University College of Swansea.

METALS and MANKIND: From Anglesey to Hiroshima

Inaugural Lecture of the Professor of Metallurgy delivered at the College on February 12th 1948

by

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The march of time is responsible for this Inaugural Lecture. In 1921 Dr. C. A. Edwards, F.R.S. was appointed as our first Professor of Metallurgy, and his retirement in 1947 brought to a close a period of most fruitful activity as University teacher and researcher. The long list of nearly fifty published papers from the Metallurgical Department is a witness to some of the work which Dr. Edwards inspired and encouraged whilst in South Wales, and we all join in wishing the Emeritus-Professor many happy years free from administrative cares.

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Introduction and Summary

THE importance of metallurgy shows no signs of diminishing, for we are still in the Age of Metals. The ambition of the late Henry Ford actually to " grow " a motor-car is a reminder that organic compounds known as " plastics " may replace metals to some extent, yet the approach of an era when power will be obtained from metallic atoms considerably increases the responsibilities of metallurgists. Furthermore, the necessity of reducing production costs in our factories means a demand for more efficient processes. The training of metallurgical students must therefore be undertaken with these two prospects in mind.

Historical considerations have prompted the title of this lecture, for the history of a technical subject forms a link with its human aspect. It may be helpful if I summarise the ground which will be covered. I propose to give some particulars of a few isolated periods connected with the development of metal-working in Britain. Emphasis will be placed on the metallic property of ductility, for craftsmanship has relied upon it from very early times. The results which have been obtained leave us marvelling at the inherent capabilities of mankind, but unfortunately swords are always in demand as much as ploughshares, and destructiveness cancels much of the progress which is made. Praiseworthy researches in universities about the structure of the atom and the reason *why* metals are ductile have finally left us with that ambiguous gift, the atomic bomb. The conclusion may be drawn that the present crisis of our Metal Age is not brought about by any shortcomings of physical science. It is due to a poor technique on the part of mankind in adopting rules which are necessary for the Good Life. Since the universities have given us the atomic bomb, they should equally exert themselves as civilising influences to counteract its possibilities for evil.

I have said that metals entered the service of man because of their ductility. Gold for instance, may be beaten out into leaves only 1/300,000 of an inch in thickness. The cold rolling of steel is a great industry in South Wales which depends upon this property. There is something paradoxical about the metallic state for whilst it chiefly implies plasticity and toughness, yet it also suggests durability and hardness. A given piece of metal may sometimes possess either type of property depending upon its previous treatment. This is why metal replaced flint and bone, but since it was pleasing in appearance and scarce at first, the initial use was for precious ornaments. Almost at once came the production of cutters and hammers and axes in bronze. We then encounter the mixed nature of man who will employ raw materials indiscriminately for tools, weapons, ornaments and the accessories of religious practice. Throughout the ages the arts of war and peace have competed with each other, and treasures and monuments painstakingly acquired are lost periodically as a result of conflicts. A primitive metal smith will one day hammer-out a lump of ductile iron, bend-over the sheet and rivet it to make a handbell. Next day he will fashion a bronze casting to produce a sword. The medieval foundrymen who cast the large church bells eventually modified the design and produced the first great mortars for the armies. The artillery contest of the irresistible projectile and the impregnable defence is still with us, and new hard cutting-alloys which will turn glass in lathes as though it were cheese now find employment as anti-tank bullets. Natural philosophers have busily speculated for centuries on the ultimate nature of metals, and unitary theories of matter, backed by the needs of princes, prompted the quest to transform base materials into the " perfect " element—gold. Men of science have at last succeeded in effecting various transmutations, from which it has been but a philosophical stone's throw to atom-splitting or nuclear fission. The atom bomb burst open a new era with consequences for good or evil which remain to be seen, and now the race is on for metallic uranium which is probably the key strategic material in the world to-day. This is the picture for our further study.

Ancient Welding and Early Tinplate

You will remember that the Bard in Gray's famous poem saw from a mountain in North Wales the pageant

of the past and the shape of things to come. As a starting place I would invite you to Holyhead Mountain, for Anglesey has special points of interest. During a holiday there I came across at Ty Mawr, on the western slopes of the hill above South Stack, the remains of some prehistoric circular huts. One of these proves to be the dwelling place and workshop of a metallurgist who flourished during the second millenium before Christ. This was the time when Ireland was beginning to produce flat copper axes and beautiful ornaments of pure gold, and on very clear days our smith would be able to see the Wicklow Hills which were the source of all this remarkable wealth. Anglesey lay on a sea route which made it susceptible to Irish and Scottish influences, and the dawn of the Age of Metal in Wales depended upon geographical factors.

The traffic from Ireland included the lunulae or " little moons " of thin gold about 8 inches across which adorned the necks of very important persons. The distribution of finds of gold ornaments of the Bronze Age shows that some were discovered in Anglesey and one in Glamorgan. An archaeologist's reconstruction* of Ty Mawr workshop depicts, built into the wall, a small bellows furnace having a well at the bottom about 1 ft. diameter and two inches deep. Charcoal and pounded ore produced a cake of bronze in the well which was subsequently melted in crucibles. Close beside the furnace was the casting pit to accommodate a mould for either axes, spear-heads or swords. A fire towards the centre served for the smaller operations and for domestic purposes, whilst on a work-bench located near the door, the cast metal was hammered into sheet with stone tools. The smith probably travelled from one chieftain to another and carried his tools, together with a supply of metal upon which to work.

