Metallurgical Researches of Michael Faraday.

PRIOR to 1819, when Faraday published a paper on the composition of Indian Wootz steel, his contributions to knowledge had been represented by comparatively short communications, with no very obvious connexion. His first research of any magnitude was, therefore, the one on the alloys of steel with other metals, on which he was engaged for the next five years. This work, carried out in collaboration with a Mr. James Stodart, a manufacturer of cutlery and surgical instruments, led to the publication of two further papers in 1820 and 1822. Of these, the former is an account of small scale experiments made in the laboratory of the Royal Institution, and the latter, on ingots, 10 lb.-20 lb. in weight, melted in Sheffield. The cause of this interest in steel cannot now with certainty be determined, but Faraday's association with Stodart, and a decision of the Board of Management of the Royal Institution of 1812 that it was desirable that experiments should be undertaken on the alloys of metals, may both have played important parts.

That Stodart's influence was probably considerable is indicated both by the subject of Faraday's first metallurgical contribution and by the fact that after Stodart's death, in 1823, no further paper on this subject appeared. Faraday's diary contains but three further references to steel, the last of which is dated June 28, 1824. That Stodart was much impressed by the Wootz steel is shown by his trade card, preserved in the British Museum, which reads: "J. Stodart, at 401, Strand, London, Surgeons Instruments, Razors and other Cutlery made from Wootz, a steel from India, preferred by Mr. Stodart to the best steel in Europe after years of comparative trial". The desire to imitate this steel for surgical and other cutlery was clearly one of the main objects of Faraday's research, the other to prepare an alloy suitable for mirrors which would not corrode.

Before discussing the results to which this work led, it is not without interest to attempt to discover why it came to such a sudden and untimely end. For this, Stodart's death must in some measure be held responsible; for after giving Faraday every credit for his (in all probability very large) share in the work, the practical experience and keen interest of his collaborator must have exercised a considerable influence. This, probably, with a growing enthusiasm for other lines of research, and a feeling of disappointment with the results obtained from his work on steel, evidently caused his interest to wane. The opinions of his scientific contemporaries are well indicated by the following extract from the obituary notice to Faraday in the *Proceedings of the Royal Society*: "The results of the paper on steel by Stodart and Faraday to the Royal Society in 1822, were of no practical value, and this, one of his first and most laborious investigations, is strikingly distinguished from all his other works by ending in nothing".

That the research was laborious is well shown by one of Faraday's own letters, in which he says: "Pray, pity us that, after two years' experiments, we have got no further; but I am sure, if you knew the labour of the experiments, you would applaud us for our perseverance at least".

What, then, were the fruits, if any, of this five years of continued research? It is to Faraday's credit that, for the first time, a series of steels were examined with sixteen different metallic additions and of varying concentrations. Secondly, he determined, in all probability as accurately as has been done even to the present day, the solid solubility, which he gives as 0·2 per cent, of silver in steel. This was, the writer believes, the first time that such a determination had ever been made. He further showed that both platinum and rhodium dissolve in steel in all proportions; for the former metal this was confirmed in 1907, whilst for the latter it still remains the only research ever carried out.

Faraday prepared the first of the 'stainless steels'. That the alloy contained 50 per cent of platinum, and hence found no useful application, does not detract from a scientific discovery of first-rate importance. Next, by treatment of a steel with acid, he prepared from it a "soft, grey, plumbaginous powder" which, he says, "appears to be a carburet of iron". Priestley, it is believed, had done this at an even earlier date, but Faraday's rediscovery of iron carbide in steel appears to have been entirely independent. By heating a polished surface of his chromium steel, Faraday developed its structure; the very first use of the process now known as 'heat-tinting'. In considering the effect of titanium on steel, he came to the conclusion, which is most generally accepted to-day, that this element does exert a distinctly beneficial effect, but that it finds no permanent place in the steel to which it is added. Considering his experiments on the rusting of the special steels, he points out that nickel reduces the tendency to corrode, and that, other things being equal, a high carbon steel rusts more rapidly than does one of lower carbon content. Finally, he observes that his rhodium steel is more resistant to softening by tempering than a plain carbon alloy is, a conclusion which, if followed up, might well have led to the production of steels of the high-speed type long before they were actually devised.

This, then, is part of the fruit of a research which "ended in nothing". If, however, both Faraday and his scientific contemporaries failed to realise the importance of the results which had been obtained, and to build upon the foundations which he had laid, there are clear indications that a certain section of the producers of steel were greatly impressed. The one steel which Faraday picks out from all he produced was that containing a small percentage of silver. In his own words, "its alloy with steel is the most valuable of those which we have made. To enumerate its applications would be to name almost every edge-tool. It is also probable that it will prove valuable for making dies,

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especially with the best Indian steel." In the later paper, dealing with the large scale experiments, he again says that it "was harder than the best cast steel or even than the Indian Wootz, with no disposition whatever to crack either under the hammer or in hardening—its application will probably be extended not only to the manufacture of cutlery, but also to various descriptions of tools; the trifling addition of price cannot operate against its very general introduction. The silver alloy may be advantageously used for almost every purpose for which good steel is required."

