believed in the use of both, some for one purpose and some for another. He hoped to show specimens of each. Mr. Andrews.

Mr. Andrews subsequently exhibited a series of lantern slides showing the chemical composition of steel rails and fractures and flaws in rails.

Correspondence.

Mr. Jordan.

Mr. W. L. JORDAN observed that Sir Lowthian Bell had given a clear explanation of the manner in which a fast train might run in safety over a fractured rail which could not carry the same train if moving slowly; he presumed, however, that it was nevertheless generally recognised that the vibration caused by a fast train might break rails, or shake to pieces girders, which would not be injured by the passage of the same train moving slowly. He alluded to this for the purpose of suggesting that Sir Lowthian Bell might perhaps be able to add some further information to the interesting statement he gave regarding the relative number of rails broken on different parts of the North Eastern line. A point of special interest in connection with the subject seemed to him to be as to whether the same rule for spacing sleepers prevailed all over the Company's lines, or whether any particular rule for spacing prevailed in the areas in which breakages were most numerous.

Mr. Stead.

Mr. J. E. STEAD considered it a great triumph in metallurgical research when Professor Arnold proved that the sulphur in steel, or at least the greater part of it, separated out in combination with iron or manganese, and did not remain in combination with the mass of the steel in the way phosphorus did, but was thrown out of solution and appeared as envelopes to the crystalline grains of steel under certain conditions. Mr. Stead had noticed they were more usually in the form of minute globules in large ingots. When the steel ingots were rolled out into rails, these globules were elongated and appeared in longitudinal section as lenticular forms; but in reality, as he had shown in a Paper[1] on the causes which tended to produce fracture in iron and steel, they were of torpedo or cigar shape. When the original section of the ingots was greatly reduced, these sulphide globules were rolled out and became elongated threads. He had observed that they

[1] Proceedings of the Cleveland Institution of Engineers, 1898-99, p. 12.

Mr. Stead. were usually quite separated one from the other. From an engineer's point of view, they were not more harmful than cinder or any other non-metallic foreign matter. When this discovery was clearly established, it came as a great relief to his mind, for now it was proved that the sulphides were only mechanically mixed and were not chemically combined with the cold steel.

He would like to ask Mr. Andrews if he considered that he had clearly and logically proved that the separated sulphides were responsible, in any way, for the wear of the rail he examined. It appeared to Mr. Stead that, to have proved this point, a companion rail, identical in composition with the rail in question (excepting as regards the sulphur which should have been say 0·06 per cent.) should have been subjected to the same conditions of treatment, the wear of each being noted. It was stated that the rail had "been subjected to very considerable grinding and abrasion," and the manner in which the steel had been beaten, or forced out transversely into extensive lateral fins showed that it had borne a large amount of work. It was also stated that the physical properties were highly satisfactory, and judging from the fact that the elongation was 27 per cent., and the reduction of area on pulling it asunder was 44 per cent., he quite agreed with Mr. Andrews that it was excellent steel. Was not this strong evidence that the separated sulphides could certainly not be considered as "germs of disease," or "flaws," tending to cause disintegration during vibratory stresses, or excessive wear during crushing forces?

At the conclusion of Mr. Andrews' remarks, speaking of rails generally and not, presumably, of rails high in sulphur, he said, "There are tunnels in which rails ought not to be retained in the permanent way for a longer period than 3 years or 4 years"; clearly showing that it was his opinion that under certain conditions average rails in tunnels would wear much more rapidly than the example brought forward, which had done good service, and had, according to Mr. Andrews, enjoyed the maximum life allowed of 7 years.

It appeared to Mr. Stead that Mr. Andrews' results would tend to remove from engineers' minds the lurking fear that sulphur was a great evil in structural material, for here was an excellent rail with 0·12 per cent. of sulphur in it, which had been subjected to the worst possible conditions and treatment, yet it came through the ordeal triumphantly, and did not show any deterioration in its mass after 7 years' percussive and vibratory stresses. On examining the Table giving the dimensions of the so-called sulphur flaws, it would be seen that not one of them was longer than 0·0036 inch, and the average was certainly much less. They appeared great when magnified 300 diameters, but in reality they were exceedingly minute. If the whole of the sulphur in the rail was in combination with manganese the actual weight would be 0·31 per cent. He thought that if Mr. Andrews would look at the question from this point of view, he would scarcely conclude that an excess of 0·15 per cent. of sulphides, which was equivalent to cinder, would be responsible for the rapid wearing of the steel rail. Mr. Stead.

Sulphur, in excess, usually made steel redshort, and rails unfit to send out of the maker's works. Manufacturers, in their own interest, aimed at keeping that element within limits, and with such success that during the last few years they had greatly reduced the proportion of wasters by adopting methods of keeping the sulphur down. Mr. Stead's experience was that, provided the rails were sound and were free from visible flaws, about 0·1 per cent. sulphur did not appear to cause rapid wear or produce fracture, and he did not think Mr. Andrews had proved the reverse to be the case.

Sir Lowthian Bell.

Sir LOWTHIAN BELL, in reply to the Correspondence, gave the following particulars of rails found broken on the system of the North Eastern Railway Company, which he had abstracted from information communicated to the Board of Trade Committee on Rails.

The percentages of phosphorus in the two following Tables being, in some cases, lower than usual, he had added two series of analyses, being eight specimens from the North Eastern line and eight from the Lancashire and Yorkshire. In both of these the analyses had been made by Professor Thorpe in the laboratory of the Board of Trade. The tests of strength had been made in the presence of certain members of the Rails Committee appointed by the Board of Trade, the late Major Marindin, Government Inspector, being of the number.

The rails had been classified, beginning with those withstanding the highest aggregate fall of the weight; the absence of any correspondence between the composition of the specimens and the force required for fracture was too noticeable to require further comment. Professor Thorpe had had made a special examination of these specimens, and in explaining the consistency of a high percentage of phosphorus with superior strength, he considered that this element might exist in a rail under two distinct forms, one of which conferred brittleness, while the other was harmless in this respect. In the event of further investigation confirming this view a question of importance would follow, viz., was there

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RESULTS OF TESTS AND ANALYSES OF TWENTY-SIX STEEL RAILS BROKE UNDER 5 FEET OF FALL OR LESS. WEIGHT

Feet of fall .	0·5	0·5	0·5	0·5	0·5	0·5	1·75	1·75	1·75	1·75	1·75	2·0
Composition—												
Phosphorus	0·09	0·08	0·053	0·014	0·082	0·07	0·02	0·08	0·07	0·03	0·05	0·49
Carbon .	0·50	0·42	0·42	0·53	0·35	0·39	0·61	0·58	0·45	0·30	0·30	0·48
Sulphur .	0·14	0·09	0·04	0·11	0·12	0·08	0·02	0·12	0·12	0·10	0·11	0·13
Silicon .	0·05	0·08	0·103	0·051	0·06	0·11	0·06	0·07	0·15	0·08	0·08	0·07
Manganese	0·68	0·75	0·80	0·59	0·56	0·72	1·34	0·53	0·98	0·49	0·49	0·60
Totals .	1·46	1·42	1·416	1·295	1·202	1·37	2·05	1·38	1·77	1·00	1·03	1·77
Years in use.	19	19	10·16	17·33	23·58	19	17	20	15·75	16·75	16·75	19
Loss per yard lbs.	3·13	4·75	12·20	4·63	9·38	6·25	5·13	5·63	10	14·12	12·12	2·75
Worn head .	down	down	down	up	down	up	up	up	up	up	up	down

RESULTS OF TESTS AND ANALYSES OF TWENTY-TWO STEEL RAILS BROKE UNDER MORE THAN 5 FEET OF FALL.

Feet of fall . .	9·5	17·5	23·5	24·5	24·5	26	37	44·5	44·5	44·5
Composition—										
Phosphorus . .	0·05	0·04	0·04	0·05	0·06	0·038	0·06	0·026	0·031	0·070
Carbon . . .	0·40	0·37	0·55	0·49	0·39	0·41	0·39	0·54	0·41	0·398
Sulphur . . .	0·10	0·10	0·04	0·04	0·06	0·12	0·12	0·05	0·06	0·075
Silicon . . .	0·08	0·08	0·19	0·15	0·48	0·066	0·08	0·102	0·153	0·041
Manganese . .	0·81	0·72	1·53	1·16	0·98	0·98	0·80	0·58	0·86	0·477
Totals . . .	1·44	1·31	2·35	1·89	1·97	1·614	1·45	1·298	1·514	1·061
Years in use . .	18·66	16·75	17	17	17	21·41	18·66	19·08	19	19·83
Loss per yard lbs.	11	10·75	2·75	3·25	2·63	3·13	8·25	10·63	8·30	7·63
Worn head. . .	up	up	up	down	down	down	up	down	down	down