Anglesey has recently yielded some more metal objects of this early period. During 1943, a new aerodrome was being made near Valley, and the work required the removal of peat from a bog at Llyn Cerrig Bach. An inspector noticed that the local farmer was towing his agricultural machinery with a curious iron chain. It transpired that this had been recovered from the bog, and expert examination indicated prehistoric metal. Eventually, the peat yielded about ninety objects (probably not of local origin) of the 1st or 2nd

* Maryon, H., *Proc. Roy. Irish Acad.*, 1938, 44, 181.

century B.C., including swords, spears, parts of vehicles, horse furniture, welded slave gang chains, iron currency bars (a kind of coinage) and a trumpet from Ireland.†

A glance at Table I shows that the slave chain is somewhat higher in phosphorus than Roman irons of a later period.

TABLE I.—CHEMICAL ANALYSES OF ANCIENT IRON SPECIMENS

	British Slave Gang Chain ex Anglesey	Roman Bloom† ex Corstopitum nr. Hexham	Roman Chisel ex Chesterholm*
Carbon	0·07%	0·06%	0 - 1·3%
Silicon	tr.	tr.	0·038
Manganese	tr.	tr.	tr.
Sulphur	tr.	0·008	0·011
Phosphorus	0·15	0·063	0·016
Remarks	Probably made in East Anglia. Welded.	Weighs 3 cwt. Welded in sections.	8 in. long. Steely zones. Not carburised. Martensitic patch at part of chisel edge $H_D = 579$

† *J. Iron and Steel Inst.*, 1912, **85**, 118.
* *Proc. Univ. Durham Phil. Society*, IX, p. 141.

A cast bronze chariot axle cap bore the ancient emblem of the swastika—but we may surely consider it as denazified after a submersion of twenty centuries. There were some iron tyres—probably for chariot wheels. One of them is 2 ft. 6 in. in diameter and 1·5 in. wide and consists of a strip of metal which had been joined by welding. An ornate horse bridle bit of wrought iron had been coated all over with bronze by the casting-on process. The work had probably been done in Gloucestershire and should interest those of us who live in the tinplate area. A site at Bredon Hill has yielded similar prehistoric bridle bits of iron coated with tin—an anticipation by eighteen centuries of the subsequent introduction of tinned iron into the Severn region. Some iron currency bars were also found in Anglesey. Nearly 2,000 such bars are known and it is interesting that these new finds prove to be of one of the previously recognised standard weights of 300 grams.

About 500 B.C. the Irish gold trade was waning but objects of copper alloy continued to be made in Wales. It was around this time that bronze and iron working took place at Merthyr Mawr near Bridgend, and bronze razors of this period have been found in the region. After the Roman invasion, the occupying power in both South Wales and Anglesey carried out considerable

† See "*Interim Report*," Sir Cyril Fox, Nat. Museum of Wales, 1946, Cardiff

metallurgical operations, and its great exploitation of the copper ore in Parys Mountain near Amlwch reminds us of this once-famous source of Welsh copper. The local copper smelters at Neath imported the Anglesey ore from 1768 onwards, but the traffic which reached its zenith in 1787 (4,000 tons output of copper) has now ceased, and the derelict plant at Amlwch is a sad reminder of a once-flourishing industry. The invaders from the north who descended upon Anglesey after the departure of the Romans, left behind some metallurgical objects of the 6–9th century A.D. comprising silver brooches and armlets.

Cornwall and Tin

Finds of the Bronze Age are very extensive and are fairly evenly distributed all over Britain. * Appreciable quantities of tin ore would be needed for making the alloy, and this must have come from Cornwall. Whilst admitting the existence of prehistoric workings in that county, examination shows that there is practically no justification for the belief that the Phoenicians from the Eastern Mediterranean traded with Cornwall for the metal. Their supplies came from "The Cassiterides"—the tin islands, but it is the identification of these which is the problem. A suggestion that one of them might be St. Michael's Mount applies almost as well to Mont St. Michel in Brittany. The documentary evidence for the Cornish tin mines only dates from 1156, so we are left to archaeological evidence and speculation. The protagonists of the Phoenician story eliminate various possible sources for that traffic of knuckle-bone shaped ingots which went on through Marseilles, and they are finally left with Cornwall. It seems however, that Brittany and Spain would do just as well.† Julius Cæsar mentions that the Britons smelted tin, but states that it was done in the midland districts, and apart from one single known Roman ingot of the metal found at Carnaton there is no evidence that the Romans exploited the Cornish deposits to any great extent.

The later discovery of tin in Cornwall is said to be due to St. Perran‡ who was born in Cork or Ossory about 350 and settled near Padstow. A black stone used in his hearth was found to have "melted" and

* "Historical Geography of England," H. C. H. Darby
† See also "Roman Mines in Europe," O. Davies, Oxford, 1935.
‡ See *Nature*, 21/1/28 and 3/3/28.

produced a white metal. From this simple reduction process a method of quantity production was devised, and Perran became the patron saint of Cornish tin miners with a feast day on March 5th.

