Man, Metals and Magic: The Ancient History of Metallurgy

500 A.D. – 1500 A.D.

Chapter VI

ALCHEMICAL THEORY did not permeate the western world for some time. While the Moslem empire of the Arabs grew around the Mediterranean, England – invaded by the Angles, Saxons and Jutes – passed through its most obscure period. Historically the period is a vital one to Britain for during the two centuries that followed the Romans' departure, changes took place – with little enough significance to the people that experienced them – that among other things, were to determine very largely the character of the people, their economy and their language.

The obscurity of this period is primarily due to a deficiency in valuable contemporary documentation. Such evidence might have been literary, as it was to some little extent in Roman times and to a greater degree in the middle ages. Or it might have been provided by material remains, as much of the history of the Roman Empire and before has been put together from relics that archeologists have unearthed with the hand of care and interpreted with the eye of faith. But there is a lack of such useful evidence in early Anglo-Saxon times for most material pertaining to this period is obtained from cemetery sites.

The objects, which were buried in the early Anglo-Saxon grave, included articles that the occupant had made or that were thought to be valuable. But sufficient iron implements and weapons have been found in excavations to enable the archeologist to say with certainty that iron making was still playing a valuable part in that dark period of the 5th, 6th and 7th centuries.
Excavations have shown that iron was used for weapons and agricultural implements. More importantly, there had been no decline in manufacturing skill that prevented the production of domestic articles like chains, bowls, caldrons and personal ornaments such as brooches and buckles. The smiths of pagan Saxondom then, did not lose their art. Indeed, the view has been expressed that as a result of the departure of the Romans, they were able to work with a new originality. Nor had they lost the independence that we have come to associate with the smiths for around 700 A.D. when Ecgwin, Bishop of Worcester, went to Alcester in Warwickshire to preach the doctrine of Christianity (at this time Christianity had spread pretty well throughout Britain), they demonstrated their feelings by clanging their hammers and anvils so the bishop could not be heard above the din.

By the late 7th century pagan practices had become rare, and the habit of burying the dead with their personal belongings came to an end. Christian doctrine was generally accepted in England, and the crude civilization of the last 100 years developed into a much finer way of life. This was reflected in many directions, both in arts and in industries. Culturally, Britain was further advanced than the rest of Europe.

Northumbria, which included most of what is now Yorkshire, was the focus of rejuvenated industry and produced knives of a fine quality, which found their way into Europe where they were acknowledged to be superior to other types. They were made of iron that was work hardened and carburized during forging. The cementation process of steel-making (which involves a controlled carburization, by packing pieces of iron into carbonaceous material and heating them to a temperature of 1800-2200^{O}F.) was not introduced into England until the 17th century, although it was known in Spain and other parts of Europe much earlier. The process of carburizing used by the makers of English knives was, in effect, fairly similar. As the knife was of thin section, carbon would be absorbed pretty well throughout, and the consistent quality of the products implies that the process was "understood" and controlled. The fact that English knives of the 7th and 8th centuries were far-famed has an interesting significance, for evidence shows that such cutlery was made near Sheffield, which retained its reputation as a steelmaking center.

The centers of learning were the monasteries where, in addition to the more worldly arts, iron making and metalworking were practiced. Laymen who lived in their homes outside the monasteries helped the monks in these pursuits. The metals were often used within the monasteries for ornamental and utilitarian purposes, for screens, lamps, and bells. The iron that was made was used in the monastery, disposed of locally, or sold to merchants from farther a field.

The monks became well known for their iron making and bell founding. Notable among them were Ethelwold, Bishop of Winchester, and Dunstan, Bishop of Abingdon, who in the 10th century founded bells for the Abbey at Abingdon. Each of these bishops has, apart from his greater contributions in other directions, metallurgical achievements to his credit. There is a legend of an encounter between St. Dunstan and the Devil, during which St. Dunstan seized the Devil's nose with the tongs he used at the forge. Although it is only a colorful story, it does somewhat illustrate the association between monastic life and industry (and possibly between industry and the Devil), particularly with respect to iron making. The records they left substantiate that monks were skilled in metalwork. In the early 11th century the Abbot of Abingdon, a most capable goldsmith, was requested to make a crown for Henry IV.

