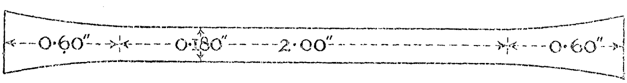
observed on the other. When S represents areas of whole sun-spots or of umbræ, the agreement between observed and calculated ranges is nearly though not quite as good, especially in horizontal force, as when S represents Wolfer's sun-spot frequencies; but when S represents areas of faculæ the agreement is much inferior, especially in years of sun-spot maximum. The mean differences between the ranges calculated from Wolfer's frequencies, and from either the spot areas or the umbræ is considerably less than between any one of the three sets of calculated ranges and the observed ranges. Also the differences between the observed ranges and those calculated from Wolfer's frequencies nearly always possess the same sign at Kew and Falmouth.

Both phenomena point to the conclusion that the differences between observed magnetic ranges at individual stations, and those calculated from any of the above measures of solar disturbance, though small, cannot be regarded as wholly fortuitous.

"The Effect of Liquid Air Temperatures on the Mechanical and other Properties of Iron and its Alloys." By Sir JAMES DEWAR, F.R.S., Hon. M.I.C.E., and ROBERT ABBOTT HADFIELD, M.I.C.E., President elect Iron and Steel Institute. Received November 24,—Read December 8, 1904.

As many iron alloys have shown anomalous results in their physical behaviour at ordinary temperatures, it became advisable to ascertain the exact effect of very low temperatures upon such bodies, and, accordingly, a series of tests were carried out on standard iron and iron alloyed with other elements, the specimens being selected from a large collection made by one of the authors, which is located at the Hecla Works, Sheffield. In the course of the enquiry some 500 specimens have been examined, and the detailed description of each test will appear later on in a special Monograph. In the meantime the more important results are submitted to the Royal Society.

For the purpose of the experiments, the irons were taken in the form of forged bars, and the iron alloys in the form of cast ingots $2\frac{1}{2}$ inches square. They were then carefully heated to the required forging temperatures and reduced to rods $\frac{1}{4}$-inch diameter, and from these rods finished test-bars 0·180 inch diameter were accurately machined to the following sketch:—



The bars were then forwarded to the Royal Institution Laboratory, and there tested in a small hydraulic testing machine, similar in principle to that described in 'Proceedings of the Royal Institution, 1894,' to which the necessary arrangements could be applied for breaking the specimens while immersed in liquid air.

The present research confirms, in a larger field, the conclusions set forth in the discourse of one of the authors at the Royal Institution in 1894 on the "Scientific Uses of Liquid Air," in which the results of tests on metallic wires and cast metals at low temperatures were discussed. The results of the present series of tests corroborate the inference previously drawn, viz., that all common metals and alloys increase in tenacity at low temperatures, and this whether the ductility increases or decreases, and, further, that the increase of tenacity is solely due to the low temperature, and persists only during its continuance.

The Results of Low Temperatures on Irons.—The first specimen examined in this class was Swedish charcoal iron, this material in its composition most nearly approaching that of pure iron. The analysis of this specimen gave C 0·045, Si 0·07, S 0·005, P 0·004, Mn trace, Fe 99·82 per cent. This iron, after careful annealing, gave 20 tons per square inch tenacity and 20 per cent. elongation at normal temperature; after cooling in liquid air the tenacity rose to 38 tons, with substantially no elongation. Another specimen, after being quenched at 950° C. and again at 600° C. in water, showed similar results in liquid air. Two other specimens in the unannealed condition and one after special heat treatment, showed similar properties. Specimens immersed in liquid air and allowed to return to the normal temperature before testing, showed almost exactly the same tenacity and elongation as before cooling, showing that the brittleness is entirely a function of temperature.

Several specimens were then quenched from 600° C., 800° C., and 950° C. in liquid air, and allowed to return to the normal temperature before testing. It might have been expected that with this extraordinary chilling a considerable hardening effect would have been noticed, but singular to say, whilst the tenacity is practically the same in each case, the ductility is improved rather than reduced. It may be mentioned that the specimens quenched from high temperatures in liquid air remained red hot in the liquid air much longer than would have been expected. In order to determine the hardness of these Swedish charcoal irons, a series of tests were carried out by the Brinell ball test, which showed that the hardness is increased nearly 200 per cent. by quenching in liquid air. The specimens, though, no doubt, much stiffer than at normal temperature, could be readily filed at $-182°$ C. Magnetic tests also showed that no marked change takes place at low temperature as regards this quality.

