THE RISE OF METALLURGY

WITH SPECIAL REFERENCE TO

SHEFFIELD DISCOVERIES INVENTIONS AND RESEARCH

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Frontispiece: Bessemer Gold Medal.

SHEFFIELD MOTTOES

Mottoes are usually expressive and it would indeed be difficult to find better ones than those formulated in our City of Sheffield by the Wise Men of the past :—

(1) The Motto of our City with its many centuries of past history is " DEO ADJUVANTE LABOR PROFICIT " — " With God helping labour prospers."

(2) That of our ancient Cutlers' Company of Hallamshire, dating from 1624, " POUR Y PARVENIR À BONNE FOI " is " To attain one's aim by good faith."

(3) And that of our University, now in its twenty-eighth year, is " RERUM COGNOSCERE CAUSAS "—" To find out the real causes of things."

(4) Whilst our Chamber of Commerce has not yet adopted a Motto it is suggested that the following words might be used as a basis for consideration, namely " Quality always tells," for did not Ruskin consider the quality of our Sheffield handicraft so high that he left us for ever those precious mementoes now enshrined in our Ruskin Museum, which it is hoped that at any rate some of the Members of our Iron and Steel Institute will visit during their stay in our City ? The adopted form of the Motto would of course afterwards be Latinised.

ILLUSTRATION of OBVERSE and REVERSE

of the

BESSEMER GOLD MEDAL

founded in 1873

by SIR HENRY BESSEMER

I. INTRODUCTION

IT is with special pleasure that the author of this address welcomes the visit of the Members of the Iron and Steel Institute and other friends to the East Hecla Works of Messrs. Hadfields, Ltd. His colleagues on the Board, Mr. P. B. Brown, Major A. B. H. Clerke, Mr. W. J. Dawson, Captain E. H. M. Nicholson, Mr. W. B. Pickering and Mr. A. Roebuck, also join in this welcome.

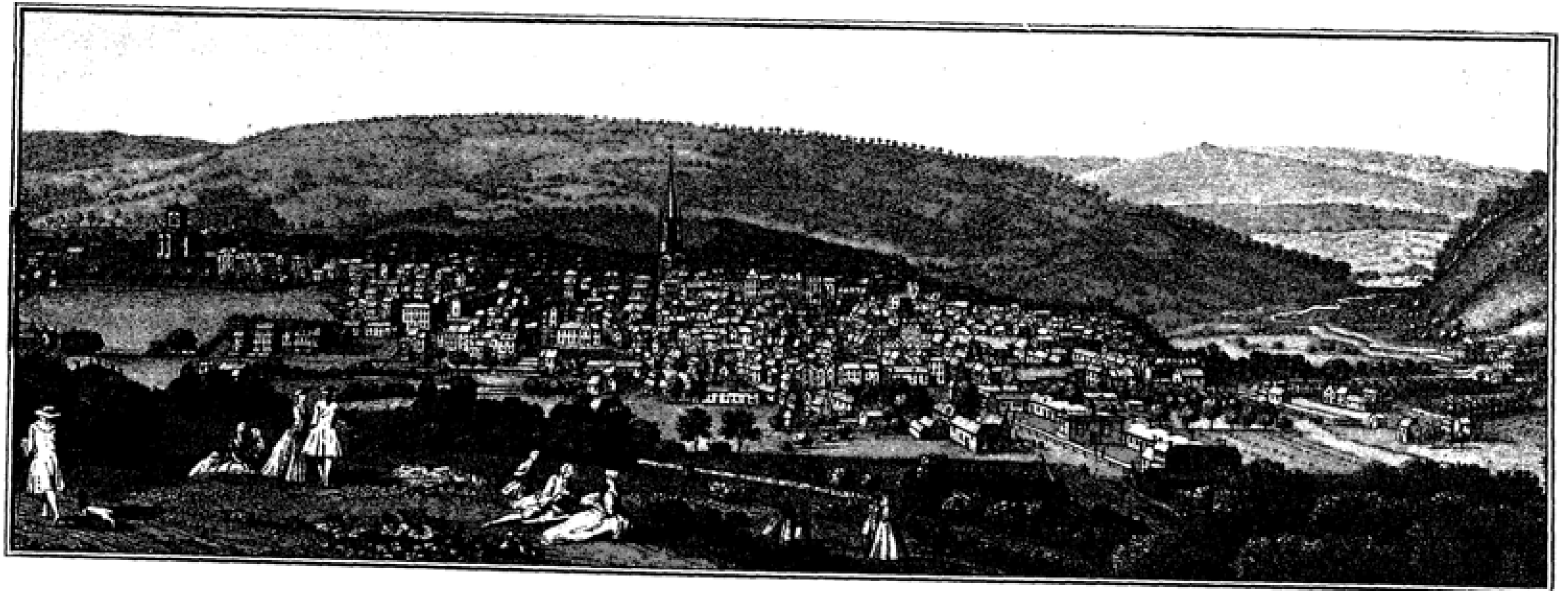
In this address the author proposes to survey broadly the rise of metallurgy, more particularly so far as our City of Sheffield is concerned. With each year that passes a review of this nature becomes more difficult, so rapid is the rate of progress. It is, however, important that this task should be essayed, not only as affording some assistance and, perhaps, inspiration to the younger men, but also as a labour of love to maintain our sense of perspective, and specially to place on record, however inadequately, our recognition of the great debt of gratitude owing to workers of the past.

The author greatly appreciates this opportunity of paying his own tribute to those earlier metallurgists from whose labours, in the face of innumerable difficulties, the vast structure of modern metallurgy has sprung. Moreover, having been connected with Sheffield and with the science and practice of metallurgy from his earliest years, the author regards it as a privilege to have this opportunity of making special reference to the part played by Sheffield in connection with metallurgical discoveries, invention and research. The author's own metallurgical work commenced nearly sixty years ago with a small crucible furnace in the cellar of his father's home, and it was conducted with such vigour, at least as regards heat and draught, that he almost succeeded in burning the house down, besides melting some eight or ten pounds of steel, which was the actual end in view. Now, in the words of one of the reviewers of his book, *Metallurgy and its Influence on Modern Progress*, the author's association has been long enough to be a connecting link with the generation for which modern metallurgy had barely begun to exist, but not so long as to have ceased to be in the centre of its technical progress.

Visits of the Iron and Steel Institute to Sheffield

It is a great disappointment to every member of the Iron and Steel Institute that, owing to ill health, our President, Mr. W. R. Lysaght, C.B.E., is unable to be present with us at this our Sheffield meeting. For the general arrangements of the meeting in this district, the Members in attendance are greatly indebted to the work of the Local Executive Committee, of which Dr. W. H. Hatfield is Chairman, Mr. Fred Clements the Hon. Treasurer, and Professor J. H. Andrew the Hon. Secretary ; also to the Ladies' Committee. The excellent arrangements made by the two committees for the comfort, pleasure and entertainment of those attending this meeting are appreciated by all.

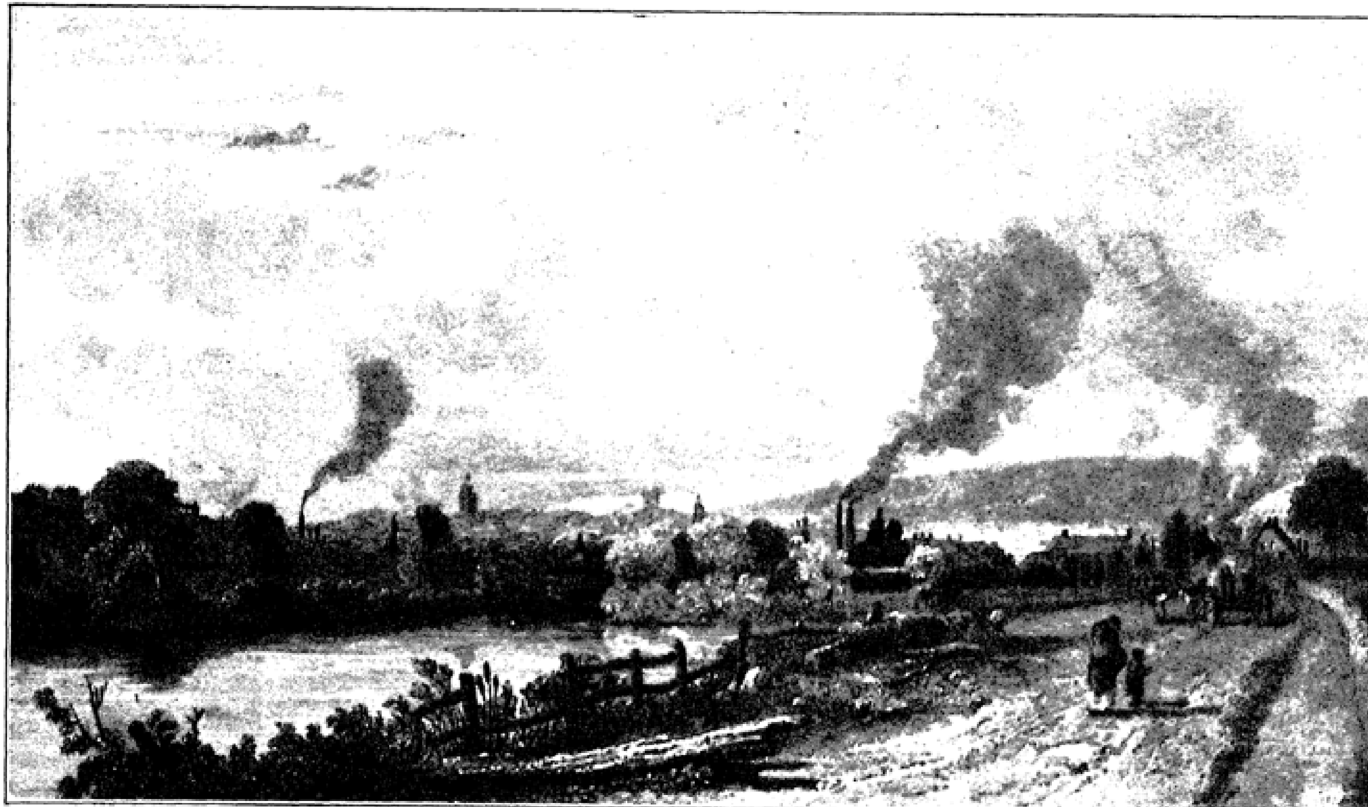
Figure I



THE EAST PROSPECT OF SHEFFIELD, IN THE COUNTY OF YORK (A.D. 1745).

Sheffield or Sheafield stands in the Southern part of the West Riding of Yorkshire where the two Rivers Dun and Sheaf meet, to which last it owes its Name. This Town was anciently famous for making the iron heads of Arrows, and is celebrated by Chaucer 300 years ago for the Blades of Knives worked there; by degrees it hath much Improved in all manner of Cutlers ware. Its Situation is delightful and somewhat uncommon, it being seated on a Round Hill in the Midst of a Valley, which is surrounded by many higher Hills. This supplies it with many valuable Falls of Water necessary for carrying on the Manufacture of the Place. This Advantage of Streams to turn their Mills, together with great plenty of Coal in its neighbourhood render it perhaps the fittest place in the Kingdom for the Business which is here carried on. It had a very strong Old Castle which belong'd to the Lovetofts, the Lords Furnival; and the Talbots, Earls of Shrewsbury. In which Mary Queen of Scots remain'd a Prisoner for 16 or 17 years under the Custody of George Earl of Shrewsbury. This Castle was built in the Reign of King Henry III and after the death of King Charles I was demolish'd. Here is a market every Tuesday and Thursday. Fairs, one on Tuesday after Trinity Sunday, and another on the 17th November. The Mannor of Sheffield which extends in length 18 miles and in breadth upwards of 8 miles, did formerly belong to the Earls of Shrewbury; but now to his Grace the Duke of Norfolk.

FIGURE II



ENGRAVING OF SHEFFIELD IN THE YEAR 1819

Figure III

RIVER DON, AT OR NEAR TO TINSLEY
From oil colour on paper by Chas. Cusworth, 1871

It is now 28 years since the Iron and Steel Institute first visited Sheffield in 1905, during the author's presidency of the Institute. On that occasion the members in attendance visited the works of Hadfields, Ltd., and it may be recalled that the many notabilities present included Viscount Hayashi, the celebrated Japanese Minister, who took the opportunity of making the first announcement of the Treaty between England and Japan when addressing the gathering at lunch.

Now, on the occasion of the second visit of the Institute to this city, it is not possible to promise the revelation of any new treaty, but we can with justification regard this visit as marking a revival in confidence and optimism based on concrete evidence of better times in store. The author had the pleasure of a conversation with General Smuts a few days before he left this country, in the course of which the General expressed his firm conviction that Great Britain was sound and would emerge triumphantly from the world crises and buffetings of recent years. Such cheering words coming from such a reliable source should encourage us all. The Bankers' Clearing House returns, the railway traffics, and many other indices of prosperity show that we are at last on the upward grade. Full recovery must naturally be a matter of time, and there is no doubt that the iron and steel industry, not only in this but also in other countries, has been hard hit, but there are substantial grounds for believing that the worst is over and that we shall soon see a return to former prosperity.

The Iron and Steel Industry and Great Britain

How great is the stake of this country in the metallurgical industries in general, and the iron and steel industries in particular, it is hardly necessary to say. The city of Sheffield has metallurgical associations extending far back into our history, certainly far more than 500 years, and as regards Great Britain's part in the development of the steel industry, with which Sheffield is primarily and inseparably associated, the author cannot do better than recall a remarkable tribute paid by Mr. Charles M. Schwab, of the Bethlehem Steel Company and a former recipient of the Bessemer Gold Medal. Addressing members of the Institute of Fuel on October 19th, 1932, in acknowledgment of the award of the Melchett Medal, Mr. Schwab said that in the steel industry most of the great inventions had their origination in Great Britain. In America they were merely developers of what had been started in Great Britain ; they were willing perhaps to go ahead with more courage, more risk and more enterprise than Great Britain, but, after all, they were merely developers of what had originated in Great Britain.

These are indeed words of high praise, generous but a not undeserved tribute to those workers of the past and present, so many of whom have wrought with that wonderful metal iron and its alloys within the boundaries of Sheffield and, in some instances, within walls still standing.

II. THE RISE OF SHEFFIELD

Situation

There can be few, if any, other industrial cities situated as picturesquely as Sheffield. It is indeed, in the words of Lord Palmerston, "A black picture set in a golden frame." Chatsworth, Haddon, Hardwick, Bolsover and Castleton; the glorious Peak District; Wharncliffe Crags; Welbeck, Clumber and the glades and woodlands of Sherwood Forest—these and other beauty spots are almost within sight of our city. The sylvan view shown in Figure III, alas, is no more; it represents what the valley of the Don was like in 1871. The East Hecla Works of the author's company are now within half a mile of this spot. The picture, which is in the possession of my friend Mr. Charles Sandford of Sheffield, by whose kind permission it is here reproduced, was painted in 1871 in oil colour on paper by the famous artist, Mr. Chas. Cusworth. It represents the River Don at or near to Tinsley. It is almost Turneresque in effect. With the progress of combustion engineering, the increasing use of the electric drive and of electric furnaces, and persistent attack upon the problem of housing, the author is hopeful that our "golden frame" will be indefinitely preserved while the picture itself becomes less black. In the past there has been justification for the Yorkshire saying, "Where there's dirt there's money," but, with modern plant and methods, it is now possible to earn money, even in a great metallurgical centre, without an undue emission of smoke, fumes or other "matter out of place."

Historical Associations

The history of Sheffield has been fully dealt with by such able local chroniclers as Hunter, Leader, Gatty, Addy and others, but there are some facts which may appropriately be recalled, specially in connection with the rising importance of the city and the early mentions of Hallam, Aterclive and Escafeld, names which are easily recognised in their modern forms. The local history of Escafeld (to use the original form of "Sheffield") can be traced to the time of the Conquest. There were probably three manors in 1086, Hallam, Aterclive and Escafeld, though the Domesday Book mentions only "Aterclive and Escafeld," and it is not clear whether Hallam formed a separate parish or, as Hallamshire, was a separate division in the district. As regards "Aterclive and Escafeld," there appears to have been a considerable struggle amongst the scribes regarding the two designations, but "Shefeld," or "Sheffield," predominated, certainly not later than the thirteenth century.

From the time of Waltheof, last of the Saxon earls, whose hall is believed to have stood on the site now known as Castle Hill, Sheffield has been closely connected with many historic characters and events. After the rebellion and execution of Waltheof in 1075, the Manor passed to the Norman family of De Lovetot, and in due course, by the marriage of Maud de Lovetot, to the family of Furnival, in the reign of Richard I. Of the warlike deeds and royal friendships of the early Furnivals, no more than passing mention can here be made,

[*Reproduced by kind permission of The National Portrait Gallery*

CARDINAL WOLSEY
1471-1530

PLATE 3

[*Reproduced by kind permission of The National Portrait Gallery*

MARY QUEEN OF SCOTS
1542-1587

but we cannot pass over Thomas Furnival, that great benefactor who, as Lord of Hallamshire, raised the town in 1297 to dignities which it has never lost. He it was who obtained royal authority for a weekly market and annual fair and secured other important rights and liberties for our citizens. Furnival's charter is the earliest record we have of the existence of the system of local government called "The Burgery." Soon after the death of Lord Thomas Furnival an Inquisition revealed the curious fact that " his ancestors held the Castle and Manor of Sheffield of a certain King of Scotland by the service of rendering two white greyhounds yearly."

Roman cohorts would stand amazed could they return to their Templeborough camp and other local sites, whence steel for all the arts of peace and war pours forth in quantities and qualities that "Cæsar never knew." On the other hand, their shades, if observant, have had ample opportunity of becoming accustomed to the local iron and steel industries, for they have been a long time a-growing. Of this, more is said later in this address (Section IV), where it is shown how our metallurgical records extend back through the centuries, growing less frequent in remoter days, but, significantly enough, being connected repeatedly with the lives of our citizens and their rights and privileges.

Among the many famous personages of the past who have been associated with Sheffield may be mentioned Cardinal Wolsey (Plate 2), who arrived at the Manor House in November, 1530, and soon afterwards left under escort on the last stage of his tragic journey. Far longer and even more tragic was the association with Mary Queen of Scots, who as a captive under the Earl of Shrewsbury spent many weary years during the period 1570 to 1584 in the Turret House, where the room she occupied is still to be seen (Figure V). No one who has read Charlotte M. Yonge's *Unknown to History* can fail to find added interest in the place of the Queen's incarceration.

The panels in the dining-room in the author's Sheffield home, Parkhead House, came to him through the well-known Sheffield architect, the late Mr. Mitchell Withers, who obtained them from the Manor House where the ill-fated Queen often dwelt, so undoubtedly she saw and lived from time to time with these self-same panels.

Save for the stormy period of the Civil War, when Sheffield Castle was besieged and taken by the Parliamentarians in 1644, the seventeenth century brought to Sheffield an era of peaceful existence and the beginning of important activities and institutions that have continued to the present day. Our grammar school was founded by Thomas Smith, of Crowlands, Lincolnshire, in 1604; Robert Sorsby was our first Master Cutler in 1624; John Wesley paid his first visit to Sheffield in 1732; Benjamin Huntsman moved to Sheffield in 1740; the first Sheffield newspaper, Lister's *Sheffield Weekly Journal*, was founded in 1754; and in 1822 we find Michael Faraday sending carefully prepared mixtures for his "Alloys of Steel" by coach from London to Sheffield, to be dealt with at Sanderson's works.

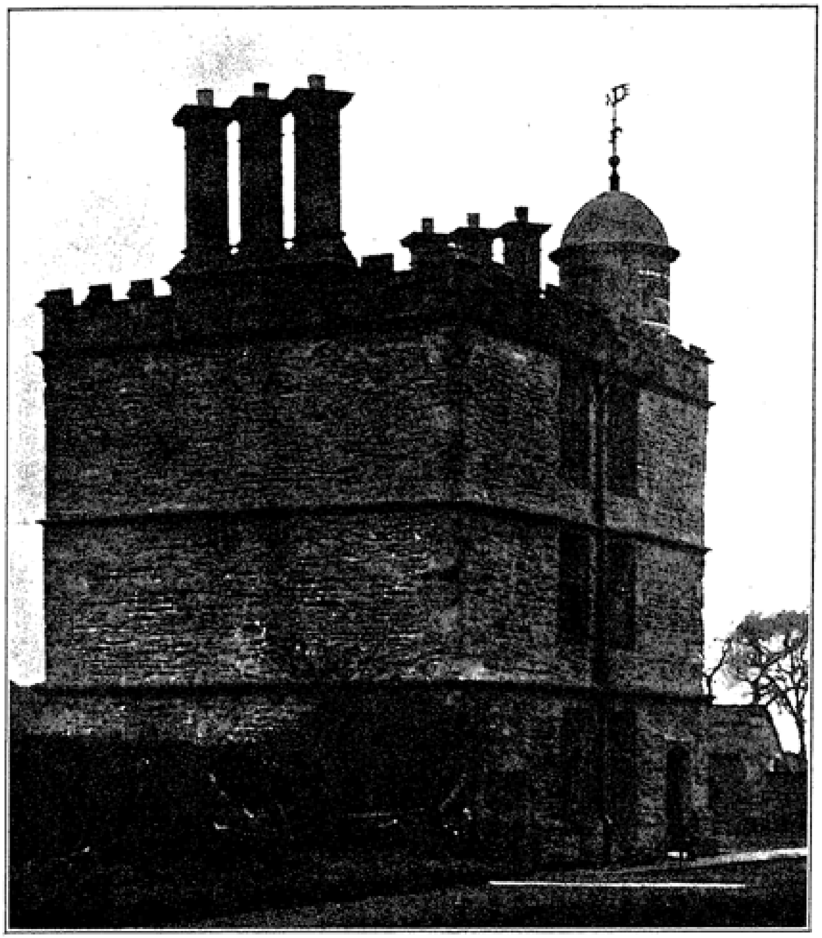
These are some of the names and events that spring most readily to mind in a rapid survey of Sheffield's past, and they serve in some measure to set the stage on which such worthies as Ebenezer Elliott; Samuel Bailey, the Bentham of Hallamshire; Hunter the historian; Chantrey; Montgomery; Sterndale Bennett; Earnshaw, and many other leaders have played, or are still playing, their parts.

Civic Growth

Though Sheffield was recorded in Domesday Book, some 850 years ago, its taxable value was then only 40s., a rather modest sum, but the value of money was, of course, very different in those days. In the year 1289 the total taxes were returned at £8 5s. 1¼d., the statement showing a meticulous accuracy which is still associated with Yorkshire! In 1624 the first annual feast of the Cutlers' Company cost 6s., plus 24s. for wines. In 1710 there were 6,000 persons employed in the cutlery and other trades, and a value of about £100,000 was produced. Many years later, in 1749, the Cutlers were only spending £2 2s. 9d. on their feast, including such items as ale and punch, but by then the population of the city had risen to some 20,000, and during the next century it increased about sevenfold and the rateable value rose to £272,000. Thereafter, that is, since the middle of last century, the rate of progress has been even more remarkable. This period has witnessed practically the whole growth of iron and steel production on the scale to which we are accustomed today, and the city of Sheffield has now a population of some 512,000, and a rateable value of nearly 2¾ million sterling, or about ten times what it was 80 years ago, which makes one, at least in this respect, sigh for the "good old days"!

It was not until the Reform Act of 1832 that Sheffield was allowed to elect its Parliamentary representatives, and, as pointed out by Mr. Leader, to whom this city is so greatly indebted for his many important antiquarian researches, it was exactly 600 years after the establishment of the Burgery that the late Duke of Norfolk, a descendant of Lord Thomas Furnival, became the first Lord Mayor of our city. This privilege was bestowed by Her Majesty Queen Victoria in commemoration of her visit to Sheffield in 1897.

Figure IV



The Turret House, Manor House, Sheffield, known as Queen Mary's Lodge

FIGURE V

Interior of the Living Room occupied by Mary Queen of Scots

III. THE IMPORTANCE OF IRON AND STEEL

"Iron—Cold Iron"

A leading article on "Nature and Science in Poetry" in *Nature*, August 26th, 1933, recalls that Wordsworth, writing early in the nineteenth century, looked forward to the time when the poet would find inspiration in aspects of scientific achievement and industrial progress. "The remotest discoveries of the chemist," he said, "the botanist, or mineralogist, will be as proper objects of the poet's art as any upon which it can be employed, if the time should ever come when these things shall be as familiar to us, and the relations under which they are contemplated by the followers of these respective sciences shall be manifestly and palpably material to us as enjoying and suffering beings." That time has surely arrived, and in the works of Rudyard Kipling the metallurgist and engineer find many an undying tribute to their activities and the spirit which animates them. Surely no engineer can read *M'Andrew's Hymn* unmoved, and in *Rewards and Fairies* the metallurgist will turn again and again to *Cold Iron:*

> "*Gold is for the mistress—silver for the maid!*
> *Copper for the craftsman cunning at his trade.*
> 'Good!' said the Baron, sitting in his hall,
> 'But Iron—Cold Iron—is master of them all!"

In a recent personal letter to the author, Mr. Rudyard Kipling gave his kind permission to reproduce from this poem and also added the following interesting words: "I suppose the mystery and the changing forms of Iron must have been one of the first of the mysteries to Early Man—quite apart from the fact that the Iron blade—sword or spear—made him Master of the Beasts and his neighbours."

Then, too, there is the ancient Chinese proverb that he who holds the iron of the world will rule the world—a saying which may gain in significance as time goes on, for China herself appears to have extensive deposits of iron ore, and it seems not unlikely that these may be fully exploited at no very distant date. As long ago as 1910 the author crossed the Pacific in a vessel carrying the first consignment of Chinese pig iron to the western shores of America, and in view of the vast mineral wealth of China that occasion may ultimately be seen to have been of considerable historic interest.

Meanwhile, however, it is not merely "holding the iron of the world," but the knowledge and ability to make full use of the properties of the metal and its alloys that are essential to metallurgical supremacy. Without iron and simple carbon steel we should be thrown back to the resources of the Dark Ages, but these materials alone are hopelessly inadequate to meet the requirements of civilisation as we know it today. Without special or alloy steels, representing a much higher degree of metallurgical development than carbon steel, the motor-car, the aeroplane, and many another devices we have come to regard as essential, would be physically impossible, to say nothing of our railways and steamships. Armour and guns, and the projectiles which they fire, though we may lament the necessity for such weapons, have been evolved by metallurgical research that has brought compensating advantages in knowledge applicable to more peaceful productions. But for steels of special magnetic qualities, electric generators, motors and transformers could not be built as they are today, and the limits of submarine cables would be greatly restricted. In short, iron, steel and special steels are literally essential to our modern civilisation.

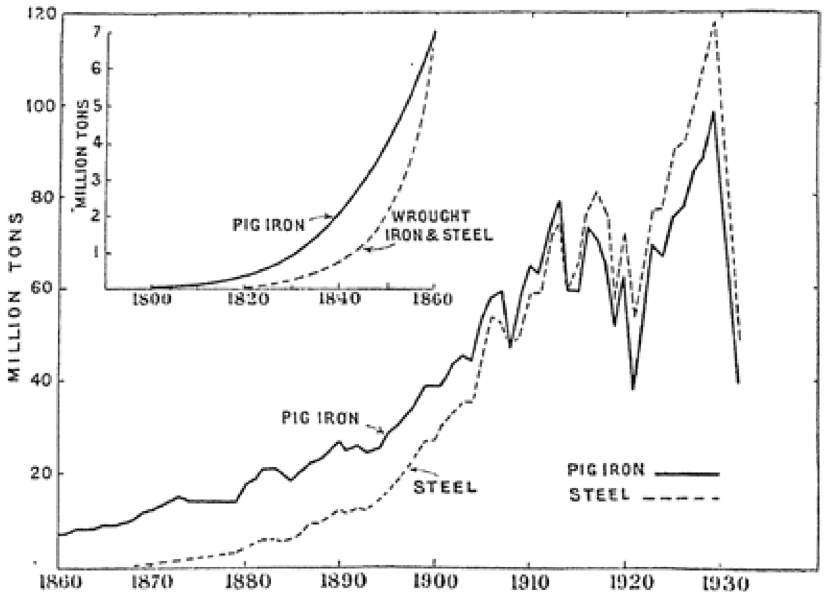
Truly, *Iron—Cold Iron—is master of them all*, and in acknowledging the importance of special steels we must not forget that iron is the essential basis common to them all. For example, though silicon steel, invented by the author, has largely replaced unalloyed iron in many electrical applications, owing to its superior qualities of magnetic permeability, low hysteresis and high electrical resistance, nevertheless iron is present to the extent of 96 to 97 per cent. This further emphasises the importance of iron itself. In many of its most important applications *Ferrum* is literally irreplaceable.

Production of Pig Iron and Steel

The statistics relating to the output of pig iron and steel 150 years ago are not very clear, but the following may be taken as approximately correct. In 1796 the output of pig iron in Great Britain was about 125,000 tons, and in 1820, when Faraday was fairly embarked on his important series of researches on "alloys of steel" (mentioned further in Section IV), there were produced some 250,000 tons of wrought iron and 20,000 tons of steel, including cemented steel from imported bar iron. In 1824 the total output of pig iron in Great Britain appears to have been about 450,000 tons, with about 200,000 tons of puddled and scrap bar iron, produced from the pig iron tonnage mentioned. The production of steel in 1846 was about 40,000 tons, with about an equal production in other countries, and certainly less than 100,000 tons for the whole world. These figures appear almost negligible and, in fact, hardly credible compared with the immense figure of nearly 120 million tons for the world production of steel in 1929, yet it is a fact that the total output increased 1,200-fold in less than ninety years.

Since the year 1929 there has been a serious reduction in the world production of iron and steel, owing to the general dislocation of industrial activity by the economic crises in all countries. The figures for pig iron and steel production may, in fact, be taken as a very fair index of the general state of economic prosperity or depression, and in this connection it is interesting to refer to the accompanying chart showing the world's output of steel (1860–1932) and pig iron (1800–1932). It will be noticed that, up to the commencement of the war, the output of pig iron was greater than that of steel, but that subsequently the position was reversed.

Some encouragement, much-needed in these difficult times, can surely be derived from this chart. The similarity between the depression of 1930–32 and that of 1921 is obvious, and there are reasonable grounds for supposing that it may be followed by a similar sharp rise which, even if it does not go up to the peak level of 1929, will yet bring welcome relief to our industry.



The world's stock of iron and steel in use is about 1,200,000,000 tons, and the loss due to wastage in 1932, by corrosion and by wear and tear, is estimated to be about 67,000,000 tons, or some 19,000,000 tons in excess of the actual production for that year. Clearly the natural demands of the world are represented more nearly by the 1929 output of nearly 120,000,000 tons of steel than by the smaller output of recent years, which has not been sufficient to cover wastage. The world has literally been starving itself in its production and consumption of steel during the past three years or so. Either the crisis must now become extreme and seriously affect our modern civilisation, which surely cannot happen, or there must soon be a great change for the better in the demand for steel of all types.

IV. EARLY DAYS OF METALLURGY IN SHEFFIELD

Importance of Sheffield's Contributions

For centuries past, Sheffield has been inseparably associated with the making and working of iron and steel. Today, though we are faced by an amount and degree of competition undreamt of a generation ago, Sheffield maintains its world-wide reputation for the quality and varied character of its products. The rise of the industry is linked inseparably with the names and works of such pioneers as Huntsman and Bessemer, Siemens, John Brown and J. D. Ellis, the Firths, the Jessops, Cammell, Sorby, Arnold, and many another mentioned more fully elsewhere in this paper. In the aggregate, the men of Sheffield have contributed more to the science and practice of iron and steel metallurgy than any other community in the world. This is a proud claim, but one that is fully justified and, needless to say, in advancing it the author has not the slightest intention of belittling the important work done in other centres.

