

Mr. Jenkin. trains in goods yards without driving the whole line electrically. With steam-locomotives on the main lines, they put in electric shunting-locomotives with a single overhead wire and the device worked extremely well. There was no insuperable difficulty in doing it, such as had been referred to by Mr. Webb. It had been suggested that the trolley-wire or conductor should be placed at the side of the line, but that at once involved difficulties at points and crossings. If the conductor was on one side, it was necessary, where lines branched off or crossed, to have gaps in the conductor to let the other line through. It was simpler to keep the conductor over the top of the train and to collect the current from beneath it.

Correspondence.

Mr. Behr. Mr. F. B. BEHR remarked that the Authors' interesting Paper, though containing a large amount of valuable information and setting forth in a striking manner the different systems of electrical traction, seemed to proceed on the assumption that, if sufficiently perfect electrical machinery could be designed, the question of working the large railway systems of Great Britain, such as the London and North Western or the London and South Western Railway, by electricity, would be solved. To him it appeared that the first point to be considered was whether it was likely, assuming that the arrangements for electrical working were sufficiently perfected, that a complicated system of railways such as those of England could be worked entirely electrically. He considered this was absolutely impracticable, unless central generating-stations and conductors could be dispensed with altogether; and this had been tried in the Heilmann locomotive, and had proved a failure. Even if the most perfect system of electrical traction involving central stations and conductors was applied to any one of the great railway systems, it must end in absolute financial failure. In order to pay commercially, electrical traction had to deal with as nearly constant loads as possible, and must employ the total capacity of the generating-station as fully as possible. Sudden and exceptionally heavy demands on the traffic could not be dealt with economically by electrical traction. Considering, for instance, the London and South Western Railway, with its numerous race-meetings, when many thousands of people who did

not travel on other days had to be carried during one or two hours Mr. Behr. of the day, and supposing there were sixty such days in the year; if the electric station and the conductors were to be able to cope with such special traffic, the initial capital expenditure would evidently be enormously increased, and a great deal of it would be unproductive for the larger part of the year. Such instances could be multiplied indefinitely, *e.g.*, the traffic on Derby Day, the Saturday and Sunday excursions on the London, Brighton and South Coast Railway during the summer, the special trains for the Liverpool Grand National. In fact, it might be said that on all great railways there were some very large and sudden increases of traffic which taxed the companies, even under the existing conditions, to the utmost, and could not be provided for with economy by means of central power-stations and conductors. Further, the difficulties of shunting in complicated goods yards seemed absolutely prohibitive: how could places like Clapham Junction or Willesden Junction or Crewe be worked electrically? On the other hand, it was hoped by some that the injury done to the railway companies in their suburban traffic by the competition of electric tramways would be counteracted by applying electricity to the railways; but would that actually be the case? The injury was really due to the facts that tramways went nearer to the destinations of many people than the railways could possibly go, and therefore it was in many cases more convenient to use them; that the fares were comparatively cheaper; and that there were more frequent departures. He did not think any of these causes would be counteracted by electrifying a large railway system. On the contrary, he believed that it would prevent the possibility of increasing the number of trains, and certainly it would not enable the company to lower its fares to pay for a large increase of capital. However, the nucleus of more or less constant traffic which existed in every great railway system could be dealt with by electrical traction; and he believed that in each case the complications on the existing systems, which gave rise to a great deal of extra cost and at the same time prevented the greater frequency of trains, could be reduced. By removing this more or less constant traffic on to special lines worked by electricity, the competition of the tramways would be met in a large measure, the receipts of the railways would be increased, and the expenses would be reduced; leaving a large portion of the traffic to be handled by the present rolling stock and engines, which would be done more advantageously by those means than by electricity. In conclusion, he

Mr. Behr. might point out that in order to suggest any practical amelioration of the existing railway systems it was absolutely necessary not to recommend something which would start by rendering a large portion of the existing capital useless and adding to it an immense amount of new capital; because, even if there were some great advantages in one way resulting from such a recommendation, the financial feature of it would render it ineffective commercially: whereas by bringing to the aid of the present traffic arrangements electrical traction as an auxiliary for such portions of the traffic as could employ it with advantage and economy, the comparatively small amount of new capital necessary would be amply repaid by the economy, speed, and frequency of trains which would follow; and for that purpose the existing machinery for electrical traction seemed quite sufficient.

Mr. Brown. Mr. C. E. L. BROWN, of Baden, remarked that he quite agreed with the opinions put forward by the Authors; but there were one or two points on which he would like to offer some comment. It was stated in the Paper that with polyphase systems lost time could not be made up, implying that the continuous-current system was superior in this respect. All railway plants had to be calculated for a certain speed; in the case of polyphase systems the normal speed only differed from the maximum by a small fraction, that was, the speed was practically constant for all loads; whereas in the case of continuous-current systems the speed was highest at light loads and with full pressure, and lowest at heavy loads. It was obvious that the principal need of making up for lost time on railways arose when the traffic was heavy, involving delays owing to longer stops at the stations. But just when a high speed was required to make up for lost time, the continuous-current motors failed, as they ran more slowly, the carriages being heavily loaded, and possibly the pressure lower than usual. It followed that a continuous-current railway, working under economical conditions, namely, without wasting power in rheostats at the normal speed, was inferior to a polyphase railway, which adhered to the scheduled speed in times of heavy traffic and ensured punctuality. Under ordinary conditions lost time could be made up only on down gradients; this could be done not only on continuous-current railways, but also on polyphase railways. Moreover, the result arrived at by the foregoing theoretical considerations was confirmed by his experience on the Burgdorf-Thun line, which showed that it was easier to keep to scheduled time regularly with constant speed than with variable speed, as illustrated by the

steam-hauled trains which ran on the same metals. In connection Mr. Brown with the Authors' remarks on three-wire systems, it might be of interest to mention that there was an example of a three-wire 1,000-volt tramway near Grenoble, and that another line was in course of construction in the same neighbourhood. Coming to the conclusions arrived at by the Authors, he quite agreed with them that a composite system, and especially one using a high-tension single-phase transmission-line combined with a motor-generator on the locomotive, had many points in its favour. He considered it a great advantage that no rheostats were needed, giving a perfect and economical control for the full range of speed. He would like to point out that Messrs. Brown, Boveri & Co. had used this system of control as early as 1891 for the first (800-HP.) Heilmann locomotive, and that such good results had been obtained therewith that the two later Heilmann locomotives, each of 1,200 HP., had also been equipped with it. As a further consequence the firm had employed the system for a trolley-locomotive in St. Germain in 1895. This locomotive had carried a motor-generator consisting of a continuous-current motor wound for a tension of 500 volts to take current from the line, coupled to a dynamo generating current at a variable pressure of from zero to 400 volts. In addition to these applications, they had studied, in 1897, the question of employing the same system for the Burgdorf-Thun Railway; they had intended to transmit the energy as single-phase or three-phase high-tension alternating current and to place a motor-generator on the locomotive. But it had been found that the locomotive would become too heavy; and so, although quite appreciating the advantages of the system, they had decided not to employ it in this instance. They were of opinion that the great weight which the locomotive must necessarily have was the main drawback of the system. They had, however, lately had occasion to reconsider the idea, as they now saw a means of reducing the weight by employing high-speed machinery, with which their experience of steam-turbine work had rendered them more familiar.

