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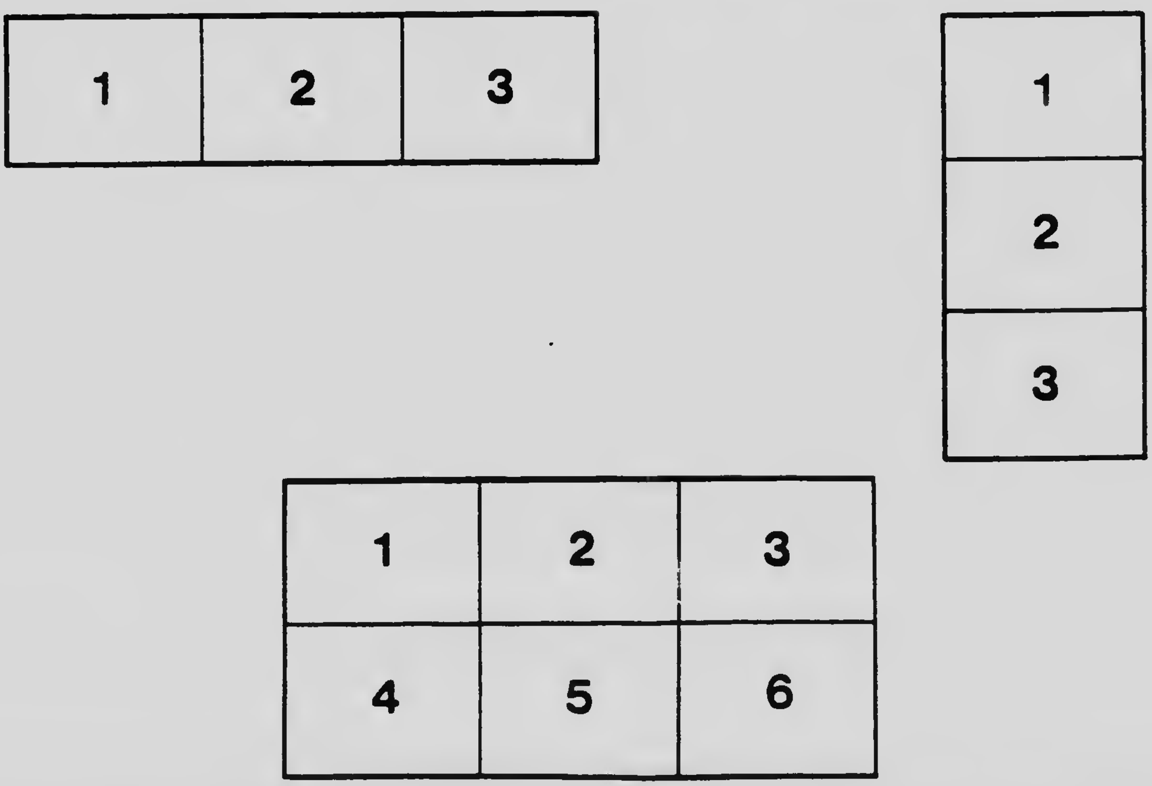
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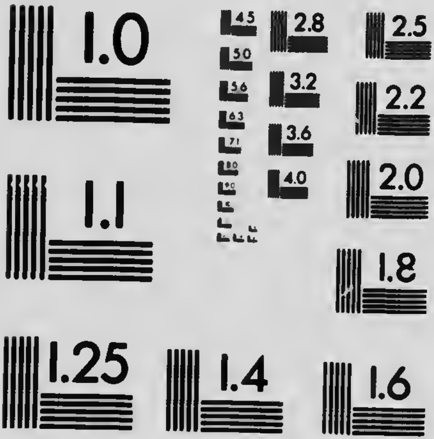

OXFORD PAMPHLETS
1914–1915

BRITISH & GERMAN STEEL METALLURGY

BY

J. O. ARNOLD, F.R.S.
PROFESSOR OF METALLURGY IN THE UNIVERSITY
OF SHEFFIELD

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BRITISH AND GERMAN STEEL METALLURGY

In *The Times* of January 23, 1915, there appeared the following paragraph :

Civilization and 'Kultur'