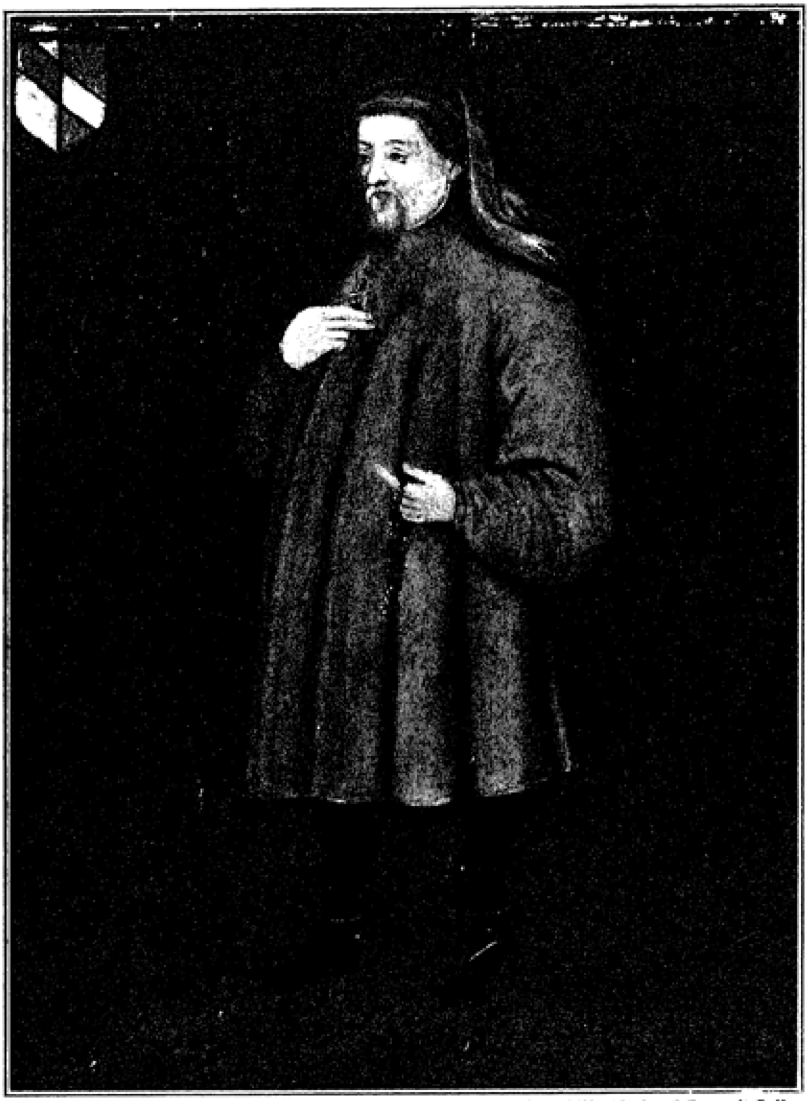
Early Metallurgical References

In any survey of Sheffield's part in the rise of metallurgy it is natural to enquire what led to the city becoming such an important metallurgical centre. There are many evidences of ancient workings of iron ore in the district. The Romans taught the British much in this respect, and the Normans brought over many smiths and other skilled artisans. About the year 1100, one of the earliest Norman lords obtained a charter to erect forges for the working of iron at Kimberworth.

Unfortunately, our ancestors of the Middle Ages omitted to record many facts and figures which would have been of extraordinary interest to us today. In particular, they did not leave any very adequate references to the early ironworking activities of Sheffield. We do find, however, in Chaucer's *Canterbury Tales*, a character of whom the author says: "A Shefeld thwytel bare he in his hose," showing that nearly six hundred years ago Sheffield cutlery was well known and esteemed. This couplet has often been quoted, but the author does not remember ever having seen a portrait before of the great English poet. Through the kind permission of the National Portrait Gallery he is able to present Plate I, reproduced from a drawing of him by Occleve. An even earlier reference and probably the first recorded identification of the city with cutlery is the entry *Cultellum de Shefield* in a list of articles issued from the Priory Wardrobe at the Tower in 1041. This interesting note is included in an admirable outline of the history of Sheffield in *The Quality of Sheffield*, published by the Sheffield Chamber of Commerce, under the able editorship of Mr. A. J. C. Walters, Secretary, and Miss G. M. Freeman, Assistant Secretary.

Coming to later years, the poll tax records of Richard II (1379) show that the making of knives was an important local industry.

PLATE I



[Reproduced by kind permission of The National Portrait Gallery

GEOFFREY CHAUCER

1340-1400

Mr. John Derry, in his interesting *Story of Sheffield*, recalls that Leland, who travelled through England between the years 1536 and 1542, said there were "many smiths and cutlers in Hallamshire," and also "very good smiths for all cutting tools" at Rotherham. Between 1554 and 1570, sixty-one trade marks were granted by the Lord of Hallamshire (the Earl of Shrewsbury) through his Court at Sheffield, to the master cutlers in his lordship. At this time iron was being imported into Hallamshire from Sweden and Spain, through Hull and Bawtry, and the arrival of six barrels of steel from Bawtry is noted in the memorandum book of the Earl's steward on October 8th, 1574.

In his book, *The Writing Schoolmaster*, Peter Bates (1590) gave advice regarding the making of quill pens: "First then be the choice of your pen-knife. A right Sheffield knife is best." The dramatist Nash also uses the term "right Sheffield" to signify the best quality. The city's fame in this connection has steadily increased and, in more recent times, it has built up an equally high reputation in the heavier applications of ferrous metallurgy, including, of course, special steels. Sheffield has also been engaged for many years in the manufacture of non-ferrous products, including silver, electroplating and similar developments.

Natural Advantages of Sheffield

Whether or not Dr. Gatty was correct in his suggestion that the Roman rigg, or ridge, extending from Wincobank to Templebro', had led to local ironstone being exposed, the fact remains that phosphoretic ore such as existed in this part of the country could not have made good steel, whether worked up direct or made into wrought iron and carburised by cementation. No doubt iron was produced locally, but it would not have been suitable for steel, even of medium quality. In the early days, Sheffield's steel products must have been made almost entirely from imported Swedish, German and other foreign steel. The material was, no doubt, originally bought in its cemented condition, but afterwards the cementation was done here. The pre-eminence of Sheffield in steel manufactures was therefore due, not to the presence of superior local ore, but to the abundance of wood and, later, to the discovery of coal, the presence of many streams for working grinding wheels and tilt hammers, the generally favourable situation for manufacturing and, last but by no means least, the ever-increasing accumulated skill of its workmen, gradually aggregating themselves into associations and guilds.

Sheffield's proximity to supplies of excellent stone or millstone-grit for grinding and other stones, has also been of considerable advantage. In the same way, the well-known Sheffield gannister and fireclay of excellent refractory quality are ready to hand in abundant quantity. Whereas the ironworks of the south country fell into disuse when coal replaced wood, that change and most of the subsequent events in our industrial development have increased the advantages of Sheffield as a metallurgical centre.

The Company of Cutlers of Hallamshire

In any mention of the rise of metallurgy in Sheffield, more than passing reference must be made to the ancient and honourable Company of Cutlers of Hallamshire, a guild which existed long before 1624, the year of its official foundation. It was the author's proud privilege, in 1899, to be installed Master Cutler of this famous Company, the influence of which is in many respects quite as important today under the Mastership of Colonel A. N. Lee, as in the earlier centuries of its foundation.

The first legal enactment for regulating the special conditions of the cutlers of Hallamshire was made by royal Ordinance issued by Queen Elizabeth under date September 2nd, 1589. Provision was made in this Ordinance for the appointment at the local law court, that is, the Earl of Shrewsbury's Manorial Court, of a special jury, consisting of 12 cutlers, who were to adjudicate and administer all matters pertaining to their trade, and, subject to the consent of the lord and his steward, to issue regulations which were generally binding upon the whole trade. Owing to the prerogatives accorded to the Lord of the Manor and his steward, the legal validity of this Ordinance was impugned, and in the twenty-first year of the reign of James I, the House of Commons passed, on August 23rd, 1624, "An Act for the Good Order and Government of the Makers of Knives, Sickles, Shears, Scissors, and other Cutlery Ware in Hallamshire and the Parts near adjoining."

By the Act of 1624 the Cutlers' Company was to consist of 33 members, including the Master, two Wardens, six Searchers, 24 Assistants, and finally the "Commonalty," most of whom were probably "freemen." The latter have been dropped, perhaps to the Company's disadvantage, as no doubt a wider sphere of influence was obtained and more general interest sustained in the work done. The powers granted were very considerable. Heavy fines could be imposed, and the "Searchers" had the right to enter any house where they had cause to suspect the existence of "deceitful goods." One of the advantages—or disadvantages, according to one's point of view—of trade marks was demonstrated a few years after the incorporation of the Cutlers' Company, for the knife found in the body of the Duke of Buckingham, assassinated in 1628, was stamped with a corporate mark which led immediately to the discovery of its maker!

The Cutlers' Company is doing today, as it has done in the past, excellent work in protecting Sheffield's interests. In addition to the general business which goes on in committee, it has important duties regarding the registration of trade marks. This work probably dates back to an even earlier time that that of Queen Elizabeth, and many of the seventeenth-century trade marks are in use today. Quite apart from the many ordinary duties the company performs, Sheffield would lose considerably if the Cutlers' Company were not in our midst. There should be much value put down to it under the head of "Goodwill," as the very fact of its existence is deterrent to those who might act against the interests it protects.

Then, too, it is an historic heirloom which we can ill afford to lose. A city is all the richer for its traditional associations, and few manufacturing cities can claim such an honourable link with the past.

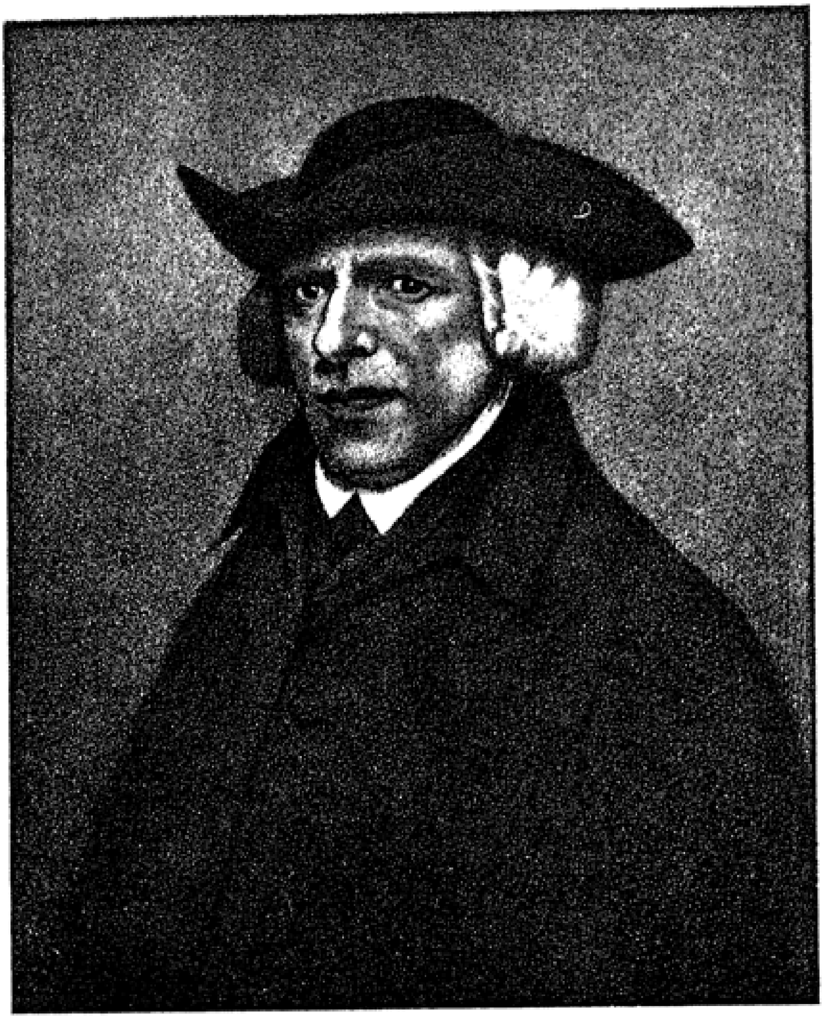
Many years ago there appeared in the German periodical *Stahl und Eisen* an appreciation of the work of the Cutlers' Company, which still forms an excellent summary of its activities and is of special interest as showing how highly the Company is respected abroad. The writer said: "While the mediæval organisation and position of the Company as a trade guild has for the greatest part lost its value and significance, a coincidence of several circumstances has helped to establish a new basis for its position and influence in the registration of trade marks practised by the Company for over two centuries. In this respect the Company now occupies an official position as a public authority invested with extensive powers. In addition to its position as a branch or sub-office of the London Patent Office, the Company in a certain sense occupies the position of a Chamber of Commerce for the steel trade, or a kind of steel exchange, its body of members being constantly supplemented from the number of the first and most prosperous steel manufacturers of Sheffield; and Sheffield, being the chief centre of the British steel trade, is the focus on which all news concerning this branch of industry and the respective business orders from all countries converge."

Benjamin Huntsman and Cast Steel

It is not always fully appreciated that the enormous use of steel in modern times would have been quite impracticable but for the developments in the manufacture of cast steel. Engineering structures as we know them today, to say nothing of the whole field of alloy steels, would be beyond our reach if we were restricted to pig iron, wrought iron, and steel prepared by the cementation process. The first successful steel-melting process on a practical scale was devised by Benjamin Huntsman, and it may fairly be claimed that his work in Sheffield led the way in the melting and casting of steel.

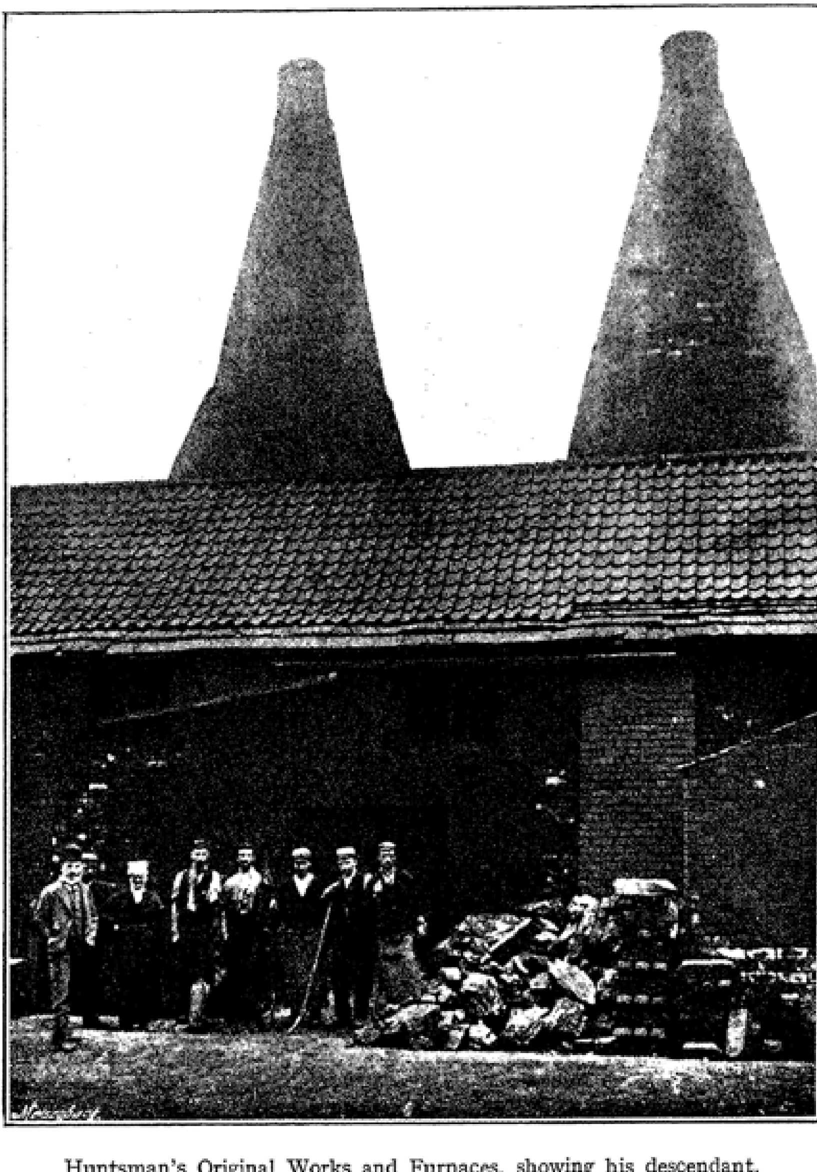
Naturally, Huntsman's crucible process could only be used on a relatively small scale, but it was a great advance on anything previously known. The next great step in this direction, the Bessemer process, was largely worked out in Sheffield, and was followed by the Siemens-Martin open-hearth process, and later by electric furnaces.

It was probably about 1730, or a little earlier, that Huntsman commenced his experiments which led, by his labours primarily and those of others later, to the present successful condition of the high quality steel trade for which Sheffield is justly famous. The latest developments in the production of special steels by aid of the electric furnace may be regarded as lineal descendants of Huntsman's crucible process, the heating medium being different and more powerful, but the principle of melting in refractory chambers or vessels under conditions guaranteeing control and purity being essentially the same.



BENJAMIN HUNTSMAN'S SON

Figure VI



Huntsman's Original Works and Furnaces, showing his descendant, Mr. H. Huntsman

As some have questioned the importance and originality of Huntsman's work, it may be recalled that our Past-President of the Iron and Steel Institute, the late Dr. John Percy, F.R.S., who had special claim to authority, said: "Formerly, so far as I am aware, steel was never melted and cast after its production; and in only one instance, viz., that of Wootz steel, was it ever molten during its production. Indeed, by the founding and casting of steel after its production, its heterogeneousness is remedied, and ingots of the metal can be produced perfectly of uniform composition throughout; and for the practical solution of this important problem we are indebted to Benjamin Huntsman of Sheffield."

Whilst the mere melting of materials in crucibles was not novel, Huntsman's invention consisted in successfully solving the great difficulties to be overcome before the process could be applied to the practical production of steel. Probably his skill lay largely in producing crucibles of sufficiently refractory nature to withstand the high temperature of the melting operation; also in finding the correct type of melting furnace and the flux to be used, the latter a point then of special importance. By the trade his method is still often called "steel refining," though, of course, in the sense of purification this term is not quite correct. The great drawback then experienced by manufacturers was that whilst imported material from Sweden and Germany was of excellent purity, whether as bar iron or crude steel, the cementation process employed to effect the change or "convert" the bar iron into steel or blister steel gave a product of uncertain temper. The Huntsman method of fusion obviated many of the difficulties met in the cementation process, and it certainly proved to be the first practical solution of the important problem of how to make steel of homogeneous and uniform quality.

The author had the privilege of knowing both the great-grandsons of Benjamin Huntsman, the late Frank and Harry Huntsman. The firm still carries on the manufacture of the highest qualities of Huntsman's cast steel. The record of this firm is a striking example of continuous success—already extending to four generations—in a business founded on the production of material of the highest quality.

For the accompanying excellent illustration of part of Benjamin Huntsman's original works, in front of which the late Mr. Harry Huntsman can be distinguished on the extreme left, the author is indebted to the kindness of the late Professor J. O. Arnold, F.R.S., who added proficiency in photography to his many other attainments. This illustration is of special historic interest as showing where crucible steel was first produced on a practical and commercial scale. Besides meeting his own requirements, Huntsman supplied considerable quantities of crucible steel to others in this country and abroad, specially to France, for clock and watch springs, fine tools and other high-quality purposes. In this connection it is interesting to note that a fine grandfather clock, dating from about 1750, the works and face of which were made by Huntsman himself, bears the inscription: "*La Pendule de cette Horloge est faite avec la Première pièce d'Acier fondu connu dans le monde entier!*"

Metallurgical Practice in the Eighteenth Century

Two interesting records may be cited as throwing light on the state of metallurgical development in Sheffield at the beginning of the eighteenth century. Mr. R. E. Leader, in his well-known book, *Sheffield in the Eighteenth Century*, refers to the fact that in 1709 Mr. Samuel Shore bound a steel converter to work for him only, for ten years, at six shillings a week, with sixpence extra as a charitable grant to his widowed mother. Steel was thus converted here at least 217 years ago. The other record mentioned is a carved stone in the Wortley ironworks of Mr. T. Andrews, F.R.S., bearing the date 1713 and showing a tilt hammer of the type then used.

Before the time of Huntsman, who effected the first important advance in the manufacture of cast steel, the materials used in the manufacture of cutting instruments, at least as regards high quality goods, were drawn from outside Sheffield. This is confirmed by the statement that in 1750 no less than 4,000 tons of Swedish iron were worked up here. Supplies are also said to have come from Spain. Probably after this import trade first commenced, some of the material was converted into blister steel at the then port of entry, Newcastle.

For one of the best accounts of the methods practised in Sheffield about the middle of the eighteenth century we are indebted to a distinguished French metallurgist, Gabriel Jars (1729–1808), who published, in 1774, a book, *Voyages Métallurgiques*, describing visits paid between 1757 and 1769 to Germany, Sweden, Norway, England and Scotland. On his journey through England, Jars visited Sheffield, and thus describes the manufacture of crucible steel as practised here in 1764:—

"Blister steel is rendered more perfect by the following operation. Ordinarily, the scrap and cuttings from articles of steel are used. Furnaces of fire-clay are used, of similar design to those for brass cuttings. They are, however, much smaller, and receive the air by an underground passage. At the mouth, which is square, and at the surface of the ground, there is a hole through the wall, from which ascends the chimney stack. These furnaces contain only one large crucible, 9 to 10 inches high and 6 to 7 inches in diameter. The steel is put into the crucible with a flux, which is kept secret, and the coal, which has been reduced to coke, is then put round the crucible and the furnace is filled. Fire is then put to it, at the same time the upper opening of the furnace being entirely closed with a brick door surrounded by a band of iron. The flame goes through the pipe into the chimney.

"The crucible is five hours in the furnace before the steel is perfectly melted. Several operations follow. Square or octagonal moulds, made in two pieces of cast iron, are put the one against the other, and the steel poured in at one extremity. I have seen ingots of this cast steel which resemble pig iron. This steel is worked under the hammer, as is done with blister steel, but it is heated less highly and with more precaution because of its liability to break.

"The object of this operation is to make the steel so homogeneous that there may be no flaw, as perceived in that which comes from Germany; and this, it is said, can only be done by fusion. This steel is not extensively used; it is used only for purposes requiring a fine polish. Of it are made the best razors, knives, the finest steel chains, some watch-springs, and small watch-makers' files."

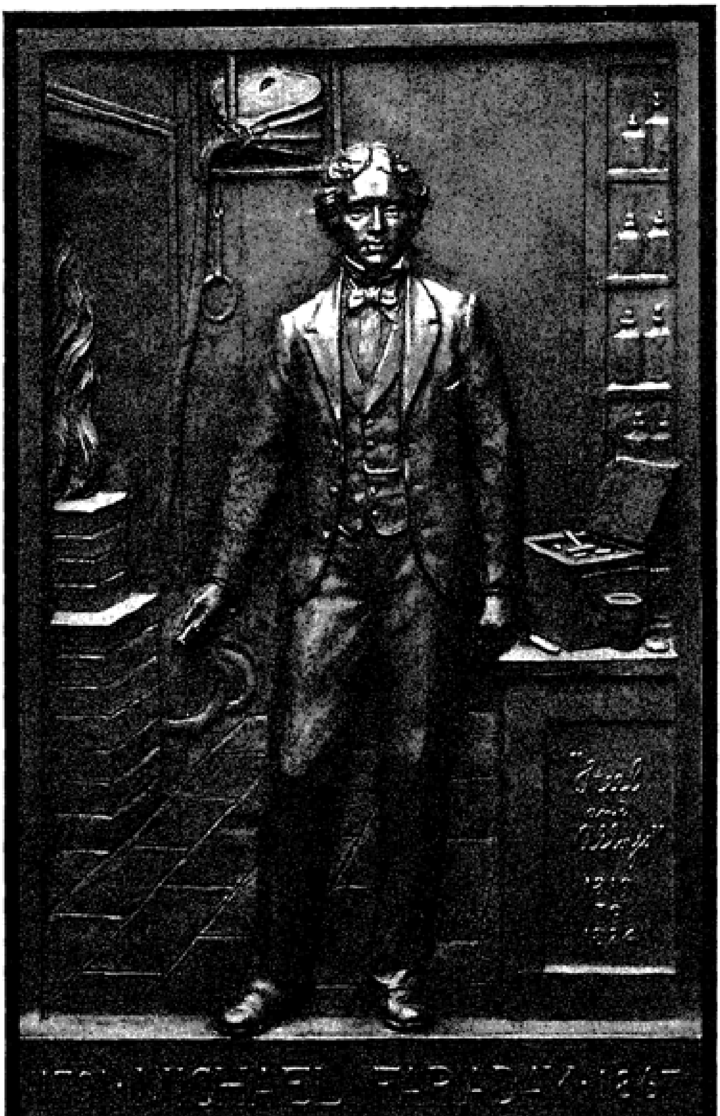
The credit for first producing cast steel on a large scale undoubtedly belongs to Benjamin Huntsman, but another passage in Jars's book shows that as early as 1765 attempts were being made in Newcastle to imitate Huntsman's methods. He says: "We were told, also, that south of Newcastle old files or other old steel articles or blister steel are cut into pieces and put into a crucible with a flux, which is kept secret. It is said that each workman has his particular recipe. These crucibles are placed in a furnace to melt the steel. One person in particular has undertaken this process, two miles away from this town (Newcastle), but he has succeeded badly."

Such attempts were evidently by no means isolated, for in 1787 a Sheffield Directory published by Gale and Martin showed five firms to be engaged in melting and refining, in addition to Huntsman's firm, then trading as Huntsman and Asline; and in 1792 Fourness and Ashworth, "Engineers to their Royal Highnesses the Prince of Wales and Duke of Clarence," published, of their own volition and at their own expense, a pamphlet proclaiming in no uncertain terms that "Mr. Huntsman makes the best Cast Steel in this, or perhaps any other country. . . . We have made trial of different kinds of Cast Steel, but never met with any that would abide the same execution as Huntsman's." After enumerating at length the many virtues and applications of the Huntsman steel, these disinterested friends say: "We are still the more induced to present to the public this impartial but imperfect character [*i.e.*, testimonial] of Huntsman's Steel, as we understand that during the course of more than thirty years of time devoted to the manufacturing of it, he has so much neglected his own interest and credit as never to give the public, thro' any general or circular medium, any account whatever of his Steel." All of which tallies well with our knowledge of that fine old Quaker whose character is revealed by the fact that he would not allow any portrait to be taken of himself (to our enduring loss), nor would he consent to be made a Fellow of the Royal Society in 1750, when his fame had already begun to spread.

Michael Faraday's Researches on "Alloys of Steel"

It has been shown that the innovation introduced by Huntsman, by *melting* steel as an essential to its production in a pure and homogeneous state, constituted an important advance and may justly be regarded as marking an epoch in the history of metallurgy and in that of Sheffield. Prior to his time "blister," or shear steel, was the best material available, and excellent though it was for

PLATE 5



MICHAEL FARADAY
1791–1867

many of the purposes of those days, it was not to be compared with the Huntsman crucible steel for use in springs, tools and, in fact, all the finer uses of steel.

Passing on to the nineteenth century, it is necessary to refer at some length to the association of Sheffield with the researches of Michael Faraday during the period about 1822 to 1826, specially as the full importance of this association has only been recognised comparatively recently. It is hardly too much to say that it marked a stage of metallurgical advance of even greater potentialities than the work of Huntsman, but, unlike the latter, there were no immediate and lasting practical consequences. For the definite realisation of the value of alloy steels, which Michael Faraday made the object of his first major research, the world had to wait yet another half-century, that is, until the discovery and invention of manganese steel by the author in 1882.

As recorded fully in the author's book, *Faraday and His Metallurgical Researches*, that wonderful pioneer, Michael Faraday, carried out, between 1819 and 1824, a series of most remarkable researches on "alloys of steel" with no less than 12 non-ferrous metallic elements, including chromium, copper, gold, iridium, nickel, osmium, palladium, platinum, rhodium, silver, tin and titanium. These researches were carried out, as far as Faraday himself was concerned, entirely in the laboratories of the Royal Institution, London, but it is recorded, in the paper "On the Alloys of Steel," presented to the Royal Society in 1822 by Stodart and Faraday, that materials for the manufacture of alloys "on a large scale" were prepared in London and sent to Sheffield (to Sanderson's works) to be melted, poured, forged and then returned to Faraday for mechanical and chemical examination.

It further appears from Faraday's Diary and papers, as well as from certain letters, all of which are quoted fully in the abovementioned book, that alloys of steel with silver, platinum, rhodium, iridium and osmium were all made "in the large way" and, in particular, that Faraday's alloy of steel with silver was used by the Sheffield firm of Green, Pickslay and Co. in the manufacture of cutlery, stove fronts and fenders, certainly during the years 1824 to 1826 and possibly longer.

Hadfield Research on Faraday's Specimens

Thanks to the kind permission of the Managers of the Royal Institution and the Director of the Science Museum, South Kensington, in regard to specimens of Faraday's steel in their charge, the author was able to subject these precious, century-old specimens to complete examination. The total weight of 88 specimens (79 from the Royal Institution and 9 from the Science Museum) amounted only to 8 lb. 3¾ oz. before the author commenced his researches. Of this quantity, only 1 lb. 4½ oz. was used for test bars, drillings and other purposes. In addition, ¼ oz. of metal was removed from certain razors of the same period, making a total of 1 lb. 4¾ oz. of metal used, yet no less than 866 tests were made, including 493 chemical analyses, 131 hardness tests, 55 micrographic examinations, and many magnetic, electrical, thermal and other investigations. This unique research, necessitating the greatest care in order to obtain full data without destroying the original specimens to any serious extent, gave a wealth of information which cannot here be reproduced, even in summarised form. It demonstrates clearly that, long acknowledged as a leading chemist and as the founder of the electrical industry, Faraday was also a metallurgical investigator of great ability and brilliant inspiration. His metallurgical work was accomplished in the face of difficulties which it is almost impossible to appreciate today, and many years before the iron and steel industry had the materials, the resources or even the incentive fully to follow the lead thus given them.

Facilities of the highest order are now available for the melting and preparation of steel, whether in the crucible, open hearth, converter or electric furnace, including the latest type of the latter, the high-frequency induction furnace. Faraday's equipment in these respects was limited to crucibles of variable quality, and a hand-blown "blast furnace," to use his own phrase. He had nothing at all comparable with modern electrical and optical pyrometers for the convenient and accurate measurement of high temperatures, and he appears to have made no attempt to measure the temperatures of fusion of his various alloys. He was, however, aware of the importance of heat treatment and the general utility of pyrometers as then available, but, if he had wished to measure the melting points of steel alloys, the only means at his disposal would have been the "thermometer pieces" of clay devised by Josiah Wedgwood, which could only afford comparative data on an arbitrary scale, or the Daniell pyrometer, an apparatus which formed part of the equipment of the Royal Institution Laboratory. The many types of furnaces and pyrometers now available for the melting and heat treatment of steel and alloys find no parallel in the equipment available either to Faraday or to the Sheffield firms who made and used some of his alloys.

It is gratifying to know that the importance of Faraday's metallurgical work is now definitely established for all time, and that sufficient, though fragmentary, proof has been collected of the assistance rendered by Sheffield in this great work. There was no immediate and continuous commercial development from Faraday's researches in this field, but they aroused a great deal of interest both at home and abroad at that time, and there need be no hesitation in claiming Sheffield's share in the work as one of the many contributions it has made to the cause of metallurgy.

The historic specimens made by Faraday some 110 years ago, and now recognised as representing the first systematic investigation of a wide range of alloy steels, are safely housed in what may justly be termed the two most famous collections of scientific apparatus and materials in the Empire, if not in the world. One set consisting of 79 specimens is exhibited in the ambulatory of the

Royal Institution, London, while the smaller set, consisting of only 9 specimens, but including some remarkable high-alloy pieces, is on view in Gallery No. 23 on the first floor at the Science Museum, South Kensington. The author regards it as a great honour and privilege to have been allowed to subject both sets to complete examination, thus establishing definitely their high importance in the history of metallurgical development.

V. MODERN METALLURGY AND SHEFFIELD

Rapid Expansion between 1750 and 1850

Though in no way comparable with the phenomenal growth that later followed the introduction of the Bessemer process and open hearth furnace, there occurred during the later part of the eighteenth century and the first half of the nineteenth an expansion of the steel industry in Sheffield which paved the way for the coming of the modern Steel Age. This development was by no means confined to Sheffield, but the available statistics for this city are specially interesting and representative.

In 1787, or only ten years after Huntsman's death, Gale's Sheffield Directory showed, by five or six firms entered under the heading of "Steel Refiners," that the men of Sheffield had not been slow to take advantage of the improvements effected by Huntsman. There were in that year about a dozen firms engaged in the converting or cementation process; also, about 50 makers of edge tools, 40 of files, 300 of pen, pocket and table knives, 50 of razors, close upon 100 of scissors, and some 60 or 70 engaged in the manufacture of scythes, sickles, and shears. Many of the names of manufacturers then engaged in the Sheffield trades are well known today, and their continued existence is a good proof that the motto of the Cutlers' Company, "*Pour y parvenir à bonne foi*," has faithfully represented their aims. That the city has made continued progress in this special manufacture is shown by the following figures: In 1835 there were 56 converting furnaces and about 564 melting holes; in 1842 there were 97 converting furnaces and about 777 melting holes; in 1856 there were 105 converting furnaces and about 874 melting holes; in 1899 there were over 2,000 melting holes.