Mr. A. B. CHATWOOD observed that he had read the Paper with Mr. Chatwood. great interest, but he was sorry that it had not been rendered still more comprehensive and complete by the consideration of the advantages to be gained by electrical over steam traction. Several times during a number of years he had suggested that advantages were to be gained by electrical traction quite apart from those of generation of power in bulk by fixed engines; these advantages being that owing to the absence of reciprocating parts

Mr. Chatwood, and to the continuous nature of the torque obtained with electro-motors, the power would be more efficiently applied between wheels and rails, the speed would not be limited except by considerations outside the engine, and the life of the rolling stock would be increased. He had suggested as a profitable experiment the mounting of a small generating-station on the train itself, in order to ascertain how far these advantages would go towards compensating for the losses in efficiency due to the two extra energy-transformations.

Mr. d'Alton. Mr. P. W. D'ALTON remarked that he proposed to touch only on one or two concrete points immediately germane to the detail of the Paper, and in no sense to deal with it from an abstract point of view. In the earlier part of the Paper some comparisons were established between the system in use on the City and South London Railway and that of the Central London Railway; and, judging by the diagrams, it appeared to him that the latter was superior to the former, in that it required a much smaller amount of running machinery. In the Central London system a high-tension polyphase machine took the place of four 500-volt dynamos required for the five-wire system of the City and South London Railway, and three rotary converters were used in place of three balancers and four reducers. At the same time a large saving in cables was effected, owing to the increased pressure of the Central London system. The capacity of the rotaries used in that system was 900 kilowatts, and although there were in all seven of these machines installed, they had never given a moment's trouble; while the cost of conversion from three-phase to continuous current was wonderfully small—about 0·025*d.* per kilowatt, including all charges. The “disadvantages” of the composite system were, he thought, somewhat exaggerated by the Authors. As shown, the skilled attendance was not a serious drawback; static transformers could be made which practically never failed, and cost little or nothing in upkeep; and speaking from his own experience, he had no hesitation in saying that, well-designed and properly treated, rotaries gave no trouble at all. It was not easy to reach their limit of ill-treatment, for they would stand an astonishing amount of overload, provided there was ample copper in the primary of the system, without showing any signs of overheating or coming out of synchronism. As an example, it might be mentioned that one of the rotaries at the Marble Arch sub-station had given 23,000 kilowatts in 17 hours without any sign of distress, save a comparatively small increase in temperature. Such machines were self-starting, and

motors for running them up to synchronism appeared to be Mr. d'Alton. superfluous. On the Central London Railway the first machine was started as a three-phase motor, and from it the others were run up as continuous-current motors, being synchronized in the usual way as required, and, as he had stated, without hitch or any polarity trouble. An experiment had been made one Sunday morning, before the traffic began, by starting two alternators at the power-house, putting five rotaries in parallel with them in the usual way, and then starting a sixth rotary from the three-phase side at the Post-Office sub-station, which was about 6 miles from the power-house. The effect of this had been to reduce the voltage to about 3,000 volts, but no machine had come out of step, and as the machines had come up to synchronism so the voltage had risen; which, he ventured to suggest, demonstrated that the stability of the system left little to be desired. Motor-generators for lighting were no doubt excellent machines, but for traction a good rotary converter was difficult to beat. The floor-space occupied was very small. The rotaries on the Central London Railway stood upon a floor-space 12 feet by 9 feet 6 inches, and there were at Notting Hill Gate sub-station two such machines, with transformers, switch-gear, blowers, and everything else necessary, in a single pit 30 feet in diameter, there being plenty of room. With regard to the Table of costs given by the Authors at p. 53, a rotary converter, capable of carrying 50 per cent. overload for 1 hour and 100 per cent. without serious sparking, could be bought for £3 per kilowatt of rated load (less than £2 per kilowatt of maximum momentary output). Some of the other figures in the same Table should be accepted with reserve, unless it might be taken that the statement in the bottom line of the page covered a multitude of parts. At p. 82 of the Paper a comparison was made between the costs of the Central London and City and South London Railways "per passenger." He hardly thought that such a basis was a sound one, unless it was known that the passengers had actually travelled the same number of miles. For instance, on two lines of equal length, where the average passenger travelled, say, two-thirds of the length of one line and one-third of the length of the other, the train on the former would have to be of greater capacity, and consequently heavier. Such an analogy was probably not a fair one as between the two railways named, because, as the City and South London Railway had both its termini in the suburbs and its more or less central point in the City, it was unlikely that the average distance travelled by its passengers was as long as the

Mr. d'Alton. average on the Central London Railway with its more important terminus in the City, and its less important one at Shepherd's Bush. With regard to alternating-current motors, such as those proposed by Messrs. Ganz and Co. and other continental engineers, the fact that a fixed speed could not be exceeded would, he felt sure, prove a great drawback on any main-line system, or even on a small underground line where a rapid service was maintained. Loss of time by one train from any cause would mean delay to the whole traffic, with consequent decrease in the carrying capacity of the whole line for the day. The Authors gave some hope that the trouble caused by the weakening of the fields in series motors, which was necessary for speeding up, had been solved, and this of course would greatly increase the range of the series-parallel controller, which had the fault that there were only two, or at the most three, notches on which any efficient running could be done. Another point about alternating currents was, as pointed out by the Authors, the increased resistance of the rails; and this seemed to be a more serious factor than was generally supposed. Should a periodicity be used sufficiently high to allow of good lighting off the power-circuit, it seemed likely that the losses would be somewhat troublesome. The results of some tests made on the Central London Railway between the power-house and Notting Hill Gate—a distance of about $1\frac{1}{2}$ mile—showed the apparent resistance of the third rail to be about twenty times as high for alternating current at 25 cycles per second as for continuous current, and that of the running-rails seven times as high; so that on an open road without tunnels something between seven times and twenty times would be expected, such as Mr. Blathy had obtained. The current-density in these tests had been about 35 amperes per square inch. In iron tunnels there was considerably more leakage from the running-rails than there would be on an open road or on a road run through brick tunnels. Of course by the use of two insulated rails of copper, instead of steel, better results could be obtained; but the difficulty at crossings would be serious on a main line, and could not very well be overcome, as shown on the experimental line between Earl's Court and High Street, Kensington, where he believed no crossings or points were, so to speak, "wired in." Bearing in mind the failure of the Heilmann locomotive, scepticism about composite machinery on trains was natural; but he was sure that when the arrangement of Mr. Ward Leonard described by the Authors was put into practice, its working would be watched with keen interest by all engineers. It had been stated that the

overhead trolley system in the Central London Railway depot at Mr. d'Alton. Shepherd's Bush had had to be replaced by steam-locomotives for purposes of shunting and yard-work generally. This, however, was not so; the steam-locomotives had been employed from the first for such work, the trolley system being an alternative one.

