Mr. Webster. the factor of "safety" would be a misnomer. He was strongly of opinion that the factors of safety adopted in bridgework should be based upon the breaking strains of the materials employed, and not upon their limits of elasticity; although it might be advisable under certain circumstances to specify the latter also.

Mr. Barlow. Mr. W. H. BARLOW, President, thought the members of the Institution were greatly indebted to the Author for bringing forward a subject of a philosophical character, thus usefully leading their minds a little off the ordinary track which they were accustomed to pursue. It was perhaps true that the Paper did not take such a wide range as it might have done, but it could not be expected that any individual member should carry such a subject to its extreme limits. They were not only indebted to the Author for his Paper, but for the excellent discussion which had arisen from it, and the valuable information contained in the remarks of Mr. Adamson, Dr. Siemens, Mr. Longridge, and Prof. Kennedy. He desired especially to refer to Prof. Kennedy's offer to place his testing machine, when he could do so without disturbing the ordinary course of his avocations, at the disposal of the Institution. He had no doubt that the offer would be gladly accepted by the members, and that the result would be a great addition to their knowledge with reference to such subjects.

Correspondence.

Mr. Anderson. Mr. W. ANDERSON regretted that the chemical composition of the metals experimented on had not been given. It was now generally agreed among metallurgists that by "iron" should be meant pure iron only, and that by "steel" should be meant a combination of iron and carbon only. When those metals contained other substances they ceased to be iron or steel in the strict sense of the terms; their properties became different, and many of the apparent anomalies which had arisen during experiments on metals might be accounted for by the fact that chemically the substances were not the same. Mr. Chernoff had illustrated the importance of this remark in the following communication, in which he showed that the presence of phosphorus made the steel with which it was allied more brittle in cold weather, while pure steel was not affected by cold. The "cast-steel," which had been tested, it was presumed, was crucible steel, forged or rolled after casting, and not steel castings. According to Chernoff, steel castings, in the form of steam-hammer heads, seemed to be affected by cold much as cast iron had been shown to be.

Mr. Chernoff.

Mr. D. CHERNOFF, through Mr. W. Anderson, doubted if there existed records of systematic experiments on the influence of frost on the strength of iron and steel in Russia, but he had a few facts which related to the question. It had been proved that the presence of phosphorus in iron and steel became apparent in frost; the more phosphorus the metal contained the more brittle it was in cold weather. Among others, Mr. Lundicheff communicated the following facts. On the 8th of March, 1875, in the rolling mills of the Chief Society of Russian Railways, at a temperature of $-7^\circ\cdot5$ Centigrade, the following tests were made, by means of falling weights, on rails of phosphoriferous steel. The specimens stood the fall of 648 lbs. from a height of 10 feet, but broke, the pieces flying asunder, when the same weight fell 13 feet. After the experiments the halves of the broken rails were laid aside till the weather should get warmer, and on the 19th of May of the same year, and under the same apparatus, at a temperature of $+12^\circ\cdot5$ Centigrade, the tests were repeated. After two blows from a weight of 1,152 lbs., falling 10 feet, and one blow from the same load, falling 15 feet, the rails were bent to an angle of 120°. A weight of 2,232 lbs. was then dropped from a height of 15 feet 4 inches, when the rail did not break, but was bent to an angle of 100°. The presence of phosphorus was recognised as injurious by the Ministry of Ways and Communications, and special rules had been laid down by the Ministry for testing for phosphorus. It was absolutely necessary, in receiving rails for service, that they should be tested by bending in special localities where an artificial temperature of $-12^\circ\cdot5$ Centigrade had been produced. At the Abouchoff works, with good materials, tires, whether made of Bessemer, Siemens-Martin, or crucible steel, were tested under falling weights in winter. In 1879, for example, one of the deliveries of tires took place at a temperature of -19° Centigrade, yet all the specimens selected stood the required test.

He had often observed that, during winter, breakages took place most frequently immediately after the works had been standing idle during holidays. These fractures occurred especially to the hammer heads and anvils of the steam-hammers, and to the chains of the cranes if these had not been well heated up to about 100° Centigrade. It was now an established rule that in winter the chains of the hammer cranes, and the hammer heads and anvils, should be warmed before work commenced. The hammer heads and anvils of the large steam hammers, especially, required to be heated for a long time. For example, the heads of the 50-ton hammer, weighing from 8 to $9\frac{1}{2}$ tons, had to be heated nearly the whole night before the resumption of work, and without this precaution they would infallibly break. He might add that the hammer heads and anvils were made both of steel and of cast iron, and heating was found necessary for both materials. Mr. Chernoff.

Mr. Carlile. Mr. H. CARLILE agreed with much that had been advanced by the Author. He thought, however, that a temperature of 5° above zero Fahrenheit was much too mild to give any very decided experimental results, and would rather propose that the experiments should be extended to such temperatures as 25° and 35° below zero Fahrenheit, when he had no doubt unmistakable results would be arrived at. To show that in Russia it was accepted that steel was rendered brittle by great cold, he begged to quote the following translation of an extract from the last Russian Government rules for testing Bessemer steel railway rails: "Should the delivery of the rails take place at such a season when the temperature is warmer than 10° to 15° below zero (Réaumur), it is indispensable that the two rails which are to be subjected to the blow-test be tested at the lower of the above-mentioned temperatures. The artificial reduction of the temperature will be attained through a mixture of 2 parts by weight of ice and 1 of salt. For this purpose the pieces of rail to be subjected to the refrigerating process are to be laid in wooden boxes 8 feet long, 3 feet wide, and 2 feet deep, half filled beforehand with the aforesaid mixture of ice and salt, and is then to be covered with a like layer of the same mixture. The temperature of the rail will be determined by means of a thermometer inserted in a depression bored in the head of the rail, and filled with quicksilver." Experience of railway traffic in Russia showed that most of the failures in rails, wheel tires, and bearing springs, occurred during hard frost, due, probably, partly to the low temperature, and partly to the rigidity of the permanent way. There were fewer breakages in November and the beginning of December than, with the same degree of cold, in January and February, when the frost had penetrated deeper into the ground, and rendered it harder and less elastic.

Mr. Furness. Mr. H. D. FURNESS would confine his remarks to experience gained on three railways in Northern and Central Russia, extending over a period of nine years as Locomotive Superintendent. In the first place he must take exception to the remark (page 161), "that in those countries where the winters are longer and more severe than in Great Britain, no such records of fractures are kept." He could safely say that in Russia returns were kept

Mr. Furness. that would bear favourable comparison with those of any country. In fact, the history of every axle, wheel, and tire was noted and duly registered. 1st. The mileage done every month, and the total mileage at the end of such month by each of the above. 2nd. The fractures that had occurred to each, with the date. 3rd. The repairs done and the nature of the repairs. This was all recorded so accurately, that he was sure that anyone examining the books in the Locomotive Superintendent's Office—take, for instance, the Dunaburg and Witepsk railway—would find in the case of, say, axle No. 100, by whom it was made, the date of manufacture, under what wagons it had been, if it had been bent and then straightened, what mileage it had run up to the end of 1879, and the same for the wheels and the tires. The system of doing this was not so difficult as it looked. The method of ascertaining fractures was simply by paying a small premium to those persons finding such fractures. Regarding the fracture of tires, so far as breaking across the tire was concerned through contraction, impact, or other cause, his experience had been that the greatest number of such fractures did not occur in the severe winter months, but generally in those months in which the greatest variation of temperature took place, and from this he always considered that the difference between the expansion of the wheel and tire found out the weak places, the tire always giving way at the weld when of wrought iron, and invariably at the bolt hole in steel. There could be no doubt that the majority of fractures in winter resulted from the hard and frozen state of the track, but this arose from the tires that had been turned up a time or two, which were absolutely drawn out in the transverse section, forming a curve, in some instances $\frac{1}{4}$ inch deep at the centre; thus after they had been considerably drawn out cold by impact on a hard road, they split round the circumference of the tire. From these remarks it would be seen that unless the nature of the fracture were known, not even the Board of Trade statistics could be relied upon to form data as to the effect of low temperature on iron and steel.

