Iron Manufacture and Heat Generation.¹

By Prof. HENRY LOUIS.

THE date and even the place of the first use of iron by mankind have never been determined; it appears to be generally held that iron was first produced in workable quantity on the southern flanks of the Caucasus, and the date assigned is usually somewhere about 3000 B.C., though for my purpose both the place and the exact or even the approximate date are matters of secondary importance. My main object is to indicate that the history of iron manufacture shows it in the light of a consequence of the ever-increasing power which mankind gradually learnt to exercise over the production of heat, and I hope to be able to show that the history of iron and the history of heat generation have gone hand-in-hand throughout the ages, and that the former has been absolutely dependent upon the latter. It is certain that, before iron came into use, the metallurgy of bronze was already highly developed. Articles of bronze of the Later Bronze Age show that the art of bronze-founding had already reached a high stage of perfection. The art of making cored castings was undoubtedly known, and it seems probable that even the *cire perdue* process had been invented.

No doubt the simple reduction of metallic iron from its ores would have been well within the capabilities of these primitive metallurgists, but from the simple reduction of the metal to its fashioning into any useful form is quite a far step. Oxide of iron is reducible to the metallic state at a very low temperature, not exceeding 500° C., but the iron so produced is more or less pulverulent and useless for all practical purposes. To weld it into

is derived from Egyptian mural paintings. All the earlier ones—for example, one from the frescoes of Beni-Hassan (Fig. 1), said to date from about

FIG. 2.—The earliest known form of bellows (Egypt). From Wilkinson's "The Ancient Egyptians".

a, b, k, o, the leather case.
c, e, l, n, the pipes conveying the wind to the fire.
d, m, the fire.
h, g, charcoal.
k and o are raised as if full of air.

2500 B.C.—show men blowing up a fire beneath a crucible by means of mouth blowpipes made of reed and tipped with clay, and it is evident that with such rudimentary appliances only very small pieces of iron could be produced.

The first known representation of any mechanical means for producing a blast is from the walls of a tomb of the period of Thothmes III., supposed to be from about 1500 B.C. This primitive bellows (Fig. 2) apparently consists of a flat pot covered with skin, in the centre of which is cut a hole that can be closed at will by the heel of the operator, which thus forms a valve, the skin, when released by the heel, being pulled up by a cord in the worker's hand. It is interesting to note that this identical type of bellows is still used in India by certain tribes for the purpose of iron manufacture, the only improvement in more than 3000 years being the use of a couple of light bamboos which act as springs to pull up the hide cover. A photograph of a native lad working these bellows (Fig. 3), taken a few years ago by the late Mr. Seymour Wood, shows the method; moreover, these bellows have been figured in full detail by Dr. John Percy in his classical work on the "Metallurgy of Iron and Steel".

The position at a tolerably reliable date can be well estimated from the British Museum excavations at Djerabis on the Euphrates (the Charchemish of Biblical times); as recorded in Biblical writings, this place was attacked and captured by Nabuchadnosor, King of the Babylonians, in 604 B.C. The finds consisted of broken swords and spear-heads, all of bronze, and of numerous arrow-heads, both of bronze and of iron; there was also found a beautifully finished bronze mould

FIG. 1.—Blowing up the fire by the mouth blowpipe (Egypt). From Wilkinson's "The Ancient Egyptians".

a coherent mass capable of useful application requires not only a considerably higher temperature, but also for articles of any size a considerable body of heat, and this would apply equally to the forging of meteoric iron. The only information that we have as to the early means of producing the necessary heat

¹ From the presidential address delivered to the Iron and Steel Institute on May 2.

for casting the bronze arrow-heads, and it is particularly noteworthy that these bronze arrow-heads are far superior in execution and finish to the iron ones—the iron ones being all tanged, whilst most of the bronze arrow-heads are socketed.

