broad bands by absorption. I have never expressed the opinion, that the disappearance of the light between the D-lines in the absorption spectrum of dense sodium vapour is only a result of the strong dispersion; but I warned against always ascribing the observed dark bands to absorption only.

Wood's recent researches are very important as a contribution to our knowledge of dispersion in general. For the present their bearing on the spectral phenomena exhibited by the light from the chromosphere and from sun-spots, seems not to be so direct, because, most probably, the density of the vapours is much less in the solar atmosphere than in the dispersion tubes used by Wood in his brilliant experiments.

"On the Increase of Electrical Resistivity caused by Alloying Iron with Various Elements, and the Specific Heat of those Elements." By W. F. BARRETT, F.R.S., Professor of Experimental Physics in the Royal College of Science for Ireland. Received December 16, 1901—Read February 6, 1902.

In the following note I wish to draw attention to a connection which appears to exist between the electric conductivity of certain alloys of iron and the specific heats, and hence atomic masses, of the particular elements with which the iron is alloyed. In a paper published in the 'Transactions' of the Royal Dublin Society the electric conductivity and magnetic permeability of a very large and, I believe, unique collection of alloys of iron is given.* These alloys, it may be mentioned, have been prepared with great care by my friend, Mr. R. A. Hadfield, Managing Director of the Hecla Steel Works, Sheffield. Of the alloys made, 110 different specimens were found homogeneous, and could be forged and rolled; these were analysed at the Hecla works, and submitted to similar heat treatment—all being carefully annealed under the direction of Mr. Hadfield.

The specimens were in the form of rods, of nearly circular cross-section, about one-half a centimetre in diameter and 104 cms. long. The conductivities were found by the potential method, a standard of pure copper being employed. Although the determination of the mean sectional area of the specimens was made with great care, by numerous measurements of each rod with a micrometer screw, and also by means of water displacement, yet, owing to slight irregularities in the diameters of the rods, and the numerical importance of this value in

* "On the Electrical Conductivity and Magnetic Permeability of Various Alloys of Iron," by W. F. Barrett, F.R.S., W. Brown, B.Sc., and R. A. Hadfield, M.Inst. C.E., 'Trans. Royal Dublin Society,' January, 1900.

estimating the conductivity, the results obtained can only be regarded as a more or less close approximation to the true value.*

A more formidable difficulty is the impossibility of obtaining such a collection of alloys free from the admixture of disturbing impurities. Slight variations in the amount of these impurities, especially in the amount of carbon present, produce in the low percentages a profound effect on the conductivity and also on other physical properties of these alloys. However, in most of the specimens Mr. Hadfield has succeeded in reducing these impurities to a lower amount than any other large collection of alloys yet made. Carbon, manganese, and silicon were the impurities most commonly present, and the sum of these in the specimens selected was, as a rule, under 1 per cent.

There were sixty-eight specimens of these alloys having various percentages of a single element added to iron; these were as follows (the element with which the iron is alloyed being named in the first column):—

Manganese....	18	specimens	ranging from	$\frac{1}{2}$	to	$18\frac{1}{2}$	per cent. of	Mn.
Carbon	13	,,	,,	$\frac{1}{30}$	,,	$1\frac{1}{4}$	,,	C.
Nickel	12	,,	,,	$\frac{1}{2}$	,,	31	,,	Ni.
Tungsten	4	,,	,,	1	,,	$15\frac{1}{2}$	,,	W.
Chromium....	3	,,	,,	2	,,	$9\frac{1}{2}$	,,	Cr.
Copper.......	3	,,	,,	$1\frac{1}{2}$	,,	3	,,	Cu.
Aluminium...	3	,,	,,	$\frac{3}{4}$	,,	$2\frac{1}{2}$	,,	Al.
Silicon	2	,,	,,	$2\frac{1}{2}$	,,	$5\frac{1}{2}$	,,	Si.

In addition to these there were fifty-two other specimens having two or more of the above elements alloyed to iron in various proportions.

In every case, with the doubtful exception of copper,† a decrease in conductivity was found to result from alloying iron with another metal, even when that element, as in the case of aluminium, had itself a conductivity far higher than that of the iron. From the conductivities of the specimens, their specific resistances were calculated; these were plotted against the percentages of the added element. A series of fairly smooth curves were thus obtained for each alloy. These curves are shown in fig. 1. It will be noticed that the addition of silicon or aluminium to iron produces the greatest increase in electric resistance and tungsten the least, and that a remarkable change in the electric resistivity of nickel steels occurs at high percentages. There is obviously no connection between these curves and the electric conduc-

* It was satisfactory, however, to find that in a dozen or more specimens which were drawn into wire, and the specific resistances of which were measured in the ordinary way, the results obtained corroborated the values found from the rods.