Mr. Cuningham. Mr. W. M. CUNINGHAM supplied the following statement (see next page), showing the number of rails broken and deteriorated on a railway in Northern Russia during 1878.

Dr. Hopkinson. Dr. J. HOPKINSON observed, that the blow required to break a body by impact should not be proportional to the steady stress required to break it was precisely what should be expected. For the purpose of illustration, suppose a beam supported at its extremities a unit weight hanging at its middle caused deflection a, a weight W would break the beam, the deflection before breaking would be

Mr. Cuningham.

Works.	To 1st Jan. 1879. Length of Rails.	Average life of Rails to 1 Jan. 1879.	In the course of 1878, Broken and Removed Rails.		Temperature (Reaumur) in 1878 ranged from — per Month.	Month.	Steel Rails.				Iron Rails.		Totals.
			Pieces.	Percentage of Versts.			English Works, No. 1.	English Works, No. 2.	French Works.	Belgian Works.	Type No. 4.	Type No. 3.	
	Versts.	Years.			° °								
Steel rail, type No. 5, (66 lbs. per yard)—													
English works, No. 1	323·197	0·694	11	0·044	+ 1 to − 20	January .	..	2	1	1	997	986	1,987
" " No. 2	426·189	0·696	14	0·053	+ 2 " −12	February .	1	2	1	..	1,618	954	2,576
French " . .	66·327	2·39	31	0·123	+ 8 " − 9	March . .	..	6	3	..	1,485	828	2,322
Belgian " . .	28·518	3·843	3	0·011	+ 7 " − 2	April . .	..	..	2	..	869	495	1,364
Steel rail, type No. 3.					+ 6 " +16	May . .	1	..	1	2	863	392	1,255
English works, No. 3	2·41	11·25	..	..	+11 " +21	June . .	..	1	..	..	762	353	1,116
" " No. 2	2·046	12·249	..	..	+ 9 " +19	July . .	1	..	..	..	733	400	1,134
Iron rails, type No. 4.					+10 " +16	August .	..	1	6	..	807	424	1,238
Various works . .	433·113	unknown	12,565	34 versts	+ 5 " +13	September	3	..	1	..	805	358	1,163
Iron rails, type No. 3—					+10 " − 6	October .	..	1	1	..	1,044	715	1,761
Various works . .	370·819	unknown	6,642	18 "	+ 4 " −20	November.	3	1	10	..	1,475	372	1,847
Totals . . .	1656·616	..	19,266	52·231	+ 1 " −12	December .	2	..	5	..	1,107	389	1,503

Note.—Verst = ⅔ mile. The worst steel rails prove to be those of the French works. The greatest number of breakages of iron rails took place in February and March; of the steel rails 24 per cent. broke in November.

Dr. Hopkinson. a W if the deflection was proportional to the weight, the work done in deflecting the beam till it broke was $\frac{a^2 W}{2}$; if a weight P falling from a height h just sufficed to break the beam, then $h \, P = \frac{a^2 W}{2}$.

If change of temperature increased W, the load that could be carried by the beam, it by no means followed that it would increase h P, the blow needed to break the beam, for the effect of the change might be to diminish a, or render the beam stiffer, and so render it more liable to break under a blow, although increasing the strength of the material. This illustration was sufficiently trite, but he thought it well to repeat it, as one continually heard expressions of surprise that rupture under steady stress and under impact were not found to vary together.

In most cases the phenomena of rupture under impact were by no means so simple. Passing over the fact that stress and strain were proportional only if they were small, a variety of complicated time-effects ensued. First came the question whether the deformation was effected so rapidly that the change might be considered adiabatic, or whether there was time sufficient for conduction to have a sensible effect in equalising the temperature.

Secondly, the stress in a body at any time depended not only on the strain at that time, but on the strains which had preceded. This subject had been much studied in Germany under the name of "Elastische Nachwirkung." It was probably not of great practical importance to the engineer, but it was intrinsically interesting. Suppose a wire, or better a thread of glass, to be twisted for an hour and released, it would not at once come back to its unstrained state, a small twist remained which slowly diminished and disappeared. The most curious thing was that the thread had the trick of remembering a good deal of its past history. Twist it for an hour in one direction, then for five minutes in the opposite direction, and release it; a small and rapidly decreasing twist remained in the direction of the last twist it received; this soon disappeared, and the effect of the longer previous distortion made itself manifest; the fibre showed a twist in the other direction, which slowly attained a maximum, and then still more slowly decreased to zero.

Thirdly, and he thought this was important, a body might break under impact, the reaction being not against supports but against its own mass. Some years since he investigated the simplest case of rupture in this way.[1] A wire was hung vertically, stretched by a weight sufficient to keep it straight; a block of cast iron weighing 26 oz. grasped the wire near the bottom firmly, but without danger of cutting; a spherical weight with a hole through it could slide on the wire and drop freely on to the clamping block, so inflicting on the wire a purely tensile blow. Theory showed that if the wire were very long it would break just above the clamp; that if the wire were not very long the fall needed to break it close to the clamp would be the same as if the wire were very long; that correcting for the mass of the clamp the height of fall was the same for all weights. The last rather astonishing result was verified; a ball of 41 lbs. had to fall 5 feet to break the wire at the clamp, whilst a ball of 7¼ lbs. weight accomplished the same with a fall of 6 feet 9 inches; correcting them for loss of velocity due to the inertia of the clamp, the heights obtained were 4 feet 7 inches and 4 feet 6 inches. He then tried cooling the wire just above the clamp with ether, and found that a smaller height of fall was needed to break the wire; an effect in this direction might arise from decrease of tensile strength, from increase of coefficient of elasticity, or from increase of density of the material. Dr. Hopkinson.

Dr. Joule. Dr. J. P. Joule observed that the conclusions drawn by the Author, from his elaborate experiments on the strength of iron and steel at low temperatures, agreed in the main with those deduced by Mr. Spence and himself from their respective experiments.[2] They all showed that the reduction of strength by exposure to cold, was, if any, so small that, as the Author stated, it might be neglected in the design of structures. Mr. Webster, however, made an exception in the case of cast iron. It appeared to him that the results recorded in Tables III. and IV. did not bear out this exception, inasmuch as they showed almost equal breaking weights for the different temperatures of the cast-iron bars employed. In Table VIII. it appeared to him that the trials were too few to establish any discrepancy. One of the greatest necessities in experiments of this nature was that of securing, as far as possible, the perfect uniformity of temperature in the specimens under trial. On this account among others, he chose "garden nails," the small dimensions of which prevented any great variation of temperature throughout their mass. The like precaution seemed

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[1] *Vide* Proceedings of the Literary and Philosophical Society of Manchester, vol. xi., 1871–72, pp. 40, 119.

