MAGNETISM.[1]

II.

WHEN one considers that the magnetic property is peculiar to three substances—that it is easily destroyed by the admixture of some foreign body, as manganese—one would naturally expect that its existence would depend also on the temperature of the body. This is found to be the case. It has long been known that iron remains magnetic to a red heat, and that then it somewhat suddenly ceases to be magnetic, and remains at a higher temperature non-magnetic. It has long been known that the same thing happens with cobalt, the temperature of change, however, being higher; and with nickel, the temperature being lower. The magnetic characteristics of iron at a high temperature are interesting. Let us return to our ring, and let us suppose that the coils are insulated with a refractory material, such as asbestos paper, and that the ring is made of the best soft iron. We are now in a position to heat the ring to a high temperature, and to experiment upon it at high temperatures in exactly the same way as before. The temperature can be approximately determined by the resistance of one of the copper coils. Suppose, first, that the current in the primary circuit which we use for magnetizing the ring is small; that from time to time, as the ring is heated and the temperature rises, an experiment is made by reversing the current in the primary circuit, and observing the deflection of the galvanometer needle. At the ordinary temperature of the air the deflection is comparatively small; as the temperature increases the deflection also increases, but slowly at first; when the temperature, however, reaches something like 600° C., the galvanometer deflection begins very rapidly to increase, until, with a temperature of 770° C., it attains a value of no less than 11,000 times as great as the deflection would be if the ring had been made of glass or copper, and the same exciting current had been used. Of course, a direct comparison of 11,000 to 1 cannot be made: to make it, we must introduce resistance into the secondary circuit when the iron is used; and we must, in fact, make use of larger currents when copper is used. However, the ratio of the induction in the case of iron to that in the case of copper, at 770° C., for small forces is no less than 11,000 to 1. Now mark what happens. The temperature rises another 15° C.: the deflection of the needle suddenly drops to a value which we must regard as infinitesimal in comparison to that which it had at a temperature of 770° C.; in fact, at the higher temperature of 785° C. the deflection of the galvanometer with iron is to that with copper in a ratio not exceeding that of 1·14 to 1. Here, then, we have a most remarkable fact: at a temperature of 770° C. the magnetization of iron 11,000 times as great as that of a non-magnetic substance; at a temperature of 785° C. iron practically non-magnetic. These changes are shown in Fig. 8. Suppose now that the current in the primary circuit which serves to magnetize the iron had been great instead of very small. In this case we find a very different order of phenomena. As the temperature rises, the deflection on the galvanometer diminishes very slowly till a high temperature is attained; then the rate of decrease is accelerated until, as the temperature at which the sudden change occurred for small forces is reached, the rate of diminution becomes very rapid indeed, until, finally, the magnetism of the iron disappears at the same time as for small forces. Instead of following the magnetization with constant forces for varying temperatures, we may trace the curve of magnetization for varying forces with any temperature we please. Such curves are given in Diagrams 9 and 10. In the one diagram, for the purpose of bringing out different points in the curve, the scale of abscissæ is 20 times as great as in the other. You will observe that the effect of rise of temperature is to diminish the maximum magnetization of which the body is capable, slowly at first, and rapidly at the end. It is also very greatly to diminish the coercive force, and to increase the facility with which the body is magnetized. To give an idea of the magnetizing forces in question, the force for Fig. 8 was 0·3; and as you see from Figs. 9 and 10, the force ranges as high as 60. Now the earth's force in these latitudes is 0·43, and the horizontal component of the earth's force is 0·18. In the field of a dynamo machine the force is often more than 7000. In addition to the general characteristics of the curve of magnetization, a very interesting, and, as I take it, a very important, fact comes out. I have already stated that if the ring be submitted to a great current in one direction, which current is afterwards gradually reduced to zero, the ring is not in its non-magnetic condition, but that it is, in fact, strongly magnetized. Suppose now we heat the ring, whilst under the influence of a strong magnetizing current, beyond the critical temperature at which it ceases to have any magnetic properties, and that then we reduce the current to