Professor Rein, of the University of Vienna, in an article on 'Germany's Unpopularity', offers the following definition of *Kultur* :

> We Germans distinguish between civilization and *Kultur*. By civilization we mean the work which embraces the control of nature for the raising and perfection of external conditions of life. By *Kultur* we mean the efforts directed towards the organization of a people's life, in which the highest ideals of religion, morality, art, and science are to come to realization. Here the human will is directed towards the most difficult and deepest problems of humanity. A people which is satisfied with mere civilization is no *Kultur* people. In the intellectual sphere the Germans have acquired a leading part in deeds which benefit humanity. The superiority constituted by this fact is, it seems, inconvenient for many peoples. Thence arises the dislike which the weaker is very apt to feel for the stronger.

If Professor Rein's dictum that 'by civilization we mean the work which embraces the control of nature for the raising and perfection of external conditions of life' be true, then the work of the scientific steel metallurgist constitutes the greatest civilizing agent the world has ever seen. In the June number, 1911, of the *Revue Économique Internationale*, edited in Brussels by M. Paul Doumer, ex-President of the French Chamber of Deputies, a professor in a British University concluded an article on the Iron and Steel Industries of Great Britain in the following words :

> The man in the street comprehends very imperfectly the enormous importance to humanity of the metallurgy of iron and steel. If one enunciated the proposition that the greatest agent of civilization the world has ever known is steel, divines and statesmen, artists and lawyers, authors and leather-makers would tumble over each other in their haste to prove the absurdity of such an affirmation. Nevertheless, if one could take away from the world that alloy of iron and carbon called steel, in less than a century humanity would have taken a huge step backwards towards barbarism. Imagine this planet without steel and iron, and we have a world without railways, without steamships, without great bridges, and without machinery : in a word, a community incapable of producing the thousand-and-one articles which constitute the necessities of modern civilization.

But unfortunately a truth has more than one side. If the shield be reversed one contemplates an aspect of steel metallurgy not only hideous but presenting a brutality hardly surpassed in the annals of barbarism. Imagine an 1800 lb. shell fired miles away from the barrel of a 15-inch naval gun, penetrating the armoured turret of a battleship and bursting therein its fiendish charge of high explosive ! In the twinkling of an eye the inmates of that turret, composed of accomplished officers and gallant bluejackets, become loathsome masses of torn and bloody flesh and shattered bones. This, however, is an inevitable product of that 'Kultur' originally enunciated by Frederick the Great of Prussia, whose creed was embodied in the following words :

> He is a fool, and that nation is a fool, who, having the power to strike his enemy unawares, does not strike and strike his deadliest.

It would be interesting to know if Professor Rein considers that one of the 'highest ideals of science' has been realized in such engines of naval warfare. Scientifically developed, such *Kultur* mainly becomes the 'armed menace' which, for the last fifteen years, has always been hovering over the North Sea, at first as a cloud no bigger than a man's hand, then as that threatening blackness which, six months ago, burst in storm, and is now shaking the civilized world to its foundations : and the handmaiden of all these horrors is steel.

The Story of Cutting-Steels

The early history of wrought-iron and cutting-steel metallurgy is shrouded in an almost impenetrable obscurity. The meagre data obtainable are rare, and consist of casual references in prose, poetry, and monastic records. That steel, or rather steely iron, obtained direct from the ore, was known to the ancients about 800 B.C. seems to be proved by a passage in the ninth book of Homer's *Odyssey*, which can only have reference to steel. It was translated by Pope thus :

> And as when armourers temper in the forge
> The keen-edged pole-axe or the shining sword,
> The red-hot metal hisses in the lake :
> Thus in his eye-balls hissed the plunging stake.

In Great Britain, perhaps from a lack of interest on the part of literary men, or more probably from the secretive habits of steel-makers, which endure even to the present time, there is no early mention of the art of producing steely iron.[1] In one of the later volumes of the Domesday Book there is a record of an ironworks of considerable extent at Kimberworth, near Sheffield, worked by the monks of Kirkstead Abbey in 1160.

Scott, who visited south Yorkshire to gather materials for his romance *Ivanhoe*, appears to have obtained information which suggests that amongst other things the works round Sheffield made common armour for the use of men-at-arms, whilst the knights wore the fine steel mail wrought abroad, especially in Milan and Toledo. In Scott's description of the 'Siege of Torquilstone', he puts into the mouth of Robin Hood (Locksley) the following words:

> Thrice did Locksley bend his shaft against De Bracy, and thrice did his arrow bound back from the Knight's armour of proof. 'Curse on thy Spanish steel coat,' said Locksley; 'had English smith forged it, these arrows had gone through an as if it had been silk or sendal.'

The period to which Scott's novel has reference would be about 1196.

The steel industry of Sheffield seems at least six hundred years old. Chaucer in 1386, in *The Reeve's Tale*, in describing a miller of the time of Edward III (who was crowned in 1327), says 'a Shefeld thwytel bare he in his hose'. This seems to indicate that the

[1] Until comparatively recently in Zululand the heads of assegais, battle-axes, &c., were made by peripatetic families of ironworkers who visited various centres along the Zululand belt of iron ore, and by means of charcoal produced and afterwards forged into shape lumps of steely iron. Their operations were always conducted in secret, and these families seem, to a large extent, to have detached themselves from their fellows.

fame of Sheffield cutlery was so well established at that time in the south of England as to have reached the ear of a London poet. Macaulay states that Sheffield made no fine steel till about 1750, but in 1590 Peter Bales, in *The Writing Schoolmaster*, recommends Sheffield pen-knives and razors for cutting quill pens, for which purpose fine steel is indispensable. In 1760 Horace Walpole, writing to George Montague, remarks: 'I passed through Sheffield, which is one of the foulest towns in England in the most charming situation. There are 22,000 inhabitants making knives and scissors. They remit £11,000 a week to London.' Antiquarians state that the reason why Britain's chief steel industry originally settled round Sheffield was the juxtaposition of iron ore and coal in the district. To a metallurgist this argument is unconvincing, because charcoal and not coal was the fuel used, and the small deposit of iron ore existing near Sheffield was clay iron-stone, so impure with phosphorus as to be unfit to be the source of fine cutting implements. The real reason why, hundreds of years ago, the steel industry settled mainly at Sheffield was the unique situation of the town, which lies in a valley watered by the river Don, which runs into the Humber at Goole. Four other valleys to the west of Sheffield have each a rivulet, namely, the Sheaf, the Loxley, the Rivelin, and the Porter. These little rivers have their confluence with the Don at Sheffield. Thus by the construction along these five rivers of small dams, water-power was obtained at a low cost to work the tilt hammers and turn the grindstones of the old-time cutlers. The region was well wooded, and hence could produce a sufficient supply of charcoal. In addition, refractory materials for furnaces and millstone grit for grindstones were plentiful in the neighbourhood. The basis metal from which the old Sheffield steel was prepared by cementation in charcoal was the wonderfully pure bar iron of Scandinavia [1] and Spain, which was brought by pack-horses or by water-carriage from Goole. In 1442 the citizens of Sheffield obtained a royal warrant permitting them to make tow-paths along the river Don. There is positive evidence in the accounts of the Sheffield Church Burgesses for 1557 that Danish and Spanish iron were then being imported into Sheffield. The price in present money works out to about £60 per ton. The two items in the Church Burgesses' accounts are as follow :

> Paid to Robert More for one stone and quarter of Danske Yron XXIId.
>
> Paid to ye same Robt. for X lib of Spanysche Yron XVd.

There is evidence that in the beginning of the eighteenth century cutlery and other steels were also being manufactured in London, Birmingham, and Newcastle.

Up to 1740 all steel was made by hammering bar iron carburized by cementation, and was known as blister steel or shear steel according to the amount of forging work put upon the carburized bar iron. The name 'shear steel' was due to the fact that the clothworkers of the country insisted upon having this steel for their cloth-cutting shears, and at the present time this kind of steel is always branded with rude representations of cloth-cutting shears.