[2] *Ibid.*, vol. x., p. 91.

Dr. Joule. to have been employed by Knut Styffe, whose experiments appeared satisfactory in all respects.

Mr. Millar. Mr. W. J. Millar was much interested with those parts of the Paper referring to the strength of cast iron at low temperatures, and the peculiar curved fractures of the steel bars, as he had made some experiments of a like character. One point, however, must be borne in mind, viz., that to get reliable data from experiments on cast iron, a large number of tests were required. This arose from the great variation in the strength of the test bars. Even when such bars had been cast from the same running, it was not unusual to get a high result from one of the bars, whilst a neighbour broke at a comparatively low strain, yet both bars would show perfect soundness, no apparent difference being observed in the fractured surfaces. On a comparison of the bars of high and low temperature given in Table IV. of the Paper, it would be found that the highest strength was shown by No. 11 bar, of the low-temperature series, and if bar No. 8 were kept out, as it was exceptionally low in strength for such span and section, the average of the remaining four bars was 29 cwt., with a deflection of 0·275 inch. Comparing this average with the average of the highest four bars of the higher-temperature series, the result was 29·15 cwt., with a deflection of 0·31 inch, the values of the breaking strength being practically the same in both cases. There appeared, however, a slight decrease of deflection in the bars subjected to cold. Lately, whilst testing some bars, three were exposed to the action of cold by being buried in snow; the average transverse strength of these was 3,133 lbs., with a deflection of 0·372 inch, whilst the three companion bars not subjected to cold gave 3,055 lbs., with a deflection of 0·400 inch as an average. There appeared also in this case a decrease of deflection for the cooled bars.

In respect to the peculiar curved wedge-shape fractures in steel bars, this form of fracture was said by some writers to occur in cast-iron bars, but although he had tested several thousand bars, not a single case of such a form of fracture had been observed. It appeared, however, to occur in steel bars, as observed by the Author, by Mr. Kirkaldy, and by others. The curves when met with in cast-iron bars were of the annexed form (Figs. 9, 10, 11), and the two pieces always fitted together. He had found that such curves invariably occurred when the fracture had commenced at a point removed from the centre of the span, and pointed towards the point of application of the load. When rupture occurred at or near the centre of the span, the fracture was

Mr. Millar.

straight. The position of the fracture could therefore be determined by the form it assumed. Similar shaped fractures were got when experimenting with glass and sealing-wax bars, and these followed the same law as he had found to apply to the

Glass Bars.

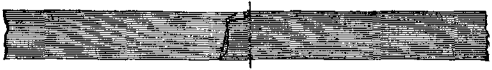
FIG. 2.


FIG. 3.

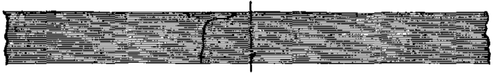
FIG. 4.


FIG. 5.


FIG. 6.

Sealing Wax Bars.


FIG. 7.


FIG. 8.

Cast-Iron Bars.

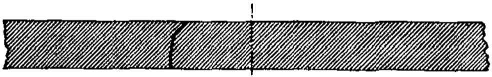
FIG. 9.

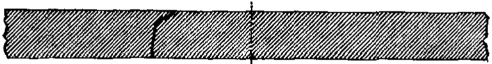
FIG. 10.

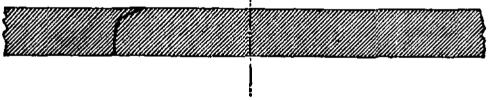
FIG. 11.

Steel Bar.


FIG. 12.

cast-iron bars. He believed that the formation of such curves was due to the unequal length of the two pieces of the bar, the larger piece on straightening diverting the upward line of the fracture. The form could have no reference to the position of the neutral layer before fracture, as, immediately on rupture commencing, the

Mr. Millar. position of the neutral layer would be altered. The glass bars (Figs. 2, 3, 4, 5, and 6), indicated very fine curved fractures, but it could be shown by the action of polarised light that the neutral layer lay at the centre of the depth, even when the piece was strained to the breaking point. In the case of a steel bar broken by impact (Fig. 12), the fracture was similar to that obtained in the cast-iron bars so that the wedge-shape form of fracture did not always hold in steel. The probable explanation of the wedge-shape form might be that where it existed, a broad surface had been used for applying the load, and not a narrow edge, as usual. The load being distributed over a short distance, as appeared likely from the size of the falling weight used by the Author, the tendency would be for the fracture to run in the direction of D or E (Fig. 1, p. 175), that is to say, towards the points of the span where bending might be said to commence. It would be interesting to have exact outlines of the forms of the curves, and to know if the line of fracture lying below C (Fig. 1) was at the centre of the span or to one side of it, as he had been handed by a friend a sketch of some fractures of steel bars, in which the wedge-shaped part appeared to have occurred at the lower or tension side. The rounding of the fractured parts at A D and E B (Fig. 1, p. 175), was similar to that in the sealing-wax bars (Figs. 7 and 8).

The experiments by the Author upon the transverse strength of bars under impact were very interesting; the height, however, of fall given for the cast-iron bars seemed small. In some experiments which he had made in this direction, bars of similar section and span had been subjected to a weight of 13 lbs., falling from heights up to 6 feet, but had remained unbroken after repeated blows. With an 18-inch span one bar stood five blows, and remained unbroken up to a fall of 6 feet. Another bar of the same span broke at the second blow, with a fall of 5 feet. A bar of 36 inches span stood seven blows of a 27½-lb. weight falling from varying heights; the eighth blow from a height of 6 feet broke it. The companion bar cast along with this one broke at 4,000 lbs. of a transverse load gradually applied, and showed an ultimate deflection of 0·418 inch.

Mr. Lightfoot. Mr. T. B. Lightfoot said Messrs. J. and E. Hall had at their works at Dartford a cold air machine capable of reducing the temperature to about 50° below zero Fahrenheit. He had much pleasure in offering the use of the machine to any members who might desire to experiment upon the behaviour of materials at low temperatures. The only difficulty was that they had no testing

Mr. Lightfoot. machine, though for such purposes as impact some contrivance could easily be made. The machine, as at present arranged, discharged into a wooden chamber. The use of the plant would, of course, have to be obtained by previous arrangement.

Mr. Parfitt. Mr. J. PARFITT remarked that iron and steel rails, if of good quality, would stand the same test both in summer and in winter, the only difference being that the amount of deflection of the rails was somewhat less in winter; but if the metal was of inferior quality, rails which would endure a certain test in summer would, with a few exceptions, break under a similar test in winter.