† The specimens of copper-iron alloy were very few, and the results masked by the varying impurities they contained; very little alteration of the conductivity appeared to be produced by the addition of copper to iron.

tivity of the added element; *e.g.*, the metal aluminium is a far better conductor than nickel, and yet alloyed with iron it decreases the conductivity of iron far more than nickel. Silicon and aluminium alloys of iron are extremely soft, and we should expect them to be better conductors than the hard tungsten steels, and far better than the

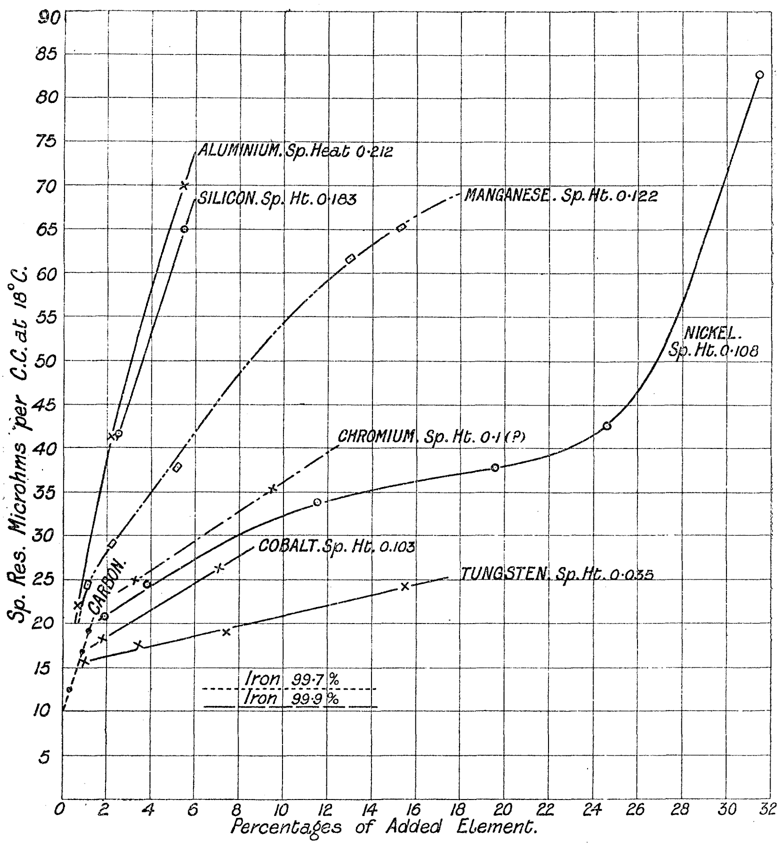

Fig. 1.—Specific Electric Resistance of Alloys of Iron.

manganese steels, which are very hard, but the reverse is the case. Owing to their extreme softness, the alloys of silicon and aluminium with iron have an enormously high magnetic permeability, which will be referred to in the sequel.

The resistance of iron containing 0·1 and 0·3 per cent. of carbon and other impurity is shown by the horizontal dotted lines in fig. 1. From these data the *increase* of resistance produced by alloying iron with a given percentage of any of the elements named can be determined by

selecting that specimen of iron which has about the same carbon or other impurity as that contained in the particular alloy and subtracting the resistance of the iron. The result is shown in the next table.

Table I.—Approximate *Increase* in Electric Resistivity (in microhms per c.c. at 18° C.) of Annealed Iron Alloys produced by adding to Iron Different Percentages of the Elements named in the first column.

Alloys of iron with	Percentage of added element.			
	2 per cent.	3 per cent.	5 per cent.	
Tungsten	4·0	5·0	6·0	microhms
Nickel	7·0	9·0	13·0	,,
Chromium	10·0	11·5	14·0	,,
Manganese	16·0	18·0	24·5	,,
Silicon	26·0	34·0	49·0	,,
Aluminium	28·0	36·0	54·0	,,

Dividing these values by the percentage at the head of each column, it will be seen that as the alloy becomes richer in the added element the increase of electric resistivity becomes less and less for every *one* per cent. of the element added. The comparative effect of carbon is difficult to ascertain owing to various causes, (*a*) the impossibility of making homogeneous alloys of iron with large percentages of carbon, the highest carbon in our specimens being $1\frac{1}{4}$ per cent.; (*b*) the different conditions in which the carbon may exist in the alloy; and (*c*) the difficulty of excluding impurities such as manganese and silicon, minute amounts of which exert a serious effect on the conductivity. However, by comparing the conductivity of alloys of iron having nearly similar quantities of Si and Mn, but containing different quantities of carbon, a close approximation of the effect of this element on the conductivity of iron is arrived at. The result shows that the increase of *one-tenth of one per cent.* of carbon in iron containing 0·03 carbon causes an increase in the specific resistance of nearly 2 microhms per c.c., but when the carbon is raised from 0·13 to 1·13 the increase in specific resistance is at the rate of 5 microhms for 1 per cent. of added carbon, about one-fourth of the rate of increase at the smaller percentages. The position of carbon on Table I therefore appears to lie near to chromium. From specimens of two impure alloys containing cobalt with iron, the increase of resistance produced by cobalt was estimated to be somewhat less than nickel but greater than tungsten; its position in Table I would therefore appear to lie near to nickel.

