Mr. Arnold. fering widely in their chemical constitution, and consequently, mechanical properties. It would be just as reasonable to charge with inconsistency any one who stated that a steel containing 1·00 per cent. of carbon would harden, whilst a steel containing 0·10 per cent. would not harden. In conclusion he trusted that the anomalous and discrepant experiences, brought to light during the discussion, might prove valuable as finger-posts pointing out paths for further research.

Correspondence.

Mr. Appleby. Mr. C. J. Appleby regretted that the record of investigations had been limited to metals containing chromium, and what seemed to him exceptional proportions of manganese, and that but brief reference (p. 128) had been made to tempering in oil, and none at all to the usual mode of annealing by lengthened exposure to heat in a closed chamber. He had found that the results obtained by the last named method were irregular and unreliable. As regarded oil-tempering, he had made many experiments with open-hearth, Bessemer and crucible steel, and, whether high or low in carbon, he had found that immersion in oil, at temperatures suitable to the character of the metal, invariably improved its quality, and more especially its tenacity. He thought that the following list of tests of oil-tempered Bessemer-steel axles, made in Sheffield, had a direct bearing on the question under consideration, because, after all, a quality of steel was sought which would be reliable under the severe conditions which tires and axles must constantly fulfil. The axles referred to were forged from ingots of the usual size, and the tensile-strength of the steel when forged was 26·1 tons per square inch, with an elongation of 28·6 per cent. in a length of 8 inches, and reduction of area of 60·2 per cent. The tests of the steel, after oil-tempering, gave a tensile-strength of 27·5 tons per square inch, an elongation of 26·87 per cent. in a length of 8 inches, and reduction of area of 58·44. The dimensions of the axles were:—length, 7 feet 4 inches; diameter at wheel-seat, $5\frac{3}{4}$ inches; diameter at centre, $4\frac{1}{2}$ inches. The first test consisted of twenty blows from a 1-ton tup, with 20 feet free drop on the centre of the axle, the bearings being 3 feet apart. The axle was turned half round after each blow, and the deflections were:—1st blow, deflection $2\frac{5}{8}$ inches; 2nd, straight; 3rd, $2\frac{3}{8}$ inches; 4th, straight; 5th, $2\frac{1}{4}$ inches; 6th, $\frac{1}{4}$ past straight; 7th, $2\frac{1}{4}$ inches; 8th, $\frac{1}{4}$ inch past straight; 9th,

$2\frac{1}{8}$ inches; 10th, $\frac{3}{8}$ inch past straight; 11th, $2\frac{1}{8}$ inches; 12th, $\frac{1}{2}$ inch past straight; 13th, 2 inches; 14th, $\frac{1}{2}$ inch past straight; 15th, $2\frac{1}{8}$ inches; 16th, $\frac{3}{8}$ inch past straight; 17th, $2\frac{1}{8}$ inches; 18th, $\frac{3}{8}$ inch past straight; 19th, $2\frac{1}{8}$ inches; 20th, $\frac{1}{2}$ inch past straight. The tests were then continued by giving the tup a fall of 26 feet with the following results:—21st blow, deflection $2\frac{7}{8}$ inches; 22nd, $\frac{15}{16}$ inch past straight; 23rd, $2\frac{3}{4}$ inches; 24th, 1 inch past straight; 25th, $2\frac{5}{8}$ inches; 26th, $1\frac{1}{8}$ inch past straight; 27th, $2\frac{1}{2}$ inches; 28th, $1\frac{1}{8}$ inch past straight; 29th, $2\frac{1}{2}$ inches; 30th, $1\frac{1}{8}$ inch past straight, thus showing gradual fatigue; but there was no fracture, and nothing to indicate that these severe tests had caused permanent injury to the steel. The bending-tests were made on pieces $1\frac{1}{4}$ inch square by 8 inches long, machined out of the axles before and after oil-tempering, and were bent double when cold. The untempered steel showed signs of tearing in the bend, whilst the tempered pieces gave no indication of this kind. There was a wide difference in the fractures, the untempered steel being open and crystalline, whilst the tempered specimens were much closer in the grain, with an entire absence of crystals, and had a silky appearance, the colour being darker than in the untempered steel. As might have been expected, steel, higher in carbon, which had a tensile-strength of 35 tons per square inch before treatment, increased in strength in a higher ratio than the low-carbon steel above referred to. The increase in tensile-strength after oil-tempering was 3 to 4 tons per square inch, but there was no material alteration in the elongation nor in reduction of area. The well-known fact, mentioned by the Author, that steel low in carbon did not harden, might have gone far towards creating the widely-held impression that Bessemer steel would not harden. This was a fallacy; probably but few engineers were aware how large a quantity of Bessemer steel was daily worked up into springs, and even cutting tools of all sorts. Bessemer steel had not quite outlived its character for uncertainty in quality; but his experience showed that steel, singularly even in quality, was produced in those works where analyses of the pig-iron and spiegeleisen were systematically made before they were charged into the cupola, and of the ingot when cast, due care being exercised in manufacture by using pure coke, &c. It would be remembered that the effect of immersing heated steel in heated oil was referred to at considerable length in the discussion on General Maitland's Paper on "The Treatment of Gun-Steel."[1] Mr. Appleby.