Mr. Paterson. Mr. JAS. PATERSON observed that wrought iron, when subjected to a tensile strain, appeared to be very slightly altered by change of temperature, the ratio being as 1 to 1·007 in favour of the higher temperature. Mr. Kirkaldy in his researches on the strength of iron, found that a $\frac{3}{4}$-inch bar tested at 64° Fahrenheit was ruptured at 24·87 tons per square inch, while another portion of the same bar tested at a temperature of 23° Fahrenheit broke under a strain of 24·28 tons, being in the ratio of 1 to 1·024 in favour of the higher temperature. In the case of steel the tensile strain was increased under the lower temperature to the extent of 1·004 to 1. The generally accepted opinion hitherto had been that the compression of wrought iron by hammering increased its tensile strength, and reduced its elongating properties, but this view was not supported by the Author in his experiments on iron. Whether the increase in the tensile strength of steel was due to increased compression through the influence of cold, or whether from some difference in the molecular structure of the steel, was uncertain. In the case of cast iron, the transverse strength did not appear to be greatly altered, being reduced under the lower temperature in the ratio of 1 to 1·028 or 2·8 per cent. When subjected to impact the conditions seemed to be seriously altered. Taking the average height of fall for the low temperature at 1, and the height of fall at the higher temperature as 1·36, the ratio was 1 to 1·5 against the low temperature. Not improbably the molecular state of the iron would be equally altered through the influence of cold when placed under the respective tests; but in the transverse strain, the pressure being applied gradually might probably tend to liberate the latent heat of the bar and raise the temperature at the point of compression. His experience of cast-iron girders fixed to the supporting columns of gasholders rather favoured this supposition. In the case of one erected a few years ago, having a diameter of 97 feet, supported by ten cast-iron columns and girders, the trough guides being also of cast iron, Mr. Paterson. fixed to the columns in the usual way, 6 feet apart from centre to centre, three of the guides gave way during the severe frost in January 1879; and a similar casualty occurred during the severity of the frost early in the following December, when three guides again gave way and threw the gasholder out of position. Two of the broken guides had since been tested, and one of those not broken. The bearings were placed 5 feet apart from centre to centre, temperature 60°. The first broken guide was fractured at a pressure of 2 tons 18$\frac{3}{4}$ cwt., the ultimate deflection being $\frac{1}{2}$ inch. The second, placed under similar conditions, gave way at a pressure of 2 tons 10 cwt., the ultimate deflection being $\frac{3}{8}$ inch. The unbroken guide gave way under a pressure of 3 tons 5$\frac{1}{4}$ cwt., the ultimate deflection being $\frac{9}{16}$ inch. It was highly probable that the weakest guide first gave way, and that the impulse communicated by the weight of the gasholder ultimately broke the two adjoining to the right and left. They had now been replaced by others of wrought iron.

Mr. Pihl. Mr. CARL PIHL, of Christiania, had made inquiries respecting the behaviour of iron and steel when exposed to extreme cold in Norway. Mr. Sinclair, who had been engaged twenty-eight years as superintendent of permanent way on the Kongsvinger railway, a line of 70 miles' length, and exposed to extremely low temperatures, had informed him that only one iron rail had been broken in the course of fifteen years, and one steel rail during the last four years in which steel rails had been in use. The iron rail broke more from accident; the steel rail from imperfection in the manufacture. The rails wore away much more during winter than summer, in consequence of the very hard frozen road, the frost penetrating from 4 to 6 feet below the rail. Axles, tires, and springs were broken more during winter than summer; but this he also considered to be caused by the hardness and unevenness of the road, and by the heavier traffic in winter than in summer, and not from low temperature. In bridges he found no difference. He thus concluded: 'In my opinion the only difference between summer and winter in damage to road and rolling-stock lays alone in the hardness and unevenness of road." The temperature experienced on the railway in question had yearly been − 22° to − 35° Fahrenheit. The extreme cold, however, did not last more than three or four days at a time. Three or four times, however, the temperature had been so low as to freeze quicksilver, consequently at − 40° Fahrenheit.

The next report he had received was from Mr. Mellbyo, engineer and traffic manager of the southern portion of the Hamar-Drontheim railway of 3 feet 6 inches gauge, 269 miles long, crossing the Dovrefjeld in N. latitude 62° 30′ at Róros copper-mines, at an elevation of 2,200 feet above the sea. He mentioned two instances of locomotive steel tires springing, one 2 inches thick at a temperature of 18° Fahrenheit, the other 1 inch thick at – 15° Fahrenheit. No iron tires had sprung, and only one stock rail sprung, in several pieces, when a locomotive passed over it, at a temperature of – 4° Fahrenheit. The lowest temperature generally reached was from – 30° to – 40° Fahrenheit, that being the extreme cold in Norway. From this it might be inferred that the breakages mentioned were caused, as in the former instances, rather from the hard and uneven road than from the effect of low temperature, the road getting very uneven by being lifted by the frost, sometimes to the extent of 18 inches above the ordinary level. Mr. Pihl.

Though the above observations and opinions were not derived from direct experiments, and though they gave no conclusive evidence, yet he trusted that, as the results of many years' experience, they would be of some practical interest.

Finally, he had received a report, from which the same conclusions might be drawn, from Mr. Krefting, the engineer and traffic manager of the Christiania-Drammen-Randsfjord narrow-gauge railway, together with its branches 111 miles long, and having 40-lbs. steel and iron rails.

As an illustration of the effect of want of elasticity in the road on the rolling-stock, Mr. Pihl mentioned that some years ago he had introduced india-rubber pads between the axle-boxes and springs, which had effected a reduction of $\frac{3}{4}$ or $\frac{5}{6}$ in the turning of the wheel-tires from what had been necessary during the previous winter.

Mr. Sandberg. Mr. C. P. Sandberg, having been largely employed for twenty years by Scandinavia, Russia, and Canada, as inspector of rails, the subject was naturally of great interest to him. At the instigation of the Swedish Government he had been requested, ten years ago, to make some experiments, of which the Author had quoted an abstract in the Paper, along with those of Styffe and Fairbairn. It was gratifying to find a private individual devoting so much time and cost in trying to solve a question, for which the above-named countries, in colder climates, would be greater gainers than England with its comparatively mild climate. It was surprising that so little had been done in the way of experiment by these countries. The Swedish Government had instituted the experiments made by Styffe and his colleagues, and had paid all their

Mr. Sandberg. expenses, but he was not aware that either Russia or Canada had done anything of the sort. The wide range of the subject, if it should be thoroughly investigated so as to be of practical utility, demanded more time and cost than could be expected from any private individual; but any such work done deserved high praise, however small it might be: and in this respect he could not agree with Dr. Siemens, that the information in the Paper was deficient. The Author was wrong in supposing that Mr. Sandberg had compared the results obtained from long rails with those of half lengths. The results were taken by comparing the strength against impact of ten rails, all in halves, tested one half at 10°, the other at 84°, although he admitted that the Table included also the results of long rails tested for impact; but they were not taken into comparison, as was explained in the few lines after the Tables, and before the conclusions were given.[1] He thought there was but one opinion as to cold affecting the strength against impact of those classes of iron and steel which contained certain impurities, called hardening substances, such as phosphorus, carbon, silicon, and even manganese; and this should not be a matter of doubt considering the well-known term of cold short iron. This term had not been applied to steel because formerly steel was only made from pure material, such as Swedish iron melted in crucibles. With the introduction of the Bessemer and Siemens processes for the manufacture of large quantities of cheap steel, and the application of Thomas and Gilchrist's process in the Bessemer, and the production of the so-called phosphor steel by the Siemens process, he feared the public would be as familiar before many years with the expression of "cold short steel," as they were now with that of "cold short iron." Taking a broad view both of the Paper and of the discussion, there seemed to be a want of practical ability. For instance, speaking of testing, as a practical man he would make a distinction between scientific tests for discoveries of the nature of the material, and such as were applied in practice, although the former were of great value, and must form the basis of rules for the latter. He thought progress was much retarded by not working the former on a larger scale, and in a more practical way, than had been done by experimentalists. For instance, testing the materials used for a certain purpose should be as nearly as possible effected in the same way as it would be in practice. The test should be simple, require no expensive

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[1] *Vide* "Iron and Steel," by Knut Styffe. Translated by C. P. Sandberg. Appendix, pp. 156 and 157.