It is therefore evident that at this date, even in the centre of the highest civilisation of the time, skill in working iron had not reached anything like so high a level as that of the bronze-worker; the finds are, of course, not conclusive evidence that no larger weapons of iron were in use at the time, but I think that the conclusion may fairly be drawn that they must have been far scarcer than the bronze weapons, and that the difficulty of working even moderately large pieces of iron had by no means been fully overcome, and that whilst small articles of iron could be made readily enough, there must still have been difficulty in producing the larger articles which required a considerable body of heat. This emphasises the essential point which I want to bring out, that the means of generating the requisite heat must have been the controlling condition in the manufacture of iron. Furthermore, as is well known, whilst iron reduced at a low temperature, even from impure ores, is sufficiently pure not to be brittle, it must necessarily be very soft, and it may readily be supposed that a well-made bronze sword was for quite a while superior to a soft-iron one. This difficulty must have persisted until a much later date in northern Europe, since the Norwegian sagas more than once record that a warrior had a sword so soft that he had to stop to straighten it underfoot in the course of the conflict.

On the other hand, it is quite certain that in the countries bordering on the Mediterranean, where the knowledge of metallurgy was much older and civilisation was much further advanced, temperatures high enough to cause some carbon to combine with the iron and thus make relatively low carbon steel or steely iron had been attained at a very much earlier date, as is evident from the oft-quoted passage in Homer's *Odyssey*; from this it is obvious that steel or steely iron capable of being hardened by quenching was known in Homer's time, though the carbon content could not have been excessive, seeing that the metal so treated was not too brittle to prevent its being used as an axe; yet there must have been enough carbon present to cause perceptible hardening by quenching, seeing that Homer states that such quenching gives strength to the iron. On the other hand, Homer's frequently repeated epithet for iron "wrought with much toil" shows that the manufacture of iron was still in an elementary stage;

it will be remembered that Homer certainly wrote before 800 B.C.

It could, however, not have been very long after the beginning of our era before, with the employment of larger furnaces and, therefore, the production of a greater body of heat, a true steel was produced, and this would, of course, be the case more readily when manganiferous ores happened to be employed instead of ordinary iron ores. Thus both Horace and Ovid refer in their poems to the high quality of Noric iron. The Noric kingdom corresponded to the region now known as Styria and Carinthia, and it is quite probable that this Noric iron was made from manganiferous spathic iron ores of the Styrian Erzberg of Eisenerz. Jars, who visited the Erzberg in 1758, directs

FIG. 3.—Bellows as used in India.

attention to the fact that steel was readily produced by smelting certain of these ores. Similar ores appear also to have been worked in Spain, and they, too, must have produced steel or steely iron, and we have evidence that some at any rate of this material consisted of iron combined with sufficient carbon to be capable of being appreciably hardened by quenching. It must be remembered that the above statements as to the use of iron refer only to the region which at that early date was the centre of human civilisation; it is generally held that iron was not introduced into Britain until 500 B.C., and that its manufacture did not commence in these islands until about a century later.

Before Caesar's invasion, iron was certainly being made in the south of England, though the Brigantes in the north appear still to have been in a Stone Age. Before Caesar's time, iron currency bars were in use in southern Britain—a fact which would seem to imply that, although iron was being made, it was still scarce and comparatively valuable. The manufacture of iron continued in Britain throughout the Roman occupation. The largest

mass of Roman iron found in Britain, if not in the world, is the mass discovered at Corstopitum, near Corbridge, in Northumberland, described by Sir Hugh Bell. Its date is considered to be between A.D. 350 and 380, and its weight was about 3 cwt. It is quite clear that the method of iron production throughout all this period was always the same—namely, direct reduction by charcoal in furnaces probably not more than 3 ft. or 4 ft. high, and blown by bellows worked by man-power, in which the temperature was only high enough to produce soft malleable iron, or, at the best, with suitable ores a steely iron or a steel. Apparently this method of iron-making must have continued during the next thousand years or so; probably furnaces were steadily increasing in size, larger lumps of iron were being made, and probably steely iron or even steel was produced at will. The art of letting down or tempering steel must also have been discovered, and the technique of iron working, as distinct from the extraction of iron, made immense strides.