If now we compare the increase of resistance in iron produced by alloying it with these elements, with the atomic weights of the added elements, we find, as a rule, that those elements with the *highest*

atomic weight produce the *least* increase in electric resistivity and *vice versâ*. For the sake of such a comparison, the *molecular* weights of these elements, if we knew them, rather than the atomic weights, should be taken. This is especially true in the case of carbon, the molecular weight of which, if this analogy holds good, would appear to be four times its atomic weight. If, instead of the atomic weights, we take the *specific heats* of these elements, so far as they are known, we are likely to arrive at a better knowledge of their relative atomic or molecular masses, and a comparison of the order of specific heats with the order of increase of electric resistivity is very striking. This is shown in the next table.*

Dividing the increase in electric resistivity by the percentage of the added metal, we obtain the increase in the specific resistance of iron produced by 1 per cent. of the added element. This is shown for a 2 per cent. alloy (except in the case of carbon) in the second column of Table II, along with the specific heats and atomic weights of the elements named in the first column.

Table II.

Alloy of iron.	Increase of resistivity for 1 per cent.	Specific heat.	Atomic weight.
Tungsten	2·0	0·035	184
Cobalt	3·0	0·107	59
Nickel	3·5	0·109	59
Chromium	5·0	0·1 (?)	52
Carbon†	5·0	0·160‡	12
Manganese	8·0	0·122	55
Silicon	13·0	0·183	28
Aluminium	14·0	0·212	27

I venture to think that the correspondence shown in columns 2 and 3 of the foregoing table is something more than a chance coincidence. It is, however, desirable to have exact determinations of the resistivity of a larger number of alloys of iron before any definite conclusions can be reached.

A series of experiments are in progress for the measurement of the relative *thermal* conductivity of the foregoing alloys. About forty determinations have been made, and so far the order of thermal

* The values for the specific heats are taken from Landolt and Börnstein's great work on Physical Constants. The specific heat determinations are chiefly by Regnault, between 9° and 97° C.

† For a 1 per cent. alloy.

‡ As *graphite*; as *diamond* the specific heat of carbon is 0·113, according to H. F. Weber.

conductivity has been found to be the same as that of their electrical conductivity.

As regards the *magnetic permeability* of these alloys, the order is very different from that of their electric conductivity. The most highly permeable alloys are those formed of aluminium and silicon with iron. In fact, the magnetic permeability of an alloy of iron with $2\frac{1}{2}$ per cent. of silicon exceeds that of the best and purest annealed iron up to a field of 10 C.G.S. units. Still more remarkable is a pure and well annealed alloy of aluminium and iron; although it contains a considerable percentage of non-magnetic elements, its magnetic permeability and maximum induction up to a field of 60 units exceeds the best and purest annealed iron that I can obtain, a specimen of Swedish charcoal iron containing 99·9 per cent. of iron, all the specimens having been subjected to a precisely similar annealing process.

It is possible the increased magnetic susceptibility given to iron by aluminium, and to a less extent by silicon, may be due to the strong chemical affinity which these elements have for oxygen, whereby any of this gas which might be dissociated in the molten iron would be removed, and the texture of the metal thus rendered closer and more uniform. In the same way, by combining with the oxygen, they would remove, as my colleague Professor Hartley suggests, traces of oxide of iron, more or less diffused through all iron; and the presence of which would certainly lower the magnetic susceptibility.

The remarkable magnetic properties of these two alloys, especially of the aluminium-iron alloy, is a matter not only of considerable theoretic interest but obviously is also of great practical importance in electrical engineering.

"On a Pair of Ciliated Grooves in the Brain of the Ammocœte apparently serving to promote the Circulation of the Fluid in the Brain-cavity."

By Arthur Dendy, D.Sc., F.L.S., Professor of Biology in the Canterbury College, University of New Zealand. Communicated by Professor G. B. Howes, LL.D., F.R.S. Received February 7,—Read February 20, 1902.

The peculiar and apparently hitherto undescribed structures which form the subject of the present communication, were first discovered in the course of an as yet unfinished investigation of the parietal organs in the New Zealand Lamprey (*Geotria australis*). The Ammocœte of this interesting species is known to us only through two specimens: