even recover the remaining iron in the scoriæ. These waste piles became veritable mines. It has been said that in the Forest of Dean, in England, there was such a vast amount of this waste that twenty furnaces were supplied with ore for three hundred years from the waste piles of earlier centuries.

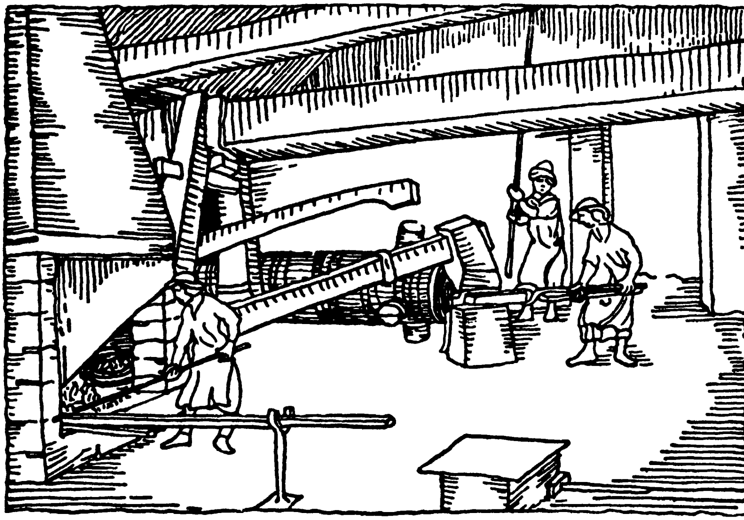
Water power brought more to iron making than the power-driven bellows and the high furnace, for it also made possible the tilt hammer which was to do for wrought iron what the high furnace had done for cast iron. The tilt hammer was a huge sledge with a head weighing a hundred pounds or more and a long handle pivoted in the centre. This sledge was also worked by cams on an axle-shaft of a water-wheel. It was so placed in the shop that the cams on the wheel-shaft would strike downward, as they turned, on the butt of the sledge helve, and in doing this they would raise and drop the hammer head. Because of its weight the head would fall with great force upon the anvil set beneath. Sometimes the force of the blow was increased by adding a long heavy tinker beam above the hammer. This beam

FRENCH SEVENTEENTH-CENTURY TILT HAMMER

would rise and fall with the hammer head, greatly increasing the power of the blow.

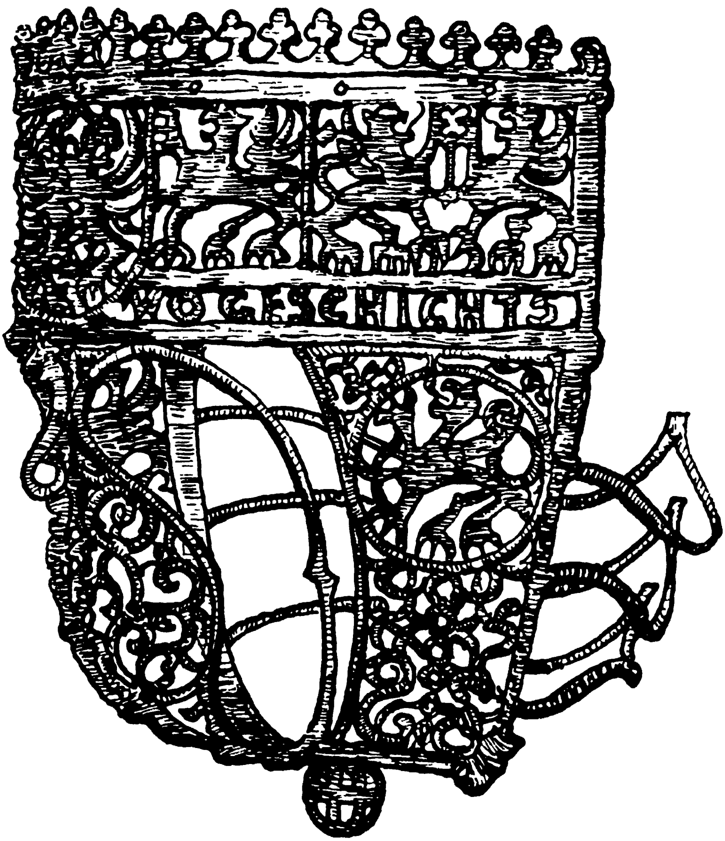
Before the invention of the tilt hammer all the heavy work of roughing large forgings or the beating out of blooms had to be done by hand. This meant that the pieces must be fairly small and the work slow. All this was to be changed by the tilt hammer which could do the work of twenty smiths.

Agricola says that even in his day, late in the Middle Ages, blooms were dragged from the furnace on to the earthen floor of the shop and there beaten by the smith and his helpers with heavy, long-handled wooden mallets. This got rid of the larger pieces of slag that stuck to the bloom and started the knitting of the fibres. The bloom was then broken up into smaller pieces and the work finished on an anvil. Although such pieces could be fairly large, this roughing-in work was slow and hard. The tilt hammer came as a great boon to the smith for heavy work, but it was probably never used for finishing.



FRENCH TILT HAMMER—SEVENTEENTH CENTURY

For that the smith and his helpers stood in a ring around the anvil, each helper with a long-handled sledge and the smith with a short, heavy hammer. When the iron is ready the smith draws it from the fire, white-hot and spitting sparklets like tiny meteors, and throws it on the anvil. Not a word is said—it would be useless, for who could hear orders above the roar of the water-wheel and the clatter of the bellows? Besides, there is no time for anyone to think—everything must be done in swift and perfect rhythm, for the work must be finished before the metal cools. Holding the iron with tongs in one hand, the smith strikes the face of the anvil with his hammer. It is the signal to the helpers: "Be ready, follow me." Then he strikes the metal and the sledges of the helpers rise and fall in turn so fast it seems



MEDIÆVAL GERMAN HORSE MUZZLE

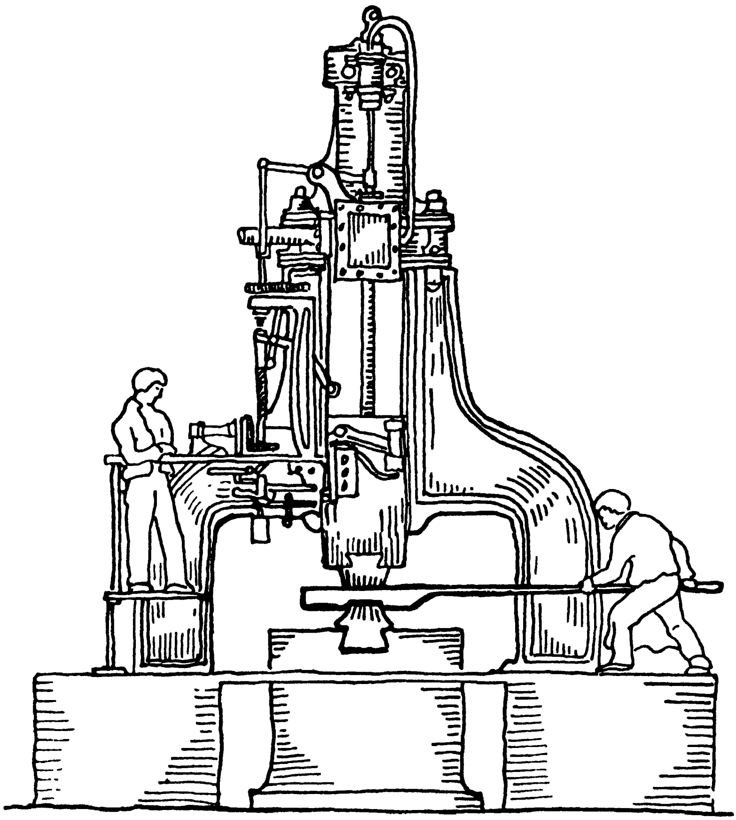
impossible that one head will clear before the next one strikes. In a blur of hammer heads the helpers follow exactly the blows of the master smith, striking where he strikes and with just the force his own blow commands. It is marvellous teamwork; the whole group moves as a single man. The blows weave and shift, following the metal as the master turns it from side to side, as though drawn to it by a magnet—light blows, heavy blows. Flat on the anvil, the glowing iron begins to form, then swiftly moves out on the anvil horn for the curve and back on its side for the edge; twisting and turning under the drumbeat of blows the wrought iron takes its final shape just as the last of its heat is fading. Then suddenly the master smith drops his hammer side-face-up on the anvil and the helpers' sledges halt in mid-swing. The job is done.

How many long and weary hours you worked as a boy, beating a piece of lead to learn that perfect timing, that precision, aim and rhythmic swing! How many years went into the instant feeling for the metal that has become a very part of you, so that hands and eyes and nerves and the muscles of your arms now act together more swiftly than the mind can think!

How large a forging can a smith and his helpers make? In India at Delhi there is a column called the Delhi Laht. It is sixteen inches in diameter and stands twenty-two feet out of the ground, beneath which it is believed are buried another thirty feet. And this whole column is made of wrought iron. It was made so long ago that no one now knows just how the work was done. We do not think they had tilt hammers at that time. Even if they had, such a hammer would have been of little use. How were these ancient Indian smiths to handle such a mass of metal upon an anvil? If we grant that they may have had slings and tackle to raise and swing such a column over an anvil, it is very doubtful if they could have developed heat enough to forge so great a mass.

I think the column was forged in place, welded layer by layer and, as the column grew, scaffolding could have been used to raise the workmen and the forges to the proper height. That would take far less heat and need no cranes; but if it was done in this way, it was a marvellous piece of workmanship, for in the column there is no trace of a joint.

Another interesting thing about this column is that it shows no signs of rusting, although nothing is done to preserve it. Iron which has once rusted slightly can be rubbed clean and then oiled, and if kept oiled it will last indefinitely. But so far as



NASMYTH HAMMER

we know, this was never done to the Delhi Laht. There is a possible explanation, however. The naked children of Delhi for centuries have played about the column, climbing to the top and sliding down, and it is quite probable that just enough oil gets rubbed into the iron each year from their bodies to keep it free from rust.

Up to modern times the size of a piece of iron to be forged was limited, not so much by its weight as by the amount of heat that the workmen, who must stand close, could bear on their skins. When a large bar, say eight or nine inches in diameter, has been brought up to an even forging heat over the whole surface of one end, the intensity and amount of heat that is given off is terrific. An anchor bar nine inches in diameter was once forged by twenty-four hammermen each with an eighteen-pound sledge. That is the largest hand-wrought piece of iron of which I know.

It was not until 1839 that James Nasmyth, in England, invented the steam hammer. This gradually replaced the tilt hammer until to-day we have steam hammers which will strike two and three hundred blows a minute with a force far greater than any that could be developed by the tilt hammer. These modern hammers can be so perfectly adjusted that you could place your watch on the anvil and crack the crystal without stopping the watch hands.

High furnaces, strong blast bellows and tilt hammers had come into being with the coming of water power, and iron making leaped ahead. But before the great modern age of steel could begin, however, there was one more problem to solve, and that was the problem of the fire itself, or rather of the fuels with which the fire was fed.

VIII. *Steel*

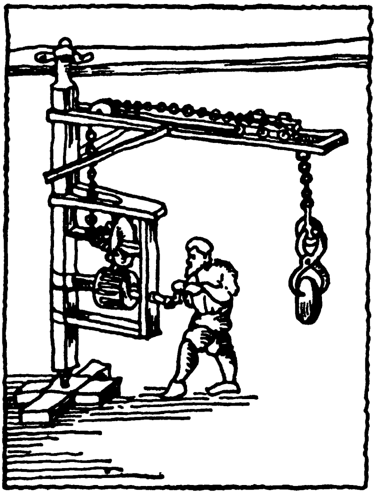
"BY skill with fires and fluxes is made that kind of iron from which comes steel." So wrote Agricola four hundred years ago. And it is, indeed, new fuels and hotter fires that have made possible the vast quantities of steel we use to-day.

In the beginning of copper smelting, wood served as the fuel, but quite early in the Bronze Age someone discovered charcoal. The heat from a wood fire is irregular, sometimes very hot and then cooling suddenly. A charcoal fire, on the other hand, burns slowly and with a steady even heat. And what is even more important, in metal work, you can raise or lower this heat, at will, by the amount of blast you force from your bellows.

Charcoal is made by heating sticks of wood in an oven until all the water and sap in the green lumber have been driven off, leaving only the fibre of the wood, charred into almost pure carbon. In the ancient days this was done by stacking wooden billets in loose piles and then building a dome of earth or turf over them so that, during the burning, no air could get to the billets from outside. The heat of a wood fire was then passed through this oven so that, without actually setting them on fire, the charcoal billets would become hot enough to give off their water and sap juices as steam and heavy oils. At a temperature of about three hundred degrees all the water and a good deal of these oils come off. At about seven hundred degrees the charred wood becomes almost pure carbon, porous and quite light; in fact, it now weighs only about one third as much as did the original wood. The first of these charcoals is the the smelters and the last is the fuel of the smith.

In the old days charcoal burning was a slow process taking many days, and for thousands of years it was done in the forest where the wood itself was cut. The favourite woods at that time were oak and chestnut, but almost any other hardwood served well enough. The softwoods, like pine and spruce, however, were avoided because they contained too much heavy oil.

Up to modern times all the gases that came off in the burning were wasted, but to-day we find these gases are more valuable to us than is charcoal itself. Collected, separated and treated by modern methods these gases can be changed into quite a number of new forms, and these are used in making such widely varied things as medicines, artificial silk, road surfacing, waterproofing, photographic materials, and even motor-car parts.



MEDIÆVAL CRANE

The charcoal burners were craftsmen of no little skill in their trade, even in earlier days, for they had to know which kinds of wood made the best charcoal for each particular use and they must burn their billets to a very regular standard. No smith would buy a charcoal upon which he could not depend.

Charcoal is still used by some smiths in forging, and in some parts of the world it is still used in blast furnaces, but its use is growing rare, for we have better fuels now. But through nearly thirty centuries the charcoal burner, living alone in the forests, served the smith faithfully, and though his art is now fading from the number of crafts, it has left its mark in the world on all the great iron work of the past. Just how dependent the smith was on the charcoal burner you may see from a law passed in France about two hundred years ago. This law required all the fuel merchants who brought their wares to the port of Paris to hold whatever charcoal they had in their cargoes until the smiths had been given a full three days in which to buy what they might need. Only after that could any charcoal be sold to the baker, the housewife or the cook.

We do not know exactly just when coal was first used, but the Greeks and Romans knew about it more than two thousand years ago. We read how the mother of the Emperor Claudius made briquettes of coal dust and wax for her own household fires. Roman coal workings have been found in England. In fact, not long ago lump coal was found in the cellar of the ruins of a Roman house, where it had been left some two thousand years ago. But it is very doubtful if the Romans used much coal, and even more doubtful if they ever used any in metalworking.

There is an old tale of the discovery of coal in France. The legend says that in Liège, in the year 1049, there lived a Flemish ironworker named Hollos. One day when he was out of money he went to a charcoal burner begging for fuel to carry on his trade, but the burner shut the door of his house in the smith's face. As Master Hollos turned away disconsolate, there suddenly appeared an old gnome whom the smith had befriended in better days. The gnome pointed to the ground beneath the smith's feet and then vanished. Master Hollos understood, and digging below the surface of the soil, he came to a bed of black rock which burned with a hot flame when he set it afire. The rock was coal.

Whatever the truth of this, coal, although well known throughout Europe in the Middle Ages, seems to have been but little used. It is not difficult to understand why smiths preferred charcoal, for although coal does make a hotter fire it is not an even and steady fire, and it is difficult at times to tell exactly how hot a coal fire actually is. When you are working with small, thin pieces of iron, such as those which Biscornet used in making the hinges of the doors of Notre Dame, you have to be very careful, for such iron is quite likely to burn, and once burnt it is worthless. But besides this there seems to have been another and even more important reason why coal was not more often used, and this was a curious kind of superstitious fear of coal itself, something like the fear thousands of years earlier that so long delayed the use of iron. There was no reason for it, but the prejudice was strong and widespread all over Europe. There were many tales of all sorts of evils that were thought to come from the use of coal. In France less than four hundred years ago, a law was passed forbidding any workman to burn any coal on pain of severe punishment, because the people of Paris believed that an epidemic there had been caused by coal fumes.

In China, however, where the use of coal began about the same time as it did in the Roman world, almost the opposite happened, for when Marco Polo, a merchant of Venice, travelled there some five hundred years ago, he saw coal used almost everywhere, and he wrote in his book: "It is a fact that all over the country of Cathay there exists a kind of black stone, found in beds in the mountains, which is dug out and burnt like wood. If you supply the fire with it at night and see that it is well kindled, you will find it alight in the morning. The Chinese have plenty of wood, but coal is cheaper and better." It is strange to see Marco Polo so excited at seeing coal, for he came from Venice which in his day was a very great and rich city, perhaps the greatest in Europe, and apparently he had not seen coal before. In one European country, however, coal was used for a short time a good deal earlier than elsewhere. This was in England during the reign of Queen Elizabeth, and it came about because the queen found that the charcoal burners were rapidly destroying the forests. Just at this time England had great need of all the timber they could get for the building of ships. It was the time of the great explorations and the long naval war between Spain and England. So a law was passed prohibiting the charcoal burner from making any fuel. In fact a little later even the making of iron was stopped because it led to burning up so much wood.

"Touching Yron Milles neere unto the Cittie of London and the ryver of Thames," the law stated that, on account of the great consumption of wood as fuel in the iron mills, recently erected there, no wood growing within twenty-two miles thereof was to be converted or employed "to cole or other fewell for the making of yron or yron mettell in any yron milles furness or hammer." The penalty for doing so was to be a fine of forty shillings for each load of wood so used.

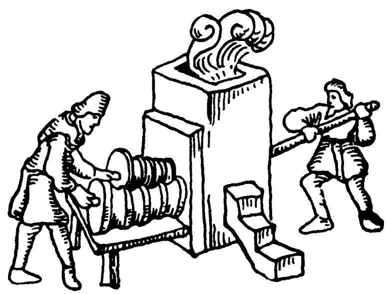
The law further provided that thereafter no new iron works might be set up within twenty-two miles of London under a penalty of one hundred pounds fine. The act was not applied to any wood that grew in any part of the wealds of Surrey, Sussex or Kent beyond the prohibited distance. The effect of this law as of others passed by later rulers was to cut down the number of furnaces operating by three quarters of their number. The amount of iron made at one time amounted to nearly 200,000 tons a year and this fell to but 18,000 tons by the year 1740. The result of this was to force the iron maker to seek a new kind of fuel.

About the time of Queen Elizabeth, Dud Dudley began to experiment with new kinds of fuel. He tried pit coal, sea coal, peat and turf, and he actually succeeded in making both wrought iron and cast iron in coal-burning furnaces. He wrote a letter to the queen, urging that coal be used in making iron and telling how much more iron he could make in his furnaces than the ordinary smelter could make with charcoal. "They can make only one little lump or bloom of iron in a day and that not a hundred weight, nor fusible, nor fined, nor malleable, until it were long burned and wrought under hammers." About this same time coal came into use for metalworking in both France and Flanders, but there, as in England, the charcoal burners were far too strong. They were determined to stop the use of coal for fear it would take away their work, and they succeeded for nearly another hundred years. Finally, however, about 1735, Abraham Darby made coke from coal in almost exactly the same way as charcoal is made from wood. The story is told that he built a fireproof hearth in the open air and piled upon it a mound of coal, covering it with clay and cinders and leaving just enough air to cause slow burning. In this way he succeeded in making coke. He then ordered a furnace to be filled for smelting, using this coke instead of charcoal. It took six days and nights to do this, during which time Darby never left the furnace, having all his meals sent to him at the furnace top. On the sixth night the smelting began, and as the first iron ran from the furnace, Darby, overcome with fatigue and relief, fell sound asleep on the furnace top from which he was lifted and carried home by his men.

Once coke was discovered, the craft of the charcoal burner was doomed, for coke could be made more cheaply than charcoal and it gave a better and hotter fire. The use of coke had a great deal to do with the increased use of cast iron and steel. In less than one hundred years after Darby's time the amount of cast iron used in the world rose from practically none to more than a hundred million tons a year, and steel has come to be the most important metal the world has ever known.

Steel was well known in the ancient world; you will remember how the Hindus made wootz from natural steel ores in small clay pots, and it is quite probable that the barzel of the Black Sea folk was steel. An ancient Chinese writer says, "When I was in Tze Chow, to visit the factories there, then I understood for the first time that steel was in iron like worms in meal. Let it be subject to fire a hundred times or more and it becomes lighter each time until it is pure steel." That is more poetry than truth, because pure iron is certainly not steel, nor anything like it. Leih Tze, who lived in 400 B.C. in China, wrote that "steel will cut jade as a knife cuts mud." We may doubt that a good deal, too, because jade is one of the hardest stones known and very probably no steel then made would cut it so easily. But the story is interesting, in itself, because it shows that steel was known in China then.

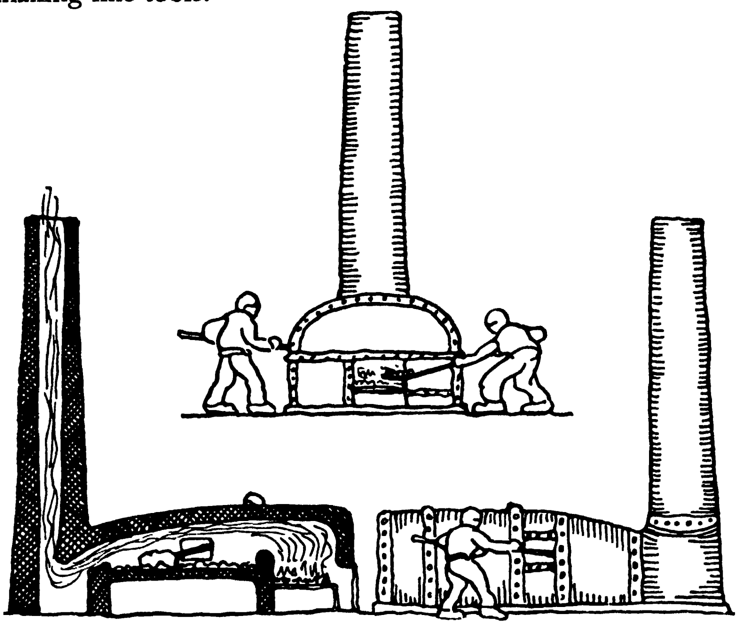
The steel of the ancients, however, was not so often made by smelting as by a process which we call cementation. Cementation consists in working wrought iron at red or yellow heat on an anvil in the presence of a very little pure carbon dust. What actually happens is that during the beating of the hot iron this carbon works into the metal itself and becomes a part of it, forming steel. It is very difficult, however, to get an even strength throughout the whole billet in this way. The steel sword blades which were made in Damascus and Toledo, and which were so highly prized, were probably made by cementation, but only the greatest smiths could make a thin, perfect piece of steel by such a method. In Toledo, the smiths had two tests for their blades; with the long, straight, slender sword, drawn out and tapered, polished and wrought to a sharp, clean edge, they struck a hard, straight blow across a block of iron. To pass, the blade must not show the slightest dullness after this test. Then some of the blades were bent to form one quarter of a circle; better blades were bent to a half-circle; but the very finest of the Toledo swords could be bent until the tip touched the hilt, and would then spring back again as straight and true as they were before.



SMALL GERMAN FURNACE WITH ACCORDION BELLOWS. THIS MAY HAVE BEEN A PUDDLING FURNACE AS THE METHOD OF PUDDLING IRON WAS KNOWN IN AGRICOLA'S TIME

In Agricola's time steel was made in Germany by adding wrought iron to molten cast iron in crucibles. The same method was used in China about the time of Genghis Khan. It is thought that the Greeks and Romans knew this method, too, but I doubt that they used it very much, because in their time it was very difficult to get any good cast iron.