An invention that must have contributed no little to the increase in the size and power of the medieval furnace was that of mechanical blast production. Agricola, whose well-known work is dated 1556, figures and describes in much detail the construction of a bellows with valves of quite modern type, worked by a water-wheel, and it is on record that such bellows were in use at Göllnitz in 1435. A natural result of the increase in the height and power of the furnace and of the attendant higher heats thus generated was the production of white cast iron, and it is tolerably clear from Agricola's writings that this was known in his day. No doubt this unexpected result of the higher furnace temperature must have been a disagreeable surprise to the early metallurgist, who found in his furnace a lump of this hard, brittle, useless material instead of the mass of malleable iron or steel which he hoped to produce. In the course of time, however, he would discover that this useless metal could have its pristine malleability restored to it, or, as he expressed it, the iron could be 'freshened' by heating it in another (or possibly the same) furnace. When this technical stage had been reached, the iron-worker no doubt soon learnt to appreciate the advantage of a continuous process in which the metal could be made to flow out from his reduction furnace, over a discontinuous process in which the lump of metal had to be dragged out of the furnace either by tearing down the furnace front or by lifting the lump bodily out of it. This step would lead to a still further increase in furnace and bellows capacity, and this in turn would bring about a further increase in furnace temperatures, with the again unexpected result of producing grey cast iron, as soon as the temperature became high enough to reduce sufficient silicon. It would soon be found that such iron ran very fluid and was admirably adapted for making castings.

Apparently one of the very earliest forms of iron castings was the iron stove plate, which originated in Germany. The oldest known cast-

iron stove plate is dated 1497 and was from the Eifel, which appears to have been one of the earliest centres at which castings of this kind were made. No doubt it took the early founders some time before they learnt to adapt their bronze-founding technique to this new material, very much in the same way as in our own time iron-founders have had to learn to modify their methods for the successful production of steel castings; but the superior qualities of articles made of cast iron would be a sufficient incentive to urge these early workers to find out how to overcome their difficulties. Once this was done, a demand for such pig iron would arise and the blast-furnace making charcoal iron was evolved. The next step was the substitution of coke for charcoal, thus attaining the production of still higher temperatures; it is, by the way, interesting to note that the first coke furnaces still used bellows worked by a water-wheel, just as in Agricola's time, and that these continued in use up to the middle of the eighteenth century. About that date they were, however, replaced by iron blowing cylinders, capable of generating a more powerful blast, and, therefore, of producing higher temperatures, whilst Neilson's invention of the hot-blast in the year 1828 enabled still higher temperatures to be attained in the blast-furnace.

The next stage was the production of mild steel in the Bessemer converter and the Siemens open-hearth furnace, to be followed by the important modification of Thomas and Gilchrist, which we know as the basic process. Necessarily, these processes involved the use of still higher temperatures than had hitherto been attained, and finally we reach the production of alloy steels in the electric furnace with its capacity for generating still higher temperatures.

I do not wish to imply that each one of these successive stages immediately and definitely put an end to all use of the earlier processes. Quite the contrary is the case, for there are many examples of the old and new methods working side by side. Even to-day in India and in many other similar countries the direct process is still in use. Again, although Abraham Darby successfully made pig iron with mineral fuel so far back as the year 1735, charcoal blast-furnaces are still in operation in Sweden and various other parts of the world, and there was even one still at work in Great Britain at Backbarrow, near Ulverston, until Dec. 17, 1925. In spite, however, of this overlapping of processes and of the survival of the older methods alongside of newer ones, the line of progress is quite unmistakably defined.

It will, I hope, be admitted that this rapid review of the history of iron manufacture is correct, at any rate, in its main features, and that my contention that the power to produce high heats has throughout been the controlling factor, is well founded; I want to make it clear that I consider that the various stages of iron manufacture and of the generation of ever higher temperatures are not two independent concurrent parallel lines along which the development of human civilisation has

travelled, but that they are distinctly related as cause and effect. This being true of the past, what can we say as to the future? Just as there is a lower heat limit below which iron capable of being usefully applied in the arts could not be produced, so there must be an upper limit, and I suggest that this limit is reached when our furnaces are capable of generating a temperature sufficient to volatilise the iron; it seems fairly obvious that heats higher than this cannot well be usefully employed. Such heats are, however, now readily attained in the electric furnace, and it would therefore seem that from this point of view the limiting condition has already been reached by the metallurgist. On the other hand, there seems but little inducement to increase the quantity of output, seeing that our potentialities of production appear to be now actually ahead of the world's requirements, and that there is every indication that even our present appliances will enable us to keep pace with any future demands.

