Discussion.

Sir DOUGLAS FOX, President, testifying to the deep interest with which the members had listened to the Papers, observed that they contained so much food for thought that it was difficult to carry away more than a portion of the information they offered. The Institution was very much indebted to the Authors, one of whom had given a very practical description of a most interesting piece of engineering work, and the other a very frank and detailed account of the electrical equipment of the Waterloo and City Railway. The Institution was further indebted to Mr. Galbraith and to Dr. Kennedy, Members of the Council, for permitting the various particulars to be presented to the Institution. He accordingly moved a vote of thanks to the Authors for their Papers. Sir Douglas Fox.

Mr. BERNARD M. JENKIN exhibited upon the screen a series of photographs illustrating various portions of the plant and rolling stock dealt with in his Paper. Mr. Jenkin.

Professor GEORGE FORBES observed that in the electrical equipment of the Waterloo and City Railway, the problem was not so complicated as some which had occasionally to be dealt with in England or abroad, and therefore it presented few features of great novelty. The line was short, and the cost of the other parts of the work was so considerable that there was no necessity for great economy in conductors. The traffic was not so great as to require a large reduction of the headway of the trains; the rolling stock belonged entirely to the one line; and there was no mixture of traffic from outside lines. At the same time special features of interest had been introduced which deserved careful consideration. The power-house contained no units of exceptional size or character, and the plant generally was of familiar type. He noticed, however, with pleasure that carbon brushes were fitted to all the dynamos. He was aware that Messrs. Siemens had for a considerable time employed carbon brushes, but it had taken a long time to introduce them generally in England, and it was only after their adoption by foreign countries that they had been recognised as desirable, especially in larger dynamos. Reference had been made to the extremely good governing of the engines. That, undoubtedly, was of great importance, considering that the lighting and the power were supplied by the same dynamos. It Prof. Forbes.

Prof. Forbes. would have been injudicious to take the lighting of the stations and tunnels from the same feeders which supplied the power, and therefore a special circuit was supplied and contact was made as near the dynamo as possible. It was stated that the lighting was perfectly satisfactory and free from flickering under all conditions of working, and yet he noticed that the dynamos were compound-wound, so as to give from 500 volts to 530 volts—a difference of 6 per cent.—which would hardly be consistent with perfect uniformity of the light. However, if in actual practice it was found satisfactory, that was all that was necessary. It was also stated that no flickering could be observed in the light in the trains except with the most careful watching. That seemed remarkable when the lights were supplied by the same feeders as the motors. If it were the case all he could say was that the motors might have been supplied with feeders giving a much larger variation without any detriment; but in the present case he could understand it was thought the expense of the extra copper was insignificant. There did not appear to be 20 tons of copper in the feeders altogether, so that that part of the work was probably well done. He noticed that no accumulators had been used, and probably in so short a line they would not assist in the motive power. Whether they would have been of benefit for the lighting under those conditions was also perhaps doubtful, but it might be thought that in the train, steadying accumulators of small size would have been desirable. He did not understand the purpose served by the cut-outs. The fact of their being made to work with 50 per cent. over load seemed to indicate that sometimes the normal load in starting two or three trains at the same time was sufficient to make the cut-out to act. He would like to know what was done in the station when the cut-out acted. Presumably it was immediately set back again, or a spare automatic cut-out introduced; but if it was found that the automatic cut-out still acted, then it had to be tried again until it ceased to act. In the Niagara transmission to Buffalo, short-circuiting, either through malice or accident, was very common. In those cases it generally happened that after the current had been left on for a minute fraction of time the short circuit burnt out. Whenever such an occasion arose, and trouble was caused by the breaking of the circuit—and the breaking of an 11,000-volt alternating-current circuit was a much more serious and undesirable thing than such a case as the Paper dealt with—an automatic cut-out with a clockwork arrangement was introduced, so that when the short circuit occurred the clockwork was set in action, and after a few seconds it appealed to the cut-out arrangement to ask whether it was to act or not: in other words, it did not act until a few seconds afterwards, and then it acted if the short circuit had not been burnt out already. In nearly every case the short circuit had burnt out by that time. That method was found to be extremely satisfactory and simple, and saved a great deal of trouble. There was a clockwork arrangement at the Niagara Falls end of the transmission line of 25 miles which acted 4 seconds after an indication had been given of short-circuiting, at the Buffalo end of the line $3\frac{1}{2}$ seconds to 3 seconds, and in the Buffalo mains 1 second afterwards. He considered the account of the pumps worked by electro-motors at the low levels specially interesting; they could be put into action from the power station itself, where there were also indicators, controlled from the sumps, indicating when the pumps ought to be working. It was only one of a great number of cases where electricity would come in to help the railway engineer in his ordinary working. Regarding the conductors and feeder arrangement, he could only express satisfaction and agreement with the methods adopted by Messrs. Siemens. The only question he would ask was as to the character of the bonds connecting the third rail or the channel iron and the bonds connecting the rails which acted as the return. It was stated that the resistance of the third rail was 0·051 ohm per 1,000 yards, and that the resistance of the total return circuit was 0·015 ohm between the scissors crossing and Waterloo Station. He wished to know whether tests had been made at various periods after corrosion and oxidation had set in, and whether the bonds had proved as satisfactory then, because the bonds always worked well at the beginning. With regard to the rolling stock he noticed that the motors were of about 42 B.HP., with a maximum specified output of 60 B.HP. It was very important to know the rise of temperature which was allowed, because the rating of a motor depended entirely upon the temperature rise after a given time. In the United States it had been usual to rate a motor as the power which it would give off when its rise of temperature was 45° C. after 1 hour's running. There were peculiarities in the running of the Waterloo and City Railway which distinguished it from others. There were four carriages making up a train, and, as he understood, those four carriages were always connected, in fact, they might be one long car were it not for the impossibility of going round curves. There was also the desirability of taking out one of the cars occasionally for repairs, although he hoped that was of very rare occurrence. It was a matter that made a little difference in considering the

Prof. Forbes.

Prof. Forbes. question whether the trains were ever broken up or not. The arrangements were made for breaking them up very easily, and it would be noticed that there were motors in the front car and motors in the back car, each of these cars having two motors. In order to regulate the speed of the motors it was necessary to have cable connections of a somewhat complicated character between the front and the rear cars which contained the motors. So complicated was the character of those connections that there were actually eleven cables running the whole length of the train, with breaks between each pair of carriages; and all those eleven connections had to be made between each pair of carriages whenever the train was made up, which was an undesirable feature. It would be bad enough if the cables were simply carrying a small current, but it was worse when some of them had to carry the whole current used for the motors, and all of them a large proportion of it. At the same time, given the fact that there were motors on the front car and motors on the rear car to be controlled, it might be that that was the best arrangement that could be adopted. The feature that, more than any other, distinguished the electrical equipment of the train from all others was that, instead of the ordinary method of having two arrangements of the motors, *i.e.*, in parallel or in series, and having only two running speeds, a combination of four motors had been made use of to give three running speeds, using all the motors four in parallel, two in parallel and two in series, or all in series. That gave three running speeds, according to the arrangement of the motors, besides the intermediate speeds with resistances, which were not running speeds, but which might be put on for a short time. In most electrical railways which had been equipped in the past that had been found hardly necessary, because the gradients and curves had not been so serious; but in the railway under consideration he had no doubt that it was the heavy gradients and short curves that pointed to the desirability of three variations of speed. He thought the arrangements that had been adopted fulfilled the purpose extremely well. With regard to the alternatives which might be adopted, in a line so exceptionally simple for the reasons he had stated, the question arose, why was not a locomotive used in the present case? or, why were not all the motors put on the front car? He thought it was extremely probable that the reason was the difficulty of transferring that car to the front when the train was reversed at the other end of the line. If that were the case, the

Prof. Forbes.

engineers naturally had an objection to shoving the train from the rear end—a most undesirable arrangement; and yet in the arrangement that had been adopted there was half the power pulling and half the power pushing. If it was objectionable to push the train under any circumstances, it was objectionable even when half the work of the train was done by a pull. It undoubtedly made it more dangerous to go round curves. It might not be seriously dangerous, but it certainly was more dangerous, and probably that was the reason why the Board of Trade objected to the speed which had been arranged for the train to go round the sharp curves. The speed selected by the engineers was based upon the working of the London and South Western Railway on a particularly sharp curve, but no one would be prepared to support the contention that the working of the London and South Western Railway, with its locomotive at the head of the train, was comparable with the Electrical Railway with a locomotive in front and also a locomotive pushing behind. That, therefore, had diminished the speed at which the trains were allowed to run, and had made, as the Author indicated in the Paper, a very sensible difference in the general speed of carrying on the traffic. He took it that no very great speed was required, and that the supply of trains was amply sufficient as it was. There was, however, the alternative of having all the carriages driven by motors, and the superlatively satisfactory arrangement which could be made with electro-motors of having motors on every axle of the train. He believed it was Sir Douglas Galton who first drew attention to the advantage of that method when he was reporting on the Westinghouse brake in 1876. He himself had drawn attention to the same thing shortly afterwards, and there was no one who had been more insistent upon that point than Mr. Sprague, whose efforts in electric traction had led to such great results in the past. Mr. Sprague had quite lately introduced on the South Side Elevated Railway road in Chicago what he called the multiple-unit system, a system in which each car was complete in itself in such a way that a train could be made up of any number of cars in any order, and would be properly connected up, so that the driver had only to go to the front car and work his master controller, and so actuate all the controllers of the different cars. The current was taken up by each car which had its own controller to convert from series into parallel, and *vice versâ*, and the whole of the cars were controlled from the master controller. It was

Prof. Forbes. necessary to have several wires going the whole length of the train, but not so many as in the Waterloo and City line, and the wires did not take the whole working current but only a very small current sufficient to work the motors which actuated the controllers. He thought it was well to direct attention to the admirable system which had been introduced by Mr. Sprague at Chicago. He would also say that there were other means of equipping electric railways at the disposal of engineers, which, however, were not before the Institution in connection with the Paper. The three-phase system was, in many instances, perfectly adaptable to the case, and still more so on a permanent railway like all the railways which had been dealt with in London. Tramways had been worked by that method with success. In a railway, however, it was very much to the point. There were many other methods, and wherever a case presenting special difficulties did arise, it needed careful consideration to determine what was required. It was fortunately the case that the Metropolitan Railway would be shortly equipped with electrical power, and he was sure the members would be glad to know that two such eminent Past-Presidents of the Institution were engaged in working out the details of that arrangement. It opened a field for originality and pioneer work, which, if rightly accomplished, would be a credit to this country in electrical engineering.

Mr. Scott. Mr. E. K. SCOTT noticed from Fig. 9, Plate 5, that each axle of the bogie carriages had four bearings, two for the axle-boxes and two for the motor. Now the movement of the motor was very slight, being only that due to the compression of the springs at starting and stopping. It did not therefore appear necessary to put the motor on to the axle, for projections could be made from the axle-box to form "cannon bearings," and the motor placed on them instead. The present arrangement had the wheels inside the bogie frame, but he did not see why it should not be a cantilever axle with the wheels outside. In that way each axle would have two bearings instead of four, the motor field frame being kept in true alignment by means of the cannon bearings above mentioned.

He had tested a Belliss engine of the same size and at the same time as these railway plants were on the testing bed, and he could not help comparing the size of the barring wheel which Messrs. Belliss put on their ordinary standard engine, and which was $3\frac{1}{2}$ feet in diameter, weighing about 1 ton, with the large wheel $5\frac{1}{2}$ feet in diameter and 21 inches face, and weighing nearly 6 tons, which was put on these railway sets. In each case very good speed-regulation was important, but whereas in one case the dynamo machine was itself a fly-wheel, in the other case it was of the ordinary two-pole type, the consequence being that an extra large fly-wheel had to be added. On this account he thought it would have been better to have adopted the multipolar type of dynamo. There was one point with regard to this railway where one of the advantages of three-phase traction did not quite apply on account of the speed from station to station varying so considerably because of the curves. The three-phase system of traction had the advantage that the speed of the motor was governed by the frequency of the alternating current supply; therefore with ordinary gradients, there was nearly constant speed. If the three-phase system had been applied in the present case the motors would have had to be regulated down to pass round the sharp curves, and regulation of multi-phase motors meant less efficiency than in continuous-current motors, unless indeed the lower speed was obtained by so arranging the stator coils that the number of poles could be halved. Mr. Scott.

Mr. E. W. MONKHOUSE, referring to the objection of the Board of Trade to the speed round the curves, thought it unfortunate that engineers should be allowed to design a railway and that the Board of Trade should then step in and say that the speed which had been found safe on other lines should not be permitted on that railway. If the whole train were pushed from behind, no doubt the question raised by Professor Forbes would apply, but as the train was half pulled and half pushed he thought there should be some good reason given by the Board of Trade for making their objections. Mr. Jenkin had referred to the varying amount of energy used by different drivers; that had been the universal experience. On several lines watt-meters had been put on each car, with the result that there was a healthy rivalry between the drivers to see who could use the least amount of energy, even if a small premium was not given to the men who used the least. As to the controller for the railway, he noticed a very good arrangement, and that was a carbon switch for breaking the current every time it required to be broken. One of the great troubles with controllers was that the contacts wore out owing to arcking; and some arrangement such as Messrs. Siemens had adopted in their controller was a capital way of getting over the difficulty. Among the heaviest expenses in repairs to tramcars was the replacing of the controllers and putting them right. An excellent thing in connection with the railway also was the good workshop arrangement that had been made for overhauling Mr. Monkhouse.

Mr. Monkhouse. the plant. He had had some conversation early in the year with a gentleman in America who had to do with a line of the same type, and he made a strong point of the fact that in general the arrangements made in the running shops for overhauling the plant were not nearly good enough. The shops ought to be well lighted and every possible facility afforded for inspecting the motors. He believed that gentleman was right, because one of the chief expenses of an electrical railway was the repairs to the motors and the electrical equipment of the cars. The governing of the Belliss engine had been mentioned, and in connection with that he might say that his firm had some small Belliss engines running on a traction circuit in London with ordinary fly-wheels which were not extra heavy, and those little engines had been found to govern extremely well, even with the light fly-wheels.

Mr. Morrison. Mr. G. J. Morrison observed that the regulation of the Board of Trade, limiting the speed of the train on the 5-chain curve, had resulted in the time of transit of the train being considerably increased, not only because of the loss of time on that curve, but because it had rendered it impossible to work the line on the switchback principle. It seemed that with a proper amount of superelevation on the rail the speed proposed for the 5-chain curve, with carriages running on bogies, with such small wheel bases, was by no means excessive; but it was possible that there might have been a considerable shock in entering the curve. He asked if any means were taken to introduce an elastic or transition curve between the straight line and the 5-chain curve. He had not the least doubt that a 5-chain curve with a good elastic curve at the end of it was more easy to run over than a 10-chain curve, where the curve started at a tangent to the straight line. As very little extra trouble was involved in work of that sort, he hoped the Author would state if any means were taken to introduce that curve or not; and if not, whether the shock on entering the curve had anything to do with the decision of the Board of Trade in refusing to allow a train to be run at the speed originally intended.