Another metallurgical patron is St. Dunstan, who commenced his work at Glastonbury. After appointment as Archbishop of Canterbury late in the 10th Century, he lived at Mayfield amongst the Sussex ironworkers. In the palace are still preserved his anvil and hammer and the tongs with which, according to the Saxon Chronicle, he fought the devil:—

" St. Dunstan so the story goes,
Once pulled the devil by the nose
With red hot tongs which made him roar,
So he was heard three miles or more."

The Goldsmiths Company of London still relies upon the saint to keep the devil in his proper place. The City Companies were always imbued with a religious spirit, and we may note that " God, the only Founder," is the motto of the Founders Company.

Monastic Mining and Metallurgy

In his recent inaugural lecture, the Professor of Education paid a tribute to the cultural work of the monasteries in Wales during the Middle Ages. It is not generally appreciated that these religious foundations also played a considerable part in the development of mining and metallurgy. When the barbarian hordes overthrew the Roman Empire and swept across Europe, it so happened that Ireland escaped and remained an undamaged power-house of culture. From the time of its conversion to Christianity until about the 11th century, the western isle maintained monasteries which were not only seats of learning but centres of metalwork. The Celtic missionaries who then brought Christianity eastward to Wales, Scotland, Northumbria, France, Switzerland and North Italy also carried with them their Irish metalcraft. " Hibernian art at its best was, even in matters profane, essentially a monastic phenomenon," states Adolf Mahr.* An example of this splendid work is the 11th century container for St. Patrick's bell, shown in Fig. 1. Early monastic handbells from Wales of a similar shape and probable origin, are preserved in the National Museum at Cardiff.

* See Mahr, A., " Christian Art in Ancient Ireland," Dublin; also Hudson, D. R., *Metallurgia*, April and May, 1945; and " Celtic Art in Pagan and Christian Times," J. Romilly Allen, London, 1904.

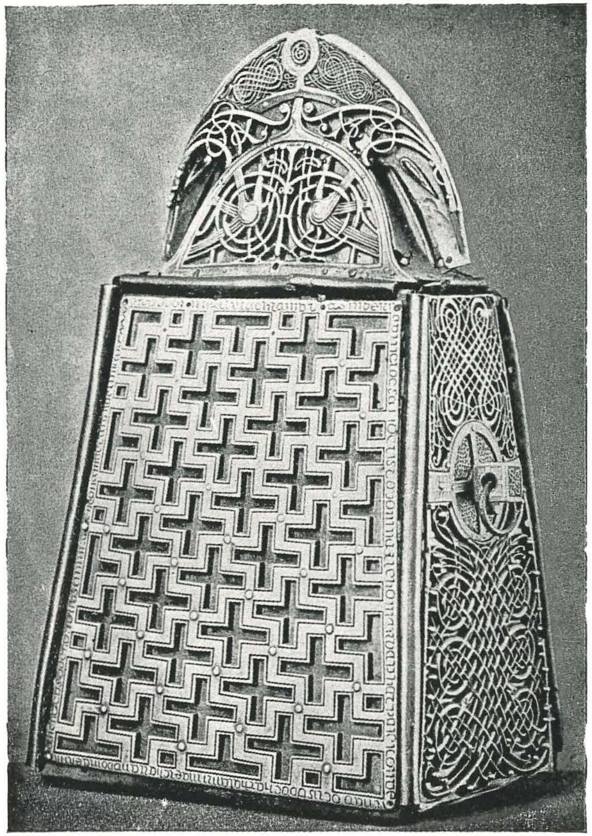

Fig. 1.—Shrine of the Bell of St. Patrick's Will in gold. (A.D. 1091) Note the cross and swastika pattern, and the interlacing metal work at the side. Reproduction one-third actual size.

We should therefore, expect the subsequent development of the Benedictine houses in Britain to lead to renewed metallurgical activity, especially since the author of the Benedictine rule expressly stated that his followers were to look upon themselves " as true monks, when they have to live by the labour of their hands." The Cistercians were associated with much of the mining work in the Pennines especially in the 14th century, for this congregation had been engaged in making iron and steel since the 11th century, at the