In order to determine whether there is a critical point where the abnormal rise in tenacity and loss of ductility occurred, four specimens were tested at + 18° C., − 80° C., − 100° C., and − 193° C. respectively. The results clearly show that there is no critical point, *i.e.*, gradual decrease in temperature is accompanied by gradual increase in tenacity.

Other irons tested were L.S.S. Swedish iron, English Bowling, and Cooke iron, all showing increase in tenacity and corresponding decrease in ductility upon quenching in liquid air.

The next class are *Iron-Carbon Alloys.* This class is of special interest and importance, as upon the various percentages of carbon present in steel depend chiefly its physical properties. The specimens first dealt with are those in which manganese is absent, or present in only very small quantities. Test No. 74 (C 0·14, Si 0·08, Mn 0·07 per cent.) represents very mild or soft steel; it enables a comparison to be drawn between the Swedish charcoal iron previously described and soft steel. In the case of this specimen the tenacity was nearly trebled, but it is apparently more ductile than Swedish charcoal iron. A specimen containing (C 0·78 per cent.) showed a considerable rise in tenacity in liquid air, the ductility being reduced to practically nil. A specimen of the same material was also submitted to the liquid air temperature, and allowed to return to normal temperature before testing; it showed a similar result to the original specimen not so treated. It may, therefore, be said that the effect produced by liquid air is of a physical and temporary character.

Other specimens, viz., Nos. 115 (C 0·83, Mn 0·25 per cent.), 9 (C 0·85, Mn 0·32 per cent.), 10 (C 1·09, Mn 0·32 per cent.), 13 (C 1·23, Mn 0·14 per cent.) showed the usual behaviour at liquid air temperature. Specimens of No. 115 (C 0·83 per cent.) were then quenched in liquid air from 700° C. and 750° C. respectively, and tested at normal temperature. As with the Swedish charcoal iron, the quenching from these comparatively high points has not produced the effect that might be expected; in fact, instead of the ductility being reduced, it is now quite considerable, viz., 13 per cent. from the 700° C. and 8 per cent. from the 750° C. Specimens of No. 13 (C 1·23 per cent.) also showed the same singular effects after quenching from 700° C. and 750° C. in liquid air. It is certainly most remarkable that a specimen containing $1\frac{1}{4}$ per cent. C., suddenly lowered 930° C., is so little injured as regards ductility. If these specimens had been quenched from the same condition in ordinary water or oil, they would have been unfileable and of extraordinary hardness. These specimens were as magnetic at − 182° C. as at normal temperature, and readily fileable.

In connection with this series, specimens were also taken of various iron-carbon alloys in which the Mn percentage was higher than in

the preceding specimens, *e.g.*, Test Nos. 110 (C 0·19, Mn 0·52 per cent.), 1 (C 0·20, Mn 0·50 per cent.), 2 (C 0·50, Mn 1·00 per cent.), 3 (C 0·58, Mn 0·58 per cent.), 5 (C 0·75, Mn 1·00 per cent.), 11 (C 1·05, Mn 0·58 per cent.), 12 (C 1·20, Mn 0·62 per cent.), 31 (C 1·68, Mn 1·11 per cent.). All these specimens showed the usual rise in tenacity and fall in ductility, and although Specimen No. 31 is of abnormally high carbon, yet this does not appear to have interfered with the ordinary effect of the liquid air treatment. In the case of Test No. 1, after quenching specimens of the same material in liquid air from 700° C. and 750° C., the same peculiar behaviour was noticed as previously described, *i.e.*, considerable increase in ductility.

Having now dealt with the iron-carbon alloys, the various other alloys may be dealt with :—

Iron and Silicon
Iron and Aluminium
Iron and Tungsten
Iron and Chromium
Iron and Copper

Specimens were tested representing all these alloys, but the results do not call for any special comment, the usual increase in tenacity and fall in ductility being noticeable at low temperature.