Mr. Lawson. Mr. A. J. Lawson observed, from the results of a day's test given in the Appendix to Mr. Jenkin's Paper, that the efficiency was only $66\frac{2}{3}$ between the units generated to those used for propelling the trains. He considered this a poor result for an underground system where there was no chance of leakage from bad contacts or from conduction away through water, etc. With regard to the water used and the consequent coal-consumption, taking coal at 18*s.* per ton, it would work out at the rather high rate of about 0·8*d*. per unit, but that was explained later, when considering the load factor, where only 33·5 per cent. of the capacity of the plant was used throughout the day's run. In other words, the plant running was capable of developing two-thirds more than was used. He believed that a better load factor could be obtained by overloading the sets at the time of the maximum load, and a very much lower coal-consumption would result therefrom. It was astonishing to find that the Waterloo and City Railway throughout the year would only require approximately 700,000 units, *i.e.*, if the service now was about the same as the service given on the day of the test. Notwithstanding the low load factor and the high cost of fuel, that was not so bad when the small output of the station was taken into account. The maximum load—the momentary load—was only 330 kilowatts, and he might mention that on a service of sixteen tramcars on a tramway line he had observed a momentary maximum load of 150 kilowatts. The small loss from the mean voltage at the generating station was exceptionally good, showing exceedingly good regulation, but that might be expected on an underground line where there were no difficulties from the weather to contend with. Mr. Lawson.

Prof. CARUS-WILSON desired to draw attention to the gain accruing from the use of roller bearings. From the curves in Mr. Jenkin's Paper, he found that the average resistance per ton of load was between 6 lbs. and 7 lbs., a result which agreed with other experiments. Taking a train of 105 tons climbing a gradient of 1 in 88, the use of roller bearings enabled it to travel up that gradient at 12½ miles an hour. If ordinary bearings were used, such as those on the City and South London Railway, for which Mr. McMahon had given the friction at about 13 lbs. per ton,[1] the speed on a gradient of 1 in 88 would be only 10 miles an hour, so that there was an actual gain of 25 per cent. of speed due to the use of roller bearings. Prof. Forbes had alluded to the peculiar arrangement of putting the four motors in series at the moment of starting. He thought that was rather overdoing the series-parallel principle. The great value of the series-parallel controller was not so much in obtaining different speeds as in saving energy at the moment of starting. He had calculated the actual saving due to the series-parallel controller on this railway. Taking the amount of energy per trip from Mr. Jenkin's statement, the average energy of the up and down trip was 5,810 watt-hours per trip; the saving due to the Prof. Carus-Wilson.

[1] Journal of the Institution of Electrical Engineers, vol. xxvii. p. 510.

Prof. Carus-Wilson. ordinary method of putting the motors two in series and two in parallel, was 610 watt-hours, or 10 per cent., and the saving due to the method of putting the motors four in series at the start was an additional 120 watt-hours, or 2 per cent. In other words, the complicated controller and the multiplication of cables along the top of the train simply effected a saving of 2 per cent. in the energy used per trip. He sympathised with the engineers who had the designing of the railway, in the fact that the switchback principle had been almost neutralized by the action of the Board of Trade. He should like to supplement the remarks made by former speakers with a request that some further data should be given on that point. He thought that electric railways would enable trains to travel round curves of a much shorter radius than was possible on steam railways, and he knew that engineers were now designing electrically-driven railways on that assumption. He asked if Mr. Galbraith would describe the experiments he had made on which he based the opinion that was spoken of in the Paper. The effect on the general scheme of the curtailing of the speed round the sharp curves should perhaps not wholly be put to the credit of the Board of Trade. The fact was that the motors were already extremely heavily loaded. It was stated in Mr. Jenkin's Paper that the trains were originally estimated to weigh 72 tons. Taking that load, the current at the maximum specified output, namely, 100 amperes, would only just suffice to move the trains up a gradient of 1 in 60, leaving a margin of about 5 per cent. of power, which meant that the motors would be unable to start the train if it were, for any reason, stopped on the grade. It seemed a mistake that motors should be constructed so heavily overloaded that they could not get up speed on a grade without very largely exceeding their maximum current. Taking the actual weight of the trains at present running, namely, 105 tons, it was found that a current of 100 amperes would only suffice to take the train up a gradient of 1 in 88. The motors had to be overloaded 25 per cent. to get the train up a gradient of 1 in 60, and 50 per cent. in order to start, even on a level. It was therefore clear that not only were the motors extremely overloaded at present, but they were unable to speed up on the gradient, if occasion should require it, without still further overloading. That was the reason why the failure of the switchback principle had had such a serious effect. The fact was that the motors, while of ample power, had not sufficient reserve of force. They should be made much more able to accelerate, without having their brake HP. increased. He noticed that the

Prof. Carus-Wilson.

Authors had made experiments at lower voltage in order to overcome the difficulty, but he hoped that that was not a sign that they contemplated running the railway at a lower voltage. Electric railways were already running at too low a voltage; 500 volts was too low for such railways, as he hoped to show subsequently. In the case of the Waterloo and City Railway, the engineers had been attempting an almost impossible task; they had been trying to run very heavy trains with extremely heavy gradients on the automobile principle. Former speakers had already alluded to the question of the use of locomotives *v.* automobiles. The great difference in the use of a locomotive and the use of an automobile was that in the locomotive there was a fair amount of head-room, but in the automobile the head-room was restricted. In locomotives, such for instance as those on the Central London Railway, the diameter of the driving-wheel could be increased, and a larger motor could be employed on account of the increased space there was to put it in, and that motor could carry a very large current. When automobiles were used, as in the present case, the head-room was restricted, and motors of small current-carrying capacity had to be used. There was one way in which a greater accelerating force could be obtained from automobile motors, other than by increasing the current-carrying capacity of the motors—and that was by diminishing the diameter of the driving-wheel. If that could be done, a greater accelerating force could be obtained, providing the pressure of the line could be increased. This was illustrated in Table I. At present the

TABLE I.

Gear Ratio.	Diameter of Driving Wheel.	Line Pressure.	Speed.	Current for a Pull of 825 lbs.	Pull for 100 Amperes.	Mechanical Efficiency.	Gain in Pull.
	Inches.	Volts.	Miles per Hour.	Amperes.	Lbs.	Per cent.	Per cent.
1·0	33	500	25	100	825	96	..
1·0	22	500	21	75	1,240	..	50
1·0	22	570	25	75	1,240	..	50
1·5	33	570	25	85	1,040	83	26
2·0	33	750	25	73	1,370	83	66

motors were running on 33-inch wheels at 500 volts, and the maximum brake HP. was such that they travelled up a gradient of 1 in 88 at 25 miles an hour, or would do so if they could get up speed, the draw-bar pull being 825 pounds. In order to do that a current had to be carried of 100 amperes, which was the

Prof. Carus-Wilson. maximum for which the motors were rated. If 22-inch wheels could be used instead of 33-inch wheels, the train could travel up that gradient taking only 75 amperes, and giving exactly the same amount of draw-bar pull, namely, 825 lbs. With a current of 100 amperes the maximum pull would not be of 825 lbs., but 1,240 lbs., or a gain of 50 per cent. The train would, however, be travelling up the gradient at a reduced speed, namely, 21 miles an hour, and in order to get up the rated speed the line pressure would have to be increased from 500 volts to 570 volts. Thus the same motors could haul the train up the gradient with the rated speed and rated draw-bar pull, and have 50 per cent. surplus of tractive effort in order to accelerate on the gradient if occasion required. The objection to that was the limited clearance over the rail. Mr. Jenkin had stated that the clearance was already reduced to $3\frac{1}{2}$ inches over the top of the rails, so that it would be an impossibility to put on a 22-inch wheel in this case. Exactly the same result could, however, be obtained by the use of gearing. He believed the time would come when electric-railway engineers in Great Britain would become reconciled to the use of gearing. If instead of taking a gearless equipment, he might assume a gear ratio of 1·5, then what might be accomplished with a 22-inch wheel could be carried out with a 33-inch wheel, namely, the train could run up a gradient of 1 in 88 and have a surplus of force for acceleration. The increased friction due to the gear had to be taken into account; taking that at 83 per cent. would make an actual gain of 26 per cent. If the pressure of the line could be increased to 750 volts, a gear ratio of 2 to 1 could be used, and there would be a surplus of force of 66 per cent. instead of 26 per cent. for acceleration on the gradient. The engineers of the Waterloo and City Railway had been trying to handle very heavy loads on heavy gradients with gearless equipments and ordinary voltage. His own opinion was that, if railways of that kind were to be extended, they would have to make up their minds to adopt geared equipments and higher pressures.

Mr. Galbraith. Mr. W. R. GALBRAITH said the discussion had turned mainly upon the electrical working of the line and the electrical appliances, and before he said anything about the construction of the line he should like to express his regret, and he was sure he would be joined in that expression by all the members, that Mr. Greathead, his colleague in the construction of the railway, was no longer among them. It was not suggested that Mr. Greathead was the inventor of a shield for tunnelling; but there was no doubt whatever that Mr. Greathead, by his perseverance and the ingenuity with which he had applied the shield principle, had been really the pioneer of underground railways in London. One of the disadvantages under which the Waterloo and City Railway had laboured was that just about the time of approaching the construction of the electrical works and designing the electrical equipment, Mr. Greathead, who was to have taken that part of the work in hand, died. The result was that valuable time was lost, and the electrical appliances of the line were somewhat hurried. The line unfortunately was opened rather sooner than it would otherwise have been, because being finished and so much capital sunk in it, the directors were naturally anxious to commence working. There was no doubt it would have been very much better to have had a little more time in experimenting before passengers were carried. The Waterloo and City Railway was the second electrical railway opened in London, and he would like to say a word on one or two points with regard to electrical railways generally. The Central London Railway, which was sanctioned before the Waterloo and City Railway, would be probably opened in the spring of 1900. By reason of the great length of the Central Railway, and the number of problems involved in its construction, the Waterloo and City Railway, although sanctioned later, had been opened considerably earlier. It seemed to him that electrical railways had hardly had justice done them by the authorities in London. If one would take the trouble to look at one of the Electrical Railway Acts he would see numberless restrictive clauses which had been introduced very unfairly. Electrical railways were designed and sanctioned by Parliament for the purpose of clearing the traffic of the streets, and that being so, those who had run the risk of putting their money into them and carrying them out ought to have had more assistance than they had from the authorities. On the contrary, no sooner did an Electrical Railway Bill appear in Parliament than hosts of petitions appeared against it. There was never an electrical railway which the parishes did not oppose, and all kinds of restrictive clauses were put upon the railway company, he thought rather unfairly. Electrical companies ought to be met more fairly by the parochial authorities. The most stringent clauses would be found in such Acts: streets were not to be broken, nothing was to be done to the surfaces of the streets, no facilities were given, and restrictions were put upon cartage and upon construction of every kind. He had no doubt the members would sympathize with him when he said that was hardly fair. He wished the matter

Mr. Galbraith.

Mr. Galbraith. could be ventilated in Parliament, where it would have more weight, because it seemed to him the Parliamentary Committee did scant justice to electrical railways. One would think, from the clauses that were put in, that electrical railways were a sort of fever hospital, and any opening made in the street would endanger the public health of London. He must say, however, that after the line was sanctioned the Company were generally let alone, on the whole, very fairly. Although the County Council put very stringent clauses upon the Waterloo and City Railway Company, they were left to carry out the work very much in their own way, as they ought to be, because the whole liability for any damage to buildings was thrown upon the Railway Company. If anything happened to streets or to houses the companies were liable, and there were numberless cases where engineers were appointed to look after the railway engineers, and arbitrations could be forced upon them; and yet if the works were carried on even according to the direction of an arbitrator, the companies were not released from liability. He thought that was a position which was hardly fair. The railway companies ought to be left to their own devices, having regard to the very heavy liabilities they incurred. There was another point he would like to mention. Wherever a railway company proposed to construct a station in the streets, there was found a clause that they must set back the frontage, or improve the corners, or do something of that sort, which involved a very great expense. Why should an underground railway be put to that great expense of improving the streets of London because it was introducing something which was for the benefit of London? Most expensive operations were going on in Davis Street in connection with the Central London Railway in the way of street improvements, simply because the Company wanted to buy a few houses at the corner of Davis Street for a station. The Baker Street and Waterloo Company were about to construct a station in Oxford Street at the corner of Argyle Street, and a clause was introduced that if certain houses were purchased the frontage must be improved, thus involving the Company in very great expense. Underground railways were costly enough as it was, and those extra expenses greatly increased their cost. Another thing was that there ought to be some special facilities granted for putting stations under the streets. The expense of buying property in London for stations was enormous. The Baker Street and Waterloo Railway Company wanted to make a station at Charing Cross, but the cost of buying property at

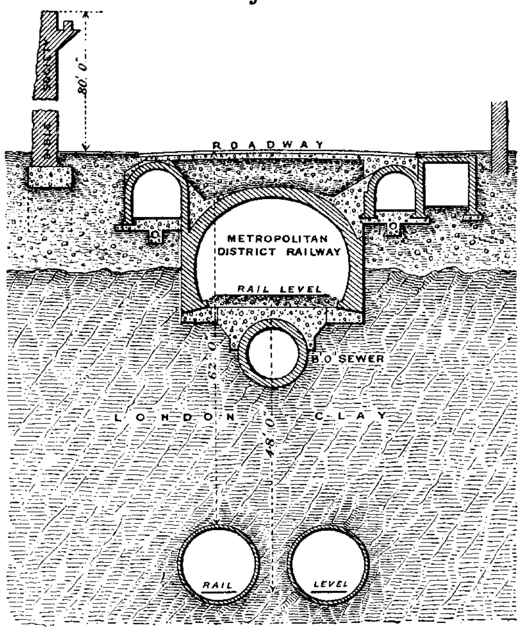
Mr. Galbraith.