Heath and Manganese

From the records available it appears that the value of manganese in steel-making was appreciated, at least by some workers, nearly forty years before a cheap and reliable "ferro-manganese" could be obtained as a convenient means of introducing the metal into steel. Heath, about 1840, was probably the first to recognise fully the utility of manganese in the manufacture of steel, and he applied the black oxide to the production of crucible cast steel. Robert Mushet later used manganese alloys on a much larger scale to cheapen crucible and Bessemer steel. Henderson, at Glasgow, rendered important service by making excellent alloys of iron and manganese containing 25 to 30 per cent. of the latter metal and offering substantial advantages over spiegeleisen, but it was left to the Terre Noire Company, of France, to produce "ferro-manganese" containing up to 80 per cent. of manganese at a relatively low price, making possible the wholesale manufacture of excellent soft steels.

The Bessemer Process

In the year 1856 Sir Henry Bessemer, F.R.S., announced his pneumatic process of removing the impurities from molten pig iron by a blast of air forced through the fluid metal. Until that time, steel could be made only by the crucible process or by cementing puddled iron, and it was Bessemer's process that first made it possible to produce cheap steel in the quantities to which we are accustomed today. Many difficulties had, however, to be overcome before the process was a practical and commercial success, and Sheffield men, among them Sir John Brown, the late Mr. J. D. Ellis, and the late Mr. W. Allen, of Messrs. H. Bessemer & Co., assisted greatly in the successful development and working of the process in this country.

In the words of Sir Henry Bessemer's autobiography: "The early experiments were so far successful as to justify myself and some of my friends in erecting in the town of Sheffield a steelworks under the style of Henry Bessemer & Company, Limited. These works were established both for commercial purposes and also to serve as a pioneer works or school where the process was for several years exhibited to any iron or steel manufacturers who desired to take a licence to work under my patents." The Bessemer process was being operated also by Messrs. John Brown & Co., at the Atlas Works, Sheffield, in 1861.

The remarkable metallurgical development of America in the seventies of last century was largely due to this pioneering work, the great American metallurgist, Holley, receiving his training in the Bessemer process at Sheffield. In this connection it is pleasing to recall the generous words of Mr. Charles M. Schwab, when President of the American Iron and Steel Institute. Speaking at the annual dinner of our own Iron and Steel Institute, May 3rd, 1928, Mr. Schwab said: "There has not been a great process in iron and steel that has marked America or any other country's development that did not have its origin here in Great Britain. Bessemer led the way, and that revolutionised the industry. I know exactly how we were taught to make steel in America, but it originated in Great Britain. Then came the development of the open hearth, the Siemens open hearth, and others, all of which were originally developed in Great Britain."

Thomas and Gilchrist

The extension of the pneumatic process to dephosphorising iron in a basic-lined converter was discussed by Snelus, and finally brought to practical success by Thomas and Gilchrist. All three received the Bessemer medal of our Institute. This completed a series of inventions of the highest importance from the standpoints of producing good and cheap steel, and saving fuel in the manufacture. The part played by Sheffield in assisting these developments, and applying them to the benefit of the nation, should not be forgotten.

Siemens-Martin Open-Hearth Process

While these great changes were in progress the brothers Siemens were successfully applying their open-hearth "regenerative" furnace to the economical manufacture of steel, the perfection of the development being also influenced by the joint work of Pierre Martin, of France. The Siemens-Martin method made it possible in due course to produce ingots up to 150 or even 200 tons in weight, a feat which had hitherto been impossible. Indeed, as comparatively recently as 1850 it was thought to be a remarkable achievement when Messrs. Turton, of the Sheaf Works, produced an ingot weighing 25 cwt., afterwards shown at the Great Exhibition.

A paper describing the Siemens regenerative furnace and its application to reheating furnaces was presented to the Iron and Steel Institute by J. T. Smith in 1869, and it is interesting to recall that Mr. T. E. Vickers contributed to the discussion on that occasion. Messrs. Vickers started their open-hearth melting shop in 1871, and were thus one of the first, if not actually the first, in the Sheffield district to put down open-hearth furnaces.

Basic Bessemer and Basic Open-Hearth Processes

The development of these processes was well described by J. E. Stead in his Presidential Address to the Iron and Steel Institute, 1920. It was in 1877 that S. G. Thomas conceived the idea of rendering the Bessemer and Siemens processes capable of removing phosphorus, basing his ideas on the researches of French metallurgists regarding the use of a lining of limestone instead of silica. Trials were made at the Blaenavon Steelworks with the assistance of P. C. Gilchrist and E. P. Martin. Work was continued actively on these lines during the ensuing year, the dephosphorising action being more clearly elucidated and a number of technical improvements being effected. Important trials were made at Brown, Bayley and Dixon's works in Sheffield during 1879, under A. Cooper, and it was discovered that on running off the slag before the action of spiegel no rephosphorisation took place. As regards the basic open-hearth process, J. H. Darby, in 1885, carried out this process at the new Brymbo Steelworks, this being the first establishment in Great Britain to produce basic open-hearth steel by the pig and ore process.

Other Workers of the Nineteenth Century

Progress in the metallurgical history of Sheffield became cumulatively more rapid as the nineteenth century advanced, and it is impossible here to present any fully adequate survey of that period. Brief mention must, however, be made of a few outstanding names. Lucas, in 1815, was one of the first to perfect malleable cast iron. Robert Mushet discovered, in 1858, a self-hardening tool steel which could be run at high speeds without losing its temper. That eminent citizen of Sheffield, Sir John Brown, added greatly to the city's renown, not merely by assisting the development of the Bessemer process, but also by his pioneering activities in the rolling of armour plates, the invention of conical spring railway buffers, and other important work. So the tale goes on. The names of Brown, Jessop,* Cammell, Firth, Ellis, Sanderson, Mappin, Wostenholm, E. Reynolds, T. Vickers, Wilson, Turton, Andrew, Fox, Seebohm, Howell, Doncaster,* Beardshaw, Bedford, Hall, Marsh, Ward, Colver, Jonas, Allen, Senior, Osborn, Spencer,* Stubbs, Balfour, Tozer, Rodgers, Hoyle, Wardlow, Ellin, Flather, and many others call to mind those who laid foundations on which later workers have built much of the science of metallurgy, the prosperity of Sheffield and the position of our Empire. Nor are all these names associated only with the more recent developments of metallurgy in Sheffield; those marked with an asterisk are to be found also in Gale's Directory of Sheffield, published in 1787.

Reference to the remarkable services rendered by Dr. H. Clifton Sorby, F.R.S., in regard to the discovery and development of the science of metallography is reserved for a later section of this paper. So, too, are references to the world's indebtedness to metallurgical chemists, and others who have contributed to the many branches of metallurgical knowledge and practice. The rise of alloy steel also demands separate consideration (Section VI), but it may here be briefly mentioned that following the discovery of manganese steel came nickel steel, silicon steel, aluminium steel, chromium steel (which later included the splendid work by Brearley in discovering the application of certain types of chromium steel to cutlery and many other purposes), vanadium steel, tungsten steel (with regard to which in its early stages we were indebted to Mushet, who worked in this city with the well-known steel makers, Messrs. Osborn), and many other binary, ternary and quaternary alloy steels amongst them the more recent corrosion-proof and heat-resisting steels of today. Many of these are of compositions which would have been thought most extraordinary—in fact, impossible—even at the end of the last century.

World Metallurgists

Even from the brief outline in the foregoing pages it can be seen that this country, and Sheffield in particular, can claim to have led the way in the development of modern high quality steels and alloy steels, without which modern engineering applications could not have reached their present remarkable state of development. At the same time, invaluable contributions have been made by many others in most of the leading countries, and with the desire to render full recognition of the importance of their work, the author has prepared the following "national lists," which may be useful for references.

Though it is impracticable to give here the names of all those who have made the metallurgy of iron and its alloys what it is today, some of the more prominent workers are mentioned below, specially as regards the heat treatment and metallography of alloy steels, and references to others are given elsewhere in this paper. Many of these, alas, have passed away, but their work will endure and their names should not be forgotten.

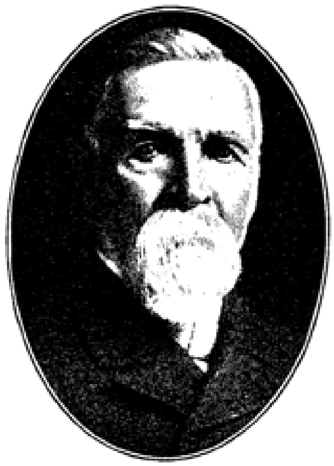
Great Britain.—To the credit of Great Britain there is the work of Sorby, Roberts-Austen, Stead, Riley, Vickers, Spencer, Cooper, Dale, Martin, Richards, Arnold, Rosenhain, Carpenter, Louis, Desch, Harbord, Rylands, Samuelson, Williams, Wright, Sandberg,

PLATE 20

International
U.S.A.

A. L. Holley
Bessemer Medallist 1882

Professor H. M. Howe
Bessemer Medallist 1895



John Fritz
Bessemer Medallist 1893

Professor Albert Sauveur
Bessemer Medallist 1924

C. M. Schwab
Bessemer Medallist 1928

PLATE 21

France
(early)

de Réaumur
1683—1757

Vauquelin
1763—1829

Lavoisier
1743—1794

Berthier
1782—1861

Berthollet
1748—1822

PLATE 22

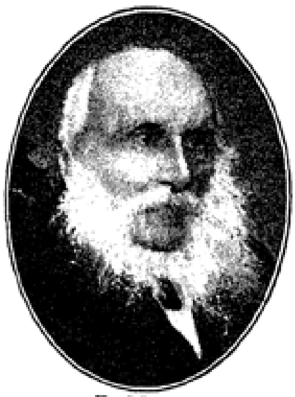
France

(Modern)

F. Osmond
Bessemer Medallist 1906

A. Pourcel
Bessemer Medallist 1909

H. le Chatelier
Bessemer Medallist 1911



P. Martin
Bessemer Medallist 1915

Eugene Schneider
Bessemer Medallist 1930

Dr. Leon Guillet

Charles Frémont
Bessemer Medallist 1921

Turner, Talbot, Saniter, Aitchison, Brearley, Hatfield, Henshaw, Andrew, Swinden, Dickenson, Monypenny, Kayser, Edwards, McCance, and others. The late Sir Frederick Abel conducted a number of valuable researches, particularly in reference to carbon steels, and for these and other research work he received from the Iron and Steel Institute the much prized recognition of the Bessemer medal.

In the early days of the author's work in Sheffield he received much help and encouragement from his father, Mr. Robert Hadfield ; the late Dr. Clifton Sorby, F.R.S. ; Dr. W. M. Hicks, F.R.S. ; Professor W. Ripper ; the late Professor L. T. O'Shea ; Professor J. O. Arnold, F.R.S., whose valuable researches in the metallurgical laboratories of the Sheffield University, including work on the development of high-speed tool steels, have contributed largely to modern progress ; Mr. T. Andrews, F.R.S., and many others.

The world at large should be specially grateful to the band of scientific workers—amongst others, such men as Gore, Barrett, the Hopkinsons, father and son, Roberts-Austen, Arnold, Bauerman, Callendar, and those of other nations mentioned below—who thought that the study of metallurgy was worthy of recognition. It is largely owing to their efforts that we have been able to progress so rapidly, and to establish metallurgy as a part of science instead of an empirical art.

United States of America.—Prior to about the middle of last century the United States could claim little in the way of contribution to metallurgy, but since that time there have been many who have helped on the work of research and application. Amongst them may be mentioned R. W. Raymond, A. L. Holley, T. Sterry Hunt, William Metcalf, R. W. Hunt, Thomas Egleston, Abram S. Hewitt, H. M. Howe, John Fritz, J. D. Weeks, E. G. Spilsbury, Charles Kirchhoff, James Gayley, John Hays Hammond, Judge E. H. Gary, J. A. Farrell, Charles F. Rand, Herbert Hoover. Also there are such names as those of Benneville, Wellman, Keep, Clamer, Sauveur, Hibbard, Burgess, Campbell, Moldenke, Jeffries, Northrup, Stoughton, J. L. Cox, Strauss, Howe Hall, Becket, Hoyt, Beck, Waterhouse, and others.

France.—Without presuming to establish any order of precedence or merit, the author's mind turns first, as regards French metallurgists of modern times, to the work of Osmond and le Chatelier, specially in connection with pyrometric developments, the preparation of heating and cooling curves, and other advances in physical methods. Then, too; there is Dr. Léon Guillet, Member of the Académie des Sciences and Professor of Metallurgy at the Conservatoire des Arts et Métiers, Paris, who has made important contributions to our knowledge of iron alloys and other metallurgical problems. Another tribute to the important metallurgical work carried out in France in modern times must certainly include the names of Brustlein, Grüner, Barbier, Euverte, Gautier, Van de Monde, Baclé, Charpy, H. le Chatelier, A. le Chatelier, Cheneveau, Chevenard, Dumas, Robin, Fréminville, Frémont, Frémy, Girod, Guillaume, Guillery, Grenet, Harmet, Heroult, Jourdain, Pierre Martin, Moissan, Muguet, Osmond, Pourcel, Portevin, Saladin, Schneider, Werth, Weiss, Cornu-Thenard, and others.

Germany.—In attempting to make a selection from among the names of German workers who have contributed greatly to modern metallurgical knowledge, the following names immediately suggest themselves: Wedding, Ehrensberger, Mars, Martens, Maurer, Strauss, Ledebur, Oberhoffer, Wüst, Fry, and others.

Other Countries.—As regards other nationalities, there must certainly be mentioned: *Belgium*, Greiner; *Sweden*, Akerman, Brinell, Benedicks, Westgren; *Russia*, Belaiew, Tschernoff; *Italy*, Giolitti; *Spain*, de Elhuyar, de Zubiria; *Holland*, Onnes; *Japan*, Honda.

A further tribute to the "internationality of metallurgy" is given in Section XII, in relation to the cosmopolitan scope and work of the Iron and Steel Institute itself. At the same time, while the ramifications of metallurgical work and progress extend all over the world, it redounds greatly to the credit of Sheffield that almost every leading metallurgist of modern times has not only visited Sheffield, but has also kept continually in touch with its activities either by correspondence and co-operation or by actually working here for many years.

PLATE 23

Germany

Friedrich A. Krupp
Bessemer Medallist 1902

A. Ledebur
Hon. Member

Dr. H. Wedding
Bessemer Medallist 1896

Professor Richard Akerman
Sweden
Bessemer Medallist 1885

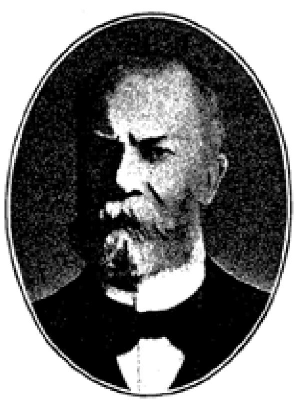
Dr. J. A. Brinell
Sweden
Bessemer Medallist 1907

Dr. Carl Benedicks
Sweden
Bessemer Medallist 1927

Professor F. Giolitti
Italy
Bessemer Medallist 1919

Professor K. Honda
Japan
Bessemer Medallist 1922

Professor H. K. Onnes
Holland



Professor D. Tschernoff
Russia
Hon. Vice-President

Colonel N. T. Belaiew
Russia

VI. ALLOY STEELS

Importance of Alloy Steels

Just as, without iron, we should revert to the conditions of the Dark Ages, so, without alloy steels, we should be cast back, in many respects, to the conditions of a century ago. Iron and the simpler forms of steel will not give us, for example, the hard-wearing toughness of manganese steel; the greatly reduced rusting qualities of chromium, chromium-nickel and other steels; the wonderful energy-saving properties of silicon steel as used for electric generators motors and transformers; the special magnetic properties of tungsten and cobalt steels for permanent magnets, of manganese steel for applications where non-magnetic material is required, and of certain nickel-iron alloys where extraordinarily high permeability at low inductions is required. In addition, there are non-scaling steels, steels which are strong and tough at low temperatures, steels possessing considerable strength at high temperatures, and many others.

Rise and Development of Alloy Steels

The first use of alloy steels on a practical and commercial scale, leading subsequently to the remarkable range of materials now available, dates from the author's discovery and invention of manganese steel in 1882. In the words of the famous French metallurgist, the late Professor Floris Osmond, who was awarded the Bessemer Gold Medal of the Iron and Steel Institute in 1906: "The Hadfield discovery and invention of manganese steel was not only the discovery of a new alloy, curious, of great scientific value, and yet useful, but in the history of the metallurgy of iron it ranked as a discovery equal in importance to that of the effect of quenching carbon steel, and was the only one of the same order which it had been reserved for our age to make."

Then followed the author's invention of silicon steel and his original paper on chromium steel, presented to the Iron and Steel Institute in 1892, with, later, researches on nickel, tungsten, molybdenum, vanadium and other steels. Careful estimates have shown that the Hadfield inventions of manganese steel and silicon steel alone have already saved the world between £700 and £800 millions—manganese steel by its extraordinary and unique qualities of durability and toughness, and silicon steel by greatly reducing energy losses in electrical machinery and apparatus.

While the credit for the initial development of alloy steels undoubtedly belongs to Sheffield, workers in many countries have helped to bring alloy steels to their present position of high importance. It would be difficult to mention all who have assisted, but the following list represents most of those chiefly concerned: As regards Great Britain, Aitchison, Arnold, Brearley, Carpenter, Desch, Dickenson, Gowland, Harbord, Hatfield, Heycock, Mushet, Riley, Rosenhain, Saniter, Stead, Turner, Vickers; in the United States, Becket, Burgess, Campbell, Hibbard, Howe, Zay Jeffries, Mathews, Metcalfe, Sauveur, Stoughton, Strauss, White; in France, Brustlein, Charpy, Dumas, Girod, Guillet, H. Le Chatelier, Heroult, Moissan, Osmond, Portevin, Pourcel, Schneider; in Germany, Ehrensberger, Ledebur, Mars, Martens, Maurer, Monnartz, Strauss, Wedding; in Sweden, Akerman, Benedicks, Brinell and Westgren; in Italy, Giolitti; in Japan, Honda; and in Russia, Tschernoff and Belaiew.

Manganese Steel

As recounted more fully in the author's book, *Metallurgy and its Influence on Modern Progress,* it was largely a brochure issued by the Terre Noire Company at the great Paris Exhibition of 1878 that inspired him to undertake a series of experiments on alloys of steel. This in turn led to his discovery and invention in 1882 of manganese steel.

Figure VIII shows the original specimens exhibited by the author at the reading of his first paper on Manganese Steel before the Institution of Civil Engineers in 1887, in which he described the researches which led to the discovery of this material.

The alloy now generally described as the Hadfield manganese steel, consisting of an alloy of iron with from 11 to 14 per cent. of manganese and about 1·25 per cent. carbon, is still one of the most remarkable materials yet produced. Whilst the composition of the alloy is the same as that first produced by the author, the manufacture of the material has been greatly improved, including the heat treatment, to which its most useful qualities are largely due. Its principal characteristics may be summarised as follows:—

(*a*) When water-quenched, it is practically non-magnetic, notwithstanding the fact that it contains about 86 per cent. of iron.

(*b*) It is greatly toughened by quenching instead of being hardened and made comparatively brittle, as is the case with carbon steel. Conversely, it is rendered brittle and magnetic by annealing for some 40 hours at about 500° C.

(*c*) It has high tensile strength (60 to 70 tons per square inch when suitably heat-treated), combined with extraordinary elongations, viz., 50 or even 70 per cent., far exceeding that obtainable with the purest iron.

(*d*) Its resistance to wear by abrasion is greater the more severe the service to which it is applied.

Even a slight deformation of an article made of manganese steel is accompanied by a considerable increase in hardness of the material, and the highest wear-resisting qualities are developed under the hardest working conditions. In the undeformed state it is relatively soft, the hardness being then about 200 as measured by the Brinell test, but under mechanical deformation the Brinell hardness number rises to 500 or even 580.

As already noted, water-quenched manganese steel is practically non-magnetic, and for this reason it has been employed in armoured and other structures near the magnetic compass in ships and aeroplanes. Its electrical resistance is 71 microhms per cm.-cube, or seven times that of pure iron; the average thermal conductivity between 0° and 100° C. is 0·027 c.g.s. units, or about one-sixth that of pure iron; and the mean coefficient of expansion between 0° and

100 ° C. is 0·000018 per 1° C., or about $1\frac{1}{2}$ times that of pure iron. These properties are the more remarkable when it is remembered that manganese steel contains about 85 to 87 per cent. of iron.

This steel has excellent casting qualities as regards fluidity and ability to fill moulds of intricate shape. Its fluid contraction is rather greater than that of ordinary steels and amounts to from 0·30 to 0·33 inch per foot, and the castings made from it are particularly free from blowholes. It is now possible to weld manganese steel parts successfully and to recondition worn parts by the use of an uncoated electrode of a material ("Hadmang") which contains all the essential constituents in the welding rod itself, forms no slag and exhibits in the deposited metal all the characteristic properties of manganese steel as normally supplied.

The extraordinary combination of toughness and great strength obtainable in manganese steel by proper heat treatment and working renders it invaluable for such applications as special railway and tramway track work, the jaws and other wearing parts of crushing machines capable of dealing with up to 1,000 tons of ore per hour, the wearing parts of excavators and dredgers, wheels of mine cars, of which hundreds of thousands are at work, wire-line sheaves for oil-well machinery, sprockets, clutches and hundreds of other articles exposed to severe conditions—in fact, wherever special resistance to shock and abrasion is required. Among the many applications of manganese steel in connection with world-famous engineering schemes may be mentioned its use in crushers supplied to prepare material for the great Cauvery Mettur dam, and the use of manganese steel rails in the permanent way and approaches of the famous Sydney Harbour Bridge.

Some remarkable examples of the use and wearing qualities of manganese steel are mentioned fully in the author's book, *Metallurgy and its Influence on Modern Progress,* and such instances could be multiplied almost indefinitely. A certain lay-out at a junction on the London and North Eastern Railway at the entrance to the Central Station, Newcastle-on-Tyne, constructed of "Era" manganese steel was put to work on October 30th, 1912, and was in use in 1924. This lay-out comprised 71 crossings and 21 rail crossings, with 77 intersections, and during the twelve years it was in service, compared with only four or five years for the carbon steel lay-out formerly employed, the lay-out was traversed by some $3\frac{1}{2}$ million trains, representing a total of 1,240 million tons, a large proportion of this being heavy express and fast main line trains. A further similar lay-out now in use is showing the same remarkable durability.

Another instance, in some respects even more extraordinary, is to be found in the "Era" manganese steel lay-out made for the Sheffield Corporation Tramways and installed in Fitzalan Square. The traffic at this central point is so heavy that the carbon steel rails and other parts formerly employed had to be removed every few months, or even every few weeks in some cases, but the first manganese steel lay-out was in use for six years, and was then replaced only because extra tracks were required. The larger lay-out then installed gave twelve years' service, and a similar lay-out is now in use with equally satisfactory results.

On the basis of very careful estimates, the total savings effected by the use of manganese steel now amount to the very considerable sum of £550,000,000. This takes into account representative but conservative estimates of the ratio of savings to first cost of manganese steel in various classes of applications, a ratio which ranges from four to six or even more times the original cost of the alloy steel. Also, in addition to the direct saving effected by the greater durability of manganese steel, a saving which increases with the severity of the service, there is an important saving in the cost of dismantling and renewing worn parts, to say nothing of the indirect costs that may be occasioned by the interruption of normal working where and when parts are being renewed.

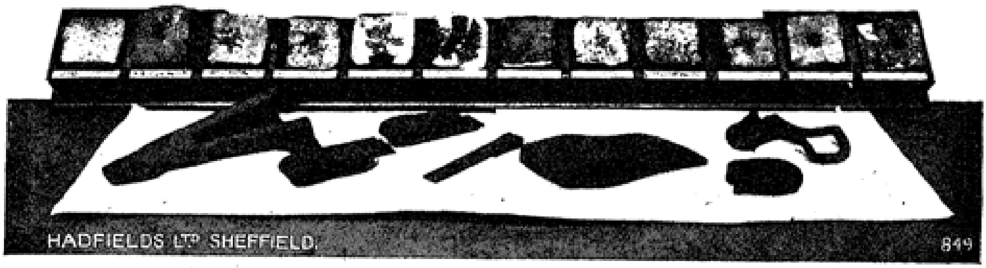
Silicon Steel

The whole of the electrical industry of today, in all but certain weak-current applications of relatively minor importance, depends essentially on the magnetic properties of iron and their utilisation in conjunction with Faraday's remarkable discovery of electromagnetic induction. The total production of electrical energy by public supply stations in Great Britain alone exceeded 12 million kw. hr. in 1932, in spite of the industrial depression, but only an infinitesimal portion of this energy could have been produced, and practically none for industrial purposes, without iron, alone or in alloyed form, in the magnetic circuits of the generators, transformers, motor generators, rotary converters and motors employed. The use of iron here considered is as a magnetic medium and quite apart from its mechanical applications in the same and associated equipment.

The essential part thus played by iron in electrical apparatus and machinery is well known, though we are rather apt to take it for granted without fully considering what our position would be if iron were not cheap, plentiful and highly magnetic. The other magnetic metals, nickel and cobalt, certainly could not take its place, even if they were less costly than they are. Iron itself, however, is by no means an ideal material for the magnetic cores of electric generators, motors, transformers and other apparatus, though it is an essential constituent thereof.

The author's attention was specially directed to the effects of silicon on iron as long ago as the year 1882. Thereafter, as the outcome of many years of research, the invention and application of silicon steel were developed and perfected. Numerous difficulties were experienced in the early stages of the introduction of this steel made under the author's patents. The history of these developments and how the difficulties were overcome is given in his book, *Metallurgy and Its Influence on Modern Progress*, where reference is also made to the series of researches, these being chiefly of a physical nature, which he carried out with the late Sir William Barrett, F.R.S., and Professor W. Brown on manganese, silicon, aluminium, chromium, nickel, tungsten and other alloy steels.

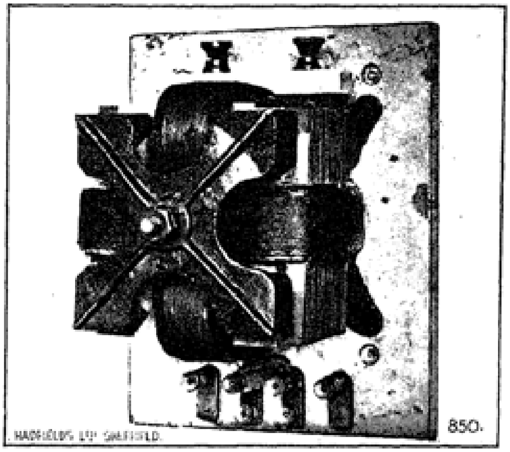
Figure VIII



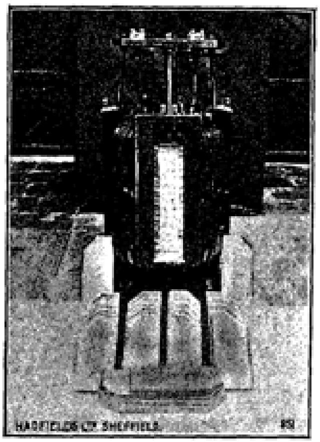
Specimens from the original Iron Manganese Alloy ingots made by Hadfields in 1882

Manganese Steel specimens as exhibited before the Institution of Civil Engineers in 1887

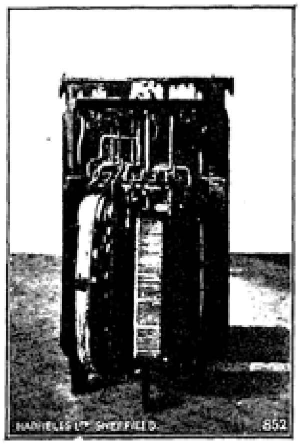
Miscellaneous castings in Manganese Steel as exhibited before the Institution of Civil Engineers in 1887



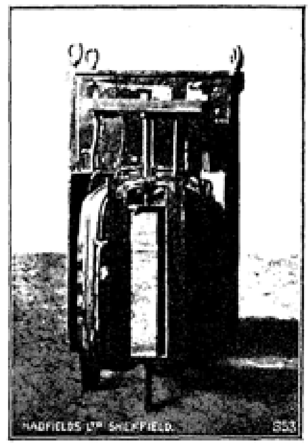
The original small ½ kW Transformer constructed in 1903



The 40 kW Transformer made in June, 1905



The 60 kW Transformer made in July, 1906



The 40 kW Transformer of the best Transformer Iron constructed in 1905

The 60 kW Transformer taken out of service October, 1927, after being at work for twenty-one years

The first practical application of silicon steel took place in Sheffield, and special credit is due to Mr. S. E. Fedden, then General Manager of the Sheffield Corporation Electric Supply Department, for his foresight and enterprise in this connection. Mr. Fedden, in October, 1903, constructed the first transformer ever made from the author's silicon steel.

This was followed in 1905 and 1906 by further transformers of 40 and 60 KW capacity, which were put to use on the Sheffield supply system.

From these three transformers, which are illustrated in Figure IX, and which now occupy an honoured place for all time in the Science Museum at South Kensington, sprang the enormous present-day use of silicon steel. It is further of interest that these transformers were made to the designs of Mr. W. E. Burnand, the well-known electrical engineer of Sheffield, whose work in the improvement of the design of transformers is also represented in the Science Museum.

Steels containing about 3 to 5 per cent. of silicon have higher permeability at low magnetising forces, lower hysteresis loss and higher electrical resistance than pure iron; consequently, under magnetisation by alternating currents, it has lower eddy-current loss than pure iron. The maximum permeability of rolled sheets of silicon steel is about 25 per cent. higher than that of pure iron, whilst the hysteresis loss is initially about two-thirds that of pure iron and has been found to decrease during a period of years in service. This property of improving during use, instead of ageing, is in marked contrast to the behaviour of charcoal iron and the early dynamo and transformer steels, for the hysteresis loss in these materials often increased by 100 per cent. or more after a few months, and necessitated the periodical dismantling and annealing of transformer plates. Owing to further improved practice in manufacture, silicon steel can now be produced having a total magnetising loss only slightly exceeding 1 watt per kilogram when tested at 10,000 gauss maximum induction and 60 cycles per second, and a permeability of 8,000 can be reached.

Chromium Steels

As far as can be ascertained, the first correlated and complete study of chromium steel—that is, such as was possible with the chromium ferro-alloys then available—was contained in the author's paper on "Alloys of Iron and Chromium," presented to the Iron and Steel Institute in 1892. During the preceding two years, investigations had been made on a series of fifteen alloys containing from 0·22 to 16·74 per cent. of chromium. Amongst these alloys there were four which may be regarded as the forerunners of the present-day rustless steels; their compositions were as follows:—

	Carbon. Per cent.	Silicon. Per cent.	Chromium. Per cent.
Specimen L	0·71	0·36	9·18
,, M	1·27	0·38	11·13
,, N	1·79	0·61	15·12
,, O	2·12	1·20	16·74

In a report presented in 1892 by the late Professor Osmond, and forming part of the author's paper previously mentioned, he stated that "the etching of Specimen 'L' (0·71 per cent. C, 9·18 per cent. Cr) with nitric acid may be continued as long as two minutes without sensibly altering the appearance of the sample. The polyhedrons continue brilliant and highly polished." He also added that "as the amount of chromium increases, a compound of iron, chromium and carbon appears to be formed, which is only partially attacked by acid, and possess great hardness."

In 1904 two series of chromium steels, with chromium increasing by steps up to 36·34 per cent., made at the Imphy Steel Works, were examined by Professor L. Guillet, principally from the point of view of their metallographic constitution and mechanical properties. One of the specimens analysed contained 0·14 C and 13·60 Cr, another 0·38 C and 14·52 Cr, and a third 0·21 C and 22·06 per cent. Cr. These resemble in their composition the high chromium steels of today.

The subsequent development and perfection of rustless chromium steel and the later types of corrosion-resisting steels have been the product of many minds and much research. Friend, Bentley and West, in their paper on "The Corrosion of Nickel, Chromium and Nickel-Chromium Steels," published in May, 1912, appear to have been the first to have published data showing that chromium steels possessed merits as regards their resistance to the ordinary forms of corrosion by air and water as distinct from acids. They showed that, under alternate wet and dry conditions of exposure, a 5·30 per cent. chromium steel was corroded at only 21 per cent. of the rate of ordinary unalloyed steel, practically the same figure being obtained for its corrosion in sea water. In tap water the figure was 43 per cent.

From about 1912 to 1914 Mr. Harry Brearley carried out his well-known experimental and practical work on high chromium steels, regarding which Dr. W. H. Hatfield, in a paper on "Stainless Steels," read before the Midland Institute of Mining, Civil and Mechanical Engineers in 1922, stated that "it was in 1912–13 that Mr. Brearley discovered that the 12 per cent. to 14 per cent. chromium steels, when in the hardened condition, resisted successfully general atmospheric and many other active influences which lead to corrosion." The manufacture and heat treatment of this type of steel, and its application to cutlery, were further developed by Mr. H. Brearley, Messrs. Thomas Firth and Sons, and Dr. W. H. Hatfield, to all of whom special credit is due. The Iron and Steel Institute, in 1920, fittingly awarded the Bessemer Gold Medal to Mr. H. Brearley for his research work.