Mr. D. DRUMMOND remarked that engineers directly interested in Mr. Drum-
the question must admit there was a clear line dividing the respec- mond.
tive suitabilities of steam and electric motive power for application
to the working of long- and short-distance traffic; and in no case
could electric motive power be produced cheaply so long as steam-
power was used to produce the electric current. There could be
no question, however, as to the advantage of electrical traction
over steam for traffic in large cities, either above or below
ground, when worked by light trains running at frequent
intervals, and provided with reliable short-distance automatic
electric signalling. To attempt to extend electrical traction
beyond city limits would only end in failure, and harm would
be done to its progress by attempts to extend its use beyond the
limit warranted by the existing knowledge of the subject. Main-
line traffic, to be economically worked over long distances, must
be dealt with by heavy train-loads with the minimum of dis-
location by failure of engines or other causes that would tend
to delay the working of trains over long distances and for
long periods of time. Engine-failures were easily located and
seldom happened to be so serious as to prevent the engine from
taking the train on to a refuge-siding, causing the least possible
inconvenience to the following traffic. A train having its own
motive power, subject in every way to the control of the men
on the foot-plate, must appeal to the intelligence of engineers
as superior to one in which the driver had no control over or
knowledge as to the cause or location of failure. As to the
important question of the comparative cost of the two systems
per train-mile, the cost of electric power for any long distance was
still an unknown quantity, and many of the advocates of electrical
traction based their comparative calculations on the cost per train-
mile as furnished by the half-yearly reports of the railway
companies, which was altogether misleading, as there was between
30 per cent. and 40 per cent. of the total engine-mileage which
was not shown in such reports, and the expense of which was added
to the cost of working per train-mile. Thus, to take the cost per
train-mile under these conditions was not only misleading, but
gave credit in favour of electrical traction to which the latter was

Mr. Drummond. not entitled. With steam-locomotives which could haul 15 tons of gross load over 1 mile for every pound of coal consumed in the fire-box, and were possessed of many other advantages for the particular work they had to perform, British railway companies were not likely to discard the use of locomotive engines costing £40,000,000 for any other means, until it was proved conclusively that it would pay them to do so. Electrical engineers had a wide field of work in which to gain further experience before they attempted to deal with the larger question of universal electrical traction; and he ventured to say that they had barely reached the border line of economical traction, which must form the essence of the whole question of railway transport.

Mr. Huber. Mr. E. HUBER, of the Maschinenfabrik Oerlikon, remarked that the way in which the Authors arrived at their conclusions was thoroughly scientific; he had not thought that a question so eminently governed by practical considerations was capable of so successful a treatment as it had found at their hands. The firm with which he was associated had arrived at the need for single-phase current by a much cruder method. They had thought it essential to reduce the contact lines to a minimum, and had therefore given the preference to a single line. For the equipment of such a line as the St. Gothard railway, they had desired to keep the currents to be collected from the contact lines within the limits of successful street-railway practice. Nothing would meet these considerations but single-phase alternating current of high voltage. What this voltage ultimately would be, practice must fix. They had found that 10,000 volts was not generally high enough, but that there seemed to be no necessity to go above 15,000 volts; and they took, as an average, at the locomotive, a pressure of 14,000 volts. This would generally keep the current within 50 amperes. There was much available experience of working at this pressure, and it was feasible to wind the motors of the locomotive converter for this pressure directly, without the use of transformers. With regard to the frequency, they had begun with 50 periods per second. At present they were building a locomotive to be operated with current at 16 periods. This meant increased weight for the converter motor; but the loss of pressure in the rail-return was reduced in the ratio 8:3, as compared with the loss for the frequency of 42 periods per second used on the Burgdorf-Thun railway. In this connection the question of the disturbance of telephones and telegraphs was a very important one; experiments now being continued in this direction might, however, possibly allow a

return to the higher frequency. If, for instance, on a double-track Mr. Huber. road 60 kilometers in length six trains were run, each taking 45 amperes from the line, two of them being 20 kilometers, two 40 kilometers, and two 60 kilometers from the feeding-point, then the loss of pressure on these 60 kilometers of return rail would be about 270 volts at 16 periods. If 60 periods were used, the loss would be about 720 volts. But if the boosting could be carried out efficiently, a large loss of pressure would not be more objectionable than a small one, and then a higher periodicity might be advisable in order to economize weight and cost of the alternating-current transformers and motors. They considered, however, that boosting would only partially do away with the return-rail drop, and to keep the remaining drop as low as possible, 16 to 20 periods per second would be necessary. Undoubtedly this was a matter for which a standard should be fixed as soon as possible.¹ The single-contact line of the single-phase system was the ideal as regarded branching off at junctions and sidings. The use of the simple bow instead of the trolley-wheel, solved the problem satisfactorily. They had moreover introduced a two-pressure system in this way, so that certain portions of a road, especially large stations with complicated points, with sheds, yards and the like, were supplied at a low voltage, say 700 volts to 1,000 volts; the current being collected by bows on the locomotives and conducted to the low-pressure terminals directly. It had been necessary, however, to provide a device for the collection of the high-pressure current, that would not get entangled with the low-pressure line and collector. This they had accomplished by a conducting-rod pivoting, in a plane perpendicular to the direction of travel, about an axis on the locomotive, and pressed by a spring or otherwise against the contact-wire. The latter might therefore be suspended along the side of the track without span- or cross-wires (but might also, at certain places, be suspended above the track), the contact-rods always sliding along the wire, making contact from above, from the side, or from below, according to the circum-

¹ Since Mr. Huber made this communication he has informed one of the Authors that investigations on this point which have recently been actively pursued have so far shown that apparatus using weak currents seems to remain unaffected by currents of a frequency above 40 periods per second. The loss of voltage in the rails is in any case very small owing to the small current densities; and the speed of the locomotives being perfectly independent of periodicity, it looks as if the system would be a solution of alternating-current traction with periodicities now in use in the majority of power-distribution installations.—
The Authors.

Mr. Huber, stances. By curving the rod convex towards the wire, they made it, with regard to wires suspended above the track, a sort of bow pivoting in the said plane about an axis at one of its ends, and capable of running under branching-off wires exactly as did the ordinary bow. In this way one highly objectionable feature of contact-wires, the hanging of them above the track on span-wires, was done away with for all open sections of road, and was confined to those sections where there were branching-off wires and tracks. At the same time it became possible to have two constructionally independent contact lines, one on each side of the track—one constituting a reserve. There were many points of interest about this line-construction, as, for instance, the passing from a high-pressure to a low-pressure section without interruption in the supply of current to the locomotive, and many other points which were necessary to make the whole scheme workable. He would call attention to the great confidence now placed in the contact-lines of railways. Practically no attention was given to their condition during working. This could not be permitted in responsible main railway working, and the Maschinenfabrik Oerlikon proposed to make sections of possibly 10 kilometers each, where the contact-line current and voltage, the rail-return current, and the rail voltage-drop could be read, and the insulation of the line could at any time be observed. At these points there would also be switches to cut feed- or contact-wire sections in or out, to enable a breakdown to be confined to comparatively short sections, which could be repaired. A system of double insulation, with devices to discover a breakdown in the insulation even from a passing train, had also been designed. It was obvious that neither the English Board-of-Trade regulations, nor even the new and liberal regulations in Switzerland, would at present allow contact-lines of bare copper at 15,000 volts. But all such regulations were bound to give way, if high pressure proved to be necessary for traction purposes. The Maschinenfabrik Oerlikon had offered¹ to the Swiss State Railways the equipment of a line $12\frac{1}{2}$ miles long and the hauling of all scheduled trains on this line, comprising several goods trains daily weighing about 200 tons each. The locomotives with motor-transformers became, as a rule, heavier than was required to give the necessary adhesion. As a rule, locomotives for lower speeds than 20 miles to 30 miles per hour weighed about 10 tons per ton of net tractive effort at the coupling. This

¹ The offer has since been accepted: see p. 157.—The Authors.