Charing Cross for a station for putting in lifts and booking-offices was almost incredible; so much so that the Company were driven to go to Parliament last year for powers to construct a station at the junction of the streets near the Nelson Monument. After opposition by the parish and a great deal of trouble the Company were granted what they asked, and thus secured a good station at Charing Cross for which, in return, they had to make a number of expensive subways. Having blown off some of his steam in that way he would like to make one or two remarks about the Waterloo and City Railway. The size of the tunnels of that railway was 12 feet. The smaller tunnels on the City and South London Railway very much interfered with the success of that line. There were certain times in the day, in the morning and evening, when there was a great glut of traffic which the trains were not able to carry, and the result was that traffic had to be turned away. When the Waterloo and City line was laid out, it was thought to be better to have 12-feet tunnels. The tunnels were really 12 feet $1\frac{1}{2}$ inch, the $1\frac{1}{2}$ inch being allowed for a little irregularity of the tunnel linings, but on the whole there was 12 feet. He thought it was a pity that what he might call the main underground railway of London—the Central London Railway—had been restricted to 11 feet 6 inches. It was like the 4 feet $8\frac{1}{2}$ inches gauge, which was a conventional gauge, and no one knew why it was adopted. He thought it would have been much better to have had the extra 6 inches. The station tunnels for the Waterloo and City line were 23 feet in diameter; those for the Central London Railway were 21 feet. He thought the company would have well spent its money if it had gone in for 23-feet tunnels. The extra cost was not very great, but the extra width of platform which 23-feet tunnels gave would have been well worth the extra cost. The only question really that had been raised about the construction of the Waterloo and City line was with regard to the 5-chain curve. It was a pity the 5-chain curve was there, and it happened at rather a critical point; but the reason was that, before the sitting of the Joint Committee upon underground railways, the law was that, if a property was passed under by a railway, the company almost invariably had to buy the whole. When the Waterloo and City line was laid out, instructions were given that private property was to be avoided as much as possible. From Stamford Street, private property had to be passed through down to the river. There was a factory at this point which would involve, it was

Mr. Galbraith. assumed, a large amount of compensation, and the 5-chain curve was put in to avoid that property. It was also put in because on the City and South London line they were working curves of 130 feet radius, something like 2 chains, and it was thought that a 5-chain curve worked by bogie carriages was an ample curve for running at a good speed. When Professor Kennedy came to him and said the trains would have to run over this 5-chain curve at something like 25 miles an hour, he asked the South Western Company to allow him to make some experiments at Southampton, where they had in the docks a curve of 300 feet radius, over which trains ran to the ocean steamers. The experiments were made with a six-wheeled contractor's coupled-engine having 11 feet 6 inches centres. The engine was run up to 35 miles an hour, which was the limit. The resident engineer said that when it reached 35 miles he got off. It was worked safely round the curve quite comfortably at 25 miles an hour, and there was no check rail on the curve. Therefore he told Professor Kennedy that he did not see why trains could not run round the curve at 25 miles an hour, and therefore the electrical appliances were designed for that speed. The superelevation of the outer rail was 4 inches and a check rail had been introduced. The curve did not run sharply off the straight, but was gradually led up to, so that anyone riding over the line would be surprised to see how easily the trains ran over the 5-chain curve. There was no shock at all. The Board of Trade officer, when inspecting the line, said the speed must be restricted to 12 miles an hour, but was persuaded to allow 15. The Board of Trade were not bound to give any reason; they simply said the speed was to be 15 miles an hour and there was no appeal from their decision. He had spoken to Sir Francis Marindin on the previous day, who shook his head and said, "I daresay you run over that curve at more than 25 miles an hour." Perhaps they did, but unfortunately the limitation was 15 miles an hour, and some of the drivers did not exceed the limitation. The traffic department was perhaps a little nervous and thought the effect of running off the line in the tunnel would be awful. He thought there would be no harm in running at 20 miles an hour, and he would feel perfectly safe and comfortable in running at 25 miles an hour. He had travelled over the line that morning and made a note of the time. Including the slowing into the station the journey was done in 5 minutes 25 seconds, and by running more boldly into the station it might be done in 5 minutes. If done in 5 minutes there would be no cause of complaint as to the length of the journey. With an alteration of the motors the speed might be increased. The motors were designed for a greater speed over the 5-chain curve, but without considerable expense in altering the rolling stock that could not be done. The London and South Western Railway, who were working the line, were about to try engines instead of the double bogie carriages with motors at each end. A little disappointment had been felt with the wearing of the rails; on some of the curves it had been very great. It was, however, diminishing, as the carriages were adapting themselves to the curves and running round much better then they did at first. All kinds of theories were propounded to account for the wear, the most persistent being that the pushing and pulling action had something to do with it. Whether that was so or not he did not know, but at all events the wear was just as great in the 5-chain curve at the top of the gradient near Waterloo as in the other 5-chain curve where the trains ran at greater speed. When the new engines came it would be seen whether they worked better than the motor carriages. With regard to the hooded shield, there was just one point he would like to refer to. There was no difficulty in working in the clay, but in the water-bearing strata on the south side of the Thames the system adopted was that which seemed to be in vogue, that practically a wooden tunnel was first made. The tunnel was boarded up and the shield pushed under it; the ironwork was then erected and grouted up. He did not think it right that such an enormous quantity of timber should be introduced. The shield should do its work without the timber. When Mr. Hay propounded the hooded shield and the system of excavating a ring gradually and filling it up with clay, he thought Mr. Hay hit the right rail on the head. He was certain that that was the right thing to do. Mr. Hay was a perfect enthusiast in tunnel-driving, and his shield on the clay system was a great improvement. It was said that it would never work, that it would be very slow, and so on; but the speed was greater than in the other system, and the shield worked with the greatest ease. He strongly recommended it to any engineers who were going to drive tunnels in towns where there was danger of settlement. It was a different matter in the country where it was of no great consequence whether the ground subsided or not; but in towns, where it was all-important to preserve the buildings, he would certainly give Mr. Hay's shield a trial. It was a very good one, and great credit was due to Mr. Hay. There had been a good many claims for settlement of the ground and cracks in buildings. Of course, it was not admitted that the railway cracked any buildings, but people said it did. It Mr. Galbraith.

Mr. Galbraith. was a very difficult thing to see how a settlement could occur when the tunnel was in the London clay with about 20 feet of cover over it, and where the space left by the shield was grouted up the moment the shield was pushed forward. There was a theory that the moment the clay was exposed it began to creep or subside, but he could not fall in with that view. The grouting seemed to him to get over that, at all events any settlement on the top. Some experiments were made on the railway with grouting with "Nelson's Cock Brand" of blue lias lime. It did exceedingly well. About one part of sand was mixed with three of lime, and it set beautifully. Demonstrations had been given of its setting and of how well the interstices were filled. Near the City station, where the scissors crossing was put in, there was a 23-feet tunnel, but the contractors drove a 12-feet tunnel first. That tunnel had to be cut out afterwards for about 100 yards, and it was found that every interstice was filled with the grout, which was quite hard. In the station tunnels in the City the grouting was partly done with cement, the lower part with neat cement, and the upper part with cement and blue lias lime. Six cross passages had to be driven for communicating between the two platforms, and it was found that the grout had perfectly filled all the interstices. Sir Benjamin Baker, who came to look at the tunnel, suggested that it should be seen whether the grout was perfect in the top. Two pieces about 6 inches or 7 inches square were cut at random, and the grout was found to be perfect. It seemed to him that the grout, if properly injected, did its work, and there ought not to be any settlement. There was some settlement, as there had undoubtedly been cracks, but mostly in cellars. His experience was that where buildings had been properly founded on a good bottom the main walls had stood. There was another matter peculiar to the Waterloo and City Railway—that there were no lifts. At Waterloo the railway was about 41 feet below the rails of the London and South Western Railway. It was never intended that there should be lifts, as it would be very difficult to get them in underneath Waterloo station. It was arranged that there should be inclines, which were 1 in 8. At the City it was intended there should be lifts, but the cost of the property to put in the lifts and booking-office was so very great that it was determined to try the effect of inclined passages. He was rather nervous about that, because the difference in level from the streets to the platforms was 59 feet; but he believed it had been quite a success. He had asked often whether there had been many complaints from people about walking up the inclines, but there had been very few. The Waterloo passengers used the subways of the Central London Railway, and so entered the streets at various points. The two present accesses were temporary. The stairs, which were now rather long, would be taken up and stairs of quite moderate depth would be put in; so that when the Central London subways were ready there would be a very great improvement of access to the various streets in the City. Fig. 15, Plate 3, showed the underpinning of the arches at Waterloo. That was a Mr. Galbraith.

Fig. 1.



great success. Fig. 16 showed the operation of cutting athwart the piers, which was very difficult. Another point was the cutting away of the pier where the large arch was put in. The first thing was to introduce the key before anything was touched; then the segments were turned on either side of the key, and the pier cut away. This operation also had been a great success. There was not a single settlement either on the viaduct or the station buildings under which the tunnels were driven. That reflected great credit on the contractors. Under the Company's

Mr. Galbraith. booking-office at Waterloo a portion of cut-and-cover work was introduced, which was not quite watertight. The iron tunnels throughout the line were perfectly watertight, and had been a great success, but in the short length of cut-and-cover there was a certain amount of leakage, which had been removed by the electrical pumps, or by the hydraulic pumps when the electrical pumps were not working. Before closing he should like to bear testimony to the admirable manner in which the tunnel work had been carried out by Messrs. Mowlem and the station work at Waterloo by Messrs. Perry; Mr. Hay was also entitled to great credit for the way in which the tunnel lines had been kept. The tunnels on the Waterloo and City Railway were beautifully accurate both as to line and level. It was a pleasure to go through the work and see how very well it was done. It reflected great credit both upon the engineers and upon the contractors who had had charge of the work.

He had prepared a diagram (*Fig. 1*) showing a cross-section of the Waterloo and City tunnels and the District Railway in Queen Victoria Street, opposite the office of the British and Foreign Bible Society, which indicated how the tunnel could be carried out under very complicated conditions where grouting was properly done. The sewer was some distance away, but as the tunnels advanced up Queen Victoria Street the sewer dropped towards them, and ultimately in Cannon Street, the top of the tunnel was only 2 feet 6 inches from the sewer. There had been absolutely no subsidence of the ground, and no complaint had been received from anyone in Queen Victoria Street.

Mr. Deacon. Mr. G. F. Deacon thought that probably no work of civil engineering was likely to have more influence on the future of the metropolis than the class of tunnelling that had been dealt with in the Paper. In connection with the subject it was desirable to remember the pamphlet "On the Relief of London Street Traffic," by the late Mr. Peter Barlow, M. Inst. C.E., F.R.S., issued in the year 1867, in which he proposed tunnelling chiefly through the London clay by a system of small tunnels for omnibuses on rails actuated mainly by the force of gravity somewhat in the manner of the switchback, hydraulic lifts being provided at the stations. Electric traction had been the means of enormously increasing the value of that idea. The impermeable London clay, comparatively little thought of then, was now known to extend to a minimum depth below its surface of something like 100 feet, in many places 400 feet. Therefore there existed close to the surface an enormous thickness of soft, easily tunnelled, permeable material incapable of giving any trouble in the matter of water. It appeared to him that to tunnels electrically worked through that medium the future relief of the enormously congested traffic and the insanitary conditions of the streets in some weathers, would be chiefly due—perhaps he ought to add along with the motor car, when the motor-car ceased to be noisy and to smell. With quick working hydraulic or otherwise actuated lifts, arranged in parallel and working in series, there could be no difficulty whatever in dealing rapidly with any amount of passenger traffic, and this being so, it seemed to him a pity that in the schemes hitherto propounded, the main tunnelling work had been brought so near to the surface. It had introduced many difficulties which would otherwise not have existed. Mr. Deacon.

Mr. Galbraith had expressed the very natural wish that municipal authorities and owners of properties would not insist upon the introduction of so many annoying clauses into Acts of Parliament. He sympathised with that feeling, and had often experienced it; but he saw no way of moderating the difficulty other than by devising physical means which would render such precautions unnecessary. The first of those means appeared to him to be to go a little farther below the surface to avoid, so far as the tunnelling was concerned, penetrating the water-bearing sands and gravels above the clay. In connection with tunnelling through the London clay, the view had been expressed that the motion of the clay could not commence directly the supporting pressure was removed. The whole of the London clay in which tunnelling was likely to take place was below the level of the natural plane of saturation. This clay, completely saturated as it was, would move with exceedingly small pressure, and flow in any direction in which it was unsupported, and there seemed no reason whatever why that movement should not begin as instantaneously as the movement of a stream of water would begin. Of course inertia would prevent the instantaneous movement being as rapid as it would become a few seconds later; but after a few seconds, or at any rate minutes, it would appear that the mass of clay must be in motion towards the unsupported area at a more rapid rate than at any subsequent period, because at subsequent periods it had received a strain which considerably retarded that motion. But Mr. Galbraith had admitted that, notwithstanding his doubt as to immediate movement, cracks did occur in buildings near the line of tunnelling, even when the tunnel was a considerable distance below the surface of the London clay. That, he, Mr. Deacon, had reason to know, was the case. It appeared to

Mr. Deacon. him that much of the disturbance which had lately been observed in tunnelling of that kind was largely due to changes in the mode of tunnelling. The inception of the cylindrical shield came from Mr. Peter Barlow, and Mr. Greathead had admirably prosecuted the system. It was originally intended by both those engineers that the clay should be supported by the cylindrical shield, and that the cutting edge of the shield should penetrate the face around its periphery so that the area of the face only was left unsupported. Contractors, however, or their piece-paid workmen, discovered that the hydraulic shield was an extremely useful excavator. If against the cutting edge, or the flanges to which the cutting edge was bolted, were placed short timber piles with pointed ends penetrating the clay face in a direction converging towards the axis of the tunnel, and if then the shield as a whole was pressed forward by the hydraulic rams, the piles broke out masses of clay and very considerably reduced the manual labour. But in order that this might be done effectively, the shield had to begin its journey 2 feet to 3 feet back from the face of the clay—the cutting edge must not be against the face, because, in order that the piles might be thrust into the face, the shield must be capable of forward motion towards the face—and that led to the cutting out of the face by manual labour to a diameter somewhat greater than that of the cutting edge and the shield following it, so that from the tail of the shield to the face of clay, a length of more than 9 feet, the clay received no efficient support whatever. He had seen this system in operation. He did not doubt that it increased the rate of progress, but it had the effect also of multiplying the unsupported area about four times as compared with what it would be if the cutting edge penetrated the clay and grouting were carried on continuously as the shield advanced. A similar objection existed to the use of the heading which was commonly driven 10 feet or 12 feet in advancing the face. He was bound to say that he thought the difficulties which had undoubtedly arisen in respect to surface movement had been largely due to those changes. If, on the other hand, the cutting edge was held firmly against and penetrated the clay face, a greater hydraulic pressure was necessary, but not nearly so great a pressure as Mr. Deacon had employed in the case of the Mersey aqueduct tunnel, or as had been employed elsewhere, and the avoidance of increased pressure was another incentive to the mode of working he deprecated. Another difficulty arose from the looseness of the annular shield upon the cast-iron tunnel. In order that the shield might turn a curve, an annular space was necessarily left, and the indifferent staunching by the timbers placed between the end segments and the ram-heads was quite insufficient to hold up the grout which had free access to that annular space. Therefore the grouting had to be kept back, not merely from the face or the cutting edge, but from the edge of the last finished lining to a considerable distance. If the tail of the cylindrical shield consisted of two thicknesses, and if those thicknesses were cut longitudinally, and the cuts broke joint with one another, so that the tail hugged the outside of the cast-iron lining, there was exceedingly little room for either water or grout to pass the shield. He felt satisfied that if some such system as that were adopted in connection with the penetration of the face of clay by the cutting edge, and if the heading were done away with altogether, a little practice would result in exceedingly little, if any, disturbance at the surface. He would reiterate his previously expressed opinion that tunnels under London ought, wherever possible, to be well below the surface of the London clay; that access ought not to depend so much upon steps as upon numerous hydraulic lifts; and that in the construction of the work the grouting pressure should be continuously maintained quite up to the shield, while the cutting edge should always penetrate the face of clay. He believed that the observance of these conditions would be beneficial to everyone concerned. Mr. Deacon.

Mr. FRANCIS FOX had had the good fortune to visit the works on two or three occasions, and he was able to appreciate the difficulties under which the work was being carried out. In sand or gravel and under compressed air it was necessary to visit the works in order to understand the difficulties to be coped with. With a falling pressure, an escape of air, a falling temperature, the increase of fog, the tendency of the shield to droop, and with water coming up at the feet, in order to thoroughly enjoy such amenities the site ought to be visited. The works, as they were approaching Waterloo Station, afforded a very good illustration of the pertinacity and the courage of the British engineers and others who carried out the work under very considerable difficulties. He also had had the pleasure of visiting the work Mr. Deacon had referred to—the Mersey aqueduct tunnel—when it was in the midst of its troubles, under high atmospheric pressure, with silt and with constant inrushes of the material; and really it seemed to him as if it would be almost impossible to get workmen, engineers and others, to face the difficulties that presented themselves there. Mr. Hay, in referring to the shield, had called it the Greathead shield. He thanked him for that, because, Mr. Fox.