It would be difficult to over-estimate the importance, not only to Sheffield, but also to the world at large, of the development of "stainless" steel, leading, by the labours of many workers in different countries, to a whole range of corrosion-resisting and heat-resisting steels which have literally revolutionised many branches of engineering and other industries. Further developments followed in the evolution of austenitic stainless steels, in which many workers participated, including those in Sheffield, also in Germany, France, America and elsewhere, until now, on foundations established by Sheffield metallurgists, the world has the inestimable advantages of special steels meeting the requirements of modern industry, whether as regards resistance to acids, alkalis or other corrosive substances, or high temperatures and the attack of gases and slags in furnaces of all kinds. Moreover, the remarkable retention of strength of the latest heat-resisting steels at high temperatures is an invaluable quality where the valves of internal combustion engines or the blades of gas turbines are concerned. Even within the present limitations of space, some reference must be made to recent developments in each of these fields.

Chromium-Nickel Steels

The development of high chromium-nickel steels of varying types has arisen out of, and been associated with, the numerous investigations of the Neo-Metallurgie Co., Monnartz, Maurer, Strauss, Gruner, Haynes, Brearley, Messrs. Firth-Brown, W. H. Hatfield, Messrs. Brown Bayley's Steel Works, Ltd., J. H. G. Monypenny and others. Much valuable research work and many practical applications of these classes of steel have also been carried out in France by La Société Anonyme de Commentry Fourchambault et Decazeville, including the important special investigations by Dumas, Guillaume, Chevenard and others at the famous Imphy works of that company.

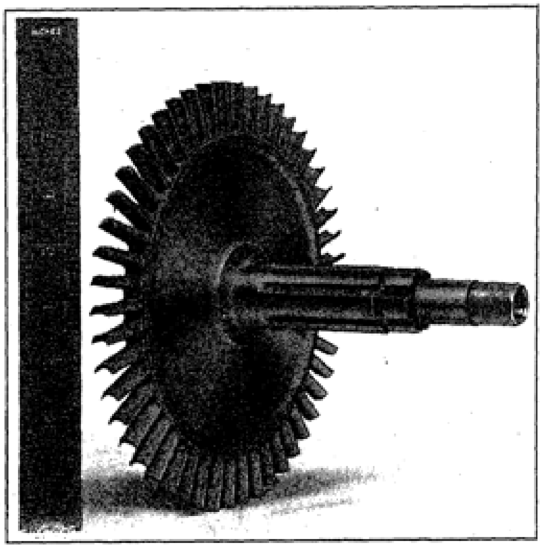
In addition to their own previous work on chromium-nickel steels, the author's firm, La Société Anonyme de Commentry Fourchambault et Decazeville, of France, and Messrs. The Midvale Steel Co., of Nicetown, Pa., U.S.A., now collaborate and unite in developing this and other special alloy steels under their group of patents and manufacturing practice.

The most generally used types of high chromium-nickel steel are low in carbon and contain from 15 to 22 per cent. of chromium, with 7 to 14 per cent. of nickel. Such alloys have a specially wide range of resistance to corrosion, and overcome many of the difficulties experienced in the chemical industries. The technique of their production has now been fully established, making them available in all the various forms required, including castings and forgings, rolled sheets, and bars, tubes and wire. With suitable modification of machining methods, they are also readily machinable. In view of the extended use of welded constructions, it is also satisfactory that each of the several welding methods can be applied to these alloys, the process being in all cases of an autogenous character.

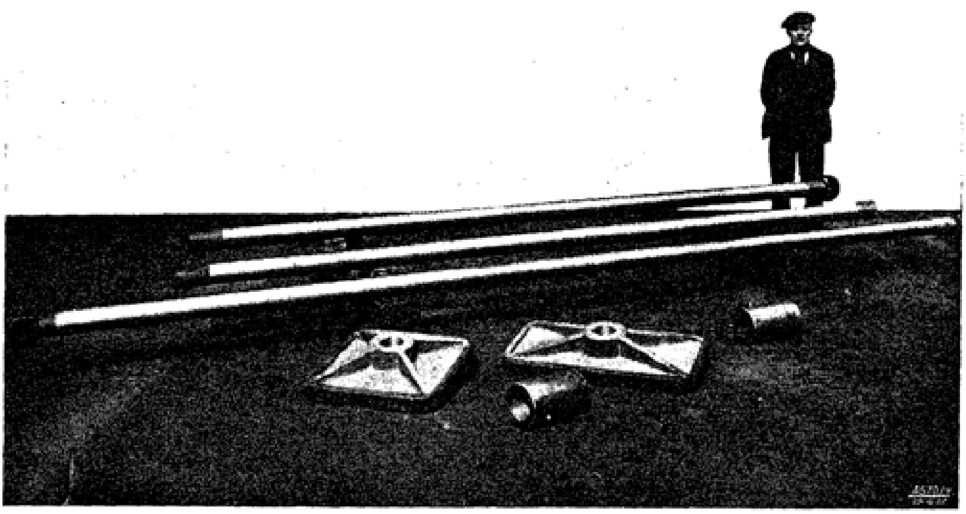
Heat-Resisting Steels

The term "heat-resisting" steels refers to an important series of special steels which resist oxidation or scaling and other forms of corrosion at high temperatures, while also retaining a high degree of mechanical strength. In general, the alloys contain high per-

FIGURE X



"Era/ATV" Heat-Resisting Steel as used in the rotors of gas turbine engines



Reinforcements made of Corrosion-Resisting Steel for the pillars supporting the Dome of St. Paul's Cathedral centages of nickel and chromium, variable in amount according to the uses and properties demanded. The addition of other elements, such as silicon and tungsten, in comparatively small proportions, has been found beneficial in special cases. The iron content of some of the later products barely exceeds 50 per cent.

High chromium (12 to 14 per cent.) steel possesses useful characteristics in regard to maintained strength, and scaling to a much less degree than ordinary steel up to moderately high temperatures. On the other hand, the strength of this material decreases rapidly at temperatures above 650° C., and it practically loses its non-scaling characteristics at 850° C. Consequently, for example, it is unsuitable for the valves of modern high-duty aeroplane engines or for such articles as the boxes in which steel parts are heated with their carbonising mixture for case-hardening, the temperature in this instance reaching 1,000° to 1,100° C.

The addition of silicon, in amounts up to about 3 per cent., has been found to produce a marked improvement in the non-scaling characteristics of high chromium steel, and to result in some improvement in strength at high temperatures. Beyond, however, about 800° C., the qualities are still below practical requirements in many directions.

Prolonged research by the author's firm in collaboration with the Société Anonyme de Commentry Fourchambault et Decazeville, of Imphy, has resulted in the evolution, amongst others, of the type of high percentage nickel-chromium steel known as "Era/ATV," which has quite exceptional strength and non-scaling properties at high temperatures, while still being of reasonable cost. This steel has proved more than equal to the highest requirements yet imposed by the designers on the exhaust valves of motor car and aeroplane engines. It is used at bright red heat and under high centrifugal and other stresses in the rotors of exhaust gas turbines working at a temperature of 800° to 930° C. and speeds of from 30,000 to 50,000 r.p.m. These rotors, illustrated in Figure X, are of further interest in that certain portions are at the same time subjected to the very low atmospheric temperatures experienced at high altitudes, which may reach as low as −50° C., a striking illustration of the extraordinary duties which modern alloy steels are called on to perform.

The use of modern heat-resisting steels is rapidly increasing in boiler-house work, furnace construction, recuperators, retorts and, in fact, high temperature apparatus and processes of all kinds. Marked advances have been made during recent years, not only in the composition and properties of these materials but also in the methods of preparing and working them, which are of great importance as regards their application. Castings of such steels can now be made from a few ounces to several tons in weight; forgings in all sizes; rolled products from large bars down to sheets, strips or wire; and tubes in cast, rolled or drawn form. The progress made in regard to ductile heat-resisting steel enables drawn tubes to be produced capable of resisting oxidation up to 1,100° C.

At the other end of the scale from the many industrial applications of this material, a case recently came to the author's notice in which it was found very advantageous to use heat-resisting steel, instead of the cast iron formerly employed for the bars of a domestic central heating stove burning coke or anthracite. Whereas the cast iron bars burnt to less than half their weight in a few weeks, the heat-resisting steel showed no appreciable deterioration or loss of any kind after six months in service. At this rate, the whole cost of the heat-resisting steel bars would be covered in considerably less than a year by the elimination of the cost of renewing the "cheaper" cast iron bars. As there is every indication that the heat-resisting steel will last indefinitely in this service its use will prove a most profitable investment.

Corrosion-Resisting Steels

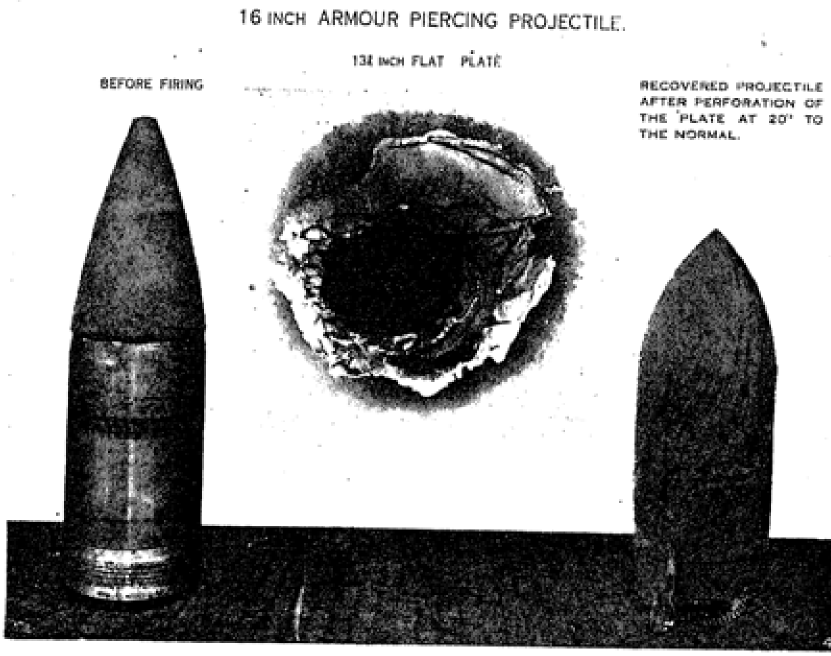
The highest resistance of these steels to the attack of many chemical agents, together with their superior mechanical strength, renders them specially suitable for industrial plant exposed to the attack of active chemical substances. Certain grades, rolled in sheets, can be readily pressed to form motor car radiator fronts, domestic utensils, and articles of a similar character. Others, made in the form of casting and forgings, are used in pumps and for parts of machinery working in corrosive liquids. Their resistance to the action of wet and damp atmospheres and deleterious liquids has led to their wide adoption for road studs for the guidance of traffic.

Specially interesting, too, is the use made of non-corrodible steel in the preservation of St. Paul's Cathedral, London. Tie rods made from ordinary steel or wrought iron would doubtless have lasted many years before their eventual destruction by corrosion, but the committee responsible for this important work wisely took advantage of the latest metallurgical progress, which indicated that corrosion need not be regarded as an inevitable evil. Figure X shows the new reinforcements for the pillars supporting the dome, and replacing those of wrought iron originally used by Sir Christopher Wren, F.R.S., consisting of tie bars, 3 and 4 inches in diameter, of high chromium-nickel steel having a tenacity of 45 to 50 tons per sq. in., with cast couplers and wall plates of the same material. The use of Sheffield non-corrodible steel in the restoration of St. Paul's also includes a large chain for encircling and reinforcing the famous dome itself. Non-corrodible steel is now being used extensively in this country, the United States and elsewhere for vital parts of new buildings as well as in renovations.

Armament Steels

It is obviously impossible to give precise information concerning the composition of steels used for modern armament and ordnance. It may, however, be said that alloy steels play a vital part in all the means and instruments of defence and offence. Happily, too, the development of alloy steel for the purpose of peace has been largely assisted by research and experience in their application to war material.

Figure XI



16 in. armour-piercing projectile, after passing unbroken through a hard-faced armour-plate 13⅜ in. in thickness, inclined 20°

As some indication of what may be expected from modern armour-piercing projectiles, it may be mentioned that projectiles of 15 in. or 16 in. calibre, made by the author's firm, pass completely through a hard-faced armour plate 12 in., 14 in., or even 16 in. in thickness, not merely normally, but with the plate inclined 15°, 20°, and even 30°. Moreover, the projectile remains unbroken with its explosive charge ready to burst inside the armoured vessel. In a typical case (Figure XI), the projectile fired at a velocity of about 1,750 foot-seconds, equivalent to 1,200 miles per hour, passed through a 12 in. plate in 0·0039 of a second, and was recovered unbroken. The amount of energy absorbed in accomplishing this task was about 25,000 foot-tons, and 720 lb., or 1¼ cu. ft., of metal had to get out of the way of the projectile in about the four-thousandth of a second!

The important fact in these days of peace—and long may they continue—is that the skill, experience and equipment required to achieve these remarkable results is available for, and is applied to, the manufacture of peaceful products equally satisfactory in the uses for which they are intended.

Steels for Steam Turbine Blades

The conditions to be met by any material used for the blading of modern steam turbines are extraordinarily difficult. They include not merely the retention of satisfactory mechanical properties at high temperatures, as regards strength and resistance to fatigue, but also resistance to corrosion and erosion by wet and possibly contaminated steam. That these requirements have been met will be gathered from the fact that the Hecla/ATV steel, developed by collaboration in research and practical application between the author's firm and the Commentry-Fourchambault Company, of France, has already been adopted for steam turbines totalling about 3,000,000 H.P. These applications include, it may be noted, the new French liner *Normandie* and the latest and fastest French destroyer. The complete blading of the four main turbines of the *Normandie*, developing 160,000 H.P., required the use of 66 tons of this alloy steel. The proven resistance of the steel to corrosion and erosion, and the retention of favourable mechanical properties at high temperatures were decisive factors in its adoption. The fact that the coefficient of expansion of the steel is very nearly equal to that of the nickel-steel discs is a further practical advantage of great importance.

In the 85,000 kW plant of the Imperial Chemical Industries, Ltd., at Billingham, "ATV" steel is employed for the rows of turbine blading subjected to the most severe conditions, that is, at the high pressure end of the primary turbines. These turbines are required normally to operate with steam at 630 lb. per sq. in. gauge, and a temperature of 433° C. (833° F.), exhausting at a pressure of 275 lb. per sq. in.

Tool Steels

Some of the most complex steels yet developed have been for use in machining other steels at high speeds and with heavy cuts. The

22, CARLTON HOUSE TERRACE,
S. W. 1.

October 25th 1933

WITH SIR ROBERT HADFIELD'S COMPLIMENTS.
and best wishes

Rai Bahadur Daya Ram Sahni,
Director-General of Archaeology
in India.

pioneering work of the Mushets, father and son, in regard to self-hardening steel will always be remembered in this connection. Though largely empirical in nature, as was inevitable in the 'fifties of last century, it represented an important practical advance on anything previously available. Later, and specially about the commencement of the present century, important advances were effected in America, and a vast amount of research was devoted to the subject in Sheffield—including the work of Arnold in the University laboratories, in demonstrating the great value of vanadium additions. As years went on, tool steels became even more complex and their performance yet more remarkable. Mushet's tungsten steel permitted a cutting speed about 50 per cent. higher than would be used with ordinary carbon steel, but from 10 to 20 times the speed attainable with carbon steel tools are now regularly employed where modern tool steels are used.

A remarkable instance of the advance in tool steels is to be found in the fact that there is now available a material containing no fewer than nine elements, namely, iron, carbon, manganese, chromium, nickel, tungsten, cobalt, vanadium, and molybdenum, which is capable of machining manganese steel itself. This achievement—for many years considered impossible—has led to an extension of the already varied applications of manganese steel.

Structural and High Tenacity Steels

In the space here available it is impossible to do more than outline the nature and application of the many special steels which have been developed for general engineering and constructional purposes. The complexity of the subject is increased by the fact that, in certain instances, ternary and quaternary alloys have been found most suitable for some special purposes. Leaving out of consideration manganese and silicon steels, which have already been fully discussed, high tenacity engineering steels are mainly, but by no means invariably, of the chromium, nickel or nickel-chromium type, sometimes with the addition of other elements.

Specially interesting examples of the use of high tenacity alloy steels on a large tonnage basis for general constructional purposes, as distinct from machine parts, tools and industrial equipment, are to be found in the field of shipbuilding. From the earliest days in the replacement of wood by iron in shipbuilding, the ferrous metallurgist has contributed enormously to the size, strength and general efficiency of ships. Apart from developments in power, where the use of alloy steels has been of revolutionary effect, specially as regards the blading of steam turbines and the valves of Diesel engines, further reduction in the weight of the hull without loss of strength and rigidity has always offered an incentive, which it has been the endeavour to satisfy by the adoption of steels stronger than the usual mild steel. Any such reduction is naturally available either as useful cargo tonnage or in providing displacement for propelling machinery of increased power. For the highest performances in speed, the use of high tensile steel appears, in fact, to have become essential. It is understood that the *Bremen* and her sister-vessel *Europa* owe their success largely to the extensive use of such steels in their hulls. In the first-named some 7,000 tons, with a tensile strength of 33 to 38 tons per sq. in., were incorporated, resulting in a reported saving of about 800 tons in weight. The hull of the new French liner *Normandie* is stated to include 5,000 tons of high tensile steel.

Notwithstanding all the difficulties associated with any special heat treatment of tonnage steels, such as ship plates, and the fact that the modulus of elasticity of high tensile steels does not increase to any important extent with the ultimate tensile strength, there has been considerable progress in the alloying of tonnage steels with a comparatively small percentage of alloying element. Special steels with tenacities up to 43 tons per sq. in. and a proportional limit up to 17 tons, with excellent ductility and toughness, are now included among those governed by official specifications. Ordinary mild steel ship plates have a tenacity of 28 to 32 tons, and a proportional limit which is low and indefinite. The steels employed contain a comparatively small proportion of silicon or of manganese—in the first instance about 1 per cent., and the latter from 1 to 2 per cent.

Steel of the former type was used for a considerable portion of the superstructure of the *Mauretania* and *Lusitania*, resulting in each case in a reduction in weight of from 200 to 300 tons, with, at the same time, an appreciable increase in strength in the portions concerned. The latter type contains manganese to the extent of 1·1 to 1·4 per cent. Its useful properties have become well established in many other directions by the author's firm since the year 1894, and it has been regularly adopted by the British Admiralty, under the designation "D quality," for certain classes of high tensile ship plates. One of the latest instances of the use of high elastic limit steel is in topsides of the s.s. *Empress of Britain*, a vessel which has deservedly attracted much attention as a fine piece of shipbuilding fully meeting the high requirements of today.

Considerations of expense and the necessity for proceeding cautiously with the use of new materials in bridges and other heavy structures will make the rate of progress slower than in smaller constructions, but developments in this direction have already commenced, and they will not cease. Alloy steels, when properly selected and properly treated, can be used under abnormally difficult conditions with as high a factor of safety as ordinary mild steel under its usual working conditions.

The foregoing brief review of some of the more recent developments in the uses of alloy steels purposely makes no mention of the important heavier industries such as the manufacture of armour plate and the production of very large forgings. Such references, the author feels, may best be left to those more specially concerned in these branches of manufacture, in which our local firms, the English Steel Corporation and Messrs. Firth-Brown, have established a high reputation.

VII. METALLOGRAPHY AND HEAT TREATMENT

The Rise of Metallography

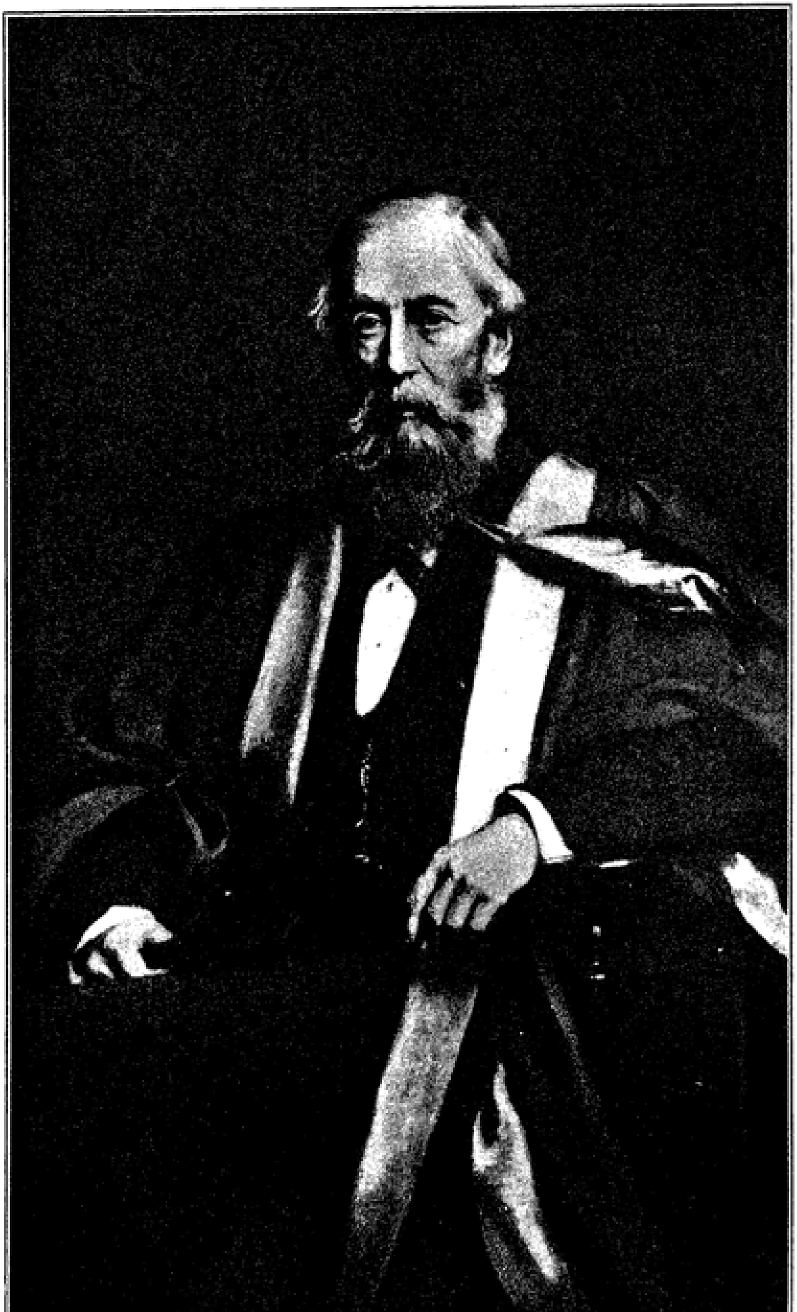
The honour of discovering and initiating the science of metallography, and of leading the way in the study of the microstructure of metals undoubtedly belongs to that famous citizen of Sheffield, the late Dr. Henry Clifton Sorby, F.R.S. On the foundations he laid, the intricate science of modern metallography has been built up with the assistance of many able workers in many countries, but the first steps were taken by Sorby alone. Without metallography and the knowledge of the structure of steel that has been obtained by its aid, the art of heat treatment could not have been reduced to the precise science that it is today.

Sorby prepared, in 1849, the first rock slice ever made for microscopic examination; and his first microscopical study of igneous rocks was presented in a paper read before the Geological Society of London on December 2nd, 1857. For a long time his methods and conclusions were treated with derision. Professor Judd, one of Sorby's friends and chemist at the Cyclops works, stated that about the year 1870 "microscopic petrography was always ridiculed by the powers that were." They said: "You can't study mountains through microscopes," but time has shown that Sorby was right.

It was in 1885 that Sorby was first able to show the true composite nature of the "pearly constituent" of steel as an aggregate of parallel plates. This was the earliest recognition of the separation of a constituent of definite composition from a solid solution, and may be considered the crowning achievement of his microscopical research. These important facts were announced to the Iron and Steel Institute in 1886.

After Sorby's paper of 1886, and specially after his great paper on "The Microscopical Structure of Iron and Steel," read before the Iron and Steel Institute in 1887, much activity was displayed by other investigators in the field which he had so brilliantly started to explore. Actually, however, the pioneer work was done by Sorby during the 'fifties and 'sixties. As M. Frémont, the well-known French engineer and metallurgist, recipient of the Bessemer Gold Medal, has said: "It was Sorby's discovery of the method whereby the structure of a metal was laid bare to microscopic examination that gave him the right to the title [of pioneer]. The method he used to prepare his rock sections failed him with metals, because the latter, even in very thin sections, are not transparent. Sorby, however, discovered that by suitably etching a perfectly polished surface of metal, the structure was revealed to microscopic examination."

A remarkable collection of Sorby's early etched specimens of iron and steel for micro examination is preserved in the Museum of the Applied Science Department of Sheffield University. There are no fewer than sixty of these specimens dating back to the years 1863 to 1865; and it was from work on these particular specimens that modern metallography arose.

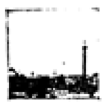


Dr. H. C. Sorby, F.R.S.

High Magnifications

Progress in the methods and equipment of microscopy has been an essential factor in the present high development of metallography. Magnifications up to 8,000 diameters of iron and steel specimens were effected as early as 1921 in the Hadfield Research Laboratories, and magnifications of 500, 1,000 and 1,500 diameters are of course quite common.

The following table may be of interest as showing the extent of such magnifications. If the largest magnification mentioned, that is, 8,000 diameters, could be applied to the whole area of a micro-section 0·48 in. square the enlargement would be 11,400 sq. yds. in area, or about the size of Trafalgar Square. Or, to put the same fact in an even more striking manner, if the accompanying photograph of Trafalgar Square, which is reduced to 0·48 in. square, could be examined at 8,000 diameter magnification the objects would all appear approximately full size. Actually, of course, the grain of the photographic emulsion would prevent any detail being visible at such an enormous magnification.



Size of Specimen.	Magnification (Diameters).	Area as magnified. Sq. yds.	Sq. ft.
0·48″	125	2·8	25
square	250	11	100
	500	44	400
	1,000	178	1,600
	2,000	711	6,400
	4,000	2,844	25,600
	8,000	11,378	102,400

Present Importance of Metallography

No branch of metallurgical progress has done more to help on our intimate knowledge of ferrous products than metallographic examination. Without its aid it would have been impossible to make use, with the same understanding of their properties, of the various and numberless alloys of steel developed during the last 25 or 30 years. Tens of thousands of photomicrographs must now be produced annually throughout the world showing, with much advantage to the metallurgical industry, the structure of our products, the results of our manifold thermal treatments and their effects upon mechanical and physical qualities of various nature, and how these qualities may vary from the lowest to the highest temperatures.

An interesting application of metallographic examination at high temperatures is described by Esser and Cornelius in *Stahl und Eisen*, May 18th, 1933. It is believed that this is the first time microscopic examinations have been made at temperatures up to as high as 1,100° C. There is no doubt the method opens out a wide field and it is to be hoped that others will come forward and devise means for examining metals of all kinds at low temperatures down to absolute zero, specially in view of the important papers which are presented this year on the subject of the mechanical qualities of various alloy steels at low temperatures in the range from $-182°$ down to $-252{\cdot}8°$ C.

Heat Treatment

Two of the essentials to successful heat treatment are metallography for examining the structure of metals, and pyrometry for measuring the temperatures to which the material is subjected. The importance of Sorby's work in studying the structure of metals has been mentioned above, and there is no doubt that this work, followed later by the introduction of the thermo-couple by Professor H. le Chatelier, together with the study of heating and cooling curves and thermal changes by Gore, Barrett, Osmond, Roberts-Austen, Stead, Arnold, Rosenhain, Carpenter, and others, formed the basis of the great scientific advance in metallurgy, raising it from an empirical art to a more or less exact science.

It is hardly too much to say that prior to le Chatelier's work on the pyrometer and the pioneer work of Gore, Barrett, Osmond, Roberts-Austen, and Arnold concerning the effects of thermal treatment on the molecular structure of iron and steel, we had to trust largely to rule of thumb methods in heating these metals. Indeed, many of the " methods " were little better than guesswork. Yet steel is one of the most sensitive of materials as regards heat treatment; in fact, the "thermal history" of the metal is as important as its chemical composition in determining its mechanical and other properties. It is curious to reflect that as comparatively recently as March 25th, 1893, that is, forty years ago, the state of our science was such that the author was able to say, when addressing the Metallurgical Society of the Technical School, Sheffield, " Why should it not be possible to know, with the aid of the valuable le Chatelier pyrometer, the temperature of our furnaces, whether melting, heating, or annealing, just as we observe the temperatures of our rooms? We should then be led to study more carefully the laws relating to molecular structure, of which at present we know comparatively so little, that is, as regards their application in a practical way. No doubt the steel-maker of the future will send out his products labelled with the exact temperatures to be employed in order to get the maximum hardness with the minimum of brittleness. At present almost every toolsmith has his own empirical method of determining hardening temperatures." What then might have seemed a bold prophecy has long since come to pass.

Extensive experience and much research have been needed to discover the best methods of preparation and heat treatment for special steels, and the fact that heat treatment is an essential factor in the preparation of alloy steels for service, and the remarkable results thus obtained, have led to an increased appreciation of the possibilities of heat treatment in connection with carbon steels. An excellent indication of the wide range of temperatures covered by modern research, together with a most useful presentation of data relating to the different elements and other substances of interest to the metallurgist, is afforded by a new temperature chart recently completed by the Hadfield Research Laboratories. The temperatures dealt with range from absolute zero up to that of the electric arc, about 3,700° C., and a large amount of information is presented in a form specially convenient for reference and comparison.

VIII. METALLURGICAL CHEMISTS

Importance of Chemistry in Metallurgy

It is impossible to exaggerate the debt of the metallurgist to chemistry. In fact, for more than fifty years past, it has been essential for the metallurgist himself to be a chemist of no mean qualifications, so closely does chemistry enter into every phase of metallurgical research and practice. In addition, the metallurgist must be able and willing to co-opt and apply the resources of physics in regard to metallographic examination, mechanical, electrical, magnetic, thermal and other tests. But first comes chemistry without the application of which it is impossible either to make steels or to ascertain their composition when made.

At the time when the author was commencing work, chemical analyses were costly, difficult, and doubtless of much lower accuracy than those of today. For example, a document received by the author's father some fifty years ago, from a certain chemical laboratory in Sheffield where analytical work was conducted, stated the percentages of half a dozen elements—carbon, graphite, silicon, sulphur, phosphorus and manganese—in a sample of pig iron, together with the charge for the analysis—ten guineas! On such terms, one regarded the analysis of steel with appropriate respect, and it was an expensive luxury to obtain figures upon which alone systematic research could be conducted. During the war, the author's firm made about 600 separate analyses every day, all involving high accuracy. Had these been at the prices of 1880 the cost would have been prohibitive.

Rise of Metallurgical Chemistry

It is about 150 years since the study of steel by chemical methods began, for one of the earliest records of such a study is contained in a dissertation by Tobern Bergman, of the University of Upsala, published in 1781. A little later followed the work of the French chemist, Berthollet, who recognised that the differences in the varieties of iron were determined by the carbon contained therein. In 1827 Karsten separated from soft steel a compound of iron and carbon, thus preparing the way for the work of Sir Frederick Abel, F.R.S., who isolated the carbide compound now recognised as of fundamental importance in the metallurgy of steel.

The author would also mention Mr. Edward Riley, who in 1853 joined the staff of the Dowlais Ironworks as a chemist, and there in 1857 helped to carry out the first experiments on an industrial scale with the Bessemer process, which is still of prime importance in the steel industry; also Dr. John Percy, F.R.S., who rendered so many important services to scientific metallurgy. Then follow the world-renowned names of Messrs. Thomas, Gilchrist and Snelus, who effected a revolution in steel manufacture by the introduction of the basic process.

Amongst British metallurgical chemists may be mentioned Sir W. C. Roberts-Austen, A. H. Huntington, J. E. Stead, and J. O. Arnold. Much service, too, has been rendered by F. W. Harbord, including that in his well-known book, *The Metallurgy of Steel;* by Henry Louis, Sir Harold Carpenter, W. Rosenhain, E. H. Saniter, T. Turner and many others. Of those abroad may be mentioned R. Akerman, S. Arrhenius, C. Benedicks, E. D. Campbell, A. S. Cushman, H. Egleston, G. Freminville, F. Giolitti, H. M. Howe, Zay Jeffries, A. Ledebur, F. F. Lucas, A. Pourcel, H. Moissan, Baraduc-Müller, A. Sauveur, D. Tschernoff, H. Wedding and others.

Light Metals and Steel

The applications of aluminium and other light metals and their alloys have increased enormously during recent years, specially, of course, in the automobile and aircraft industries. Whether these materials can make any very serious inroads upon the use of steels for structural purposes, as distinct from their use in new applications for which steel is too heavy, may well be doubted. Certainly such special steels as manganese steel, silicon steel, heat-resisting steels, high-speed tool steels and other special alloys can never be replaced in their valuable applications by any light metal alloys yet known or even remotely in prospect.