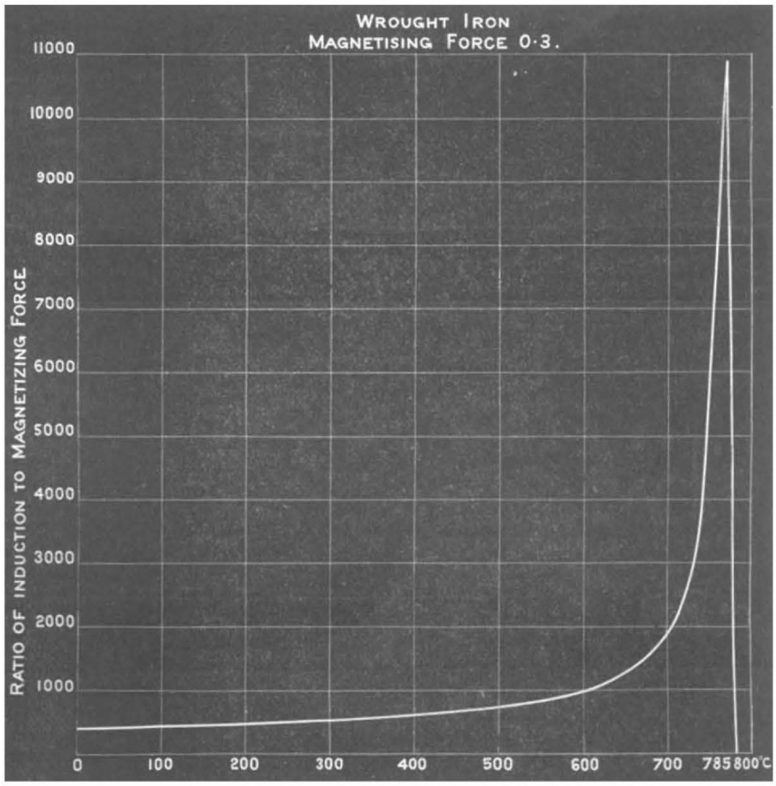

FIG. 8.

[1] Inaugural Address delivered before the Institution of Electrical Engineers, on Thursday, January 9, by J. Hopkinson, M.A., D.Sc., F.R.S., President. Continued from p. 254.

zero, we may in this state try any experiment we please. Reversing the current on the ring, we shall find that it is in all cases non-magnetic. Suppose next that we allow the ring to cool without any current in the primary, when cold we find that the ring is magnetized; in fact, it has a distinct recollection of what had been done to it before it was heated to the temperature at which it ceased to be magnetic. When steel is tried in the same way with varying temperatures, a similar sequence of phenomena is observed; but for small forces the permeability rises to a lower maximum, and its rise is less rapid. The critical temperature at which magnetism disappears changes rapidly with the composition of the steel. For very soft charcoal iron wire the critical temperature is as high as 880° C.; for hard Whitworth steel it is 690° C.

The properties of an alloy of manganese and iron are curious. More curious are those of an alloy of nickel and iron. The alloy of nickel and iron containing 25 per cent. of nickel is non-magnetic as it is sure to come from the manufacturer; that is to say, a substance compounded of two magnetic bodies is non-magnetic. Cool it, however, a little below freezing, and its properties change: it becomes very decidedly magnetic. This is perhaps not so very remarkable: the nickel steel has a low critical temperature—lower than we have observed in any other magnetizable body. But if now the cooled material be allowed to return to the ordinary temperature it is magnetic; if it be heated it is still magnetic, and remains magnetic till a temperature of 580° C. is attained, when it very rapidly becomes non-magnetic, exactly as other magnetic bodies do when they pass their critical temperature. Now cool the alloy: it is non-magnetic, and remains non-magnetic till the temperature has fallen to below freezing. The history of the material is shown in Fig. 11, from which it will be seen that from −20° C. to 580° C. this alloy may exist in either of two states, both quite stable—a magnetic and a non-magnetic—and that the state is determined by whether the alloy has been last cooled to −20° C. or heated to 580° C.