Mr. Fox. without going into the question of who was the actual inventor of the shield, the credit of its practical application was due undoubtedly to that gentleman. He wished to say a few words on the subject of the ventilation of the tunnels, particularly during construction. He did not want the members to think him a mere enthusiast on the subject of fresh air, but he did think it was due to engineers, contractors and workmen, that an ample supply of fresh air should be supplied to tunnelling under all conditions. To see those men going into the tunnels and coming out the colour of white wax was not a desirable thing. Many a poor fellow had been sent to his grave because there was not a sufficient supply of oxygen to keep his system going. Every £1 expended in ventilation saved at least £10 in wages, delay and fixed charges, during the construction of the works. It was, therefore, false economy to try and drive the tunnels, whether by the Greathead shield, or under ordinary tunnelling conditions, without thoroughly good ventilation, especially in compressed air. It was the wisest policy, as had been found out in connection with the Simplon Tunnel, to furnish an ample supply of fresh air to the workmen at the face. The underpinning of the work at Waterloo was a matter of very considerable risk and anxiety, and he thought the Author, and Mr. Galbraith, were to be congratulated upon the way in which the work had been done below the water-level, and the removal of the central pier and the substitution of the arch shown in Fig. 16, Plate 3, had been effected. That work required, no doubt, the greatest care and attention, and, he understood, had been carried out without a crack. An interesting feature at that station was that there was 10 feet of hydrostatic head on the brickwork; and he understood, also, that it was very fairly watertight. At the present time he was giving his attention to a building which would have foundations with 20 feet of hydrostatic head, and he should be grateful to Mr. Dalrymple-Hay if he would kindly tell him how to keep the water out. With regard to grouting, he noticed in some cases, in the lower half of the tunnel, that neat cement was found to be the best, whereas, in the upper half, equal parts of cement and lime were used. He would be glad if the Author could kindly state something more on that subject. There was a reference in the Paper to the question of work done on Sunday, and he desired to take that opportunity of referring to that question. Unfortunately, Sunday was regarded as a day on which anything could be done that it was at all inconvenient to do on weekdays, and any excuse was made for Sunday work. As a profession, he thought Engineers ought to set their faces Mr. Fox. resolutely against Sunday employment, unless it was absolutely necessary. Mr. Jenkin, in his Paper on the electrical equipment, had referred to the engines being high-speed with 385 revolutions a minute, and with a flywheel of 6 tons. It had been his good fortune this year to visit America, and he had seen what they considered there the latest and the most perfect practice. The practice there was to adopt units of very large power. In the Ninety-Sixth Street Power Station the units adopted were engines of 3,500 HP., each capable of working up to 5,000 HP., and in one single engine-room there were eleven of those engines capable of working up to 55,000 HP.; also it was found that large, heavy flywheels weighing from 56 to 65 tons, keyed on to the same shaft as the dynamos, were the proper things to use. The type of engine used was the marine vertical type, cross compound condensing, and in all cases low-speed. Engines of 1,000 HP. they would never allow to be run at a greater speed than from 80 to 100 revolutions, smaller engines never exceeding 150 revolutions. He ventured to think that was a practice which it would be wise to follow in this country. He had observed that at Shepherd's Bush, on the Central London Railway, the American system was very wisely being adopted. Direct driving was almost universal, and the flywheels and the dynamos were keyed to the same shaft. The question of short-circuiting had given rise to a great deal of thought in times past, and he certainly was very much struck by a remark made by Mr. F. S. Pearson in New York, who said that, so far from being afraid of short-circuiting, it was invited. Mr. Pearson specified that all his dynamos should be short-circuited by means of a solid bar of copper held on for 15 minutes. He had asked American engineers as to the type of generator advised by the highest electrical authorities in that country, and they told him they had come to the conclusion that the revolving armature, with fixed pole-pieces generating continuous current, was the best for electrical traction. In conclusion, he desired to throw out a hint. It might not be of value, but, on the other hand, it might be. Everyone was looking forward in the future to the extension of the electrical system of railways in London as the one means of solving the tremendous problem of interchange of traffic from one part of the City to the other. Although several of those railways had been made, it would undoubtedly fall to the lot of some of the members to make a great many more, and he ventured to think the proper thing to do would be to adopt the New York system, and instead of

Mr. Fox. installing a power station for each independent line, have one, two, or three large power stations of considerable magnitude up to 50,000, 60,000, or 70,000 HP., so placed geographically as not to require long conductors, and thereby supply current for several of the railways. In that way the costs of the railways would be kept down, and it was to the interest of the engineering profession engaged in their construction that they should be made to pay. The best way to make them financially successful was to cut down the expenses, and anything that could be done to that end, and to bring a rapid return to the shareholders, was so much to the benefit of the engineering profession.

Mr. Mott. Mr. Basil Mott said that unfortunately Mr. Hay's hooded shield had not been used on the South London Railway, as it had not then been invented. On that railway the old method of timbering the face as shown in Fig. 8, Plate 2, was used. Undoubtedly the hooded shield had great advantages in that respect, and he wished they had been able to adopt it on the South London. The clay packing in the face would have assisted the progress very considerably. He would like to ask Mr. Hay whether he had found any tendency of the shield to revolve on its own axis. In other cases that had occurred, and considerable difficulty had been experienced in consequence. On the Central London, shields had revolved to as much as 45°. If that occurred with the hooded shield he imagined that circumstances might arise in which the hood would be a disadvantage rather than an advantage. With reference to Mr. Deacon's remarks as to tunnelling without heading, and using the shield as an excavator, he could only say that in the very early days, when Mr. Greathead first designed the shields for the South London Railway, he always looked upon the shield as an excavating machine; and adopted iron-shod wedges forced forward by the shield for breaking down the clay into the front heading after the first two settings had been removed in the usual way. The cutting edge had always been used as an excavator, 3 inches to 4 inches of clay being invariably left for the cutting edge to remove. On the South London, headings had been used, given up, and then used again. It was found that one of the great features in executing tunnelling without trouble was the expeditious manner in which the work was carried forward. The slower the progress of the tunnel, the greater the liability to trouble. The cases where trouble had been experienced were those in which the heading had been abandoned; where the heading had been given up and the speed of progress had been lessened, it was found the trouble had been greater than where there was a heading, and the speed consequently increased. He was very much inclined to think that one of the principal desiderata in tunnelling was to carry the work forward continuously night and day. He was sorry to suggest working on Sunday, but he thought that if work could be carried on throughout continuously, even on Saturdays and Sundays, there would be even less trouble than was experienced now, although in most of the cases he had been fortunate enough to be interested in there had been practically no trouble whatever, except where the ground had been specially difficult and the circumstances had been peculiar. With regard to the train-service, on the Waterloo and City Railway there appeared to be only one train every 6 minutes. One of the diagrams showed the intermediate signals between Waterloo and the City, but it did not appear that those signals were used in actual practice, otherwise the train-service might be made quicker than every 6 minutes. The complete journey from Waterloo to the City took 6 minutes, but if intermediate stops, or, as they were called on the South London, "outer home" signals were adopted, it appeared to him that, unless there were some circumstances he was not aware of, the train-service might be considerably accelerated. On the South London the gradients were steeper than on the Waterloo and City, and the curves were sharper, yet they were able to run a $3\frac{1}{2}$-minute service, owing to the use of the intermediate stop-signals between the stations. He would like to know whether anything could be done in that direction on the Waterloo and City Railway. Mr. Mott.

Mr. E. W. Moir gathered from the Paper that the Author imagined the hooded shield to be a novelty. He was sorry to say, for the Author's sake, that it was not; it was introduced by a Swede, named Andersen, in Brooklyn, many years ago for driving a tunnel. There was considerable difficulty in keeping the nose up, and he gathered from what Mr. Dalrymple-Hay said there had also been considerable difficulty in the present case. When the shield was being designed for the Hudson Tunnel he suggested to Sir Benjamin Baker that a hooded shield should be used. Sir Benjamin condemned it, because he said there would be a great difficulty in the settlement of the nose, and he insisted on having a square front. In the case of the Blackwall shield, a hood was adopted, and the skin was allowed to project 10 inches round about, with the view of making an air seal in the ballast; but the bottom was not cut away. The novelty in the case of the Waterloo and City Railway seemed to be in introducing pockets of clay round the cutting edge, which, according to the Mr. Moir

Mr. Moir. Paper, had been a great success, the clay acting as a sort of skin to hold up the ballast when the shield had gone ahead, until the grout could be inserted. Mr. Hay had drawn attention to the fact that more pressure was required on the bottom of the shield in driving it through gravel than was generally required through clay. No doubt that was so, and it was found to be the case at Blackwall, so much so that the number of jacks in the bottom was increased by 200 per cent. when the gravel was reached, and the whole power of the shield was increased by 50 per cent., the whole addition being placed at the bottom. Even with that largely increased pressure (it sometimes amounted on the whole shield to over 4,000 tons), and although the gravel was stirred up by jets of water, and blasting charges were put in front of the shield, sometimes only 4 inches of push were made at a time. Only about 400 feet had to be traversed in crossing the gravel-bearing part of the river, but as an instance of how much friction there was on the outer skin of the shield, he might mention that, although the work was being carried on in salt water, the shield was delivered into No. 3 shaft quite bright and polished outside, which showed that the friction must have been enormous. He was sorry the Author had not given some information as to the question of settlement. A very interesting description of the possible settlement had been given by Mr. Deacon. Settlement was undoubtedly a very serious thing in tunnelling, and there was very little doubt that it occurred sometimes in front of the shield even. He believed it was a fact that in streets under which some of the recent railways in London had been constructed the curb-stones had tilted inwards. He believed they did so in part of Queen Victoria Street, and he had also heard of them tilting elsewhere. He had not heard of any explanation as to why these curb-stones tilted inwards, but he had been told by some of the contractors on the staff of the Central London Railway that if there was any settlement the line of cleavage was about $1\frac{1}{2}$ or $1\frac{1}{4}$ to 1 from the outside tangent to the outer tunnel. It would appear that there might be a narrowing of the street due to settlement. If there were a narrowing of the street it would account for the tilting of the curb, because the difference in level between the pavement and the road surface was the place, if the street came together, where there would be the most probable sign of movement. He thought it would be found, if careful measurements were taken, that probably the street grew slightly narrower, perhaps $\frac{1}{2}$ inch or something of that sort. He had made experiments himself on London clay in reference to the horizontal flow, and he found that

even on a strutted face, if an auger were driven into the face Mr. Moir.
8 feet or 10 feet in advance of the shield, and its position measured with a plumb line, it came forward to a measurable extent. If the face was not strutted, no doubt during working hours that continuous movement might be going on, though with rapid progress this might not be so. At the St. Clair Tunnel, before introducing air-pressure, they used to excavate from the face, which was like potter's clay, comparatively soft, about twice the cube they excavated after air-pressure was introduced. It was always said that air-pressure was introduced into the St. Clair Tunnel to prevent the excessive flow of the plastic clay into the shield. He quite agreed with Mr. Mott that Mr. Deacon must be misinformed as to what was done with shields in the present day. They did not excavate in front of the shields; they were putting far more power into them, and making them stronger. Mr. McDonald would bear him out in the statement that where the Blackwall Tunnel shield passed under his railway at Poplar there had been no settlement, but a heap of material 3 feet high was ploughed up, and lifted all Mr. McDonald's roads. That was going to the other extreme. Through the courtesy of the authorities of the South City Elevated Railway in Chicago, he had recently had the opportunity of examining the new system of electric traction which had been introduced there with marked results. When he mentioned that the working expenses of the steam haulage amounted to 75 per cent. or 80 per cent. of the takings, and that, under the scheme he was referring to, they had been reduced to something like 45 per cent., members could easily imagine that a vast improvement had been made. The railway was run on the Sprague multiple-unit system, which had proved successful. He believed that the most efficient method of electrical traction was to rapidly accelerate the train, by first getting it up to the highest possible speed in the shortest possible time, and using the momentum of the train to carry it to the next station. If an electrical locomotive were used, only a limited load could be put on the wheels, and there was a limited tangential effort which could be put upon the drivers. If the number of wheels acting as locomotive drivers were increased, the effort to produce acceleration could also be increased greatly. With the Sprague multiple-unit system, nothing was thought of getting a speed of 35 miles an hour in 30 seconds. The speed had gone so much higher that people had been nearly dragged off their seats. If it was desired to increase the average speed, or, as it was called in the United States, the "scheduled speed," through-

Mr. Moir. out the line, it was necessary to accelerate very rapidly, and the only way to do that was to get more effort on the driving wheels. Only a certain amount of adhesion could be obtained from any loaded wheel, and it was no good driving a wheel round when it was slipping on the rails. The Sprague system therefore equipped most of the cars—sometimes all of them—as locomotives. One of the great benefits of the Sprague system was that the main current was not carried along the train. He saw, according to the Paper, that in the Waterloo and City Railway there were a large number of heavy cables passing along the train. In the Sprague system each car was a locomotive complete; it could either run with ten others, or it could run alone. It could be in the front or at the back of the train—it made no difference, as it could control not only itself but the whole train. The controller was handled by means of a key not much larger than that which wound up an 8-day clock. The rheostat, instead of being worked by hand, as he understood it was worked on the Waterloo and City Railway, was worked by an electric motor, and the current to work that electric motor was the only current carried along the train. If it was necessary in the slack time to drop off three or four carriages, it could be done at a siding without any difficulty, and when they were wanted again they could come on themselves to any point where they were required. They were quite mobile in themselves; any carriage could be a locomotive. The only feature of a locomotive that differed from an ordinary carriage was that there were some doors and shutters which formed into a little cabin, to protect the driver from the weather when he was going along at a high speed. When the car was used for passengers, the cabin was simply shut back, and what was the floor of the locomotive was just as efficient for a passenger entrance or exit as the entrance or exit of any other car. The controller was exceedingly compact. There were two little handles, and a little disk of about 6 inches in diameter was all that was seen in front of the car. The safeguards were also very complete. If the man let go his handle the rheostat immediately went back to its primary position. If the current was cut off any motor, it immediately went back; so that if a man were paralysed, or became ill or affected in any way, the train immediately stopped. He thought it would be granted that the shuttle system of trains was very much better for a rapid service in Y switches at a terminus than a train handled by locomotives. With the block system it took as long to block the locomotive as it took to block a whole train. Every pound carried was of passenger-carrying capacity; whereas by using a heavy locomotive to rapidly accelerate a train, it was all so much dead tonnage; and in running backwards and forwards in shunting, so much dead mileage. In overhead structures there was one thing that became very important. By not using heavy locomotives, the structure could be very much lighter, because the isolated loads were much less. As he had said before, in Chicago the working expenses had been reduced to 45 per cent. of the gross takings, and there were very few railways in this country which could compare with that; and in America the working expenses were generally very much higher than they were here. Mr. Moir.