might be considered a drawback; but there was not more dead Mr. Huber. weight than was necessary to make adhesion reliable under all conditions of the permanent way. In countries depending on other countries for their coal, the question of economy was of the first importance. The introduction of electrical traction did not depend upon a matter of 10 tons more or less in a locomotive of 800 HP. In any case the saving on the contact-line in cost of plant and power, the simplicity of the line, the perfect speed-regulation, the absence of machinery running idle, and the close supervision of the locomotive plant by the drivers, weighed so heavily in favour of single-phase current at high voltage, that the question of the weight of the converter-locomotive was relatively unimportant. The Maschinenfabrik Oerlikon had made a study of different types of locomotives. The first type had been a 4-axle bogie-locomotive, the converter being situated at about the centre of the truck. Locomotives of about 1,000-HP. could be built on this plan. A more recent and interesting type was the twin locomotive. In this an 800-HP. locomotive was composed of two 400-HP. locomotives, coupled together with their ends carrying the driver's cab. The governing of the combined locomotive was performed by the same driver, the governing switches and resistances being coupled together mechanically or otherwise. This meant having fewer types of locomotives, and having in each locomotive a certain reserve, the locomotive consisting actually of two duplicate parts. The method of speed-control was a very important feature. It must be admitted that the Ward Leonard method of 1891, pure and simple, met nearly all requirements. But for returning energy, for regulating the turning moment automatically during the starting and so on, it was necessary to improve on it. The operation of braking should be interlinked with the regulating switch to prevent the driver from making wrong movements. A novel feature of these locomotives, consequent on the use of single-phase current, would be, that the converter-motor would be provided with two separate windings, one for the high-pressure and one for the low-pressure current, thus avoiding the carriage of heavy static transformers on the locomotives. The single-phase alternating-current system for traction possessed important features besides the single line and the method of speed-control; though the latter, if based on the Ward Leonard principle, in any case greatly improved the efficiency and the power-consumption diagram. The figures for an 800-HP. to 1,000-HP. four-axle low-speed twin locomotive were—

Mr. Huber. OERLIKON SINGLE-PHASE ALTERNATING-CURRENT GOODS TWIN-LOCOMOTIVE.

Normal speed	21 miles (34 kilometers) per hour.
Traction effort (normal)	6·2 tons (6,300 kilograms).
Diameter of drivers	3 feet 11 inches (1·2 metre).
Number of driving-axes	4
Driving-wheel base of each carriage	13 feet 1½ inch (4·0 metres).

Length over the buffers of the whole locomotive, about 42 feet 7 inches (13 metres).

Average normal speed of axle motors, 645 revolutions per minute.

Ratio of gearing about $4\frac{1}{2} : 1$.

Consumption of current at 16·5 cycles, = 870 kilo-volt amperes.

Each of the two non-synchronous single-phase motors 970 revolutions per minute wound for the two pressures and currents, viz.:—

14,000 volts \times 31 amperes,

and

700 volts \times 620 amperes.

Each of the two continuous-current generators, 345 kilowatts (600 volts \times 575 amperes).

Each of the 4-axle motors, 200 B.H.P. (600 volts \times 287 amperes).

Excitation for two motors, 100 volts \times 40 amperes.

Excitation for one generator, 100 volts \times 30 amperes.

Each of the two exciting-generators, 100 volts \times 70 amperes, driven by non-synchronous single-phase alternating-current motors making 950 revolutions per minute, each consuming 17 amperes at 700 volts.

	Tons.
Weight of each of the two carriages	10·0
2 motors with gears	6·0
1 main-converter	9·5
1 static transformer for exciter-motor; air-compressor, lighting	0·5
1 exciter-converter	0·6
1 air-pump with motor, 2 high-pressure collectors, 1 low-pressure current-collector, switches, regulating-resistances, instruments and conductors	1·4
Total	<hr/> 28·0 <hr/>

Weight of the complete locomotive 56 tons.

It would be noticed that the motors were geared. They were mounted on frames above the axles, supported on springs independent of the spring-suspensions of the vehicle, and coupled to the frame of the vehicle in a peculiar way. This arrangement brought the motors within easy reach of the driver. Locomotives for high speeds would of course be equipped with motors mounted on the axles without gearing, in one of the well-known manners. These remarks might sufficiently prove that the conclusions arrived at by the Authors were capable of being put into practice, and that a system such as that sketched answered the following further requirements:—(1) The possibility of two different pressures for the trolley current, a high pressure for the long open sections, a low one for large stations, yards and the like:

(2) the possibility of having the contact-line along the side of Mr. Huber. the track: and (3) the possibility of having, along the two sides of the track, two contact-lines, one being a reserve for the other. It afforded him great satisfaction to find two companions of the competence of the Authors in a radical departure from well-established methods. He could not help expressing his admiration of the clear and logical way in which the Authors arrived at their conclusion with regard to what they very properly called a "comprehensive" system. The application of single-phase current to electrical traction constituted a method which had probably been least expected by the great majority of engineers. He hoped that practical results would before very long give the Authors the satisfaction of knowing that the conclusions they arrived at in what might be called a theoretical way were of practical value.

Mr. GISEBERT KAPP observed that the modification of the Ward Leonard system which the Authors proposed for the propulsion of trains bore a strong resemblance to the system introduced by Mr. Heilmann some years ago on a French railway, the chief difference being in the prime mover. Mr. Heilmann had used a steam-boiler and engine, whereas the Authors proposed a single-phase asynchronous motor. In so far as weight, and possibly also over-all efficiency, was concerned, the Authors' proposal meant an improvement over the Heilmann arrangement, but it might be doubted whether the improvement went far enough to turn the Heilmann system into a success. The Authors gave no figures by which their proposal could be compared with the usual system of working trains by continuous current supplied through a third rail or trolley-wire; it was possible, however, to make the comparison with the materials at hand. It was known what could be done with the continuous-current system, and the features of the various elements which entered into the combination required by the Authors for the conversion of the alternating into a continuous current were also known. The Authors started with the assumption that the train-motors required at starting a large current at a small electromotive force, and when running at full speed a small current at the full electromotive force; and that therefore the generator need never give the large current and the full voltage at the same time: consequently the capacity of the generator need not be equal to the capacity of all the train-motors combined, but might be smaller. This reasoning was fallacious. There was a time when both the large current and the full electromotive force were required by the train-motors, and the generator must give the corresponding out-

Mr. Kapp. put. It was true that it needed to give it for only a few seconds during the period of starting, and, in so far as the size of a machine was determined by heating, there would be a reduction in size and weight as compared with a machine which was called upon to give the full output continuously. This reduction might be estimated at 40 per cent.; and, making allowance for it, the weight of the generator would not be less than 45 lbs. per kilowatt, while that of the motor would be 56 lbs. per kilowatt. It was hereby assumed that the machines were of large size and were run at the highest speed compatible with mechanical safety, say a circumferential speed of 6,000 feet per minute. A train weighing 160 tons and worked at starting with an acceleration of 2 feet per second per second, required a supply of about 500 kilowatts to its motors in the first half of the accelerating period and 1,000 kilowatts during the second half. The power required began to fall off only after the speed had reached about three-fourths of the maximum. At full speed the train-motors required very little current, and in short runs such as had to be provided for in town railways no current at all, since the rest of the run was performed by coasting. The converting-set would therefore have to be capable of giving an output of 1,000 kilowatts, and would not weigh less than 45 tons. This weight, and the space required for the converting-set, precluded the possibility of carrying it in one of the passenger coaches, and a separate tender would have to be provided for it. The weight of this tender, say, about 15 tons, must be added to the 45 tons of machinery, making in all 60 tons. Since the whole train weighed 160 tons, this left only 100 tons for that part of the train which was available for the accommodation of passengers, a reduction of 37 per cent. as compared with a train which received continuous current from a third rail, or which was driven by three-phase current supplied by two overhead wires and the running-rails. The Authors made a point of the fact that, by the system advocated in the Paper, the loss in the starting rheostats was avoided. This was an advantage, but not so great an advantage as the Authors had assumed. They overestimated the rheostatic losses in the older system. A train weighing 160 tons and making a run of $\frac{1}{2}$ mile between stations in 92 seconds, would take from the working-conductor about 19,000 kilowatt-seconds, and of this total only 20 per cent. at most would be wasted in the starting-resistances. If, then, the Authors could not materially reduce these 3,800 kilowatt-seconds, their system had no advantage over the older system in point of energy required per ton-mile. But even if they could save the whole of