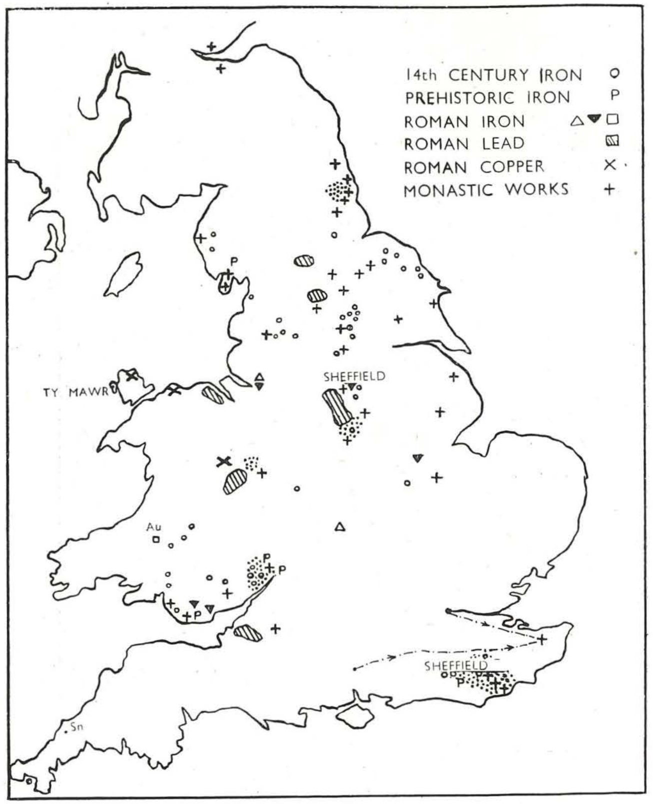

Fig. 2.—Monasteries associated with metallurgical work in Britain during the Middle Ages, together with sites of pre-historic and Roman workings. (The Pilgrims' Way from Winchester and London to Canterbury is shown as a dotted line). Roman iron workings are shown as dotted areas.

Grande Chartreuse in France.† The cross and globe trade mark seen on bottles of Benedictine liqueur is also to be found on the medieval iron and steel products which issued from this great monastery.

The earliest reference to iron mining in Wales, for which I am indebted to Mr. Wyndham Wilkin, is an indenture dated 1253, granting to the monks of Margam Abbey " all manner of iron and lead mineral " on lands at Cornelly, near Pyle. There is a similar grant to the

† Brangwyn, J., " Reasons for France," 1939.

monks at about the same date involving an annual rent of a coulter and a ploughshare as long as they use the mineral. It seems probable that the monastery would make the ploughshare and pay it to the landlord. Another grant gave the monks the right to obtain mineral coal. Charcoal, however, was used for smelting and the " bloomeries " were sometimes portable and were moved about amongst the " bell pits " from which the ore was obtained. The refined iron was at first forged by hand after heating in a hearth fitted with hand bellows as may be seen in a 12th century drawing of blacksmiths.

A list which I have collected of nearly fifty religious houses engaged in mining and metallurgical work in Britain during the Middle Ages is given in Appendix A. The location of each monastery associated with such operations is shown in Fig. 2 and the sites of pre-historic and Roman workings are also marked. It is probable that the one grew successively out of the other. The monasteries and churches also needed bells to ring the hours for Office, and monks were directly associated with this type of metal founding. The bells were sometimes cast in the churchyards or even in the church or sacristy itself.

I think it is fair to say that, although these Middle Ages were lacking in the amenities which we know to-day, they were permeated by a philosophy which gave unity and meaning to life. The Churchmen founded the universities and maintained an integrated connection between the different Faculties which it is generally regretted is now being lost in Britain. They took a long view of things—even in metallurgical affairs. There is a hint* that in order to preserve the woods which yielded charcoal for smelting, a conservative policy of woodcutting was adopted. After the Dissolution, the new landlords continued to get rich quickly by burning up the forests and thus landing the trade in difficulties. Similarly, although barbarous conflicts were plentiful in medieval times and Churchmen went to war, yet they succeeded in mitigating some of its horrors by encouraging chivalry and instituting measures like the Peace of God (990) and the Truce of God (1027), which imposed limitations on the destruction. It has been left for our times to sink back to total war.

* Schubert, H. R., *J. Iron and Steel Inst.*, April, 1947.

Sheffield in the Middle Ages

War and peace are associated with cutting tools and my native Sheffield has a long-standing reputation for cutlery. Ordinary tools in medieval Britain were made from various local irons, but steel for the finer tools and weapons was imported.† A high standard of cutlery manufacture was attained in Northumbria in the 8th century.‡ Sheffield believes that its fame goes back to an entry of 1041 in the Priory Wardrobe of the Tower of London, which refers to "Cultellum de Sheffield." Then again, there is the 14th century Miller in the Reeve's Tale of Chaucer who is a noteworthy person amongst the Canterbury pilgrims because "a shefield thwytel bare he in his hose." Metallurgical references to Sheffield at those times are somewhat ambiguous, for whilst the map (Fig. 2) shows Sheffield in Yorkshire (Hallamshire district), there is also a second one in Sussex, exactly on the meridian of Greenwich and seven miles north of Lewes. To-day, it is a small spot reached from Sheffield Park Station on the Southern Division of British Railways. A digression to compare the claims of these two places as being famed for cutlery in either the 11th or the 14th centuries may be of interest.

There is a shortage of records about Hallamshire, but there are plenty of documents about the Weald. We know that horse-shoes, nails and bars of iron went up to London from Sussex at an early date. We saw that the finds in Anglesey included prehistoric iron tires for wheels, and a trade in these articles also flourished in the south. The Guild of Feroners (Ironmongers) of London, lodged a complaint about 1300 against the smiths of the Weald for making and selling iron tires too short for use. The result was action which forestalls our British Standards Institution; for it was ordered that standard length rods were to be set up in the markets.

As regards the necessary metallurgical materials, there was plenty of wood in both districts, and certainly plenty of furnace lining refractory in the north. Phosphoric iron ore of poor quality existed at the two sites, and prehistoric iron slags have been found in both places. There was only one Roman bloomery at

† Schubert, H. R., *J. Iron and Steel Inst.*, Dec., 1947.
‡ Schubert, H. R., *J. Iron and Steel Inst.*, Sept., 1947

Templeborough near Sheffield, but twelve have been traced amongst the extensive ancient workings in the Weald.