Mr. F. HUDLESTON wished to add a few words to what Mr. Mott had said about the method of working the Greathead shields at the present moment. It certainly was not the practice now on the Central London Railway, where more tunnelling had been done than on all the rest of the railways put together, ever to excavate the whole of the front right out beyond the cutting edge. He did not think he had ever heard of a case occurring such as that. On the Central London they never went nearer than 4 inches or 6 inches, and the shield invariably cut out all the rest, and left a perfectly sound backing to the skin. There was no space whatever outside the cutting edge at any time. He could not believe that any damage had occurred from that method of working in clay. The damage on the Central London altogether had been extremely slight; there had been very few claims, and the amount of them had been extremely small. Everybody knew from the newspapers that there had been one or two cases where the railway had had to pay. Mr. Moir had referred to rapid acceleration. It was well known that rapid acceleration was the most economical way of getting quickly from one point to another; dynamics demonstrated that. If acceleration was rapidly acquired, far less energy was used in going from A to B in a given time than if the acceleration was obtained slowly. An advantage was obtained when it was possible to use motor-cars and get a large amount of adhesion throughout the whole of the train; but that could not always be done in deep-level tunnels. In such tunnels there was no room to put motors on to each carriage. Fig. 6, Plate 5, showed that the axle was almost touching the floor of the carriage. Mr. Greathead's original intention was to make the carriages as large as possible; and, on the other hand, he made the tunnels as small as he reasonably could, so as to save prime cost. Between the axle and the underside of the floor, he would undertake to say there was not 3 inches. On the Central London there was even less. It was not possible to get a motor in, and Mr. Hudleston.

Mr. Hudleston. consequently he could not see how it could be expected to get motor-cars satisfactorily into such deep-level tunnels. The subject of electrical railways divided itself into three broad heads, small, deep-level tunnels, ordinary tunnels and surface lines. In the small deep-level tunnels a full-sized carriage body could be got, although the same height could not be kept between rail-level and floor-level, for if the full clearance was obtained, as in the case of an ordinary railway, the size of the tunnel was increased tremendously, and had to be paid for. There was an instance where that had been done for other reasons, but in the bulk of the deep-level railways the tunnels had been kept purposely small, so as to economize the first cost, and the floor of the car practically sat on the axle. When that was necessary, an engineer was driven to do what Mr. Galbraith and Dr. Kennedy had done on the Waterloo and City, and if it was desired to use motor-cars, the motors had to be put in one or two carriages. Mr. Galbraith and Dr. Kennedy got them in two. They did not really economize weight; the cars had to be made unusually heavy to carry the motors and counteract the strains involved by them, and, as a matter of fact, he believed it had been decided to give them up and go back to locomotives, but why he did not know. On the Central London Railway the trains weighed no more per seat—in fact, they weighed rather less—than the Waterloo and City trains, according to the total weight of the latter given by Mr. Jenkin, viz., 90 tons, unloaded. He did not see there was much chance of motor-cars being used in deep-level railways, especially multiple-unit cars such as Mr. Moir had spoken of. In the open it was another matter altogether. On an elevated structure, where the prime cost of the girder-work made the real cost of the railway, an enormous saving could be effected if the concentrated rolling load could be reduced. In cases of that kind there was undoubtedly a great field for motor-cars, and if Mr. Sprague would turn his attention to that point, he would be pleased to see it, but there was not an open field in deep-level tunnels. With regard to ordinary railways, where the lines were laid on the ground, and the weight did not matter very much, then the two things met on an equal footing. In those cases it was rather a moot point whether any set of motor-cars, such as had been referred to, could be any more economical or very much lighter than the trains drawn by an electric locomotive. So far he did not think that had been altogether proved. On the Chicago South-Side Railway, to which Mr. Moir had referred, and which was on girder-work, Mr. Sprague took a five-coach train, each coach weighing about 15 tons. Formerly they were drawn by a 28-ton steam-engine, and Mr. Sprague, he thought, altered them and put on his motors. The motors weighed $3\frac{3}{4}$ tons, and five times $3\frac{3}{4}$ was a long way off the weight of the Baldwin engine, which, as he said, was 28 tons. Mr. Sprague lightened his train by 10 tons, and obtained an enormous increase of acceleration, because he obtained so much more advantage from the extra weight put on his motors. A steam-engine had very seldom its full weight on its wheels, and he did not think the Baldwin engine had. With an ordinary railway on the ground he did not think it mattered a great deal to the working whether the engine weighed 40 tons and the train 90 tons, that is 130 in all, or whether the train with the motors on it weighed 10 tons less, viz., 120 tons. Certainly there was a lighter weight, but after all, all that was saved was coal. Of course a little was saved, but with the heavy roads put up in London to satisfy the Board of Trade, he did not think it mattered quite so much, and therefore it was hardly necessary to aim so much at lightness. Although on an elevated railroad of girder-work construction there was very little doubt the motor-car had a great future before it, yet coming down to mother earth, it was doubtful which would win in the long run; but in deep-level tunnels he could not see there was any great possibility for motor-cars. Mr. Hudleston.

Major CARDEW said that the first point he wished to refer to was with regard to the signalling arrangements. He certainly agreed with what Mr. Basil Mott had said, viz., that the advanced starting signals which had been put in on the Waterloo and City line were not altogether judiciously placed, and that an outer home signal would have been much more effective; in other words, a train could have started from Waterloo before another train had absolutely reached the other end, as soon as it got under the protection of the outer home signal. He thought the advance starting signals were too close to the starting point. A great thing in the switch-back arrangement was that the driver, when he had started, should know that he had a clear road before him, to take advantage of the acceleration down hill. If he had to be continually keeping his train in hand he lost a great deal of that advantage. In the particular case of the City and Waterloo Railway, the curve had to be taken into consideration. He did not want to be critical, but there was one thing which he could not understand, with regard to the signalling arrangements, where Mr. Jenkin had said that owing to the nature of the line it was not possible to fix catch-points anywhere, and a substitute had to be found to prevent Major Cardew.

Major Cardew. accidents should a train pass a signal when at danger. He did not quite understand what Mr. Jenkin meant by that, because it did not seem to him to be the ordinary use of catch-points. Whether Mr. Jenkin meant that a catch-point would be set to take a train if it did go past a signal at danger he did not know. With regard to the controlling arrangement, the use of four motors in series had been adversely criticised. That appeared to be a very useful arrangement. It was true that it did not save much energy in the run, but it did save the starting current; and as, in that case, there were only very few trains running at that time, any means by which the starting current could be reduced was of great importance with regard to the amount of power plant to be put in at the generating station. The four motors in series obviously gave the same starting torque with half the current that would be required if they were started with the two in parallel. With regard to the lighting arrangements, the Author had said that both at the stations and in the trains the lighting was extremely satisfactory. He had only been a few times on the line, but on those occasions there had been a noticeable variation; and he thought it was really worth consideration whether it was desirable to light lamps directly from the power circuit, considering the great amount of feeders that were required, when a railway was proposed to be worked in which heavy currents were to be used to maintain sufficiently good uniformity of potential. That was a source of rather unnecessary expense, and probably it would be found better to resort to a few accumulators in the train to keep the lights absolutely constant. In the City and South London the lighting was decidedly objectionable on the starting of a train. With regard to the bonding, he noticed that it was extremely rigid, and possibly the Author would say whether any failure had been found owing to working with those rigid bonds. It certainly seemed that the running might have caused the rivets to loosen in places. With regard to the multiple-unit system, everybody was talking of it, and no doubt the system was a very pretty thing; but he thought it would be as well not to be in too much hurry to adopt the newest thing until it had been studied somewhat closely, and experience had been gained with it. It was not necessary to adopt a multiple-unit system in order to distribute the driving power over, say, a four-car train. In the present case two motors were placed at each end, but one motor might have been put on each car with the same connections as had been worked out, and the same controlling arrangement. There was the question, of course, of the wear of rails, which he understood had occurred to a considerable extent on the railway. Very possibly that might to some extent be due to pushing from the rear. If the driving power were distributed over the train, there must be certainly some pushing at high speeds, because the leading car was necessarily much more retarded than the others, and was retarded by wind and at every curve. It was the first to feel the retardation. Very possibly that might have something to do with the excessive wear of the rails. Major Cardew

Dr. A. B. W. KENNEDY said that in the very courteous remarks with which Professor Forbes opened the discussion on the Papers, he said, quite rightly, that there was not much that was novel or remarkable about the electrical part of the Waterloo and City line. At the same time, if anyone would take the trouble to compare the conditions of that railway with the conditions of any other railway that had yet been built, he would perhaps be surprised to find how very different they were from the others, and therefore how very largely the whole matter had to be thought out and worked out for itself. Without dwelling on all the points of difference, there was one he would particularly like to mention. Most people thought of an electric-traction load as a very evenly distributed load, and one, therefore, which might be very cheaply supplied with power. That was absolutely true when dealing with very large traction systems, having very large numbers of tramway cars running simultaneously. In the present case the load was singularly unequal, and therefore uneconomical. Mr. Jenkin had some lantern slides which he would exhibit when he replied to the discussion, showing an average diagram of the load on the line during ordinary work. He thought he might put it shortly thus, however, without the diagrams, which could not be shown at that moment. A train ran in each direction every 6 minutes, and every 6 minutes during the day the load curve was as nearly as possible a reproduction of the 24-hour load-curve of an electric-light station. Now, when the great hump or peak occurred once in every 24 hours, the working could be made fairly economical, because engines could be put on as the load increased to work the part of the plant that was working pretty much up to its full load. But he need not point out that when those variations occurred about every 6 minutes, the same engines had to work nearly all the time, and, therefore, the load factor of the plant actually working was very low indeed; he thought on that line it was 33 per cent., instead of the load factor of 70 per cent. or 80 per cent. that was found in electric-light works, and instead of the Dr. Kennedy.

Dr. Kennedy. almost uniform load for hours together that was obtained in any big traction scheme. In a line of the kind referred to, with a small number of very heavy trains, there were conditions of working which were perhaps the least uniform and the most subject to all the economical drawbacks which came from variations of load. As to the general arrangement of the train, about which a good deal had been said, he thought, on the whole, although he did not entirely agree with him, that Mr. Hudleston had very fairly summed up the matter. It was a question in a line like the Waterloo and City, an underground line, between the use of locomotives and the use of motors at the end of the train. He did not think the Sprague system, enthusiastically as it had been advocated by that gentleman's friends, would meet the case. The Sprague system in Chicago was quite a different matter, being on an overhead line. The question, whether there should be motors at the two ends of the train, or whether the train should be drawn by a locomotive, was a very important and difficult one; one which could only be discussed on its engineering merits and with the recognition that there were advantages both ways. Some time after the Waterloo and City line had started there was found, as Mr. Galbraith had said, in two or three places, but only locally, excessive wearing of the rails. There was much difficulty in finding out the precise cause of this wear, and it was suggested that it must be due to the pushing action of the two motors at the back of the train. When it was pointed out that the same thing ought then to happen on the Liverpool Overhead Railway, the reply was that there were no bad curves there and the trouble was not felt. In consequence mainly of that feeling, the South Western Company had ordered a couple of locomotives which they were going to try on the Waterloo line. They would not, he thought, replace the motor-cars, but, as far as they went, they would work a couple of trains. But, chiefly in order to see how far there could be anything in the idea, certain experiments had been made. Each train, it would be remembered, consisted of four coaches; a motor-car, two trailers, and then another motor-car. A train was separated into two halves, the first half consisting of a motor-car and a trailer, and the second of a trailer and a motor-car. The halves were then taken through the tunnels, the first half, of course, pulling through the up-tunnel and pushing through the down, and the second half pushing through the up-tunnel and pulling through the down, and the most careful measurements were made of the power used on the journeys.

The experiments were carried out at night, and were very carefully conducted, the same drivers being used throughout, and the measurements agreed wonderfully well. Mr. Jenkin probably could afterwards give the figures in his reply, but, speaking generally, the actual difference between the power required in the pushed and in the pulled train was about $1\frac{1}{2}$ per cent.; in other words, it was far within the limits of error of observation. Therefore no additional resistance appeared to be due to pushing round the curves. He confessed that this was contrary to what he had himself expected, but sometimes one had to take facts as they were found! He was very much interested when he was in America last spring in seeing that the Westinghouse Company, who were arranging to work the New York Elevated Railways electrically, had schemed for their train on that line a four-coach train with motors in the front and the back coaches, exactly as was being used on the Waterloo and City Railway. He felt very happy to think that for once, at any rate, the very latest idea in America was, perhaps, not absolutely in front of what had been done in this country. In one respect, however, that train was much in front of the train here. He was very much impressed with the arrangement the Westinghouse people had schemed for the management of their controller from either end of the train, without the use of the cables which were taken from one end of the train to the other on the Waterloo and City Railway, and which undoubtedly, as Professor Forbes and other speakers had pointed out, constituted a drawback. If the Westinghouse arrangement had come into existence earlier, he would have considered very seriously indeed whether that was not the proper arrangement for the Waterloo and City Railway. He need not describe the system; it had been described in print; but it seemed to be a most mechanical, well-thought-out arrangement, and the best that he had seen for that particular purpose. As to the working of a line under the particular circumstances of the Waterloo and City Railway, he suggested long ago, and he believed the suggestion was being carried out, that during the light-hour traffic, which lasted from eleven in the morning to four in the afternoon, when nobody required to go from Waterloo to the City or from the City to Waterloo, it would be best to carry a simple tramway traffic from one end to the other, namely, to have a one-coach train. He believed that arrangement was likely to be carried out, and he was sure it would be much more economical than running a very large train for such a very small number of passengers. There again the Waterloo and City Dr. Kennedy.

Dr. Kennedy. Railway was unlike anything else. There were no tramway lines, happily for the tramway companies, in which the whole of the traffic was concentrated into a couple of hours in the morning and a couple of hours at night. As to the sad question of speed on the curves, he cherished a kind of lingering hope that Sir Francis Marindin would go down to the line and go round the curves quite privately, and then tell the Company that he was willing to allow a greater speed. Some of them certainly had been round the curves at 25 miles or 30 miles an hour (not with passengers), and they had found themselves quite as happy at 25 miles as at 15 miles. His friend Mr. Galbraith indeed always said he liked it very much better. No fault could be found with the Board of Trade for their decision in the matter; it rested entirely with them, and they were responsible to the public in the matter of safety, and must do what they thought right. But he hoped, after the experience that had been obtained, that the rule with regard to the present limited speed might be relaxed, as it would be to the great advantage of the line from the engineering point of view. Mr. Francis Fox had alluded to Sunday work. Dr. Kennedy was a confirmed idler himself, and objected to Sunday work, or any other work he could help, and he did not want to make people work on Sundays! But he thought that if civil engineers did not want people to work on Sundays, they should seek in designing lines to make their tunnels of a proper size, and not tie the electrical engineers down to 12 feet. There were considerations of expense no doubt; but leaving for a moment all such considerations on one side, he would like to see all the tunnels big enough to take ordinary rolling-stock. Then one could get along them at any time, and attend to them at any time, to a limited extent. He need hardly point out that in the Waterloo and City tunnels, and still more in the 11-foot 6-inch tunnels, no human being could live while the train was moving. He had been in the tunnels and tried to get round a coach which was standing still, and even that was a very uncomfortable proceeding. Of course absolutely no work of any kind could be done during running hours. If a man had to go to the sump in the middle of the tunnel, the train stopped to put him down there, and he waited in the recess until another train picked him up. Nobody could look at a rail or sleeper, or do anything whatever, except late at night or on Sundays. Whether the absence of Sunday work would be a sufficient inducement to the people who found the capital to put in big tunnels he did not know!

One thing about the Waterloo and City electrical station, as it affected particularly himself, he would like to mention. The line was being run with high-speed engines and direct-driven dynamos. He did not for a single moment suggest that high-speed engines were better than any other kind of engines; on the other hand, he absolutely denied that any other kind of engines were better than high-speed engines, and he wished to stick to that point. He had had the pleasure of examining a great many stations in America, and was much struck with them. He saw many things that pleased him very much; but one of the things that did not please him was the engines. The state in which big engines by very noted makers were, after they had been running 2 years or 3 years, was not such as he would have felt proud of had he been one of the makers. The space they occupied, as it seemed to him quite uselessly, was also a drawback which, to his economical Scotch mind, seemed a very serious matter indeed. If exactly the same result could be got in about a quarter of the space, and he ventured to think that it could, it meant an enormous saving. Whether an engine of 3,000 HP., 4,000 HP., or 5,000 HP., could be run at what was called "high speed," he did not know. But within the last fortnight he had had a 1,200-HP. engine running at 230 revolutions put to work in Edinburgh. The engine had never been connected up to its dynamo before; it was put down and was lined up with the dynamo, and the two were coupled up and started. They were running on circuit about a couple of hours after they had been started, and had run on circuit every day since. He thought that was a pretty good experiment in the way of high-speed engines on a fairly big scale. But what he particularly wanted to emphasize was a thing he had often said in that room before—that the scheming of a traction station was simply a matter of common-sense engineering, just like all the work engineers had to do. There was no fetich about one particular kind of engine or one particular dynamo. If mechanical engineers used their own common sense as to how to proportion their engines and govern them, a perfectly satisfactory result might be arrived at in a great many different ways. As far as that was concerned, he claimed from the year's experience in connection with the railway that they had arrived at an extremely satisfactory result under some difficult circumstances with the plant that had been put up. He was a little amused at some remarks of Professor Carus-Wilson that the Waterloo and City railway officials were afraid to overload their motors, or something of that kind. The fact was he Dr. Kennedy.

Dr. Kennedy. did not believe any one on the Waterloo and City Railway ever cared an atom what the loading on the motors was. They just made them run for all they were worth whenever they wanted them, and they had never given any trouble. The speaker seemed to have an idea somehow or other that they were to be treated like new-born babies, and taken some very special care of. He hoped they had been well taken care of, but he was bound to say it never entered into the idea of anyone that they should not be overrun! Indeed he thought they had been overrun constantly in very important respects.

In the annexed Table the first column referred to the City and

—	—	City and South London.	Liverpool Overhead.	Dublin Tramway.	Waterloo and City.	Central London.
		Non-condensing.	Condensing.	Non-condensing.	Non-condensing.	
1	Coal per unit generated (actual) . . Lbs.	8·4	6·4	9·6	8·6	
2	Coal per unit generated (Welsh) . . Lbs.	7·5	4·8	9·6	7·1	
3	Weight of train loaded Tons	40	38	10·8	105	150
4	Number of cars in train	Three and locomotive.	2	1	4	Seven and locomotive.
5	Number of seats in train	96	114	53	204	336
6	Average speed without stops	13·5	15	8	14	
7	Units per train-mile .	3·35	2·66	0·99	4·39	
8	Units per car-mile . .	1·67	1·33	0·99	1·1	
9	Watt-hours per ton-mile	83·8	70·0	91·7	41·8	
10	Seats per ton of loaded train	2·4	3·0	4·9	1·95	22
11	Watt-hours per seat-mile	34·6	23·3	18·7	21·4	

South London Railway, and the figures were taken from a Paper read before the Institution a long time ago. Mr. McMahon could now probably give some different and better figures. In the second column were the figures of the Liverpool Overhead, which were also taken from a Paper read before the Institution, as were the figures in the third column in connection with the Dublin Tramways. The fourth column contained the figures of the Waterloo and City Railway, and in the fifth column a few figures relating to the Central London Railway, obtained from such information as had been published, had been put in for comparison. He would be much obliged if Mr. Hudleston would correct them, or add a few more, if necessary. The first lines were merely a question of coal per unit. The Liverpool Overhead was working condensing, and the figures showed very much the best of the four. The other three were not so very different. The total weight of train loaded came in the third line; the Liverpool Overhead and the City and South London were both light, and the tramline was only one-tenth of the Waterloo and City line. Then followed the number of cars and so on, the number of seats in the train, and the average speed. He thought the figures below that were figures of some little interest. In line 7 were given the units used per train-mile, which varied from 1 unit on the Dublin Tramway, as was not uncommon on lines of that kind, up to $4\frac{1}{3}$ units on the Waterloo and City line. If the units per car-mile were taken, treating the City and South London as being two cars, not counting the locomotive, it would be seen to come out at 1·67, while the Liverpool Overhead was 1·3. The trams and the Waterloo and City were practically 1 unit per car-mile, or counting the locomotive on the South London as being a car, they all came to about 1 unit per car-mile. The watt-hours per ton-mile were somewhat interesting, because one was rather surprised at the last two figures. The very high number of watt-hours per ton-mile corresponded, not unnaturally, to the very light weight of the train. It might have been thought that it would come the other way round. In that particular matter the Waterloo and City had a very low figure. Line 10, giving the number of seats in the train per ton of weight, was also a matter of considerable interest; the South London and Waterloo and City were not very different, although of course in the South London the weight of the locomotive came in. The South London gave 2·4 seats, the Waterloo 1·95. The Liverpool Overhead was higher, and naturally the tramcar was higher still, that was, they had more seats per ton of train. The watt-hours per seat-mile went naturally the other way, in a somewhat interesting fashion. The watt-hours per seat-mile on the City and South London was 34, the Liverpool Overhead and Waterloo and City 23 and 21, and the Dublin tramways 18. He thought when the members had leisure to look at those figures, it would be found that they contained a good many interesting suggestions, and he left the members to discover some further units. In reference to the switchback system, he had had occasion to work out its results in connection with other lines, and they seemed to him to be so extremely advantageous that he was rather surprised the system had not been more generally adopted in cases where the surface of the line was normally level, but where, at a very small additional expense, the line might be made to dip

Mr. Kennedy.

Dr. Kennedy. between each pair of stations. Anyone who took the trouble to work out in detail the results to be obtained by helping the acceleration by gravity and braking by going up-hill would find out how very advantageous it was.

Mr. Heap. Mr. D. T. Heap said that at Dr. Kennedy's request he had pre-

Fig. 2.

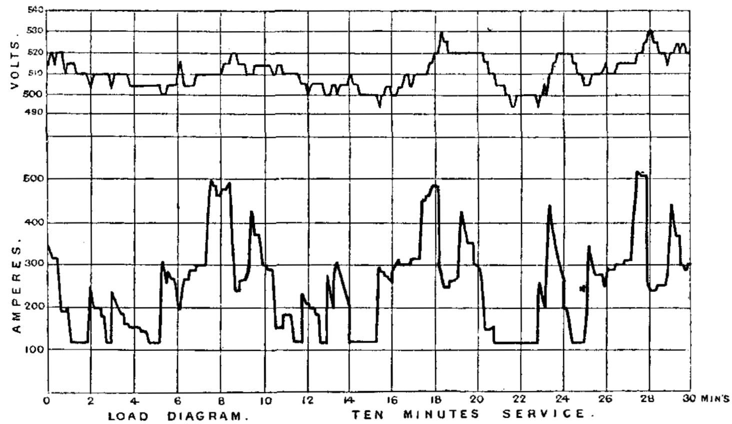
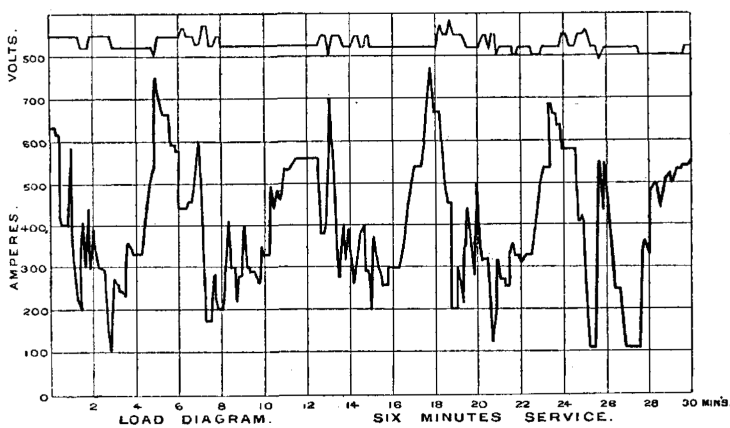


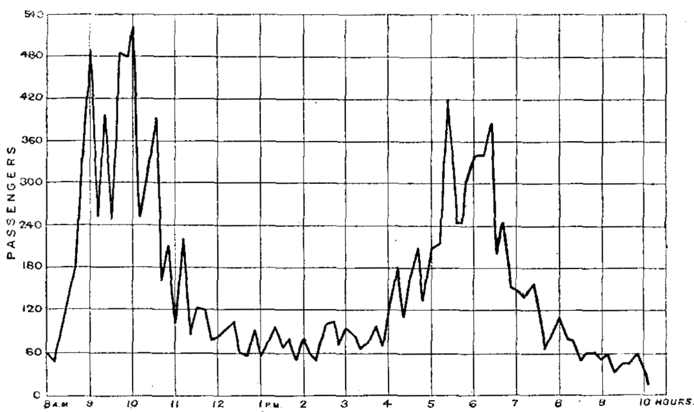
Fig. 3.



pared three diagrams, showing variations of load on the six-minutes service and the ten-minutes service. *Fig. 3*, in which three engines were used, showed the difference due to a six-minutes service. In *Fig. 2*, where only two engines were used, the compounding effect of the machine was shown fairly clearly. *Fig. 4* Mr. Heap. was the passenger-load diagram. During the middle hours of the day, from 11·30 to about 4 o'clock, there were very few passengers, the bulk being carried in the morning and evening. The diagram showed the number of passengers at the different periods of the day.

With regard to the motors, he thought the chief drawback had been that they could not be paralleled; if that could have been done a very different arrangement would have been made. The specification of the motors stated that the speed of the trains on the 5-chain curve was not to exceed 24 miles per hour, and they could only just be paralleled at that speed. He thought they

Fig. 4.



PASSENGER LOAD DIAGRAM.

should have paralleled at about 15 miles an hour. With regard to the official test referred to at page 91, when that was carried out the railway had only been running about five months, and therefore the discrepancy between the drivers was very natural. At the present time an effort was being made to bring them up to some standard and the results were more satisfactory; but the amount of current taken was not entirely due to bad driving. For instance, on the up-road on the day of the test one man took 3·7 units, and his speed was greatly in excess of that allowed by the Board of Trade; another man on the same day took 5·5 units, but his speed was 15 miles an hour over the 5-chain curve. That accounted to a great measure for the difference in the units taken by the men. It was intended to adopt the bonus system mentioned

Mr. Heap. by Mr. Monkhouse, as no doubt advantages were to be gained by it, from the point of view of both the men and the Company. With regard to the whole-day test he thought Mr. Jenkin had forgotten to mention that he had not included the coal and water used by a fourth boiler that was supplying steam to all the steam auxiliaries, which amounted to something like 10 per cent. of the total steam used. With regard to the method of bridging over the running rails in the cross-overs, the arrangement described in the Paper had not proved at all satisfactory for the simple reason that the distance between the ends of the conductor rails was excessive, being something like 44 feet. It was being altered and carried out on exactly the same lines as on the Liverpool Overhead Railway in 1894, that was, the conductor rail was taken up to the running rail and run parallel with it. The only drawback was that the clearances were very small—there was not an inch between the lowest part of the motor-car and the conductor rail. The motors were running very well indeed. The sparking was slight, but of course they were only being run two in series in parallel with two in series. Few complaints were received with regard to the lighting; in fact, everyone remarked how satisfactory it was both in the trains and in the stations. The effect of switching on a train in the City station was so slight that an ordinary passenger would not notice it. With regard to the bonding, several bonds have been cut out at different times, mostly for renewal of rail, and in no case had he found the rivets slack. They were perfectly good.

Mr. Siemens. Mr. ALEXANDER SIEMENS desired to refer to points which had been mentioned regarding the motors on the Waterloo and City Railway. Experience on the City and South London had shown that the trains were much heavier than was contemplated in the specification, and all the trouble experienced on that railway really arose from that fact. Being well aware that history was liable to repeat itself, when his firm had to design the motors for the Waterloo and City Railway they did not count on trains weighing 70 tons, but anticipated that the weight would be exceeded, and for that reason they made the motors much stronger than they need have been for a train weighing only 70 tons. He did not understand Professor Carus-Wilson's pity for the motors which were so very heavily overworked, nor his statement that the proposal to reduce the voltage to 400 volts was a proof that the motors were too weak. He thought it was a proof that the motors were amply strong enough. The circumstances under which the reduction in voltage was proposed were perhaps

Mr. Siemens.

interesting. The plan of the railway showed that there were—he hoped he was only using a parliamentary expression—some atrocious curves. Those curves totally spoiled the railway, and should be a warning to all engineers in future, when their directors advocated economy in first outlay, to resist them, and not to do what Mr. Galbraith said the engineers had done in that case—to avoid some private property—inserted a 5-chain curve on a down gradient. That spoiled the running of the train in two ways: first, the Board of Trade objected to the trains running at more than a certain speed around such a curve, and, secondly, the curve obstructed the signal which was in the middle of the railway at the dip. He thought Dr. Kennedy had mentioned that when the driver started from Waterloo he did not know whether he could run straight to the City or not, the consequence being that he dared not let go his train as much as the Board of Trade would allow him, and he had to hold it back, and thereby the speed necessary to put the four motors in parallel was never really attained in the regular working. It had also been explained by Professor Carus-Wilson that to have three different steps in the regulation really only amounted to a saving of 2 per cent., or something like that; but only two steps were actually used. At starting the four motors of the train were connected in series and then they were connected two in parallel and two in series. But the speed never reached 23 miles an hour, sufficient to allow the four motors being thrown in parallel, and that was the reason why the service was comparatively slow. During the experimental runs, when there were no passengers in the trains, but the trains were loaded with weight to represent passengers, and there was no Board of Trade official present, the trains were run through at full speed, as was intended, and there was no difficulty in reaching the City from Waterloo, and *vice versâ*, in $3\frac{1}{2}$ minutes, certainly in 4 minutes. So that the motors and the present plant were perfectly capable of giving a 5-minute service at the least, and he would not be afraid of maintaining a 4-minute service between the two terminals, only the Board of Trade and the signals would not allow it. The so-called Sprague system, in which each axle in the train had a motor, and each car was independent of the others, the regulation being effected automatically by an auxiliary motor on each car, had also been mentioned. In judging such a system first principles must be relied upon. What was the aim an engineer ought to have before him when planning the working arrangements of such a railway? Clearly before the speed in the service it was the safety of the