At the same time it is interesting to note the opinions of Dr. W. J. Hale, Director of Organic Chemical Research in the Dow Chemical Company, as expressed in the course of a fascinating book entitled *Chemistry Triumphant: The Rise and Reign of Chemistry in a Chemical World*, one of the excellent "Century of Progress" series published in America by the Williams and Wilkins Company. Referring to the uses of the light metals, aluminium and magnesium, Dr. Hale says: "The age, therefore, that is now upon us we call the mag(nesium) plus al(uminium) or magal age. The steel age *par excellence* comprises that period between 1856 and the present or about 1930-32. The price of steel at 2 cents per pound still holds advantages over aluminium at 20 cents, but this latter must be rated at 7 cents per equalised volume, as aluminium has only one-third the specific gravity of steel. The now reduced price of magnesium at 30 cents per pound is at once equalised with aluminium at 20 cents, as magnesium has only two-thirds the specific gravity of aluminium. Thus, at 7 cents per unit volume of magal, against 2 cents for steel, and the soon to be instituted lower prices for these lighter metals, there is less and less chance for the old-fashioned steel to withstand the competition. Especially and more drastically will this fact be emphasised as we appreciate the value of lighter and lighter material in all walks of life, it being understood at all times that a sufficiency of strength can be supplied by these light alloys for every requisite.

"The advent of these light alloys marks the closing stage of the metallic period of human history. Though this introduction already is a fact, it is hardly proper to date their ascendancy before 1932. Naturally their use will overstep steel in tonnage, but yet a few years will pass before this complete transition. Just as with the earlier ages described above, it must not be thought that any succeeding age eliminates the use of preceding art. All alloys of steel will always find specific uses."

For the reservation in the concluding sentence of this quotation the ferrous metallurgist will doubtless be duly grateful. It is indeed certain that, whatever the advances of light metals, "all alloys of steel will always find specific uses." Moreover, these uses, in the author's opinion, will increase in number, amount and importance.

Chemistry and the Crisis

As regards the bearing of chemistry on world affairs of the present day, Dr. Hale says in his book mentioned above: "We are now in the second great world revolution. The economist of the future will attribute the cause of this second cataclysm to the increasing replacement on a large scale of much of nature's output by direct chemical adaptations springing from the genius and industry of man. On the other hand, adaptations of agricultural resources to fit into the changing chemical world were totally neglected; hence the upheaval. The stage was admirably set for this chemical revolution even in 1913, with the replacement of naturally occurring nitrates by the synthetic product. It needed only a spark to set off the world war that came in 1914. The urge to produce gained increasing momentum, with only a slight set-back during a few years following the war, till in 1929 financial credits were broken. As credit had been extended both here and in all parts of the world, everything that could be marketed was rushed to sale at highest prices, no matter what the intrinsic worth. The result was destined to be a panic.

"Following this great panic came deflation, and the return of prices of basic products to levels commensurate with true chemical values. In opposition to this necessary trend, attempts of late have been made to bolster up commodity prices by artificial means, such, for example, as the stabilisation schemes for rubber, coffee, sugar and wheat. All such attempts of interference with the laws of supply and demand have and always will come to the same dismal end—failure."

There is much in these words that deserves careful consideration, not only as regards the tremendous powers of chemistry, but also regarding the danger of attempts to establish trade on an artificial basis.

IX. EMPLOYMENT AND EQUIPMENT IN MODERN STEELWORKS

Following upon the general outline given in the preceding sections concerning the rise of metallurgy, and of the iron and steel industry on a world basis, with special reference to Sheffield's share in this development, it is not without interest to consider what the progress of the past half-century or so has meant in the way of industrial expansion and the provision of employment. The employment in question extends, of course, not merely to the men required to operate the steelworks plant, but also to those who build this equipment, those who produce the materials and supplies required from outside, and those who use and apply the finished product. Without iron and steel, employment in most branches of civilised activity would practically cease. Conversely, increased activity in the iron and steel industry leads at once to an all-round extension of employment.

Over fifty years ago, when the author was engaged in the discovery and invention of manganese steel, the firm of Hadfields was a comparatively small concern employing only several hundred employees. Now it employs between 5,000 and 6,000 persons in normal times of peace, between 3,000 and 4,000 even in the worst times of the recent depression, and over 15,000 during the War. These figures and those given below are presented for no personal reason, but simply to show what one great modern steelworks alone means to the country in the way of investment, productive or unproductive, according to the state of trade; and in the way of employment, actual or lacking, according to the demand for its products. Similar facts and the same conclusions might be given for other steelworks in this city, varying only with the size of the works and the nature of their manufactures.

Foundries.—The total area covered by the Hadfield Works and depot is 214 acres, of which 51 acres are covered by workshops and other buildings. The main steel foundry at East Hecla, 1,200 feet in length and covering 7 acres, is the largest in the world, and in marked distinction to the facilities of Huntsman and Faraday about 200 and 100 years ago.

Steel Melting Plant.—Including open-hearth, electric and other steel-melting furnaces of the latest type, the firm has a melting capacity of some 3,500 tons of steel per week, and is capable of turning out pure steel possessing the very low total combined content of 0·025 per cent. sulphur and phosphorus, or even less. No fewer than 62 furnaces are available for the heat treatment of castings and forgings, some of these being of large size.

Forge and Rolling Mills.—The forging plant, in addition to the ordinary type of steam hammers, includes two 1,500-ton hydraulic forging presses and one of 1,000 tons. Three electrically-driven rolling mills of the latest types are in service. Of these, the largest is a reversing 28-in. blooming and finishing mill, which at times absorbs as much as 11,000 h.p. This mill is capable of rolling 1,500 tons of special or other steel ingots per week, weighing 1½ tons each, down to billets as small as $2\frac{1}{2}$ in. In addition, there are 14 in. and 11 in. bar mills for rolling billets to various commercial sizes of steel bars, round and square, also for the production of high tensile and special alloy steel products.

In addition, to serve what may be termed the major metallurgical equipment, there is a vast amount of auxiliary equipment, all equally necessary to the operation of the complete works, and including over 21 miles of standard and narrow gauge railways, over 750 electric motors ranging from $\frac{1}{2}$ h.p. to 3,200 h.p., 250 heating furnaces, 2,300 machine tools, 300 cranes, 50 presses, fully-equipped chemical, physical and mechanical testing and research laboratories, and many departments which have not even been mentioned.

Contemplation of such figures as these, specially in these difficult times, helps to impress upon us the importance of the iron and steel industry as a national asset and a factor in international trade. Also, it should surely increase our sense of obligation to those many worthies of the past whose labours have brought the science and industry of ferrous metallurgy to their present high level, and to the immense total output already mentioned in an earlier section (Section III).

X. NATIONAL DEFENCE

From Arrow to Shell

The associations of Sheffield with national defence go back to very early days, for tradition says that the victories gained at Crécy and Agincourt were largely due to the Sheffield arrowheads, the "projectiles" of that day, being too much for the French armour. Johnson, the antiquary, found a record which stated that Sheffield had at that time furnished to the Government no less than 5,000 arrowheads, at a price of fifteen pence per 100.

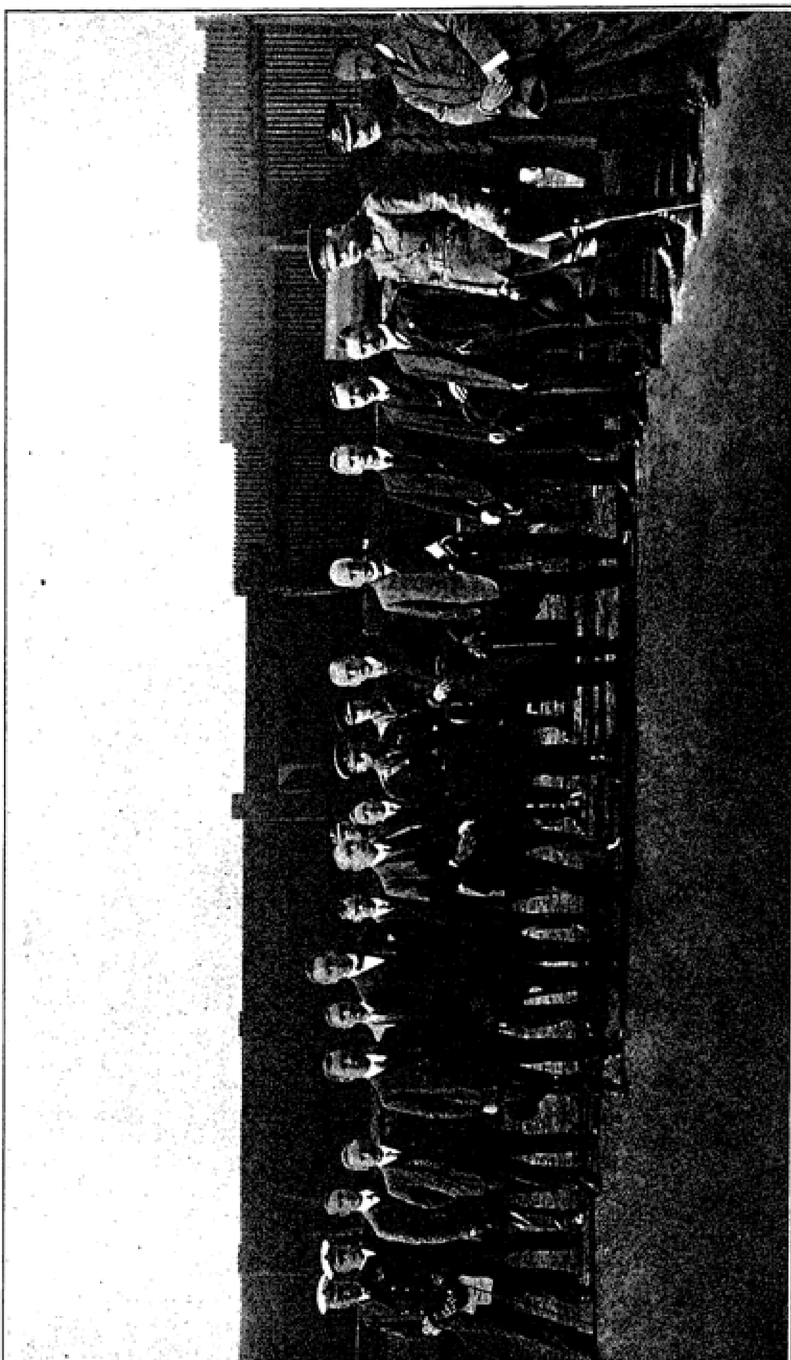
Those outside the iron and steel industry cannot realise as clearly as do those who are engaged in it, all the skill, enterprise and investment of time, labour and capital that has been provided by manufacturers of armaments to meet the ever-changing and increasing demands imposed upon them, not only during the latter part of the last century when wrought iron gave place to compound, steel and hard-faced plates, but in even greater measure during the present century, culminating in the supreme efforts demanded during the Great War. It is indeed to be hoped that the horrors of that ordeal will never be repeated; and while expressing that hope in all sincerity, we may surely spare a moment to reflect upon the truly vital services then rendered to the Empire by Sheffield and upon the no less vital importance of finding adequate peaceful employment for the men, machines and furnaces no longer engaged in national defence.

Readiness to Serve

In times of peace it is only too easily forgotten what large quantities of costly machinery and other equipment have to be kept in this city, ready for full use in the manufacture of armaments, even though they may not be actually employed to the extent of less than 20 per cent. of their capacity. This represents Sheffield's permanent and continuing contribution to national defence. It is one which the city is willing and proud to bear, but there is no denying that the burden is heavy in these days of severe taxation and, above all, restriction in other fields of manufacture. No one would wish either that war should come again or that there should be extravagant expenditure on armaments merely to keep existing equipment in use. On the other hand, it must be recognised that the steel industry of this city cannot continue indefinitely to give of its best in the cause of national defence entirely from its own resources. The nation might very reasonably give some tangible assistance during periods of peace—the longer the better—to the men and the works that are expected in the hour of need to be ready with the latest guns, projectiles and armour plate.

As some indication of the standard of production now attained, showing that Sheffield's skill has not abated, it may be mentioned that the Hadfield armour-piercing projectiles of the larger calibres and of the latest improved type are capable of penetrating hard-faced armour of the latest and best quality over one foot in thickness at an angle of 30 degrees and a velocity equivalent to a range

FIGURE VII



VISIT OF HIS MAJESTY KING GEORGE V
to the East Hecla Works of Hadfields Ltd., Sheffield, 29th September, 1915

of 15,000 yards. Moreover, the projectiles remain unbroken after penetrating such armour in about one two-hundredth of a second!

War Work

The part played by Sheffield during the years 1914–1918 was one of which the City may justly be proud. At the same time it is a measure of the responsibility which rests upon us to be ready for an equal or even greater effort should it ever be required. The total output of shell from the Sheffield National Factories alone, of which Messrs. Hadfields and Messrs. Thomas Firth and Sons each ran one for the benefit of the nation, amounted to many millions of shell. Concerning the figures for other firms the author is unable to speak, but his own firm employed some 15,000 persons during the war and did work to the value of about £36,000,000. Besides some 3½ million projectiles, including armour-piercing shell, chiefly of large calibres, 12 in., 13·5 in., 14 in., 15 in. and 18 in., there were supplied guns, howitzers, trench mortars, conning towers and many other products, among which special mention must be made of some 7,000 tons of improved manganese steel, this being in the form of nearly 4 million helmets, which undoubtedly saved the lives of tens of thousands of men.

Full credit must be given to our workpeople for the magnificent manner in which they worked during that trying period. Much of the work performed was of the heaviest possible character; for example the making of high explosive shell up to 15 in. and armour-piercing projectiles up to 18 in. calibre; in fact, the whole of this latter class of projectile was made in Sheffield. At the other extreme there was a vast amount of delicate work to be done with the highest precision; for instance, 179,750 analyses were made in the Hadfield laboratories during the year 1918 alone. Then, too, housing schemes were also carried out by the Sheffield Corporation, nearly 1,500 houses and cottages being built, in addition to hostels and colonies for over 2,000 workers.

In another direction the manufacturers of Sheffield rendered invaluable service by throwing open their works for training thousands of persons, including the representatives of other firms, giving away their inmost secrets to help the Empire in its hour of need. Though this service was given gladly, it should not be forgotten that it represented a very real sacrifice to the common weal. In the case of the author's firm alone, tuition in the manufacture of high explosive shell was given to fifty-eight firms, many of them competitors in times of peace, and six projectile manufacturers. In addition, thirteen Corporation Munitions Committees and thirteen National Projectile Factories received tuition at Hadfields in the manufacture of high explosive shell, and information on this subject was given to seven Government Departments. Five home and foreign firms received instruction in the making of cast blanks for high explosive shell, and four in the making of sound ingots. Seven foreign firms received other instruction or information, and the number of special visitors to the works coming to obtain information ran into thousands.

Sheffield and Imperial Defence

The lesson to be drawn from this brief record is surely the importance of our city in Imperial defence, over and above its normal contribution to national prosperity. Now, as truly as ever in the past, the best guarantee of peace is to be prepared for war. The history of naval architecture, from the *Victory* of 1805 to the *Rodney* and *Nelson* of today, shows that effective measures have been taken to meet every invention for the destruction of the capital ship, and there is no reason to doubt that equally successful measures will be devised to meet future menaces. Aerial warfare introduces new methods and new problems, but it will be many years before the battleship becomes obsolete. The policy of defence by air is financially attractive, but it cannot replace sea power. Our splendid Air Force is essential, but its function is to support and not to supplant our Navy.

In putting forward these views, the author has not forgotten the wise words of Admiral Sir Ernle Chatfield, who, speaking at the Cutlers' Feast in 1925, said that: "It would be a bad day for the Empire if the plant and skilled men who designed it, who brought it into existence, and who used it, were allowed to decay. History showed that the fall of nations had been hastened by the neglect after great wars of the weapons that brought victory. It was not surprising, therefore, that those should arise now who proposed similar steps. They had been told that it had suddenly been discovered that nations were using dying weapons, and that battleships were of no use. The type of ship that now existed—cruisers, submarines, destroyers—might alter or completely vanish; but there was one type that would always remain—the capital ship."

Need for Empire Development

Contemplating the figures in the preceding pages, which naturally relate to only a part, though an important one, of the contribution made by Sheffield to the cause of the Allies, it is possible to form some idea of the vast potential capabilities of this city in the way of peaceful production. The utilisation of these capabilities, over and above the normal vast output of the city's peaceful products, will become of greater urgency in proportion as we are able to replace the possibility of future wars by the certainty of established peace. The day has not yet arrived when we can safely beat all our swords into ploughshares, but this country has already given the rest of the world a great lead in the direction of reducing armaments. Partly owing to this, and partly owing to the difficulties of international trading during recent years, there is much equipment and there are many thousands of men not fully employed in Sheffield. These men and this equipment could be restored rapidly to useful production if only the vast resources and opportunities of our Empire were developed more effectively.

This is a matter which cannot be dealt with at length in this address, but no apology need be offered for mentioning it, because, apart from its general bearing on every phase of national prosperity, it will undoubtedly affect the future of metallurgical work in Sheffield

—favourably if Empire resources are developed fully under a correlated scheme, but unfavourably if they are neglected.

Proposed Empire Development Board

The author's suggestions for an Empire Development Board to deal with the whole question, on lines suited to the individual needs of each part of the Empire, have been developed as the outcome of repeated discussions with many distinguished leaders from the Dominions and Colonies, and the proposals advanced have secured a gratifying measure of approval, which justifies a most optimistic estimate of the magnitude of the opportunities awaiting all parties concerned—the oversea members of the Empire no less than ourselves.

Broadly, the plan is based on the creation of an Empire Development Board consisting of representatives of industry and commerce from all parts of the Empire. Apart from improving the existing facilities for trade and transport, and helping on any special undertakings already in hand, the Board would devote its major attention to the work of expansion by assisting the development of new roads, railways, canals, tramways, harbours, docks, dams, the construction of hydro-electric power plant, the foundation of new industries, the opening up of new districts to agriculture, the control of forestry and, in fact, the furtherance of every development which would add permanent wealth to the British peoples.

There is, in these directions, work and to spare for all our capital and labour, and, moreover, this work would be productive in the highest sense of the word. The area of the British Empire, including mandated territories, is now considerably over 14 million square miles and it includes many areas offering exceptional opportunities for development.

Unfortunately, there is still a tendency to consider the matter only in the light of fiscal policy, or as regards wheat, cotton, wool or some other staple product. Any such restriction is, in the author's opinion, not only unnecessary but also foredoomed to failure. Our Empire as a whole includes practically all climates and conditions, almost every need and resource, and nothing less than a whole-time Board consisting of representatives from all parts of the Empire can run to best advantage what is, or ought to be, one vast business concern.

To be successful, an Empire Development Board must not attempt to usurp any of the functions of the home or overseas governments, and it must be entirely non-political in its constitution. Granted these conditions, and working solely for the development of the Empire as a whole for the benefit of all, the Board would enable the Empire to rise to the heights of prosperity without injury to those of other nations simply by the creation of new wealth from assets which are at present unproductive. That, surely, is the rational line of development.

XI METALLURGICAL EDUCATION

Increasing Importance of Education

It is not always fully realised that the importance of education increases year by year, with every advance in knowledge. Addressing the students of Sheffield University College some thirty-four years ago, the author said: "A man must today commence life with more accumulated definite information than the greatest man of a century—nay, half a century—ago possessed at the end of his career." The significance of those words has since increased and must continue to increase as long as science and technology advance. Students taking a metallurgical course today must learn much that was unknown to all of us thirty or forty years ago, and the problem of the educationist is how to instil an ever-increasing volume of dearly won facts and principles into the minds of the younger generation within a reasonable period of time and without cramping their powers of originality in thought and enterprise in action.

The need has been, and still is, to combine instruction with inspiration, and to help the younger men over rough roads and past pitfalls without causing them to adhere to the beaten track or overlook the innumerable ways to future progress. This difficult task has been tackled from the first, in Sheffield, by methods admirably suited to the needs of this city. It is impossible to estimate how much the metallurgical and other industries of the district are already indebted to the pioneering efforts of such men as Hicks, Sorby, Greenwood, Ripper, Arnold, and many others mentioned later in this section. Also, in the words of Dr. H. A. L. Fisher, speaking at the Degree Congregation on July 3rd, 1913, under the presidency of the Duke of Norfolk, then Chancellor: "The University does not exist only for the benefit of Sheffield; it is Sheffield's gift to the world. Discoveries made in the laboratories of the University have exercised and will continue to exercise a sensible influence in every quarter of the globe. Nor, of course, is the field of the University's influence broad only in the geographical sense. It extends all over the world, and benefits every class of society. The industrial worker is, indeed, one of the first to benefit by greater employment and improved conditions from each fresh discovery in the realms of science.

"No course of training can turn out as a finished product a thoroughly efficient engineer, metallurgist or chemist. On the other hand, in these days, it is impossible for any man to become an efficient engineer, metallurgist or chemist capable of dealing with present-day problems, much less advancing the boundaries of knowledge, without a course of suitable training. It is the work of educational institutions such as our University to provide such training, including not merely tuition in established facts but also the encouragement of original thought and research. From every standpoint, whether as regards training in theory and practice or the provision of facilities for research, the work accomplished in the City of Sheffield is surpassed by no other metallurgical centre."

Pioneer Work in Sheffield

Sheffield can justly claim to have taken a leading part in the development of technical education in this country, specially in the field of metallurgy. Also, our citizens can pride themselves that not only were they very early in the field but their first efforts were entirely voluntary. The successive stages of development, from the foundation of the Firth College in 1879, and the Technical School in 1886, down to the opening of the University in 1905, are traced in the following paragraphs where, also, tribute is paid to those who have done so much to maintain the city's educational pre-eminence.

The Firth College and the Technical School

It was in the 'seventies of the last century that the movement towards comprehensive scientific and technical training in Sheffield was commenced by the foundation of the Firth College. This excellent institution owed its birth to the beneficence and foresight of Mr. Mark Firth, and was opened by Prince Leopold on October 20th, 1879. Dr. H. C. Sorby, whose great work in metallography is mentioned in Section VII, assisted actively in the foundation of the College and was President of the Council and Chairman of the Executive Committee from 1883 until 1897, when Firth College became part of University College.

Aided by the liberality of a few noble-hearted citizens, specially by the enthusiasm and generosity of Sir Frederick Mappin, Sheffield took steps in 1883—that is, six years before the Technical Instruction Act of 1889—to establish a Technical School. The first meeting of the Committee to consider this scheme was held on December 13th, 1883, Alderman W. H. Brittain, then Mayor, presiding, and the School itself was opened by Sir F. Bramwell on February 3rd, 1886, in the old Royal Grammar School buildings.

Amongst those who supported this good work by monetary assistance and an ungrudging measure of time and effort, were Sir Frederick Mappin, Sir Henry Stephenson, Dr. Sorby, the Duke of Norfolk, the Rev. S. Earnshaw, a former Senior Wrangler, Messrs. Cammell, Brown, Firth and many others; also the City Guilds of London and the Drapers' Company. The Technical School immediately embarked upon a career of usefulness in which it was greatly assisted by the generous financial help continually received from the City Council. That this money had been a sound investment, well spent and usefully applied, goes without saying.

Professor W. H. Greenwood was the first Professor of Metallurgy at the Technical School, and there are many in Sheffield and further afield who remember with gratitude the instruction received from him in those early days. Great assistance in the development of the training of metallurgists was also rendered by Professor W. Ripper,

PLATE 14

Sheffield Educationists

Mark Firth
1819–1880

Sir Frederick Thorpe Mappin
1821–1909

Sir William Clegg
1852–1932

Sir Henry Stephenson
1826–1904

Colonel H. K. Stephenson, D.S.O.
1865–

Professors of Metallurgy in the Sheffield University

Professor W. H. Greenwood
First Professor of Metallurgy
1886–1889

Dr. J. O. Arnold, F.R.S.
Bessemer Medallist 1905
1889–1919

Dr. Cecil H. Desch, F.R.S.
1919–1932

Professor J. H. Andrew, D.Sc.
1932

happily still with us. Professor Ripper was not a metallurgist himself, but he had on his staff Mr. J. O. Arnold, who, later as Professor of Metallurgy, rendered such valuable services in connection with his co-ordinated studies of iron and steel comprising composition, melting, forging, rolling and heat treatment, mechanical and many other physical tests.

The University College

Since the period 1879 to 1886, there has been in Sheffield a continually increasing provision for higher education of all kinds. First there was the Firth College teaching science, literature, classics and art, then came the Technical School, giving instruction of an immediately practical kind. These two admirable institutions and the Medical School merged into the University College in 1897, which in turn was chartered as the University in 1905, with Dr. W. M. Hicks, F.R.S., as its first Vice-Chancellor, a fitting crown to his association with the Firth College and University College as Principal and Professor of Physics during a term of twenty-two years, from 1883 to 1905, also for his active assistance in the founding of the University. Preferring the Professorship of Physics to the post of Vice-Chancellor, Dr. Hicks resigned the latter position afterwards in favour of Sir Charles Eliot, and continued to guide the destinies of the Physics Department until his retirement in 1917.

On November 21st, 1899, nearly 34 years ago, it was the author's privilege, as Master Cutler, to distribute prizes to students of the Sheffield University College, and in the course of his address he made a special plea for practical education. That plea was endorsed by many of those present, including Professors Ripper, Arnold and Hicks, and there can be no doubt that the excellent results produced by metallurgical instruction in the University College and, later, the University have been, and still are, due to the fact that the training is pre-eminently practical. Much instruction in theory is, of course, essential, but it is and should always be directed towards practical ends, for the ultimate aim of the metallurgist is to make improved materials that will give better service under conditions increasing in variety and severity year by year.

In the list of prizemen on the occasion mentioned there appeared the names of at least two men who have since become prominent Sheffield metallurgists actively engaged in splendid scientific and practical work, viz., Mr. W. J. Dawson and Dr. W. H. Hatfield. The prize handed to Mr. Dawson was a special award for geology; that to Dr. Hatfield was for practical metallurgy (first year course).

Mr. Dawson, who later took the Associateship in Metallurgy at the University, is now the author's colleague on the Board of Directors of Hadfields, Ltd., and takes a prominent part in its councils.

As regards Dr. W. H. Hatfield, his many activities in the cause of metallurgical science and progress are well known, and we rejoice that he has this year been awarded the Bessemer Gold Medal by the

Council of our Institute. Dr. Hatfield, it is interesting to recall, was the first President of the Sheffield Metallurgical Association, an important Society with a membership at the present time of some 137.

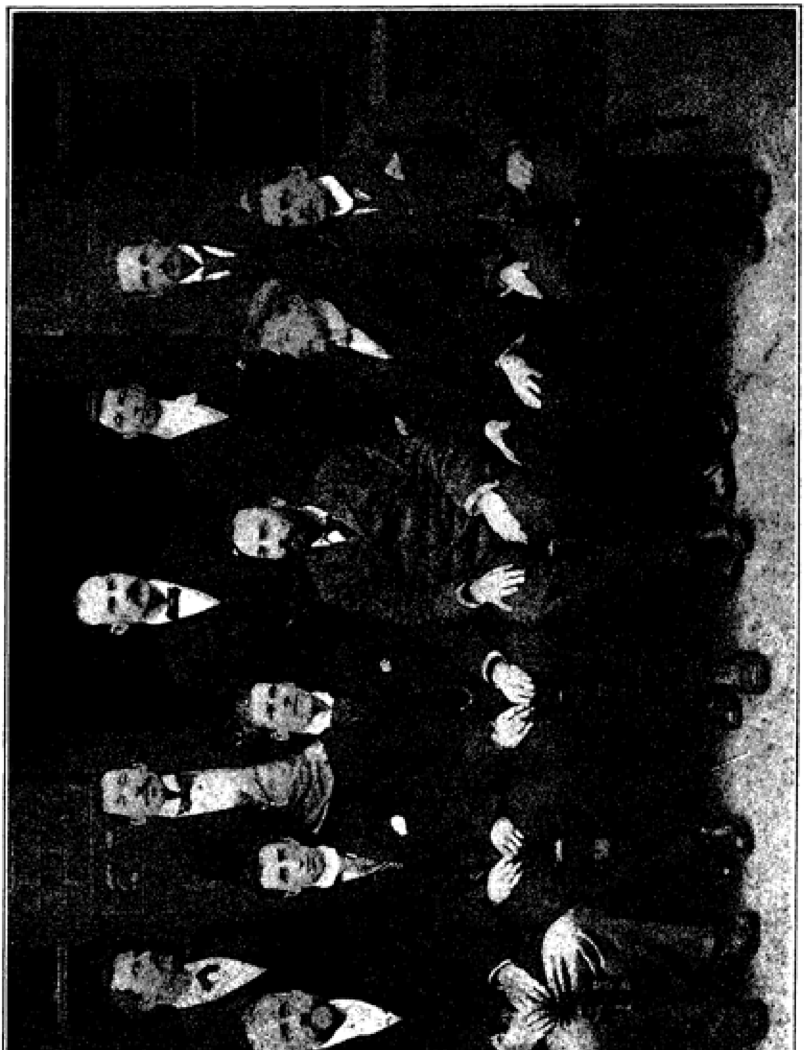
The accompanying Plate No. 18, representing the Third Year Class in Metallurgy at about the period now referred to, will, it is believed, bring to many at the present time, who in their younger days passed through the Metallurgy course at the Technical School, pleasant recollections of their happy relations with the staff. In the photograph, with Professors Arnold and MacWilliam and Mr. F. K. Knowles, will readily be recognised among the students several who have since occupied prominent positions, including, among others, Dr. Percy Longmuir, Mr. W. J. Dawson and Mr. S. M. Schindler.

The University of Sheffield

During the closing decade of last century there was a rapid growth of interest in technical education in Sheffield, as indeed in other centres, and in the course of the above-mentioned address to the students of the University College on November 21st, 1899, the author referred to the fact that further progress was being crippled, not by want of interest, but by lack of adequate accommodation and means. The author urged the need for a new university worthy of the fame and future of the city, and expressed his confidence that such an establishment would be an excellent investment from all points of view, and that every support should be given to Sir Frederick Mappin, Sir Henry Stephenson, Sir George Franklin, Sir William Clegg, Dr. Hicks, Professor Arnold, Professor Ripper and others, who were in the forefront of this great movement on behalf of the city's educational advance. That our optimism was finally justified goes without saying. The University of Sheffield was opened by King Edward VII in 1905, and has since gone from strength to strength, acquiring a world-wide reputation of which we may justly be proud.

No fewer than fourteen new Chairs under professors have been established since 1905, the number of other members of the staff increasing from 61 to 216. In 1905 the amount of scholarship money was about £7,000; now it exceeds £100,000, mainly owing to local benefactors, including Sorby, Allen, Styring, Hunter and others.

One of the chief features of Sheffield University is its Applied Science Department, housed in the building in St. George's Square and adjoining sites, and as a further indication of the progress that has been made it is interesting to compare the numbers of students in the Applied Science Department of the University during the session 1932–33, and the "peak" year 1919–20 with those of earlier days. Thanks to the kind assistance of the Registrar, Mr. W. M. Gibbons, M.A., the following interesting table has been prepared showing the nature and extent of present-day tuition in the Applied Science Department.



THIRD YEAR CLASS IN METALLURGY
SHEFFIELD TECHNICAL SCHOOL
1897

SHEFFIELD UNIVERSITY APPLIED SCIENCE DEPARTMENT

NUMBER OF STUDENTS

	Session 1932–1933	"Peak" Year 1919–1920
Day—		
Faculty of Engineering	166	334
,, ,, Metallurgy	59	134
Total	225	468
Evening—		
Mechanical, Electrical and Civil Engineering	434	
Metallurgy	190	
Building	91	
Oxy-Acetylene and Electric Welding ..	145	
Fuel Technology	25	
Special Courses for Adult Workers engaged in the Cutlery, File, Tool Spring, Rolling and Forging Trades	413	
Special Advanced Courses of Lectures on Metallurgy	41	
Special Advanced Courses of Lectures on Gas Engineering	44	
Miscellaneous	21	
Total	1,404	2,062
Saturday Afternoon Courses in Glass Technology	21	
Grand Totals	1,650	2,530

These figures compare in a remarkable and gratifying manner with the roll call of 99 in the Technical School for the session 1886–87. Also, they show a remarkable advance on the evening class figures for the Technical Department of the University College in 1899, the closing year of last century, when the figures were: Engineering students, 244; iron and steel, 103; building, 172; electrical engineering, 87; mining, 86; miscellaneous, 122; total, 814. Direct comparison between these figures and those for 1932–33 is impossible owing to the rearrangement of classes and the many new courses introduced to meet the ever-increasing requirements. It must be remembered, too, that the figures for the Applied Science Department today represent only a fraction of the University's activities, the total number of students being very much greater and the courses of instruction covering all branches of knowledge.