these 3,800 kilowatt-seconds, there would be no improvement over Mr. Kapp. the older system, since the saving of 20 per cent. in energy was not an equivalent for the loss of 37 per cent. in passenger accommodation. To make their system equally efficient with the older system they must save at least 37 per cent. of the energy; and a simple calculation showed that this was impossible. The frictional losses in both machines and the iron-losses in the motor were going on all the time; the excitation of the generator must be provided nearly all the time, and only the copper-losses in the two armatures were materially reduced during the greater part of the run. The sum of all these losses amounted to about 12,000 kilowatt-seconds. From this figure must be deducted the energy returned through electric braking. In a $\frac{1}{2}$ -mile run the train would reach a maximum speed of 27 miles per hour, and at the end of the coasting period its speed would be 21 miles per hour. The energy then stored in the train was 7,000 kilowatt-seconds, of which amount about 60 per cent. could be recovered. Deducting the 4,200 kilowatt-seconds from the 12,000 kilowatt-seconds loss in conversion, the net loss remaining was 7,800 kilowatt-seconds, or more than twice as much as the rheostatic loss in the older system. In the latter 1 ton-mile, under the conditions stated, would require a supply of energy amounting to 67 watt-hours, while for the Authors' system the figure was 86 watt-hours. It should be remembered, however, that the number of watt-hours required per ton-mile was not the only criterion by which the efficiency of a system must be judged. The proper criterion was the number of watt-hours required per passenger: and judged by this standard, the Authors' system fell hopelessly short of the older system, since it required about double the energy. The difference would not have been so large had the Authors abandoned the use of continuous current altogether and adopted three-phase motors for driving the train. A three-phase motor supplied with single-phase current at two of its terminals would, when running synchronously, give off three-phase current from these two and the third terminal; it would, in fact, act as a converter of single-phase to three-phase current, and, since the conversion took place in the same machine, its weight and the space required for it would be considerably less than with the Authors' converting-set, which consisted of two distinct machines. The weight of a 1,000-kilowatt converting-set would be about 25 tons, and as three-phase motors were a little lighter than continuous-current motors, about 5 tons to 8 tons might be saved in the train-motors themselves. A separate tender would probably not be required for

Mr. Kapp. carrying the 25 tons of converting machinery, so that 20 tons was the total additional weight to be taken into consideration, leaving 140 tons for the rest of the train. The losses would also be reduced, and it was difficult to see why the Authors had gone only half way towards the use of alternating current. Had they gone the full way by suggesting the system here sketched, their suggestion would not have fallen so hopelessly short of the older system, although it was doubtful whether it would have been an improvement on it. He was inclined to think that it would not be an improvement on the ordinary three-phase system. The only advantage it had was that one overhead wire was saved, and against this must be set the necessity of carrying a converting-set on the train, the loss in conversion, and the reduction in the passenger capacity. It must also be remembered that the single overhead wire must contain more copper than the two wires together in the three-phase system. In his opinion, the Authors had exaggerated the difficulties of a double trolley-wire; and they had hardly laid sufficient stress on the very objectionable nature of a third rail on a level with the running-rails. They objected to the third rail mainly on the grounds of expense on long lines and complication in the shunting-yards. In such places they would not even tolerate the single overhead trolley-wire, but preferred to use a battery locomotive. He could not share their objection to overhead wires, although he quite agreed with them in condemning the live conductor on the ground. The work in a shunting-yard was in itself not free from danger, and if the men during their work were compelled to dodge the live rail, in addition to looking out for moving cars, the number of accidents would certainly increase. It must also be remembered that in some cases it might be necessary to put down a fourth rail for the return current, and the fact of there being two rails side by side, the one dangerous and the other not so, was an additional objection to the system. Much had been made in the recent Metropolitan-District arbitration of the danger of the overhead trolley-wire in case of its breaking. No trouble from this cause had yet been experienced on the three-phase railways on the Continent; but if there should be any doubt on this score it was easy to set it at rest by using for the overhead conductor not a wire but a double T rail, which could be put up as securely as a roof, bridge or any other iron structure. In a shunting-yard or a tunnel or a station it would certainly be advisable to replace the wires by such rails, but on main lines in the open country this would not be necessary. In analyzing the various possible systems, the Authors came to the

conclusion that for transmission alternating current was best, Mr. Kapp. while for driving continuous current was preferable. Their objections against three-phase driving did not seem to be very convincing. The most important was that referring to the necessity of using two overhead wires. Practical experience had shown that there was no insuperable difficulty in this respect. On the Valtellina line two wires were used throughout, not only on the main line but also in the yard. The objection that the speed could not be increased beyond the limit corresponding to synchronism was not justified; for this property of driving by three-phase current was rather an advantage than otherwise. With continuous current a careless driver, on a falling gradient, might allow the speed to rise to a dangerous amount, as had been shown some years ago by the accident at Fiesole, near Florence. This was impossible with three-phase driving. If provision was made for working the motors in concatenation, the train could travel at either half speed or full speed without rheostatic loss. With continuous current, rheostatic loss did not take place at half speed, and at from three-quarter to full speed only by alternately accelerating and coasting; that was, continually varying the speed between narrow limits. This threw more work on the driver, so that the alternating system was, if anything, preferable as regarded constancy of speed. Another objection raised by the Authors was that referring to waste of energy. The measurements which he had made on the Valtellina line with runs of 1 mile had shown that the input of energy was about the same as would be expected with continuous current. At starting the rheostatic loss was a little larger, but the difference was made up by the energy returned when braking by concatenation.

Mr. O. LASCHE, of Berlin, remarked that the views of the Authors Mr. Lasche. were set forth with such clearness and ability in the Paper, and so thoroughly supported by facts, that it seemed to be scarcely possible to deal more fully with individual points. He would, however, venture to add a few words upon the question of high-speed railways. The generating-station for the high-speed railway near Berlin was at Oberspree, about 9·3 miles distant from the track conductor. The current was generated at 6,000 volts, transformed up to 12,000 volts, and supplied at this potential to the overhead wire. This potential of 12,000 volts was sufficient for transmission of the current, as the distances in question were short. As pointed out by the Authors much higher potentials had already been employed for long-distance transmission-lines. It seemed exceptionally risky, however, to wind railway motors for this potential of

Mr. Lasche. 10,000 volts to 12,000 volts, as it was naturally far simpler to maintain a transformer in proper condition for a number of years, even if such a transformer were merely insulated with air. With this consideration in view, transformers had been built into the car, and had naturally added greatly to its weight. In future projects, therefore, under similar circumstances, a potential of 2,000 to 3,000 volts would be adopted for the overhead conductor, as for these potentials it was possible to construct motors which would have a satisfactory life. The overhead conductor consisted of three wires, arranged in a vertical plane above the side of the car, and at a distance of 1 metre apart. Such an arrangement was, of course, only possible when the line was not crossed by other lines, by bridges or by tunnels. In cases of that kind the conductors must be placed differently, in order to avoid the disadvantage of being obliged to include the lofty double or treble conductor in the clear height required above rail-level. With reference to the periodicity, it might be said that frequencies varying between 25 and 50 periods per second had been used, and it had been found that the motors developed the same torque so long as the ratio between frequency and potential remained constant. Tests had been made with these changes of frequency, and, moreover, observations had been taken when travelling at low speed, while using the highest frequency; and it had been proved that the liquid starting-resistance behaved well, and also acted satisfactorily with the rise of energy at starting, and with the reverse current developed when the brake was put into action. Braking by means of the reverse current had given no appearance of trouble, in spite of the important rise in potential in the armature-windings and starter. The continuous-current brake had not as yet been tested upon the line, because naturally continuous-current braking was most efficient at the highest speed, while at low speeds the air-pressure brake was assisted but little by the electrical brake. As to the running tests, he might add that hitherto these had been merely of the nature of preliminary and tentative trials, as nothing more had been possible; but the work would be continued in the summer of 1902.