Even to-day there is on the market the so-called 'silver-steel', which, in general, is quite free from that metal, the name referring merely to a high-class, high-carbon crucible alloy. The writer well remembers a visit to a crucible steel works in Sheffield some twenty-five years ago, and seeing the head-melter, with much ostentation, dropping a sixpenny piece into the 'pot' containing some sixty pounds of liquid steel, which addition he was assured would confer on the metal superlative qualities. There can be very little doubt that both the name and the practice are the direct result of Faraday's work, and provide some indication of the esteem in which it was held by the actual steel-makers.

What has become of the ingots cast in Sheffield will in all probability never be known, but of the steels prepared in the Royal Institution we have now a most interesting and detailed knowledge. A wooden box labelled 'Faraday' and 'Steel and Alloys', the former probably, and the latter almost certainly, in his own writing, has recently come to light. This contained seventy-nine specimens, which were handed over to Sir Robert Hadfield for investigation. An account by him of an examination of these, which historically is of the very first importance, has now been published (*Phil. Trans.*, A, vol. 230, p. 221, and British Assoc., Sept. 24, 1931). The scrupulous care taken of this unique material is indicated by the fact that although about 430 separate chemical estimations have been made, with 210 other determinations of structure, hardness, specific gravity, resistance to corrosion, magnetic and electrical characteristics, etc., more than $6\frac{1}{2}$ lb. of the steel still remains, from an original weight of less than 8 lb., representing more than

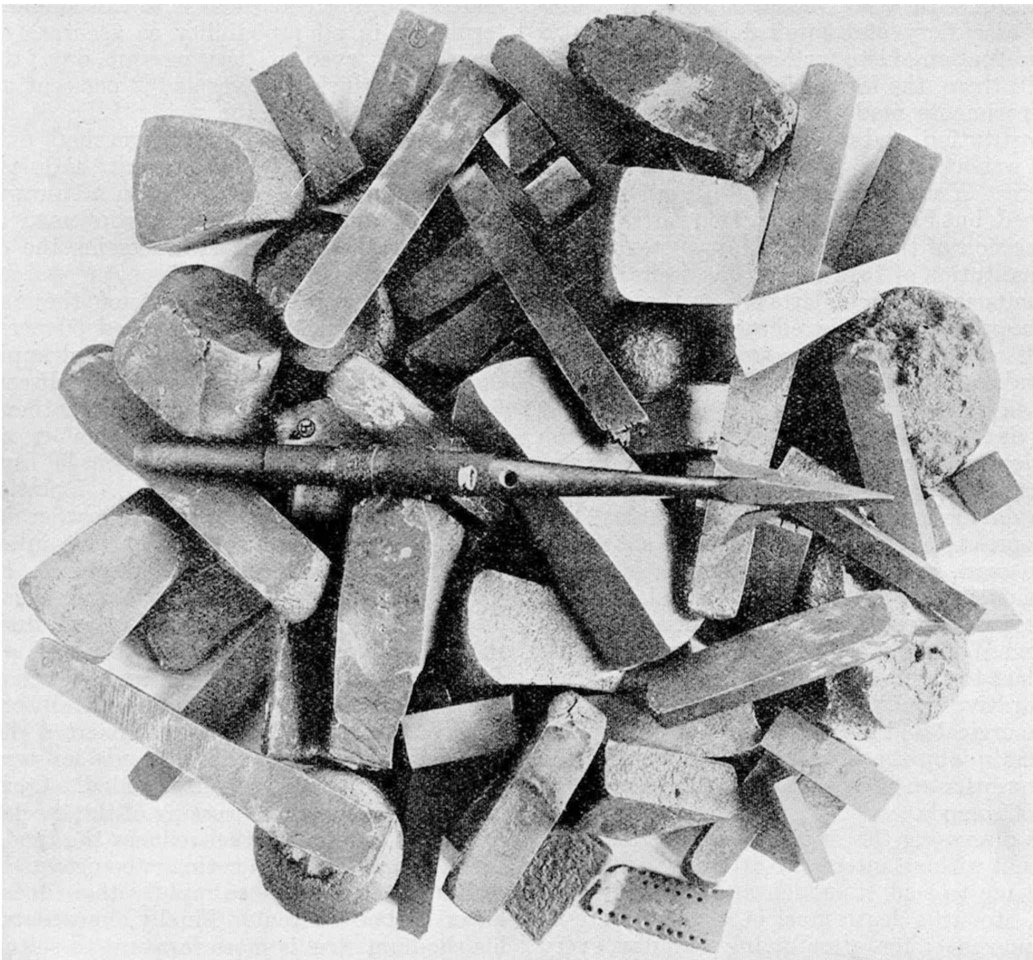

FIG. 1.—The seventy-nine steel specimens taken from Faraday's box. Reproduced by courtesy of the Royal Society from *Phil. Trans.*, A, vol. 230.