In 1917 the Faculty of Applied Science was divided into the Faculty of Metallurgy under Professor Arnold, and the Faculty

Sheffield Dignitaries: Civic, University

The Lord Mayor
(Mr. Ernest Wilson)

The Master Cutler
(Colonel A. N. Lee)

The President of the Chamber
of Commerce
(Mr. W. B. Pickering)

The First Chancellor of the
University
(The late 15th Duke of Norfolk)

The Chancellor of the University
(The Rt. Hon. The Marquess
of Crewe, K.G., P.C.)

PLATE 16

Sheffield Dignitaries: Civic, University

The late Sir John Brown
(relative of the author)

Sir Arthur Balfour, Bt., K.B.E.

Sir Henry Hadow

Dr. W. M. Hicks, F.R.S.

Dr. A. W. Pickard-Cambridge

Professor W. Ripper

The late Alderman George Senior

of Engineering under Professor Ripper, thus providing a further instance of the rapid growth and increasing importance that have characterised all the University's activities.

Special reference should also be made to the part taken by the University in adult education in connection with the Workers' Educational Association. Classes are held during the winter in many outlying mining and industrial districts, these being attended by some 700 or more students, each pledged to a three years' course of organised study.

Metallurgy and Foundry Degrees

With the establishment of Metallurgy as an independent Faculty, the University of Sheffield granted degrees in this branch of science, namely, Bachelor, Master and Doctor of Metallurgy. One of the author's colleagues on the board of directors of Hadfields, Ltd., the late Mr. I. B. Milne, was the first to receive one of these degrees, and the author himself felt greatly honoured when, in 1911, he received the degree of Doctor of Metallurgy. Literally, thousands of students, not only in our own city, but from all parts of the world, have been trained in scientific metallurgy under this Faculty of Metallurgy.

We in Sheffield claim to have been the first to recognise the proper position of metallurgy in establishing this new faculty. No one doubts the wonderful work done by the Royal School of Mines in London, the Freiburg School of Mines under the late Dr. Ledebur, and other famous centres, but it was Sheffield who first stamped metallurgy as a branch of science distinct and separate, although metallurgists gladly recognise that the full realisation of their work depends upon co-operation with the chemist, physicist, metallographist and engineers of different branches.

In keeping with its progressive spirit, and in recognition of the ever-increasing importance of scientific methods in all branches of industry, the University of Sheffield has taken into favourable consideration the important suggestion put forward by our Professor of Metallurgy, Dr. J. H. Andrew, with regard to the establishment of a Founding Course in the Faculty of Metallurgy, with degrees in foundry science for those who qualify. It is hoped that before long Professor Andrew's ambition will be realised. A successful student would be known as a Bachelor, Master or Doctor in Metallurgy, the word "Founding" being inserted in brackets after the degree.

Founders of Technical Education in Sheffield

Having given in the preceding pages a chronological outline of the rise and development of technical, specially metallurgical, education in Sheffield, some of those who have laboured in this cause may now be mentioned with a brief indication of the part they have played. As already mentioned, Mr. Mark Firth was specially associated with the foundation of Firth College, and Sir Frederick Mappin with that of the Technical School. Their work was supported and continued by the labours of many able and enthusiastic helpers, amongst them the late Duke of Norfolk, Sir Henry

Stephenson, Earnshaw, Sorby, Arnold, Firth, Osborn, Franklin, Hughes, Hobson, Ellis, Roberts, and many others as time went on. There was also the invaluable assistance of corporate bodies, including the City Council of Sheffield, the City Guilds of London, and the Drapers' Company.

Amongst those most active in the formation and development of the University were Sir Henry Stephenson, Chairman of the University Council, followed by Sir George Franklin, who was Chairman in its first most difficult years; Sir Frederick Mappin, who remained Chairman of the Technical Department and was succeeded by Mr. Joseph Jonas, Sir William Clegg, Sir George Franklin, Sir Albert Hobson, Dr. Douglas Vickers, Alderman George Senior and others. The City Council continued to contribute handsomely to the Technical Department, and resolved to give permanently a penny rate yearly to the University. Amongst the many gifts and bequests by which the great work of the University has been assisted, special mention may be made of the Drapers' Company donation of £15,000 towards the cost of the Applied Science buildings; the Edgar Allen Library, opened in 1909 by His Majesty King George V, then Prince of Wales; and the £10,000 bequeathed by Dr. Sorby to endow a Chair of Geology, £6,500 to purchase property adjoining the University site, and £15,000 left to the Royal Society to establish a Fellowship for researches to be conducted in the University of Sheffield. The Sorby Research Fellows have been Prof. J. F. Thorpe, F.R.S. (1909–14), Mr. B. Lightfoot (1914–20), Dr. F. C. Thompson (1920–21), Dr. N. K. Adam (1921–29), and Dr. W. H. George (1929 to date).

It is also specially gratifying to be able to acknowledge the great help rendered to educational progress in this city by Labour representatives. Such men as the late Alderman Stuart Uttley, and Alderman W. F. Wardley, one of our Labour Lord Mayors, have rendered double service by not only assisting the development of educational facilities, but also encouraging their use by those for whom they are intended.

The Chancellors, Pro-Chancellors and Vice-Chancellors who have done so much for the University since its foundation are as follows.

CHANCELLORS	Duke of Norfolk	1905–1917
	Marquess of Crewe	1917
PRO-CHANCELLORS	Sir Frederick Thorpe Mappin	1905–1910
	Sir George Franklin	1905–1916
	Sir A. J. Hobson	1916–1923
	Sir William Clegg	1923–1932
	Colonel H. K. Stephenson	1910
	Mr. Walter Newton Drew	1932
VICE-CHANCELLORS	Dr. W. M. Hicks	1905
	Sir Charles Eliot	1905–1912
	Dr. H. A. L. Fisher	1912–1916
	Professor W. Ripper	1917–1919
	Sir W. H. Hadow	1919–1930
	Dr. A. W. Pickard-Cambridge	1930

We are specially fortunate in now having as Vice-Chancellor Dr. A. W. Pickard-Cambridge, M.A., who is admirably fitted to preside over the affairs of the University in these difficult times, and we all wish him every success in his important task.

In the development of Sheffield's educational life there should be most certainly mentioned the guiding and helping hand of those representing the Sheffield Press, who have specially appreciated the value of technological training suitably adapted for our city's requirements and assisted in the good work. To these our warmest thanks are due. Whilst, alas, some of them have passed away, we can never forget the assistance rendered by such men as Sir William Leng, Mr. C. Leng and his successors, Sir Charles Clifford, Mr. J. D. Leader and his family, Mr. Oakley, Mr. Derry, Mr. Chisholm and others.

As regards the actual carrying into effect of the educational work made possible by those mentioned above, the University has indeed been fortunate in its Professors. Amongst those who were associated with the Technical School, first in its original form, then as the Technical Department of the University College, and finally as the Applied Science Department of the University, special mention must be made of Professors Hicks, Greenwood, Arnold and Ripper. Reference has already been made to the long association of Professor W. M. Hicks with Firth College, University College, and the University itself. He proved himself a most loyal worker and a splendidly unselfish man. Professor Greenwood was the first Principal of the Technical School and occupied his post until the year 1889, when he went to Birmingham and took a leading position in the Birmingham Small Arms Company. He was followed on the metallurgical side by Professor J. O. Arnold, whose association with the School, and subsequently the University, extended over a period of thirty years, that is, from 1889 to 1919, the year of his retirement. During that time he made, as all the world knows, most valuable contributions to metallurgical science. Then came Dr. C. H. Desch, who did much to keep Sheffield in the forefront as a centre of metallurgical training, and he, in turn, was succeeded in 1932 by Dr. J. H. Andrew, who is continuing the great work in a most able manner.

The engineering side, over which Professor F. C. Lea now presides so ably, grew up under the care of our much respected citizen, Professor W. Ripper, who discharged his duties with great enthusiasm and success during the period 1889–1923, that is, for thirty-four years. Formerly Principal of the Technical School, he became Dean of the Faculty of Applied Science and Professor of Engineering in the University, and his services include two years as Vice-Chancellor (1917–19) after Dr. H. A. L. Fisher left the University to become President of the Board of Education.

There should also be mentioned the following names of those who assist in the work of the Applied Science Department under the Committee, whose present Chairman is Mr. Joseph Ward. In Geology, Professor W. G. Fearnsides, Dean of the Faculty of Pure

Science; Mining Engineering, Professor E. C. F. Statham; Chemistry, Professor G. M. Bennett; Physics, Professor S. R. Milner; Mathematics, Professor P. J. Daniell; Glass Technology, Professor W. E. S. Turner; Metallurgy, Senior Lecturers Dr. F. Ibbotson and Mr. F. K. Knowles; Fuel Technology, Professor R. V. Wheeler, and Mr. W. J. Rees, Lecturer in Refractories; Civil Engineering, Professor J. Husband; Economics, Professor D. Knoop; and Dr. T. F. Wall, Lecturer in Electrical Engineering. This list of names would not be complete without reference to the able help rendered in past years by the author's old friends, the late Professor L. T. O'Shea and Professor A. MacWilliam.

Laboratory Facilities

The laboratory equipment of the University is suited to research work of the highest order, and a vast amount of such work has been and is still being carried out in a manner worthy of the high traditions of the city. In the field of metallography our equipment and our investigations are of the high standard demanded by the work of Sorby and Arnold. Full provision for the testing of materials is to be found in the Jonas Laboratory, shared by the Engineering and Metallurgical Faculties. The Edgar Allen Laboratory is arranged specially for research concerning the magnetic properties of steels, and there are adequate facilities for studying refractories and fuels. The new engineering and metallurgical laboratories opened by the author on July 2nd, 1926, on the occasion of the twenty-first anniversary of the University, provide all that is needed for the application of physical methods to metallurgical research. The importance of such work is at least as great as that of chemical examination.

A parchment scroll sent to the University of Sheffield by the Royal Institution on the occasion of the opening of these new laboratories expresses cordial greetings and contains the following words, which are unusually interesting in view of the reference to Faraday and his work on alloys of steel, specially bearing in mind that some of his alloys were made here in Sheffield, first experimentally and later on a commercial scale: "Remembering the early researches in the laboratories of the Royal Institution of Great Britain by Sir Humphry Davy on the combination of the metals and his successful decomposition of the alkalies, and of Michael Faraday on the alloys of steel, the Royal Institution takes a special pleasure in congratulating the University of Sheffield on this auspicious occasion. The epoch-making discoveries in all branches of metallurgy which have been made in the laboratories of the University of Sheffield, abundantly testify to the fact that the University has taken full advantage of its unique environment as the centre of the Steel and Metallurgical Industries. The Royal Institution expresses the hope that the University of Sheffield may continue to flourish and prosper in the future as in the past."

The equipment of the various laboratories covers the needs of advanced research, and includes a high frequency induction furnace for melting iron and steel in vacuo when required, also a high frequency furnace for producing very high temperatures in exhausted vessels supplied with current from a large thermionic valve. There are also large micrographic outfits and high power microscopes for the examination of surface details. A high temperature thermostat and dilatometer are used in investigating the physical properties of metals, and a special apparatus devised in the Department makes use of thermionic valves to investigate the deformation of metals beyond the elastic range. There is apparatus for determining the effects of strain on magnetism; and complete equipment for the spectrographic examination of metals by X-rays and otherwise; also apparatus for investigating fully the behaviour and properties of metals at high temperatures. The whole of this and other apparatus is kept in first-class condition and it is modified and added to as required by the progress of science.

Better evidence of the value of the work being done by the Applied Science Department of the University could not be afforded than the benefactions which continue to be made by industry for the purpose of extending its scope and equipment.

In July, 1929, a laboratory for the cold working of steel and other ferrous metals was opened by Dr. E. A. Ebblewhite, of the Worshipful Company of Ironmongers, who thereby inaugurated a Department, which, it is hoped, will make a great and important addition to the research work of the University in its bearing upon one of the most vital of our local industries. The Cutlers' Company, feeling that a great need for research in the practice of cold working existed, took the matter in hand and rendered most valuable assistance.

The opening of this Department has been rendered possible by the public spirit and munificence of the Worshipful Company of Ironmongers, who generously offered a grant of £800 per year for seven years to be devoted to the encouragement of study and research in the cold working of steel and cognate subjects. This grant is expended on one Research Fellowship and two Research Scholarships.

An appeal was made to the industries concerned for assistance in procuring the necessary equipment, and thanks to the generous support from those concerned a cold rolling mill and wire drawing block and other equipment have been installed.

The Department is controlled by a Committee representing the Worshipful Company of Ironmongers, the Company of Cutlers, of Hallamshire, the University and the industry. The more detailed control of the research is delegated to a Technical Advisory Sub-Committee consisting of certain members of the Main Committee and leading members of the industry, presided over by Mr. Percy W. Lee, J.P., to whom the University is under a special debt for the eminent service he rendered when the Department was founded. It was Mr. Lee, who, as Master Cutler, represented to the Worshipful Company of Ironmongers the need for research in cold working and he made a successful appeal to the industries for the equipment of the Department.

Since the Department's inauguration research has been carried out on lines laid down by the Committee. Some of these have developed into original research of a highly technical nature and dealing with fundamental problems. Great pains have been taken to identify the Department with the industry. This object was deemed to be most important as the University welcomes calls for assistance and seeks to convince manufacturers that all their problems will be treated with proper attention and in strict confidence. That the University is gradually being successful in this direction is evident in that several firms now write regularly to the Department, sending defective wires and asking the University to ascertain the cause of failure and to suggest the correct procedure to remedy the fault.

Reports on the work carried out in this Department to December, 1932, have been published and may be obtained from the Registrar.

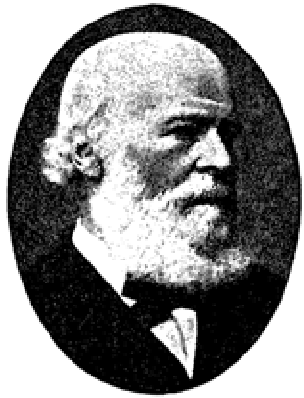
The new building for the Department of Mining was opened on June 14th, 1932, by Dr. W. Benton Jones, Chairman of the South Yorkshire Coal Trade Association. The opening was attended by representatives of the coal industry, Government Departments, Local Authorities and Scientific and Technical Societies, who made a tour of the laboratories and lecture rooms after the ceremony had been performed. This substantial and important addition to University buildings was made possible by the liberal grants of the Miners' Welfare Committee and the generosity of the coal industry —especially the South Yorkshire Coal Trade Association. Its spacious laboratories and modern plant and scientific equipment provide increased facilities for teaching and research; they place the University Mining Staff in a position to render even greater service than it has in the past to employers and employed in one of the most important coal areas of England.

The University is much indebted to Dr. J. H. W. Laverick, the Chairman of the Mining and Fuel Committee, for his service in assisting to obtain the funds necessary for the erection and equipment of the building.

PLATE 6

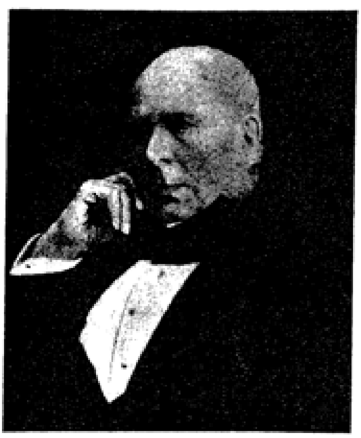
Some of the Past-Presidents of the Iron and Steel Institute, also the present President

William,
7th Duke of Devonshire
First President (1869–1871)



Sir Lowthian Bell, Bt., F.R.S.
Bessemer Medallist 1874

W. R. Lysaght
President



Sir Henry Bessemer, F.R.S.

Sir William Siemens, F.R.S.
Bessemer Medallist 1875

PLATE 7

Some of the Past Presidents of the Iron and Steel Institute

Sir Frederick Abel, F.R.S.
Bessemer Medallist 1897

Sir William Roberts-Austen, F.R.S.

Dr. John Percy, F.R.S.
Bessemer Medallist 1877

William Whitwell

Dr. Andrew Carnegie
Bessemer Medallist 1904

XII. METALLURGICAL SOCIETIES AND INSTITUTIONS

Introductory

In the course of his book, *Metallurgy and Its Influence on Modern Progress*, the author presented classified data showing that there were then some 600 scientific and learned societies in Great Britain and Ireland alone, and that the membership of the principal engineering societies of the British Empire amounted to nearly 68,000. Leading information was there given concerning a number of these important bodies, specially those with which the author has been associated during a period of many years. In the space here available it is only possible to pay a general tribute to the invaluable services rendered by these societies and institutions in the collection and dissemination of knowledge on a world-wide basis. Special mention may, however, be made of the formation of the Iron and Steel Institute in 1869, and the great work it has since accomplished; also, of certain local societies and associations which have done much for metallurgical workers in and around Sheffield. One of the most promising auguries for the future of metallurgy in this country is to be found in the ever-widening appreciation and support, not only of such bodies as the Iron and Steel Institute, the leading representative of ferrous metallurgy, but also specialised and local associations of all kinds, down to more or less informal societies and clubs such as are now to be found in almost every trade and college.

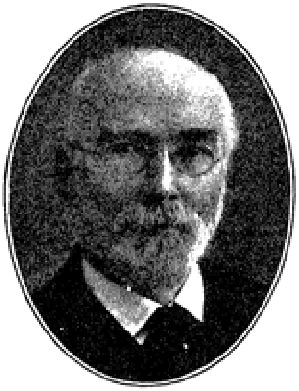
Formation of the Iron and Steel Institute

From the time of its foundation in 1869, the Iron and Steel Institute has played a most important part in encouraging research and disseminating scientific and practical knowledge concerning ferrous metallurgy at home and abroad, irrespective of nationality, and the author counts it a special honour to have been President of this great Institute and to have received from it the award of the Bessemer Gold Medal. The Institute was founded with the objects of affording a means of communication between members of the Iron and Steel Trade upon matters bearing upon their respective manufactures, excluding all questions connected with wages and trade regulations, and of arranging periodical meetings for the purpose of discussing practical and scientific subjects bearing upon the manufacture and working of iron and steel.

The suggestion that such an Institute should be established was originally made at a quarterly meeting of the Iron Trade of the North of England, held in Newcastle-upon-Tyne, on September 29th, 1868, by the late Mr. John Jones, of Middlesbrough, at that time the Secretary to the North of England Iron Trade. In accordance with resolutions then passed, a meeting was convened at Birmingham on October 8th, 1868. Mr. William Menelaus presided, and it was resolved unanimously to take steps for the establishment of an Iron and Steel Institute with rules based upon the general principles adopted by kindred societies, rigidly excluding all questions connected with wages and trade regulations. A provisional committee

Plate 8

Some of the Past-Presidents of the Iron and Steel Institute



Sir Hugh Bell, Bt.
Bessemer Medallist 1926

Dr. J. E. Stead, F.R.S.
Bessemer Medallist 1901

Sir William Ellis, G.B.E.

F. W. Harbord, C.B.E.
Bessemer Medallist 1916

Benjamin Talbot
Bessemer Medallist 1908

Percy C. Gilchrist, F.R.S.
Honorary Member

was formed, who considered it desirable that the proposed Institute should have its headquarters in London, but that periodical meetings should be held in the various ironmaking districts. A second meeting of the provisional committee was held in London at the Westminster Palace Hotel on December 17th, 1868, and at which Sir (then Mr.) Lowthian Bell presided. Rules were drawn up, and it was resolved that the late Duke of Devonshire, K.G., Chairman of the Barrow Steel Company, should be requested to become first President of the Institute. On January 11th, 1869, another meeting was held at Washington Hall, Newcastle-upon-Tyne, and 101 candidates were elected members of the new Institute. The first general meeting of members was held at the Westminster Palace Hotel, London, on February 25th, 1869. In 1899, thirty years after its foundation, the Institute was incorporated by Royal Charter.

Cosmopolitan Membership and Activities

The Transactions of the Iron and Steel Institute already extend to 126 volumes, and no less than 1,650 papers have been presented to this body, including communications on almost every important development in ferrous metallurgy during the past 64 years. From its earliest years the Iron and Steel Institute has always been a cosmopolitan body, and its members at present represent no fewer than 26 nationalities. The total membership is now some 1,800, compared with about 2,000 in 1905–6, the year of the author's presidency. No doubt the numbers will again increase rapidly when more prosperous times return. The largest membership list is that of London, with 224 members; next comes Sheffield, with 191. With a little effort, Sheffield should eventually head the list, and it would be very appropriate that it should do so!

Twice during the present century, Sheffield men have been Presidents of the Iron and Steel Institute, Sir William Ellis in 1924–25, and the author in 1905–7, while six of our citizens, Messrs. J. D. Ellis, Hadfield, Arnold, Saniter, Brearley and Hatfield, have received the Bessemer Gold Medal, the much coveted blue riband of metallurgy. The Sheffield representatives on the Council of the Institute are Mr. Fred Clements, Sir William Ellis, Sir Robert Hadfield, Dr. W. H. Hatfield and Mr. Ernest H. Saniter.

As emphasised repeatedly in the course of this address, the magnificent structure of modern metallurgical science and practice is the result of continual research and endeavour by workers all over the world. Further proof of this fact, if any be required, is to be found in the Transactions of the Iron and Steel Institute, in the list of its Past Presidents and, to an even greater extent, in the list of those eight nationalities who have been awarded the Bessemer Gold Medal in recognition of their services. The following lists of famous Presidents and Bessemer Gold Medallists, ranged in alphabetical order, mark out the history of modern metallurgy and show that metallurgy indeed knows no geographical boundaries: William, Duke of Devonshire, our first President, 1869–71; Sir Frederick Abel, 1891–93; Lord Airedale of Gledhow, 1889–91; Sir Henry Bessemer, 1871–73; Sir Lowthian Bell, 1873–75; Mr.

Royal Recipients of the Bessemer Medal

Her Majesty Queen Victoria

His Majesty King Edward VII

Andrew Carnegie, 1903–5; Sir William Ellis, 1924–25; Professor Henry Louis, 1929–31; Mr. W. R. Lysaght, 1933–34; Mr. E. P. Martin, 1879–99; Dr. John Percy, 1885-87; Sir William Roberts-Austen, 1899–1901; Rt. Hon. Sir B. Samuelson, 1883–85; Sir William Siemens, 1877–79; Dr. J. E. Stead, 1920–22; Mr. Benjamin Talbot, 1928–29; Mr. William Whitwell, 1901–3; Sir Charles Wright, 1932–33.

Amongst the famous Bessemer Gold Medallists have been Her Majesty Queen Victoria, 1899; His Majesty King Edward VII, 1906; Sir Lowthian Bell, who was the first, 1874; Sir Frederick Abel, 1897; Richard Ackerman, 1885; Dr. J. O. Arnold, 1905; Lord Armstrong, 1891; Sir Hugh Bell, 1926; Dr. Carl Benedicks, 1927; Mr. H. Brearley, 1920; Dr. J. A. Brinell, 1907; Mr. Andrew Carnegie, 1904; Sir Harold Carpenter, 1931; Professor H. le Chatelier, 1911; Mr. J. H. Darby, 1912; Mr. J. D. Ellis, 1889; M. Charles Frémont, 1921; Mr. John Fritz, 1893; Professor F. Giolitti, 1919; Dr. W. H. Hatfield, 1933; Mr. F. W. Harbord, 1916; Professor Kotaro Honda, 1922; Mr. A. L. Holley, 1882; Professor H. M. Howe, 1895; Herr F. Krupp, 1902; Professor Henry Louis, 1932; M. Pierre Martin, 1915; Mr. Robert Forrester Mushet, 1876; Professor Floris Osmond, 1906; Sir Charles Parsons, 1929; Dr. John Percy, 1877; M. Alexandre Pourcel, 1909; Dr. W. Rosenhain, 1930; Mr. E. H. Saniter, 1910; Professor A. Sauveur, 1924; M. Eugène Schneider, 1930; Mr. Charles M. Schwab, 1928; Sir William Siemens, 1875; Mr. G. J. Snelus, 1883; Dr. J. E. Stead, 1901; Mr. Benjamin Talbot, 1908; Mr. Sidney Gilchrist Thomas, 1883; Professor Thomas Turner, 1925; Dr. Peter Ritter von Tunner, 1878; Dr. Hermann Wedding, 1896; Sir Joseph Whitworth, 1878; Dr. Henri de Wendel, 1900.

Carnegie Research Fund

An important landmark in the history and career of the Institute was the wide and munificent foundation in 1901 by Mr. Andrew Carnegie of the Carnegie Research Scholarships and Gold Medal, which have been of such inestimable value in encouraging metallurgical research. Here again the awards have been international.

This benefaction was subsequently increased by the late Mr. Carnegie to a sum of £20,000 to mark his Presidency of the Institute in 1903–1905. The revenue of this fund is expended by the Council in making grants in aid of original research work in the metallurgy of iron and steel and in the award of a Gold Medal for meritorious work. The value of the grants is usually about £100, and a certain number are granted annually, irrespective of sex or nationality, to applicants who can satisfy the Council that they are qualified to carry out researches of an advanced kind. The recipients are under the obligation to present their results to the Institute for publication. Approximately 200 awards have already been made.

Secretaries of the Iron and Steel Institute

Throughout its existence the Iron and Steel Institute has had the benefit of able guidance and faithful service from its secretaries. The first Secretary was Mr. J. Jones, who was assisted by

PLATE II

Bessemer Medallists
(not Presidents of the Iron and Steel Institute)


Robert F. Mushet


Sir Joseph Whitworth, Bt.


Sidney Gilchrist Thomas


G. J. Snelus, F.R.S.


Sir Charles Parsons, F.R.S.


Dr. W. Rosenhain, F.R.S.


Sir Harold Carpenter, F.R.S.

Plate 12

Sheffield Bessemer Medallists

J. D. Ellis

E. H. Saniter

Sir Robert Hadfield, Bt., F.R.S.

H. Brearley

Dr. W. H. Hatfield

David Forbes, F.R.S., acting as Foreign Secretary. He was followed by Mr. J. Stephen Jeans, then by Mr. Bennett H. Brough, and later by Mr. G. C. Lloyd. Now, after 25 years of devoted service on behalf of the Institute, Mr. Lloyd is retiring from his honourable post and carries with him the good wishes of all our members. We all congratulate Mr. Lloyd on the recent conferment upon him by the President of the French Republic of the Order of Chevalier de la Légion d'Honneur.

To our new Secretary, Mr. K. Headlam-Morley, the Council and members of the Institute offer a hearty welcome. Mr. Morley has unusual qualifications which should make his work and efforts on behalf of not only British but international metallurgy of particular value. He has the advantage of taking office at a time when the outlook for the future is brighter than it has been for many a day past, and he has the good will of all concerned to help him in his new and important post.

National Federations

No reference to metallurgical societies and iron and steel organisations would be complete without at least a mention of the signal services rendered by the Federation of British Industries under its able past Director, Sir Roland Nugent, and its present Director, Mr. G. C. Locock, C.M.G.; also the National Federation of Iron and Steel Manufacturers, representing practically all the firms engaged in the iron and steel industry, whose Director, Sir William Larke, K.B.E., assisted by Mr. L. Birkett, has rendered invaluable service for many years. This Federation has rendered great service in the establishment of special Committees for the encouragement of research in collaboration with the Iron and Steel Institute.

Sheffield Societies

As regards local Metallurgical Associations special mention must be made of the excellent work done by the Sheffield Society of Engineers and Metallurgists, whose 375 members are at present under the able presidency of Professor F. C. Lea; and the Sheffield Metallurgical Association with some 137 members and Mr. J. H. S. Dickenson to preside over them. The activities of these Associations, in bringing together members to the benefit of all, have assisted greatly in the development of metallurgical knowledge, and the greater the number of such societies in different parts of the country the better for our future progress.

The author remembers with great pleasure his year of office as President of the Technical School Metallurgical Society as long ago as 1893, and specially their Conversazione held on March 25th, 1893, when delivering his presidential address. This was one of the earliest efforts to bring what was then the Technical School into more intimate touch with the main industries of our city. There were demonstrations of a number of scientific experiments and practical operations, as well as an interesting collection of exhibits including metallurgical specimens; and the great French metallurgist, Moissan, was kind enough to send specially from Paris one of his experimental electric melting furnaces, a rarity indeed

PLATE 9

Secretaries of the Iron and Steel Institute

John Jones
1869-1877

J. Stephen Jeans
1877-1893

Bennett H. Brough
1893-1908

G. C. Lloyd
1909-1933

K. Headlam-Morley
1933

Presidents of Sheffield Societies

Professor F. C. Lea
President of the Sheffield Society of Engineers and Metallurgists

J. H. S. Dickenson
President of the Sheffield Metallurgical Association

National Federations

Guy Locock, C.M.G.
Director of the Federation of British Industries

Sir William J. Larke, K.B.E.
Director of the National Federation of Iron and Steel Manufacturers

in those days. It was with this type of furnace he had carried out his then recent experiments which had attracted so much attention throughout the scientific world. With it he had produced manganese, chromium, and several of the rarer metals. There were also exhibited the Huntsman clock; electric welding equipment; Le Chatelier pyrometers of the electrical and optical types, beside Murrie's and Mesuré and Noel's pyrometers; some specimens of steel made at the Technical School; and many other things of equal interest. This was probably the first exhibition of the kind in Sheffield, and it should be remembered that its scope included what were then some of the latest discoveries and most advanced methods in metallurgy and engineering.

In the course of his address on that occasion, the author emphasised the value of such Societies as a means of collecting and discussing new points and improvements—thus acting as the "mental analysis department of industrial progress"—and urged the desirability of every steel maker having representatives in the Society. A development of this kind was ultimately brought about by Professor Ripper in the foundation of the Sheffield Technical Societies. These Societies provide a connecting link between the University on the one hand and the various industries—cutlery, file, silver, edge-tool and saw, foundry, rolling, steel melting, spring, wrought iron and clay working—on the other. A governing body of practical and experienced leaders direct the attention of the trades to the various problems and issues which the lectures are planned to solve and, as the meetings are held at the University, its members are brought into direct contact with the latest knowledge and methods. It would be difficult to exaggerate the value of the work done by these Societies in helping workers to extend their knowledge of their trades. The ultimate effects will be far-reaching from both the economic and the social points of view.

Scientific Literature

Reference has already been made in the author's published addresses to the scarcity of truly scientific and practical literature prior to about 1870. That difficulty certainly no longer exists, for, in addition to the innumerable books now published dealing with every branch of science and technology there now appear, as recently pointed out in the Journal of the Federation of British Industries, about 700,000 scientific and technical papers annually, as well as about 14,000 periodicals.

In this respect the splendid work done by the Science Museum Library should be recognised. Its subject-matter index makes readily available some two million references, and about 150,000 entries are added annually. The published biographies on its shelves are estimated to contain no fewer than forty million references, thus rendering the information service of the Library probably one of the most complete that exists. Any Institution or firm desiring to be placed on the approved list for borrowing publications from the Science Library has only to make application to the Director of the Science Museum, South Kensington.

XIII. RESEARCH

Importance of Industrial Research

The present high level of attainment in metallurgical practice is due primarily to long and patient research by many workers in many lands, resulting in a steady improvement of facilities at the disposal of investigators and manufacturers alike. As the complexity of manufacture increases year by year so does the importance and, in many respects, the difficulty of research. Apart from what may be termed "pure" research, that is, general investigations carried out primarily for the purpose of making whatever new discoveries may arise, seeking simply "truth for truth's sake," there is what may be called "applied" or "industrial" research directed largely towards the solution of specific industrial problems. Obviously this latter class of research is concerned with the latest discoveries and investigations and with the highest degree of truth and accuracy, notwithstanding the fact that it is directed towards an immediately practical end. Research is, in fact, the quest for knowledge whatever the motive, and if any distinction or comparison is to be drawn between "industrial" and "pure" research then, on the whole, applied or industrial research is the more difficult because the end in view, and often the imperative need, is a workable, satisfactory and economical solution to a specific problem.

In a modern steelworks research necessarily forms part of the industrial operations and demands almost as much attention as is devoted to the manufacturing side. The research laboratories and their equipment are less spectacular than the flaming furnaces, mighty mills and other machinery, but it is in the laboratories that the secrets of new steels are discovered, and it is there that those innumerable tests are applied which are essential to control the manufacturing operations and ensure that every piece of steel sent out from the works is of the desired composition, purity and strength, properly worked and subjected to correct heat treatment, fitted in every way to give the best possible service.

Necessity for Correlation

In earlier days it was rather the rule than the exception for investigations on steel to be conducted in a more or less arbitrary manner, that is, with reference to the particular properties in which the investigator happened to be interested and without recording other properties which, as shown by subsequent experience, might actually affect the ones examined. Also the composition of the steel was often indicated in an incomplete manner; it might be stated that the experiments had been conducted on a piece of carbon steel; the carbon percentage might or might not be mentioned, but if so the data usually ended there. The full importance of complete correlation of data was clearly shown in the author's original papers in 1886 and onwards, describing manganese, silicon steel, aluminium, nickel, chromium, tungsten and many other alloys. These researches and the increasing number of investigations by others, including the valuable work done by Professor Arnold, showed that we must have complete correlation, including not only very complete chemical analyses—in many cases such data have now to be obtained for twice the number of elements formerly determined—but also mechanical tests, determinations of electrical and physical properties and, of course, full examination of micro-structure.