Iron and Nickel.—Specimen No. 45 (C 0·26, Ni 0·58 per cent.). Although the liquid air doubles the tenacity, probably owing to the lower carbon and the presence of nickel, the elongation is not reduced to the extent noticed in previous specimens. This is important, and gives material proof that the brittleness of iron at low temperatures can be modified by another element, provided the carbon is not present in any considerable percentage. In another specimen, No. 46 (C 0·14, Ni 1·92 per cent.), the nickel appears to vigorously assert itself, as the ductility at − 182° C. only decreases from 20—12 per cent., the tenacity increasing from 34—59 tons. In Specimens Nos. 49 (C 0·19, Ni 3·82 per cent.) and 50 (C 0·18, Ni 11·39 per cent.), the remarkable effect of nickel is noticeable, as, whilst the tenacity rises considerably in both cases, the ductility remains practically unaltered. The tenacity rose in a further specimen, No. 54 (C 0·16, Ni 24·51 per cent.), in which the nickel is very high, from 90—118 tons at − 182° C., the ductility being only reduced from 12—10 per cent. The specimens were non-magnetic both at normal and at liquid air temperature. The same material showed an increase of from 306—524 in hardness under the liquid air treatment.

Iron and Manganese.—These form an important class. The peculiar alloy of iron and manganese, known as "Manganese Steel," is non-magnetic, and it is possible to produce similar alloys of iron and manganese even when the former element is present in as high a proportion as 87—88 per cent. Excellent results as regards physical properties can be obtained upon exceeding $1\frac{1}{4}$ and up to $2\frac{1}{4}$ per cent., provided the carbon is low. From about 3—7 per cent. the material

is comparatively brittle, even with low carbon. Upon exceeding 7 per cent. the material now known as "Era" manganese steel is formed, and continues up to 17 or 18 per cent. Manganese steel proper is the alloy containing 11—15 per cent. of manganese with carbon varying from 0·80—1·40 per cent.

We will deal first with manganese steels having low carbon, *i.e.*, under 0·30 per cent. Test No. 14 (C 0·08, Mn 3·50 per cent.), the usual rise in tenacity and loss in ductility occurs at $-182°$ C., and on the specimen being allowed to return to normal temperature it does not appear to be injured in any way. Samples Nos. 15, 16, and 17 (Mn varying from 5·40—15·28 per cent.), which are extremely brittle at normal temperature, show very little modification at the low temperature.

Dealing now with alloys having higher percentages of carbon, several specimens tested with Mn ranging from 2·23 to 11·53 per cent. with carbon increasing proportionately from 0·41—1·66 per cent. showed normal behaviour at low temperature. An interesting specimen No. 26 (C 1·23, Mn 12·64 per cent.) was examined, representing a normal "Hadfield's Era manganese steel." At normal temperature this gave 56 tons tenacity, with the high elongation of 30 per cent., and after immersion in liquid air showed a slight rise in tenacity, the elongagation, however, falling to 2½ per cent., the low temperature thus entirely de-toughening the material. This result is somewhat unexpected, as it might have been anticipated that the great ductility of this material at normal temperature would not have been interfered with to any great extent at the low temperature. In the ordinary treatment of Mn steel for toughening, the sudden drop in temperature is about 1000° C., and in the liquid air only 200° C. A repetition test, No. 26A, gave a similar result, the tenacity at normal temperature being 65 tons, with 40 per cent. elongation, while at $-182°$ C. the ductility dropped to nil, the tenacity remaining the same, viz., 64 tons.* Similar specimens of this steel cooled down and allowed to return to normal temperature again exhibited the usual extraordinary toughness of the material, thus showing that the de-toughening or embrittling action is only temporary, as with the Swedish charcoal iron and ordinary steel specimens.

It is certainly curious to find that a specimen of steel, which only a few moments before would break in the easiest manner, can again be bent double. This is produced by a change in temperature conditions of about 200° C. These results also show that manganese steel, notwithstanding its many peculiarities, in this respect falls into line with and is subject to the same laws as iron

* It is very extraordinary that the metal iron, no matter what its treatment, never becomes so ductile as the treated and quenched manganese steel—mainly composed of iron—with an original ductility of 40 per cent.