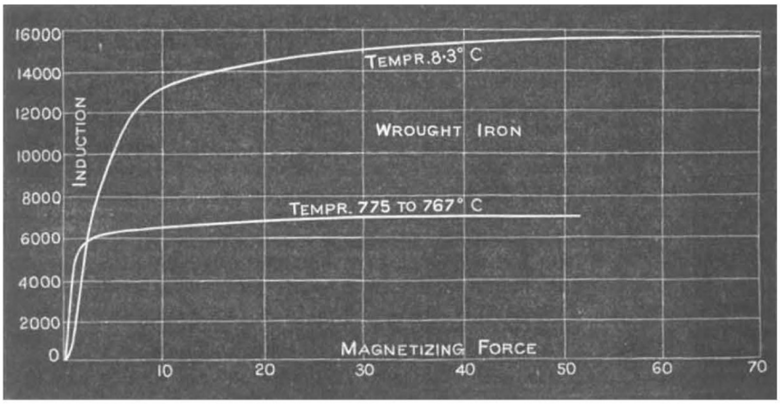

FIG. 9.

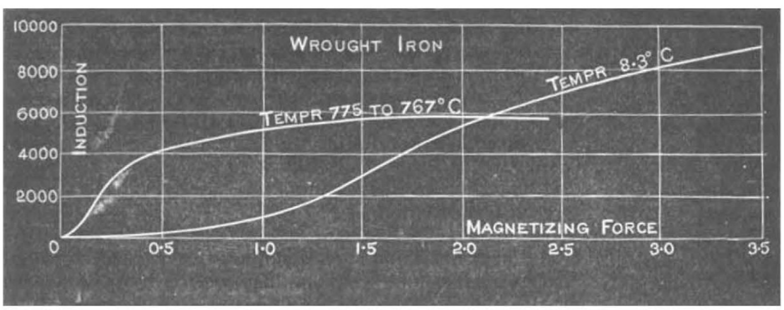

FIG. 10.

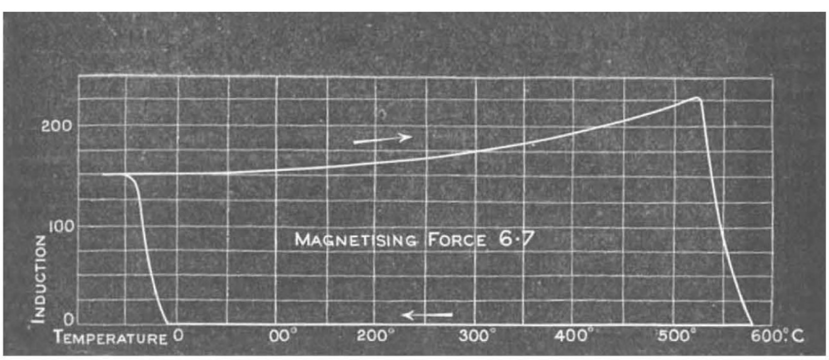

FIG. 11.

Sudden changes occur in other properties of iron at this very critical temperature at which its magnetism disappears. For example, take its electrical resistance. On the curve, Fig. 12, is shown the electrical resistance of iron at various temperatures, and also, in blue, the electrical resistance of copper or other pure metal. Observe the difference. If the iron is heated, its resistance increases with an accelerating velocity, until, when near the critical temperature, the rate of increase is five times as much as the copper; at the critical temperature the rate suddenly changes, and it assumes a value which, as far as experiments have gone, cannot be said to differ very materially from a pure metal. The resistance of manganese steel shows no such change; its temperature coefficient constantly has the value of 0·0012, which it has at the ordinary temperature of the air. The electrical resistance of nickel varies with temperature in an exactly similar manner. Again, Prof. Tait has shown that the thermo-electric properties of iron are very anomalous—that there is a sudden change at or about the temperature at which the metal becomes non-magnetic, and that before this temperature is reached the variations of thermo-electric property are quite different from a non-magnetic metal.

Prof. Tomlinson has investigated how many other properties of iron depend upon the temperature. But the most significant phenomenon is that indicated by the property of recalescence. Prof. Barrett, of Dublin, observed that if a wire of hard steel is heated to a very bright redness, and is then allowed to cool, the wire will cool down till it hardly emits any light at all, and that then it suddenly glows out quite bright again, and afterwards finally cools. This phenomenon is observed with great difficulty in the case of soft iron, and is not observed at all in the case of manganese steel. A fairly approximate numerical measurement may be made in this way: Take a block of iron or steel on which a groove is cut, and in this groove wind a coil of copper wire insulated with asbestos; cover the coil with many layers of asbestos; and finally cover the whole lump of iron or steel with asbestos again. We have now a body which will heat and cool comparatively slowly, and which will lose its heat at a rate very approximately proportional to the difference of temperature between it and the surrounding air. Heat the block to a bright redness, and take it out of the fire and observe the resistance of the copper coil as the temperature falls, due to the cooling of the block. Plot a curve in which the abscissæ are the times, and the ordinates the logarithms, of the increase of resistance of the copper coil above its resistance at the temperature of the room. If the specific heat of the iron were constant, this curve would be a straight line; if at any particular temperature latent heat were liberated, the curve would be horizontal so long as the heat was being liberated. If now a block be made of manganese steel, it is found that the curve is very nearly a straight line, showing that there is no liberation of latent heat at any temperature. If it is made of nickel steel with 25 per cent. of nickel, in its non-magnetic state, the result is the same—no sign of liberation of heat. If now the block be made of hard steel, the temperature diminishes at first; then the curve (Fig. 13) which represents the temperature bends round: the temperature actually rises many degrees whilst the body is losing heat. The liberation of heat being completed, the curve finally descends as a straight line. From inspection of this curve it is apparent why hard steel exhibits a sudden accession of brightness as it yields up its heat. In the case of soft iron the temperature does not actually rise as the body loses heat, but the curve remains horizontal, or nearly horizontal, for a considerable time. This, again, shows why, although a considerable amount of heat is liberated at a temperature corresponding to the horizontal part of the curve, no marked recalescence can be obtained. From curves such as these it is easy to calculate the amount of heat which becomes latent. As the iron passes the critical point it is found to be about 200 times as much heat as is required to raise the temperature of the iron 1 degree Centigrade. From this we get a very good idea of the importance of the phenomenon. When ice is melted and becomes water, the heat absorbed is 80 times the heat required to raise the temperature of the water 1 degree Centigrade, and 160 times the heat required to raise the temperature of the ice by the same amount. The temperature of recalescence has been abundantly identified with the critical temperature of

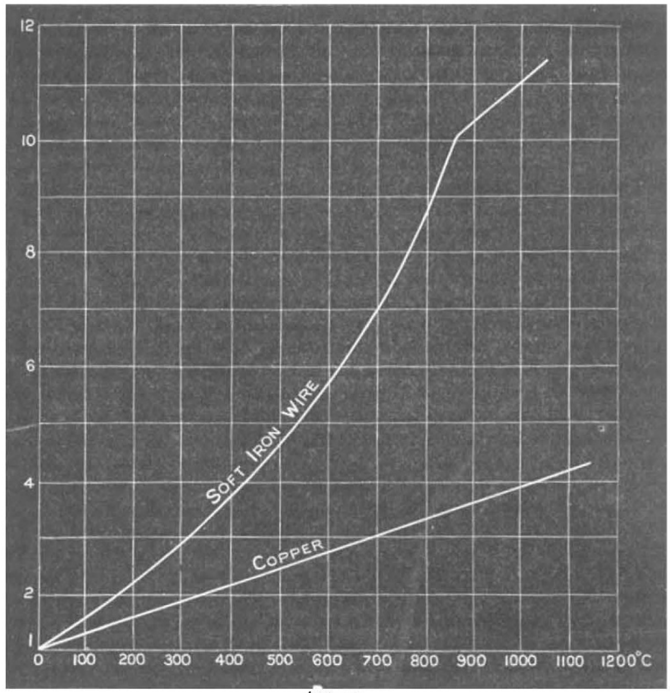

FIG. 12.

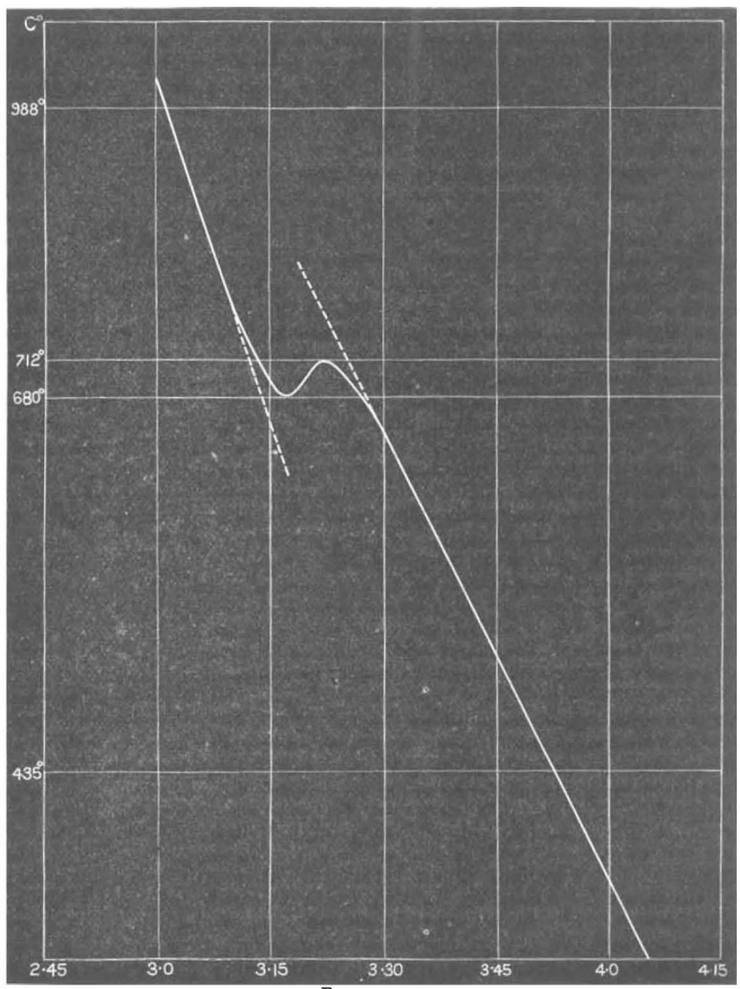

FIG. 13.

magnetism.[1] I am not aware that anything corresponding with recalescence has been observed in the case of nickel. Experiments have been tried, and gave a negative result, but the sample was impure; and the result may, I think, be distrusted as an indication of what it would be in the case of pure nickel. The most probable explanation in the case of iron, at all events, appears to be that when iron passes from the magnetic to the non-magnetic state it experiences a change of state of comparable importance with the change from the solid to the liquid state, and that a large quantity of heat is absorbed in the change. There is, then, no need to suppose chemical change; the great physical fact accompanying the absorption of heat is the disappearance of the capacity for magnetization.

What explanations have been offered of the phenomena of magnetism? That the explanation must be molecular was early apparent. Poisson's hypothesis was that each molecule of a magnet contained two magnetic fluids, which were separated from each other under the influence of magnetic force. His theory explained the fact of magnetism induced by proximity to magnets, but beyond this it could not go. It gave no hint that there was a limit to the magnetization of iron—a point of saturation; none of hysteresis; no hint of any connection between the magnetism of iron and any other property of the substance; no hint why magnetism disappears at a high temperature. It does, however, give more than a hint that the permeability of iron could not exceed a limit much less than its actual value, and that it should be constant for the material, and independent of the force applied. Poisson gave his theory a beautiful mathematical development, still useful in magnetism and in electrostatics.

Weber's theory is a very distinct advance on Poisson's. He supposed that each molecule of iron was a magnet with axes arranged at random in the body; that under the influence of magnetizing force the axes of the little magnets were directed to parallelism in a greater degree as the force was greater. Weber's theory thoroughly explains the limiting value of magnetization, since nothing more can be done than to direct all the molecular axes in the same direction. As modified by Maxwell, or with some similar modification, it gives an account of hysteresis, and of the general form of the ascending curve of magnetization. It is also very convenient for stating some of the facts. For example, what we know regarding the effect of temperature may be expressed by saying that the magnetic moment of the molecule diminishes as the temperature rises, hence that the limiting moment of a magnet will also diminish; but that the facility with which the molecules follow the magnetizing force is also increased, hence the great increase of μ for small forces, and its almost instantaneous extinction as the temperature rises. Again, in terms of Weber's theory, we can state that rise of temperature enough to render iron non-magnetic will not clear it of residual magnetism. The axes of the molecules are brought to parallelism by the force which is impressed before and during the time that the magnetic property is disappearing; they remain parallel when the force ceases, though, being now non-magnetic, their effect is nil. When, the temperature falling, they become again magnetic, the effect of the direction of their axes is apparent. But Weber's theory does not touch the root of the matter by connecting the magnetic property with any other property of iron, nor does it give any hint as to why the moment of the molecule disappears so rapidly at a certain temperature.

Ampère's theory may be said to be a development of Weber's: it purports to state in what the magnetism of the molecule consists. Associated with each molecule is a closed electric current in a circuit of no resistance; each such molecule, with its current, constitutes Weber's magnetic molecule, and all that it can do they can do. But the great merit of the theory—and a very great one it is—is that it brings magnetism in as a branch of electricity; it explains why a current makes a magnetizable body magnetic. It also gives, as extended by Weber, an explanation of diamagnetism. It, however, gives no hint of connecting the magnetic proporties of iron with any other property. Another difficulty is this: When iron ceases to be magnetizable, we must assume that the molecular currents cease. These currents represent energy. We should therefore expect that, when iron ceased to be magnetic by rise of temperature, heat would be liberated; the reverse is the fact.

So far as I know, nothing that has ever been proposed even attempts to explain the fundamental anomaly. Why do iron, nickel, and cobalt possess a property which we have found nowhere else in nature? It may be that at lower temperatures other metals would be magnetic, but of this we have at present no indication. It may be that, as has been found to be the case with the permanent gases, we only require a greater degree of cold to extend the rule to cover the exception. For the present, the magnetic properties of iron, nickel, and cobalt stand as exceptional as a breach of that continuity which we are in the habit of regarding as a well proved law of Nature.

[1] I have only recently become acquainted with the admirable work of M. Osmond on recalescence. He has examined a great variety of samples of steel, and determined the temperatures at which they give off an exceptional amount of heat. Some of his results are apparent on my own curves, though I had assumed them to be mere errors of observation. For example, referring to my Royal Society paper, there is, in Fig. 38, a hint of a second small anomalous point a little below the larger one. And, comparing Figs. 38 and 38A, we see that the higher the heating, the lower is the point of recalescence; both features are brought out by M. Osmond The double recalescence observed by M. Osmond in steel with a moderate quantity of carbon I would explain provisionally by supposing this steel to be a mixture of two kinds which have different critical temperatures. Although M. Osmond's method is admirable for determining the temperature of recalescence, and whether it is a single point or multiple, it is not adapted to determine the quantity of heat liberated, as the small sample used is inclosed in a tube of considerable mass, which cools down at the same time as the sample experimented upon.

NOTES ON A RECENT VOLCANIC ISLAND IN THE PACIFIC.

In 1867, H.M.S. *Falcon* reported a shoal in a position in about 20° 20′ S., and 175° 20′ W., or 30 miles west of Namuka Island of the Friendly or Tonga Group.

In 1877 smoke was reported by H.M.S. *Sappho* to be rising from the sea at this spot.

In 1885 a volcanic island rose from the sea during a submarine eruption on October 14, which was first reported by the *Janet Nichol*, a passing steamer, to be 2 miles long and about 250 feet high.

The U.S.S. *Mohican* passed it in 1886, and from calculation founded on observations in passing, gave its length as $1\frac{4}{10}$ miles, height 165 feet. The crater was on the eastern end, and dense columns of smoke were rising from it.

In 1887 the French man-of-war *Decres* reported its height to be 290 feet.

In the same year an English yacht, the *Sybil*, passed it, and a sketch was made by the owner, H. Tufnell, Esq., which is here produced.

The island has now been thoroughly examined and mapped, and the surrounding sea sounded by H.M. surveying-ship *Egeria*, Commander Oldham.

It is now $1\frac{1}{10}$ mile long, and $\frac{9}{10}$ of a mile wide, of the shape given in the accompanying plan. The southern portion is high, and faced by cliffs on the south, the summit of which is 153 feet above the sea. A long flat stretches to the north from the foot of the hill.

The island is apparently entirely formed of ashes and cinders, with a few blocks and volcanic bombs here and there, especially on the verge of the hill.

Under the action of the waves, raised by the almost constant south-east winds, this loose material is being rapidly removed; continual landslips take place, and Commander Oldham is of opinion that the original