It is sometimes suggested that Sheffield on the Don in Yorkshire and nearby Rotherham on the Rother, were natural centres for cutlery because of abundant streams for working waterwheels to blow furnaces, forge metal and turn grindstones. But Sheffield on the Ouse in Sussex, and nearby sites on another adjacent river Rother, were equally well provided with waterpower. In any case, the forge at Byrkeknott (Durham) as late as 1408 is the first definite example of a water-driven hammer—though Domesday Book records what may be four water mills for iron at Lecheswrde in Somerset, and there is a French reference to "moulin a fer" in 1249.* Saltzman† states that bellows were generally worked by hand prior to the 15th century, so that the waterpower argument is not convincing. A power-hammer is known to have existed in 1496 at Newbridge (or perhaps at Steel) in the Weald, whereas the smithy wheel at Norton for example, near Sheffield, dates from 1560.‡ There must have been earlier ones, and after the adoption of waterpower in the late 15th century, there was a phenomenal rise of the Hallamshire cutlery trades. This, of course, suggests that there had been some previous experience of the work.

There was a traffic in high quality Swedish bar iron to South Yorkshire in the Middle Ages, and it has been suggested that this material was turned into steel locally by carburising in small cementation furnaces. Unfortunately, the earliest definite mention of a Steel works is 1523 and in Sussex, with several "steel" furnaces reported at Robertsbridge in Sussex in 1609. Ellyot and Meysey obtained a patent for converting iron into steel by a cementation process in 1614 and established works near London, where "at this day probably the best and finest knives in the world are made," as a contemporary put it. This may be painful reading for people from the banks of the Don, but one must note that Overseers of Cutlery were appointed for London in 1344 and a charter was conferred on its Cutlers Company in 1415. It was not until 1624, and after overcoming objections from the City, that the

* Straker, E., "Wealden Iron," 1931.
† "English Industries of the Middle Ages," L. Saltzman, Oxford, 1923.
‡ *Engineering*, 1948, **165**, 165.

Cutlers Company of Sheffield and Hallamshire was incorporated. Its earliest ordinances date from 1565 and the movement was in existence before that date.

From the beginning of the 13th century, the Weald rapidly began to supplant the Forest of Dean as the great iron-producing district, and Sussex was our Black Country in the Middle Ages.* Its Sheffield mills had eight men working in them in 1549 and 23 in 1594. High quality products could have been produced, for a considerable amount of good Spanish ore was imported into the district from an early date. Although the Poll Tax records of Richard II for 1379 note one cutler resident in " Sheffield," and Leland (16th cent.) found long-established cutlers in Rotherham and Sheffield, yet there is a strong suspicion that the knife carried by Chaucer's miller had come from the Sussex district only a few miles distant from the Pilgrims' Way.

Iron and Steel in South Wales

There is a link between the Weald and Glamorgan following upon the Dissolution of the Monasteries, for the Abbey of Robertsbridge in Sussex was given in 1541 to Sir William Sidney, father of the poet. He started ironmaking there and imported some German workmen. The venture was not very successful and in 1565 they were brought away to premises at Pentyrch, near Cardiff. In Elizabeth's time, a gun founding and iron casting industry developed in Taff Vale and Caerphilly, the "charcoal iron" industry appeared in Monmouthshire in 1558–1603, and tinplate was introduced in 1665–1720. The old mine workings af the Weald and South Wales were very similar in type, apart from practices in the latter district known as " hushing " and " scouring."† The 17th century saw a great set-back in iron production all over Britain owing to the denudation of the forests, but local activity was renewed about 1770 when pit coal replaced charcoal. Mention may be made of the old Welsh Bloomery process in Glamorgan and also of a method‡ of converting iron to steel by passing it nine times through a fire composed of charcoal,

* Delany, M. C., " The Historical Geography of the Wealden Iron Industry," 1921.

† Topley, " Geology of the Weald."

‡ Tradition recorded by Edward Williams (1812) in the Llanover MS. in the National Library of Wales. In the early 17th century the art of making steel was kept a secret. See " Vom Ursprung und Werden der Buderus' schen Eisenwerke Wetzlar," Munich, 1938.

horns, hoofs and bones. This was associated with the saying :—

" Tri chaled Byd, y maen Cellt, Dur naw Gwynias, a chalon. Mab y Crinwas " ;

which has been translated :—

The three hardest things in the World—a flint stone ; the steel of nine fires ; and the heart of a miser.

The components of this fire are those of a good carburising mixture such as is used in case-hardening, and it is easy to appreciate that cemented steel could be produced in this way. Finally, there came Dr. Siemen's melting furnace at Landore, producing soft open hearth steel to replace iron (1875), and to-day, we have the developments of the Steel Company of Wales.