and ordinary steels. It is therefore all the more curious that the iron-nickel-manganese alloy (1414B) described later, entirely differs in this respect, where the effect of low temperature is not only nil, but there is a positive increase in ductility. The ball tests on specimen No. 26 shows an increase in hardness at $-182°$ C. of 70 per cent., viz., from 205 to 372. Three other specimens, Nos. 26 E, F, and G are also interesting as showing the effect of quenching upon Mn steel, from temperatures of 605°, 800°, and 950° C. in liquid air, the tests being then carried out at normal temperatures. The specimens E and F give similar results to those that would be obtained by quenching in ordinary cold water at 600° and 800° C., *i.e.*, little or no increase in ductility. On the other hand, in specimen 26 G, quenched from 950° C., there is no doubt the result obtained, 66 tons tenacity with 38 per cent. elongation, is excellent, but it is not any better than can be obtained by quenching in water at 15° C. It is important to here mention that the three specimens E, F, G, were all non-magnetic at $-182°$ C., showing that there is no change in the magnetic properties of manganese steel at low temperatures. This experiment finally settles quite a number of misunderstandings in metallurgical literature which have arisen on this subject, namely, that at no range of increase or decrease in temperature (provided this is not, as regards high temperature, sustained for any length of time) does any marked change in magnetic property occur in manganese steel.

The effect of low temperature on *Iron alloyed with Two other Main Elements.* Taking first the alloys of *Iron, Nickel,* and *Chromium.* Tests Nos. 78 (C 0·25, Cr 0·64, Ni 2·67 per cent.) and 81 (C 0·89, Cr 2·00, Ni 1·92 per cent.).—In the first instance in the presence of low carbon the nickel shows its toughening influence, as at $-182°$ C. the tenacity rises from 38 to 61 tons, the elongation only falling from 20—17 per cent. In the latter specimen the effects of the nickel are not so apparent owing to the higher carbon, but the elongation does not entirely disappear. Another specimen of this latter material after quenching in oil at 760° C., and then water at 650° C. showed an increase in tenacity at $-182°$ C. of from 81—105 tons, the elongation being, however, reduced from 7½ per cent. to nil. The embrittling influence of the carbon is seen in both instances. In the next specimen, No. 79 (C 0·31, Cr 1·80, Ni 2·60 per cent.), the ductility is not affected, remaining at 15 per cent. Notwithstanding the considerable presence of chromium, the nickel asserts itself in this specimen, the tenacity rising from 49—79 tons. A similar result was also noticeable in specimen No. 107 (C 0·17, Cr 1·55, Ni 3·02 per cent.), the tenacity rising to 59 tons, and the ductility dropping only from 25—20 per cent. Test No. 80 (C 0·64, Cr 2·01, Ni 12·24 per cent.).—In this specimen the very high tenacity at the normal temperature (115 tons) does not appear to be affected by the

liquid air, in other words, a steel having high tenacity at normal temperature is practically unaffected by liquid air.

Iron, Nickel, and Silicon *Iron, Manganese, and Chromium* *Iron, Manganese, and Silicon* *Iron, Chromium, and Aluminium* *Iron, Chromium, Silicon* *Iron, Chromium, Copper* *Iron, Chromium, and Tungsten*	Tests were carried out in liquid air on specimens representing these alloys, but the results do not call for any special comment, in all cases the specimens behaving in the normal manner, *i.e.*, showing increase in tenacity and decrease in ductility in liquid air.

Iron, Manganese, Copper.—Test No. 19 (C 0·25, Mn 2·01, Cu 1·39 per cent.) shows a remarkable rise in tenacity, the elongation remaining unaffected by the low temperature. It is remarkable that the copper, which is present only to the extent of $1\frac{1}{2}$ per cent., absolutely neutralises what would be the action of manganese, which clearly produces brittleness and hardness at low temperatures.

Iron, Cobalt, Manganese, Silicon *Iron, Chromium, Manganese, Silicon* *Iron Nickel, Manganese, Aluminium*	Tests were carried out on specimens representing these alloys, but the results do not call for any special comment.

Iron, Nickel, and Manganese.—In this class a number of specially interesting results were obtained. There is an important alloy, No. 1109D (C 0·60, Mn 5·04, Ni 14·55 per cent.), including two elements, which, if added separately in the same proportions to iron, would cause extreme brittleness. Most singular to say, this double combination now confers extraordinary toughness. This alloy is probably the most ductile form of iron alloy known, in several cases an elongation of no less than 75 per cent. having been obtained at normal temperature. Taking the first specimen, No. 60, under liquid air treatment, this material drops in elongation from 70—25 per cent., this remaining ductility even now being very great. This is the first specimen met with in which the ductility remains comparatively high. A further test carried out on the same steel shows a similar result. It may be mentioned that the magnetic qualities of the specimen remained unchanged at $-182°$ C. 1109D may be termed almost non-magnetic, though not so much so as manganese steel. 1109D is much more sensitive to magnetic changes by temperature, though to an ordinary magnetic test it appears inert.

The next specimen, No. 61 (C 1·00, Mn 6·05, Ni 17·91 per cent.), shows a further increase in nickel percentage, and this is clearly the factor in preventing loss of ductility at $-182°$ C., the ductility only decreasing from 57—42 per cent. Another specimen taken, No. 114

(C 1·18, Mn 6·05, Ni 24·30 per cent.) shows a still further increase in percentage of nickel. For the first time in this series of tests there is now met with a specimen in which there is an actual rise in ductility at − 182° C. The tenacity now rises from 51—84 tons, and the ductility from 60—to 67 per cent. This is remarkable. It is curious that the considerable percentage of manganese does not interfere with the toughening of the iron, of which there is 68 per cent. In any case it cannot be claimed that manganese confers this, as it must be remembered that a similar percentage of manganese in an iron alloy containing no nickel shows remarkable brittleness either at normal or low temperature. Nor does an iron alloy containing a similar high percentage of nickel and no manganese show much ductility. In face of these apparent anomalies it is difficult to offer a satisfactory explanation of the remarkable effects noticed. A repetition of the above test showed even more remarkable results, the ductility rising from 42—57 per cent.

The liquid air experiments on this series (iron, nickel, manganese) bring out in a much clearer manner than any other tests have yet done, the remarkable toughness and ductility of the iron alloys containing 6 per cent. Mn and 14—24 per cent. nickel. They show what an extraordinary molecular combination has been produced. In other words, these particular iron alloys have almost non-magnetic properties, possess the highest electrical resistance of any known alloy, and also represent the most ductile iron alloy yet known.

The Concluding Group includes Metals and Miscellaneous Alloys.—The first specimen taken in this group was No. 120 forged nickel (C 0·09, Ni 99·27 per cent.), representing an excellent quality of commercial nickel. This was tested in the forged condition, and in liquid air the tenacity was increased from 29—46 tons, and ductility from 43—51 per cent. This may be considered a remarkable result, and probably explains why in iron-nickel and iron-nickel-manganese alloys the presence of nickel (provided the carbon is low) prevents low temperature injuring iron. It is difficult to explain why this should be so, in view of the similar position of these two elements in the chemical classification of the elements.

Although no absolutely pure specimen of the metal manganese is yet available, that containing about 98 per cent. shows comparative brittleness, and in this respect, therefore, entirely differs from the metal nickel. This, to some extent, explains why nickel-iron alloys are remarkably tough, but still leaves unsolved why manganese steel, which contains 12 per cent. of Mn, is so extraordinarily tough when alloyed with iron and some carbon, and quenched from high temperatures.

Test No. 131 (copper 99 per cent.) shows that whilst the results obtained from this metal resemble nickel, the tenacity being increased, it is to a much less degree, the ductility not being materially altered.

It is curious to find that by chilling down the metals iron, nickel, and copper to $-182°$ C. their absolute and ultimate—if the terms may be allowed—qualities are shown more truly than at the normal temperature. The effects here noticed also explain in a more satisfactory manner than has yet been possible, why nickel is so valuable in nickel-iron alloys; that is, it tends to counteract the constant tendency of the sensitive metal, iron, to become embrittled on the slightest provocation. If this research reveals this one important fact, it will have well repaid the labour.

From the results it would seem to be indicated that copper might be a useful metal to alloy with iron. There are, however, difficulties in the way of this, at any rate as regards forged metal, as copper-iron alloys containing no manganese are considerably red-short, and cannot be readily manipulated. For some reason not yet explained it also does not alloy well with iron, but this may be a question of temperature effect at fusion point. At any rate, these experiments are suggestive for further research and investigation.

In the case of aluminium, Test No. 113 (Al 99·50 per cent.), the metal shows a remarkable increase in tenacity, viz., 8 to 15 tons, the elongation being nearly quadrupled, viz., from 7 to 27 per cent. Singularly enough, when alloyed with iron, such increases in both tenacity and ductility are not noticed; in fact, a contrary effect was produced.

Specimens of cupro-nickel (Cu 95, Ni 4·85 per cent.) and Bull's metal showed only slight changes at low temperature, whilst specimens of delta metal and manganese copper showed a rise in tenacity and ductility.

Various experiments carried out in connection with this research deal with contraction, electrical properties, micro-structure, magnetic and brittleness tests, all of which will be included in the special monograph.

General Conclusions.