[1] Minutes of Proceedings Inst. C.E., vol. lxxxix. p. 114.

Mr. Appleby. In nearly all cases it was spoken of as "oil-hardening," perhaps "tempering" would be a more accurate expression; and it seemed desirable that the difference between "hardening," which increased the tensile-strength and largely diminished the ductility, and "tempering," which added greatly to the tenacity of the metal without materially reducing its ductility, should be clearly recognized. It seemed to him extremely doubtful whether exceptionally high tensile-strength gave to tires and such like things the qualities attributed to it. But even if high tensile-strain should be considered essential, he believed a judicious use of oil-tempering would give results more reliable than any which could be obtained by the use of chromium, and the high percentage of manganese mentioned by the Author; because the metal, being purer, would be less liable to deterioration during manufacture, and to failures due to change in molecular structure, than the less pure steel not oil-tempered.

Mr. Brustlein. Mr. H. A. Brustlein observed that the metal experimented on by the Author was really a manganese-steel with a small percentage of chromium; whilst in his communication to the Iron and Steel Institute,[1] he referred exclusively to a carbon and chrome-steel compared with carbon-steel alone, and his later practice had confirmed the statement he had made on this subject. In his opinion he could hardly admit that the difference between the results shown in the first and third tables (p. 123) could be attributed to the effect of the blows of the falling weight. He rather attributed it to other circumstances which it would take too long to explain. At the Unieux Works he had never recorded a like observation under a blow, although since tool steel was especially made there, steels containing so much sulphur, phosphorus and manganese, and so little carbon, were never worked. As the Author too observed, chrome-steels were very sensible to annealing and tempering; but the readiness with which they could be put in one state or the other, might be turned to advantage. Moreover chromium had a great superiority over manganese, in that it behaved well when associated in large proportions with carbon; whilst manganese alloyed with carbon, except in the very high percentage adopted by Mr. Hadfield, rendered the steel brittle and untrustworthy. The influence of the length of the test-pieces on the results of tensile-tests had been carefully studied by Mr. J. Barba of Creusot, who had communicated a Paper on the subject to the Society of Civil Engineers of Paris.[2]

[1] The Journal of the Iron and Steel Institute, 1886, p. 770.

[2] Mémoires de la Société des Ingénieurs Civils, 1880, p. 693.

Mr. F. W. Harbord stated that his experience in the manufacture of mild steel had led him to the same conclusion as the Author, namely, that high tensile-strains in steel could only be obtained by increasing the proportion of metalloids, and this was always at the expense of ductility and general reliability of the material, especially when it was subjected to continued vibration. He had also found that chromium was a most useful element where high tensile-strength was required; and that within moderate limits it could be employed without diminishing the ductility, or otherwise deteriorating the material. Mr. Harbord

Mr. J. W. King observed that since the experiments quoted by the Author had been made, now several years ago, there had been a great advance by steel-makers in general in controlling the state of crystallization of finished pieces of steel, such as axles, tires, guns, &c., so much so that tire-steels could be made with great regularity to register, after falling-weight-tests, strains as high as from 45 to 50 tons per square inch, at the same time giving an elongation and reduction of area equal to steel 20 tons lower in tensile-strength. Mr. King.

Sir Alexander Rendel, K.C.I.E., could give no accurate information on the results of the present testing of steel tires, as he got none from India. But there were few failures here in testing, and he had no complaints, so far, of failures in India, except in two cases where tires had been found broken on wheels just arrived in India, the result evidently of their having been put on too tight. He had raised his tests to their present standard, because well-known makers of tires which had a high reputation, and which were made to very high tests, wanted him to specify their make. This he declined to do, but specified their tests. Since then he had experienced no difficulty in getting tires capable of sustaining these tests from other manufactures, quite as well as from the makers to whom he referred. He only specified tires to these high tests for locomotives and tenders. They were made by the Siemens-Martin process. He had been obliged to give up steel for carriage and wagon axles altogether. The following was an analysis of a steel tire made at Leeds by the Siemens-Martin process. The analysis had been recently carried out by Mr. Arnold Philip, one of the chemists employed at the Royal Indian Engineering College, Cooper's Hill. There was no chromium in the sample. The tensile-strain obtained with this tire was 45·3 tons per square inch. The contraction of tested area at the point of fracture was 21 per cent. The extension on a length of 6 inches was 15·4 per cent. A weight of 20 cwt. was allowed to Sir A. Rendel.