About 1740 the crucible fluid-steel process was invented in Sheffield by Benjamin Huntsman, of Doncaster, and in 1752 he commenced to manufacture on a considerable scale, so founding an industry destined to become

[1] Many thousands of tons of this fine iron are at the present time imported annually into Sheffield from Sweden.

permanent and world-wide. Indeed at the present time Krupps, at Essen, are making gun-steel ingots, each weighing 110 tons, by the process evolved from the brain of an Englishman 175 years ago. It will be seen later that, in reference to scientific steel metallurgy, Germany, by the cunningly devised and mendacious paragraphs of her pressmen, has endeavoured to convince the world that in scientific steel metallurgy German *Kultur*, as in all other branches, is supreme.[1] This idea is not in accord-

[1] At the same time it is only fair to Germany to state that their megalomania in connexion with metallurgical science has been aided and abetted by many English public speakers, who, ignorant of the facts, in effect took up with reference to technical education the offensive German parrot-ery, 'Deutschland über alles.' A partial awakening, both of German and English educational dreamers, was brought about by an eminent and also honest German professor, who attended the Steel Congress in Sheffield in 1905.

Speaking on the Education Estimates on October 11, 1905, the Lord Mayor of Sheffield said:

'A fortnight previously the Iron and Steel Institute had visited Sheffield, and among the company were several foreign gentlemen who were authorities on technical and other education, and who looked most minutely into our educational system. They went round the Technical School and University, and made other inquiries. They were leading educationalists of their country, and not leader-writers of newspapers (Laughter). One of them was Dr. Wedding, who would not write what he did not think was true. Commenting in the *Cologne Gazette* on the metallurgical department, Dr. Wedding had said: "A most hospitable opportunity was given for the inspection of this department. The University in question has, in addition to its medical, philosophical, and philological faculties, also a very important department for applied sciences, viz. machine-construction and metallurgy. Fifteen years ago a small pioneer institute for practical metallurgy had already been established, to which has now been added a complete plant for steel production, for the use of students. A small Bessemer converter, a 2-ton Siemens-Martin furnace, a cupola, hammers with re-heating furnaces, also gas and coke crucible furnaces, form the basis for a plant supplemented by numerous laboratories: such plant as is, in this form, totally unknown by us in Germany. With us the same purpose can only ance with the facts. In naval construction, for instance. Germany has followed closely the lead of Britain. After sneering at the size of the guns of our huge super-Dreadnoughts, the *Warspite* and the *Queen Elizabeth* (which have a speed of about 25 knots and a main armament of eight 15-inch guns, each throwing 1800 lb. shells), Germany soon feverishly began to follow suit by starting to build the *Ersatz Wörth* and the 'T', each probably having a speed of about 23 knots and having eight 15-inch guns for their chief armament.

The names of the Britons, including admirals, naval architects, engineers, and metallurgists, whose genius brought these giants into being, are to a great extent unknown and will remain unknown to the man in the street.

To revert to the development of British metallurgy, Robert Forrester Mushet, about 1858, discovered the remarkable influence on tool steel of the element tungsten, and up to about 1870 seems to have been patiently experimenting in the Forest of Dean. At the latter date he commenced to make 'Mushet Steel' on a considerable scale in Sheffield. Mushet's invention, although subjected to the discouraging predictions of Dr. Percy, of the Royal School of Mines, was destined to be the

be obtained by the year of practical work laid down for students at German Technical Schools. The duration of the courses of study in the metallurgical as well as in the machine-construction department, which are equipped equally well, is fixed to three years for day students, whereas the evening students, who are said to number 1,200, require at present seven years of hard work to achieve their purpose. The extensive new equipments give one the impression that the well-known complaint of English people, that in the way of education they are much behind, does not apply any longer to Sheffield, particularly not as regards the metallurgic and machine-construction sections. On the contrary, there is much, indeed very much, for Germany to learn there." '