Mr. Sandberg.

machinery, cost little, and above all be speedy. What engineers aimed at was of course to get a sufficiently good, strong and safe article at the cheapest price; any overdoing in this respect would always be a loss, although it was better to be on the safe side. He held that the materials, iron and steel, should be tested by impact in all cases where the articles would be subjected to it in practice; when the articles were to be subjected only to dead loads, the testing of elasticity and tensile strength would be sufficient; and here it was that most of the faults lay. For instance, a rail should be submitted to concussion; for when a train ran over it at high speed, it suffered more from concussion or impact than from wearing effects. He could not conceive it to be right that the German engineers, in their steel rail specifications, only included the test for tensile strength but no falling test. The former test he thought would be better applied to boiler plates than to rails, as they were both slow and costly and not to the point; for no connection had yet been arrived at between these two tests and that of impact. It was with this view that he operated upon rails, in testing the effect of cold in Sweden, and he was glad to find that M. Chernoff had adopted the same plan. He was opposed to the application of mechanical tests to the material in smaller dimensions than what were used naturally, for not only was a change incurred in taking the skin off, or otherwise reducing the material to minute dimensions, but any unevenness or non-uniformity would yield misleading results. He preferred large dimensions, even if the arrangements were somewhat crude and rough, and therefore he did not advocate, with Dr. Joule, operating on garden nails. The next point of importance was the number of experiments that could be made quickly, to guide, if possible, the maker in the completion of the manufacture, according to desire; but if that could not be done, it would serve to assort the metal for different purposes. For instance, in the Siemens process, the testing of the steel before it was tapped, so as to obtain the exact degree of hardness wanted, was of the greatest importance and value. In the Bessemer process this method was only applied where the Thomas and Gilchrist process was used; for, by judging of the fracture and blowing, say, another half a minute, success in making strong steel out of pig iron containing 2 to 3 per cent. of phosphorus, entirely depended. Unfortunately the tests that could be applied by inspection of the finished article were much too costly and complicated. Thus, only 1 per cent. of the rails, axles, or girders were tested, and it must be taken for granted that all the others were alike; and this necessitated a surplus of strength, Mr. Sandberg. so as to be on the safe side. In this respect he thought a conclusion could be drawn on the effect of cold on iron and steel when the material was impure, so that there must be a special material made for cold countries. Here the tests, sufficient for structures in mild climates, would have to be increased, in order to secure safety for similar structures in cold climates. He was therefore of opinion that falling tests for rails intended for Russia should be different to those for England, and that there should be different heights of fall according to the temperature at the time of testing. Rails tested at the place of manufacture, in a mild climate, could not be expected to stand the same blow or impact in a cold country; and it remained to settle the proportion of the height of fall according to the different degrees of cold. He had tested rails in Russia shortly after a cold of 40° Fahrenheit below zero, but it was thawing at the time; still the rails were exceedingly brittle. As mechanical tests gave different results if time were allowed to act, so it seemed also that this was the case of the effect of cold. In fact, the metal had a tendency to regain its former condition to a certain extent if only sufficient time was given.

Dr. Siemens had pointed out the value of chemical tests in conjunction with mechanical, and in this Mr. Sandberg concurred; but more as an explanation of the mechanical conditions, than as an indication of the constitution of the metals. This subject had lately received great attention in America. The Pennsylvania Railroad Company had charged their chemist, Dr. Dudley, to conduct chemical and mechanical tests of all rails on their line, some of which had done good service and others bad, and to compare them. His conclusions led to the following formula being recommended for and prescribed in their specifications for steel rails:—

Phosphorus not above	0·10	per cent.
Silicon „	0·04	„
Carbon between 0·25 and 0·35, say . .	0·30	„
Manganese	0·35	„

This metal was to have a tensile strength of 65,000 lbs. per square inch. Now this was all very well, but he thought it would be impracticable to carry it out in practice. He would strongly recommend engineers not to stipulate chemical compositions in their rail specifications, because the proper composition was not yet known, and even if it were, no rail-maker could undertake to produce it. This was the conclusion arrived at when Dr. Dudley's Paper on the chemical composition and physical properties of steel rails was discussed before the meeting of American mining

Mr. Sandberg.

engineers.[1] He had received confirmatory evidence of the correctness of this view from what had happened on the Cologne Minden railway on the 26th of December, 1879. A steel rail broke in no less than seventeen pieces by the express train passing over it, fortunately without accident. The rail had been laid six years, and the pieces analysed and tested gave just the results that Dr. Dudley prescribed, or very nearly so. The steel contained—

Carbon	0·024 per cent.
Phosphorus	0·080 ,,
Sulphur	0·030 ,,
Manganese	0·120 ,,
Contraction of area	54·500 ,,
Elongation	25·000 ,,
Tensile strength	5,000 kilogrammes per square centimètre.

With the prescribed physical and chemical conditions fulfilled, still breakage would occur, and he thought it would be well to wait a few years longer before stipulating conditions which might not be safe, and which, with the present mode of manufacture, makers would be unable to carry through.

Finally, he might mention that he had been commissioned by the Swedish Royal Administration of Government Railways, ten years ago, to visit Russia to investigate the effect of severe cold on iron and steel used as railway plant, and from the private report "On Railways in countries with a cold climate," which he had made, after careful study on the spot, he would quote the following conclusions:—

"There can be no doubt that iron and steel are very sensibly affected by changes of temperature, and the more extreme these changes are, and the more suddenly they are brought about, the greater will be the extent to which the strength of the material is affected. In support of this proposition I may state that in St. Petersburg, where the climate is more changeable than in Moscow, the evil effects are more keenly felt, and the railway plant is much more subject to breakage. In St. Petersburg the temperature in winter often changes from 0° to $-40°$ C.; but in Moscow, when once the winter has set in, the cold is much more constant.

"Since great differences exist in the quality of iron, and in its power to resist any particular kind of strain, it behoves every railway engineer to select in any given case that kind of iron whose chemical composition shall best suit it to the special work in question, and also to study its mechanical properties, so that it may be adapted to the kind of work which it may have to perform.

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[1] *Vide* Transactions of the American Institute of Mining Engineers, vol. vii., p. 201.

Mr. Sandberg. Thus, we find that the presence of phosphorus in iron has the most injurious effect when the metal is exposed to concussion at a low temperature, while its effects are by no means equally prejudicial to the tensile strength of the iron at the same temperature; hence such metal, when exposed to severe cold, will break like cast iron under a blow, but may nevertheless be able to sustain the same dead load in winter as in summer.