I emphatically do not mean to imply that we have reached finality in the metallurgy of iron, but I do hold that future progress will have to be along

different lines. Fortunately, we are already able to see what direction this progress must take. Recent advances have all been in the direction of improvement in quality and in the attainment of properties in which ordinary iron by itself is deficient. In other words, the future of the metallurgy of our metal will be directed, not by the crude methods of trial and error of the past, but by the application of principles developed by the methods of scientific research. For something like four centuries Great Britain has led the way in the great improvements in the iron industry along the old lines which I have been describing; we are, however, also the inventors of the science of metallography and of alloy steel; we may, therefore, fairly claim that even in modern scientific methods we are equally leading the world in the metallurgy of iron, and there is every reason to presume that the great work which members of the Iron and Steel Institute have done in the past in developing that iron industry which is the basis of our modern civilisation will still continue in the future, although, as I have suggested, that work will be carried on by means of modern methods and be based upon entirely different principles.

Progress of the Great Barrier Reef Expedition.

By Dr. C. M. YONGE, Balfour Student, University of Cambridge

IN the three months which have elapsed since the last report, the work of the Great Barrier Reef Expedition, in all its branches, has made excellent progress. Naturally, the weather conditions have not been so favourable as they were in the winter; heavy rains and humid heat, with wet bulb readings so high as 86° F., have been experienced, but work has been interfered with far less than was anticipated. The most serious drawback has been the state of the tides, the day low tides being very poor, which necessitated much collecting by night. On the other hand, sea work has proceeded without a hitch in spite of the previous gloomy accounts of the storminess of the summer months.

A great loss has been experienced in the departure from Low Island on Dec. 12 of Mr. and Mrs. F. S. Russell and Mr. G. Tandy, who were compelled, owing to the termination of their leave of absence, to return to England. Dr. T. A. Stephenson has succeeded Mr. Russell as second in command, while Mr. A. P. Orr has taken over charge of the boat party, Mr. J. S. Colman carrying on Mr. Russell's work on zooplankton. There is, unfortunately, no professional botanist to succeed Mr. Tandy, though Miss Glynne is expected for two months later in the year; meanwhile Mrs. Stephenson is doing what she can to continue the collection of algae. Mr. M. Spender, of the geographical section, is now with us permanently, while Miss E. A. Fraser, of University College, London, and Dr. S. M. Manton, of Cambridge, join us shortly. Both will work in co-operation with the reef party under Dr. Stephenson.

The regular plankton and hydrographic observations at the station 3 miles east of Low Island

have been continued with scarcely an interruption; a further station has been worked in Trinity Opening, all from the *Luana*; while on two occasions the powerful motor launch *Merinda* has been hired from Cairns for work beyond the Barrier. For the hauling in of nets and hydrographic gear from deep water a friction winch with a small motor has been purchased, and this renders work both easy and relatively speedy.

At the inside station Mr. Orr reports that temperature has risen steadily to 29° C. at the surface and 28.8° C. in deeper water, while salinity has fallen and continues to fall as a result of the heavy rains. On several occasions there has been a definite gradient in temperature and salinity, accompanied by a fall in oxygen saturation in the deepest layers, though without any production of phosphate, but this has never lasted more than a week at a time or ever been considerable enough to withstand a wind of more than 20 miles per hour. The hydrogen ion concentration has remained steady throughout. Observations made at a depth of 600 metres beyond the Barrier showed that temperature was constant down to 50 metres, beyond which it fell rapidly to 10.9° C. at 600 metres. Below 50 metres, pH value and oxygen saturation sank and phosphate content rose. On Linden Bank, a coral formation beyond the Barrier and covered with 34 metres of water, the conditions were very similar to those inside the Barrier. The turbidity of the water is far less beyond than within the Barrier.

Miss S. M. Marshall and Mr. Colman are continuing routine work on the phytoplankton and zooplankton respectively. As the lack of nutrient salts in the water indicates, there has been no