Mr. Shoolbred. Mr. J. N. SHOOLBRED considered that the Paper was not only highly interesting and lucid in treatment, but was extremely opportune at the present time, when, in connection with electrical propulsion, a network of communication throughout a large part of Great Britain was being contemplated for passengers, goods and minerals, on a scale which had never before been attempted. The essential feature of such a network, if the fullest

benefits of convenience and economy were to be the results to the community at large, must be uniformity throughout, and interchangeability of the various parts. That was to say, there must be uniformity in the gauge of the vehicles and in the electrical pressure employed. As a first step, it must be realized generally that, as the Authors remarked, there was no natural distinction between electric railways and electric tramways; a statement which applied not merely to technical arrangements, but also to the material interests of both the railway and the tramway. The Board of Trade, however, appeared to think otherwise. Judging from their recent instructions to the Light Railway Commissioners, they seemed to consider that active hostility between railway and tramway must exist. Nor did they appear to realize that each could be of advantage to the other. As a contrast to this, he might mention a recent expression of opinion by the general manager of one of the leading railway companies in England, who had remarked to him that he considered competition between railways and electric tramways was the coming question, and it must be faced—but in a friendly spirit, to their mutual advantage, and not in dogged hostility. If this general inter-communication in the modes of transport by electricity was to be effected, uniformity of gauge was the most essential point. The railways having all adopted the 4-foot 8½-inch gauge, it was imperative that the electric tramways should adopt the same gauge, despite the narrowness at certain points of streets and highways. The variety of the different gauges which were in use—some differing but little from others—seemed incomprehensible. The action of certain County Councils in memorializing the Board of Trade in favour of the 4-foot 8½-inch gauge, and also themselves strongly opposing any other, was exercising a beneficial effect towards arriving at the uniformity which was so desirable. The next most material point was uniformity in the electric working-pressure. The action of the Board of Trade in fixing 500 volts as the maximum working-pressure for both electric railways and electric tramways, and in adhering to the same limit in the recent arbitration as to the electrification of the metropolitan underground lines, had done much towards ensuring uniformity in this direction. As regarded the actual system of generation of the electric current, it was the simplicity and safety attending its working-arrangements that must cause the continuous current to prevail over the alternating, as had been the case in many large electric-lighting generating-stations, especially in the Metropolis. Again, the devices adopted by Mr. McMahon on the City and

Mr. Shoolbred.

Mr. Shoolbred. South London Railway for the extended use of continuous current over longer distances, were not only very ingenious, but they gave ground also for the hope, which he trusted would soon be realized, that other devices might follow, by which continuous current could be used over long distances such as occurred on main lines.

Mr. Thrupp. Mr. EDGAR C. THRUPP remarked that at p. 51 the Authors, in referring to the City and South London system, observed that it was quite possible that system would be found more economical, both in first cost and in working-expenses, than the Central London system. That was a remarkable admission; and if, as he understood was the case, the efficiency of the Central London system was somewhat overstated in the Paper, it would be emphasized thereby. It was not clear from *Fig. 2* whether the "reducers" at London Bridge and at Islington were worked independently on each side of the middle wire, or were coupled so as to form one machine with four armatures on a single shaft. There would appear to be no reason why the two sides should not be so coupled, while, on the other hand, there would be a distinct advantage in making them act as perfect "balancers," and thus dispensing entirely with the separate balancers. No reason had been given by the Authors for dismissing this system as unsuitable for long lines. If it was to be assumed as an axiom that a line, however long, must be worked by one generating-station, of course the Authors were right in dismissing the system; but the policy of adopting one generating-station was by no means beyond question. The usual argument in favour of high-tension current was that it saved copper; but if its adoption also involved longer feeders that argument lost much of its force. For instance, a line 100 miles long, served by one generating-station, would have feeders averaging 25 miles in length; while the same line, worked by ten generating-stations placed 10 miles apart, would have feeders averaging $2\frac{1}{2}$ miles in length. To show any saving in copper in the feeders in the first system the pressure must be more than ten times as high as in the second system, or over 20,000 volts, to compare with 2,000 volts in the latter case. Another argument in favour of the use of a single generating-station was that it saved skilled attendance at numerous points; but the cost of such attendance in connection with works of the magnitude required on main lines was really a mere trifle, and could not be expressed in pence per unit without using three places of decimals. A main line would require upwards of 5,000 HP. on every 10 miles of its length, if the traffic was of such a character as to justify the

introduction of electrical traction at all, and the power was more likely to be 10,000 HP. Could it be contended that stations of these outputs were not workable economically? A new argument had now appeared in favour of extra-high pressure, namely, that it rendered the collection of the current on a trolley-wire more easy. In connection with this argument it was also contended that such pressures on overhead wires were after all not so very dangerous. This point would require serious consideration, and it was unwise to lay down the law either for or against it; but was it necessary to use high pressures for such reasons? If the current was too large to be picked up at one point, it could easily be picked up at several points, so as to reduce the volume at one contact. If it was conceded that a pressure of 2,000 or 3,000 volts was admissible on trolley-wires, then it must follow that a continuous-current three-wire system, using 2,000 volts on each side, was also reasonable. The introduction of electrical traction on main lines was generally admitted to be somewhat remote, but it was suggested that its consideration now might prevent the adoption on short lines of systems which were unsuitable for long lines, and the point was a sound one. Had it occurred to the Authors that in the course of the years which would elapse before the main lines were electrified, the use of very large gas-engines would become one of the most important accomplished facts in connection with large power-schemes in Great Britain? The types of large gas-engines which had recently been so successful on the Continent were not suited to driving alternators, but they were suited to drive continuous-current dynamos. Possibly improvements might be made which would alter this state of affairs; but it would be a deplorable mistake to adopt on railways generally an electrical system which, from its very nature, would prove a bar to the introduction of gas-power, and a consequent saving of 50 per cent. or more in the fuel-bill.

Mr. B. H. THWAITE remarked that the Authors might be congratulated on having done a timely service by their analysis of the present position of electrical traction applied to railways. He considered, however, that as far back as 5 years ago, the evidence of success then obtained had been sufficient to justify British railway companies in at least tentatively adopting the system. Unfortunately for the future prosperity of the country, the same arguments were used by the railway companies that were often employed by many British manufacturers in their objection to the employment of more economical and efficient processes and appar-

Mr. Thrupp

Mr. Thwaite.