pioneer of a revolution in the art of cutting-metals, an operation imperfectly realized by most people, but nevertheless of vital importance to the development of the arts of war, and in the arts of peace to the comfort and well-being of humanity. The plain carbon Huntsman type of steel, although, after quenching from a red heat, it possessed the hardness of rock crystal, was thermally unstable and completely broke down with the heat of friction at a temperature of 300° C., thus reverting to its soft state. Mushet's tungsten steel, later fortified with a little chromium, was thermally much more stable and hence could be run at higher speeds with greater cuts and traverses on the lathe. Thus mechanical engineers were able to accelerate their outputs of machines for use in the industrial arts of peace (and war), a fact of far-reaching economic importance in view of the rapidly increasing population of the world. The gradual development of the cutting power of Mushet's pioneer type of steel proceeded by cumulative improvements from 1880 to 1912; it was influenced in 1900 by the discovery in what is now the University of Sheffield of the astounding influence on steel of relatively small quantities of the somewhat rare element vanadium, an influence which, unlike that of tungsten, extended also to structural steels. In connexion with the latter it was found that the vital factor of structural steel known as the elastic limit, could be almost doubled without an undue sacrifice of toughness and ductility. By reducing the carbon in the original Mushet steel from 1·8 to 0·7 per cent., much increasing the tungsten and chromium, largely reducing the manganese, and adding 1 per cent. vanadium, the thermal stability of the cutting hardness was easily doubled, rising from 300° C. to well over 600° C. In fact such steel can be run for several minutes cutting cleanly at a red heat, a proposition which, twenty years ago, would have been regarded as capable of enunciation only by a madman. The net result of the researches in British cutting-steels which were made between 1740 and 1912 has been in certain cases an improvement in cutting-power of about 900 per cent. Messrs. Taylor & White, associated with the Bethlehem Steel Co., of America, first exhibited to the engineering world, at the Paris Exhibition of 1900, tool steel running at a low red heat. An example of German jealousy of British supremacy in the science of manufacturing high-speed tool steel was comparatively recently exhibited by a German firm, which added to the composition of standard Sheffield steel the element cobalt, and under the authority of a certificate from Charlottenburg claimed that the new German steel was twelve times as powerful as the best British product. This obviously absurd statement was challenged by both British and German steel-makers, and researches in Sheffield University have since shown that the claim is without foundation in fact, because upon the cutting power of the best type of high-speed steel the element cobalt has no influence whatever. It is interesting to know that this German steel was largely advertised as 'iridium' steel, possibly because in its composition iridium was conspicuous by its absence.

The Story of Structural Steels

In this, the 'Steel Age', it is a little difficult to realize that, in the first half of the nineteenth century, the materials of construction for bridges were either cast or wrought irons. The materials for railway work were cast and wrought irons with a limited amount of costly crucible steel. Wrought-iron rails lasted about five years, steel rails last from fifteen to twenty years. Ship and boiler plates were exclusively of wrought iron, and the same remark applies to the early armour plates for battleships. In 1856 Henry Bessemer, a native of Hertfordshire, invented his pneumatic process for the purification of molten pig-iron. British and other scientific societies originally regarded his plans with a more or less tolerant amusement. For the tedious and laborious puddling of pig-iron into wrought-iron, he proposed to take a mass of say ten tons of molten cast-iron and to blow through it a strong blast of air and so oxidize its impurities, present to the extent of about 7 per cent., and thus obtain a mass of say nine tons of pure iron. In the early sixties he started a works at Sheffield: other firms took up the process under royalties and the 'heavy' steel industry of Sheffield was thus founded. In most text-books and by many lecturers the Bessemer process has been hopelessly mis-described. It is almost invariably stated that it consists in first blowing out all the carbon, and then converting the resulting iron into different kinds of structural steel by adding suitably differing amounts of carbon contained in the alloy called spiegeleisen. The facts are as follow: Bessemer's blown and purified iron was so full of dissolved oxygen as to be absolutely useless for a commercial product, because it would not pour soundly nor would it forge at all, but fell to pieces under the hammer at a yellow forging heat. The process was made a success by an invention of Mushet for deoxidizing molten iron by the addition of metallic manganese, which seized the oxygen dissolved in the iron and carried it up in the form of oxide of manganese into the supernatant slag. The process in its early days was not very satisfactory because insufficient manganese was used, the practice being to leave only about $\frac{1}{4}$ per cent. excess of manganese in the finished steel. Afterwards it was found that 1 per cent. excess manganese was necessary to obtain an easily forgeable steel. In justice the method should be called the Bessemer-Mushet process. This method long ago reached its zenith and is now used mainly for making rails. It has been superseded by the Open-hearth method, called on the Continent the Martin process, in England the Siemens method or alternatively the Martin-Siemens or Siemens-Martin process. This method was made practicable by the invention of the regenerative heat system of the late Sir William Siemens, a British subject of German descent. In this process equal weights of pig-iron and scrap-steel are purified by the addition of solid oxygen in the form of red hematite ore. In acid-lined furnaces of this type seventy tons of steel are sometimes made at one operation. Mushet's deoxidizing addition of manganese must also be used in this process, leaving about ½ per cent. of metallic manganese in the finished steel. Ingots upwards of 150 tons in weight are occasionally made in Sheffield armament works by this process.