Sir A. Rendel. fall seven times from a height of 12 feet, until the tire deflected $\frac{1}{6}$ of its diameter (5 feet 6 inches external), but it showed no sign of fracture:—

	Per cent.
Carbon (by combustion)	0·527
Silicon	0·148
Phosphorus	0·052
Manganese	0·492
Sulphur	0·101
Copper	0·050
Tungsten	0·000
Titanium	0·000
Chromium	0·000
Arsenic	0·018
Iron (by difference)	98·612
	100·000
Carbon (by colour-test)	0·575

Mr. Sowerby. Mr. W. SOWERBY observed that the experiments recorded in the Paper were hardly on the exact lines as tests of the ability of tires to endure the treatment to which they were subjected when in use; for, except when there was collision, they seldom or never had to undergo such violent concussions as were indicated in the experiments; nor were they ever subject to any tensile-strain. But they had to undergo and endure constant and continuous impact on the rails over which they travelled, and the amount of such impact depended greatly upon the velocity of the trains, and the gradients of the railways over which they passed. A train, especially when at high speed, had a tendency to follow the parabolic line of a projectile; and, as it descended the gradient, the foreparts of the wheels were very slightly raised above the rails, and there was a continuous fall or thump. In ascending a gradient this thumping was behind the wheel, and so distinct was this thumping on steepish gradients, that anyone with a quick ear could easily detect whether the train was going down or up an incline; and it was this continuous thumping to which railway wheel-tires were subjected. If the material of which the wheels were made was good metal, then this continued impact would have a tendency to improve, toughen, and strengthen the tire; just as old horseshoe nails were said to be toughened by being long worn, and thus subjected to similar impact. It was this kind of continued impact or hammering that a Persian or Indian sword-blade underwent to make it perfect. If the steel from which the tires were made was not good, then the constant impact would have a tendency to crystallize and destroy the strength of the metal, just as the constant blows of a hammer would destroy and crystallize the best bar of iron if suspended vertically or horizontally. The gradients of a railway having such an effect, the natural conclusion was that they should be made to suit the circumstances. Italian engineers, he believed, had made some lines with parabolic gradients; and more than forty years ago he graded the sections of some lines he was then engaged upon, one being the London District of the Great Northern Railway. He found that such a system of grading would have had several advantages, amongst others that of saving 25 per cent. in the earthwork; but it would be troublesome to lay down such gradients, and he was somewhat surprised to find the idea carried out literally on the Switchback Railway at the American Exhibition. Whether the Americans had adopted parabolic gradients on their railways he was unable to say, but if they had, they had done wisely. Much, doubtless, had been learnt from the primitive workers in iron in India and in Spain, especially in the use of manganese and chrome ores for making steel, and also in the mode of tempering steel by cooling it in oil; and there was still much that might be learned from them in the way of preparing and mixing ores, fuel and fluxes, and subsequent manipulation. It was by constant and continued hammering or impact that the finest Persian, Damascus, and Toledo blades were made, and they were tempered and marked by waving or swinging them in the air whilst cooling. Even the mode of making great steel guns by coils was not new to the Indian "Lohars"; for many years ago he saw just such a gun lying at the hill fort of Teree in the Himalayas; it was about 12 feet long, 5 to 6 inches bore, and it was built upon a spiral form exactly on the same principle as the Armstrong guns, and that gun must have been one hundred and fifty, or two hundred years old. Mr. Sowerby.

Mr. BARTLETT W. WINDER observed that his work had been more especially confined to the higher grades of tool steel, and here similar phenomena were met with, particularly and strikingly in high-carbon steels. A portion of carbon, which in the ingot or hammered bar had existed as combined carbon, assuming during the rolling the free or graphite state; the fracture, which should have been of a close silky white colour, appeared as a coarse black fracture, owing to the presence of the free carbon. The free carbon, on hardening, disappeared or took another form, but did not again return to its previous combined state, as on annealing it again appeared in exactly the same position. What state the carbon assumed on hardening could not, up to the present, be explained Mr. Winder.

Mr. Winder. even after the most careful analysis. How far this molecular alteration would affect the after-working of the steel, he was not prepared to say. In many other kinds of steel, equally marked molecular change occurred, and very generally in irons. Fibrous iron rapidly assumed the granular state. He fully endorsed the Author's opinion, that until maker, consumer, chemist, and microscopist united, this most vital question in the steel trade—the change appearing so unexpectedly, so powerful in its action, and about which so little was known—would remain unsolved.

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11 December, 1888.

SIR GEORGE B. BRUCE, President,
in the Chair.

The discussion on the Paper by Mr. John Oliver Arnold, "On the Influence of Chemical Composition on the Strength of Bessemer-Steel Tires," occupied the entire evening.