After the Norman Conquest, the position became very different. The newly appointed Norman abbots had no traditional skill in metalworking or, for that matter, in most arts. What was worse, many pieces of existing craftsmanship were destroyed or looted. As a consequence, laymen who were employed for that purpose executed most of the necessary works of art in the monasteries. Sometimes, however, a man so employed became a monk and possibly trained others within the monastery. Even so, craftsmanship was no longer so integral a part of the monastery, and it was particularly the more delicate arts, wood carving and precious metal working, that suffered.

The learning of the monks continued, however, and began to spread outside the monasteries. Arab alchemy, and through the Arabs, the earlier Greek ideas, began to be known in Europe. This was aided by the manufacture of paper, although the wider dissemination of written work was impossible until the later introduction of printing. Among European philosophers of this period, Roger Bacon, a Franciscan monk, is outstanding for his strenuous and fearless battle against prevailing ignorance, for his amazing forecasts of scientific developments, and for his insistence on experiment. Brilliant men are necessarily born before their time, and the worth of Roger Bacon was not immediately appreciated.

The iron making of the monks did not suffer like their finer arts after the Conquest and contributed to the general expansion of the iron industry in England during the 12th century and after. One reads of three forges given by the Norman Lord of Monmouth to the Benedictine Priory in exchange for land, of the forge in Louth Park belonging to the local monks who had permission to fell beeches and elms for charcoal burning, and of the Abbey of Flaxley in the Forest of Dean, where monks were allowed to take two oak trees each week as fuel for their forges.

There are two features in connection with the iron making of this period that are particularly important. First, the same process, essentially, was used to make iron as the Hittites, e.g., it was forged to remove the slaggy material and hammered into shape. Second, the furnaces and forges were heated by charcoal. During the expansion of the iron industry, this inevitably led to a severe cutting of the forests in which the forges were operated, which eventually produced a most critical situation in Britain.

Iron ore was taken from the earth by digging a pit about six feet in diameter. When the miner struck a seam of ore, he dug away all around it, leaving a bell-shaped hole. There were none of the elaborate tunnellings that were used for mining lead. The ore was easily obtained and when the miner had taken all the readily available ore from one bell pit he dug another. The ore was carried to the smelting furnace, which was usually situated in a wooded locality. It was more economic to carry the ore than the wood, for so much wood was needed. As trees were consumed, the furnaces were moved. Terrific amounts of timber must have been used, for in the Forest of Dean alone in 1282 there were 72 forges and, one presumes, many furnaces.

Nevertheless, the supply of iron in England was not enough to meet home demands, and foreign metal had to be imported from Spain and Germany, where techniques were similar in most respects to those in England. In fact, the type of furnace used in England, the Catalan forge (the word forge is misleading for it was a furnace) was first used in Spain. It was a simple hearth type of furnace built of stone, into which the ore, flux and charcoal were charged on top of a wood

fire and blown by an air blast introduced by a tuyere into the charge. The slag and sponge iron collected at the bottom of the hearth, and after about six hours, the lump of iron was removed and taken to the forge.

Here it was softened by a fire (encouraged by bellows) and worked until the metal was fairly free from slag and in the form of a round ball, called a half-bloom. This was taken hot to be beaten into a bar of a useful shape, and in this operation the iron had to be re-heated several times. The hammers were no longer wielded at the expense of a sweating brow and bulging biceps, but were usually actuated by a water wheel, whose projecting arms raised the hammer, which then fell on the hot iron. Water wheels eventually became widespread, particularly in Sussex when that county was the center of English iron making in the 16th century.

The First Blast Furnace

The furnace used by the Germans was similar to that used by the Spanish, but the furnace was heightened early in the 14th century, which made necessary a greater pressure of air through the tuyere. Actuating the bellows by a water wheel mechanism attained this. As a result of further increases in height, the charge took progressively longer to travel through, and the time of contact between the sponge iron and charcoal was increased. Now, while the melting point of iron is 2800^{O}F, this is progressively reduced as the iron absorbs more and more carbon. At a composition of 4% of carbon the melting point is only about 2100^{O}F – a temperature that was attained in a furnace of this kind. So the product was no longer a pasty, slaggy mass, but molten.

This, then, was the first blast furnace. Over the years it has been made bigger, the number of tuyeres has been multiplied and the blast pressure increased. Consequently its production is vastly greater. Undoubtedly it has become the most essential of all metallurgical devices, for upon it depends the production of pig iron, from which in turn, steel is made. This was not so in the 14th century, of course. But we are now in a position to appreciate, as we can look back and see discoveries fall into their proper perspective, that this small furnace in which molten iron was first produced was the seed from which all modern industry has sprung. The production of iron by this method is the most noteworthy advance since the manufacture of bronze. As far as our civilization is concerned, it is possibly the most important discovery ever.