It was not until the eighteenth century that steel began to replace wrought iron in the making of tools and weapons. About 1740 Benjamin Hunsman, an English clockmaker, began to experiment in steelmaking in order to produce better springs for his clocks. He first made steel by remelting wrought iron which had been made into steel by cementation. Then the process was improved to one in which wrought iron was remelted in a clay crucible for two or three hours while slight amounts of alloys were added. Hunsman's process was costly and made but a small quantity at a time, but it produced a superb steel. Crucible steel is made to-day in electric furnaces. The steel so made is too expensive to be used for shapes or plates; it is chiefly used in making fine tools.

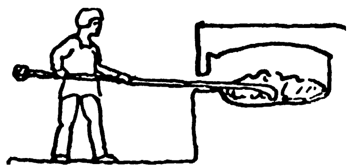


PUDDLING FURNACE

The puddling furnace is used to make wrought iron. It is a reverberatory furnace having the fire at one end separated from the hearth by a low baffle wall. As the flame sweeps over the hearth its heat is reflected from the arched roof of the furnace on to the metal placed on the hearth. Through an opening in the side wall the puddler stirs the metal with a long rake called a rabble. This exposes all parts to the heat so that impurities and excess carbon are burned away and the metal is gradually reduced to a pasty granular condition resembling boiled rice. At intervals flux is thrown in to collect ash and impurities. The puddler collects the granules into a ball, rolling it back and forth over the hearth and finally withdrawing it at exactly the right moment. This ball is then passed through squeezers or is worked under the hammer into bars

In 1784 Henry Cort, an Englishman, took out a patent on a rolling mill. Metal had been rolled into thin plates long before Cort's time, especially gold and silver for coins. Cort improved the method and invented grooved rollers with which he could roll bars and rods, flat strips and other shapes. With Cort's mill began the vast modern industry which makes railroad rails, armour plate, bars, rods and structural shapes of every kind with which ships, buildings and bridges are now built. Without rolling mills the steel industry, as it is to-day, would not exist.

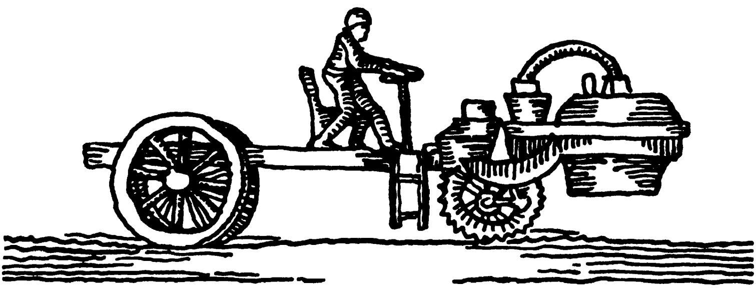
In 1783 Peter Onion, of Wales, patented a puddling furnace. A few years later Cort greatly improved it. His puddling furnace was of the type we call the reverberatory furnace, that is, a furnace in which the flame passes over the charge but does not come in contact with it. The charge in a reverberatory furnace is placed on a concave hearth. The heat is furnished by a fire at one end of the furnace from which the flame is directed against the arched roof over the hearth. As the flame sweeps along the arch its heat is reflected downward, melting out the iron and burning away the impurities. Along the sides of the furnace are openings through which the molten metal is stirred with rabbles. The finished iron is withdrawn in balls weighing about two hundred pounds apiece.



PUDDLING IRON

These two improvements of Henry Cort have been of enormous value to the steelmakers of the world, yet after a lifetime of work and the expenditure of his own considerable fortune, Cort died in poverty. Having used all his own money on experiments and needing more to carry on his work, Cort took into partnership with him a high official of the government. Years later it was found that this man had used his office to defraud the government. Cort had never known of this nor had any part in it whatsoever yet he was forced to give his patents to the government in payment for the crime of his partner. Few men have ever given to the world such sources of wealth and work as Cort did. It is almost unbelievable that such a man should have been left to starve.

The next great step in steelmaking was the development of the hot blast. In 1824 James Neilson, a Scotsman, began to heat the air blast before it entered the furnace. Shortly after this both in England and in France the hot waste gases escaping from the furnace top were recaptured and used to heat the blast. This

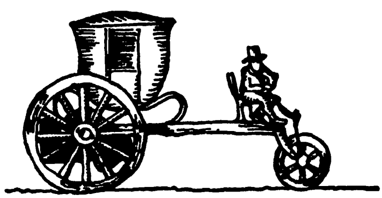


CUGNOT'S STEAM CAR

made the furnaces far more efficient; it raised the temperature in the furnace and burned out more of the impurities.

In 1705 Thomas Newcomen and Thomas Savery invented the first useful steam engine. It differed from the modern steam engine in that the steam was not used to drive the piston. Instead steam was let into a cylinder until it had raised the piston to the cylinder head. At this point a jet of cold water was shot into the cylinder causing the steam to condense suddenly. This created a vacuum below the piston head which was then forced downward by the pressure of the air outside. Crude as were these first steam engines they were useful in operating pumps and many of them were built. In 1764 James Watt was called on to repair a small Newcomen engine at the University of Glasgow. Studying the engine Watt decided that it was too bulky and that it wasted heat. He made a number of improvements on the Newcomen engine and a little later invented the modern steam engine in which high steam pressure is used to drive the piston and thus produce power. The invention had great success: Watt engines began to replace those of Newcomen and the age of steam power was at hand.

A few years after Watt had made his first engine Joseph Cugnot built, in France, the first steam-powered carriage. It was a huge, heavy, cumbersome vehicle, too large for any but a few roads of its day, but marked the beginning of a new era—the world of the horseless carriage which Roger Bacon had foreseen so long before.



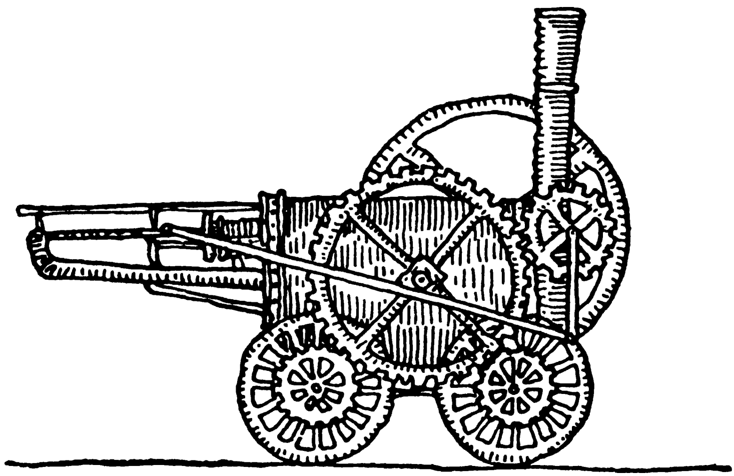
RICHARD TREVITHICK'S STEAM COACH—1801

In 1801 Richard Trevithick, in England, built a locomotive which he called Captain Dick's Puffer, and on Christmas Eve of that year he carried a load of passengers on it. A little later he built a steam coach to run on the post roads in place of the stage-coach of his day. It had some success but the time was not yet ripe for the passing of the horse-drawn coach. That was to come with the steam engine run on rails.

In 1814 George Stephenson built his first locomotive. Eleven years later the first railroad to carry passengers was opened between Stockton and Darlington in England. Stephenson acted as engineer on the first run. You can see the engine which pulled this train to-day. It stands on the platform of the Darlington Station—the oldest "No. 1" of them all.

Railroad companies were organized and tracks laid. The problem, however, was to get an engine which could pull a fair load and run without too great cost for fuel. One railroad company of this period faced with this problem sought to solve it by offering a prize of five hundred pounds for the best locomotive which could fulfil certain conditions. It must "effectively consume its own smoke"; attain an average speed of ten miles per hour, cost no more than five hundred and fifty pounds, and it must be able to draw a certain weight day after day without interruption of the service.

Trial of the contestants was to take place on October 6, 1829, at Rainhill near Manchester on a level stretch of track about two miles long. Each entrant was to do twenty round trips on this stretch and to complete this trial within a set time.



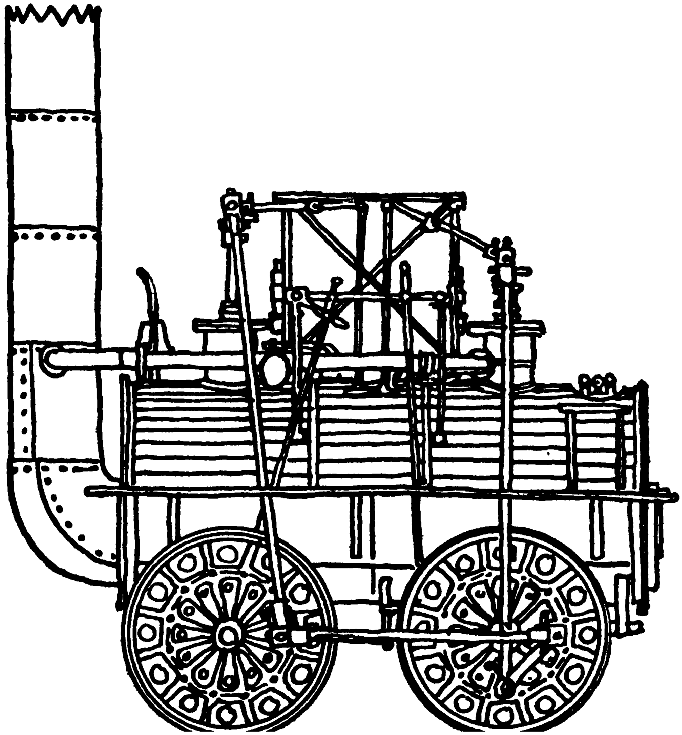
TREVITHICK'S LOCOMOTIVE—ONE OF THE FIRST LOCOMOTIVES BUILT IN ENGLAND

There were four entrants for the race:

Braithwaite & Ericsson's "Novelty"
Timothy Hackworth's "Sansparcil"
Stephenson's "Rocket"
Burstall's "Perseverance"

By the day of the trial the whole countryside had gathered along the track to see the show. Huge sums were wagered and feeling ran high on all sides. Even among the directors of the railroad and the judges of the contest there was considerable doubt that any of the contestants would fulfil the requirements. Solemn statements with elaborate proofs were made that no steam engine could possibly go ten miles an hour, let alone maintain such a speed.

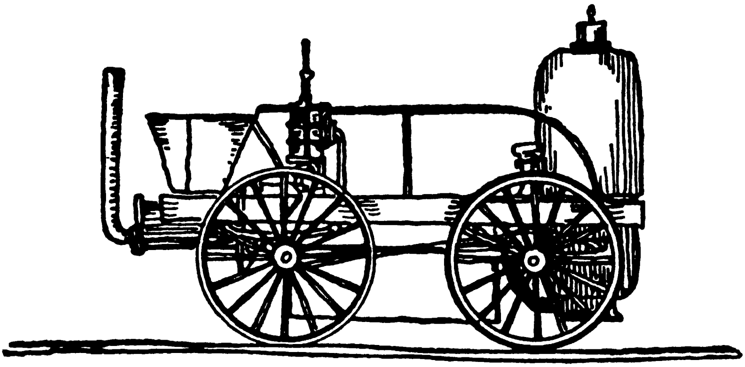
Lots were drawn to determine the order in which the trials would be made, but when the time came to begin the contest



STEPHENSON'S "LOCOMOTIVE NO. 1"

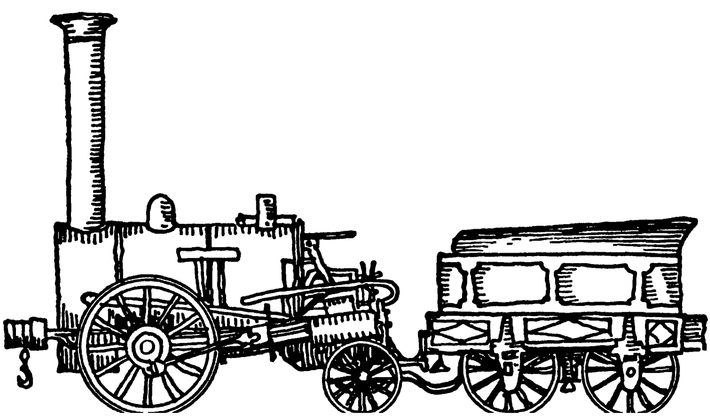
only Stephenson was ready. He took the "Rocket" to the starting point where he filled the firebox, lit the fire and had a head of steam ready in seven minutes.

The "Rocket" then made ten round trips pulling a weight of thirteen tons, requiring in all one hour and forty-eight minutes. After refuelling and overhaul, the "Rocket" then made ten more round trips in two hours and three minutes. The highest speed attained was about 29 m.p.h. and the average was 15 m.p.h.



BRAITHWAITE & ERICSSON'S "NOVELTY"

The "Sanspareil" was the next contestant to make trial, but when the boiler was filled with water it was found that the loco-



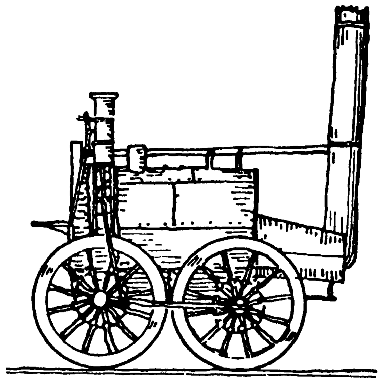
STEPHENSON'S "ROCKET"

motive weighed more than the limit allowed in the rules of the contest. It was, nevertheless, allowed to go on with the trial, but during the eighth trip mechanical difficulties developed and it was withdrawn.

The "Novelty" was long delayed in starting, in fact, it was not ready until the 10th of October. It weighed about three tons and pulled a load of seven tons. On the first trip a pipe burst and the trial was suspended until the 14th, when the Novelty again attempted to make the run and once more failed.

When the turn of the "Perseverance" came, it was withdrawn without even making a trial at all.

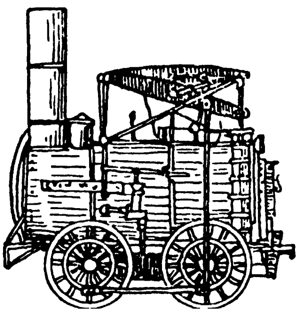
Stephenson's "Rocket" had, therefore, won the prize and the



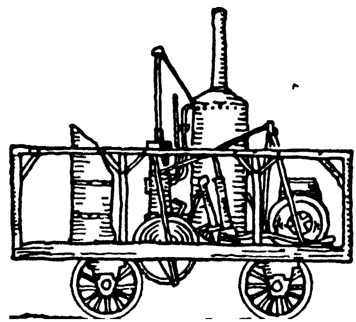
HACKWORTH'S "SANSPAREIL"—1829

favour of the directors of the railroad, but the public was not convinced as yet. There was deep prejudice and resentment against the railroad and the locomotive on the part of the country folk and the gentry who were used to coaches and coaching ways, and who had no desire to see the countryside crossed by railroad tracks or the country air filled with smoke. It was not, indeed, until many years later that this prejudice was broken down and this was accomplished by the queen herself. For early in her reign Queen Victoria travelled from London to Scotland by rail, and from that day on the railroad replaced the coach and team. But if the queen accepted the railroad her coachman did not, and he insisted on riding on top of the queen's car as he would have done on her coach. Smothered in smoke and stung with cinders, he valiantly clung to the forms of a dying world.

In the United States the Baltimore and Ohio Railroad was begun in 1829 and finished between Baltimore and Washington in 1834. The first trains used on this road were drawn by horses. In 1829 the Delaware and Hudson Railroad imported a locomotive from England called the "Stourbridge Lion," but it was too heavy for the early American rails. The first locomotive to be built entirely in America was the "Tom Thumb." It was



THE "STOURBRIDGE LION"



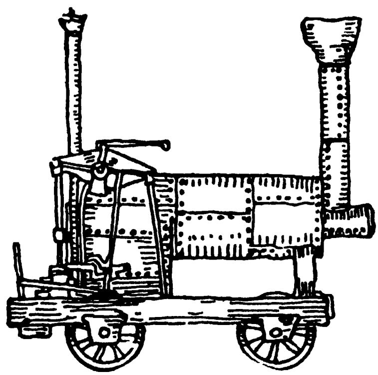
PETER COOPER'S "TOM THUMB"

constructed by Peter Cooper in Baltimore in 1830. The boiler tubes were made of gun-barrels and the whole engine weighed less than one ton.

While all this invention and improvement of railroads and locomotives was going on a similar change was taking place in ships and vessels.

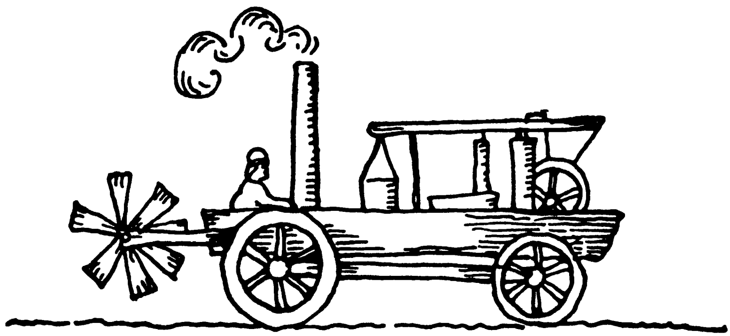
As early as 1785 Oliver Evans of Pennsylvania applied to the legislature of his state for a patent covering both steamboats and steam carriages, but he was told that his ideas were impossible and ridiculous. In 1790 John Fitch built the first steamboat. It ran between Trenton and Philadelphia on the Delaware River and was capable of a speed of seven and one half miles an hour. A few years later William Symington in Scotland built the "Charlotte Dundas," a paddle-wheel steamboat which he ran on the Clyde canal. About the same time Captain John Stevens built a steamboat on the Hudson River. It was not, in fact, until 1807 that Fulton built the "Clermont," which also ran on the Hudson. The "Clermont" was a larger boat than any that had gone before. It made a trip of one hundred and ten miles in twenty-four hours. The first ship to cross the Atlantic using steam power was the "Savannah," and the trip was made in 1819. The "Savannah," to be on the safe side, carried a full rig of sails.

The use of armour plate on warships was first suggested by Captain John Stevens during the War of 1812, but nothing was done with his idea until 1854 when the French government built a small armed vessel for use in the Crimean War. It was so successful that the French built the first real battleship, the "La Gloire," in 1857, and the English followed with the "Warrior" in 1861. The same year Erickson built the American Monitor, called "The cheesebox on a raft."



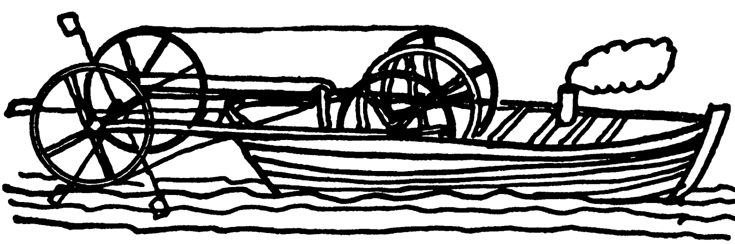
JOHNSON'S LOCOMOTIVE—1831. ONE OF THE FIRST AMERICAN STEAM LOCOMOTIVES

The century that followed the first use of steam power saw not only all these locomotives, steamboats and battleships built, but it also saw the invention of hundreds of other engines and machines, tools and implements, all of which required metal in their making. Hargreave's jenny, Arkwright's frame, Crompton's mule, Cartwright's loom, Newberry's band saw, Faraday's dynamo, Fox's planing machine, a score of nail-making and wire-drawing devices, McCormick's harvester, Franklin's stove, Fairbairn's riveting machine, Cort's roller mill, Nasmyth's hammer, Whitworth's machine tools, Davy's lantern, Mandslay's screw cutter, Robert's lathe, Miller's circular saw, Bentham's veneer mill, Morse's telegraph, the locks of Baron, Chubb, Bramah, Hobbs, and Yale. Parts of some of



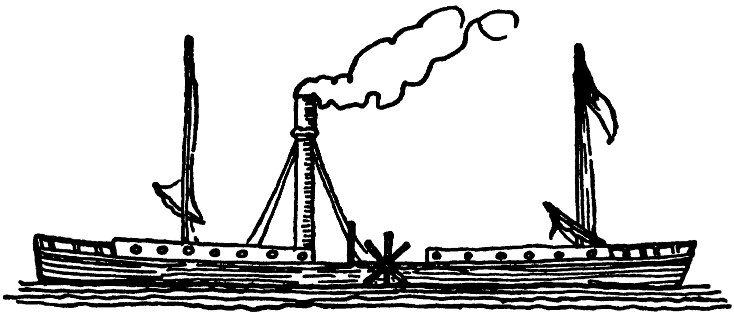
OLIVER EVANS' "AMPHIBION"—1804

these machines and tools were made of wood at first, but iron quite early began to replace wood throughout. The metal used then was either wrought iron or crucible steel. You can see the models of almost all of these machines and some of the original



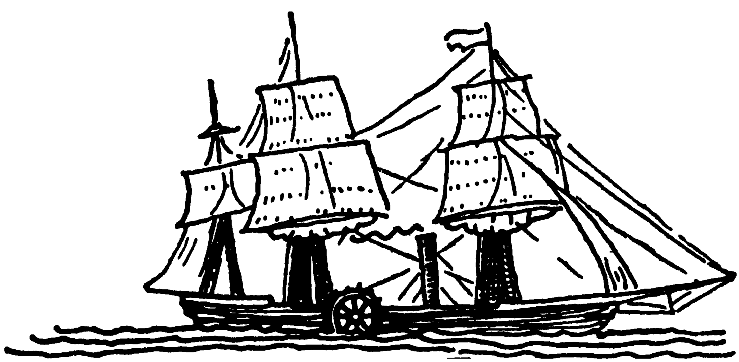
JONATHON HULLS' BOAT. THIS BOAT WAS ONE OF THE FIRST TO BE RUN BY STEAM—IT MAY ACTUALLY HAVE BEEN THE FIRST, BUT LITTLE IS KNOWN ABOUT IT OR ITS INVENTOR

engines in London at the Science Museum, South Kensington. When you do you will marvel at the skill and patience of the smiths who forged their parts. Even the great wrought-iron plates used on the first battleship were hammered into shape. But with Cort's roller mill it became more and more possible to roll out shapes and plates rather than to forge them. Wrought



THE "CLERMONT"—1807

iron, though tough and strong, was not hard enough for all the uses now demanded of metals. Moreover, while the puddling furnace had greatly increased the output of iron, it was too slow



THE STEAMSHIP "SAVANNAH'

a method to keep up with the growing demand for metal which rose more and more as new machines were invented or built.