Mr. Siemens. passengers and the certainty to them of reaching the other end. Therefore all arrangements ought to be made as simple as possible. The Sprague system, however, introduced the auxiliary motor, and although it was said that the moment anything went wrong with the signalling arrangements, or the current was interrupted, or the like, all the auxiliary switches cut off the current automatically, he could not imagine that that arrangement was quite so safe as the controller, which the driver had under his own eye and hand, and which was supplemented by one of those automatic cut-outs, which could be used also by hand, and which enabled the driver to cut off the currents entirely from the train when he wished to do so. That arrangement, to his mind, was so very much simpler and safer, that the Sprague way of governing these electric trains ought only to be adopted where there was a special reason. For instance, in electric railways which divided into branches, where it was desirable to make up a train or split it up quickly, so that the portions coming from different branches could be joined together at the junction without loss of time, and disjoined when they came the other way, the Sprague system had the great advantage that it enabled each car to run on its own branch, and at the same time join on the main line the general train; and that he should think was a very good system. But where a train had to be left coupled together he did not see that it had many advantages, and he was not even in favour of the Waterloo and City arrangements, where there were motors at both ends of the trains. It was difficult to decide where the shoving ended and the pulling commenced, and it might give rise to difficulties in more complicated lines, although he did not think it would do so on the present line. Another speaker had referred to the miserable two-pole machines, and had mentioned the 20-ton fly-wheels which were used at the generating station, holding up the multipolar machines as very much more mechanically constructed and preferable in every respect. The large units of multipolar dynamos in the United States had 60-ton fly-wheels, in addition to the armature which acted partly as a fly-wheel, and therefore the fact of using a multipolar machine did not do away with the necessity of a fly-wheel, and the reason which the speaker in question brought forward for condemning two-pole dynamos was completely irrelevant. On the other hand, the fly-wheels on the Waterloo and City Railway were made rather heavier than was absolutely necessary, but the engineers were anxious to avoid the fault of the City and South London Railway, where the passengers complained so bitterly that they could not read on account of the

Mr. Simens.

lights being so much influenced when the trains were started. As Dr. Kennedy had already pointed out, the Waterloo and City Railway worked under the most unfavourable conditions for steadiness. There was practically only one train starting at a time; shortly after starting it shut off all current, and afterwards a great deal of current was necessary to ascend the incline towards the other station. To meet those exceptionally unfavourable conditions the fly-wheels were made extra heavy, and he thought it was tolerably certain that the lights on the Waterloo and City Railway left nothing to be desired. Some speakers also had criticised the English practice of not making use of three-phase currents; but as it was necessary to have different speeds and to regulate them, a very much more complicated regulating device was required for three-phase motors than for continuous-current motors, and, as had been stated, there was a certain speed at which three-phase motors were most efficient, and at all other speeds they were very much the reverse. That, again, brought up a general point, namely, that each electric system, whether continuous-current, three-phase, alternate, two-phase, or whatever it might be, should be used in its proper place. It was at once a sign of weakness if one thing was recommended for every case. The Americans themselves had shown that they knew that sometimes a continuous-current was better. A project had been published with regard to working the Berlin Metropolitan Railway by electricity, and the engineers proposed to erect two generating stations about 8½ miles apart, and they said that if they took a conductor equal to 2 square inches of copper, then they could do away with all feeders, sub-stations, and transformers, and could use the current at 500 volts on the carriages and do away with all the complications which a three-phase system required, namely, transformers up and down and transformers to transform the three-phase current into a continuous current. He had referred to the subject at length because a general reproach had been made upon English engineers that they did not take up the three-phase current as it had been taken up in other places. The answer was that they were perfectly willing to adopt a three-phase system wherever it was really of use, but to recommend it through thick and thin would be a mistake. In the case under consideration he was quite sure that the direct-current system was the best that could have been used.

Mr. Thomas.

Mr. Eustace Thomas remarked that the Waterloo and City line presented unusual difficulties arising from the exceedingly large variation of current due to there being only two trains in service

Mr. Thomas. at any moment, with perhaps one train shunting. It was gratifying to English engineers to find that the high-speed engine employed, which was certainly more perfect than any which had been produced in other parts of the world, had proved satisfactory under such difficult conditions. But in the report of the 1-day test he noticed that there were three sets running for the heavy morning load, when there was a 6-minute service. Each of these indicated 360 HP., and would give about 220 kilowatts; the three together would therefore give about 660 kilowatts. But in a Table at the end of the Paper it was stated that the momentary observed load only reached 330 kilowatts, while the average load was about 200 kilowatts. It was rather extraordinary that three sets should be run when the maximum power required did not reach more than one-half of the total power thus provided. Later in the Paper it was stated that during the evening there were only two sets running for the same load, so that it was apparently possible to run with two sets. He understood, however, that the general practice was to run with three sets, which showed some want of confidence, probably in the smooth core generators. He did not see how an engine which governed on the throttle-valve could be expected to give the best results with such fluctuating loads. Such an engine necessarily gave its maximum economy at the highest load. In a case like the present, where the load factor was sometimes about 30 per cent., the engines must on the average be working far from the most economical condition. High-speed engines did not necessarily govern on the throttle, and those which, like the usual type of slow-speed engine, governed on the cut-off, must necessarily be more efficient for the average load than the engine which had been employed on the Waterloo and City line. Generally it was specified that an engine for traction work should carry a maximum load of some 40 per cent. or 50 per cent. in excess of the most economical load. The result was that the most economical load could be made very nearly the average load, and this the more easily as the number of trains in use became greater. If only the number of trains became great enough, the average load was very nearly constant, and the fluctuations were little above or below the actual average value. He hoped that Messrs. Belliss, who had made such perfect engines in other respects, would soon modify their method of governing for traction work. He did not think all this held to the same extent for lighting, where the load was more steady, but even there the tendency seemed to be in favour of having engines which would give considerable overload beyond their most economical load, to meet the peak in the evening with greater ease and without the employment of so much plant. Mr. Thomas.

In regard to the controller, the general arrangements of the interchangeable handles, the inter-locking, and the locking of the handle when one motor was cut out, and so on, were similar to those which had been employed most successfully in traction experience for the last 8 years or 10 years; but the arrangement of the controller for three running points was peculiar. The connection of all the motors in series was really of little value except for shunting purposes. It was of most value in such a case as that of the Waterloo and City line, where there were only two trains in service at one time, and the fluctuations were exceedingly large. The arrangement by which the current was made and broken always at a special contact, seemed complicated. The controller was rather like a small house at the end of the train. He had in his mind very much smaller controllers used on far larger systems. The greater size of the controller was due, first to the special switch for sparking, which was necessary, as other methods were not open to the greater number of manufacturers, and secondly, to the arrangement of the controller for connecting all four motors in series as an extra running point. It appeared, too, as though the great size of the controller had prevented the designers from using enough resistance-steps in going from the two-series two-parallel position to the four-parallel position. It was extraordinary to find there was only one resistance-step for this change, and it explained the impossibility referred to in the Paper of getting the motors all into parallel when running up the incline into the City. As to the motors, the Paper stated that they were specified for a maximum BHP. of 60, and a maximum full-load current of 100 amperes. He noticed that Dr. Kennedy had stated that that condition had not been carried out, since the motors were capable of taking much larger currents. This was brought out in the Paper itself, where, at times, the motors were indicated as taking 150 amperes. The specification was difficult to understand, since a current of 100 amperes would only give, on the weight of the train first estimated, something like 46 lbs. draw-bar pull per ton with the motors as actually made. Such a value, after allowing for changes from the specification, would seem to imply the assumption that everything was to work absolutely without a hitch, and that the inclines could always be made full use of. But if any hitch were to occur to cause the slowing down at the curve at the bottom of the line, it became very difficult to get up the incline at the far end.

Mr. Thomas. From the dimensions of the motor, he would have judged that it ought to take with perfect safety a current of 200 amperes for accelerating purposes. The curve for the motor did not show very clearly what draw-bar pull would be obtained at 200 amperes, but it was certain it would be such as to enable a very decent acceleration to be obtained of, say, ½ foot per second per second, or more than that, even when one was upon a 3 per cent. gradient in running up to the City. He did not think the design of the motors was quite up to the most modern lines. The number of slots was altogether different from what would be expected according to modern experience, and that perhaps might account for the fact that there seemed to be an unreadiness to employ quite as much current in the motors as would be best for the rapid acceleration wanted on account of the slowing down at the curves. It was extraordinary that the arrangements did not admit of the motors being thrown into parallel after the slow down at the centre of the line. This would be easily understood, however, when it was remembered that there was only one resistance-step between the last two running points. If the controller had been designed in the more usual way with some four or five resistance-steps, he did not see why, with a motor of that size, it would not be possible to obtain its full range. With regard to the motors generally, the whole of modern practice went in favour of making them capable of standing exceedingly heavy currents without damage from sparking, in order that a very rapid acceleration might be obtained at first, of perhaps 1 foot or 1½ foot per second per second. This would enable a given scheduled speed to be maintained with a low terminal speed and increased economy. In such a case the motors would be cut out of circuit a very short time after the train had started, and the train would coast the rest of the way. Such a method of operation was here possible, but to a modified extent, on account of the heavy gradients.

It seemed that all electric tunnel lines suffered under certain very great disadvantages. He was a passenger upon the Waterloo and City line every morning, and therefore he had considered the railway not only as an engineer but as an ordinary passenger. There was frequently an interval before the gates were opened to let the passengers on to the station. Then afterwards there was a longer wait at the door of the train itself while the passengers saw another train going out, and then there was a heavy crush before one was able to get into the train. These were evidences of the need of such a line; but experience showed that passengers objected to the waits more on underground than on open-air railways; and many deserted during the summer to be driven back by the fogs in the winter. If it were desired to make such lines a success, it appeared to him that the engineer who was laying them out would have to look first to giving the greatest possible convenience to the passengers. If it were arranged that there should be easy access, the most comfortable cars possible, short waits, such car entrances that people would not have to crush to get in at the doors, thoroughly good lighting, and a rapid and frequent service of trains, he thought such lines would be a complete success; but without these conveniences he thought a good deal of the success otherwise possible would be lost. Others present besides himself had experience of street railways which at one time would not pay at all, but which, by the introduction of more capital and by the employment of far more rapid services and much greater conveniences, had been converted into thorough financial successes. There were a number of such cases of tramlines in this country, and he was quite satisfied that the conditions which held for the street lines held still more strongly for those constructed underground. Mr. Thomas.

Sir A. R. BINNIE spoke with some sense of the responsibility of the work with which Mr. Dalrymple-Hay's Paper dealt. It, in conjunction with another Paper by Mr. David Hay and Mr. Fitzmaurice,[1] epitomised in the clearest and most distinct manner the knowledge up to the present time of tunnelling by compressed air, and under difficulties when it was not necessary to use compressed air. The different forms of shields had been described, and he thought a little misapprehension had occurred in the course of the discussion in respect of excavation being carried outside the shield. He thought that to which some of the members had alluded was excavation carried, as was shown in some of the diagrams, in advance of the shield. All who had had to do that kind of work were unanimously of opinion that the more rapidly the work was pressed forward, the less risk there was of settlement. Hence had arisen the attempt, so ably described in the Paper, to introduce a hood to the front of the shield to reduce the sloping face on which the miners or excavators might work to a practicable limit, somewhat approaching the limit of least resistance or the angle of repose. With regard to that, he certainly had not made up his mind as to what was the best, for, looking back at the earliest attempts at using the shield under Sir A. R. Binnie.

[1] Minutes of Proceedings Inst. C.E., vol. cxxx. p. 58.

Sir A. R. Binnie. difficult conditions—the most difficult—it was found that the elder Brunel, in attempting to grapple with the difficulty, proposed two expedients. In his patent, in 1830, he divided his circular shield into two portions, the lower and the upper portions, disconnected from each other, but one sliding upon the other so that the upper portion could be pressed forward as the excavation proceeded, and would be followed in due course by the lower portion. For reasons which all could understand, that system was not adopted by Brunel when he came to encounter his difficulties at the Thames tunnel; but the general idea was adopted, and was carried out, that the different cells of his great shield under the Thames had independent movement, and could press forward independently of their right- or left-hand upper or lower members. That was one way of dealing with excavation under the most difficult circumstances. He looked upon the Paper, as a whole, as one most valuable to the Institution, pointing out, as it did, the real difficulties which surrounded that kind of work; and, whether they liked it or not, engineers were bound as a profession to look very largely to that mode of underground communication, for there was no doubt that the traffic overhead in the streets and on the railways was becoming greater than the facilities of actual space would afford. Looking, therefore, to the Paper, what was the most striking inconvenience described? Great credit was due to the Authors of both Papers for the candour with which they had laid before the Institution not only their successes, but the difficulties which attended the construction as well as the working of the line. Clearly to anyone who had had any connection whatever with railway work, whether the trains were propelled by electricity or steam, the first thing that was striking was the introduction of the very awkward curves and the somewhat severe gradients—in some cases the gradients and the curves coinciding at the same unfortunate position. He had had, as the President was aware, to look into those matters in his official capacity, and he could not but think that the authors and projectors of such lines had been somewhat remiss in following the dictates of the highest authorities in the country—he spoke with all respect of a Joint Committee of both Houses of Parliament who, sitting a few years since, laid it down as a dictum that in the future railways might be projected under private property without purchase of the surface, with a mere payment to the occupiers of the surface for any damage caused by the line. It was a matter perfectly familiar to anyone who had to do with the main drainage of the Metropolis that, under the General Law of 1885, a sewer might be made anywhere, under any property, the only obligation being that compensation had to be made to those on the surface for any damage which might be done. Then he would refer to the Acts of Parliament which had recently been passed. They all knew, and had felt very severely in their younger days, those limits of upward and downward deviation which were imposed upon them, either by the Orders of Parliament or by the local authorities through whose districts they passed. But see in what an Elysium the underground railway existed. It could not extend itself upwards more than the sanctified 3 feet or 5 feet in level; but downwards there was no limit. He could not but think that engineers, in laying out the lines, were somewhat in the position of those timorous bathers to be seen on the sea-shore, who had stripped and adorned themselves in bathing costumes, yet hesitated before plunging into the briny deep. He would ask all his friends to look at the question from a purely engineering point of view. What did it mean? There was the 150 feet, 200 feet, or 300 feet of London clay in which the engineer could go about and play as he liked without harm to anyone upon the surface. The gradients could be arranged as was thought desirable, and the curves become as flat as was wished, and really the only economical difficulty in the way was the question of the lifts at the station. He asked any engineer present to balance against the working of such curves and gradients as were seen in the diagrams the little expense that would be incurred in lifting passengers at the station through an extra 20 feet, 30 feet, or it might be 40 feet. It was a mere bagatelle in comparison. He looked forward to the time when the underground means of communication would be extended very much more largely; in fact, without them he did not see how the great subject of the dispersion and circulation of traffic in the ever-increasing multitudes that dwelt in the Metropolis was to be grappled with. His friend Mr. Galbraith had been kind enough to speak of the way in which he (Sir Alexander Binnie) had administered certain provisions of certain Acts of Parliament. He felt gratified for that personal allusion, but he could assure Mr. Galbraith that his own personal conduct merely reflected the ideas and the desires of the body which, in his official capacity, he represented. He could assure the Institution and every friend of the underground mode of communication that there was no body more anxious and more willing to assist that intercommunication and dispersion of traffic than the London County Council. But he must point out where his difficulty was, and where the difficulties Sir A. R. Binnie.