It is difficult to say how much this was appreciated at first, for presumably the furnace was expected to produce only more sponge iron for the forge. Instead, it yielded a liquid iron, which on solidifying was hard and brittle and could not be forged. Probably, therefore, some time elapsed before any great importance was attached to the discovery. The medieval metallurgist did not produce steel from blast furnace iron as in the modern world, and consequently the only value of the metal was for uses to which it could be put directly – that is, as castings. The first purposeful castings in iron are supposed to have been made in Sussex, England, but the country is only accredited with the distinction because of lack of positive evidence.

Discovery of Gunpowder

Probably more dramatic in its immediate repercussions than the production of iron in the blast furnace, was the invention of gunpowder, another discovery that cannot be given an exact date or location. Throughout the centuries, clumsy weapons – the catapult, the ballista, the trebuchet and the mangonel – had been evolved. Now, concurrent with an improved skillfulness in metalworking, came gunpowder. The possibilities of this combination were obvious and the result inevitable.

Taking a rough average of all estimates, it appears that a German monk invented cannon at the beginning of the 14th century. That a monk was actually responsible is doubtful, and the date is equally questionable. The first use of cannon by the English is supposed to have been at the siege of Cambrai in 1339, or at Crecy in 1346.

It is indisputable, however, that the use of the cannon came rather before sound iron castings could be made, and therefore early guns were of bronze, brass or wrought iron, and they fired a stone. Within ten years of Cambrai, cannon already had an important place in the art of war waging. Their use, extended to naval warfare, was sufficient by 1345 to warrant the Keeper of the Wardrobe at the Tower of London being charged with the repair of ship guns and the adequate provision of ammunition for them.

One cannot help wondering whether public reaction was as confused and stunned in the 14th century by the introduction of the cannon as it was in the 20th century when the first atomic bomb was dropped in Japan. For just as the atomic bomb represented the first use of nuclear energy as an explosive force, so the cannon represented the first application of the violence of a chemical reaction to war making.

The Black Death of 1348-49 had a retarding effect upon metallurgical industries in Europe. It is said to have originated in the East, and appeared in England in August 1348, spreading throughout the country so that by 1349 Ireland and Scotland were as awfully affected. Had it not been for this terrible disease, the inevitable improvements in gun making might have come earlier. As a result of the 1,500,000 deaths (out of Britain's then population of 4,500,000) production fell, prices rose, and labor was at a premium. In an endeavor to ease the situation, Parliament passed the Statute of Labourers (1351), which among other things made it compulsory for a man to accept work at pre-Black Death wages. This law, which was re-enacted many times, was not successful despite the threatened branding of those who resisted it. Equally unsuccessful was the law of 1354, which forbade the export of iron. The general relevant effects of the Black Death, which only put them selves right gradually, were that natural progress was delayed and iron doubled in price. Steel, being very expensive and largely imported by the Hanseatic League, suffered a severe loss in demand.

European steel at this time was made only by cementation. The process had developed from the primitive carburizing technique of the Egyptians, but had not altered in principle. Because of the blisters that formed on the surface of the metal during the process, the product became known as "blister steel."

Perhaps the premature stunting of the demand for steel as a result of the Black Death explains to some extent the fact that the steelmaking process was so long delayed. It is not unreasonable to suppose that, knowing as they did the superior properties that could be conferred upon iron by carburizing, and having at their disposal the means of making molten iron, the 14th century smiths might, under less trying conditions, have introduced a melting and refining technique for steelmaking. As it was, the process of "fining" cast iron (to make it more malleable) was not discovered until the late 16th century. It was not until 1740 that steel was made by a melting process, and only in the late 19th century was a large-scale technique introduced.

No doubt the long delay is principally explained by the fact that nobody had the capability or perhaps the luck to make the necessary discoveries. Further, there was no great demand throughout the period to provide the needed incentive. Had the Death not scourged Britain the natural increase in the use of steel would probably have continued so that its eventual production on a large scale would have become necessary at a rather earlier date.