In the puddling process the quality of the metal produced

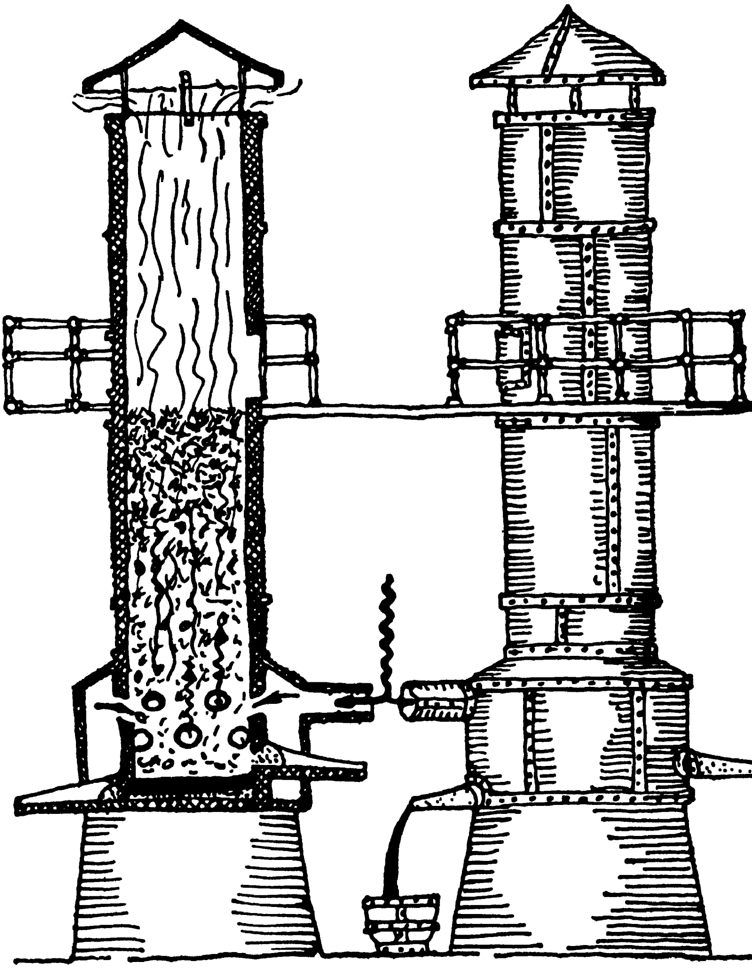
CUPOLA FURNACE

The cupola furnace is used to melt iron so that it may be cast in moulds. The outer shell is made of steel with a hood at the top. It is lined with firebrick. Part way down is the charging floor level with a door which leads into the furnace and through which the charge of fuel, iron and flux is introduced

At the base is the hearth lined with sand. At one side of the base and level with the hearth is the iron notch with a tap hole into the furnace and a spout to lead the molten metal off into ladles

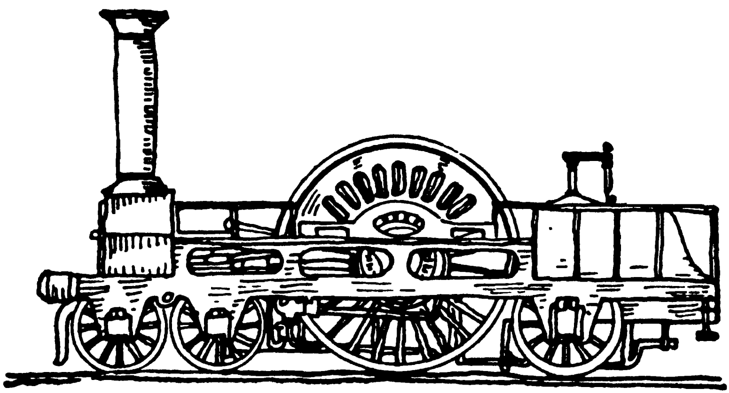
While the iron is being melted and collected on the hearth the tap hole is plugged with a breast made of clay and coke. Just above the pool of molten iron is the cinder notch through which molten slag is drawn off as it floats on the heavier iron. A little higher are the tuyères. These are the openings through which the blast enters the furnace from the wind box and from there passes through the tuyères into the furnace. About 30,000 cubic feet of air are required in the melting of a ton of iron

The common fluxes used are limestone, dolomite, marble chips, oyster shells. All gather impurities and form slag. The fuel may be hard coal or coke. It takes about a ton of average fuel to produce 50 tons of molten iron. The iron charge is made up of pig iron from the blast furnace, to which scrap is usually added



depends entirely on the judgment of the puddler. He must watch his furnace intently, gathering the metal into balls and withdrawing these at exactly the right moment. Such heavy and exhausting labour, kept up for long periods of time, could not help but dull even the best workman's judgment, with the result that he was apt to withdraw the metal too soon or too late and so produce a product of uneven quality.

Only small quantities of wrought iron could be produced in a puddling furnace at a time. In 1784 the average production



FRANCIS TREVITHICK'S "CORNWALL

was about ten tons to each furnace each week and by 1830 this had only risen to two hundred tons.

The demand for more metal and for cheaper and quicker methods of producing it brought into being a number of new methods and these, in time, made possible the mass production of cast iron and steel. Wrought iron was still made in the puddling furnace, but it became less and less important in the field of metals. In recent years a great deal of effort has been made to produce wrought iron by continuous process and it is said that such a process is even now being developed. Should this be true, wrought iron may again assume a position of importance among the products of iron ore. As it is now made, however, wrought iron accounts for less than one per cent of all the iron products made, whereas cast iron and steel, which were almost unknown a century ago, account for all the rest.

Cast iron is completely melted iron which has been poured into moulds. Moulds are usually made in sand although sometimes metal moulds are used. The sand for cast-iron moulding is prepared by grinding it with clay until each particle of sand has been coated with a thin film of clay. Coal dust or powdered charcoal is then added and the mixture kept slightly damp.

Patterns are commonly made of wood in the exact shape of the article to be cast. If the casting to be made is at all complicated the pattern is made in halves. One half is placed face downwards on a steel or wooden tray and enclosed in a boxlike frame called a flask. Sand is then packed into the flask and tamped down tightly until the flask has been filled. The other half of the pattern is now treated in exactly the same way in another flask. The flasks are then turned over and the pattern gently lifted out, leaving in each flask a cavity which represents one half of the article to be cast. The two flasks are called the upper and lower flask, or the "cope" and the "drag." If the casting is very large, intermediate flasks may be used and these are called the "mid parts."

When the pattern has been lifted out a channel intake and a vent are cut through the sand in the upper flask. The cavities in the two flasks now form the exact pattern of the outside of the article to be made. If the casting required any holes or slots through it as in the case of a pipe, or a cylinder block, these are provided for by setting cores into the mould. Coal dust, plumbago, or powdered charcoal is sprinkled into the cavities to make the sand surface slick so that it will not stick to the casting. This done, the upper flask is placed over the lower flask so that the two cavities form together the whole mould of the casting. Molten iron is poured into the intake channel, flowing into every part of the cavity that is not blocked out with a core. As the metal flows in, air is forced out through the vent.

When the mould has been entirely filled with molten metal

MODERN BLAST FURNACE

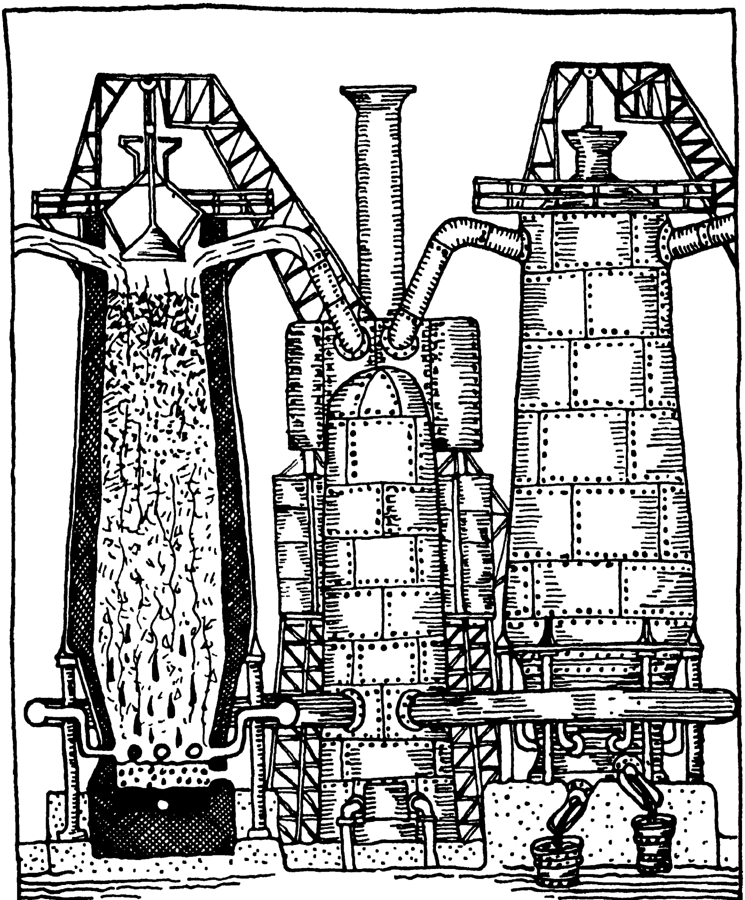
The high hot blast furnace is used to produce pig iron from iron ore. Shown at the right is the inside of the furnace. Coke, limestone and iron ore are let down from the charging floor through the hopper. Just below this and above the charge are the down-comers—large steel pipes through which the exhaust gases, fumes and smoke are led off to the dust catchers and cleaners. The outer shell of the furnace is made of steel lined with fire-brick. In shape the furnace is something like an elongated barrel—the walls being drawn together at the top and base with the greatest swell at a little below mid-height. The inward sloping walls at the bottom are called the boshes. These take up some of the downward pressure of the charge so that it does not bear too heavily over the hearth. This permits the blast to rise freely through the charge

At the base of the furnace is the hearth where the liquid metal settles in a pool and is drawn off through the iron notch which leads the metal through a spout into the ladle

Just above the surface of the molten iron is another tap hole—the cinder notch through which molten slag is removed

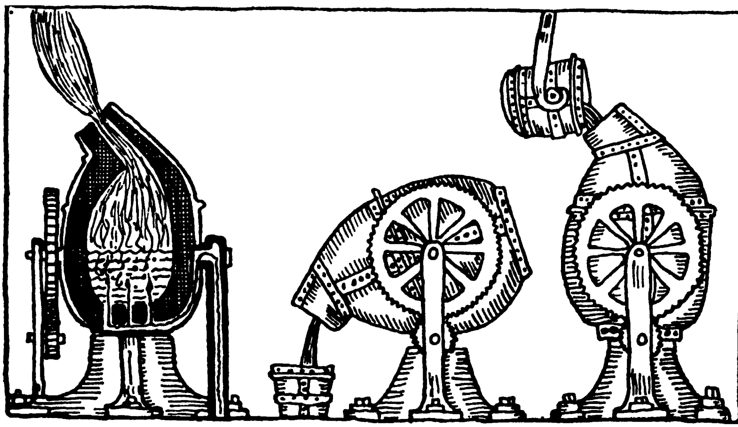
The tuyères are ranged in a row around the furnace above the cinder notch. They are the nozzles through which the blast is fed into the furnace from a large pipe which surrounds it. This pipe is called the bustle pipe and it leads the blast from the stove to the furnace. The air blast is heated in the stove by use of the waste furnace gases

At the right is shown the exterior of the furnace and between the two furnaces is the stove. Above and below the stove are the dust catchers and cleaners with the charge hoist shown in the distance. The temperature in the furnace ranges between 500° F. at the top to 3,632° at the tuyères



the casting is allowed to cool and the sand removed from the flasks. The cores are then pulled out and the casting is ready for machining.

The tools of the founder are simple and few—rammers of different shapes for packing sand; trowels or sleekers used to



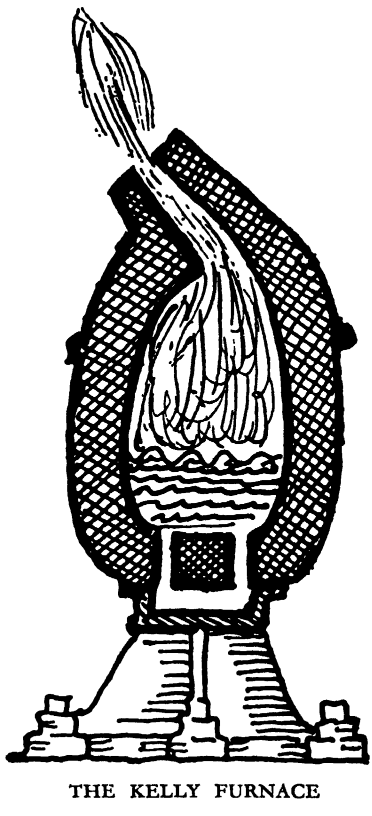
BESSEMER FURNACE

THE BESSEMER FURNACE IS USED TO CONVERT IRON INTO STEEL. MOLTEN IRON IS POURED INTO THE PEAR-SHAPED BODY OF THE FURNACE AND THEN AIR, UNDER GREAT PRESSURE, IS FORCED UPWARD THROUGH THE MOLTEN IRON CAUSING THE GENERATION OF INTENSE HEAT WHICH BURNS AWAY CARBON AND IMPURITIES UNTIL THE MOLTEN MASS HAS BEEN CHANGED TO STEEL. THE FURNACE IS THEN TIPPED TO POUR OUT THE CHARGE AND REFILLED WITH IRON

smooth out any faults in the mould; ladles in which to carry the hot metal from the cupola to the mould; shovels, sieves, rakes and riddles for preparing the sand.

Cast iron was known in the ancient world but it was very rarely made. There are two reasons for this. For one thing it takes a much hotter fire to make molten iron than is required to prepare blooms—a higher heat than could be raised in the low furnaces of the ancient world. Had there been any real need of cast iron at that time I believe the Greek and Roman smiths would have learned to make it. The products of the ancient metalworker's shop, however, were chiefly tools and weapons. Cast iron, being brittle, was not a good metal from which to fashion swords or plough points, nor would it have served for the armour of the Middle Ages.

After the invention of the hot-blast furnace which made possible the rapid and cheap production of pig iron, cast iron came quite quickly into common use, replacing wrought iron in a great many uses. But cast iron was still not the perfect metal sought by the smith. What was needed in an age of machinery, railroads, steamships and great buildings was a metal which would be strong, tough and hard, without being brittle.

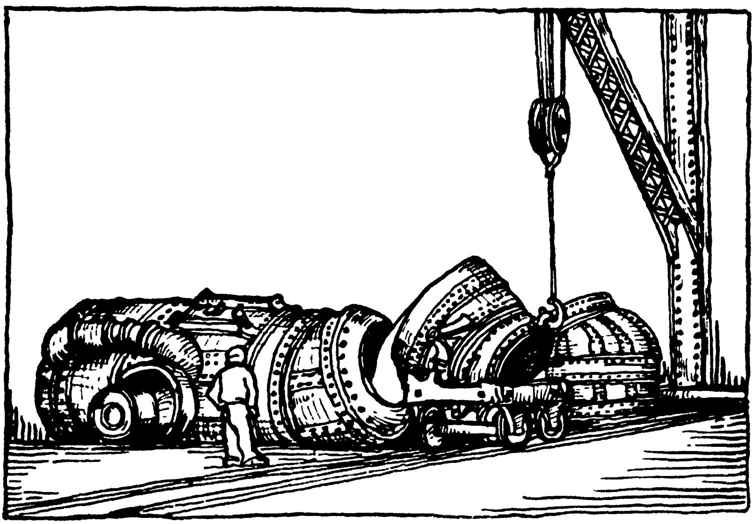

THE KELLY FURNACE

Such a metal was known then. It was steel. But steel produced by cementation or even in crucibles was far too expensive for any common usage.

About the middle of the nineteenth century several new processes for making steel came into being in rapid succession —in England, France and America.

In England in 1856 Sir Henry Bessemer read a paper before The British Association for the Advancement of Science announcing to the world the discovery of a new method for producing steel. This method has been known ever since as the Bessemer process. At first, however, it was a failure in actual practice. Then with Robert Mushet, Bessemer added improvements which made it a success.

About this same time, if not in fact a little earlier, William Kelly invented in America almost identically the same process which Bessemer was developing in England. Unfortunately for

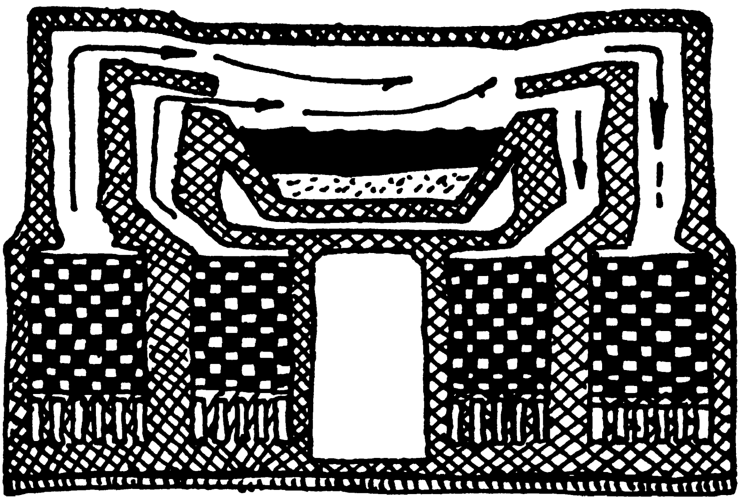


BESSEMER CONVERTERS

Mr. Kelly the United States was not yet ready for steel and he could get little support for his process whereas in England Bessemer was given great honour and wealth. Some years later Kelly secured patents on his process. The Bessemer and Kelly patents were finally combined in the United States so that Kelly eventually received substantial reward for his work.

The Bessemer process used, as a furnace, a large, open-mouthed, pear-shaped crucible. At the base of the crucible there were inlet valves through which air was blown into the crucible under great pressure. The crucible was charged with molten pig iron and the air was forced through the charge, causing great heat to be generated which burned away carbon and other impurities, thus converting the iron into steel.

The modern Bessemer furnace, which is sometimes called



OPEN-HEARTH FURNACE

AS THE HOT GASES LEAVE THE FURNACE THEY PASS THROUGH CHAMBERS FILLED WITH CHECKERED BRICKWORK. THEN, AFTER ABOUT TWENTY MINUTES, THE FLOW OF THE BLAST IS REVERSED AND AIR IS SENT THROUGH THE WHITE-HOT CHECKERWORK AND ON INTO THE FURNACE. AS IT PASSES INTO THE FURNACE IT IS MIXED WITH GAS WHICH BURNS WITH INTENSE HEAT AS IT SWEEPS OVER THE CHARGE

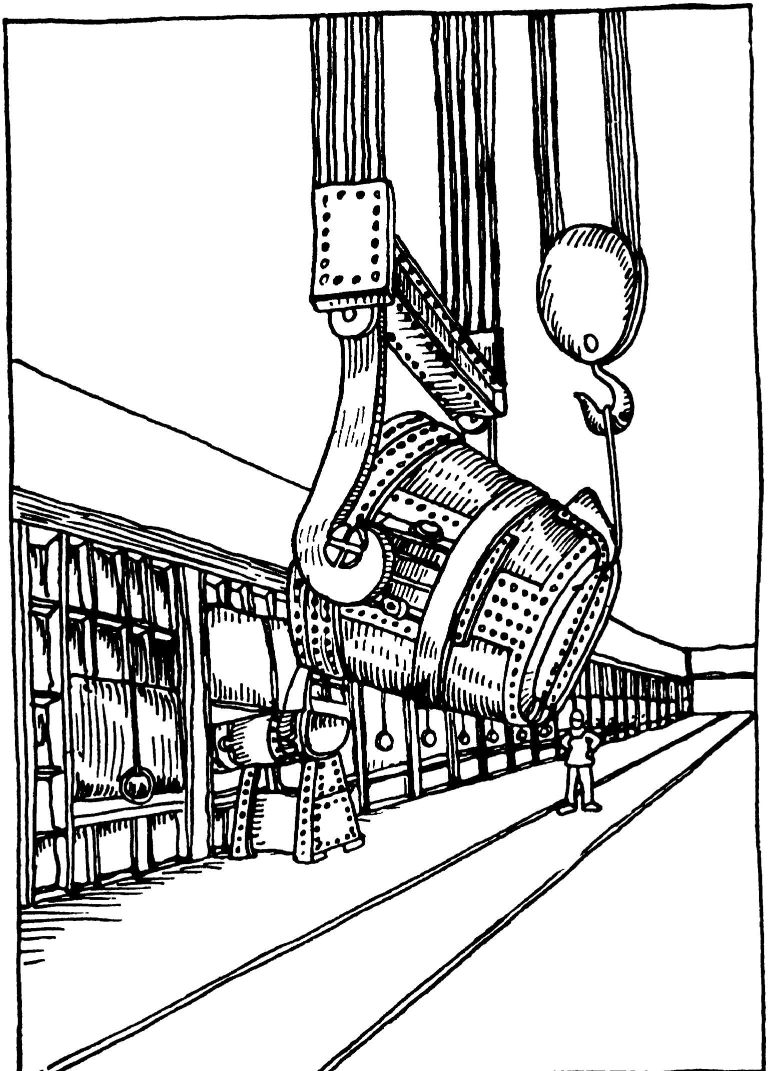
thc Thomas-Gilchrist furnace after the two men who made improvements on the earlier type, is a pear-shaped crucible pivoted so that it may be tilted. The molten pig iron is run in while the furnace is tilted to the horizontal position and the furnace is then turned erect as the blast is sent in.

The steel first made in the Bessemer furnace was called mild steel. It was actually closer to wrought iron than steel. The steel produced in the Bessemer furnace to-day is highly satisfactory for many purposes, but another process—the open-hearth process—is now more generally used.

The open-hearth furnace was invented in England by Sir William Siemens about a year after Bessemer first announced his discovery. In France the Siemen furnace was greatly improved by the Martin brothers.

The purpose of the open-hearth furnace is to convert pig iron as made by the blast furnace into steel. The open-hearth furnace is low, and, as in the reverberatory furnace, heat is deflected from the low arch towards the charge on the shallow hearth. Producer gas, natural gas, oil, tar or pulverized coal is used to furnish the flame. There are two openings at each end of the furnace. Gas and air are admitted at one end and the products of combustion are allowed to escape at the other. The direction of flow of these is reversed every fifteen or twenty minutes. The air and some kinds of gases are always preheated. Below the furnace floor at each end are two chambers called regenerative chambers. They are filled with a checkerwork of firebrick. The hot exhaust gases in passing through these chambers heat the brick. When the direction of flow is reversed these hot bricks serve to heat the ingoing air and gases. The temperature in the furnace rises to 3,100° F., at which heat all the impurities are driven off and consumed, leaving only the amount of carbon required to make steel. The furnace is charged with pig iron, limestone, iron ore and scrap iron. The molten steel and slag are discharged at the rear of the furnace. The lighter slag, floating on the molten steel, is drawn off above; the steel flows through a taphole into a ladle, from which it is poured into moulds to form ingots. Alloys may be added either in the furnace or in the ladle. Usually the open-hearth furnaces are stationary but some are made to tilt so that a part of the charge may be drawn off without removing the whole charge.

In 1722 Reaumur, in France, placed a white iron casting in an



OPEN-HEARTH FURNACE

iron box packed with fine-ground hematite ore and allowed this to be heated slowly and for a long time. Upon removal he found the cast iron had become softer, far less brittle and could be bent slightly without fracture. The iron so made is called malleable cast iron. It is still made in this way in the United States, but here sometimes iron scale and cast-iron filings are used in place of hematite. It takes from twenty-four to two thousand hours of "soaking" in an oven to complete the process; the time depending on the size of the casting. The temperature of the oven is kept at about 3,600° F.

Here, in the order of their development, is a summary of all the different furnaces used to convert iron ore into useful metal. The first group of these furnaces are the *blast furnaces.*

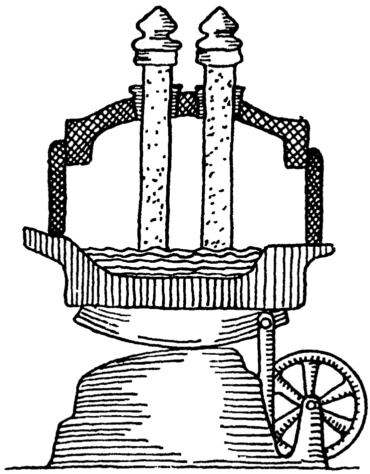
The *primitive blast furnace* was low, being merely a hearth scooped out of the earth and surrounded by a curb of stone or turf. The only blast was that furnished by the natural draft of the flue. The fuel was dried wood and the product coarse, ash-encrusted blooms which were reheated and worked into wrought iron on the anvil.