"Styffe's theory, which refers the greater brittleness of iron in winter solely to the increased rigidity of the supports on which the metal may rest, is contradicted by the experience gained on the Russian railways upon a much larger scale than in my own experience at Stockholm—experiments which were described in an Appendix to my translation of Styffe's work 'On the Strength of Iron and Steel.' Doubtless the elasticity of the base on which the metal rests does considerably affect its strength, but even if the supports have the same elasticity in winter as in summer, as would be the case with a granite rock, it is found that the more phosphorus the iron contains the more readily will it break on exposure to concussion at a low temperature. Such iron should therefore be confined in its use chiefly to countries which enjoy a temperate climate, or should be applied to such objects as are not subjected to the effects of concussion, such as roofs, buildings, plates, &c. In a railway, however, it should be borne in mind that the road when high speed is used must be subjected to concussion as well as the rolling stock—a fact which is proved by the greater number of accidents which have occurred upon increasing the speed. Indeed, experience in Russia shows that the higher the speed the more numerous are the breakages, these being consequent upon the sharper concussion due to increased speed. Both iron and steel may be regarded as composed of an assemblage of numerous small crystals, the cohesion between which—and, therefore, the strength of the metal—will be affected by the amount of phosphorus present; the effect of low temperature seems to be to lessen the cohesion between the component crystals, and hence the diminution of strength consequent upon reduction of temperature. Instead of entering upon any theoretical explanation of these phenomena, I prefer proceeding to the conclusions which may be legitimately deduced from the facts known to practical men, and which may be useful to the railway authorities in guarding against the disastrous effects of extreme cold. In stating these conclusions it will be well to arrange them in the corresponding order to that given above, and to treat successively of the road, the rails, and the rolling stock.

"The great point in connection with the road is to secure effective drainage, and to have it well laid with good coarse ballast. The sleepers must be large and numerous, for the more wood that enters into the construction of the line, the greater will be its elasticity. The rails should be placed directly upon the sleepers without the interposition of sole-plates, as these cause a shock to be communicated to the rolling stock at every joint. The joints should, if possible, be as stiff as the rails are in the middle, so that the road may become almost one continuous structure. My standard sections lately published have been designed with a view to securing these objects. The rails should be made either of steel or of iron, free from phosphorus. For their durability and safety, steel rails seem to have gained favour as much in Russia as in Canada. I have just received a letter from the Engineer-in-Chief of the Great Western railway of Canada, who writes as follows: 'We have now a gross traffic of 2¼ millions of tons per annum upon a single road, and cannot get iron rails to last over an average of four years, and hardly so long on heavy gradients. We are therefore now introducing steel rails of 65 lbs. per yard, and last autumn 1,000 tons were laid. Very soon after they were put down about twenty bars broke, but we have had no breakages subsequently. This has been almost the universal experience gained on all American railways. Several rails break almost immediately, no doubt owing to slight imperfections, but after these first defects exhibit themselves no further fractures take place. Steel rails, therefore, require equally as careful inspection as iron rails.' Steel-headed rails are giving good results in America and in Sweden, and therefore the bad results obtained in Russia must be referred to inferiority of manufacture. Iron rails should not contain phosphorus, and should be tested by the inspector at the works by means of blows powerful enough to ensure safety. The Russian test of 6 cwt. falling through 7 feet on a 72-lbs. rail has been found to be too mild, and rails which in England at the works have withstood such a shock have broken during a Russian winter. On the other hand, the Swedish test of 15 cwt. falling 7 feet on a 66-lbs. rail has been sufficient to secure the railways of Scandinavia ever since their commencement from a single breakage of rails. Having been charged with the inspection and testing of rails for the last twelve years, for Governments as well as for private railways, in Sweden, Norway, and Denmark, I have had more than one hard struggle with the rail-makers about the test of rails. The results in practice in Sweden as compared with Russia I am proud of stating. The question of determining a medium test having arisen among rail-makers, I have Mr. Sandberg.

Mr. Sandberg. been led to adopt the following rule for the ball-test: The weight of the ball expressed in cwts., multiplied into the height of the fall in feet, should be equal to the weight of the rail per yard. Tests based on this method stand between the extremely severe Swedish method and the mild Russian test, and yet, according to my opinion, secure safety even in a cold climate. It appears that Welsh rails are preferable to those of Cleveland, since the former do not contain phosphorus, while the latter contain $\frac{1}{4}$ per cent. in the rails, and not less than $1\frac{1}{4}$ per cent. in the pig iron; hence it is seen that 1 per cent. is expelled during puddling. The fact of certain rails made in Wales proving as brittle as those made in Cleveland is to be explained by Northampton ores having been mixed with the Welsh ores. Even in Wales strict care must be taken to avoid the production of brittle rails, and no better and more practical method for ensuring safety has yet been found than that of frequently examining samples by the test of concussion. As there are frequent changes in the management of rail-mills, and in the quality of the iron employed, and as it may happen that a maker who deserves a good reputation one year may neglect the quality of his rails the next year, it does not appear expedient to arrange the different works in classes according to the quality of rails produced, but it should rather be remembered that all makers can manufacture both good and bad rails; and if, therefore, railway engineers do not strictly look after their interest by careful inspection, they must naturally become sufferers.

"In regard to rolling stock, Mansel's wooden wheels, with retaining fastenings of the tire, seem to be the perfection of a wheel for cold climates. Cast-iron wheels may be economically employed where the speed is low, but they are neither safe nor economical for high speed, such as 20 miles per hour. Bessemer steel is the most economical for tires, and, if made of good raw material, is quite safe. The bad results attending the use of Bessemer steel in the form of rolling stock in England and Belgium, as stated above, will tend to check the introduction of Swedish Bessemer steel into Russia. And yet nowhere would Bessemer steel be better applied than for axles, tires, and rails in Russia, provided that due care were taken to secure uniformity and homogeneity in the manufacture, and to maintain the proportion of carbon between $\frac{1}{4}$ and $\frac{1}{3}$ per cent. Better means of communication throughout Sweden, the concentration of the works, and improved management and negotiations, are the three conditions necessary for the Swedes, in order to attempt a successful trade with their eastern neighbour. Russia, with its bad climate, is indeed equally as much in want of the splendid iron of Sweden for the development of her railways, as the Swedish iron trade, which is at present ruined, stands in need of the Russian market for its revival. Axles should be made of the best iron, or of the best cast steel. If Bessemer steel be used it must necessarily be of better quality than that which has hitherto been supplied to Russia by Belgium and England, and which has given the bad results already detailed. Every portion of the engines must necessarily be of the best material and workmanship. Cast steel seems to have gained general favour amongst Russian engineers, and is recommended both for safety and economy, while Bessemer steel is regarded with decided suspicion. There is, indeed, no doubt that Bessemer steel is not so homogeneous as cast steel, and it is difficult to make pot-steel as regular and uniform as iron. This is certainly the cause of the general objection amongst engineers to substitute steel for iron. There are, however, grounds for asserting that steel suffers less from the effect of cold than iron does, particularly if phosphorus be present in the iron. Any means tending to confer elasticity on the rolling stock is certainly desirable, such as the use of indiarubber as extra springs, and of a large quantity of wood rather than iron in the rolling stock and permanent way. The slackening of the speed in winter seems advisable, both on the score of safety and of economy." Mr. Sandberg.