The Development of the Cannon

Although the Black Death retarded the progress of the iron and steel industries, and with them, the development of the cannon, it was not very long before wrought iron guns were being made in England and used abroad. The English left two of the earliest wrought-iron guns, which like the brass and bronze guns were breech loading, at Mont St. Michel, Normandy in 1424. These are fairly typical of the cannon made in the late 14th and early 15th centuries. They weighed 5.5 tons and 3.5 tons, and were about 12 feet long with calibers of 18 and 15 inches, respectively. Wrought iron rods were lashed longitudinally onto a mandrel to make the gun barrels. The rods were held in place by heated iron hoops, which contracted as they cooled. The mandrel was then removed, and the iron bars formed a barrel securely held by the hoops. Possibly molten lead was poured into the interstices, and the bars may have been roughly hammer-welded. If so, the caliber of the gun would be sufficient to allow a hammer to be used within the barrel.

By the end of the 14th century, the art of cannon making was fairly widespread. On the Continent, cast bronze and brass were used, while England employed wrought iron as well. Despite this, it is said that Continental iron was superior to English iron. The little steel that was used in England was largely imported – principally from Spain, but also from Sweden, Norway and Germany. Frequently, the Spanish iron maker went to English fairs where he sold his metal to the bailiff, who bought what would be needed on the farm. A smith employed at the farm would

use it to make the necessary nails, horseshoes, and tools. The great fair at Stourbridge was a market for the Spanish and the Sussex iron makers alike. As a result of an insufficient amount of iron that was made in England and its importance in ordnance use, it was too expensive to be used very much domestically. Jugs and pans of brass were more common than ironware, and they served a more utilitarian purpose than decorating the mantelpiece. It is popularly believed that in the reign of Edward III (1327-77) the iron pots and pans in his possession were ranked among the Crown Jewels.

At the beginning of the 15th century, blast furnaces were introduced into England, and this together with the steady immigration of Continental iron workers to England during the 14th, 15th, and 16th centuries, led to an expansion of English iron making. Consequently the country became less dependent upon foreign supplies. Then, in 1463, an Act of Parliament restricted the importation of many iron articles, including wire, the product of an industry that was later to thrive in England.

The expansion of the iron industry coincided with the increased facilities for spreading knowledge that were afforded by the introduction of Caxton's press in 1477. This eventually resulted in a wider and more rapid dissemination of knowledge than would have otherwise been possible. Until literature became widely and cheaply available, the practical difficulties attendant upon studying was usually insuperable. The student had either to have the opportunity and means of obtaining manuscripts or of traveling so that he could acquire his information at first hand.

The discerning reader will have noticed that the preceding section on iron making has been confined to Europe, and largely to England. This is not accidental, for the art sprang up there, and apart from an unproductive period between the middle of the 16th and 17th centuries, Britain remained the greatest producer of iron until the late 1800s. Before the manufacture of cast iron is considered (a long delayed advance in view of its discovery at least 100 years before) we must leave Europe and turn westward, where in preserving the chronology of this historical survey, we (with Columbus) discover America in 1492.

The Conquest of America By the Spanish

The story of the conquest of America by the Spanish is a story of the lust for gold. It is well known that Columbus was intent rather upon finding a direct route to India and China by sailing westward, than upon exploring the world for discovery's sake. When he landed on the Bahamas in 1492, the idea that he had reached India was encouraged by the gold ornaments the natives wore, and by having been told that more gold lay towards the south. He went by way of Cuba to Haiti, where he seized the gold that the natives obtained from the streambeds there.

In the early 16th century, after Columbus' death, a Spanish expedition was sent to Mexico. Off the coast it was greeted by the envoys of the Mexican chief Montezuma, who brought with them priceless presents, and a request for the expedition to leave. Tempted by the former and unperturbed by the latter, the expedition went on into Mexico. Further promises of gold had an affect quite opposite to that intended, and after a brutal and confused battle the Spanish conquered Mexico in July 1521.

At first the gold resources of the country were disappointing. The collected treasures of Montezuma, accumulated by him and his predecessors over many years, raised the hopes of the invaders too high. But within 20 years, rich deposits of gold and silver were worked – with a percentage of the extracted wealth going to the King of Spain.

A further expedition was directed to Peru in 1531, where aided by the circumstances of a civil war at the time, the small party finally subjugated the country. In the end, and before many years had passed, the whole of the west coast of South America and on to include Mexico, was in Spanish hands. The mines and deposits in the productive areas were being worked by native slave labor in a way that would have seemed brutal 2000 years before. The deposits were rich. Smelting processes were carried out in a primitive hearth without the use of bellows, but relying upon the wind, or the breath of a slave who blew through a tube. In time methods were improved when European metallurgists were brought to the Spanish possessions. But working conditions remained pitiable for many years.