The *Catalan blast furnace* was developed in prehistoric Spain. It had a stone hearth and stone walls. The flue was extended and the blast was furnished by hand-operated bellows. The fuel was charcoal, and the furnace produced blooms and in rare instances pig iron. Both the blooms and the pig iron were reheated and worked under the hammer. The furnace produced about one hundred and forty pounds of iron in five hours.

The *Roman blast furnace* was similar to the Catalan furnace but was a little higher. The fuel was charcoal and the blast was furnished by large, hand-operated double bellows. The use of fluxes began in Roman times. The product of the Roman furnace was blooms and pig iron. Pig iron, however, was rare.

The *high blast furnace* came into use in Germany in the fourteenth century when water power was first used to operate bellows in producing a strong, continuous blast. The fuel used was charcoal and the height of the furnace was limited to the weight of ore which the charcoal charge could bear. These furnaces produced blooms and cast iron. They produced a better grade of iron and could smelt leaner ores, but the amount of iron produced by each furnace was not great. Dudley, in the seventeenth century, said it was but one hundred pounds per day.

The *high blast furnace* was greatly improved in 1735 when



ELECTRIC FURNACE

ELECTRICITY ENTERS THE FURNACE THROUGH TWO HEAVY ELECTRODES. THE ELECTRIC FURNACE IS VERY EFFICIENT. IT CAN PRODUCE A HIGHER TEMPERATURE THAN ANY OTHER FURNACE TYPE. IT IS TOO EXPENSIVE TO OPERATE FOR ORDINARY USE. THE FURNACE IS MADE SO THAT IT MAY BE TIPPED TO POUR THE MOLTEN METAL INTO LADLES OR MOULDS

Abraham Darby introduced the use of coke as the fuel. Coke furnished a hotter fire and could bear a far heavier load of iron ore than could be borne by charcoal. The blast was improved after the invention of the steam engine when huge steam piston bellows were used to provide a strong, continuous blast. The final improvement was made in 1824 when James Neilson discovered that he could use the waste gases of the blast furnace to heat the blast. Before the coming of the hot blast the weekly output of a furnace in England was about one hundred tons of iron and it required about eight tons of coal to each ton of crude iron produced. After the introduction of the hot blast it required less than three tons of coal to each ton of crude iron.

The modern high blast furnace has some improvements and refinements over those of the seventeenth century. The principal change is the use of greater quantities of scrap iron and steel mixed with raw ore. The modern furnace is larger, higher and more efficient. It has a daily average capacity of one thousand tons of pig iron. Two tons of iron ore, one ton of coke and one third ton of limestone are required for each ton of crude iron produced.

Cast iron was known in the Greek and Roman world, but it was rare and little used until recent modern times. Reaumur's method of annealing cast iron which was discovered in 1722 made cast iron more useful and the hot-blast furnace made its production cheap. It has come to be one of the principal products of iron ore in use to-day.

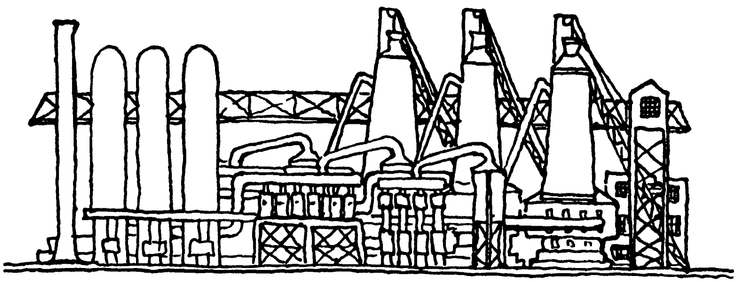
Steel was made in minute quantities in the ancient world from natural ores smelted in sealed clay crucibles. It was also made by the process of cementation—that is, the working of wrought iron in the presence of carbon. Some steel was made in the Middle Ages by melting cast iron with wrought iron in crucibles.

Early in the eighteenth century Hunsman made crucible steel in quantities by remelting steel made by cementation in sealed crucibles. *Blister steel* was made about the same time by heating iron bars packed in pots and surrounded by powdered charcoal.

The great modern development in steelmaking came with the invention of the open-hearth and the Bessemer furnaces. These brought tremendous changes in the world and steel came in less than a century to be the most important metal used by man. One hundred years ago there were but a few furnaces for making steel in all the world. There were steel works in

England, France, Germany, Spain and the United States, but almost none in other countries. To-day every important nation on earth makes steel. In 1937 there was produced by the furnaces of the world more than one hundred and thirty million tons of steel. One third of this is in the United States. Truly ours may be called the Age of Steel.

We have now seen how the useful ores were first mined and



STEEL MILL

smelted and worked into tools and weapons. Copper, bronze, wrought iron, cast iron and steel—these have been the metals of the toolmaker, the armourer and the smith throughout the ages.

Let us now go back through the centuries, stopping at a workshop here and there on the way to see something of how the smiths have worked in every age and what they made in their shops.

IX. The Blacksmith Shop

IN the modern world the metalworker, the toolmaker or the machinist rarely ever works as an individual in a shop of his own. Instead of this he usually works as a member of a team of craftsmen each of whom has a particular part to play and all of whom are required in the making of a single article. Such a team may be made up of a few workers in a small shop or it may include the many thousands of workers employed in a vast factory. Just as the modern craftsman does not work as an individual, neither does he work so much to-day with hand tools as he formerly did.

In modern times fine, close work is done in the machine shop on lathes and milling machines. It is the craft of the machinist rather than that of the smith. Much of the work that was formerly done on the anvil or in the vice is now done by the use of dies and stamping machines. Castings are made in many types of metal—brass, bronze, steel, aluminium, iron and scores of alloys. These castings are finished to very exact dimensions on machines. Sheet metal is now shaped in great presses which turn out everything from armour plate to motor-car bodies, doing in a moment more work than a smith could accomplish at his forge in many days.

The exactness required in modern machine parts is far beyond anything that could ever be attained on an anvil or by filing in a vice. It is not at all uncommon, in aircraft construction, to require parts to fit to one ten thousandths of an inch—an amount which could not even be measured a few years ago, let alone attained.

Toolmaking and machine-shop work are now done by specialists—each man being trained to handle a particular part of the work. There are so many kinds of metal used to-day and modern machines have become so complex that no single worker can be expected to know all the trades of the mechanical world.

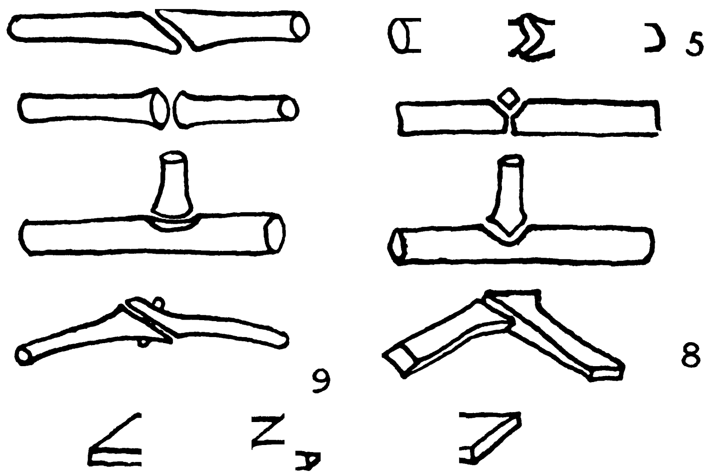
To-day every machine and device known is used to relieve the workman of excess labour and to increase his accuracy and efficiency. New machines are constantly being invented to improve manufacturing processes and to reduce costs.

The number and variety of these machines and the vast range of their uses are so great as to make it impossible to tell you of all of them here. Lathes, shapers, milling machines, stamps, presses, even a modern method of making iron castings by continuous process—these are but a few of the machine types and methods.

Many of these machines seem almost human in their automatic operation. Most of them are actually more exact and faithful in their accuracy than are the human hand and eye.

With these machines, articles are stamped or cast, shaped or rolled into the desired form, leaving the craftsman only the work of finishing and assembling. The assembling of metal parts, whether in buildings or machines, requires that all the separate pieces be fastened together. This may be done by riveting, by welding, or by the use of machine screws or bolts.

Probably the oldest method is that of welding. The heat required for welding two pieces of iron together is very near the melting point of the iron itself, and at that heat small, thin pieces of iron are likely to catch fire and burn, and once burned they are worthless for welding. "Learn to make ready the iron to the exact measure of the heat that you need, for it is no use trying to work on the anvil which has not been properly prepared," says Master Jousse, and he goes on to tell how iron was welded in his own shop. The helper would blow up the fire and then the master would thrust into the blowing charcoal the tips of the pieces to be welded, for only a poor craftsman heats more of the iron than that part on which he is going to work. He watches the fire as it grows hotter and then just when the sparklets begin to leap in a maze of bright arcs, he signs to his helper, who lifts one piece of iron from the fire with his tongs, while the master takes the other. Each of them taps his piece lightly on the anvil to jar loose any scale or ashes that may have stuck to it, and sprinkles the hot iron with dry, clean sand to cut away any grease. Now the helper sets his piece on the anvil and the master places the other piece above it, just where the joint is to be made, and strikes it lightly at first, because a hard blow might cause the pieces to slip out of alignment. Then swiftly under the increasingly hard blows of the hammer the hot iron



WELDED JOINTS

1—SCARF. 2—BUTT. 3—STUD. 4—RIVET. 5—CLEFT OR FORK. 6—V. 7—STUD. 8—SCARF. 9—LAP

knits until each piece becomes a part of the other. The joint is shaped and squared until you can scarcely see where it was made. With light finishing blows, the surface is smoothed until it looks almost as if it had been filed, with only the slightest trace of the hammer marks showing. Among some smiths, and in some periods, it has been the custom to leave heavy hammer marks on the iron surface; in fact, smiths have been known to go to considerable trouble to do this. On grilles and bars where you want an irregular surface, as a decoration, this may be done. But on most iron work, it is but false and cheap craftsmanship. No true artisan ever shows in his work any of the effort that goes into the making of it. Quite the contrary, the finest work of real masters always looks so simple and easily done that you are never aware of the skill and labour by which it was produced.

Welding must be done swiftly and with surely clean and perfectly heated metal, for if you fail to make a joint the first time you may not be able to make one at all.

Some blacksmiths to-day make their joints as Jousse did, even to using charcoal for fuel and sand for cleaning, but most smiths now use coke in their fires and clean their iron with borax or sal ammoniac.

There are several methods of welding that were not invented until modern times. One of these uses the oxyacetylene flame which is made by bringing together two streams of gas, one of oxygen and the other of acetylene. The nozzle that caps the conductor tubes is so designed that the acetylene burns in the oxygen streams with an intense, bright flame which at its heart has a temperature of about seven thousand degrees. The welder plays the flame lightly on the joint and then feeds into it thin pencils of iron which melt almost at once, forming the joint as it cools. This flame is so bright and hot you must wear a mask when you are using it, or even in watching it from near by.

By adjusting the nozzle, the flame can be brought to a fine, sharp point, and in this shape it is used as a blade to cut through the heavy steel of girders, buildings and bridges, or the armour plate of battleships, when these are broken up for scrap. The flame burns a thin straight cut through the hardest kinds of metal almost as easily and quickly as you can saw through a wooden board.

Another modern method of welding, now coming into use even for the erection of the steelwork of skyscrapers, bridges and ships, is that in which electricity is used as the source of heat. Electric welding is of two main types: flash welding and arc welding. The latter, in which a third metal is introduced, as in the oxyacetylene method, is the older. You can see the arc-welding process in use wherever new tracks or sections of track are laid in an electric railway line. The welder squats beside the rails, his eyes and hands carefully shielded, heating the metal at the juncture of two sections with his electric arc and feeding rods of metal into the joints until the space between the sections is tightly filled. This is done to insure a continuous flow of current in the rail.

Flash welding, simpler of the two processes—since it requires no third metal—has been slower to develop. However, at least in the motor-car industry, flash welding has been developed in some cases to the point where the process takes place automatically within a boxlike housing which encloses the parts to be joined, and all the worker needs do is insert the parts in a frame or jig, close a door, start the machine, press buttons as they are uncovered in turn by a moving guard, and remove the welded assembly of parts when the process is completed. This kind of welding is done by causing a current of electricity to pass through the metal where the joint is to be made. Because the current is blocked a little here, the metal becomes extremely hot, so hot, in fact, that the two pieces of iron begin to melt a little on the surface where they touch and so bind together.

The joining of two pieces of metal together by riveting is almost as old as welding. Riveting was known and used on sheet metal even as early as the Bronze Age, but it did not come to be a fine and skilled art until the Middle Ages, when it was used to fasten together the hundreds of parts that then went into making armour for horses and men. In the modern world of steel ships and buildings riveting is used more often than welding. All the steel parts of buildings and ships are cut to exact size and shape at the mill and they are there punched for rivet holes. These parts, whether the columns or beams of buildings or the struts and plates of a ship, must fit together so that the rivet holes at the joints exactly line up.

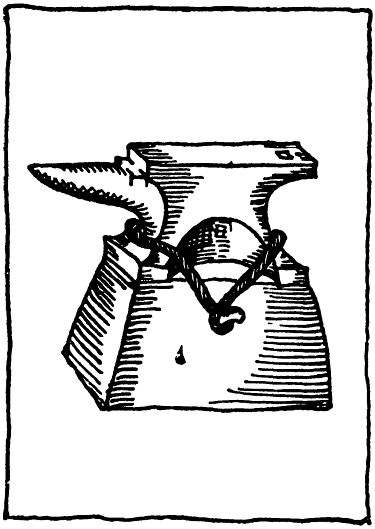
When the steel members which are to form the structural frame of a building arrive at the site they are first sorted and placed at convenient points where the hoisting engine can pick them up. The sorter, who does this, knows where each piece of steel is to go on the building by marks which have been painted on it at the shop. The actual handling of the steel is done by the heavy gang.

As the time comes for each particular piece of steel to go up, the rigger loops and ties a cable around it or clips it in the jaws of a dog, so that it is held rigidly in place as it is raised. The raising of the steel is done by the hoisting engineer who operates a derrick. So skilled are these hoisting engineers that they can lift an enormous weight of steel and lay it right in the hands of the erecting crew even though these workers may be far up on the steel skeleton; and what is almost more amazing is how gently and accurately they do this, being guided by the hand or whistle signals from a workman far above them. These signals are made by a bridgeman, who, with the bolter-up, eases the steel into place and aligns it by driving a drift pin through the rivet holes. This holds the steel steady until the bolter-up can clip it to the frame with temporary bolts. This work of bolting members into place can be done faster than the riveting crew can follow. The temporarily bolted frame is quite strong enough to carry itself and withstand the force of the wind, but it must not be allowed to get too far ahead of the riveting crew. At least one frightful collapse of a steel frame once occurred because the temporary bolting work had been pushed too far ahead of the riveting crew.

The riveting crew knits the structural steel frame together. Rivets are round, dome-headed pins with a shank long enough to pass clear through the two steel members that are to be fastened with enough shank still projecting to form another head.

A heater at a forge heats the rivets to a red-white heat and picking them up in a pair of tongs tosses them to the catcher. As needed, the rivet boy brings a new supply of cold rivets to the forge. The catcher, or rivet-sticker, takes out the temporary bolts one by one and replaces them with the hot rivet. Beside him stands a bucker-up or dolly-man who holds a heavy cup-shaped tool against the rivet head while the riveter hammers down the projecting shank tip into a round, dome-shaped head.

Sometimes the forge may be quite far above or below where the riveting crew is working. It is then you see the smooth grace and perfect timing of the steel workers as the sparkling rivet sails through the air and is caught in a cup on the riveter's hand—a cup little larger than his hand! When you think that this crew is working on footholds so narrow that the slightest mis-step may mean a plunge of thirty stories or more you get some notion of what a sense of balance and rhythm these workers have.



ANVIL FASTENED ON BLOCK

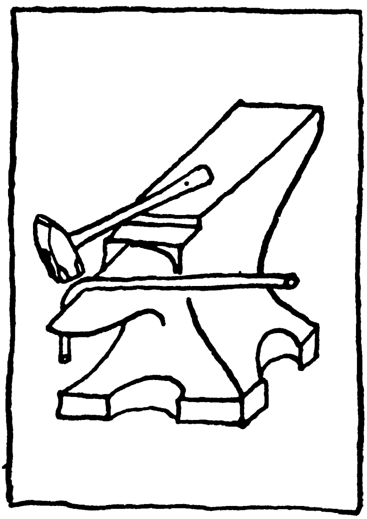
Riveting crews almost always stick together, going from job to job as a team. They know each other perfectly.

When you really know what is going on, there is almost no sight in the world so thrilling as a crew of steel erectors at work, so perfect is their team work. While you watch a building grow and take form before your eyes, you are scarcely aware of the intense, swift skill that goes into such labour.

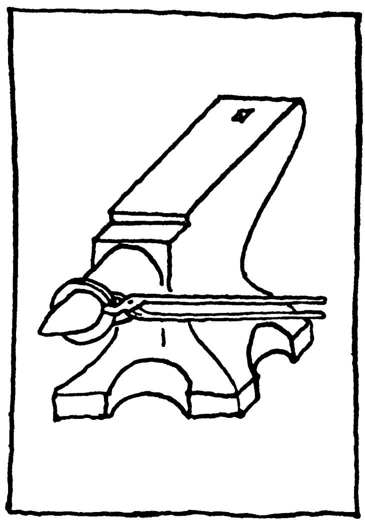
While the modern toolmaker, machine operator and steel erector work as part of a team of craftsmen, the blacksmith of but a few years ago did not.

We would find him alone in his shop or aided by a few helpers, surrounded by the many tools of his trade and engaged in a great variety of tasks.

Here are the blacksmith shop and the tools of the trade. First there are the fire tools—forge and blower, shovel, rake, hook, poker and sprinkling can. The forge itself is an open hearth with a hood overhead to lead off the smoke and fumes. The fire may be made of soft coal, gas, coke or charcoal. Coke or charcoal is best. The blast may be furnished by a pair of bellows or



USING THE ANVIL HORN TO BEND A ROD

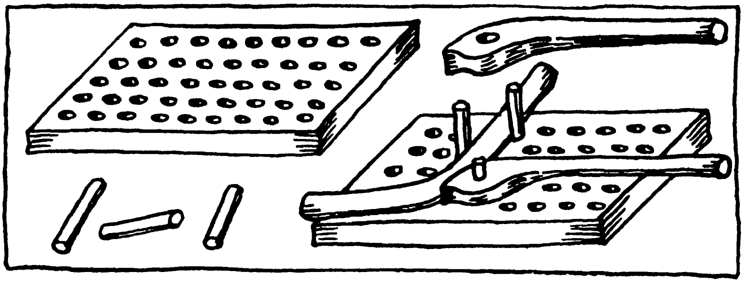


USING THE ANVIL HORN TO TURN A RING

by a fan. Near at hand in a trough is water for use in cooling iron or in dampening the fire. Near by, too, is a tempering bath of oil.

The blacksmith's workbench is the anvil. It weighs about two hundred pounds and is made of wrought iron faced with steel. The clean bell-like ring you hear when an anvil is struck is the proof mark of its quality. The anvil is shaped to serve every need of the smith—it acts as the other half of every hammer blow. The face is straight and level lengthwise but slightly crowned across. It is made in this way so that the face edge will not mark iron as it is worked across the anvil. This crown also permits a hard blow to be struck without stinging the hand. At one end of the anvil is the horn. The horn is round and tapers to a point. It is used in working curves and rounded parts. At the rear of the face there are two holes. One is square and is called the hardy hole. It receives the shank of anvil tools and holds them rigidly in place. The other hole is smaller and round. It is the pritchel hole into which the point of a punch may pass when the holes are punched through iron. The anvil tools are of two kinds—cutting and shaping tools. All have square shanks that fit into the hardy hole. The cutters are like chisels turned upwards. Iron to be cut is laid across this blade and tapped from above. Some cutters are fairly blunt—these are for cold work; others are sharp. Some of the sharp-bladed anvil tools are bevelled on both sides, others are bevelled on one face and straight on the other. These sharp-bladed cutting tools are for use on hot iron. Cutting is also done with cold or hot chisels either held in the hand or with tongs. Sometimes a cutting set is used, the set being made like a chisel with a haft. There are hot and cold sets, curve-faced sets, gouges and fullers. The fuller is like a very dull chisel with a rounded nose. It is sometimes used alone and sometimes it is used with an anvil tool, called the bottom fuller. The bottom fuller is a round-nosed blade turned upwards. Its shank is set in the hardy hole. The fuller is used to spread iron and to work in narrow places or near edges. It is used to draw iron out from a bar and to flatten it roughly. Still another cutter is made of a plate of steel pierced with holes of different sizes and shapes through which bars or rods are thrust to be cut off flush with the plate face by use of the straight-bladed chisel.

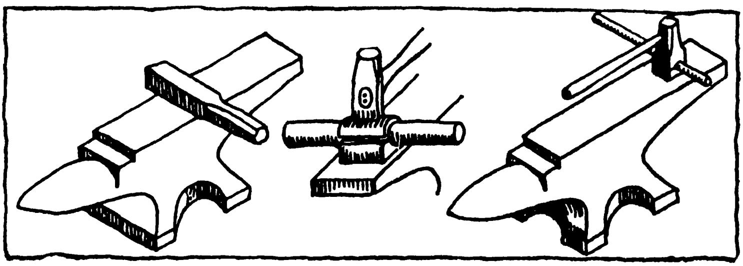
The shaping tools are usually made in two parts. There is a bottom half with a square shank to fit the hardy hole and a top half which fits over the bottom mould. Hot iron is placed between these two parts and the hammer blow struck against the butt of the upper tool. The two parts then act together as a mould to shape the iron. Most of these shaping tools are called swages. Here is a pair, each side of which is a half-round groove. A rod or bar placed between these could be worked round and smooth. There are swages for forming bolt heads —squares and hexagons. The V-shaped swage makes square



BENDING JIG

corners and square bolt heads. The two half hexagons make the common hexagonal bolt head.

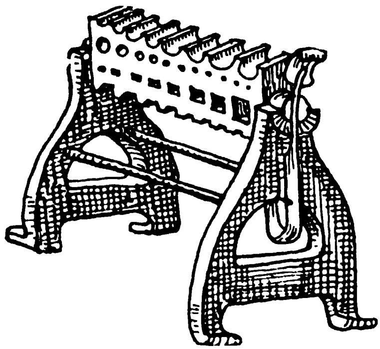
The smith needs so many kinds and shapes of swage that he usually has a swage block in the shop. This is a thick heavy slab



ANVIL TOOLS AND ANVILS

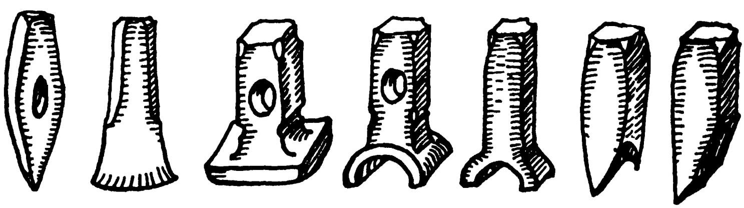
of steel which is pierced by holes of many sizes and shapes. These are used in bending and cutting rods and bars. The edges of the swage block are cut with many forms—half rounds of different sizes, large and small Vs, half hexagons, and the like. The swage block may be used flat on the anvil or set on edge, or it may have a base of its own. You may see in the drawings a number of swages and other anvil tools, shaping tools for bolts, links, joints, tees and other special forms.

The hammer, of all the smith's tools, is the one he most uses.