Physical Metallurgy

Our metal smith in Anglesey may well have pondered over the reason why his bronze behaved differently from his stone hammer, and we are still wondering about it to-day. The science of metallography started in 1864 and eventually showed that a piece of metal consists of a conglomerate of crystals. The spangles on the surface of galvanised steel sheet are crystals of zinc and the crystalline nature of the basis steel itself may be demonstrated with the microscope. By using beams of X-ray light it is also possible to obtain rainbow-like photographs which tell how the atoms are packed together in the metallic crystals. The science has now reached a stage where atomic physics is a most important consideration, and in enquiring as to the cause of ductility and electrical conductivity we have learnt a great deal about the atoms themselves. We know that the central positive nucleus of each atom is surrounded by systems of negative electrons. The nature of the electron system determines the physical properties of the atoms and of the metallic crystals built up from them. We know of nearly one hundred elements, more than half of which are metals, and they can be set out in families or groups on the basis of their atomic numbers, i.e. on the number of electrons associated with each particular atomic nucleus. When we plot the measured hardness of the metals on this basis, a periodic behaviour is observed : a rise and fall of hardness in each group (Fig. 3). Notice that magnesium has 12 electrons per atom with an indentation hardness of 30 kg./sq. mm.

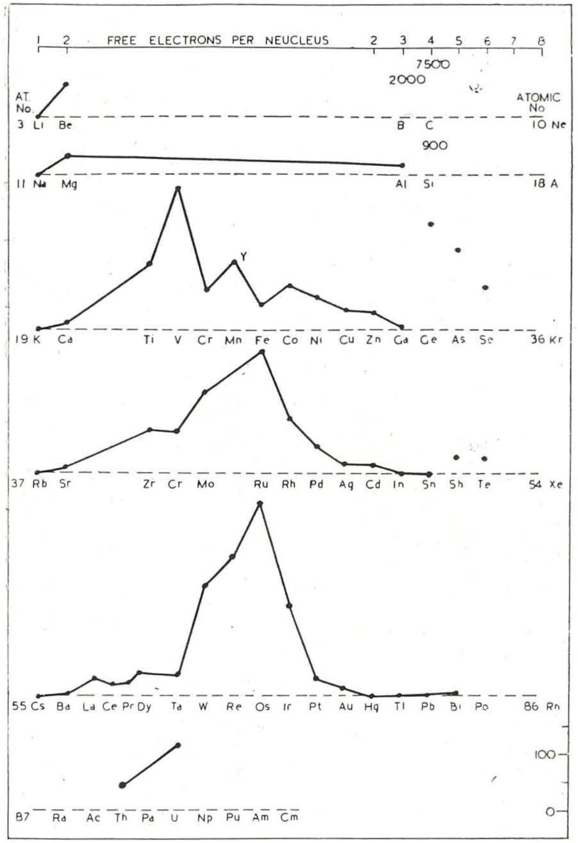

Fig. 3.—Brinell hardness and atomic number of the metals

and aluminium with 13 electrons per atom has a hardness of 16. At the bottom of the list comes uranium, which has 92 electrons, is eleven times heavier than magnesium and has a hardness of 120. Alloys of magnesium and of aluminium can be manufactured which have a strength and hardness roughly equal to that of soft steel, and we can use them in building an aircraft capable of carrying bombs. Uranium can be manipulated so that it will rapidly release enormous energy and thus act as an explosive. The aeroplane and the uranium came together over Hiroshima on August 6th, 1945, the £500 million bomb was exploded, 80,000 people soon died as a result, and Japan was brought to its knees.

The explosion came from a rapid chain reaction involving nucleur fission. By bombarding atoms of uranium 235 with atomic projectiles called neutrons, the uranium nucleii split apart with the release of great energy, injurious gamma radiation and some more bombarding particles. The latter pass on and repeat the fission process, which rapidly builds up and cascades into an explosion. It is something like dropping a lighted firework into a box of fireworks.

If the process is controlled and slowed down, then the energy can be used for heat and power purposes, and the radio-active products are also valuable. Gigantic factories are needed for preparing the materials, and a water-cooled uranium graphite pile, with its shielding, weighs many thousands of tons. The gigantic Oak Ridge Plant, Tennessee, which incorporates the Clinton National Laboratory, makes uranium 235 from the ordinary metal, and has a staff of 43,000 people. It has been stated that radio-active materials produced here might increase agricultural productivity enough to outweigh the cost of development up to now.

It is, surely, a hopeful sign that the United States Government on January 1st, 1947, lifted the atomic energy organisation right out of the military atmosphere by handing over the Army's "Manhattan District Organisation" to a purely civilian Board.* The Atomic Energy Commission of the United Nations has also shown its concern with the necessity for research and education in connection with the new processes. Since January 1st, 1948, the Oak Ridge Plant has therefore been taken over by the University of Chicago for peace-time service. The Los Alamos Plant in New Mexico is now being operated by the University of California. Nine associated eastern universities and twenty-nine participating mid-west universities are controlling the Brookhaven and the Argonne National Laboratories, respectively. The U.S. colleges are thus being given a privileged place in developing the atomic processes.

We must remember that there were great outcries at the introduction of the long bow and of gunpowder, but the atomic weapon is much more potent as a means of wrecking our civilisation. The existence of various Associations of Atomic Scientists shows that technical men are not indifferent to the tremendous dangers

* "Atomic Energy: Its International Implications," R.Inst. Int. Affairs, 1948.

which now exist. It is for mankind to set its course, perhaps at least by an attempt to abandon " total war " and agree once more upon limits to the extension of military operations. One noteworthy point about the last conflict was that poison gas was not employed. The Universities of Yale and Chicago have already taken a lead in preparing plans for international control and our colleges could play a part, not by hasty resolutions about refusing to fight for King and Country, but as realistic individual centres of culture and leadership.