Mr. Thwaite, atus; namely, that the adoption of such improved apparatus and processes would destroy much of the value of their existing plant. But if it could be shown that a new system would secure such sterling economies as to provide a sinking-fund to permit the wiping out of existing and inefficient rolling stock or other plant in a certain number of years, in addition to securing increased profits, it was surely true economy to adopt such a system. Further, it might justly be asked whether the country was to be allowed to fall away in its manufacturing efficiency compared with other countries, because the railway companies, with their Parliament-granted monopolies, refused to move along lines of progress. Too much honour could not be given to those responsible for the adoption of electrical traction on the Liverpool Overhead Railway. Nine years had elapsed since the date of the running of the first electric train on that line, and considering that the application had been in the nature of a pioneer one, its success had magnificently justified the courage of those responsible for the selection of electric instead of steam power. Of course the electrical transformation of the railway systems would be a work of very considerable magnitude and difficulty; but British engineers had infinite resources, and besides, the race that had produced Stephenson and Faraday should really have been the first to apply the electrical system to railways. In an article¹ on "The Influence of Electricity upon Railway Locomotion," he had pointed out that existing steam-locomotives could be brought into service for siding- or shunting-work, the initial electrification being confined to the trunk lines; further, the electrification of the lines could be proceeded with without seriously interfering with the running of the steam-locomotives. The article in question gave *inter alia* the comparative fuel-cost of steam and electrical traction, the economic advantages in favour of the latter equalling 103 per cent. The comparative total running-cost per ton-mile gave the electrical system an advantage of about 37 per cent. But even this comparison did not cover all the advantages of electrical traction. The coal-consumption of the Liverpool Overhead Railway (the example chosen for the comparison) could be reduced by 50 per cent.; in fact, there was no reason why, making ample allowance for absorption of energy in mechanical and electrical transformations, an actual and sustained thermodynamic efficiency of 17 per cent. should not be obtained at the axles of the electric train, compared with, say, 4 per cent., which was probably the

¹ *Engineering Magazine*, vol. xvii. p. 415.

highest obtainable everyday efficiency on the best locomotive. Mr. Thwaite. There were other all-important advantages, in the reduced wear and tear of rolling stock and permanent way, and especially the reduced depreciation of tunnels and iron bridge- and station-structures; and the electrical power would also be available for service in warehouses and on canals owned by railway companies. These advantages alone, in their accumulated measure, would provide a sinking-fund that would in a reasonable period extinguish the cost involved in the coming and inevitable displacement of the steam-locomotive. Further, railway directors, as part of the electrification programme, could adopt the American bogie goods-wagon, having a capacity of 20 tons to 50 tons, and could equip such wagons with their own electric motors. The increased profits that would result from the large reduction in working-expenses (outside the economic policy of low freight charges which he had demonstrated statistically in a lecture¹ delivered before the London Chamber of Commerce) would enable the companies to make a considerable reduction in British railway freights, which now constituted a handicap that placed the British manufacturer at a serious disadvantage compared with his American and German competitors; for instance, the goods rates for heavy raw materials were 300 per cent. to 600 per cent. higher on British railways than on the more progressive of the American railways. In the article in the *Engineering Magazine* referred to, he had suggested that the ideal method of transportation overland of heavy manufactured and raw materials and products, between industrial and inland centres and a port, or even across England—Carlisle Port to Newcastle, for example—would be by the use of electrically-equipped bogie goods-wagons of at least 20 tons net capacity. The possibility of utilizing the electric energy generated on the down gradients, by the employment of alternating-current motors, would enable electric lines over undulating country to be constructed at a minimum of cost in tunnelling, viaduct, or embankment work; and for a cross-country goods line, such as that proposed, there would be little difficulty in organizing the train service so that the returned energy due to falling gradients could be fully utilized. Railways like the Taff Vale line, South Wales, were well adapted to such an application. Besides, the main generating-station could be located at the coal-pit. The Authors' description of the working of the

¹ "On Home and Foreign Railway Rates for Goods Traffic." *The Times*, 10th Mar., 1899.

Mr. Thwaite. Engelberg electric railway constituted a remarkable illustration of the wonderful elasticity and resources possessed by electric power. No doubt it would be realized that for main-line service with corridor-coaches and goods wagons of large capacity, distributed electric motors would be found the best, both for dynamic and for static or structural reasons; and with self-propelled units there would be no difficulty at level crossings, where the conductor could be placed below the surface of the ground. But for branch railways, probably an electric locomotive would be found to be the most serviceable. The moment had arrived when the British Government should be asked to appoint a commission of railway and electrical experts to decide finally upon the best system to be adopted, otherwise the costly experience of the early railway days would be repeated, in which the use of two distinct gauges, the broad and the narrow, had been permitted, a liberty that had involved the Great Western Railway in immense losses. If in the first instance the electrification of the railways was limited to the main lines, employing steam-locomotives for shunting, the railway companies should have no hesitation, under the guidance of the Board of Trade, in commencing seriously the desirable work of electrification; and probably the Great Central Railway would offer the least initial difficulty in effecting such a transformation. Even if the system in use on the Liverpool Overhead Railway was adopted—but with power-gas plants driving three-phase generators, the stations being located along the line at intervals of 50 miles, to supply energy to intermediate distributing-stations for feeding the train-motors with suitable current—such an application would really leave little margin for further economic improvement. It was sincerely to be hoped that the “battle of the gauges” of the forties would not have its counterpart in a battle of phases, pressures and currents; such a struggle could only retard seriously the urgently desired electrification of the railways. In the article in the *Engineering Magazine* already referred to, he had proposed the use of power-gas generating-stations, the gas-engines being so arranged as to be rapidly responsive to variable demands for power, without the necessity of accumulators. The arrangement consisted in a modification of the plan described in a Paper¹ read

¹ “Economic Possibilities of the Generation of Electro-motive Force in the Coal Fields, and its Application to Industrial Centres,” by B. H. Thwaite. Transactions, Manchester Association of Engineers, 1892, p. 197. Partly written in collaboration with Mr. James Swinburne, M. Inst. C.E.

by him at Manchester in 1892. The full-power output was furnished by a number of suitable units which, when doing effective or external work, were always working at three-quarter to full power. The other engines were also kept in motion (without compression effect) at one quarter of full-power speed, being driven electrically from the main electric generators. When the load was increased, the gas-valves and the exhaust-valves of the gas-engines were, by electrical means, automatically opened or set free, and the full effective output to meet the demand was rapidly obtained. On the falling-off of the load, the valves were again electrically and automatically actuated, shutting off the gas, and the motion of the corresponding engines was again sustained by electric power; thus the output would rapidly respond to the demand, and the power-output of the gas-engines would be kept up to that corresponding to the maintenance of the highest thermodynamic efficiency and the most satisfactory cyclical regularity. He would also suggest that, as many of the British railway companies derived a considerable portion of their goods receipts from ironworks served from the main lines, and generally situated only a short distance from them (the Midland Railway Company being particularly well favoured in this respect, at least in the length between London and Leeds), the electric energy required might be generated from the waste gases of the blast-furnaces. He was already obtaining power from these waste gases evolved from two of the ironworks on the Midland Railway, the constant thermodynamic efficiency being about 25 per cent. The blast-furnaces in close proximity to the Midland main line could be relied on to provide the major part of the power required on the line from Leeds to London; and by the system described in his Paper¹ read before the Iron and Steel Institute in 1901, this power could be continually produced whether the furnaces were in constant service or not. By utilizing this blast-furnace power the railway companies would benefit one of their best customers and obtain power at a very economical figure. An important feature of electrical compared with steam traction, and one that had hitherto not been sufficiently emphasized, was that locomotives were delayed many times a day in sidings and elsewhere, and their energy was unavailable for service on other parts of the line; whereas this energy, in a central generating-station, might be diverted to another train. Therefore, with the electrical system, less than 75 per cent. of the aggregate power of the necessary steam-locomotives would suffice

Mr. Thwaite.