Mr. Schreiber. Mr. Collinghurst Schreiber, of Ottawa, after carefully watching the behaviour of iron and steel for many years, was firmly impressed with the conviction that they crystallised and were fractured with great ease when subjected to a very low temperature; and more especially was this the case when a sudden change took place from cold many degrees below zero to above the freezing point. Upon these occasions the breakages of rails and car wheels increased immensely, but immediately the metal was warmed up, its tenacity of structure apparently returned. With these sudden changes in the temperature from cold to heat, he had had to record steel rails flying into as many as twenty pieces, in lengths ranging from 6 to 18 inches. His notes went to show that, in a series of years, the breakages during the warm period of the year, say from May to December, as compared with the other six months of the year, were: steel rails as 1 to 30; iron rails as 1 to 45; cast-iron car wheels as 1 to 3½. It might be argued that this was brought about by the solidity of the frozen surface, and to a certain extent no doubt this was the case, the rigidity of the permanent way in winter contributing towards this result. At the same time he was convinced that the large preponderance in the number of breakages

Mr. Schreiber. during the cold period over those of the summer season, was to be attributed to the change which the structure of the metal underwent at a low temperature. He had never made any scientific experiments as to the relative strength of these metals in cold and warm weather, but he had been a close observer of their behaviour under varied circumstances; and it would be difficult to convince him that extreme cold did not impair their strength. He would give an example. He frequently had occasion to curve both iron and steel rails to a small radius; during warm weather this could be accomplished with freedom from fracture, whereas in the cold season (unless the metal was baked before a fire first) it was impossible to put them through the operation without breaking them. He might add another example. In drilling rocks in summer, such an occurrence as a runner "flying" was unheard of; whereas when the thermometer ranged from 25° to 55° below zero, it was not an uncommon occurrence. He must acknowledge that these were no scientific tests; but while they afforded no data upon which to found a calculation as to the strain these metals would safely bear in a very low temperature, they nevertheless, he considered, established the fact that the strength of the metals was impaired by cold, and that what might be considered as a factor of safety in a moderate climate, could scarcely be relied upon in a severe one, like that of Canada.

Mr. Wilson. Mr. J. M. Wilson, of Philadelphia, from twenty years' experience of the line of the Pennsylvania railroad, during fifteen of which he had had direct charge of the bridges, from the preparation of the designs until their erection, and subsequent annual ordinary inspection, was of opinion that, while iron was more liable to break under shocks or jars in cold weather than in warm, the question did not practically affect the strength of the material when the working stress did not exceed the standard limits, which were essentially the same as in England. Where material was under an excessive strain, and breakage might occur in warm weather, the percentage of breakage was considerably greater in winter than in summer.

In the matter of rails, complete records had been kept by the Pennsylvania railroad company for twenty years, on blanks prepared for the purpose, and reported monthly, the cause, or probable cause of breakage being always inserted in the report. The causes given were various, such as "flat wheel," "defect in iron," "frost," &c., whatever the foreman or supervisor of the division might decide. Breakages were always much greater in winter than in summer, especially when the system of reporting was first insti-

Mr. Wilson.

tuted. Of late years, however, owing to the introduction of heavier rails, and of steel, breakages had been few. It was the opinion of American engineers that the increase of breakages in winter was due more to the rigidity of the frozen road-bed, acting as an anvil under the rail, than to any brittleness of the material from the cold. The thermometer was sometimes from 10° to 20° below zero.

In reference to iron bridges, some of these had been in use on parts of the road ever since its completion, dating back to 1851, and were therefore twenty-nine years of age. The earlier bridges were computed for a live load of only 1 ton (2,000 lbs.) to the lineal foot of track, and being too light for the present traffic, had gradually been strengthened or replaced by heavier structures. Only three of these bridges were now left; one of them was to be replaced this year. They were of the "Pratt" truss form,[1] with cast-iron upper chord (boom); four wrought-iron bars for the lower chord; cast-iron vertical posts, wrought-iron brace rods, cast-iron upper and lower angle blocks, cast-iron arch, and cast lugs on the posts bearing on the arches. Rarely was any of the cast iron broken; sometimes the central angle blocks, from their shape and connection with the brace rods, had tension thrown on them. Where these were broken they had been replaced by malleable castings. The upper chord sometimes was broken, owing to rigidity over the pier, and the continuity of the chord was destroyed. Considerable load had always been adjusted on the arch in this type of bridge, without any trouble with the cast iron, either in the arch or in the bearing lugs on the posts; none of the latter had ever been known to shear off. Wrought-iron brace rods had, however, been broken from time to time, especially in winter, and it had always been customary to keep some rods on hand on the subdivisions of the road, to replace any that might be broken. In case of a rod breaking, the arch would always carry the structure until it was replaced. These brace rods were not "upset" at the screw, and have always been broken at the screw thread, that being the weakest point. All the rods were considerably overstrained. In other bridges there were no cases of winter breakage with rods up to the standard strength. He would venture the opinion that this question of cold was somewhat similar to the introduction of carbon in steel. The cold increased the strength under a steady tension, but at the same time rendered the material more brittle. Cast iron, being naturally far more brittle than wrought iron, the percentage of increase for the same number of degrees of cold was

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[1] *Vide* "The Pennsylvania Railroad." By James Dredge, p. 53.

Mr. Wilson. much greater, not depending upon and varying as the strength of the material.

In conclusion, he submitted a Table of the number of steel rails broken in the main tracks of the Pennsylvania railroad during the years 1875 to 1879, inclusive:—

Year.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Totals.
1875	50	118	55	9	2	0	2	4	5	3	5	4	257
1876	6	13	7	8	0	2	4	5	10	19	5	27	106
1877	69	20	17	5	6	0	0	1	7	2	8	3	138
1878	7	4	3	2	0	4	1	0	5	1	4	9	40
1879	30	21	19	3	5	2	4	3	1	4	10	16	118
Totals .	162	176	101	27	13	8	11	13	28	29	32	59	659
Average	33	35	20	5	3	2	2	3	6	6	7	10	132

It would be noticed that, while in general there was a large increase in breakage during the winter months, yet there were some discrepancies. Thus, in 1875, as many rails were broken in August as in December. In 1876, the number broken in October (a mild month, with seldom any frost in the ground) was far greater than in January or February.

Mr.Wrightson. Mr. T. Wrightson remarked that apart from chemical considerations, the strength of iron to resist strains depended much upon the physical conditions under which the iron was allowed to cool from its higher temperature in course of manufacture. The rate and equability of cooling and the form and dimensions of the iron itself were all conditions of importance. If a bar of wrought iron was heated to white heat and allowed to cool without hammering it deteriorated in strength. The molecules of the iron were at a greater distance apart when in a plastic state. In cooling, the outside portions of the bar would contract first, but could not return to their natural position, as the inside of the bar would still be at its higher temperature. The hammering or rolling caused an adjustment of the molecular distance, and the iron thus became homogeneous throughout. The method of cooling also altered the molecular distance. He found from experiments that best bar iron, when heated to redness and cooled suddenly in water, contracted permanently in its linear dimensions 0·125 per cent. for each immersion. A bar of common iron contracted about 0·15 per cent. He had by repeating the process shortened a bar 30 inches long about 2¼ inches in fifteen heatings and coolings.

Mr. Wrightson.

This shortening was not to be explained by the oxidation of the ends, which was very trifling. Other experiments had also shown that cast iron, copper, and steel were variously affected in their molecular state under different conditions of cooling.

That the action of heat and mechanical vibration had the effect of rearranging the molecules in some way, so as to vary the character of the metal, was well known. Chains and wheel-tires, &c., became brittle by continued use. The re-adjustment of the molecules was effected by the curious process of annealing, which was simply heating to a moderately high temperature, and then allowing to cool slowly. This seemed to restore the tenacity of the iron, and instead of breaking with a crystalline section, the iron became what was called fibrous once more. A few years ago he had carefully examined the iron cut from the plates of two different boilers, both of which had ripped at the seams and caused explosion. The heat acting on the boiler had through time so affected the iron at the thick seams as to make it brittle, and apparently crystalline in fracture, although not much affected in tensile strength. Farther from the seam the iron was, in the case of both boilers, less injuriously affected. He then took strips of the iron at the seam rip and heated them to a dull red, cooling them afterwards gradually in sawdust; after this process the brittleness disappeared and the fibrous character of the iron was restored. Thus molecular motion, whether from mechanical energy or from heat, appeared after long application to alter the disposition of the molecules and to injure the quality of the iron. The remedy of the evil lay in annealing the iron in both cases.