At the beginning of this lecture, we noticed a Welsh poet who, from his lonely mountain height, denounced the conqueror and the destructive work of warriors. We must also note that the closing lines of The Bard breathed a note of optimism which should apply to-day. The killing flash released at Hiroshima by the Allied leaders almost obscured the sun by its brightness, but we must stretch the final words of the poet to suggest a peaceful future for the atomic energy of metals :—

> " . . . think'st thou, yon sanguine cloud
> Raised by thy breath, has quenched the Orb of day ?
> To-morrow he repairs the golden flood,
> And warms the nations with redoubled ray."

APPENDIX A

References to Metallurgical and Mining Activity in Britain Connected with Monastic and Religious Establishments

Establishment	Order	County	Notes
Bath, Bishop of ..		Mine in Somerset	Richard I granted lead mine.
Battle Abbey	Benedictine ..	Sussex	Owned iron working sites. In 11th century had cast bells probably made in grounds.
Beauchief Abbey ..	Premonstrat ..	Derbyshire ..	12th century. Coal and iron workings.
Beauvale Priory ..	Carthusian ..	Notts.	Leased coal mine at Newthorpe.
Beverley		Yorks.	One of the monks was a fine goldsmith.
Bolton Priory	Austin Canons	Yorks.	1294, obtained sea coals for their *forge* near Colne.
Bridlington Priory ..	Austin Canons	Yorks.	Worked iron in 12th century at Blubberhouses in Beamsley.
Byland Abbey ..	Cistercian ..	Yorks.	1180, iron mine at Denby.
Canterbury, Abbey of St. Peter of			689, received land " in which there is iron ore."
Conishead Priory ..	Austin Canons	Lancs. .. .. (Lake District)	Iron workings.
Crowland Abbey ..	Benedictine ..	Lincs.	
Darley Abbey	Austin Canons	Derbyshire ..	Charters show iron worked in 1270, Pentrich Wood, Ripley.
Dunfermline Abbey..	Benedictine ..	Fife	1291, charter to work coal at Pittencrieff.
Durham Priory ..	Benedictine ..	Durham	12th century lead mine.
Durham, Hugh Pudsey, Bishop of ..			Later half 12th century iron mine at Rokehope for making ploughs. 1354 coal mine.
Durham, Bishop Hatfield of	.. .. ..	.. .. ..	1356, Bishop had five mines on lease to Rector of Whickham. 1492, Whickham mine had a water lift.
Durham, Bishop Langley of	.. .. ..	.. .. ..	1408, John Dalton, first known Durham iron-master, worked a forge for the Bishop.
Cardinal Wolsey, Bishop of Durham	.. .. ..	.. .. ..	1528, built furnace to smelt lead with coal. Fell from power before test could be made.
Evesham Abbey ..	Benedictine ..	Worcester ..	Walter of Odyngton in time of Henry III gave earliest instructions for *Bell* founding, and bell size for various notes.
Finchale Priory ..	Benedictine ..	Durham	Horse pump at Moorhouse Pit in 1486.

Establishment	Order	County	Notes
Flaxley Abbey ..	Cistercian ..	Gloucester ..	Iron working for five centuries in Forest of Dean.
Fountains Abbey ..	Cistercian ..	Yorks.	12th century, given forges in Nidderdale.
Furness Abbey ..	Cistercian ..	Lancs.	1270, iron ore, and water rights for washing the ore. 1291, 40 forges working.
Hastings Priory ..	Austin Canons	Sussex	Had an iron forge.
Holyrood Abbey ..		Midlothian ..	Colliery at Carriden, nr. Blackness before 1214.
Jarrow Monastery ..	Benedictine ..	Durham	8th century, abbots were noted for iron-work and bell founding. 1313, used coal in monastery.
Jervaulx Abbey ..	Cistercian ..	Yorks.	1281, right to smelt iron. 1333, acquired coal mine.
Kirkstall Abbey ..	Cistercian ..	Yorks.	Worked coal and iron at Ardsley, 1154; Kirkstall, 1200.
Kirkstead Abbey ..	Cistercian ..	Lincs.	1161, iron mine and forge at Kimberworth, nr. Sheffield.
Llantwit Major ..		Glam.	Reputed Monastic Mint.
London, Richard, Bishop of	.. .. ..	.. .. ..	circa. 1160, Treasurer of England. Wrote "Dialogus de Scaccaris" concerning assay of Silver by Cuppellation.
Louth Park Abbey ..	Cistercian ..	Lincs.	12th century, iron bloomery and forge in Derbyshire at Birley (Barlow).
Margam Abbey ..	Cistercian ..	Glam.	1253, lead, coal and iron mining.
Monk Bretton Priory	Cluniac	Yorks.	Worked coal and iron.
Newbattle Abbey ..	Cistercian ..	nr. Edinburgh ..	1210–1214, grant of colliery on sea shore at Preston (Tranent).
Newminster Abbey..	Cistercian ..	Northumberland (Blyth)	1236, sea coal. 1240, coal for iron forge at Stretton, nr. Alnwick.
Nostell Priory	Austin Canons	Yorks.	Early coal miners. By Richard II's time deep pits required drainage. 1372, new Prior made an adit.
Peterboro Abbey ..	Benedictine ..	Northants ..	Saxon Chronicle of the Abbey (853) records quantities of coal, but some think ref. is to brushwood or peat. (See "Climate and the Energy of Nations," Markham).
Repton Priory ..	Austin nuns ..	Derbyshire ..	835, Abbess leased lead mines at Wirksworth.
Rievaulx Abbey ..	Cistercian ..	Yorks.	1170, worked iron ore in Barnsley (Bilsdale) district.