¹ Journal of the Iron and Steel Institute, vol. lx. p. 149.

Mr. Thwaite, for the service. Further, the generating-machinery, being placed under cover, would be preserved in the highest state of efficiency, whereas the locomotive generator was placed, when working, under the worst conditions to secure high efficiency.

The Authors. The AUTHORS remarked that they found it impossible to reply in any reasonable space to all the points raised in the large amount of valuable matter contained in the Correspondence. They hoped that the forthcoming trials on the Swiss State Railways might settle many of these points, and provide a better basis than theory or argument for the formation of opinions. Referring to some of the criticisms, they had never stated nor supposed—as seemed to be thought by Mr. Behr and others—that electrical traction was likely to be introduced on main lines for the purpose of immediately or completely superseding steam. When once introduced for a small portion of the traffic, electricity, if successful, would no doubt gradually increase its usefulness; but even under conditions most favourable to electricity it was fairly certain that steam would remain. The important point was not to begin on wrong methods. The change must be gradual, and it was on this account absolutely essential that the system adopted for the first small part should be capable of extension to longer lines and a greater traffic. The objections raised by Mr. Behr in the first part of his communication were answered in the second part. The Authors quite agreed that, for helping to deal with exceptionally heavy occasional demands, steam would be a useful and important auxiliary to electricity, even on lines where the bulk of the work might be done by electricity. It was not a question as between steam and electricity—neither excluded the other. For an infrequent service, especially on long lines, the steam-locomotive must continue to have great advantages. Under such conditions it might some day be hard pressed by some other heat-motor, it was never likely to be superseded by electricity. For long lines with small traffic the Authors were entirely in accord with Mr. Horace Bell's criticism, in the Discussion, of Colonel Crompton's proposals for the working of the suggested Himalayan line. No water-power, however cheap, could enable electricity to compete with steam under such conditions. With regard to Mr. Drummond's suggestion that in an electrically-driven train the driver had no control over, or knowledge as to, the cause or location of failure, there was no reason why the driver should not understand the machinery under his control. The fact that it was much simpler and could all be inspected and overhauled at a moment's notice by

switching off the current, made repairing a simple matter compared The Authors. with repairing an engine with its fire and boiler, and everything hot. Again, it was possible to duplicate the driving machinery, allowing one set to be entirely cut out should it fail, leaving sufficient to take the train on. In comparing steam and electrical haulage, such points should be borne in mind as the collection of water by the moving train, the difficulty of lubricating the reciprocating parts and slide-bars for the long runs now made, the great weight and bulk of coal to be carried, the maintenance of the water-level and the steam-pressure—all essential matters in a steam-locomotive. On comparing such difficulties with the absolute simplicity of the rotating electric plant which could all be enclosed, with a few bearings only to lubricate, and nothing to do but turn a handle in order to go faster or slower, it could be realized what an immense difference there was in favour of electricity. Mr. Kapp had made an interesting suggestion for applying the method of Ferraris and Arno¹ to the construction of the travelling motor-generator, converting from single-phase to three-phase in one machine, using three-phase motors instead of continuous-current motors on the train, thus having alternating current throughout. It was quite true, as Mr. Kapp pointed out, that this method would simplify and lighten the motor-generator, but—so far as the Authors understood it—it would do so only at the sacrifice of the main feature of the Ward Leonard system, namely, the independent variable excitation of the generator which gave the variable-ratio effect and the absence of resistance-losses in the Ward Leonard method. It did not seem that the Ferraris-Arno plan could give any equivalent of this, except at the cost of variations of the power-factor so great as to more than counter-balance the gain in weight. In fact, this plan would not improve matters on the locomotive, and might cause serious difficulties on other parts of the system. Mr. Kapp had misunderstood the Authors as to the methods of working shunting-yards, as they would certainly, where possible, keep the conductor overhead, using a bow collector to avoid difficulty at points. After writing the Paper the Authors had learned from Mr. E. Huber, Managing Director of the Maschinenfabrik Oerlikon, that that Company had independently arrived at conclusions similar to their own as to the possibilities contained in a single-phase system combined with a travelling motor-generator. Since then they had been informed by Mr. Huber that the Board of the Swiss State

¹ Minutes of Proceedings Inst. C.E., vol. cxxvii. p. 484.

The Authors. Railways had formally accepted an offer made by the Oerlikon Company to apply this single-phase system. The trial line was the Seebach-Wettingen line of the late Nordostbahn, now the Schweizerische-Bundes-Bahn, and was about $12\frac{1}{2}$ miles long. The Authors were very glad to see Mr. Huber's communication, giving such full particulars of the plant to be used for this purpose, and stating his views on a number of points raised in their Paper. It was clear from Mr. Huber's remarks that his firm had gone very fully into all the details. The Authors welcomed also the confirmation of their views contained in the communication from Mr. C. E. L. Brown, who, as was well known, was responsible for the important three-phase applications on the Burgdorf-Thun line of the Swiss State Railways and on the Stansstad-Engelberg Railway. Mr. Brown, whose experience of alternating-current railway traction was unequalled, now recognized that the weight of the locomotive, which he had formerly thought would be the main drawback, was much less than he had supposed, because the motor-generator, being run at a high speed, could be comparatively light, as indeed was pointed out by the Authors. Mr. Lasche, who had had special experience on the three-phase, high-speed line at Zossen, also appeared to agree with their views: his remarks confirmed the objections to three aerial lines, and supported the view that there was no need to use frequencies so low as to be unsuitable for lighting purposes. On this point Mr. Huber's experiments seemed to lead to a similar conclusion. The question of frequency had been raised several times, and it was hoped that before long it might be possible to settle it in such a way that there would be no need for conversion from alternating- to continuous-current for lighting purposes. It was interesting to note that Mr. Huber advised the adoption of 15,000 volts on the line, and proposed to wind the motors of the motor-generator for this pressure; whereas Mr. Lasche considered 3,000 volts high enough for the motors if used for driving the train direct. If both conclusions were right they formed a strong argument in favour of the use of a high-tension motor-generator, and low-tension motors on the car-axes. It might be pointed out that during recent years in America the tendency seemed to have been to abandon the very low frequencies which had been at one time supposed by many engineers to be necessary for large transmission schemes. In many of the later schemes frequencies of from 40 periods to 60 periods per second were in use. This gave the advantage of direct application to all classes of work without any rotating transformers. Almost the only practical advantage of

low frequencies was now admitted to be the greater facilities they The Authors. afforded for the use of rotary transformers; but, as pointed out in the Paper, rotary transformers had little advantage in cost and efficiency over motor-generators, and, as compared with the latter, had some serious disadvantages for lighting, such as requiring additional transformers and rendering less easy the independent control of the pressure in the primary and in the secondary lines and of the power-factor of the primary. The communications from the experienced continental engineers mentioned were naturally of great interest to the Authors, who were glad to be able to say that the soundness or otherwise of their views would soon be put to a practical test—a circumstance which they had not expected for some years. Their object would have been attained if it was recognized that it was highly advisable to begin to use electrical traction on main-line railways on some plan which had in it the essentials which could lead to success on long lines by a gradual and natural growth of the original system. However well adapted a method might be for short lines it did not seem wise to apply it, even on short portions of long lines, unless it contained those essentials.

25 February, 1902.

CHARLES HAWKSLEY, President,
in the Chair.

The discussion upon the Paper, "Electrical Traction on Railways," by Messrs. Mordey and Jenkin, occupied the evening.