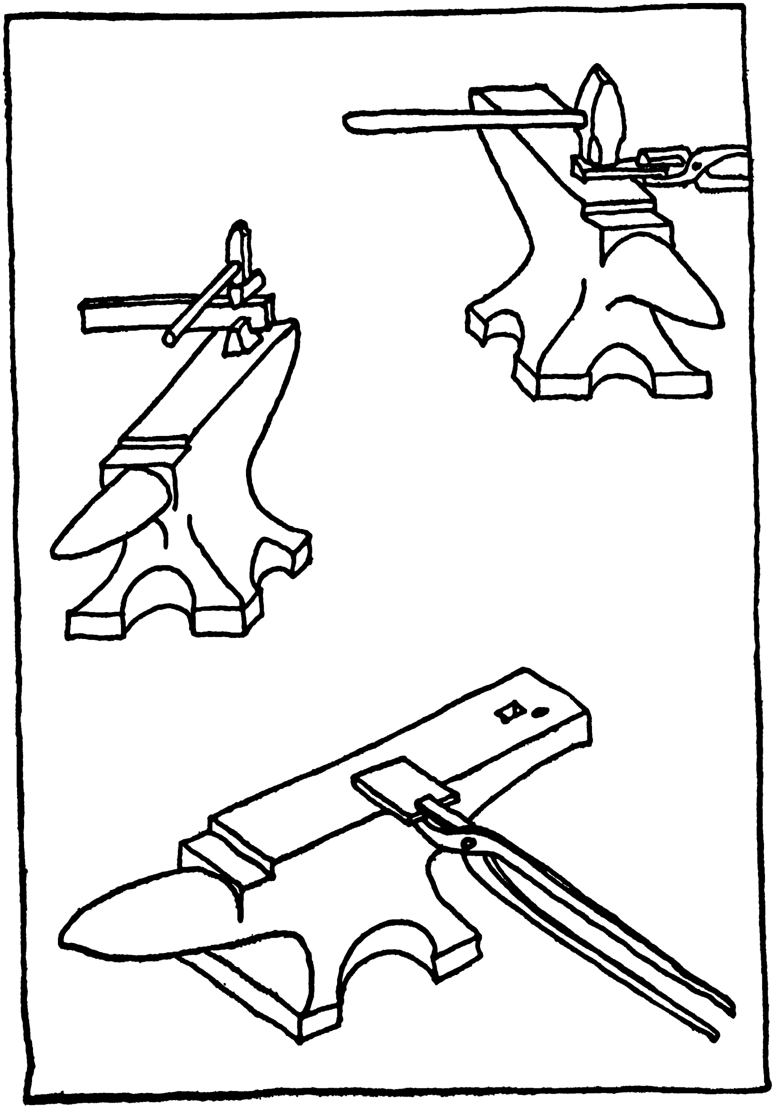
BLACKSMITH'S SWAGE

It is as much a part of his hand as are his fingers. Hammers come in a variety of sizes, weights and kinds. The hand hammer is the master smith's own particular tool. It has a handle about sixteen inches long and weighs about two pounds.



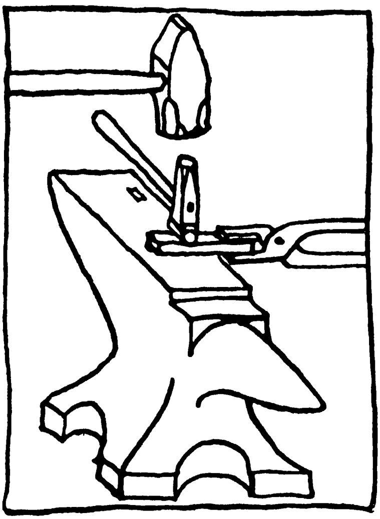
ANVIL TOOLS

The hand sledge and the swing sledge are the helper's tools. The hand sledge weighs from six to eight pounds; it has a handle about thirty inches long and it is swung from about shoulder height. The swing sledge weighs up to twenty pounds, has a handle slightly longer than the hand sledge and



it strikes with a full two-arm swing. All hammer faces are slightly rounded and the edges are carefully turned so that they will not leave hammer marks on the iron.

The rear of the hammer head may be the ball peen, the cross peen or the straight peen. The peen face is used to stretch or spread metal. The ball works out hollow curves, warping the iron in all directions at the same time. The cross peen spreads the iron lengthwise. The straight peen spreads the metal crosswise. Each of them does much the same work as the fuller.

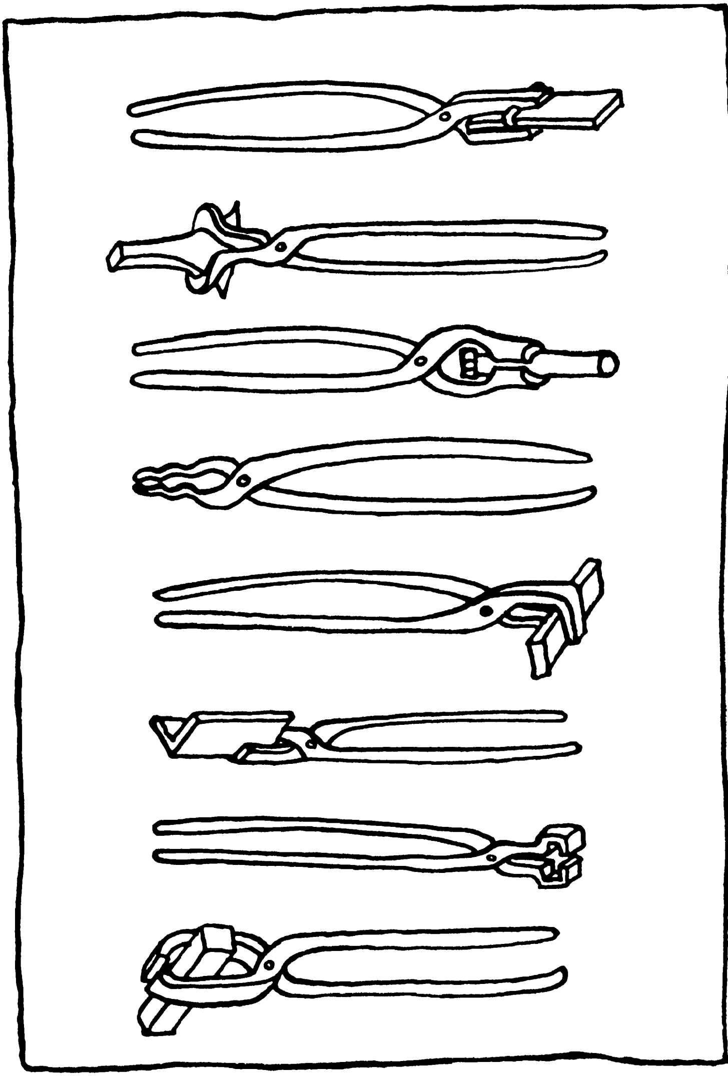


When the smith wants to smooth a joint or a surface he uses the square-set hammer on the flatter. The flatter is a set with a smooth, level face with only the edges rounded. It is held against the iron and struck with the hammer or sledge, smoothing and flattening the iron to a true, level and unmarked surface.

Sometimes when the smith is working on a long bar or rod he may hold the cold end in his hand, but more often he must grip the piece close to the heated end and for this purpose he has a number of tongs.

The head of the tongs is called the jaws; the handles, the reins, and the link which clips them together, the coupler. Tongs come in a great variety of shapes and with special jaws or bits for special purposes. There are tongs for holding rivets, tongs for bolts, pincer tongs, square-clip tongs, duck-bill tongs, angle tongs, link tongs, pipe tongs and pliers.

To measure his work the smith has the steel tape, the square,



TONGS

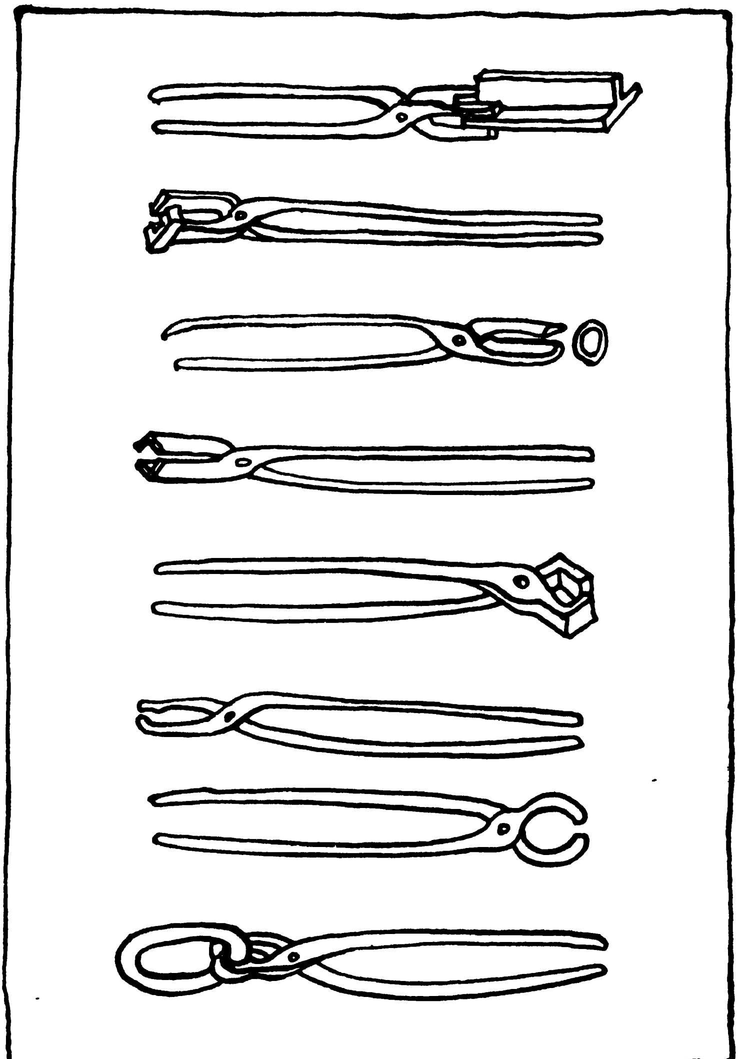
the bevel square, the metal rule, the T square, single and double callipers and the compass.

To make threads, the smith uses the tap and the die. The tap is a tapered rod having threads cut along its shank. Grooves are cut lengthwise through these threads to allow metal slivers to pass upward out of the hole as threads are cut. The tap is used for threads cut on the inside of a hole or pipe. The die, on the other hand, cuts outside threads. The die is made in two halves. It is clamped around a rod or pipe which is to be threaded. This clamping is done with the stock which has a recess into which the die fits and a set screw which forces the two jaws of the die together. There must be a separate tap and die for every different standard size of rod or pipe.

For drilling holes there are both power and hand drills each provided with bit points of every kind and size. Cutting is sometimes done with a power hack saw, or the hand hack saw may be used. A good shop would have a steam hammer for heavy work. Frequently in shops where small and delicate work is done there are a number of miniature anvils. These are set in the hardy hole of the great anvil and are used for close work or on small pieces. Besides these common tools, some smiths use a number of side sets and radius tools, but these are not so usual.

There are files in the shop—coarse and fine, rasps and smooths, flats, rounds and rattails. These are used with the metal firmly held in the vice. The art of filing is still important to the smith but not so important to-day as it was in former times.

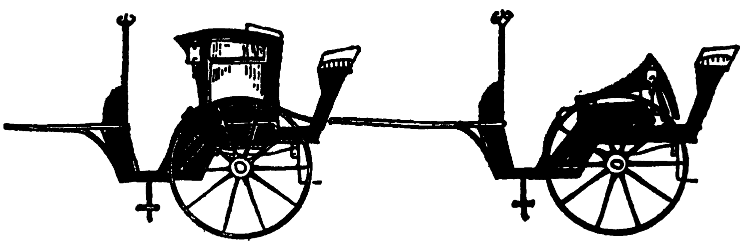
We have already seen how the coming of steam power and the use of steam engines so greatly increased the field of the metal craftsmen's work. About a century after Newcomen and Watt, two more power sources were discovered—electricity and the internal-combustion engine. Steam power had been useful in operating powerful engines, to pump water, drive locomotives, propel ships and run the machinery of mills. But the steam engine had one disadvantage: It was large and heavy.



TONGS

The electric motor and the petrol engine on the other hand could be made small, compact and light—so just as the steam engine made possible the railroad train and the steamship, so the electric motor and the internal-combustion engine brought into being the motor-car and the aeroplane.

The first dynamos and electric motors were made in laboratories by scientists, and the invention and early improvement of the petrol motor were the work of scientists and engineers. But as the motor-car and the tramcar came more and more into use there was need of mechanics to build them, and these mechanics were drawn from the blacksmith shop and the forge.



HANSOM CAB—CLOSED AND OPEN

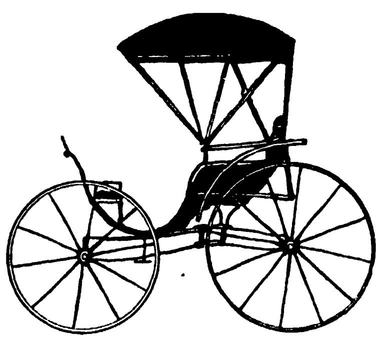
It was in a combination blacksmith shop and machine shop that the first motor-car and aeroplane were made.

While the modern world of machines and power has gone far beyond the dream of the smith of other times, the blacksmith shop has still an important part to play. There is a blacksmith shop on every ocean liner, in every shipyard and railroad repair depot. There could be no skyscrapers built without blacksmiths' work; no oil wells drilled. The blacksmith is still the pioneer of the metal trades. A few years ago he was the very heart and centre from which the great machine world grew.

In your grandfather's time the blacksmith shod horses, made plough points, built waggons and carriages, and made all kinds of tools and implements. He could turn his hand to making guns or clocks or locks and keys. Here is the kind of shop he worked in and here are some of the things he made.

In a shop of fifty years ago you would find, besides all the modern smithing tools, a lathe, a bolt cutter, a screw-making machine, a power hammer and a great many woodworking tools. For the blacksmiths of that day were wheelwrights, wainwrights, carriage builders as well as horseshoers and toolmakers. You have but to look at the graceful and sturdy carts and sleighs, waggons and carriages of a bygone day to know something of the skill and cunning of the smiths who made them.

These vehicles were as lightly made as could be to save the strength of the horses that pulled them, but they were strongly built as well. There were no such smooth, straight highways then as we know now. Wheels ran in ruts, often deep and frozen, where a sudden wrench might shatter the spokes or twist the rims of wheels less well made. The smith had to know wood as well as iron.

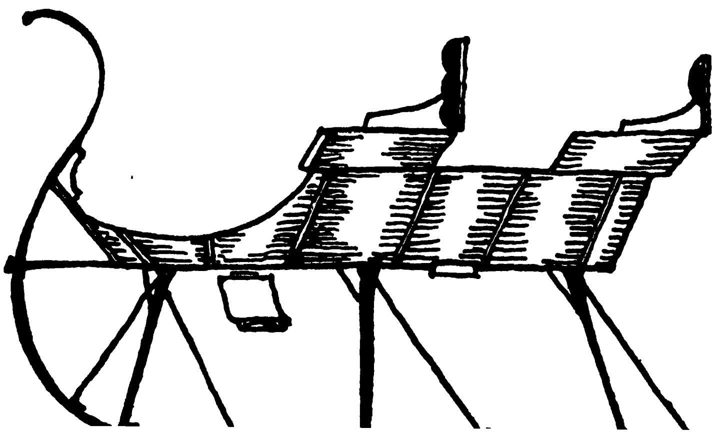


PHAETON

The styles in carriages changed in our grandfathers' day almost as often as do the styles in motor-cars to-day. The smith and his fellow-artisans, the carriage builder and the cartwright, had to be able to build any of the common kinds of vehicle as well as those of special design made to suit the fancies of their customers. There were buggies, road carts, victorias and cabs—the English surrey, the French phaeton, the Russian droshky and the Irish car. There were sleighs and sledges and a whole range of carts and waggons—delivery waggons and drays that carried the merchants' goods—the carts and wains that brought the farmers' crops to market. Part blacksmith's work, part carpentry, each called for the best of their builder's art.

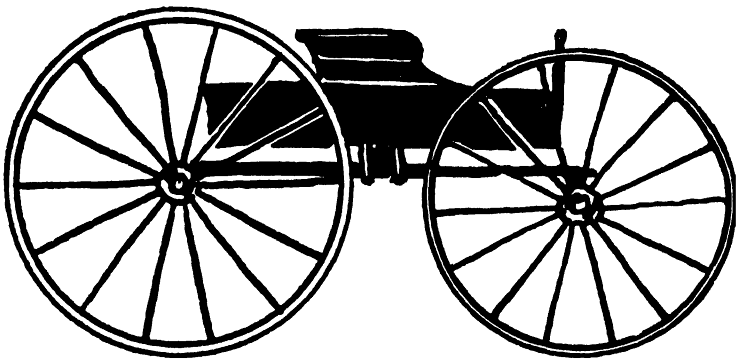
Not all blacksmiths of fifty years ago built carriages and waggons. Coach work was a highly skilled craft in itself. But if all smiths did not make vehicles, almost every smith was called upon to repair them, and especially to make new wheels or to replace worn out tyres.

A waggon-wheel may be divided into three parts: the hub, the spokes and the rim. The hub was turned on a lathe from



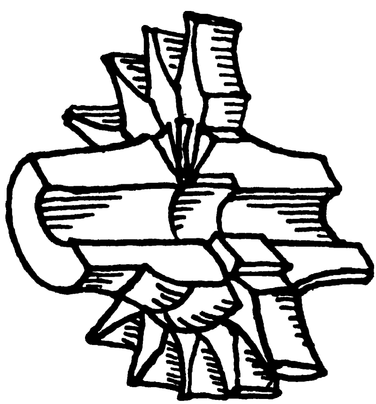
SLEIGH

well-seasoned wood—gum, hickory or ash. It was then bored through the centre with a hub auger to receive the axle-box which served as the axle bearing. Around the waist of the hub a series of mortises were cut to receive the spoke ends. These mortises were spaced far enough apart so that they did not weaken the hub too much. At the hub end of the spoke a square-faced tenon was cut so that it would fit as tightly as possible into the hub mortises without splitting the hub itself. It was driven in until the shoulder of the spoke met the hub. Sometimes this was done by hand. In better shops it was done by a spoke-driving machine. At the rim end the spoke was usually round and the tenon made to fit snugly into a mortise in the rim. The number of spokes used in different types of wheel varied greatly. In the drawing of the buggy each wheel is shown with fourteen spokes; the phaeton wheels (see p. 181)



BUGGY

had sixteen, and there were fewer in the wheels of the surrey and the cab. In some of the older carts and waggons these were sometimes as few as four. However many spokes were used

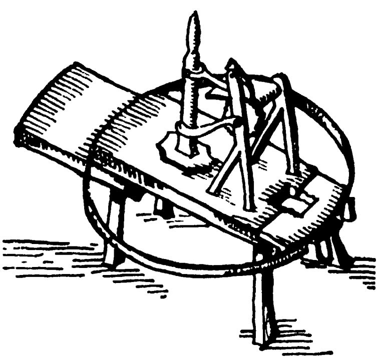


HUB

their number was almost always even so that each spoke might be set exactly opposite another and in a straight line with it. Spokes might have almost any shape in section—

round, oval or octagonal. Whatever its shape each spoke must be able to carry the entire load put on the waggon. A hickory spoke one half inch in diameter would carry a load of seven hundred and fifty pounds, while a hickory spoke no larger around than your wrist would carry four or five tons.

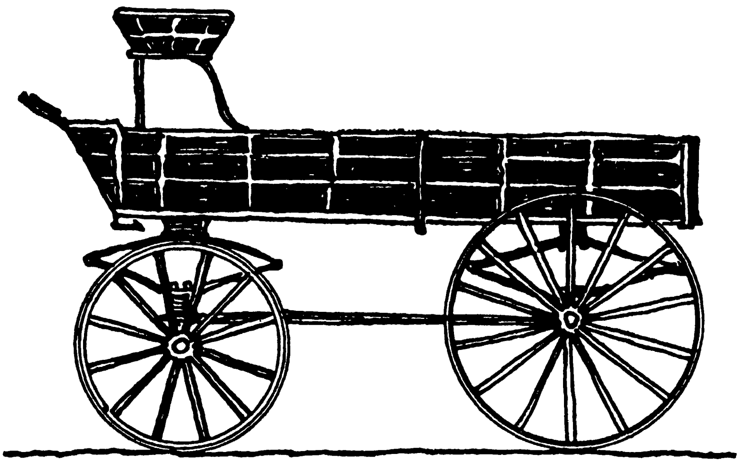
The rim was made up of the felloes and the tyres. Felloes were circular segments of wood usually made by bending a straight piece of hickory or ash to the curve required. Some woods may be bent into curves by first steaming them for a period of time and then forming them in moulds or on frames. Ash and hickory were particularly suitable because they not only bent readily after steaming but once bent they held their new shape and remained strong and tough. Where the felloes joined end to end they were sometimes jointed but more often they were held together by a clamp on the inner side of the rim.



TYRE SHRINKING DEVICE

With the spokes driven into the hub and the felloes set in place the next step was to put on the tyre. Tyres served at once to bind the whole wheel rigidly together and to provide a hard, tough-wearing surface on which the wheel might run. The smith made his tyres of flat iron strips welded to form a circle. Frequently a smith made up tyres of various sizes and weight in advance, and as these might be slightly too large or too small to fit a particular rim he had devices for stretching or reducing them. When a tyre was ready to be put on it was heated all over until it had swelled enough so that it would just slip over the rim. It was then allowed to cool. As it cooled it shrank, drawing itself tighter and tighter around the outer curve of the rim, pulling felloes, spokes and hub into a strong, rigid wheel. Sometimes the felloes were heated in a bath of hot oil which was supposed to make them more durable. Rivets were sometimes driven through the tyre to clamp it to the rim, but this was neither always necessary nor always done. Once a tyre had been properly made and set it should stay in place until it wore out; only an ill-set tyre ever came loose from the rim.

All this work of making hubs, spokes, rims and tyres required equipment—hub augers, spokeshaves, mortise cutters,

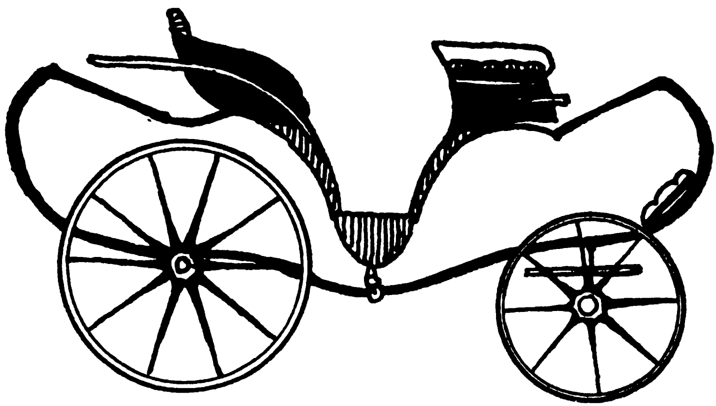


FARM WAGGON

spoke drivers, felloe shapers, heating and cooling devices for tyres, stretchers and upsetters. Wheelmaking and tyre changing were important parts of the smith's work.

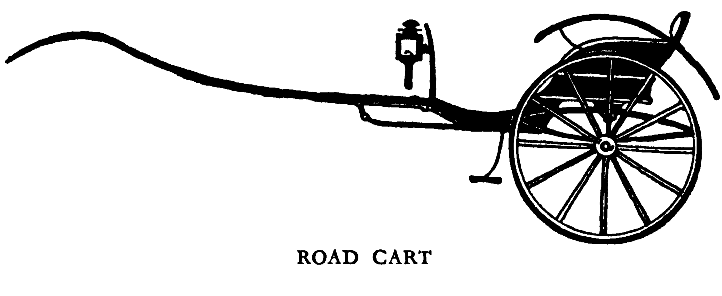
If you have ever ridden in a waggon which had no springs or in which a spring had broken you will understand why spring making and repairing were also important parts of the smith's work. Any piece of tempered steel will spring back to its original shape after bending provided it has not been bent too far or kept bent too long. Its ability to do this is called its elasticity. All springs, whatever their shape, are made on this principle—the spiral spring in your watch, the coil spring in the mattress on your bed and the leaf springs of motor-cars.