The treacherous manner in which steel and iron occasionally gave way was in a great measure to be attributed to internal strains existing in the material before the ordinary strain due to its work came upon it. These internal strains were the result of unsuitable forms of material and unequal cooling of the parts when solidifying. What engineers wanted was a more accurate knowledge of the physical changes occurring in metals at the time of solidification and cooling from high temperatures. Information on this subject was very difficult to obtain, and the opinions of metallurgists varied with regard to the simplest observations. Thus many had held that iron expanded in solidifying, others that it contracted. Mr. Robert Mallet, M. Inst. C.E., in a Paper read before the Royal Society in 1874,[1] claimed to show that, with the exception of water and perhaps bismuth, no sub-

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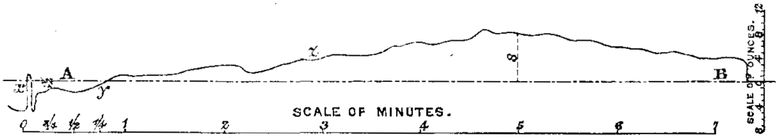
[1] *Vide* "Proceedings of the Royal Society of London," vol. xxii., p. 366.

Mr. Wrightson. stance had been proved to expand in passing from the liquid to the solid state, and cited observations and experiments from which he inferred that no such expansion could occur in the case of iron.

This diversity of opinion as to simple facts appeared to demand more exact measurement than he could find had been applied to any of the observations recorded. He therefore last year designed, and had constructed, an instrument for measuring exactly the change of volume of a body of metal as it passed from the solid to the liquid state. The principle of the instrument was as follows:—He attached a ball of the metal to be examined to a rod which was suspended from a sensitive spiral spring. This ball was submerged in a ladle of the same metal in a molten state. As the ball rose in temperature it expanded and displaced more and more of the liquid metal. This displacement of the metal varied the flotation, and this variation was read off in ounces on the spring balance. Thus, if the ball expanded to such an extent as to displace 4 more oz. of liquid metal than it did when first submerged, the flotation would be increased 4 oz., and this amount of relief to the spring could be read off to a scale of weights. By connecting a pencil point to the moving part of the spring balance, and allowing it to press on a piece of paper wound round a cylinder which revolved by clock-work, he had been able to get an automatic register of the gradual expansion of the metal ball, the vertical ordinates of the diagram showing the weight of metal displaced by expansion, and the horizontal line giving time. These diagrams were very instructive, and showed that ordinary foundry iron was at its maximum density when in a solid condition, at its minimum density when in a plastic condition immediately before liquefaction, and that in liquefying it came back to a density intermediate between these two, being very little less than that of its cold state.

FIG. 13.



Weight of ball and portions of stalk immersed . . .	252¼ oz.
Specific gravity of ditto	6·96
Maximum sinking effect	1½ oz. = 0·6 per cent. of 252¼ oz.
„ floating „	8 oz. = 3·17 per cent. of ditto.

Specific gravity of fluid metal = 0·6 per cent. less than 6·96 = 6·92.

Fig. 13 was a diagram of the melting of a 5-inch ball taken from his instrument. The horizontal line A B gave the position

Mr. Wrightson.

of equilibrium, when, if the ball was of the same specific gravity as the molten iron, there would be neither a sinking nor a floating effect. When the ball was first submerged the pencil went to position x below the equilibrium line, showing that the ball had a sinking effect of 1½ oz. As the heat of the molten iron penetrated the ball, it expanded, displacing the metal. By a mechanical arrangement which lowered or raised the whole apparatus, the ball was always kept exactly the same distance below the metal, and thus the variation in the spring was a faithful record of the variation in volume. It would be noticed that there was a sudden fall on the right of the diagram. This was when the ball melted. After the ball arrived at its greatest volume it was in a soft plastic condition, as he had shown by pulling several balls out at this stage, when he had found that an iron pin could be thrust through and through the mass as though it were putty. As soon as the ball began to melt, the vertical ordinates were useless to determine the specific gravity of the ball, as the mass was altering; but it appeared from the diagram as though the iron, when in this highly plastic state, rapidly passed into the liquid condition, the descending line returning to the position of equilibrium, in consequence of the ball having disappeared in the general molten mass. The small fluctuations in the line of the diagram were only due to slight disturbances of the spring in keeping the stalk of the ball free from floating scoria.

Now if the diagram correctly represented the changes in passing from solid to liquid when read from left to right, a reversal of the reading ought to give the changes in passing from the liquid to the solid state. From this it would be seen that there was a considerable and sudden expansion as the metal became plastic, and that it then contracted more gradually until its density was a little greater than the density of the molten iron. It was an old puzzle amongst engineers to explain why solid cast iron floated in liquid cast iron. The explanation was to be found in the lines on the left hand of the diagram. When the iron was thrown into the ladle the expansion was so rapid that in a second or two it floated. If, instead of throwing it, the ball was lowered into the ladle on an iron fork, as he had frequently done, it would be found that it sank, and then rose in a few seconds to the surface. Of course it was possible to cast and cool a ball in such a way as to have a specific gravity which would compel it to float at once, but he was speaking of castings of average and usual density made of ordinary foundry iron. He had the pleasure of showing these diagrams at the Liverpool meeting of the Iron and

Mr. Wrightson. Steel Institute in 1879,[1] and since that time had tested the truth of the theory of the change of volume by casting a large 15-inch ball of Cleveland foundry iron, and measuring its diameter at intervals until cold. The expansion was most evident, and the ball continued to increase in size for half an hour after the metal was run into the mould, subsequently contracting to a dimension a little less than the mould was originally made, exactly as shown by the reversed reading of the diagram.

It was not an unusual occurrence in the case of a cast-iron plate that days after it had been cooled it would, without apparent reason, fly in pieces, sometimes with a loud report like that of a pistol. A consideration of the cooling of such a plate, referred to in the diagram of changing volume, at once revealed the cause of this. If one portion of the plate had been cooled rather in advance of the adjoining portion, its condition of volume would be expressed by a position lower down the descending line on the left of the diagram, than that expressing the volume of the portion of plate left at a higher temperature. When this unequal condition of the metal existed, internal strains were produced, which might be so great as to permanently injure the quality of the iron at the part strained, and this tension, if near the limit of the strength of the iron, only required a slight additional strain to cause rupture. The same cause might probably be at work in producing the frequent fractures in steel. This material was looked upon by many engineers as treacherous, but he would submit that an exhaustive set of experiments, carried out on the change of volume in steel when passing from a high to a low temperature, would probably lead to alterations in the treatment of steel in manufacture, which would overcome the existing objections raised against the material.

17 February, 1880.

WILLIAM HENRY BARLOW, F.R.S., President,
in the Chair.

The discussion upon the Paper "Iron and Steel at Low Temperatures," by Mr. Webster, occupied the whole evening.

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[1] *Vide* "The Journal of the Iron and Steel Institute," 1879, Plates 6 to 10.