Establishment	Order	County	Notes
Robertsbridge Abbey	Cistercian ..	Sussex	"Iron and Steel works."
St. Albans Abbey ..	Benedictine ..	Herts.	One of the monks was an artist of great repute in metalwork.
St. Bees	Benedictine ..	Cumberland ..	12th century iron mine at Egremont.
St. David's, Bishop of		Cardigan	1326, lead mine at Llanddewibrefi.
Tintern Abbey ..	Cistercian ..	Monmouth ..	16th century iron-works at Monkswood.
Tynemouth Monastery	Benedictine ..	Northumberland	1330, leased collieries.
Wearmouth Monastery	Benedictine ..	Northumberland	8th century Abbots were skilled iron workers.
Welbeck Abbey ..	Premonstrat ..	Notts	1460, obtained right to make adit in coal mine.
Wenlock Priory ..	Cluniacs	Salop	Iron working. Wm. Corvehill, "a good bell founder," died 1546.
Whalley Abbey ..	Cistercian ..	Lancs.	1529, sea coal used.
York, St. Mary's Abbey	Benedictine ..	Yorks.	William of Towthorpe cast the mortar for the infirmary, 1308.
York, Cell of Lindisfarne	Celtic-Irish ..	Yorks.	9th century monk was skilled iron forger

Dr. E. G. West has kindly supplied the following note: The ancient industry of needle-making is centred in the Redditch district on the borders of Warwickshire and Worcestershire. There is a very strong feeling in the district, supported by some little evidence, that the reason for the location of needle and fishing tackle manufacture in that area derived directly from the Cistercian Abbey of Bordesley. It is believed that the Bordesley monks obtained their wire from the wire mill operated by the monks of Tintern Abbey which was of the same foundation, the wire reaching the Midlands by way of the rivers Wye, Severn and Avon. After the Dissolution, a few of the monks of Bordesley remained in the district spread among the various villages, and it is presumed, continued their respective trades, in due time teaching the local inhabitants. There is definite evidence that by 1690 needle making was carried on in many of the villages now surrounding Redditch.

APPENDIX B

Patron Saints and Writers

St. Eligius (Eloi), 588–659, goldsmith, native of Dinant, cons. Bishop of Noyon. Patron of metalworkers.

St. Barbara, patroness of miners and metallurgists in Spain, France, Germany.

St. Dunstan, had as pupil at Abingdon, St. Ethelwod.

Theophilus Presbyter (Benedictine monk, 11th century) wrote "Schedula Diversarium Artium." Gives a true picture of technical industry at his time, particularly in the working up of metals, something being also said about their production from ores. He was a skilled worker in metals at Helmershausen Monastery. "An Essay upon Various Arts," 3 Vols. Translated by Robert Hendric, John Murray, London, 1847, pp. 313.

Bartholomew, O.S.F., 1260, wrote of the value of iron.

Albertus Magnus, O.P. (St. Albert the Great). His writings include: "De Rebus Metallicus et Mineralibus." A transmutationist. Recommended juice of radishes and angle worms for surface hardening.

Thomas Aquinas, O.P. (St. Thomas Aquinas) was first to use the word amalgams in his writings. He supported "transmutation" on physical grounds. In his "Summa" discusses physical properties, such as hardness.

Basil Valentine, O.S.B. (15th century, S. Germany). "The Triumphal Chariot of Antimony" was published 1624. In early chemistry gold claimed all attention because of hope of producing elixir of immortality. Otherwise antimony, because of its prolific number of compounds and medicinal properties would have been studied even more. As it was, life-times were often spent on working at it. (See Chemistry and Industry, October 10th and 24th, 1924).

Roger Bacon, O.S.F., Oxford, 1214–1294. Theoretical transmutationist and philosopher.

Fr. Alvaro A. Barba. "El Artos de Metales." 1639. Describes the extraction of metals and discusses physical properties.

Assay of Silver by Cupellation. "De Necessariis Observantiis Scaccarii Dialogus"; commonly called "Dialogus de Scaccaris," by Richard Bishop of London (circa 1160 Treasurer of England). As an assay for silver the cupellation method is generally attributed to the Bishop of Salisbury early in the 12th century. This Bishop of Salisbury was the grand-uncle of Richard, and he appears to have organised the office of Treasurer of England. The Egyptians actually understood the cupellation process. (Roberts-Austen, Cantor Lecture, p. 27).

Peder Mannson (1460–1534), a monk, published a technological work in Swedish. (Engineering, 19/2/43).