The laboratories of the author's firm, as used for routine testing as well as original investigations, include equipment for every kind of test—chemical, mechanical and physical—with special apparatus for carrying out tensile, bending, endurance, impact, hardness, electrical conductivity, magnetic permeability, hysteresis, determination of thermal change points, and other tests. In a single week as many as 12,000 pyrometric observations have been made, and the equipment for the microscopic examination and microphotography of steels at all powers up to 5,000 and even 8,000 diameters is continually in use.

In 1905, on the occasion of the first visit to Sheffield by the Iron and Steel Institute, the late Dr. Wedding, of Berlin, the leading German metallurgist of his time, stated that: "The research work carried on at the Hadfield works was of a completeness which would serve as an example to every academy in Germany." Today, of course, the equipment is immeasurably superior to the best then available, and our researches are far more numerous and exhaustive.

Nevertheless, though the equipment is the best to be had, it must be freely admitted that we could not obtain the results we do were it not for the men at our disposal. We are fortunate in our Research Department in possessing a staff second to none in knowledge, skill and enthusiasm, and, in so far as their training is concerned, the author would like to pay tribute to the invaluable services rendered by the Applied Science Department of the University of Sheffield, and in other directions by the Sheffield Trades Technical Societies and, of course, the Iron and Steel Institute and other scientific and professional institutions and societies.

Co-ordinated and Individual Research

Quite recently the author was asked by the Department of Scientific and Industrial Research to make such comments and suggestions on a list of investigations put forward by the Department's Metallurgy Research Board as seemed likely to be of benefit to industry. In due course, suggestions concerning not only scientific, but also technical and practical work, were submitted to the department, and were acknowledged as being of material assistance in the light of industrial requirements and in defining work already covered by private research. These facts are mentioned as a tribute to the spirit of co-operation and enterprise that is being displayed by the department in regard to meeting as fully as possible the requirements of industry.

For obvious reasons, individual commercial concerns cannot and ought not to refrain from following with the utmost energy any and all of the research problems bearing on their particular line of work.

Such research is, in fact, part of their work and must remain so if they are to maintain their position in the industry. There are, however, many problems of general interest, bearing not so much on the needs and opportunities of individual firms as on the general advancement of knowledge which can be dealt with and co-ordinated very usefully by a central organisation and investigated, at any rate on a laboratory scale, in central institutions. Work of this class is naturally very important, and it is being carried on with a gratifying measure of success by the Department of Scientific and Industrial Research under the able direction of Lord Rutherford, Past President of the Royal Society, who has done so much for the advancement of science in this country.

As regards the extent to which centrally co-ordinated and controlled research can, or ought to, replace individual research, opinions may differ. In the author's experience, extending now over a period of nearly sixty years, while correlation of chemical, physical, mechanical and other investigations is essential in the investigation of each particular material or problem, the possibilities of co-operative research, or research by trades or by State departments, are distinctly limited. Individual effort has been the secret of our success in the past, and so it must be in future. Without belittling the value of central co-ordination of research on what may be termed problems of general interest, the author is firmly of the opinion that the key to successful industrial research is to be found in the individual effort and enthusiasm of research workers extending over the broadest possible field in the well-equipped laboratories of the firm they serve.

Fuel and Furnaces

One of the most important industrial problems of today is fuel economy, a matter which concerns engineers, metallurgists and every consumer of fuel. Primarily the problem is largely an engineering one, but the metallurgist and the chemist are also contributing to its solution. Each advance effected by the engineer, whether by increasing pressures or temperatures, by reducing deadweight, or by otherwise improving the utilisation of material, saving energy and fuel, demands and depends upon improved materials, and these the metallurgist is called upon to supply.

Notwithstanding the advances of recent years, there is still room for great savings in almost every field of combustion engineering. In a presidential address to the Conference of the British Commercial Gas Association in Sheffield some years ago, the author pointed out that from 45,000 to 60,000 cubic feet of producer gas from coal will melt 1 ton of steel. The thermal units from this amount of fuel are about 9,400,000 B.Th.U., of which less than 13·5 per cent. is utilised, and no less than 86·5 per cent. is lost. Some of the problems of furnace heating are reviewed, in the light of the latest trends of development, in an article by the author and Mr. R. J. Sarjant, M.Sc., in the *Fuel Economy Review of the Federation of British Industries*, Volume XII, 1933. The scope for improvement in existing practice is indicated, and the economic position of competitive fuels is considered. These are matters which might be thought to lie outside the province of the metallurgist. Actually they concern him most closely, not only because he uses great quantities of heat, in the form of either fuel or electrical energy, in the various operations of making and working steel and other metals, but also because his materials, specially some of the later alloy steels, enable fuels to be utilised more economically and to better effect in practically every one of their many applications.

The question of the scientific utilisation of fuel, particularly in its bearing on the carbonisation industry, is dealt with most ably in the Department of Fuel Technology of the Sheffield University under the direction of Professor R. V. Wheeler.

Following upon the sequence of development traced in Sections IV and V of this address from Huntsman's crucible process to the Bessemer process and the Siemens-Martin open hearth process there came, after a shorter interval of time, the various forms of electric furnace which have done so much to facilitate the manufacture of pure iron, steel and special steels.

Curiously enough the high frequency induction furnace, which is the latest type of equipment for melting alloy steels, is yet another practical application of Faraday's wonderful discovery of electromagnetic induction. This discovery was not made until many years after Faraday abandoned his researches on alloys of steel, and great advances had to be made in electrical technology before the discovery could be applied as it is today, but it ought never to be forgotten that we owe to Faraday not only the first systematic research on alloys of steel, but also the important discovery which led to the latest and best method of preparing modern alloy steels free from any possibility of contamination. When Faraday succeeded in preparing a specimen containing only 0·07 per cent. carbon by means of his little "blast furnace" he performed an operation of much greater technical difficulty than is now offered by the melting of pure iron in a high frequency furnace operating on the principle of electromagnetic induction which he discovered.

Low Temperature Research

In every field of ferrous metallurgy the march of progress goes on unceasingly and new researches are continually being put in hand. It is impossible here to make any attempt to indicate all the lines of inquiry at present under examination, but special mention may be made of certain low temperature investigations, which contrast strikingly with the matters of fuels and furnaces discussed above.

For many years the author has been strongly attracted to the investigation of the effects on iron and its alloys of low temperatures down to that of liquid air (−182° C.), liquid hydrogen (−252·8° C.), and liquid helium (−269° C.), approaching closely indeed to that of absolute zero (−273° C.). An important series of researches on this subject commenced by collaboration between the author and the late Sir James Dewar, F.R.S., Director of the Royal Institution, London, for 46 years. An extensive series of experiments resulted in a paper "On the Effect of Liquid Air Temperatures on the Mechanical and

Other Properties of Iron and its Alloys" presented to the Royal Society in 1904 in their joint names.

Then followed a still more exhaustive paper presented by the author to the Iron and Steel Institute in 1905, entitled "Experiments relating to the Effect on Mechanical and other Properties of Iron and its Alloys produced by Liquid Air Temperatures." This paper, based on no fewer than 2,000 individual observations, occupied 108 pages with discussion, 14 figures, 37 diagrams, 15 tables and 350 tests. This research proved to be a classic one and has been for many years a standard reference for those interested in the effect on ferrous and other metals of low temperatures ranging down to −182° C.

This was followed by a joint paper by the late renowned Professor Kamerlingh Onnes of Leiden University and the author with regard to special investigations as to the magnetic and other qualities of various ferrous alloys at the still lower temperature of liquid hydrogen (−252·8° C.) and in some cases of liquid helium (−269° C.). An account of this research appeared in the Proceedings of the Royal Society, A, Vol. 99, 1921, and has provided further information and data which have been found useful for reference, specially as regards the curious effects of such low temperatures on the magnetic and non-magnetic properties of ferrous metals.

Unhappily the death of Professor Kamerlingh Onnes occurred in 1926, but the low temperature researches have been continued at Leiden by Professor W. J. de Haas in collaboration with the author. Prolonged and painstaking investigations extending over a period of six years culminated in a joint paper presented to the Royal Society on April 11th, 1933, entitled "Research on the Effect of the Temperature of Liquid Hydrogen (−252·8° C.) on the Tensile Properties of Forty-one Specimens of Metals comprising (*a*) Pure Iron, 99·85 per cent.; (*b*) Four Carbon Steels; (*c*) Thirty Alloy Steels; (*d*) Copper and Nickel; (*e*) Four Non-Ferrous Alloys." This paper, which is to be published in the autumn of 1933, adds substantially to the knowledge previously available concerning the properties of metals at these very low temperatures. Further research is required, and will be undertaken as opportunity arises, concerning the effects of yet lower temperatures, but, as will be readily appreciated, the difficulties increase enormously with every degree of closer approach to the absolute zero of temperature.

XIV. NAMES OF THE EARLY METALLURGISTS, 384 B.C.—1882

Early Workers in Scientific Metallurgy

The actual origin of the utilisation of metals by man, whether with or without such processes as would justify the application of the term "metallurgy," is lost in the mists of prehistoric centuries. Certainly the period goes back many thousands of years. It was not, however, until comparatively modern times that the production of iron on a large scale was commenced, using coal in place of charcoal for smelting. Dud Dudley, in 1619, was probably the first in this country to smelt iron with "pit-coale" on a scale which was then considered quite large and important. Prior to that time, the names definitely identifiable with metallurgical works are few in number, and the following list includes the most important of them, and, further, extends the record down to the end of the nineteenth century :—

Aristotle (Greece), 384–322 B.C., philosopher, described the manufacture of Indian steel.

Theophrastus (Greece), 374–287 B.C., philosopher, wrote on iron ore.

Diodorus Siculus (Sicily), 60 B.C., geographer, described the smelting of Elba ore.

Plinius (Italy), 79–23 B.C., naturalist, showed that the properties of iron depend upon its treatment.

Rugerus Theophilus (Germany), monk, dealt with iron in his "Schedula diversarum Artium" (1050).

Leonardo da Vinci (Italy), 1452–1519, physicist, artist, etc., introduced blast for smelting iron.

Vanuccio Biringuccio (Italy), 1480–1539, deal with iron in his "Pyrotechnia" (1540).

Georgius Agricola (Germany), 1490–1555, dealt with metallurgy of iron in his "De Re Metallica" (published 1546).

Paracelsus (Switzerland), 1493–1541, chemist, improved metallurgical methods, discussed the distinction between iron and steel.

Lazarus Ercker (Germany), wrote on assaying (1574).

Louis de Geer (Sweden), 1587–1652, introduced the Walloon furnace.

Dud Dudley (England), 1599–1684, first smelted iron with pit coal.

Johann Rudolf Glauber (Germany), 1604–1668, chemist, discovered several metallic chlorides.

Simon Sturtevant (England), dealt in his "Metallica" with the use of coal for smelting (1612).

John Rovenzon (England), dealt in his "Metallica" (1613) with the use of coal for smelting.

Sir John Pettus, Knight (England), 1613–1690, author of metallurgical works.

Andrew Yarranton (England), 1616–1684, introduced tin-plate manufacture.

The Hon. Robert Boyle (England), 1627–1691, chemist and physicist.

Sir Isaac Newton, Knight (England), 1643–1727, scientist.

René Antoine Ferchault Réaumur (France), 1683–1757, physicist, wrote on cementation and decarburization.

Emanuel Von Swedenborg (Sweden), 1688–1772, engineer and theologian, wrote on iron.

G. Brandt (Sweden), 1694–1768, discovered cobalt (1733).

Benjamin Huntsman (England), 1704–1776, manufacturer, first to melt steel.

Benjamin Franklin (United States), 1706–1790, statesman and scientist, inventor of the Franklin stove.

Johann Andreas Cramer (Germany), 1710–1777, author, wrote on metallurgy.

Abraham Darby (England), 1711–1763, used coke for smelting.

Sven Rinman (Sweden), 1720–1792, wrote on metallurgy of iron.

Axel Frederic Cronstedt (Sweden), 1722–1765, mineralogist, discovered nickel (1751).

Joseph Priestley (England), 1733–1804, chemist, discovered oxygen (1774).

Richard Kirwan (Ireland), 1733–1812, author, first English writer on mineralogy.

Tobern Olaf Bergmann (Sweden), 1735–1784, chemist, founder of analytical chemistry, drew distinction and explained differences between pig-iron, wrought iron, and steel.

Henry Cort (England), 1740–1800, engineer, introduced puddling and the use of grooved rolls.

Karl Wilhelm Scheele (Sweden), 1742–1786, chemist, anticipated Priestley's discovery of oxygen; discovered manganese (1774), chlorine, barium, and molybdenum.

Martin Heinrich Klaproth (Germany), 1743–1817, chemist and mineralogist, discovered uranium (1789) and titanium (1794).

Antoine Laurent Lavoisier (France), 1743–1794, chemist, creator of modern chemistry.

Johann Gottlieb Gahn (Sweden), 1745–1818, chemist, isolated phosphoric acid.

Claud Louis de Berthollet (France), 1748–1822, chemist, discovered composition of ammonia.

Fausto de Elhuyar (Spain), 1755–1832, chemist, first prepared metallic tungsten (1792).

William Reynolds (England), 1758–1803, patented (1799) the use of manganese oxide for steel manufacture.

John Dalton (England), 1766–1844, chemist, published table of atomic weights.

Jeremias Benjamin Richter (Germany), 1762–1807, chemist, invented alcoholometer.

Louis Nicolas Vauquelin (France), 1763–1829, chemist, discovered chromium (1797).

David Mushet (England), 1772–1847, metallurgist, author, discovered blackband ore.

Sir Humphry Davy (England), 1778–1829, chemist, first isolated potassium and sodium.

Jons Jakob Berzelius (Sweden), 1779–1848, chemist, prepared pure iron, discovered selenium, thorium and cerium, isolated silicon, and introduced the theory of allotropy.

Pierre Berthier (France), 1782–1861, chemist, wrote on metallurgical analysis.

Robert Sterling (Scotland), 1790–1878, patented regenerative principle (1847).

Michael Faraday (England), 1791–1867, chemist and physicist, investigated the properties of iron and steel alloys.

James Beaumont Neilson (Scotland), 1792–1865, invented hot-blast (1828).

Friedrich Wohler (Germany), 1800–1882, chemist, isolated aluminium (1827).

Tribute to International Workers

The strongly international nature of this list is immediately evident, and this may be further demonstrated by the lists given in the following paragraphs. While this country and the City of Sheffield have taken a leading part in the development of modern metallurgy, no one, and certainly not the author, would for a moment desire to belittle the important contributions made by those abroad.

Arranged on a national basis for convenience of reference, the leading early metallurgists of Great Britain, France, Germany and Sweden, the countries principally concerned, are as follows :—

GREAT BRITAIN	Dud Dudley	1599–1684
	Sturtevant	1612
	Rovenzon	1613
	Sir John Pettus	1613–1690
	Andrew Yarranton	1616–1684
	Huntsman	1704–1776
	Abraham Darby	1711–1763
	Richard Kirwan	1733–1812
	Henry Cort	1740–1800
	William Reynolds	1758–1803
	The two Mushets	1772–1847
	Robert Heath	1856
	Robert Sterling	1790–1878
	Michael Faraday	1791–1867
	James Neilson	1792–1865
FRANCE	Réaumur	1683–1757
	Jars	1729–1808
	Lavoisier	1743–1794
	Berthollet	1748–1822
	Vauquelin	1763–1829
	Berthier	1782–1861
GERMANY	Theophilus	1050
	Agricola	1490–1555
	Ercker	1574
	Glauber	1604–1668
	Cramer	1710–1777
	Klaproth	1743–1817
	Richter	1762–1807
	Wohler	1800–1882
SWEDEN	Swedenborg	1688–1772
	Brandt	1694–1768
	Cronstedt	1722–1765
	Bergmann	1735–1784
	Scheele	1742–1786
	Berzelius	1779–1848

Lest the period covered by these lists be considered arbitrary, it may be explained that thay include only those workers whose main contributions were made before, or not considerably later than, the foundation of the Iron and Steel Institute in 1869, this date being a convenient and reasonable division between old and modern in the present connection. The above lists are believed to be substantially complete, but in the stress of other affairs some omissions may have escaped the author's notice.

In 1722, Réaumur published an important treatise on the conversion of bar iron into steel, and described cementation furnaces very much like those still in use, as well as a method for annealing hard iron castings by heating them when embedded in iron ore. It was he, however, who was largely responsible for the mistaken idea, prevalent amongst French metallurgists for a century or more, that the irons made in France could be treated, with the imperfect resources then available, so that they would equal the pure products of Sweden. On the other hand, the ores which gave a definitely inferior product in the eighteenth century can now be made to yield steel of the highest quality, thanks to advances in metallurgical science.

It is not always realised how much the subsequent progress of metallurgy was facilitated by the great work done in Sweden during the seventeenth and eighteenth centuries in the discovery and isolation of many of the elements now used for alloy steels. Thus G. Brandt discovered cobalt in 1733; Axel Frederic Cronstedt discovered nickel in 1751; Karl Wilhelm Scheele (1742–1786) discovered manganese, molybdenum and other elements; and Jons Jakob Berzelius (1779–1848) isolated silicon, and was the originator of the theory of allotropy; Martin Heinrich Klaproth (Germany) discovered uranium in 1789, and titanium in 1794; Fausto de Elhuyar (Spain) was the first to prepare metallic tungsten (1792); and Louis Nicolas Vauquelin (France) discovered chromium in 1797.

Though chemists of other countries discovered these important metallic elements, British workers have not been idle. Indeed, the work of Robert Boyle, Isaac Newton, Benjamin Huntsman, Abraham Darby, Joseph Priestley, Henry Cort, John Dalton, Humphry Davy, Michael Faraday, David and Robert Mushet, Henry Bessemer, William Siemens, Lowthian Bell, George Snelus, Sidney Thomas, Percy Gilchrist, and others—to say nothing of those belonging to a period nearer to our own times—contributed greatly to the state of chemical and metallurgical knowledge at the middle of last century.

Names of Authors of Early Metallurgical Literature 1546-1880

Notwithstanding all the labours of the pioneers mentioned above, results of which must be judged according to the knowledge and facilities then available, it was not until the decade of 1870 to 1890 that there occurred the great activity and advances in metallurgical science, of which we enjoy the benefits to-day.

The quality of the literature of a particular branch of science generally shows the relative position it occupies in the world, and this is well illustrated by the science of metallurgy.

The author has been fortunate in collecting a library of some three hundred books on metallurgy dating from about A.D. 1400 down to the present time. The following are the names of the chief writers on the subject between 1546 and 1880, that is, a period of over 300 years :—

Agricola..	1546	David Mushet ..	1840
Dud Dudley	1665	Faraday	1842
Sir J. Pettus	1683	Heath	1856
Réaumur	1722	Percy	1861
Swedenborg	1734	Holley	1865
Jars	1774	Whitworth	1866
Bergmann	1778	Kohn	1869
Rinman	1782	Osborn	1869
Cronstedt	1788	Crookes	1870
Berthollet	1789	Rohrig	1870
Vauquelin	1808	Gruner	1872
Karsten	1824	Greenwood	1874
Berzelius	1833	Barba	1875
Berthier..	1834	Ledebur	1877
		Jeans	1880

It will be seen that even as late as 1870, a little more than half a century ago, such literature was meagre indeed, and it can safely be said that hardly any of the books published before 1870 would be of any practical value to-day. There were few books of value on ferrous metallurgy, beyond Percy's admirable treatises and one or two others ; and there were no technical societies in this country or elsewhere dealing with this branch of science until 1869, when the Iron and Steel Institute was founded.

XV. CONCLUSION

In seeking for a note on which to conclude this lengthy, but still inadequate, review of the vast subject of the rise of ferrous metallurgy and the contributions made by Sheffield, the author believes he cannot do better than stress the magnitude of the opportunities still awaiting the younger men.

Often a beginner is rather discouraged by the success of others in the past. With so much discovered, so much accomplished, he asks, what can there be left to do within his capabilities. Actually, all that we know, all that man has done, is little compared with what yet remains to be achieved. The sigh that escaped from Cecil Rhodes at the end of his strenuous life: "So little done, so much to do!" might well be taken as an inspiration to endeavour by those who are now at the commencement of their careers.

If we are inclined at times to think we have reached the height of human knowledge, let us remember the wise words of the late Lord Salisbury: "We live in a small, bright oasis of knowledge, surrounded on all sides by a vast unexplored region of impenetrable mystery, and from age to age the strenuous labour of successive generations wins a small strip from the desert, and pushes forward the boundary of knowledge."

The boundaries of metallurgical knowledge have been pushed far forward during the past fifty years or so, but there is no reason to doubt that the future holds equally remarkable advances in store. How soon they are effected and by whom depends largely on the efforts of the younger men in all parts of the world and specially in the great city of Sheffield.

This city claims, and can justly claim, still to retain its pre-eminence as the leading metallurgical centre for the production of high quality material. All over the world, the name of Sheffield is steels—and the best steels at that. This proud distinction rewards the labours of many generations of craftsmen supplemented in more recent times by the efforts of many distinguished inventors and research workers who have applied every known method and device of science to render that wonderful metal iron, and its derivatives, carbon steels and special alloy steels, yet more extensively serviceable to man. Year by year, research discovery and invention cover a yet wider field and, armed with an ever-increasing store of knowledge and experience, the workers of Sheffield—many of them sons of Sheffield—will no doubt continue to keep our city in the forefront of metallurgical progress.

The successes of the past were won by means far inferior to those now available and in the face of many difficulties that no longer exist. The younger men of today should be encouraged, not dismayed, by all that others have done. Now, as in the past, there is no royal road to knowledge and success. The facilities offered are better than ever before, but patience and assiduity are still essential to their utilisation. Competition from abroad is greater than in the past, in the pursuit of knowledge and discovery no less than in trade and commerce. We of this country freely acknowledge all that has been contributed to the cause of ferrous metallurgy by workers abroad, and we look forward to a continuance of the spirit of international good will and co-operation which has always animated workers in the field of science, without prejudicing that vigorous legitimate competition which is the salt of life and the incentive to further progress.

The writer of this address offers most cordial thanks to those who have helped in its preparation, including Mr. R. E. Neale, Mr. W. J. Dawson, Mr. T. G. Elliot, Mr. S. A. Main, Mr. R. J. Sarjant and Mr. H. Hallatt.

He is also indebted to Messrs. W. H. Smith and Son for the assistance they have given in the production of this address, specially in view of the short time which has been available.

JE RÉPONDS À QUI ME TOUCHE

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SPEECH

by

SIR ROBERT HADFIELD, Bt., F.R.S.,

when proposing the Toast

"THE CITY AND UNIVERSITY OF SHEFFIELD"

at the

BANQUET given by the INDUSTRIALISTS of SHEFFIELD

at the CUTLERS' HALL

on the occasion of

THE VISIT of the IRON AND STEEL INSTITUTE,

September 14th, 1933

SYNOPSIS

I—The TOAST of "THE CITY AND UNIVERSITY OF SHEFFIELD"

I greatly appreciate the honour of being asked to propose the important Toast of "The City and University of Sheffield" both of which corporate Bodies have extended a most hearty welcome to the Iron and Steel Institute as they did when it visited our City in 1905.

As the time allotted to me for my Speech is only some "five minutes", I fear it is hardly possible to do justice to this Toast. However, I will do my best.

First let me say that I cannot think of a more condensed form of speech suited to this short time than by quoting the mottoes of our City and University also of our Cutlers' Company.

II—SHEFFIELD MOTTOES

Mottoes are particularly expressive because they convey the most meaning in the least number of words, and it would indeed be difficult to find better ones than those formulated in our City of Sheffield by its Wise Men of the past.

(1) The Motto of our City with its many centuries of past history is "DEO ADJUVANTE LABOR PROFICIT"—"With God helping labour prospers."

(2) The Motto of our University, now in its twenty-eighth year, is "RERUM COGNOSCERE CAUSAS"—"To find out the real causes of things." This it has certainly done, as is well known to those who have followed its history from the Firth College and Technical School to its present day position. I cannot imagine Sheffield carrying on satisfactorily or, in fact, at all, to-day without our University's aid in its many branches.

(3) The Motto of our ancient Cutlers' Company of Hallamshire, dating from 1624, "POUR Y PARVENIR A BONNE FOI" is "To attain one's aim by good faith." Our present Master Cutler, Colonel A. N. Lee, gave the 304th Cutlers' Feast last year and in this and previous Cutlers' Halls most of the leading political and other representatives of our Empire have made important Speeches at this our "Banquet of the North." For example, at my Feast as Master Cutler in 1899 my chief guest was Lord Lansdowne, just at the time of the outbreak of the Boer War, and at the Dinner I gave in 1905 as President of our Iron and Steel Institute that loyal-hearted Englishman, the late Mr. Bonar Law, eventually Prime Minister of Great Britain, addressed us.

(4) Whilst our Chamber of Commerce has not yet adopted a Motto, it is suggested that the following words might be used as a basis for consideration, namely "Quality always tells," for did not Ruskin consider the Quality of our Sheffield handicraft so high that he left us for ever those precious mementoes now enshrined in our Ruskin Museum, which it is hoped the Members of our Iron and Steel Institute will visit during their stay in our City.

III—"THE CITY OF SHEFFIELD"

The first portion of the Toast with which I am entrusted represents our Town, now the City of Sheffield, which dates back for much more than a thousand years. In the Reform Act of 1832 Sheffield was first given Parliamentary franchise and the Borough was raised to the dignity of a City in 1893. Four years later the title of Lord Mayor was conferred by Royal Charter on the Chief Magistrate. The Town Hall was opened in 1897 by H.M. Queen Victoria during her visit to our City.

Our first Lord Mayor was the Duke of Norfolk, who did so much for Sheffield's progress, educational and civic. We have had 83 Mayors, 38 of these being Lord Mayors.

Sheffield has indeed a remarkable history, for who can forget that about 600 years ago Chaucer in his famous Canterbury Tales spoke of Sheffield "thwytels" or knives, evidently famous in those days as they are now. Thanks to the National Portrait Gallery I have been able to obtain an authentic portrait of this famous and world-renowned poet, Geoffrey Chaucer who is depicted in my Address of Welcome entitled "The Rise of Metallurgy with special reference to Sheffield Discoveries Inventions and Research," with its eleven illustrations and ninety-six portraits, historical and local, relating to many of those of our Institute who have helped to make its work so renowned and famous throughout the world, for we are an International Body, "The International League of Iron and Steel" we might well be termed.

This Address has been presented to those visiting the Works of my Company, and since its publication the Sheffield Reception Committee has asked me to allow them to distribute it more widely on account of its many local as well as other general references. I shall be only too pleased to present a copy to anyone interested in metallurgy who would like to have one and will let me know.

It will be interesting for our Visitors to remember that Mary Queen of Scots (1542-1587) was a prisoner in Sheffield from 1570 to 1584. Those desiring to do so can, if they wish, see the "Turret House" still in existence where Queen Mary often resided whilst under the care of the Earl of Shrewsbury.

Cardinal Wolsey (1471-1530) passed through Sheffield in 1530, in fact, some say he remained here for several weeks, on his memorable but last and fatal journey.

Thanks to the National Portrait Gallery I have been able to present pictures of both of these historic individuals.

There is neither time nor opportunity in this brief Speech to narrate the great deeds which during its existence our City has done. The Empire knows the strenuous and invaluable aid Sheffield rendered during that never-to-be-forgotten period of the Great War, 1914 to 1918, but I am not going to refer to our City's prowess during those memorable four years. I would refer those interested to my Address of Welcome previously mentioned where they will find a brief mention of Sheffield's work.

IV—"THE UNIVERSITY OF SHEFFIELD"

We in Sheffield all know how much we owe and are indebted to the University on all sides whether as regards the "literæ humaniores," "applied science," or other Faculties.

The University of Sheffield was itself founded in 1905, and I well remember being present at the gathering when King Edward VII performed the opening ceremony.

The Coming-of-Age Celebrations of the University which took place in 1926 will not easily be forgotten. It was a great pleasure for me to represent at that gathering twelve scientific and technical Societies who sent their cordial greetings and best wishes for our continued success.

Our first Chancellor was the 15th Duke of Norfolk who reigned over us in that dignified but friendliest of manners from 1905 to 1917, and our present Chancellor is the Right Hon. The Marquess of Crewe, K.G., P.C., to whom we owe a deep debt of gratitude for his admirable services rendered now over nearly sixteen years.

The Vice-Chancellors have been:

Dr. W. M. Hicks, F.R.S.	1905
Sir Charles Eliot	1905-1912
Dr. H. A. L. Fisher, F.R.S.	1912-1916
Dr. W. Ripper, F.R.S.	1917-1919
Sir W. H. Hadow	1919-1930

Its present distinguished Head, who has already rendered splendid service to our City and University, is Dr. A. W. Pickard-Cambridge, M.A. We wish him every success in this honourable and important position, for has he not in his hands the destinies and control of our educational advancement which counts for so much in the future of our nation.

The foundation of Sheffield's modern educational system with its advantages for every citizen without distinction of any kind may be said to have commenced through the great generosity of the late Mr. Mark Firth, who enabled our first educational centre, Firth College, to be built, and in this he was ably assisted by the late Sir Henry Stephenson. We now look back and see how small seem to have been the facilities which that College then offered. Nevertheless it was the beginning of better and greater things. Then followed the Technical School in the foundation of which the late Sir Frederick Thorpe Mappin, M.P., played such a prominent part, and finally, the University itself in 1905 with its Faculty of Applied Science, including Metallurgy, Engineering and other branches. The University has made for itself a name of no mean fame throughout the world. For example, through its teaching of Metallurgical Science and its cognate branches important services have been rendered not only to our own Empire, but internationally. Its assistance has indeed been of inestimable value to our City, in fact for those of us who can look back nearly half a century it is a wonder how we got on at all without its guidance.

It is not necessary for me further to sound the praises of the University, for its work is so well known, nor is there time on such an occasion as the present. I have, however, in the Address of Welcome before mentioned endeavoured to show, both verbally and by actual portraits delineating the individuals themselves—alas many of them gone from us—who have carried out the great work to which I have alluded, how much Sheffield has done in the past and also since the establishment of the University in our midst.

DEGREES IN FOUNDRY SCIENCE.

I should like to add one word more, namely, that it is to be hoped the ambition of our present able and energetic Professor of Metallurgy, Professor J. H. Andrew, D.Sc., will be realised, that is with regard to the establishment of a Founding Course in the Faculty of Metallurgy with degrees in Foundry Science for those who qualify.

A successful student would be known as a Bachelor, Master, or Doctor in Metallurgy, the word "Founding" being inserted in brackets after the Degree.

I have special sympathy with any effort which is made to raise the status, and this will be one of the objects of this Degree, of the Foundryman, whether dealing with either ferrous or non-ferrous products. This individual has been overlooked far too long and deserves his place "in the sun," that is, in the technical world. I may add that the National Union of Foundry Workers, representing tens of thousands of Moulders of Great Britain, have expressed every sympathy and approval with the present proposal to increase the dignity, usefulness and efficiency of this branch of human labour.

V—WOMEN METALLURGISTS

In these days of increased political privilege the fact should not be overlooked that Metallurgy has amongst its devotees those of the fair sex known as Women Metallurgists.

They have shown the greatest interest in this branch of Science, and amongst their distinguished representatives may be mentioned Miss Elam, who worked under Sir Harold Carpenter; and Dr. Miss Marie Gayler, under Dr. W. Rosenhain; Mrs. Shaw Scott; Miss A. K. Osborn; Miss Olive Priest, and many others in the thousands of laboratories at home and abroad.

VI—SHEFFIELD TECHNICAL SCHOOL and the PRIZE DISTRIBUTION in 1899

Before I sit down there is a little personal incident to which I should like to refer, and I feel sure my reference will meet with your approval as it concerns two of our Members here to-night.

On the evening of November 20th, 1899, that is nearly thirty-four years ago, when I was Master Cutler of Sheffield, I was asked to make a Speech and distribute the prizes in connection with what was then known as the Sheffield Technical School.

There was in the Chair my friend the late Dr. H. Clifton Sorby, F.R.S., as we all know a scientist of great repute and a metallurgist too, for he undoubtedly founded that branch of Science known as Metallography which is so important in the study of ferrous and non-ferrous metals. We Sheffield men are justly proud of him. Another famous citizen who did so much for scientific and technical education and present on that occasion was my old friend, the late Sir Frederick Thorpe Mappin, M.P.

Now as I have said, when I look back no less than thirty-four years I find that two of the prizes I then distributed were even after this long lapse of time to two Members of special interest to us this evening. The first was to Mr. W. J. Dawson, a prominent Member of our Iron and Steel Institute and serving on several of its important Committees and who now occupies the honourable position as one of my colleagues on the Board of Directors of my Company, Messrs. Hadfields Ltd. of this City; the other prize was to Dr. W. H. Hatfield, D.Met., Chairman of the present Reception Committee, a Member of our Council, also of many of its important Committees, and recipient this year of that honourable award the Bessemer Medal, the blue riband of Metallurgy. These two early awards show how coming events cast their shadows before them.