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seventy-five per cent of the total. The samples themselves are shown in Fig. 1.

Broadly, the samples fall into the following categories: In group *A* are three 'buttons', evidently the original melts as they solidified from the furnace. These, like the samples in group *B*, weigh at most 4-5 oz., the latter section, however, consisting of roughly hammered 'blooms'. In group *C* these small 'blooms' have been further hammered into bars. One such bar, however, is far more regularly fashioned, and from its analysis Sir Robert Hadfield draws the perfectly logical deduction that it may well have formed a portion of the steel which Faraday used as the raw material for some of his melts. The other type of basis metal appears to have been an English wrought iron of low carbon and considerable purity for a material of such origin. That a low carbon base must have been employed for some of the melts is shown by the fact that among the samples which have already been analysed is one which contains only 0·07 per cent of carbon and 2·25 per cent of platinum. Some idea of the quality of this achievement, bearing in mind the primitive apparatus available, will, perhaps, be better appreciated if it is pointed out that when, some seventy years later in 1894, Arnold carried out his classical research on "The Influence of Elements on Iron" with an equipment vastly more complete and satisfactory than anything which Faraday had at his disposal, in three cases only out of ten was a smaller amount of carbon present in the alloy than in this remarkable material which Faraday turned out in his simple 'blast-furnace'.

The importance of the production of an untarnishable steel for mirrors in this research is shown by a whole group of other samples with one or more highly polished surface. Among the samples from the Royal Institution, the high platinum-metal alloys were not represented. The steel noted by Faraday which, as a result of the large proportion of platinum it contained, did not corrode, was not, therefore, examined. Quite recently, however, a further series of samples, the property of Mr. A. Evelyn Barnard, has been discovered by Sir Henry Lyons. These also have been placed at Sir Robert Hadfield's disposal for examination, and in a preliminary note in the paper read before Section G (Engineering) of the British Association, high platinum, rhodium, and palladium steels, of such a composition that they can only represent Faraday's alloys, have been found. To all interested in metallurgy, in Faraday himself, and in the history of scientific discovery, the investigation of these alloys will be a matter of the greatest interest.

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Xeromorphic Adaptations of Plants.

THE leaves of plants which are found growing in dry situations often show certain structural characteristics in common — thick-walled tissues, thick cuticles, stomata sunken below the surface, etc. These structural features seemed likely to cut down the loss of water from the leaf, and therefore, with little experimental investigation, they have been classed as adaptational mechanisms against water loss and spoken of as 'xeromorphic'. Of recent years the experiments have been carried out which should properly have preceded the adoption of any such interpretation of these characteristic structures.

The result has been considerable misgiving as to the soundness of a view that had long held its place in the elementary textbooks and a great recrudescence of interest in the problem, as is well illustrated by the symposium on xeromorphy at the International Botanical Congress at Cambridge in 1930. Papers by Maximow, Huber, Schratz, and Thoday, which were read at this symposium, have now appeared,[1] whilst an interesting résumé of some aspects of the subject has been published by E. G. Pringsheim.[2]

It is by no means easy to obtain good comparative figures of evaporation rates from different leafy shoots. It is dangerous to assume that twigs removed from the plant will give values indicative of the behaviour of the same shoots upon the tree, and Schratz points out also that the comparative rates of evaporation determined for different severed shoots will vary with the duration of time employed in making the observation.

Results with the shoots still growing upon the plant would therefore appear more valuable, but the difficulty now lies in finding a practicable method for determining the comparable rates of water loss, whilst at the same time it is clear that the structural features of the shoot tissues immediately in question, are only one amongst many variables determining the evaporation from the plant. Seybold's method [3] of treating the evaporating surface as a wet bulb hygrometer seems a step in the right direction and is applicable with the growing plant, but, as Maximow points out, the real temperature of the transpiring surface is still in doubt.

In view of the experimental difficulties, it is not surprising that there is still considerable difference of opinion as to the significance of xeromorphic structures, but a certain general measure of agreement seems to emerge when these recent papers are examined. Thus it seems to be generally agreed that xeromorphic leaves have about the same proportion of stomata to epidermal cells as less xeromorphic leaves of the same species. As the cells of the xeromorphic leaf are usually smaller, this means that the xeromorphic leaf has a larger number of stomata per unit surface, so that it is not surprising to find that, when the stomata are open and the leaves freely supplied with water, xeromorphic leaves lose water more rapidly than less xeromorphic leaves of the same plant. The point is made very clearly by Huber in his comparison of 'sun' and 'shade' leaves, where the sun leaves, borne near the top of the leafy crown of the tree, are xeromorphic as compared with the shade leaves of the lower branches. Such

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