NOTE.—The falling-weight tests referred to in these two

AFTER REMOVAL FROM THE NORTH EASTERN RAILWAY SYSTEM WHICH
OF TUP, 2,240 LBS.; SUPPORTS, 3 FEET APART.

Sir Lowthian Bell.

														Averages.
2·0	2·0	2·0	2·0	2·0	2·0	2·0	2·0	2·0	3·5	3·5	3·5	4·5	5·0	1·99
0·07	0·04	0·062	0·047	0·036	0·062	0·097	0·067	0·07	0·04	0·05	0·07	0·131	0·040	0·060
0·42	0·49	0·43	0·43	0·45	0·338	0·291	0·42	0·37	0·52	0·39	0·39	0·480	0·57	0·444
0·11	0·06	0·03	0·10	0·15	0·071	0·066	0·08	0·14	0·03	0·10	0·06	0·125	0·05	0·090
0·04	0·08	0·066	0·12	0·048	0·096	0·121	0·120	0·11	0·10	0·22	0·05	0·015	0·132	0·087
0·54	0·70	1·04	0·81	0·73	0·711	0·831	0·73	0·80	0·82	0·59	0·53	0·565	0·99	0·727
1·18	1·37	1·228	1·507	1·414	1·278	1·206	1·417	1·49	1·51	1·35	1·10	1·316	1·782	1·408
19	17	15	10	11·25	17·58	20·50	21·41	18·66	18	19	18	19	21·16	17·65
3·38	2·13	23·75	10	14·30	5·13	7·13	5·88	8·50	9	5·88	6·63	3·25	4·13	7·66
down	down	..	up	down	down	down	down	up	up	up	up	down	down	..

AFTER REMOVAL FROM THE NORTH EASTERN RAILWAY SYSTEM WHICH
WEIGHT OF TUP, 2,240 LBS.; SUPPORTS, 3 FEET APART.

												Averages.
48	58	63	65	76½	76·5	79·5	86·5	86·5	86·5	103·5	103·5	55·86
0·140	0·04	0·07	0·012	0·04	0·03	0·04	0·04	0·105	0·155	0·04	0·03	0·055
0·542	0·65	0·40	0·53	0·39	0·31	0·59	0·48	0·386	0·538	0·38	0·38	0·451
0·140	0·03	0·12	0·05	0·03	0·05	0·03	0·02	0·028	0·123	0·02	0·05	0 066
0·014	0·14	0·07	0·096	0·08	0·06	0·12	0·12	0·207	0·118	0·07	0·06	0·112
0·600	1·09	0·70	0·97	0·88	0·85	1·20	1·16	0·577	0·512	1·03	1·21	0·895
1·436	1·90	1·36	1·658	1·42	1·30	1·98	1·82	1·303	1·146	1·54	1·73	2·588
17	17	19	15·33	7·83	7·08	17	17	13·75	19	7·33	7·08	..
2·13	1·75	3·13	10	1·20	5·30	2	1	4·40	2·85	..	5·20	..
down	up	down	up	up	up	up	down	down	down	up	up	..

Tables were carried out in the manner indicated in the Paper.

Sir Lowthian Bell. any treatment capable of changing the objectionable variety into the other form?

NORTH EASTERN RAILWAY.

No.	Fall of Weight. — Feet.	Composition.						
		Phosphorus.	Carbon.	Sulphur.	Silicon.	Manganese.	Slag.	Total Foreign.
4	86½	0·155	0·538	0·123	0·018	0·512	0·064	1·410
5	86½	0·105	0·386	0·028	0·207	0·577	0·046	1·349
3	48	0·140	0·542	0·140	0·014	0·600	0·064	1·500
9	44½	0 070	0·398	0·075	0·041	0·477	0·066	1·127
2	4½	0·131	0·480	0·125	0·015	0·565	0·080	1·396
6	4½	0·078	0·454	0·062	0·041	0·614	0·072	1·321
7	2	0·062	0·338	0·071	0·096	0·711	0·078	1·356
8	2	0·097	0·291	0·066	0·121	0·631	0·088	1·294
Averages	34·81	0·105	0·428	0·086	0·069	0·586	0·069	1·344

EIGHT RAILS, LANCASHIRE AND YORKSHIRE RAILWAY.