On the carriages of the nineteenth century, the leaf springs



RUSSIAN DROSHKY

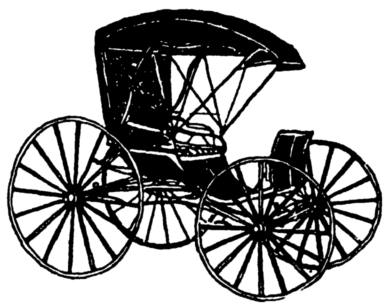
were the type most commonly used. They were made up of leaf on leaf of curved steel, each leaf being a little shorter and more deeply curved than the one next below it. The leaves



ROAD CART

touched only at their tips and they were held together by shackles. On the early carriages and waggons the springs were fairly simple, sometimes being but single leaves bent into a curve which would support the body and take up the shock of bumps. On some ancient carriages and coaches the bodies were carried in slings made of heavy leather straps which connected at their ends with springs.

The object of all carriage springs is to take up the shock of bumps and to distribute this shock so that the rider does not feel it. The heavy coaches with their leather straps and single springs must have been fairly rough to the riders, especially on the rutted roads of coaching days. In the days of our grandfathers the art of making springs had advanced until the carriages and waggons of that time were supported on a whole network of springs called the "gear." Some acted lengthwise of the carriage—some acted crosswise. These springs were so set and attached that any bump against a wheel would be smoothed out in passing through the springs to the carriage body. Only a very severe shock would jar the rider.

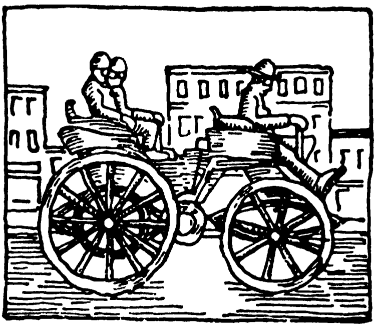


PHAETON

Whatever their kind spring making called for the highest skill both in shaping the spring and in tempering the metal from which it was made. Furthermore, almost all springs worked in pairs, and each spring of a pair must be exactly like the other, neither stronger nor more rigid, as a difference between the two would cause the body to tip.

When we look back at the workmanship and knowledge that were daily demanded of the smith we begin to realize what superb craftsmen these folk were. Not only did they make wheels and springs, set tyres and repair carriages and waggons, but they shod the horses, repaired the farmer's plough and reaper, and made tools for the carpenter and mason and the tools of a score of other crafts. The smith of fifty years ago stood at the cross-road leading to the modern world. His children have become the toolmakers, the die cutters, the machinists of to-day. And while the modern mechanic's work is more difficult and exacting in some ways than was that of the smith, no ordinary mechanic of to-day has to have the extraordinary range of skill and knowledge that went into the daily tasks of the smiths.

If we go back still another fifty years to about 1830 and look into a blacksmith shop of this earlier day we will find the smith at work at still other tasks. The smith of that time would probably not have done so much carriage work as later smiths, although he, too, would have done some wheelmaking and waggon building. His chief work, however, would have been the making of tools and implements, pots and kettles, ploughs and hayforks, sickles and scythes, axes and guns. These were the things needed in the frontier world, for in new worlds it is the farmer's tools and the hunter's arms that are the first necessities. No one had time then to send back to the old world for such articles as these—the village smith must make and mend them as best he could.



DAIMLER—GERMANY 1886

Let us watch such a smith make an axe. Simple as it is, it calls for a whole range of skills. To make an axe a smith must shape the head, temper the iron, make and shape the steel of the cutting edge, sharpen and polish the blade and fashion the haft.

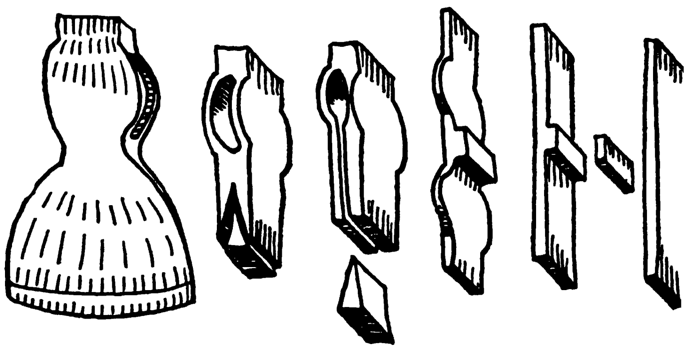
In this blacksmith shop of 1830, the iron stock is made up of bar iron bought from some near-by furnace. By this time there were furnaces in every state from Massachusetts to South Carolina and as far west as Kentucky and Ohio, and these had turned out in that year one hundred and sixty-five thousand tons of pig iron and ninety-six thousand tons of bar iron. But if iron was plentiful steel was not. The Bessemer and open-hearth processes had not been developed in 1830. They were not, in fact, to come until more than twenty-five years later. In 1830 there were but fourteen steel furnaces in the United States, and these altogether produced but sixteen hundred tons of steel a year. This steel was made in crucibles or in small furnaces; it was scarce and very costly.

For his first step towards making an axe our smith takes a piece of bar iron from his stock and works it over the anvil into a flat plate one half inch thick, four inches wide, and about eight inches long. The plate made, our smith heats the two ends in the forge and upsets these on the anvil until each has become about twice its original thickness. The centre of the plate is now heated and upset in turn until it is also about one inch thick. This centre band is to form the poll and the thickened edges will be worked into lips to hold the blade. The smith now places a mandrel across the raised centre band and turns the two wings around it until the edges almost meet. The shape of the mandrel is the shape of the shaft hole and when the two wings finally meet the shaft hole will be formed. Now the smith dresses the wing tips until they are curved and brought to their feather edges still kept a little apart. The poll is then shaped, squared, and made true on the shoulder of the anvil. The axehead is now ready for the cutting edge.

Our smith knows as much about tempering iron and the colours of temper as we do to-day. He also knows how to make steel from wrought iron by working the metal on the anvil in the presence of carbon dust. For a strong, lasting, sharp-bladed axe our smith will make his cutting edge of a small, thin piece of steel set between the lips left open on the axehead.

He may have a small stock of steel at hand, but if he does not he knows how to make what he needs. He can do this in one of two ways. He may place a bar of iron, packed in charcoal, in a closed retort and heat this to red heat for several days. During these days the iron lies in a bath of red-hot carbon, but as the retort is closed and no air can enter it does not burn. Instead the carbon enters gradually into the iron—about one eighth of an inch each day—until the whole bar has become steel. This is a slow and costly way of making steel, but the steel so made is superb.

For greater quantities of steel our smith packs a small furnace with alternate layers of bar iron and powdered charcoal. Flues lead the blast through the furnace and the whole is covered with clay to prevent any air reaching the iron and carbon. The



MAKING AN AXEHEAD

THIS IS ANOTHER WAY TO MAKE AN AXEHEAD. THE FLAT BAR IS NOT UPSET AT THE ENDS BUT ONLY IN THE CENTRE, AND A THIN STEEL STRIP IS WELDED HERE TO FORM THE POLL. THE TWO WINGS ARE THEN BROUGHT TOGETHER AND THE STEEL FOR THE BIT INSERTED

fire burns for eight to ten days, keeping the contents at red heat. Test bars are withdrawn from time to time to check the progress of the process. The steel so made is called blister steel.

However his steel is made, our smith now works a bar of it into a thin sharp wedge which he inserts between the lips of the axehead and, bringing both parts to welding heat, he fastens it in place. The cutting edge is then dressed and tempered—the tempering being done at the point of brownishpurple colour. The tempered blade is now sharpened—first by use of freestone and then polished with wood, leather and crocus.

The axehead finished, the smith now makes the haft. For this he selects a billet of well-seasoned, second-growth white hickory and shapes it with a drawknife on a bench. The American axehaft of colonial days was the finest in the world. From the earliest days axe handles had always been straight, but some colonial American smith—a toolmaker—had designed the graceful curved axe haft that is still used. It is the perfect handle of a tool, being shaped exactly to fit the hand and give the arm the greatest power with the least effort. The handle made, our smith drives it into the shaft hole, wedging it in place with a thin metal wedge. With decent care, the axe we have seen made should last its owner a lifetime.

Besides axes, the American smith of 1830 made scissors, shears, knives, household implements, ploughs and plough points for the farmer, hunting knives and guns for the hunter and the settler. In the frontier world the gun meant meat for the home and safety from marauders. In the older countries the gunsmiths' craft was an art in itself, and a man skilled in making firearms rarely made anything else. But in the villages and settlements of the New World the blacksmith made guns as he made axes, plough points and horseshoes—whenever these were needed.

The gun barrel was forged of bar iron on the anvil, a plate being first drawn from the bar and this turned around a mandrel until the edges met. These edges were welded together on a swage about two inches at a time. The finest gun-barrels were made in short lengths, each piece turned around a mandrel and then these short lengths welded together to form the barrel.

The next step was that of twisting the barrel to knit the steel fibres together and to toughen the metal. The new-made barrel was heated on the mandrel and twisted bit by bit until the whole had become a strong, tough, compact tube.

The barrel so made was now ready for boring. This was done by the use of bits, each succeeding bit being a little larger than the one which went before until the true calibre of the gun had been reached. Some, but not all, gun barrels were then grooved with a spiral groove which ran from the breech to the muzzle. The purpose of this groove was to make the rifle ball spin as it sped along its course and so keep a truer line of flight. Such, however, was the marksmanship of the frontier woodsmen that, even with the smooth-bore guns and round lead pellets, they could outshoot most of us to-day.

The gun barrel made, the smith tested it with a load of powder equal to the weight of the ball. Next he made the sights, aligning them on the barrel. The trigger, trigger guard and firing mechanism followed, each part forged on the anvil and filed to final fit for assembling.

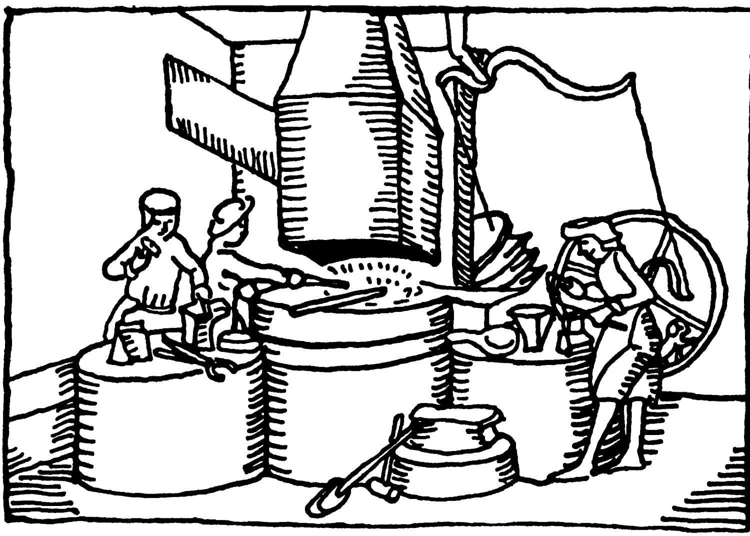
Skill and workmanship show in every line of these early guns, but it seems to me the gunsmith lavished even more affection and care on the forearm and the stock. The wood of the black walnut has always been the most favoured American wood for gunstocks, but almond, apple, beech, wild cherry, holly, persimmon, plum and yew have also been used. The graceful curve of the gunstock was shaped with the drawknife and the spokeshave and when finished it was checkered at the grip points. Checkering was done with a small tool having two or three rows of teeth pointed and edged. With this tool the craftsman cut patterns on the stock and at the grip point of the forearm. Many of these patterns are so intricate they must have taken hours of patient work to execute, yet only one who was really interested would even notice them. You have no doubt often heard the expression: "Lock, stock and barrel" used to indicate the whole of anything. Lock, stock and barrel are the parts of a gun, and in the hands of the gunsmith these were made into things of grace and beauty.

Pistol barrels were made in the same way as gun barrels. In earlier days pistols were very often made in pairs, and when this was done a single barrel was forged and then cut to form the two short barrels required.

Bullets were made in bullet moulds or by dropping molten lead from a tower. The lead used was alloyed with a small amount of arsenic to give it greater hardness. Molten lead was poured into a pan in the bottom of which were a number of holes. As the lead seeped through these holes it would form a drop which in falling would become a ball. The shot towers were built high enough so that the falling balls of lead would have time to cool and harden during the downward drop. At the base of each tower was a trough of water into which the pellets fell. The water served to break the fall and finally to cool the lead. These balls were then gathered and rolled down an inclined board. Only those which rolled all the way to the bottom of the board were accepted for use. Any others that turned to one side or the other were remelted, being rejected as not perfectly round. It was such guns as we have seen and such bullets as these that were used in the War of Independence; and others very like them were still in use in the early days of the Civil War.

If we go back to still earlier times, into the colonial days before the Revolutionary War, we will find the colonial smith busily engaged in making household tools and wares for his neighbours—spits, kettles, waffle irons, drip pans and skillets for the kitchen; ploughs, hoes and sickles and flails for the farmer; axes, saws, hammers, chisels and nails for the carpenter and shipwright.

Nail making alone had become an important task, especially in a newly settled country where so many buildings and houses, ships and bridges must be built. There were two kinds of nails made then—cut nails and wrought nails. Wrought nails were forged from thin iron rods on the anvil, pointed and headed under the hammer. They were better than cut nails, being tougher and stronger, but they were slow and costly in the making. Almost every colonial farm family made their own wrought nails, cutting and shaping them in the winter evenings, but this would not begin to fill the demand for nails. So great was the need of nails that a number of nail-making machines were invented and it was with such machines that cut nails were made. The first of these nail-making machines is said to have been made in Rhode Island by Jeremiah Wilkinson in 1777, and a few years later other machines were made. Cut nails were formed from bar iron which had been run through a grooved roller and so flattened into thin, narrow strips. These were then run through smooth rollers and cut into strips about three feet long. Heated to red heat these strips



FRENCH SMITHS MAKING NAILS IN EIGHTEENTH CENTURY

were passed under stamps which cut out a wedge-shaped nail blank which was then held between grips and headed. The first machines were not very successful, but early in the nineteenth century there were machines that could turn out two and three hundred nails a minute.

Wire drawing and pin making were also tasks of the smith. Wire making had been known since prehistoric times—gold, silver and bronze wire have been found in the ruins of Troy and in the burial places of Celtic chiefs, especially in Denmark and Ireland. Almost all of this ancient wire is flat, being really very flat, thin ribbons of metal. It was not commonly made by drawing. In the ruins of Troy, however, a jewel pierced with a small hole was found, and it is the belief of those who have seen it that this jewel was used as a drawplate in drawing wire. The Romans made bronze wire and even plaited it into cable. They also used iron wire in making chain mail. The simplest way to draw wire is to do this work by hand, first working the metal down to a thin pencil and then drawing this pencil through a small hole. Smaller and smaller holes are successively used until the wire has been pulled down to the required size. Done by hand, this must have been extremely hard work and quite early a wire-drawing bench was invented in which a lever or a windlass was used to pull the wire through the plate.

In the fourteenth century Nuremberg was the most famous centre of wire making, but even as late as the sixteenth century wire was still made by hand in England. To-day wire is made in every size, from threads so thin you can barely see them to the great woven cables which support the Golden Gate Bridge, and all this wire is drawn, annealed, cleaned and coated in one continuous mechanical process.

Curiously enough, while the early American smiths did not use wire in nail making as we do, they did use it in making pins. Pins were made from finely drawn wire which was cut into lengths, long enough to make six pins from each length. These pieces would be sharpened at the ends on a grindstone and a pin length cut off each end. What remained was again sharpened in the same way and again two pin lengths cut off. The last bit was sharpened and cut into two parts.

The pinhead was formed by spinning a coil of this wire around a wire the size of a pin shank. This coil was cut every second turn by shears and these small coils fastened on the shank by a hammer worked by a foot pedal. Common pins were made of brass, and when pointed and headed these were thrown into a copper vessel filled with tin and the lees of wine. The tin would slowly leave this liquid and plate itself on the brass. The tin-coated pin was then polished by swirling it in a bowl of bran and the dry bran removed by winnowing. Pin making became, quite early, a separate craft not so much done by the smith as in small factories where children were employed to do the work. I have read that a boy of that time could sharpen sixteen thousand pin points in an hour, but I doubt that this is so.

The first iron made in the American colony was produced in a furnace set up at Falling Creek, Virginia, by John Berkeley. It had been operating but a few years, however, when in 1622 the furnace was destroyed and all the workmen massacred, only Berkeley's small son escaping.

In 1645 "Eleven English Gentlemen" put up five thousand dollars towards the building of a furnace at Lynn, Massachusetts. So great was the colonial need for iron that this plant was exempted from taxation, its workmen released from any military service, the land upon which the factory was built donated, and other privileges granted. In a short while other furnaces were built in other colonies. By the end of the century pig iron and bar iron produced in the colonies was being shipped to England. As the American furnaces grew in number rolling mills were built, tilt hammers installed and the production of tools and wares greatly increased.

The English iron masters, seeing the colonial market slipping away from them, brought pressure on the government, and in 1750 a law was passed in England prohibiting any American iron maker from refining any more pig iron or making any further products from it.

Pig iron might still be made in the colonies, but it could only be shipped to the Port of London. This law was intended to crush the rising iron industry of the colonies. The English iron masters hoped that through this law the colonial settler would be forced to buy all his tools and implements in England, for under such a law there could be no more rolling mills, no more tilt hammers, no more steelmaking in colonial America.

But the colony refused to accept this and twenty-five years later the Declaration of Independence was signed, severing the rule of the mother country with her colony.

In the earlier colonial days, before iron furnaces had become numerous, it had been necessary to send back to England for such tools and implements as were needed. From a letter written in 1645 by a settler in Massachusetts to her relatives in England we get some idea of the things that were wanted. She asked that she be sent "6 pewter porringers, a small stew pann of copper, a peare of brasse candlesticks, and a peare of silver candlesticks—a brasse kittell, a skillet, and a few needles of different sizes, 6 table knives of ye beste steal with handles as may be—also 3 large and 3 small silvern spoones and 6 of horne." This lady must have been a person of wealth and importance in her day, for few colonial homes had such fine household goods. In colonial America wooden bowls, trenchers and noggins formed the table ware of most families; gourds were the drinking cups and clam shells set in the cleft of a stick served as spoons. Even in England table knives were scarce and table forks had only been known since the days of James I. In France in these days a gentleman upon being invited out to dine would send his knife ahead of him by a servant to the house of his host or carry it with him in his pocket.

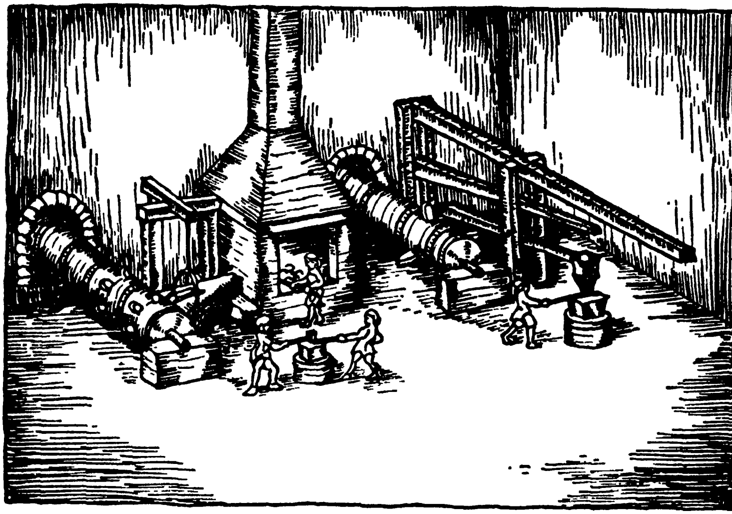
X. *Makers of Tools and Arms*

IT was in the seventeenth century, and especially in England, that the modern world of commerce and trade began. Paris, London, Vienna and Amsterdam were the great cities of Europe then, and they held their position because they were the market-places of the world to which the goods of every land flowed in. In England, France and Holland, great trading companies were organized to send out fleets of ships and armies of men to explore the world and to carry the products of Europe to foreign lands and bring back timber, tar and wax from the Baltic; spices and pepper from the East; ivory from Africa; silk from China and furs from North America.

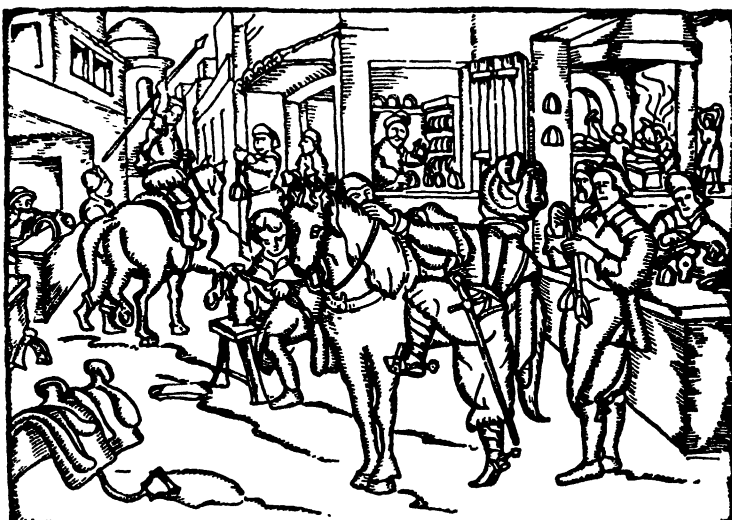
These were stirring times filled with invention and change. Newton and Boyle made experiments and laid the foundation of the modern sciences of physics and chemistry. Shakespeare and Cervantes wrote books and plays that are still read; Galileo invented the telescope and Harvey discovered the circulation of the blood; Savery and Newcomen were working on the first steam engine; Vauban created the modern army and El Greco and Rembrandt painted their immortal pictures.

It was in the seventeenth century that post roads were built so that folk now got about more—saw what others did and how they lived—learned that there was a greater world outside their own small villages. It was a period of new ideas.

Of all the changes and new ideas that came into use in this age perhaps the most important to us was the factory. Factories had been known in ancient times—there had been brick factories in Babylon and papyrus factories in Egypt. There was a sword factory in Athens, and Carthage was noted for its factories that made perfumes and dyes. Although there had been but few factories in the city of Rome itself there were scores of them scattered throughout Italy and even in remote parts of the empire—factories making arms and armour, linen



FRENCH BLACKSMITH SHOP—SEVENTEENTH CENTURY



STREET OF THE SADDLERS—SEVENTEENTH CENTURY IN FLANDERS cloth and pottery. But the factory method of working had fallen into disuse during the Middle Ages. During that long period almost all kinds of work were done by craftsmen belonging to guilds. The guild craftsmen worked in small shops —a master and a few journeymen plying their trade together. They usually made articles only after receiving an order for them—each article being designed and wrought exactly according to the wishes of the buyer.

MEDIÆVAL SMITHS

There were fairs and markets, especially in the great towns and cities, and to these the craftsmen took their wares, but in them it was the craftsman himself who sold his goods. The day of the merchant had not yet come.

Just when and where the modern world of commerce and trade began we do not know—probably it was in Italy and especially in the city of Florence. We find the records of a great number of craft guilds in this city as early as the eleventh century—butchers, bakers, weavers, dyers, smiths and carpenters—almost every conceivable trade had its company of fellow workmen. These were all working trades; that is, the artisans themselves made the wares they sold. But almost a century later we see the rise of the merchant guilds—buyers and sellers of goods. The great guilds of the thirteenth century in Florence were not the metalworkers and masons but the money changers, the sellers of silk, woollen and linen cloths, the merchants of skins and furs.