It is clear that as regards iron and iron alloys, with, however, certain exceptions, the effect of low temperature is to increase in a remarkable degree their maximum tensile stress, and to reduce their ductility to practically nothing. These changes take place to the same extent, and this is very curious in the softest wrought iron, as represented by the specimens S.C.I. (Swedish charcoal iron), L.S.S. (the famous Swedish melting iron), and also English wrought iron, and in carbon steel samples from 0·10 to 0·20 per cent. to the high percentages, such as 1·25 or 1·50 per cent. Thus, the absence or presence of carbon in ordinary carbon steel, in which other special elements are not present, seems to have but little influence. That there is no error in this statement is proved, independently of the tensile tests, by the fact that several bars of the S.C.I., and mild steel specimens, were sub-

mitted to the low temperature test, and tested by hammer immediately after being immersed. In all cases they exhibited great brittleness, breaking off instantly upon being struck. Further confirmation is obtained by the Brinell hardness ball test, under which test the hardness number of the S.C.I. increased at − 182° C. from 90 to 266, or about equal to the hardness of 0·80 per cent. carbon steel at normal temperature. This almost seems incredible when it is remembered that the S.C.I. shows by analysis 99·88 per cent. of iron, and has only 20 to 22 tons tenacity, with 25·30 per cent. elongation.

The importance of the discovery of the toughening effect of nickel upon iron at low temperatures will be seen when it is understood that whilst it has been well known that nickel in certain percentages produced important improvements in the qualities and properties of iron and steel alloys, no microscopical or chemical research work has yet proved why this came about. It seems clear that these experiments go a long way towards offering a satisfactory explanation. The experiments prove that the purest iron, as represented by the S.C.I. (containing 99·82 per cent. iron), becomes brittle to an extraordinary degree under the influence of low temperatures, whereas nickel itself, tested under the same conditions, has improved rather than deteriorated, not only in tenacity, which iron also does, but in ductility, in which latter quality iron entirely breaks down. If nickel, therefore, is present in an iron alloy containing but little carbon, or comparatively low in that element, it acts as a preventive of brittleness, or is a very considerable modifier of that objectionable quality. It may be interesting to state that at ordinary temperatures the toughness or ductility of nickel is no greater than that of iron. For example, in comparative tensile tests made on nickel and pure iron, the ductility of iron was greater.

Iron to a more or less degree, at any rate in manufacturing operations, always seems to be endeavouring to wander out of the "paths" of ductility and toughness, and will assume its apparently brittle nature on the slightest provocation. It would appear therefore that iron, a cheap and convenient metal itself, must be permeated by some element that will mask or modify its properties. Until recently carbon was the only element known to modify the properties of iron; but, as will be seen in this research, this element, where great toughness is required, only helps to make matters worse. Fortunately for iron, however, its close companion nickel acts as a preventive in keeping it from wandering out of the narrow road of metallurgical rectitude, that is toughness or ductility. Why this should be so cannot at present be explained. Iron is a crystalline metal, whereas nickel appears to be much more amorphous; it is possible, therefore, that nickel tends to prevent iron crystallizing. This action of nickel is remarkable in certain of the alloy specimens, *e.g.*, No. 114, which is an alloy of iron, carbon 1·18 per cent., nickel 24·30 per cent., and manganese 6·05 per

cent. Here the ductility is extraordinary at not only normal but low temperatures, probably the highest known for any iron alloy, and certainly for an alloy having such tenacity as 85 tons per square inch. There is still present in this alloy 68 per cent. of iron, yet the tendency of the latter metal to become brittle is not only entirely checked at the low temperature; but the elongation, already so great, is considerably increased, viz., from 60 to $67\frac{1}{2}$ per cent. There is also an increase of tenacity in both cases, viz., a rise from 10 to 38 per cent. Thus the nickel present causes the bar under high tension, and at $-182°$ C., to remain far more ductile than the very best ductile iron of one third the tenacity. Although the action of nickel has been specially referred to, it must not be overlooked that in this alloy there is also present 6 per cent. of manganese, which in its ordinary combination with iron, that is with no nickel present, would confer intense brittleness upon the iron and render it more brittle than if not present. This treble combination of nickel, manganese, and iron, appears to reverse all the known laws of iron alloys.

We have to thank the mechanician of the Davy-Faraday Laboratory, Mr. C. N. Cooke, for able assistance in the conduct of the experiments.