The World's Output of Steel

In the early eighties Great Britain was producing in round numbers about 8,000,000 tons of pig-iron and 2,000,000 tons of steel per annum. The quantities produced by America and Germany were relatively small. To-day in round numbers substantially accurate and readily remembered, Great Britain is producing about 7,000,000, Germany 14,000,000, and America 28,000,000 tons of steel per annum, made by the Huntsman, Bessemer and Siemens methods. Thus in output Great Britain is hopelessly outpaced. She is living in fact on the unsurpassed and often unapproachable average quality of her steel; and shipments of high quality steels were, prior to the war, being sent to Germany at prices, for the finest quality of steel, reaching up to 2*s*. per lb. The vast output of the United States is accounted for by their great natural resources in iron ore and coal, by the energy of the Americans, and by the fact that they have to supply a population of 92,000,000 of people with steel for their huge and ever-increasing railways and industries. The case of Germany is more remarkable because her leap into the position of the second steel-producing country of the world is due, not to her own 'Kultur', but to an appropriation of the brains of British inventors: in fact, to the invention of the basic-steel process by Thomas and Gilchrist in England in the early eighties. This process made valuable for steel-making the hitherto useless phosphoric ores of Germany. In the *Revue Économique Internationale* for June 1911, Herr Fritz Thyssen showed that Germany produced in 1909 over 12,000,000 tons of steel, and of these, over 7,500,000 tons were Thomas and Gilchrist basic steel, and over 152,000 tons were Bessemer's acid steel. In this year Germany used over 25,500,000 tons of native basic ore, importing less than 8,500,000 tons of foreign ore.

The German system of production is to keep the works going as far as possible at full output, thus keeping down the dead charges and the re-starting charges to a minimum. When by these means, at ordinary market price a necessary profit has been made by legitimate sales, the surplus steel is dumped, frequently in Britain, at say £1 per ton under British cost price. The payment for the dumped steel is an addition to the fair profit. This procedure throws the British steel-worker out of employment. In one well-known case a large British works had to close down for a year, throwing thousands of men out of work. On the other hand, certain British manufacturers using the dumped steel no doubt reaped a considerable advantage, but such gain is obtained at the price of depleting the ranks of British iron-smelters and steel-melters, and such depletion on a large scale would constitute a national danger, from a naval and military point of view. Considering the enormous debt due by Germany to British inventors, Britain owes very little to German initiative. Krupps, it is true, much improved the process for carburizing the faces of armour plates, but on the other hand they have had to adopt British improvements in armour-piercing shells. It is also true that in devising engines for blowing blast furnaces by the combustion of their own waste gases Germany has devised some admirable engines, but here again the idea of so using the gas came from the brain of a British furnace engineer, the late Mr. B. H. Thwaite, who died ill rewarded for his pains.