Something of the same thing happened in France as well, and here we find the Six Companies—gold dealers, silk merchants, grocers, drug sellers, serge merchants and ironware dealers. These were merchant companies rather than workmen guilds. In England there were the Twelve Great Companies of the City—grocers, mercers, drapers, fishmongers, skinners, haberdashers, salt merchants, wine sellers, ironware dealers and cloth sellers.

All these merchant companies needed goods and wares to sell. The older craftsmen's guilds that made but a few tools, implements or lengths of cloth at a time could not possibly keep up with the demand. It was the great growth of trade in the expanding world of the seventeenth century that brought back the factory.

In the poem, "The Pleasant History of Jack Newberry," there is a description of one of these early factories.

Within one roome, being large and long
There stood two hundred Loomes full strong.
Two hundred men, the truth is so
Wrought in these Loomes all in a row.
By every one a pretty boy
Sate making quilts with mickle joy,
And in another place hard by
A hundred women merily
Were carding hard with joyful cheere
Who singing sate with voyces cleere,
And in a chamber close beside
Two hundred maidens did abide,
In petticoats of Stammell red
And milk-white kerchers on their head.
Their smocke-sleeves like to winter snow
That on the Westerne mountaines flow,
And each sleeve with a silken band
Was featly tied at the hand.

These pretty maids did never lin
But in that place all day did spin,
And spinning so with voyces meet
Like nightingales they sang full sweet.

The poet makes the scene gay and cheerful—maidens in "petticoats of Stammell red" singing with voices like nightingales full sweet. But as we go on in the poem we come to another scene:

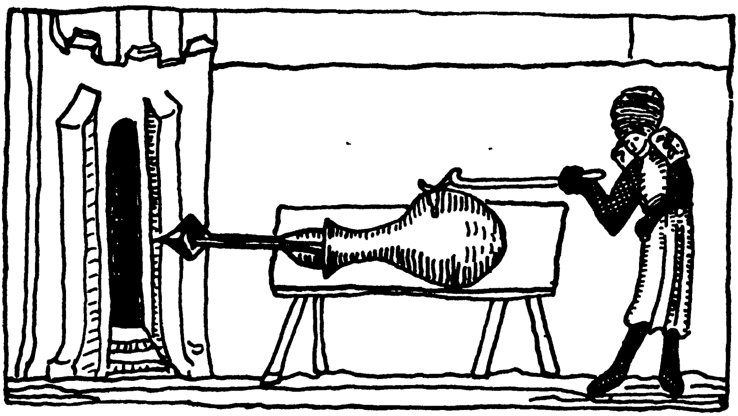
Then to another roome came they
Where children were in poore aray;
And every one sate picking wool
The finest from the course to cull:
The number was sevenscore and ten,
The children of poore silly men:
And these their labors to requite
Had every one a penny at night,
Beside their meat and drinke all day.
Which was to them a wondrous stay.

Not only had the factory come but child labour and the sweat shop were on their way!

But for all the peaceful scenes of workers in the weaving sheds and the busy commerce in the towns the great industry of the seventeenth century was war. Only four years out of one hundred saw peace in Europe; in all the rest a major war was being waged somewhere on the continent.

War by this time had become a savage and terrible thing. It was no longer a gay joust between knights as had been the wars of the Black Prince, Swedish Gustavus Adolphus, the Lion of the North; Cromwell, in England; Vauban in France led armies that had been trained and disciplined; armies that fought with guns and artillery. The crossbow had replaced the longbow and then in turn had been superseded by the arbalest and the matchlock musket. Just now the flintlock, invented in France, was coming into use. Cannon became more and more common. They were dragged into battle on wheels. They formed the armament of ships and Vauban used them in the great forts he built. With so much war and rumours of war it is not to be wondered at that the chief products of the metalworker of this time were arms and armament.

The early cannons were cast in brass or bronze. They were short and heavy and fired stones for shells. As early as Edward III in England a cannon was made "of iron bars joined together . . . and strengthened by . . . hoops of iron." In Europe some cast-iron cannon and cannon balls were made at this time but brass and bronze were still the chief metals



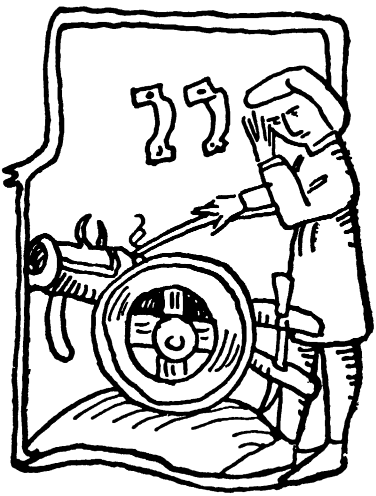
THE FIRST CANNON WAS MADE IN GERMANY IN 1313—A YEAR LATER SOME OF THOSE PIECES WERE BROUGHT TO ENGLAND. THIS IS A COPY OF A DRAWING OF ONE OF THEM MADE IN 1327

used. The art of casting iron was not to become common until the invention of the hot-blast furnace a hundred years later.

The making of arms and guns in England under Charles I had become such an important craft that the armourer's guild was directed by law to inspect and try all guns made and to approve their fitness.

And because divers cutlers, smiths, tinkers and other botchers of arms by their unskilfulness have utterly spoiled many arms, armours, guns, pykes, and bandoliers we do prohibit that no person or persons whatever not having served seven years or been brought up as an apprentice . . . in the trade and mysterie of an armourer, gun maker, pyke maker, or bandolier maker . . . do make, alter, change, dress, repair, prove or stamp any arms, armours, guns, pykes or bandolier.

Cannon, bombards, mortars, flintlocks, pikes, longbow, crossbow, arbalest—how many scores of kinds of weapons and military machines have been made by the armourer and the smith! The drawings of a few of these are shown, but these give but glimpses of the vast variety of arms that have served the soldiers of all periods. The story of the armourer and his craft is one of the most interesting tales in the whole history of work, but it is far too long to be told here—that I will do at another time and in another book. Meanwhile let us stop by the forge of one of the great ironworkers of all times—the shop of Mathurin Jousse who lived and worked in France in the seventeenth century.

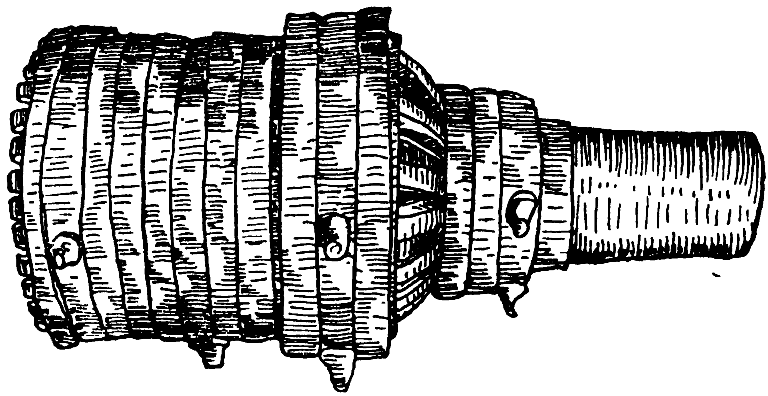


EARLY CANNON—1390

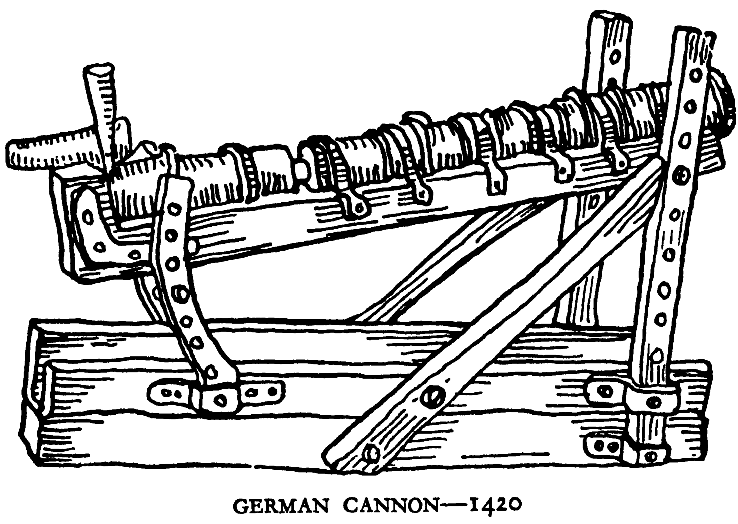
Of the events in the life of Master Jousse we know little, but of his work and his character we may learn a great deal. Carpenter, ironworker, inventor, scholar, but above all else locksmith—Jousse was the first man to put down in writing a full, clear account of the work of the smith. As you read his quaint old French, Jousse himself becomes a very real and living person—a man who truly loved and knew his craft.

He explains how he came to write his book, saying that he, a metalworker, unaccustomed to the world of letters, would never have undertaken such a task except that it so grieved him to see the knowledge and experience of a lifetime die with the craftsman and leave nothing to be passed on to posterity.

He speaks of Biscornet and points out how great was his skill, how deep his knowledge of his craft. Yet Biscornet, says Jousse, left no record of his experience, no guide to later smiths



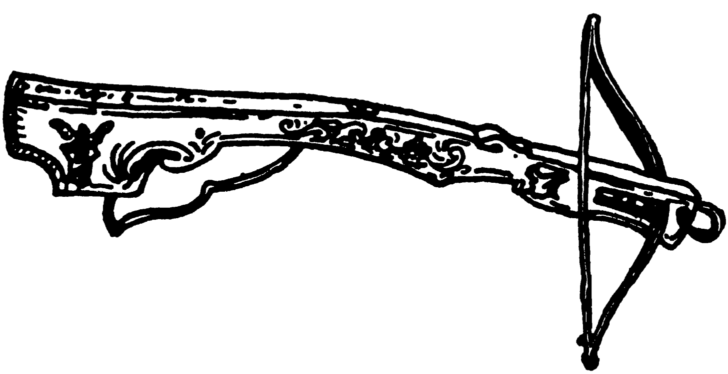
MEDIÆVAL CANNON—1425. MADE OF STRIPS OF IRON BOUND TOGETHER WITH IRON HOOPS



GERMAN CANNON—1420

as to how he produced his marvellous work. To Jousse it seemed wicked—a loss to France and to all metal craftsmen that men should be content to practise their art without thought of passing on the fruits of their knowledge to other men.

SIEGE OF A MEDIÆVAL CASTLE—SPEAR—CROSSBOW—CANNON



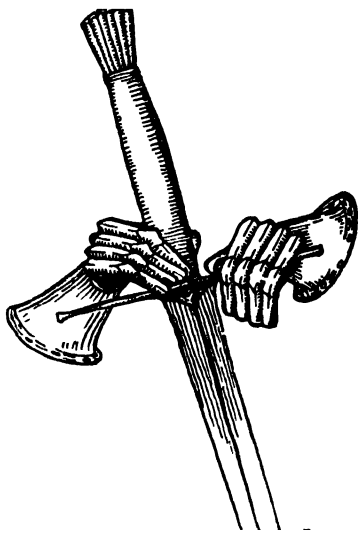
CROSSBOW

Almost in apology he says, "I would not have presumed to write this book except that it might induce other artisans to contribute in their turn what they may have learned of this noble craft."

FRENCH FIFTEENTH-CENTURY ARMOUR

The book needs no apology—through simple, clear and exact language Jousse explains each step of a metal craftsman's work, setting down his text with the same patience and wise care he would have used in forging and filing a lock and key.

He describes the fire and the tools and tells how to heat iron without burning it. "Do not allow your iron to come too near the bellows nozzle lest it be not heated enough or heated too much or heated in two places at once." You can almost see him at his forge peering into the fire, watching the iron—tense and ready to swing it on to the anvil at exactly the right moment. "Work your bellows with easy, short strokes so as not to make too sudden or too strong a blast—listen to the little sound in the fire to know when the iron is ready."


SIXTEENTH-CENTURY ITALIAN TWO-HAND SWORD

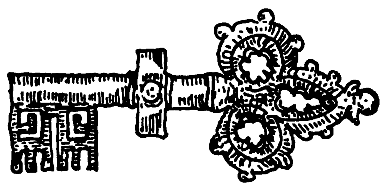
He talks about the life of a smith, tells of some of the hardships, the burning eyes, the long, hard labour, the tired feet from standing hour on hour at the anvil. He tells a boy who wants to become an apprentice to try the work awhile before deciding to enter the craft—"Better to know the hardships in advance than to embrace a life you will live coldly or a work you will quit in disgust." Jousse wanted no boys in his shop who would work halfheartedly. No one knew better than he the tedious hours of filing and the hard labour of forging iron, but he loved his craft with a very deep and ennobling love.

Above all things made by the smith of his day he most admired locks and keys. He describes the different kinds of lock known in his time and tells how they were made.

In making a lock the key was always wrought first. The smith took a piece of iron about as big around as one's thumb and three inches long. This was brought to red heat and the key bit formed at the centre, the bow at the outer end. The stem was then shaped and the bow pierced to form the ring. A good workman, says Jousse, could complete all this in a single heat.

The rough-formed key was now cut off from the remaining iron; the shoulder turned and the bit web fashioned and smoothed.

If the key was to have a ball tip at the bit end of the stem this was now turned and shaped. On the other hand, it was the more common practice, especially on fine keys, to have the key stem broached. In the locks of that time a pin was set in the exact centre of the keyhole and the broach in the key stem was designed to fit snugly over this pin, which then served to hold the key straight and true as it was turned in the lock. Most locks in those days were designed to be opened from one side of a door only.

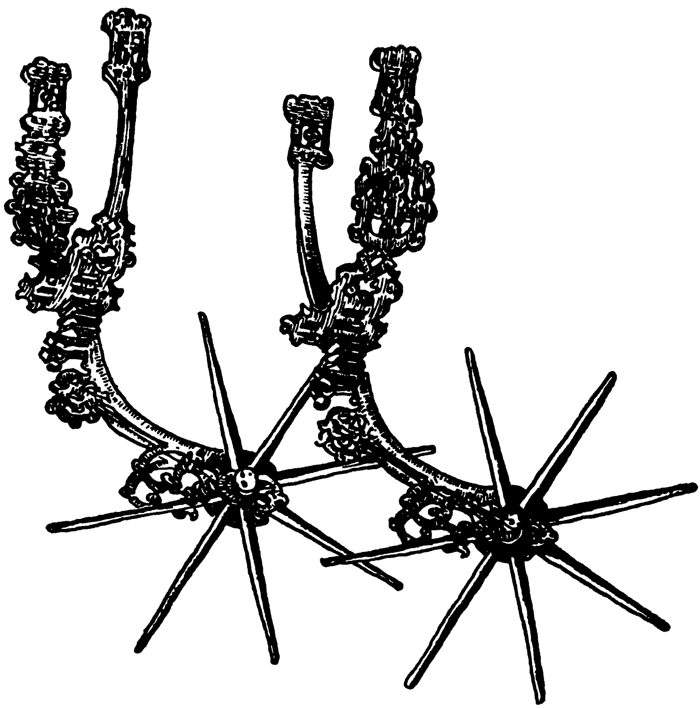


FRENCH SEVENTEENTH-CENTURY KEY

The broach was made by use of the mandrel and the drill; the mandrel being a slender, tapered punch and the drill a bow drill having a drill cap which was rested against the stomach.

The broach was sometimes left round as it came from the drill and the tapered punch, but more often and especially in fine locks it was given complicated shapes such as a star, a triangle, fleur-de-lis or the like. Whatever the shape of the broach the pin must be made to fit exactly into it, and this was the reason for these complicated shapes, since the more complex the broach and pin, the more difficult it was for anyone to use any but the proper key to open a lock.

To change the round hole into any of these shapes, delicate mandrels of special pattern and size were used. They were driven slowly and carefully into the round broach and gradually changed it into the new shape desired. This was a very exacting part of the work. The mandrels, though hard, were slender and light and might easily break off in the stem. The steel of which these mandrels were made was as hard or harder than any of the drills in the shop of the smith, so if such an accident occurred he could not drill out the broken mandrel tip; and



SEVENTEENTH-CENTURY ENGLISH SPURS

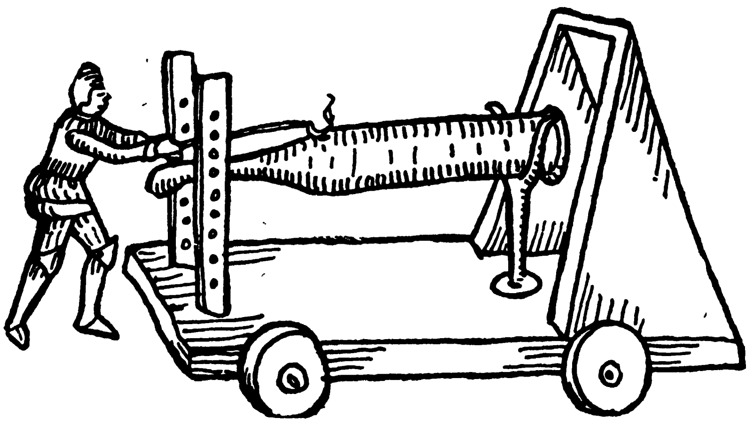
this might well mean the loss of all the smith's labour that had already gone into forming the key. To avoid such a chance, Jousse advised the smith to place a little gunpowder in the bottom of the stem, covering it with a layer of lead. Then should a mandrel break off in the stem, the broken end could be shot out by exploding the powder. I have no doubt this trick saved many a smith the need of remaking a key, but just the same I would hesitate to work with my head bent down close over a vice hammering sharp-pointed mandrels into a key stem which had a powder charge in its base!

The bow, stem and broach now made, the next step is to shape the bit so that it will pass the wards in the lock. The wards are shaped pieces of steel set in the path through which the key must turn before it can shoot the bolt. They are made in a variety of forms, some acting on the nose of the bit, others acting against the bit edges. Whatever their shape the key must be so cut that it may pass these wards. The shaping of the bit is done with files—straight files—curved files—files almost as thin as a piece of paper. The key bit is blackened in candle-smoke and the cuts marked on it with a scribe.

When you see how delicate and intricate were some of the keys of Jousse's day you marvel at the patience and skill that could fashion them—keys having bits cut into scores of slender teeth, or into designs and patterns, letters, numbers and symbols of their owner's estate. It took weeks and months to make some of these marvellous keys, and yet when chased and polished the work was only half done, for the lock was still to be made. Some day when you take a key to your locksmith to have a duplicate made and watch him place your key in one part of a machine and a key blank in another and then by simply pressing on a switch cause a perfect copy of your key to be made in less than a minute, remember the keys of Mathurin Jousse and something of the work that went into making them.

As we follow the work of the smith further and further back into the past the articles made in the blacksmith shop become heavier and coarser. In the early Middle Ages there was neither need nor time to do such work as was done by Jousse and his fellow craftsmen. The hinges of the great doors of the castle, the bands that bound the treasure chests needed no such fine, delicate work as this. Yet while those products of the forge of earlier days were not delicate they were very beautiful—no more superb iron work has ever been done than Biscornet's hinges on the doors of Notre Dame of Paris. A mass of intricate scrolls and leaves swirling and interlacing, they form an exquisite pattern against the cathedral doors.

The smiths of earlier days made grilles and gates, drawbridge chains, ploughs and tools; but more than any of these



EARLY ITALIAN CANNON

they made the arms and armour of kings and knights and men-at-arms.

There could be seen the Iron Charles helmed with an iron helm; his iron breast and his broad shoulders defended by an iron breastplate; an iron spear raised in his left hand, his right always rested on his unconquered falchion.

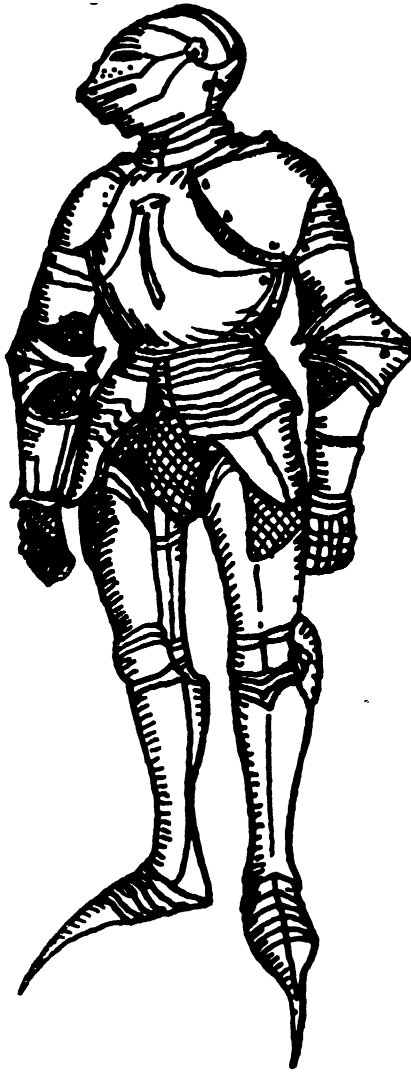
The thighs, which with most men are uncovered (that they may the more easily ride on horseback), were in his case clad with plates of iron: I need make no special mention of his greaves, for the greaves of all the army were of iron. His shield was of iron, his charger was iron-coloured and iron-hearted.

The fields were filled with iron. A people stronger than iron paid universal homage to the strength of iron. The horror of the dungeon seemed less than the bright gleam of iron.

Oh, Iron, woe for the iron, was the cry of the citizens. The walls shook at the sight of iron. The resolution of the old and young fell before iron.

So wrote the Monk of St. Gall a thousand years ago of his lord and emperor, Charlemagne.

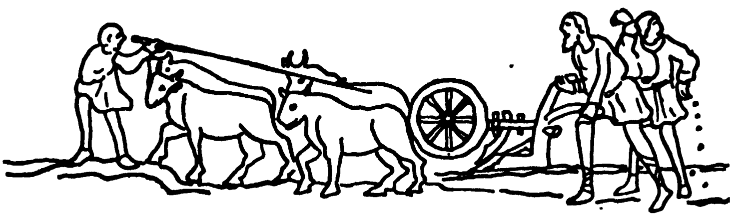
The world of that day must indeed have seemed to be encompassed in iron. Beside the emperor and the kings, every baron and overlord maintained armies of men-at-arms in their castles. Even bishops of the Church had troops at their command. In a world of endless strife and warfare there was need of all this armament. Towns and castles were surrounded by walls and moats; only the small villages and the open countryside were unprotected; and while the towns and castles might withstand the siege of attacking troops, the villages and farming land could not. Moving armies lived off the country through which they passed. The fields and vineyards of the farmer; the flocks and droves of the shepherd and the herdsman; the shops of the village craftsmen; each paid toll to every



FRENCH ARMOUR

passing band of men-at-arms. Indeed, the fields must have seemed to be filled with iron for the peasant, and the craftsman, bearing no arms and unprotected by any armour, could make no stand against men who were covered from head to foot in mail and who bore weapons in their hands. Is it any wonder that "the resolution of the old and young fell before iron," or that these folk, despoiled of the increase of their labour, could only cry out: "Oh, Iron, woe for the iron!"