VII—GOLF

Whilst the Council of the Iron and Steel Institute with its staff organisation is almost a perfect Body, I am not going to conclude these remarks of mine without touching upon one very important subject, and it represents the only fault I can find with its work, that is, whilst devoting its attention to that noble branch of Science known as Metallurgy, it has paid little or no attention to that other noble branch of Physical Science and Art known as GOLF.

I believe that I shall have the acquiescence of many of our members now here that we ought to have an Iron and Steel Institute Golfing Association, or if that is too much to expect then as I happen to be President of the Engineering Golfing Society of London with its large membership I need hardly say how pleased that Body would be to welcome an accession of Metallurgists as Members, specially in the order of those of the "plus ones" calibre. In saying this I do not mean that we should not be glad to have as members those whose qualifications and handicaps do not quite come within the class I have mentioned!

My own impression is that out of this suggestion may probably arise some great golfer with prowess in Golf equal to that in Metallurgy of a Bessemer and a Siemens or other of our great past men, also possessing sufficient capabilities to wrest the prize of the golf champion of the world from our American friends. Whilst our Institute is cosmopolitan, we would much rather that this championship remained in Great Britain from which the game first sprang.

Does not this Institute make the finest rustless steel for the clubs used in this "noble game," and should not the users of the said clubs show an equally unrivalled prowess and quality in the game itself equal to the quality of the steel from which their clubs were made.

I throw this out as a suggestion to our Council and to our new and accomplished Secretary. Although I have not had a talk with him, I feel sure that he has a golfing look in his eye.

In conclusion, if it would be any inducement, I should be very pleased to offer a silver cup to be competed for not necessarily every year, but shall we say bi-annually or triennially, for the best golfer of the Iron and Steel Institute.

VIII—REFERENCE by RUDYARD KIPLING to IRON, and CONCLUSION

I will conclude my remarks by quoting a few words from one of if not our greatest living poet, Rudyard Kipling. I have specially chosen Kipling because the Metallurgist and the Engineer find in his wonderful poetical contributions many undying tributes to their activities and the spirit which animates them. Surely no engineer can read "M'Andrew's Hymn" unmoved, and in "Rewards and Fairies" the metallurgist will turn again and again to "Cold Iron."

In a recent personal letter to the author, Mr. Rudyard Kipling gave his kind permission to reproduce from this poem and also added the following interesting words: "I suppose the mystery and the changing forms of Iron must have been one of the first of the mysteries to Early Man—quite apart from the fact that the Iron blade—sword or spear—made him Master of the Beasts and his neighbours."

Finally, let me use Kipling's words with regard to that wonderful metal Iron, in my humble opinion the most wonderful of all metals, where he says in words which burn like fire:

> "*Gold is for the mistress—silver for the maid!*
> *Copper for the craftsman cunning at his trade.*
> Good !, said the Baron, sitting in his hall,
> 'But Iron—Cold Iron—is master of them all !"

PRESS REFERENCES

regarding

The GIFT of SIR ROBERT HADFIELD, Bt., F.R.S.,

to

The SHEFFIELD UNIVERSITY

in COMMEMORATION of the

VISITS of the IRON and STEEL INSTITUTE

to SHEFFIELD

in 1905 and 1933

[Reprinted from *Daily Independent*, Sheffield, 12 Sept., 1933]

£5,000 GIFT.

SIR ROBERT HADFIELD'S LETTER.

Sir Robert Hadfield announced his intention of presenting £5,000 to Sheffield University in the following letter to the Vice-Chancellor :—

Parkhead House,
Sheffield.
September 11*th*, 1933.

Dear Dr. Pickard-Cambridge,

I thought with your approval I should like to present the enclosed cheque for £5,000 to our University in commemoration of the visit of the Iron and Steel Institute to Sheffield in 1905, when I was President, and now on the occasion of the present visit during the Presidency of my friend, Mr. W. R. Lysaght, C.B.E., who through ill-health we so much regret not to have with us.

Although I leave the application and distribution of such sum entirely to the Senate, including the Applied Science Committee of that Body, naturally I should be glad to see the amount employed in some way on behalf of advancing metallurgical knowledge.

I have, for example, great sympathy with and fully approve of the proposals of the present Professor of Metallurgy, Dr. J. H. Andrew, with regard to the establishment of a Founding Course in the Faculty of Metallurgy. Perhaps the sum I present might form a nucleus for this special purpose.

Nevertheless, as I have already said, the matter is one entirely for yourself and the Senate finally to decide.

With best wishes,

Yours sincerely,
R. A. Hadfield.

The Vice-Chancellor of the Sheffield University
(Dr. A. W. Pickard-Cambridge, M.A.).

ACKNOWLEDGMENT BY THE VICE-CHANCELLOR.

The University, Sheffield,
September 11*th*, 1933.

Dear Sir Robert,

I cannot thank you enough and I will not try to do so at this moment, as I hope to see you during the week.

But your gift is the greatest possible encouragement to all of us who are trying to make the University more useful, and I have very little doubt that it will be used to further Professor Andrew's scheme, upon which the University will have to decide next term.

Yours very sincerely,
A. W. Pickard-Cambridge,
Vice-Chancellor of the Sheffield University.

[REPRINTED FROM *The Times*, 12 SEPT., 1933.]

GIFT TO SHEFFIELD UNIVERSITY.

Sir Robert Hadfield yesterday made a gift of £5,000 to the University of Sheffield in commemoration of the visit of the Iron and Steel Institute to Sheffield in 1905, when he was President, and of the coming visit of the Institute to Sheffield this month. He hopes that the money will be used for the advancement of metallurgical knowledge.

Sir Robert Hadfield, who is a Doctor of Metallurgy of Sheffield University, built and equipped one of the metallurgical research laboratories at the Applied Science Department of the University.

[REPRINTED FROM *Yorkshire Telegraph & Star*, 11 SEPT., 1933.]

£5,000 GIFT TO UNIVERSITY.

Sir ROBERT HADFIELD'S GENEROSITY

SHEFFIELD RESEARCH.

Sir Robert Hadfield, Bt., to-day made a gift of £5,000 to the University of Sheffield.

Mr. W. M. Gibbons, Registrar of the University, communicating the news to the *Star,* said Sir Robert had indicated that his gifts were in commemoration of the visit of the Iron and Steel Institute to Sheffield in 1905, when he was President, and of the coming visit of the Institute when his friend, Mr. W. R. Lysaght, C.B.E., will be President.

So far as the allocation of the £5,000 is concerned, Sir Robert has expressed a preference in favour of the money being used for the advancement of metallurgical knowledge.

The fact of the generous gift will be communicated to the Council of the University at the next meeting, and there is no doubt, states Mr. Gibbons, that the Council will honour Sir Robert's wishes.

SUPPORTER OF UNIVERSITY.

Right from the beginning Sir Robert Hadfield has been an ardent supporter of the University's Metallurgical Department.

Despite his great personal activity and business, he has consistently kept in touch with the University's work and is a member of the University Council.

In no part of the University's activities has he been more interested than in the metallurgical department.

Sir Robert is a Doctor of Metallurgy of Sheffield University and he built and equipped one of the metallurgical research laboratories at the Applied Science Department.

He opened this in 1926, the ceremony marking the coming of age of the University.

His industrial success and the fame of the firm of Hadfields, Ltd., have been established to a large extent through research, and Sir Robert's own work is well known and fully recognised. He is a Fellow of the Royal Society.

[REPRINTED FROM *Sheffield Daily Telegraph*, 12 SEPT., 1933.]

£5,000 GIFT.

Sir Robert Hadfield's Help for Sheffield University.

METALLURGY TO BENEFIT.

A gift of £5,000 has been made to the University of Sheffield by Sir Robert Hadfield, Bt., head of the famous Sheffield steel firm of Hadfields, Ltd., and it is suggested that the money will be utilised for the advancement of metallurgical knowledge.

In a letter accompanying the cheque for £5,000, Sir Robert indicated that his gift was made in commemoration of two visits to Sheffield by the Iron and Steel Institute—the first in 1905 when Sir Robert himself was President, and the second visit opening to-day when Sir Robert's friend, Mr. W. R. Lysaght, C.B.E., is President.

At the next meeting of the University Council the gift will be formally received, and Mr. W. M. Gibbons (Registrar of the University) said yesterday that there was no doubt that the Council would honour Sir Robert's wishes in regard to the allocation of the money.

AN APPROPRIATE GESTURE.

Two facts make Sir Robert's generosity specially appropriate. The first is the coincidence of the visit of the Iron and Steel Institute, members of which will visit the Hadfields works on Thursday next, and the second is the great interest which Sir Robert has always displayed in the University's Metallurgical Department.

Himself an inventor and research worker of considerable reputation, he has always found time to maintain his interest in similar work at the Sheffield University. Indeed, he built one of the metallurgical research laboratories at the Applied Science Department and opened it in 1926 to mark the coming-of-age of the University. He holds the honorary degree of Doctor of Metallurgy of Sheffield University.

His industrial success and the fame of the firm of Hadfields, Ltd., Sheffield, have been established to a large extent through research, and Sir Robert (who is a Fellow of the Royal Society) is a distinguished scientist.

A FOUNDRY COURSE.

On a recent occasion he expressed warm approval of suggestions made by the Sheffield University Professor of Metallurgy (Dr. J. H. Andrew) in regard to the establishment of a course for foundry workers, within the Faculty of Metallurgy, and it is possible that the money may be used for some such purpose.

This is by no means the first time that his generosity has benefited the community. He has made other gifts to the Firth College, the Applied Science Department, and to other local institutions. To the Cutlers' Company he gave a special silver loving cup.

During the war his generosity was in line with his patriotism. He contributed £10,000 to the Prince of Wales' National War Fund, and during the whole of the war period he maintained at Wimereux a private hospital which was managed by Lady Hadfield, C.B.E., and through which 16,000 cases passed at an average cost of about £5 per individual patient. Also he made a gift of hospital equipment to the St. Louis Hospital, Boulogne.

Special gifts have also been made by Sir Robert to the Royal Society and the Royal Institution.

[EXTRACT FROM *Current Topics* OF THE *Sheffield Daily Telegraph*, 12 SEPT., 1933.]

As many as twenty-eight years have passed since the Iron and Steel Institute held its last conference in Sheffield. This seems a long time of absence from the city that has been so often called the steel metropolis. One has, necessarily, to deduct the war years, during which the iron and steel experts were very busy, but did not read papers in public about their discoveries. They left these to be demonstrated in action.

If the absence has been long, the return is all the more welcome, particularly as it comes at a time when Sheffield industry is asserting itself afresh. There have been years of difficulty and depression during which the industry struggled manfully, and as events have proved successfully, to hold its head up and be ready for the turn of the tide. We believe the tide is turning now; as yet progress is slow, but there are plain signs that progress is being made.

A pleasant and generous way of honouring the occasion has been taken by Sir Robert Hadfield, who was President of the Institute when it was last here in 1905, with his gift of £5,000 to the University of Sheffield. The University has rendered great assistance to the city's industry, and Sir Robert, by his gift, has given this aid a handsome recognition.

[REPRINTED FROM *Daily Independent*, SHEFFIELD, 12 SEPT., 1933]

£5,000 FOR UNIVERSITY.

GIFT BY SIR ROBERT HADFIELD.

A gift of £5,000 was made by Sir Robert Hadfield to Sheffield University yesterday to commemorate the visit of the Iron and Steel Institute to Sheffield for its Autumn Meetings this week.

Sir Robert was President of the Institute in 1905, and the gift is made partly because of his close association with the Institute and partly because of his friendship with Mr. W. R. Lysaght, C.B.E., who is President of the Institute this year.

Mr. W. M. Gibbons, the Registrar of the University, told the *Daily Independent* yesterday that Sir Robert had expressed a preference for the money to be devoted to the advancement of metallurgical knowledge, and that there was no doubt that the Council of the University would accede to his wish.

It is natural that Sir Robert, who is one of the foremost metallurgists of the age, should from the earliest days of the University have taken the keenest interest in the metallurgical side of the Applied Science Department.

Full though his life has been with all manner of activities, Sir Robert has always maintained a close personal association with the University's work, and he is a member of the University Council.

Such has been his interest in the Department of Metallurgy that for the coming-of-age celebrations of the University he built and equipped one of the metallurgical research laboratories at the Applied Science Department. He declared this open in 1926.

Sir Robert holds the degree of Doctor of Metallurgy of Sheffield University, and he has been honoured by scientific societies in all parts of the world for his work in connection with iron and steel, which has been of world-wide importance.

SUCCESS WHEN YOUNG.

When quite a young man he obtained a foremost position among engineering and metallurgical pioneers, and while he built up the firm of Hadfields Ltd., he was most generous in the way in which he shared the results of his important research work with learned societies.

Sir Robert is a former Master Cutler of Sheffield and he succeeded Mr. Andrew Carnegie as President of the Iron and

Steel Institute in 1905. He is a Fellow of the Royal Society, and has had degrees and honours conferred upon him by several Universities in this country and by many learned societies on the Continent and in America.

Sir Robert has made numerous gifts to various objects apart from his generosity to the University.

WAR-TIME GIFTS.

Notable among them are gifts during the war. He gave £10,000 to the Prince of Wales' Fund; the hospital at Wimereux, which was managed by Lady Hadfield, treated 16,000 cases at a cost of roughly £5 each; and he presented a hospital equipment to the St. Louis Hospital, Boulogne.

In addition, Sir Robert has made gifts to the Royal Society, the Royal Institution, and a special loving cup to the Cutlers' Company, besides political and local gifts.

[EXTRACT FROM *General Topics* OF THE *Daily Independent*, SHEFFIELD, 12 SEPT., 1933.]

AN AID TO METALLURGY.

The country as a whole, and Sheffield in particular, has had many reasons to be grateful to Sir Robert Hadfield. His personal assistance and his monetary gifts have been largely responsible for the inception and progress of many good works. To-day we announce another instance of this in the allocation of £5,000 to the Sheffield University, to commemorate the visits of the Iron and Steel Institute to Sheffield in 1905 and now this week.

It is stated that Sir Robert has expressed a preference in favour of the money being used for the advancement of metallurgical knowledge. I believe that he has been particularly anxious to improve the status of a certain section of iron and steel workers, but whether this munificent gift can be used to further general study and research in that direction I do not know.

One thing is certain—that the University can make very good use of the money. Although there are some who feel that a little too much stress is laid on theorising in connection with Sheffield's own industries compared with the practical side, there is no doubt that the University has been an admirable assistant to industry in many ways. Many of the things that might have been accomplished, however, have not been done because of the need for financial stringency. Sir Robert Hadfield has been aware of this need for assistance, and his giving of this large sum in such times of depression surely makes it twice as valuable.

[REPRINTED FROM *Yorkshire Telegraph & Star*, 12 SEPT., 1933.]

A FINE GIFT.

In order to mark the visit of the Iron and Steel Institute to Sheffield and a former visit in 1905, Sir Robert Hadfield (as we announced last night) made the handsome gift of £5,000 to the University of Sheffield, with the expression of the wish that the money should be utilised for the advancement of metallurgical knowledge. Sir Robert has contributed a great deal more than money for this object, for he himself is a metallurgist of very high capacity. The handbook issued by the Iron and Steel Institute pays a high tribute to Sir Robert Hadfield's original researches in the early 'Eighties when the field of alloy steels was practically unexplored. "These researches (it says) bore fruit in the discovery and invention of Manganese steel, which remains to-day the supreme material for resisting abrasion, also of Silicon steel . . . . and many other valuable and useful alloy steels." The conditions of modern industry have changed substantially since the days when great enterprises in the manufacture of iron and steel were founded by men who themselves had made important discoveries. Sir Robert Hadfield's name will be remembered in connection with those of Benjamin Huntsman, Sir Henry Bessemer, Sir John Brown, and other pioneers in metallurgy. His gift will act as a practical inspiration.

[Reprinted from *Sheffield Daily Telegraph*, 14 Sept, 1933.]

LORD MAYOR'S WELCOME.

The Lord Mayor of Sheffield (Alderman Ernest Wilson), who was accompanied by the Lady Mayoress, in his address at the opening business meeting in the Mappin Hall of the Applied Science Department of the University, said Sheffield welcomed the members and offered whole-heartedly its support to make the meetings memorable.

"Sheffield is the chief centre of the special steel industry of this country, and the Institute's sessions are being held within the precincts of the University which we regard as the principal centre of metallurgical research work and the training of those who intend to follow the metallurgists' profession," said the Lord Mayor.

The Institute's members numbered 2,000, and he understood that 30 per cent. of them were overseas, 17 foreign countries being represented. These facts created the advantage that the Institute's proceedings were continually enriched by contributions of scientific and technical character presented by metallurgists in other countries.

The Institute also carried on important research work in association with the National Association of Iron and Steel Manufacturers, and the Department of Scientific and Industrial Research.

Sir Robert Hadfield's £5,000 Gift.

When the Institute last met in Sheffield (in 1905) it was under the presidency of Mr. (now Sir) Robert Hadfield, and the Lord Mayor proceeded to refer to Sir Robert's recent magnificent gift of £5,000 to the Sheffield University. This, he said, was further evidence of the love of Sir Robert for his native city.

"Let it not be forgotten that, although Sir Robert's reputation is world-wide, Sheffield claims the distinction and honour of being his birth-place," said the Lord Mayor.

The VICE-CHANCELLOR'S WELCOME.

Giving a welcome on behalf of the University, Dr. A. W. Pickard-Cambridge (Vice-Chancellor) said the University always welcomed contact with those engaged in the practical application of the principles studied in the University.

"We are anxious to do all we can to strengthen the bonds between the studies of this University and the profession you represent," said the Vice-Chancellor. "We have received the very greatest encouragement from the noble gift of Sir Robert Hadfield, who is here to-day both as host (for he is a member of the University Council) and as a guest (being a member of the Institute).

University and Industry.

"Throughout his life he has represented both the theoretical and practical sides in the best possible way. We value his gift not merely for the greatness of his munificence, but, above all, because it gives us real encouragement and hope that we are working on the right lines. We are sure that one in his position would not have given us this fine help—both on this and earlier occasions—if we were not trying to do some of the things we ought to be doing, and it will enable us to proceed to further experiments in the development of metallurgy such as ought to be tried in a University."

Dr. Pickard-Cambridge proceeded to refer to the University's work in training persons for technical posts and research, mentioning also that research into metallurgical problems was always being made within the University.

The University also tried to help industry by carrying on an almost continuous consulting practice, much time being spent in dealing with problems of persons who consulted them.

[Reprinted from *Daily Independent*, Sheffield, 14 Sept.,1933]

THE CHAIRMAN'S REPLY.

In addition to other remarks, Sir Harold Carpenter, F.R.S., the Deputy President of the Iron and Steel Institute, replying, said he was present as a young man at the 1905 meeting of the Institute in Sheffield, which was his first introduction to such great Sheffield men as Mr. John Devonshire Ellis (father of Sir William Ellis) and the world-famous Dr. Sorby. Sir Robert, then Mr. Hadfield, presided, and he wished to express his indebtedness to the inspiration he received as a young worker from that meeting.

Speaking of the advances made since the Institute last met in Sheffield, Sir Harold said that engineering science and practice were just as successful as the available materials would allow, and the great advances in engineering in the last 28 years had depended ultimately on the improvement in quality of the metals and the range of their properties.

[Reprinted from *Sheffield Daily Telegraph*, 16 Sept., 1933.]

HELP TO UNIVERSITY.

ENCOURAGEMENT OF GIFT OF SIR ROBERT HADFIELD.

Sir Robert Hadfield's gift of £5,000 to the University of Sheffield has aroused great interest and appreciation.

In the course of a letter of thanks to Sir Robert, the Vice-Chancellor (Dr. A. W. Pickard-Cambridge) has stated that the gift is "the greatest possible encouragement to all of us who are trying to make the University more useful, and I have very little doubt that it will be used to further Professor Andrew's scheme, upon which the University will have to decide next term."

Dr. Pickard-Cambridge's letter referred to a mention made in Sir Robert's letter accompanying the gift in which he said he had great sympathy with the proposals of Professor Andrew "with regard to the establishment of a founding course in the Faculty of Metallurgy."

Sir Robert added, "Perhaps the sum I present might form a nucleus for this special purpose. Nevertheless the matter is one entirely for yourself and the Senate finally to decide."

[REPRINTED FROM *Daily Independent*, SHEFFIELD, 16 SEPT., 1933]

FOUNDRY COURSE.

Possible Use of £5,000 Gift to University.

The gift of £5,000 which Sir Robert Hadfield has made to the University of Sheffield to commemorate the visit of the Iron and Steel Institute to Sheffield may be devoted to a new scheme for giving courses in foundry work at the University.

An indication of this is given in a letter which Dr. A. W. Pickard-Cambridge, the Vice-Chancellor of the University, has sent to Sir Robert Hadfield, in which he says:

> "I cannot thank you enough and I will not try to do so at this moment, as I hope to see you during the week. But your gift is the greatest possible encouragement to all of us who are trying to make the University more useful, and I have very little doubt that it will be used to further Professor Andrew's scheme upon which the University will have to decide next term."

Professor J. H. Andrew is Dean of the Faculty of Metallurgy at the University, and the *Daily Independent* understands that a new course of instruction in foundry work has been formulated by Professor Andrew, but the details are not yet complete.

Sir Robert Hadfield, when making the gift, expressed the hope that the money would be devoted to the advancement of metallurgical knowledge.

[Reprinted from *Engineering*, 15 Sept., 1933.]

THE ENDOWMENT OF METALLURGICAL RESEARCH AT SHEFFIELD.

Considering its association with the industry of that city, it is a little surprising to be informed that it is twenty-eight years since the Iron and Steel Institute held a meeting in Sheffield. The President on that occasion was Sir Robert Hadfield, Bt., and partly to mark the return of the Institute, partly because of his association with it, and partly because of his friendship with Mr. W. R. Lysaght, C.B.E., who is now President, but is unfortunately unable to attend the meeting, Sir Robert has made a gift of £5,000 to the University, with the suggestion that it should be utilised for the advancement of metallurgical knowledge, and especially that it might form the nucleus of a fund for the establishment of a course in Founding. Sir Robert is, of course, himself a notable research worker, and holds the degree of Doctor of Metallurgy in Sheffield University, in addition to many other honours. Moreover, it is not the first time that his munificence has been displayed in a similar way, for only a few years ago he built a laboratory for the Metallurgical Department on the occasion of the coming-of-age celebrations of the University. The staple industry of the City of Sheffield has, from time to time, received considerable assistance from the work done in the University, and we are probably not incorrect in supposing that Sir Robert's gift is some recognition of that fact. It is satisfactory to realise that the days of generous endowments are not yet past, and we hope others will not be slow to follow this most recent example.

Metallurgical Research.—Sir Robert Hadfield's gift of £5,000 to Sheffield University, preferably for the encouragement of metallurgical research, happily coincides with the autumnal meeting of the Iron and Steel Institute. For this meeting, metallurgists and research workers from all parts of the country are expected to arrive in Sheffield to-night. A reception has been arranged at the University Department of Applied Science. Technical papers are to be submitted at business meetings to be held to-morrow and Thursday, and numerous visits have been arranged to representative iron and steel works in and around Sheffield. Sir Robert's interest in this form of research is well known. One of the University's laboratories was built and equipped by him. He owes much of his industrial success to scientific work, which has received fitting acknowledgment in Sheffield and over a wide sphere.

[REPRINTED FROM *Nature*, 16 SEPT., 1933.]

GIFT TO THE UNIVERSITY OF SHEFFIELD.

Sir Robert Hadfield, as head of the firm of Hadfields, Ltd., and by his generosity to the University of Sheffield, for which some years ago he built and equipped a metallurgical research laboratory for the Department of Applied Science, is well known to the citizens of Sheffield. He has now placed them still further in his debt by a gift of £5,000 to the University, expressing the hope that it may form a nucleus for the establishment of a course in founding in the Faculty of Metallurgy. Sir Robert was President of the Iron and Steel Institute when it visited Sheffield in 1905, and now, after an interval of twenty-eight years, the Institute has again held its autumn meeting at Sheffield, the President being a friend of Sir Robert's, Mr. W. R. Lysaght, C.B.E., who was unfortunately prevented by ill-health from attending. It is to mark these two visits that Sir Robert has made this generous gift to the University. The steel industry of to-day still centred at Sheffield, owes much to metallurgical research in which the universities have played their part, and Sir Robert's benefactions to the University of Sheffield are a fitting recognition of this debt and at the same time a gesture for the encouragement of so-called academic research.

Reprinted from "Yorkshire Telegraph & Star," September 18th, 1933.

EFFORT TO RAISE THE STATUS OF METALLURGICAL AND FOUNDRY WORKERS.

Sir Robert Hadfield's Support of University Degrees: Cup Inducement to Form Iron and Steel Institute Golf Club.

SIR ROBERT HADFIELD, the well-known Sheffield industrialist, in his speech at the Iron and Steel Institute banquet, suggested that the Sheffield Chamber of Commerce, like the city itself, the University, and the Cutlers' Company, should adopt a motto. He mentioned the words, "Quality always tells" as a basis for consideration. Ruskin, he said, regarded the quality of Sheffield handicraft so highly that he left for ever those precious mementoes now enshrined in the Ruskin Museum.

Sir Robert, who was proposing the toast of "The City and University of Sheffield," said that the University had made for itself a name of no mean fame throughout the world. For example, through its teaching of metallurgical science and its cognate branches, important services had been rendered not only to the British Empire but internationally. Its assistance had, indeed, been of inestimable value to the city.

It was to be hoped that the ambition of their present able and energetic professor of metallurgy, Professor J. H. Andrew, D.Sc., with regard to the establishment of a founding course in the Faculty of Metallurgy, with degrees in Foundry Science for those who qualified, would be realised. A successful student would be known as a bachelor, master, or doctor in metallurgy, the word "Founding" being inserted in brackets after the degree.

He had every sympathy with every effort made to raise the status—and this would be one of the objects of the degree—of the foundryman, whether dealing with either ferrous or non-ferrous products. This individual had been overlooked far too long, and deserved his place "in the sun"—that was, in the technical world.

The National Union of Foundry Workers, representing tens of thousands of moulders in Great Britain, had expressed every sympathy and approval with the present proposal to increase the dignity, usefulness, and efficiency of this branch of human labour.

In a reference to women metallurgists, Sir Robert said that in these days of increased political privilege the fact should not be overlooked that metallurgy had amongst its devotees members of the fair sex. They had shown the greatest interest in this branch of science, and amongst their distinguished reprsentatives might be mentioned Miss Elam, who worked under Sir Harold Carpenter; Dr. Miss Marie Gayler, under Dr. W. Rosenhain; Mrs. Shaw Scott; Miss A. K. Osborn; Miss Olive Priest, and many others in the thousands of laboratories at home and abroad.

CITY "LIGHTS" IN 1899.

On a personal note, Sir Robert recalled the evening of November 20th, 1899, when, as Master Cutler, he made a speech and distributed the prizes in connection with what was then known as the Sheffield Technical School. The chairman on that occasion was his friend, the late Dr. H. Clifton Sorby, F.R.S., as they all know, a scientist of great repute and a metallurgist, too, for he undoubtedly founded that branch of science known as metallography, which was so important in the study of ferrous and non-ferrous metals. Sheffield was justly proud of him.

Another famous citizen who did so much for scientific and technical education, and who was present on that occasion, was his old friend, the late Sir Frederick Thorpe Mappin, M.P.

Looking back no fewer than 34 years, he found that two of the prizes he then distributed were to two members of special interest at the present time. The first, in order on the prize list, was to Mr. W. J. Dawson, a prominent member of the Iron and Steel Institute, and serving on several of its important committees, and who now occupied the honourable position as one of his colleagues on the Board of Directors of his company, Messrs. Hadfields, Ltd., Sheffield.

The other prize was to Dr. W. H. Hatfield, D.Met., chairman of the Reception Committee for the Institute's Visit to Sheffield, a member of the Institute Council and many of its important committees, and recipient this year of that honourable award, the Bessemer Medal, the Blue Riband of metallurgy. Those two early awards showed how coming events cast their shadows before them.

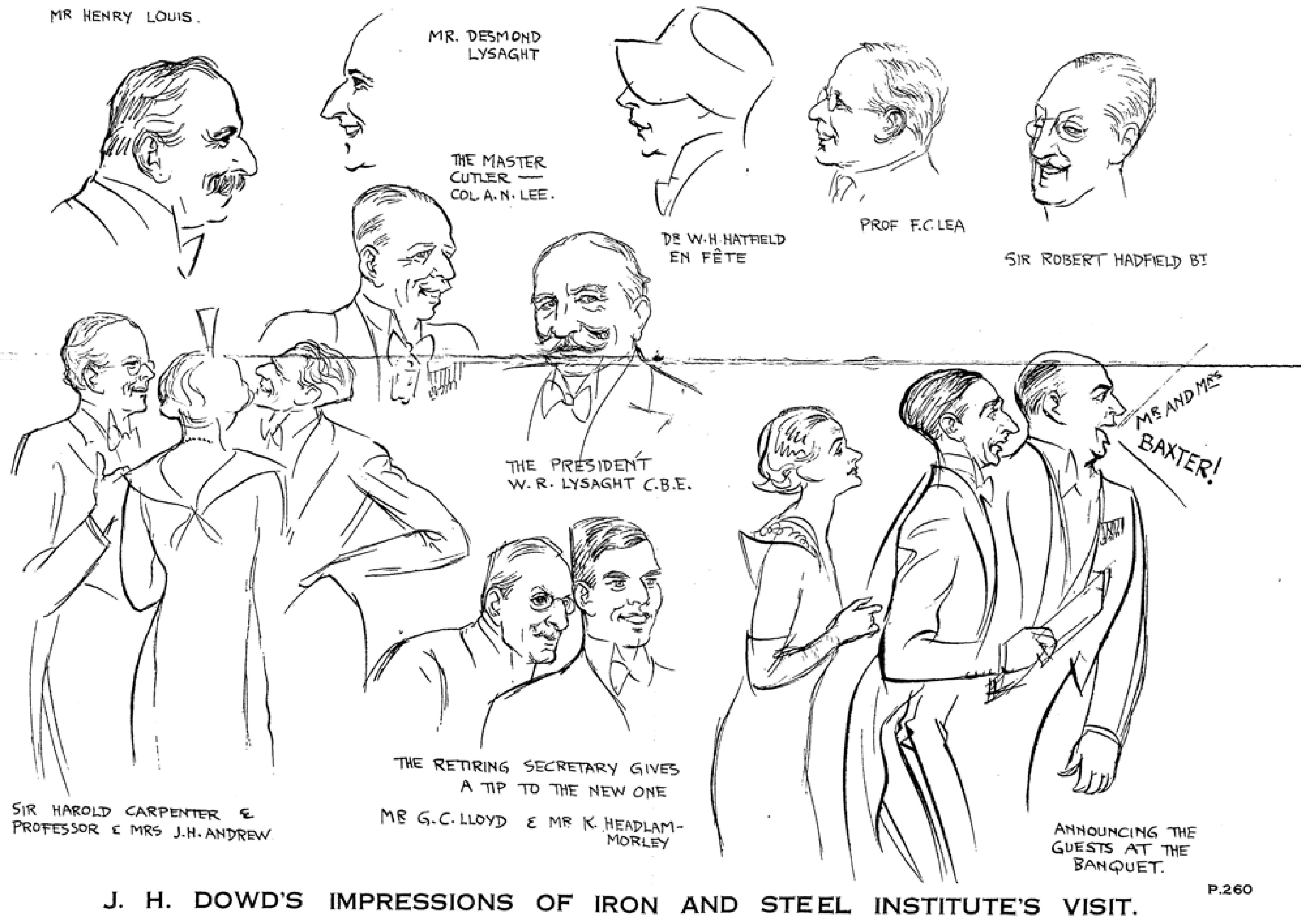
ENCOURAGEMENT OF GOLF AS RELIEF.

In further remarks, Sir Robert said that while the Council of the Institute, with its staff organisation was almost a perfect body, and devoted its attention to that noble branch of science known as metallurgy, it paid little or no attention to the sporting side of life, and he suggested the formation of an Iron and Steel Institute Golfing Association.

If that was too much to expect then he, who happened to be President of the Engineering Golfing Society of London, with its large membership, need hardly say how pleased that body would be to welcome an accession of metallurgists as members. He threw the suggestion out to the Council and the new secretary. If it would be any inducement, he would be very pleased to offer a silver cup to be competed for, not necessarily every year, but bi-annually or triennially, for the best golfer of the Iron and Steel Institute.

In conclusion, Sir Robert, with the permission of Mr. Rudyard Kipling, quoted from the latter's poem "Cold Iron," as follows:

"Gold is for the mistress, silver for the maid;
Copper for the craftsman cunning at his trade.
'Good! said the baron, sitting in his hall,
'But iron—cold iron—is master of them all.'"



J. H. DOWD'S IMPRESSIONS OF IRON AND STEEL INSTITUTE'S VISIT.