No.	Fall of Weight. — Feet.	Composition.						
		Phosphorus.	Carbon.	Sulphur.	Silicon.	Manganese.	Slag.	Total Foreign.
11	26	0·098	0·335	0·070	0·075	0·838	0·082	1·498
12	26	0·066	0·374	0·091	0·054	0·796	0·070	1·451
15	26	0·079	0·415	0·044	0·092	1·144	0·086	1·860
13	17	0·058	0·371	0·091	0·063	0·804	0·064	1·451
16	17	0·066	0·371	0·054	0·055	1·089	0·066	1·621
14	10	0·072	0·412	0·069	0·094	0·910	0·058	1·615
15	2	0·061	0·329	0·080	0·055	0·693	0·078	1·296
17	2	0·070	0·348	0·094	0·050	1·061	0·098	1·721
Averages	16	0·071	0·369	0·074	0·067	0·917	0·075	1·564

In reply to a further question by Mr. Jordan, the sleepers used on the North Eastern line had a width of 10 inches, and the distance between two sleepers was 1 foot 11½ inches. This distance between the sleepers was maintained throughout, irrespective of differences in the traffic. An exception was observed at the junction of two rails, where the sleepers were only 1 foot 3½ inches apart. In the case of sharp curves the distance between each sleeper was reduced to 1 foot 8½ inches. The rails now in use on the North Eastern system had a length of 30 feet, and weighed 900 lbs. each., or 90 lbs. per yard. They were placed in chairs of cast iron, in which they were secured by wooden keys.

Mr. Andrews. Mr. T. ANDREWS, replying to the Correspondence, remarked, in reference to the question as to whether the separated sulphides had been responsible in any way for the wear of the rail, that he had stated in the Paper that the wear of the rail had been due principally to the heavy amount of work put upon it; and after having carefully studied the structure of the rail, he considered further that the peculiar way in which the sulphides of iron and of manganese had micro-segregated in many places in this rail had undoubtedly intensified the effects of the heavy wear. The way in which these innumerable micro-segregations of the impurities had locally disturbed the normal micro-structure of the mass of the steel, and hence to that extent had affected the wearing qualities of the rail, was manifest on referring to the typical illustration given in Fig. 4, Plate 2. He observed Mr. Stead inferred that the sulphides in steel rails were isolated, and therefore mechanically harmless. This was often the case, but he had noticed in various other instances, both in fractured steel rails examined by him for various railway companies, and in fractured propeller-shafts and other forgings, that the sulphides, in a more or less attenuated condition, were not infrequently locally connected in various parts of the mass of the steel, and hence destroyed for appreciable distances that metallic contact between the ultimate crystals of the metal which was essential to ensure permanent strength. On the subject of the evil effects of sulphur in steel, he would direct attention to the series of articles he had recently published on "Microscopic Internal Flaws inducing Fracture in Steel,"[1] and on "Deterioration in Steel Rails."[2] It had been suggested that 0·10 per cent. of sulphur was not detrimental to steel rails. It should, however, be pointed out that such a high percentage would allow makers to use a commoner quality of pig-iron than was desirable for good rail-steel. He had found no difficulty in obtaining rails not containing more than 0·07 per cent. of sulphur. He had examined for railway companies rails with a comparatively high percentage of sulphur, some of which had worn down badly and had had comparatively short lives, whilst others from the same cause had actually fractured in service. He was sorry Mr. Stead attempted to minimize the evil effects of sulphur in steel rails, as it was evident that the less of such a "deadly enemy" (as Professor Arnold styled it) or impurity there was present in rails the greater their endurance would be, and advocacy of so high a percentage of sulphur as 0·10 in steel rails would appear to be detrimental to the interests of the public safety. Mr. Andrews.

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[1] *Engineering*, 10th, 17th and 24th July 1896.
[2] *Ibid*, 1897 and 1898.