There was need of many smiths, in those days, to make the arms and armour of all these troops of warriors. Every castle had its own blacksmith shop where the smith and his helpers



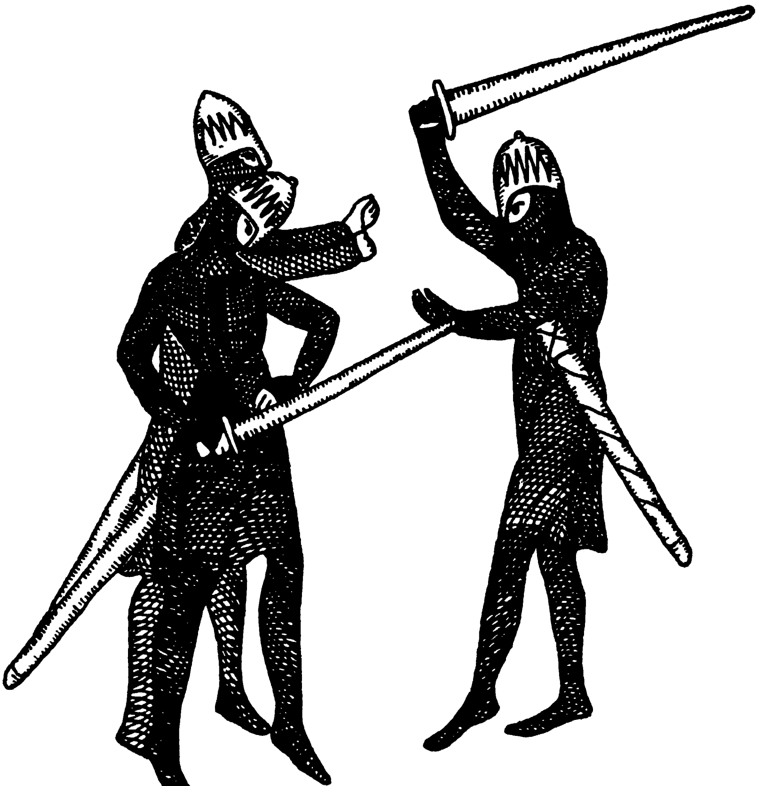
MEDIÆVAL PLOUGH

repaired the broken weapons of their masters or made new swords and shields, helmets and armour to replace those lost in battle.

When there was peace the smiths made spits for the hearth, pots and kettles for the kitchen, ploughs and pruning hooks for the farmer, locks and keys, chests and chains for the manor house and castle; but there was little peace; the chief work of the smith was making arms.

In Charlemagne's day the high furnace had not yet been invented, nor were there any water-wheels to work the bellows or to trip the tilt hammer at the forge. All the iron used had to be smelted at low furnaces which were little better than those of ancient Spain, and the blooms were worked into bars and shapes on the anvil under the hammer.

The armour worn by Charlemagne seems, from its description, to have been plate armour, but the more common armour of that time was mail. Chain mail was made up of thousands of small rings of iron linked and welded together to form a metal cloth which was at once strong enough to withstand



ANGLO-NORMAN ARMS

heavy blows and yet was pliant enough to permit the wearer to move about.

It took great skill to make such mail. Each separate link must be wrought on the anvil, shaped, and then joined to other links. Heavy iron bars were first worked down into slender rods and these in turn further reduced to thin strands of metal which was cut or welded to form mail. How well this was done we learn from old tales of mail that, though light and pliable, was yet able to resist the blows of sword and mace. We hear, too, of swords that were famous for their strength and keenness. Some of their names still live in history. "Joyeuse," the sword of Charlemagne, was one of these.

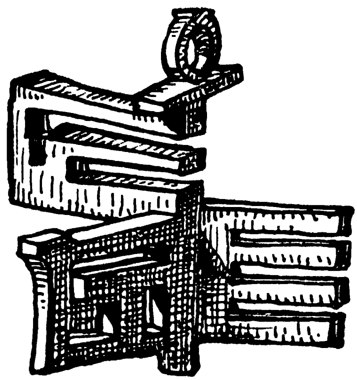
You may wonder that chain mail was not made from iron wire. The art of wire drawing had been known in Roman times and it was certainly practised in the Middle Ages. Iron when drawn into wire must be annealed after every two or three reductions in size if it is to retain its strength, and even so it is not as tough and strong as iron worked down into links on the anvil. Some chain mail of the early Middle Ages may have been made of iron wire which had not been properly heat treated. Whatever the cause, not all chain mail was well made, for we read in some of the old tales of chain mail failing its wearer in battle.

The ring-linked coat of strongest mail
Could not withstand the iron hail,
Though sewed with care and elbow bent
By Norna, on its strength intent
The fire of battle raged round—
Odin's steel shirt flew all unbound!
The earl his ring-mail from him flung—
Part of it fell into the sea—
A part was kept, a proof to be
How sharp and thick the arrow-flight
Among the sea-steeds in their fight!

So goes King Olaf Trygvesson's saga.

But if the workmanship on the arms and armour of most periods was usually skilled and exact, that on tools and locks, ploughs and implements was not always so well and carefully done. We will find this to be quite generally true as we go back into the history of metalwork. For while there were some periods in ancient times when the tools and implements of peace were superbly made, there were other times when this was not the case. There were, however, almost no periods when the arms and weapons of the warrior did not receive the greatest skill and workmanship of the metalworker and the smith.

As we go further and further back in time we find, too, more and more bronze in use and less and less iron. As we approach the days of Rome these metals divided between them the fields of arms and tools and implements. Sometimes the arms of the Roman armies were made of iron, sometimes bronze was used. In the great days of Rome, the days of the soldier emperors, Roman arms were almost entirely made of iron, but in the late days of the empire, as the strength of Rome began to fade, bronze, to a large extent, replaced iron for weapons because it was easier to work. Just as the arms were then less well made so was the army less well trained.



ROMAN KEY

The lack of discipline [says Vegetius] and of proper exercise made the Roman soldiers less able and less willing to bear the fatigues of service. They complained of the weight of their armour, which they seldom wore. They received permission to lay aside their breastplates and their helmets. The heavy weapons of their ancestors, the short sword and the terrible Roman spear which had conquered the world, slipped from their feeble hands, and thus badly armed without shields, helmet or breastplate the troops marched reluctantly into battle where they must suffer either the pain of wounds or the shame of defeat.

What a far cry was that ragged, undisciplined army of the dying empire from the legions of the great captains of earlier days! The soldiers of Caesar, Trajan, Germanicus and Constantine would never have acknowledged these as their successors. In the heyday of Roman arms a soldier carried a large, heavy shield, a short thick Spanish sword, two spears (one for thrusting and one for throwing); the head was protected by a helmet, the body by bands of metal, the legs by greaves. Bearing such a weight of metal the Roman legionnaires marched from end to end of the ancient world suffering with equal indifference the heats of Africa and the colds of northern Europe.

ROMAN ARMOUR

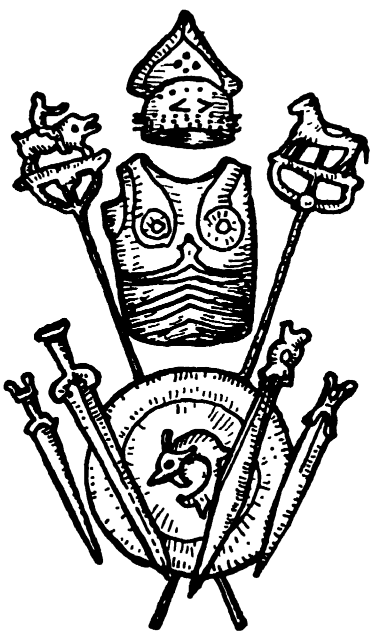
There was need in those days that the Roman troops be well equipped and trained, for they fought against armies quite as courageous and rugged as they were themselves. The Britons, Gauls and Germans lacked only the superior leadership and the arms of Rome to have remained unconquered.

In armies of the great generals there were probably more foreign troops than actual Romans, but these armies were almost always led and trained by Roman officers. We read of a battle between the Britons and a Roman army—

The Britons were armed with huge swords and small shields—they quite eluded our spears or beat them off, meanwhile pouring a torrent of their own missiles on our troops. The Roman commander, seeing defeat at hand, ordered his foreign regiments to engage the Britons hand to hand, a method of fighting at which they had been especially trained. This close attack avoided the rain of British spears, and the Roman tools, by grappling with the enemy, made the long, heavy, blunt swords of the Britons ineffective. Engaged in close encounter, the German and Gaulish soldiers plied their short Roman swords with rapid blows and drove the sharp bosses of their shields into the Britons' faces, mangling them and bearing down all who stood before them.

How many hundreds of battles of Roman days must have been won by Rome in this way—foreign troops bearing Roman arms, trained and led by Roman officers, defeating troops as brave as they but troops less well armed and led.

Through nearly four centuries Rome maintained armies in Italy, France, Spain, Germany, Egypt and in the Near Eastern countries. How great a need of arms and armour there was then! I believe it would be safe to say that through all this period by far the greater part of all bronze and iron smelted and wrought went into weapons rather than into tools and implements.



ARMS OF GAUL

But if the Roman smith and metalworker spent the greater part of his time in the craft of the armourer he was skilled as well in the arts of peace. The Roman plough was partly made of metal—the share and colter being made of bronze or iron as were sometimes the wheels as well. The tools of the carpenter, mason, miner and smith—the razors of the barber and the shears of the tailor were of metal, sometimes bronze, sometimes iron or steel, but in either case usually well cast or wrought. In the ruins of Pompeii scores of tools and implements were found. When we look at these in their cases in museums to-day they seem impersonal things, but those razors once shaved men or lanced boils. Those locks once guarded someone's little store of precious things; in those pots and pans food was once prepared. They are very real things; a closer link between us and the peoples of the past than anything words can tell you.

WARRIOR OF GAUL

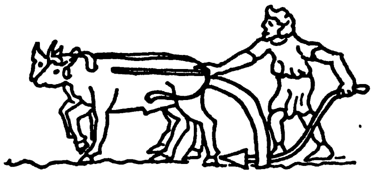
Some are made of bronze, some of iron or steel. Steel was not common but it was used, some coming from India and some from Porus on the Black Sea. Although the Romans did not know how to make steel as we do they knew a good deal about iron. They knew, for instance, that certain kinds of iron are magnetic. Pliny tells of one of the Ptolemys, a Pharaoh of Egypt, who wished to build a tomb for his sister. This tomb was to be made of magnetic ironstone so that it would hold an iron statue of the princess suspended in air. Dimochais, as architect, began the construction of this tomb, building a vault of magnetic stone surrounding the statue, believing that the vault would attract the iron figure equally from all sides and so hold it floating in the air. The project was never completed as the Pharaoh died during its construction. It is as well for Dimochais that this happened, for he would most certainly have failed in his commission. Magnetic ironstone will attract certain kinds of iron but not cast iron, and failure to carry out a Pharaoh's wish would almost certainly have cost an architect his head.

Some smiths of Roman days knew a great deal about iron; they knew how to smelt it from its ores, how to temper wrought iron in water, how to weld or rivet iron parts together. Some knew the magnetic quality of pure iron, and others had learned to make steel from iron by cementation. A few metal makers even knew how to cast iron in moulds, but this knowledge was rarely used.

Not all Roman smiths, however, knew all these things—if they had, iron would have entirely replaced bronze long before it finally did—but iron was becoming more and more common in the Roman world and even in the latter part of the Greek world that preceded the days of Rome. We place both the Roman and Greek periods in the Iron Age, yet it would be a mistake to think that iron was even then as commonly used as bronze.

Of bronze the Roman and Greek metalworkers knew quite as much as we do. They made bronze of tin and copper, adding other metals to the alloy to make it serve special purposes. They cast bronze in stone and clay moulds and used wax models in lost-wax casting. Their workmanship in bronze was as fine as any done by metalworkers since that time.

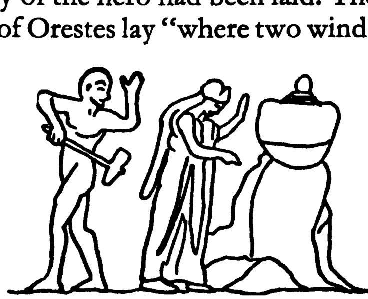
The Greeks knew iron as well as bronze and how to work with it, but they used fewer iron tools and weapons than did the Romans. Aristotle, a Greek writer, says: "The best and hardest of all kinds of iron is one made by the Chalybians, being



GREEK PLOUGH

obtained from iron by melting it repeatedly with certain kinds of stones in a furnace—a process which produced much slag and which caused a great loss in metal, on which account it was very costly." He speaks of the iron so made as "steel," and says it "is very hard, with a glittering surface, and it resists rust; but such metal is not suitable to all purposes for which less pure iron is used. The quality of 'steel' is judged by the sound given forth when it is struck on the anvil." Aristotle may have been describing the natural steel produced from ores found in the Black Sea region, and if so his description was fairly accurate. The Greeks, however, had very little steel. Some ironwork was done in each of the Greek states, but the most famous Greek smiths came from Laconia which was ruled over by the city of Sparta.

There is a story told of the Spartans that concerns a smith. It appears that they had been long at war with their neighbours, the Tegeans, and had met with nothing but defeat. Finally they sent to Delphi to ask the oracle what God they must propitiate in order to prevail against the Tegeans. They were told that they must remove to Sparta the bones of Orestes, son of Agamemnon. Unable to discover his burial place they returned again and asked where the body of the hero had been laid. The oracle answered that the bones of Orestes lay "where two winds ever blow and stroke falls upon counter stroke and evil above lies upon evil below." The Spartans, however, were now no better off than they had been before, but they continued their search diligently until at last the burial place was found by a



GREEK SMITH

man named Lichas. Lichas, being in the city of Tega and happening to enter a blacksmith shop, marvelled at what he beheld, for he had never seen a smith at work before. The smith, seeing his wonder, paused in his work and said: "Certainly, then, you Spartan stranger, you would have been wonderfully surprised if you had seen what I have seen, since you make marvel even of the working in iron. I wanted to make a well in this room, and began to dig it when, what think you? I came upon a coffin seven cubits long. I had never believed that men were taller in the olden times than they are now, so I opened the coffin. The

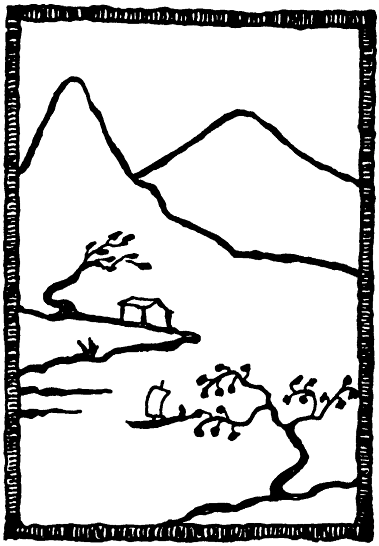
GREEK WARRIORS

body inside was of the same length. I measured it and filled up the hole again."

Lichas, turning this story over in his mind, believed these to be the bones of Orestes, for in the smithy there were two bellows—that would be the two winds. The hammer and the anvil made stroke on counter stroke. The iron, itself, lay upon an iron anvil, and since Lichas thought iron "an evil thing, discovered to the hurt of man," this would complete the oracle by being "evil above lying upon evil below."

Convinced now that the words of the oracle were fulfilled, Lichas by trickery secured entrance to the house of the smith and stealing the bones of Orestes he hastened back to Sparta. Thereafter, the tale goes, "whenever the Spartans and the Tegeans made trial of each other's skill in arms, the Spartans always had greatly the advantage."

This account is interesting for more things than the story itself, for it seems to me to be the roundabout Greek way of saying that the Spartans learned the arts of ironworking from the Tegeans and thereafter became famous for the ironwork done

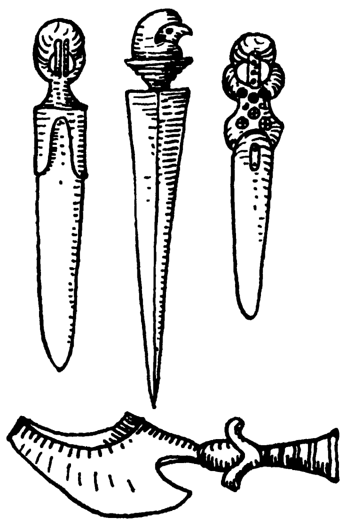


CHINESE WROUGHT-IRON PICTURE

in Laconia. Throughout most of Greek history the Spartan armies were superior to those of any other Greek state, and this may well have been because the Spartan arms and armour were made of iron.

Although iron was used in ancient Greek times it was by no means common in Greece itself, and in other places it was quite rare. Diodorus says that he knew of an Arabian tribe whose people "exchange weight for weight the gold which they get from their mines for the copper and iron which they lack." Another Greek writer tells of another country where the people "had no iron of their own and no one brought them any because of all the peoples who inhabited these parts they had the least commerce."

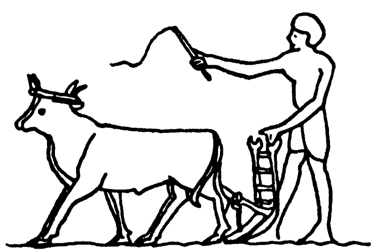
Iron was well known in China as early as the seventh century B.C. We read of a tax on salt and iron. Of iron the king's advisers said: "The officials in charge of the iron works had reported



EGYPTIAN WEAPONS

that every woman in the country must have a needle and a knife; that every field labourer must have a plough and spade, a cooking pan, a cart and a hatchet. All these being necessities of life a tax upon them would be a regular source of public revenue." Such a proposal would certainly seem to indicate widespread use of iron in China—more so, I think, than was the case in Europe at this time. It is interesting, too, that iron needles should be mentioned. These would almost certainly have been made of steel rather than wrought iron. The earliest that really good steel needles were to be made in Europe was about a thousand years later than this.

The ancient Egyptians were not great users of iron. The peoples of the Nile Valley had been among the first makers and users of metal tools, but these they made of copper and bronze, and for some reason the Egyptians seem to have been reluctant to change to iron. This is the more strange since it has been said that the Negro neighbours of the ancient Egyptians were among the first users of iron. This has not as yet been proved definitely,

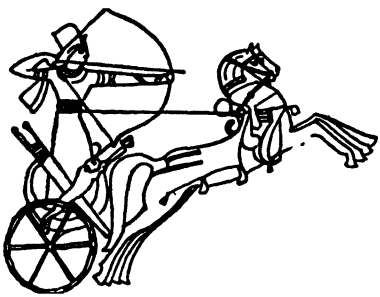


EGYPTIAN PLOUGH

but we have many accounts in later days of superb ironwork among the Negroes of Africa. When Dr. Livingstone penetrated into the interior of the continent he found iron in common use. And of the tribes he met there, the Zambezi not only made iron articles but apparently made better iron tools and weapons than were the wares offered them in trade, for these they refused to accept.

It may have been that the Egyptians did not have so great a need of iron as did their neighbours. The soil of the Nile is so light and soft it needs but little ploughing; the great building periods of Egypt occurred before the coming of iron; and finally the Egyptians were not a very warlike people—they were fairly safe in their valley protected by deserts and mountains, and so they may not have had as great need of fine weapons as did most other ancient peoples. Whatever the reason it seems certain that the Iron Age did not begin as early in Egypt as it did in other parts of the ancient world.

To the north and east of Egypt in Asia Minor there lived a people who were well acquainted with iron. They were the Phœnicians. There is a story told of an Egyptian courier who was sent into that country by his master, the Pharaoh Rameses II. One night while he slept he was set upon by thieves who stole his bow and quiver of arrows from his side, cut off his armour in the darkness, stampeded his pair of horses and broke



EGYPTIAN CHARIOT

his chariot into pieces. In such dire straits the Egyptian appealed to the king of that country, complaining that a messenger of the great Pharaoh should be so treated. The king ordered the damage to be repaired at once, and we may read in a letter written by this messenger to his royal master the account of how this was done.

The ironworkers enter the smithy, they rummage in the workshops of the carpenters; the handicraftsmen and saddlers are at hand, they do all they are requested; they put together the chariot, they put aside the parts of it that are useless; the spokes are fashioned quite new; the wheels are put on; they put the straps on the axles and on the hinder parts; they splice the yolk; they put the box on the chariot; the workmen forge the iron parts; they put the ring that is wanting on the whip and replace the lashes on it.

How little different was this shop and the work done in it from a blacksmith's shop of our own father's time!

The Phœnicians were celebrated for their ironwork, and they numbered among their greatest heroes two brothers who had discovered iron and the way to treat it. They knew well the value and importance of iron, and once, when one of their cities was about to fall before the attack of the Persians, the citizens brought away all that was left there of iron and, throwing it into the sea, said: "We will not return to our city until this iron returns from the sea."

The general use of iron began about the time of the Trojan War. At first it served chiefly for crude tools and farming implements rather than for fine tools and arms. When Achilles offered a large quantity of iron as a prize to be given to the winner of the games held in honour of his dead friend, Patroclus, he said: "It is enough iron that any farmer who might gain the prize need not go to town for more iron for at least five years."

Before the beginning of the Iron Age, the metal used throughout the ancient world for arms and implements was bronze. It was during this three-thousand-year-long Bronze Age that there arose and passed the great empires of Sumer, Babylon, Egypt and Crete. Whole nations and vast cities flourished then that have since disappeared utterly from the earth, leaving little or no record of their laws, their language or their customs. But the tools, the weapons and the ornaments of the Etrurians remain as do those of the Swiss lake folk and the dwellers in the Danube Valley. Horns and helmets, swords and knives, even furniture and mirrors have been found in the tombs of Bronze Age peoples, or in the ruins of their cities, and these give some inkling of their makers' lives. At least they show us how fine was the craftsmanship of the early smith and how great was his knowledge of metals.

The Bronze Age, which saw the beginning of metal tools, saw also the invention of writing and wheels, the establishment of governments and laws. Commerce and trade began, and the foundations of civilization, as we know it, were laid.

Before the discovery of bronze there was a brief period when copper was used for tools and weapons, particularly among the Egyptians. The wave of copper use spread eastward through India and China and eventually crossed the Pacific Ocean to North and South America. But almost immediately after the use of copper began, another wave started spreading eastward and westward from Mesopotamia and Egypt—the wave of bronze tools. In almost every part of the world the new art of bronze casting drove out the use of copper, and bronze implements and arms began almost at once to replace those made of copper. The strange exception to this, however, occurred in the Americas, for there seems to have been a break in the contact between the Old World and the New sometime soon after the use of copper began, for here there was never any Bronze Age at all and even the use of copper was very limited. The civilizations of Mexico and Peru passed almost directly from the Stone Age to that of Iron, after the discovery of the New World by Columbus.

In the older world in Europe, Africa and Asia, we come upon the earliest use of tools in the long, long Stone Age which preceded the discovery of copper and bronze; an age in which mankind first began to fashion his implements from bone and horn, shell and stone; an age which seems so remote from us as to be almost unbelievable.

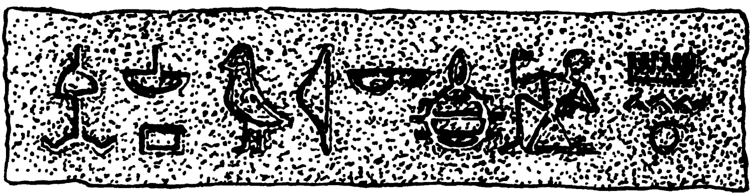
As we look backward down the tremendously long corridor of time which separates our day from the first crude beginning of tools, we feel a deep sense of wonder and awe as we see all that has been done since then to make our world what it is to-day.

In this book we have seen some of the discoveries and changes that have made this possible. Together we have watched the mining and smelting of ores, the building of furnaces and the invention of new ways by which metals are wrought or cast into tools.

As we watch the work of the miner and the smith, the armourer and the toolmaker through all the ages, and as we see them in their shops at the never-ending labour through which our world has been built and changed and improved, I think we may say with Master Jousse:

> "I may truly say that of all the mechanic arts there is not a single one which can compare with that of the iron worker, for our work is *useful and necessary*. The invention of our craft is so ancient that it seems to have taken place at the very birth of the Universe."

Or we may go still further back into the past and read this inscription on an Egyptian temple wall:



"OH, ARTISAN, THOU ART THE PERFECT MAN"

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