Education in the Application of Science to Steel Metallurgy

This subject has already been touched upon (see Professor Wedding's communication to the *Cologne Gazette* in foot-note on pp. 9–10 of this pamphlet), but it may be well at the present crisis to state in a little greater detail facts which some German Universities, authors and pressmen would prefer to have kept in the background as to the comparative development during the last twenty-five years of German and British educational methods in teaching the applied science of steel. For purposes of comparison the steel departments at Charlottenburg and Sheffield may be selected. The latter has been contemptuously described by a professor of pure science as 'a pig-boiling and ingot-slinging establishment'. It is true that pig has been boiled into steel in the main practical laboratory at Sheffield University, and that casts of such steel up to nearly two and a half tons in weight have been made: also that the ingots have been slung out of the casting-pit by means of a four-ton electric crane. Why not? It is also true that coke and gas crucible melting furnaces, and hardening furnaces of commercial manufacturing sizes are worked. There are also commercial mechanical testing machines for making static and dynamic tests. There is also a cupola for making in the foundry five tons of castings per day. Again, why not? To the examination of these products at every stage of manufacture, the pure sciences of mineralogy, chemistry, physics, and microscopy are applied to the fullest possible extent. Also it may be remarked that the University of Sheffield is unique in granting Metallurgical Degrees, namely those of B.Met., M.Met., and D.Met. The Bachelor's degree requires a candidate after matriculation, in addition to seven applied science subjects, to pass also in three pure science subjects, namely chemistry, geology and mineralogy, and either physics or mathematics. In the applied analytical chemistry of steel the German analysts are distinctly inferior to trained British chemists. Nevertheless so widespread is German scientific megalomania that about three years ago a valuable consignment of high-speed cutting-steel exported from Sheffield to Germany was rejected on the ground that its micrographic analysis was unsatisfactory. The German-trained metallographist also stated: 'No doubt you are unaware that this microscopical examination of steel is a new method just evolved at Charlottenburg and probably it has not yet reached Sheffield.' An experienced metallographer from Sheffield University subsequently found the diagnosis of the young German steel doctor to be absolutely wrong, and the rejection of the steel was cancelled. At Charlottenburg there are no practical appliances whatever, and hence the science taught there is pure and abstract rather than applied and concrete. Which system is better for training officers to command the battalions of an industrial army ? Take again, for instance, the very important subject already referred to. of metallography, i. e. the microscopical analysis of the structure of metals, which are crystallized artificial igneous rocks, built up of many rock-forming minerals. This science was founded by the late Dr. Henry Clifton Sorby, F.R.S., in Sheffield in 1863–5, and his superb pioneer sections are still examined in the micrographic laboratory of the University of Sheffield.

There are about twenty-nine constituents or sub-constituents of steel and iron. Of these twenty-six have been discovered in Sheffield, the steelopolis of Great Britain ; three in Middlesbrough, its ironopolis ; and the record of Charlottenburg in this branch of research is an absolute blank. A comparison of the quantity and quality of the researches on iron and steel of a pure science order turned out from what is now the University of Sheffield, with those evolved from Charlottenburg during the last twenty years, would be cruel because farcical. One example will suffice. The first-fruits of metallurgical research from Charlottenburg, which were announced even in British engineering journals with much beating of tom-toms, was a paper describing an investigation of the physical influence of nickel on iron. The Charlottenburg conclusions were that, when the quantity of nickel alloyed with the iron reached 6 per cent., the tensile strength fell to six tons per square inch, whilst the ductility practically disappeared. Contemporaneously the Sheffield College completed a research showing that iron containing about 7 per cent. of nickel had a tenacity of about thirty-nine tons per square inch, with a ductility of about 55 per cent., and that iron with 28 per cent. nickel had much the same mechanical properties: but when about 13 per cent. of nickel was present it formed with the iron a definite alloy possessing the enormous tenacity of nearly ninety tons per square inch associated with a ductility of no less than 45 per cent. The Charlottenburg results were, no doubt, correctly observed, but owing to a preliminary lack of practical metallurgical knowledge the experimentalists made alloys hopelessly charged with oxygen, in fact the title of their research should have been not 'The influence of Nickel on Iron', but rather 'The influence of unknown quantities of dissolved Oxygen on Alloys of Iron and Nickel'.

Another example of Teutonic mendacity is a statement made by a German writer which actually caused some alarm in this country, that owing to the superior skill of the German gun engineer and the better quality of German steel, the comparatively small guns of the German Navy excelled in power the larger British guns.

In connexion with the German realization of 'Der Tag' in the North Sea on January 24, 1915, the artillery experts of Sheffield (which city is the greatest naval armoury the world has ever seen) would no doubt like to ask the survivors of the *Blücher*, the *Derfflinger*[1],

[1] This vessel, the most powerful German battle-cruiser, carried eight 12·2-inch guns.

the *Seydlitz*, and the *Moltke*[1], to give their candid opinion on the power of the 13·5-inch guns and of the lyddite shells from those British battle-cruisers which sternly avenged the women and children so foully murdered on the East Coast.

[1] These ships are of the *Goeben* type, and carry, or carried, a main armament of ten 11-inch guns.

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