By 1567 the amalgamation process had been introduced for the recovery of native silver. The native silver, which the Conquistadores obtained, was unavoidably contaminated with earthy

material. To separate these, the mixture was washed over mercury, when the silver was captured and the dirt was swilled away. The amalgam was collected and then heated to distill off the mercury, leaving behind pure silver. As the Spaniards had vast deposits of cinnabar (a sulphide mineral of mercury) in Guancavelica, the process could be economically exploited, and it led to a greatly increased production of silver from native deposits. Later the amalgamation method found wide applications in extracting gold, which behaves in the same way as silver.

Owing to unreliable evidence one cannot be certain how far metallurgical techniques had progressed before the conquest of South America. It seems, however, that the natives had not advanced very far in any cultures and their extraction and use of metals were primitive. In most places they had only just begun to learn the value of bronze, and almost all of the pre-Conquest implements were made of copper, or even of gold and silver.

So, from our point of view, the exploitation of South American in the 16th century is of interest mainly because it opened up new resources that are still vast and vital. While there was little contribution to the progress of metallurgical methods, in forming an opinion of the Spaniards' metallurgical achievements, one must, when their conquests are considered, weigh their bravery and exploits again their brutality. Their initial lack of progress has to be balanced against the improvements that their buying power stimulated, and the slavery they enforced set against the prosperity for which they were responsible. The final state of the balance sheet depends upon the temperament of its auditors.

England's Developing Reputation for Ordnance

Meanwhile, English iron making and gun founding continued. By the end of the 15th century, cast iron cannon balls were being made, and the explosive shell had been invented. The greater precision allowed by a cast iron shell over the rough-hewn stone shot resulted in more accurate and forceful firing, while putting a greater strain upon the gun. By this time too, gunpowder was more certain and violent in its explosion. A state of affairs was reached when, due to the tendency of cannons to burst, the hazards were probably as great to those firing the guns as to their enemy. One can appreciate the birth of the expression "sticking to one's guns."

England quickly achieved a high reputation for her ordnance, and became independent of imports. Additionally, during the reigns of Henry VII and Elizabeth I there was a strong demand for her weapons abroad. In the 1580s it was suspected that Spain was importing English guns -- which, as a result of her American acquisitions she could certainly afford to do – in order to equip her Armada. For a time, therefore, the export of iron and brass was forbidden. Some, however, was still smuggled out of the country, and a number of English cannon are said to have reached Spain.

An unfortunate effect of increased iron making was the further destruction of England's forests. Fears began to be expressed about a future shortage of timber for domestic purposes and shipbuilding. Acts of Parliament were passed restricting the areas from which wood might be taken, the most limiting being the Act of 1584. It forbade the erection of new iron works in Surrey, Kent and Sussex, and ordered that iron works already in those localities were not to use timber "one foot square at the stub." Although the Acts were not strictly enforced, they served at least to check the consumption of the English forests by the iron makers. Consequently, Britain found that she had made a home market for iron that she could no longer satisfy. As a result, she had to look abroad for supplies.

With the reduction of British iron production, she looked to Sweden for iron imports, and the development of the Swedish industry roughly paralleled Britain's. Sweden however, having the natural advantage of immense forest, and without England's obligation to maintain and build a Navy, was not compelled to cut down her production as Britain was in the 16th and 17th centuries. During this period, Swedish iron making assumed an increasing importance and was eventually responsible for about one third of the world's production – 80% of which she exported. Her exports to Britain sometimes equaled the amount that Britain herself was able to make. Perhaps it should be pointed out here that Finland was until 1809, part of the Kingdom of Sweden, and therefore contributed to Swedish output.

Being, perhaps, so completely acclimatized to the gigantic production figures of the modern world's blast furnaces, we neglect to consider the small scale of 17th century operations and comparatively restricted demand for iron products. Around 1700, world production of iron was

between 100,000 tons and 150,000 tons per year, whereas by the middle of the 20th century, worldwide iron and steel production were on the order of more than 312,000,000 net tons. Regrettably, those figures did not imply that man had become any more capable of using our iron sensibly.

By 1730 Swedish production was beginning to meet serious competition from Russia. About this time, too, the world picture of iron making was completely changed by the introduction of coke, which replaced charcoal. But we are jumping too far ahead, for the discovery of coke making was preceded by quite a different sort of contribution to metallurgical progress – the publication of metallurgical textbooks.

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