Sir A. R. Binnie. that Mr. Galbraith spoke of lay. They did not arise from the central body. They arose, as he painfully knew, from the splitting up of authorities throughout the municipality of London, the various vestries that interposed clauses in the Acts of Parliament, some of them totally incompatible with each other, and which the authorities at Spring Gardens had to endeavour to harmonise. In all the projects for the helping of the population of London, he looked forward with some apprehension—he did not say with dread—to the fact that in the future the difficulties of which Mr. Galbraith complained would be increased tenfold, for not only would bodies such as the present vestries be able to introduce clauses into an Act of Parliament, in many cases of a vexatious character, but they would be able to oppose schemes in a manner which, in the past, had been totally unknown in London. A great heptarchy was being set up which would prevent London from being used as a whole for the benefit of the greater number.

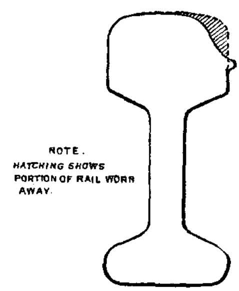
Mr. Segundo. Mr. E. C. de Segundo referred to the question whether for tractive purposes on underground metropolitan railways it was more economical to use power produced by a motor carrying its own supply-fuel or power transmitted to the motor from a generating station at some central point. In the case of steam *versus* electric traction the question resolved itself into whether the saving effected by the use of economical boilers and engines at a central point was or was not counterbalanced by the losses incurred in the various transformations of energy involved in transmission. Through the courtesy of Mr. Estall of the District Railway he had been supplied with the necessary figures to enable him to calculate that the coal-consumption per ton-mile on the District Railway for the 6 months ending June 30th, 1899, was 0·261 lb., including weight of engine. Taking the coal-consumption of the Metropolitan Railway from their published returns, and taking the figures given him by the Company as to the weight of engines and trains, the result was 0·317 lb. per ton-mile. He had included the weight of the passengers, at 140 lbs. each, and had assumed that the trains on the average were one-third full. If the weight of the locomotive were left out of account, the figures became—

On the District	0·382 lb.	per ton-mile of train (plus passengers) hauled.
„ Metropolitan	0·478 „	„ „ „ „
„ Waterloo and City	0·407 „	„ „ „ „

Under more favourable conditions of running, approximating to those on the Inner Circles for example, he considered it highly probable that electric traction might prove more economical in coal-consumption than steam traction. Mr. Segundo.

Mr. A. W. SZLUMPER wished to refer to the abnormal wear of the rails (*Fig. 5*). The first intimation of anything being wrong was the presence of a large quantity of metallic dust spread along the longitudinals and over the chairs. He had placed upon the table a little packet of the dust picked up; also a piece of worn rail. In a few months there was a notch cut out of the rail, and then it was decided that the time had arrived when the rail had better be renewed, because the tire of the wheels suffered to the same extent as the rail, and it was thought that, with the tire wearing thin and the notch in the rail, it might be possible for the tire to mount the rail. The points where the rail suffered were not only on the high rail of the sharp curves, but also at the tongues of the switches, and even on some of the flat curves. Three reasons had been advanced for the cause of the trouble: one was that the rails were probably suffering from the return current of electricity; another was that there was such a great amount of friction going on that the rails were fused. Those reasons were chimerical, and the cause generally favoured was that it was due to the shoving action of the rear motors. There was a heavy motor on each of the rear axles weighing 7 tons, dumped down upon the axles without the intervention of any springs, and it was probable that in going round the curves chisel-action occurred. Indeed, this could be traced on the rails, and also on the tires of the wheels. Mr. Szlumper.

Fig. 5.



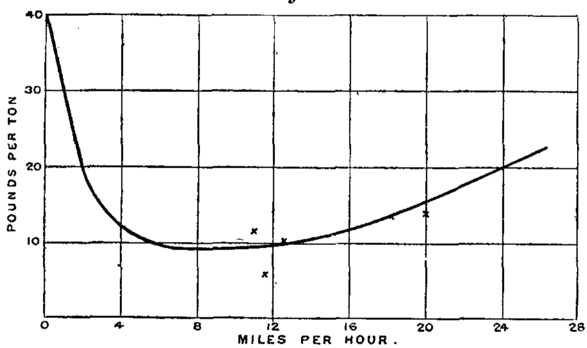
The signalling on the Waterloo and City Railway had been very carefully and elaborately considered, and the installation was about as perfect as any signalling could be. There seemed to be a little misapprehension about it. Mr. Siemens had stated that when a driver left Waterloo he did not know whether he was going right away to the City or not. That was absolutely wrong. There was a signal with two arms on the platform, and if the top arm was lowered it indicated that the driver could go right away to the City; if the lower arm was lowered it indicated that he could only go as far as the advance signal. Two gentlemen had mentioned that it was a mistake to have the advance signal where it was, and that it would be better to have an outer home signal. That was clearly wrong, because the advance

Mr. Szlumper. signals were practically central between the two stations, and when a train passed the advance signal another train could immediately follow from the rear station; whereas if this advance signal were done away with and an outer home signal were established a few hundred yards in front of the home signal, there would be very serious objections, because they would be both on gradients—at the City end on a gradient of 1 in 88, and at Waterloo on a gradient of 1 in 60, and if the train were pulled up there it would be a difficult matter to start again. Moreover, a train leaving Waterloo would have to pass right to the City before a second train could leave, whereas now the moment the train got about half way a second train could start. It would appear that the electricians wanted a scapegoat for their failures, and had selected, first the Board of Trade restrictions, then the sharp curves, and now, it would seem, the signalling.

Mr McMahon. Mr. P. V. McMahon desired to offer a few remarks by way of comparison with the results obtained on the City and South London Railway. On that railway all the motors were of the open type, and the only occasion on which a fault could be traced to this cause was when a lady's hair-pin was picked up by the magnet and got into the space between the armature and the field. The open type gave a lighter and cheaper motor for the same HP. The series parallel controller appeared very large, and it seemed to take about eight or nine turns of a wheel to get the four motors into parallel. On the South London Railway a series parallel controller had been developed which was now adopted as the standard. It occupied a space of 22 inches by 22 inches by 12 inches, and was capable of dealing with 300 amperes. These controllers had no magnetic blow-out or other spark-killing device, and some of them had run for 40,000 miles in actual everyday traffic requiring only the repair of a few contacts, costing a few shillings each. The Waterloo and City controller occupied a space of 4 feet 3 inches by 4 feet 3 inches by 4 feet. In reference to the advantage to be gained from starting with the four motors, this matter had been very carefully considered in the design of new locomotives for the City and South London Railway, and it was found that with a four-motor equipment there was very little advantage indeed to be gained by putting the four motors in series at starting, provided the motors were designed for the proper tractive force per ampere. Prof. Carus-Wilson had calculated that the loss occurring in the Waterloo and City motors, if they were not placed four in series at starting, was 2 per cent. The loss would, he thought, be greater than this on account of the low internal resistances of the armature. Gearing had been suggested as a remedy for some of the troubles, but with a higher tractive force per ampere the same results could be arrived at and all the difficulties of the gearing avoided. That was borne out on the City and South London Railway by the later locomotives that had been constructed. The older engines had an average speed of about 13½ miles an hour, and the energy consumption was 0·055 kilowatt-hour per ton-mile. The newer locomotives had nearly twice the tractive force per ampere, with the result that the average speed was 16·7 miles per hour with the same kilowatt consumption per ton-mile. Again, the kilowatt-hours per ton-mile given for the Waterloo and City trains, 0·047, seemed to be rather high when the length of the section was considered. There were nearly three sections on the City and South London for one on the Waterloo and City Railway, and as the energy required for starting was very large compared with that for the running, he thought it might be reduced, but perhaps the high kilowatt consumption was due to the motors coming down the incline on the brake. On the City and South London basis it would appear that some of the later locomotives would do the same work at about 0·0388 kilowatt per ton-mile. A comparison of the total weight per seat in the train was interesting. The Waterloo and City gave 1,000 lbs. per seat; the City and South London, with three carriages, including one of the lighter locomotives, was 710 lbs. per seat. These locomotives gave about the same speed as the Waterloo and City. The later locomotives were rather more powerful and heavier, and were intended to run a four-coach train. The weight of one of these locomotives and four coaches was 718 lbs. per seat, and the average speed would be about 16¾ miles per hour. He was unable to agree with Prof. Carus-Wilson that the low traction resistance per ton was due to the use of roller-bearings. The traction resistance per ton for speeds up to 26 miles per hour, obtained from some hundred thousands of observations on the City and South London Railway was shown in *Fig. 6*. The curve was the result of about fifty points. The tractive resistance per ton on the Waterloo and City Railway, calculated from the curve given in the Paper, *Fig. 22*, at 20 miles was 13·7 lbs. per ton; in *Fig. 24*, at 11 miles an hour, it was 11·9 lbs. per ton. In *Fig. 27*, the speed being 12·5 miles an hour, the tractive resistance was 10·25 lbs. per ton. The very low resistance to which, no doubt, Prof. Carus-Wilson referred was at 11½ miles an hour, that would be 6 lbs. per ton. It seemed that the tractive resistance on the Waterloo Mr. McMahon.

Mr. McMahon. and City was not far from that on the City and South London Railway. There must be an increase in the tractive resistance on the City and South London as compared with the Waterloo and City on account of the segments of the tunnel not being filled with concrete, as in the case of the latter, he would have expected the tractive resistance to be lower. Again, there were much smaller wheels on the carriages and locomotives of the City and South London than on the Waterloo and City line, and that would tend to make the tractive resistance higher. Tests had been carefully carried out with a train fitted with roller bearings and one fitted with ordinary bearings, and the results of eight trips showed that there was only a saving of about 5 per cent. in the power. The reason was very easily found. It could not be hoped to save anything on resistance due to the air, and when the very high

Fig. 6.



Traction resistance on City and South London Railway.
" " " Waterloo and City Railway plotted thus . . . ×

tractive force used per ton for acceleration was compared with the resistance due to the bearing friction, even allowing the theoretical saving claimed for roller bearings, the possible saving that could be obtained was about 9 per cent. With an acceleration of say 1·46 foot per second per second, about 100 lbs. per ton was used during the starting period, and, taking the average tractive resistance from the curve, up to 10 miles an hour, and allowing about 20 lbs. per ton for journal friction alone, of this assume 80 per cent. saved, then a possible saving of only about 7 per cent. was left for roller bearings.

Mr. Dalrymple-Hay. Mr. H. H. Dalrymple-Hay, in reply to the Discussion, said that elastic curves, such as Froude's, Gravatt's curve of sines, were not used because shields, being continually on the move and the tunnels having to be erected in small parts, it was very undesirable to introduce further difficulties. A little easement was allowed; instead of driving the tunnel perfectly straight on the theoretical centre line, the shield was kept slightly on the inner side of the curve, when the curve was approached and when it was receded from. The shield was made to pass round the curve in that way, the reason being that if a plumb line was taken through the centre of the tunnel the rails where the tunnel was straight would be symmetrical with reference to the centre line; but where it was necessary to put in a 4-inch cant on a 5-chain curve, the centre line of the railway was 90 per cent. of that cant on the outer side of the curve, and in order not to introduce a reversal of curvature the shield had to be kept on the inner side of the curve. With regard to the creep of the clay, whenever a hole was made in the ground there was generally some sort of movement, but experiments were necessary in order to test whether there was any creep. It was stated by Mr. Moir that he had actually driven an auger into the face and measured a sensible amount of movement with a plumb line. Mr. Dalrymple-Hay's experience, extending over some 4 years or 5 years, showed that the face of the clay was absolutely inert, it did not move. To show that, an auger was driven into the face, and to measure the movement, Dr. Kennedy's extensometer was adopted. The ratio of the two arms was about 80 to 1. The actual movement at the long end of the lever arm was $\frac{1}{8}$ inch; $\frac{1}{80}$ times $\frac{1}{8}$ was $\frac{1}{640}$ inch, and that occurred in 1 hour. If $\frac{1}{640}$ inch were multiplied twenty-four times it gave about $\frac{1}{27}$ inch, and Mr. Deacon suggested that $\frac{1}{27}$ part of an inch would crack a building in the street 30 feet or 50 feet above, which was ridiculous. The rigidity of the tunnel affected the question more than anything else, and the grout was also of importance. When it was first necessary to consider the type of longitudinal joint, the only experience available was that of the Tower Subway and the City and South London Railway. The late Mr. Greathead was in favour of a wood-packed joint; but Mr. Galbraith believed in machining the longitudinal joint, because towards Waterloo the tunnels had to be constructed principally under compressed air, close to buildings, and through ballast. In the other direction it was necessary to pass under the low-level sewer, with the District Railway on the top, and then into a street hemmed in with houses. It was only natural that Mr. Galbraith should want a tunnel as rigid as possible. It was well known that if a wood-packed joint was placed in a tunnel—there were six or seven in that size of tunnel—it was squeezed up. There was no wood packing in the longitudinal joints of the

Mr. Dalrymple-Hay.

Mr Dalrymple-Hay. Waterloo and City tunnels, and therefore there was nothing to squeeze. That was one of the principal causes that tended to produce the settlements. The engineers of the line could not be accused of not having done the very best thing possible, especially seeing that the whole thing cost such a lot of money. Mr. Deacon had, like everybody else, a shield of his own. He proposed to excavate the dumpling at the face and always keep the shield pressed into the clay. Anybody who had ever driven a shield knew perfectly well that a 5-chain curve had to be introduced sometimes. The directors said it had to be done. How was an engineer to drive a straight cylinder round a 5-chain curve without allowing some sort of clearance? The thing would not move of itself, it was too stiff; if the nose of the shield was buried in the clay he did not think it would ever move. Mr. Deacon had also referred to the general lowering of those railways into the clay, but he thought his idea really was that they could not be constructed without cracking buildings. The Author thought they could be constructed, and the real thing was to use good grout. He did not altogether agree with Mr. Mott or with Sir Alexander Binnie as to the very high speed at which the tunnels should be driven. There was a critical speed, and it depended very much on the grout. If a tunnel could be driven at 20 miles an hour and the grout was perfectly solid that would be right enough. But grout took time to set, and it was necessary to go only sufficiently fast to have it set properly. If the grout was very bad and 50 feet of tunnel was constructed in a week, and it was not perfectly solid, but fairly soft, the ground could not be expected to hold up. Mr. Moir had referred to the hooded shield, and mentioned that he, Mr. Dalrymple-Hay, evidently thought it was a novelty. As a matter of fact he was careful to put in the Paper very little about his connection with it, and it was not until Mr. Galbraith was kind enough to refer to the humble part he, Mr. Dalrymple-Hay, had played in designing the apparatus that the question was raised. It might have been designed by a Swede, but he could tell Mr. Moir that he had designed it in Westminster and did not know of anything that happened in America or elsewhere. Since then very many things had been found out about shields, but unless it had the clay-stopping system the hooded shield was not much good. It had been said that Sir Benjamin Baker objected to a hooded shield which was proposed for the Hudson River tunnel. Possibly he did, and he had no doubt Sir Benjamin was perfectly right. The difficulties were entirely different. Only the other day the contractors of the

Mr. Dalrymple-Hay.

Baker Street and Waterloo Railway had to consider how they were going to put two tunnels across the river in the best way they could. The matter was submitted to Sir Benjamin, who, instead of condemning a hooded shield, had passed it. Mr. Galbraith would no doubt be pleased to give the members in the next month or two an opportunity of seeing it with the clay-stopping system. The only difference was that where the work was particularly difficult it was necessary to put in iron screw shutters, or something of that kind. They were going to introduce the bird-fountain arrangement used by Mr. Deacon in the Mersey Tunnel for stopping any sudden rush at the face. There had been numbers of hooded shields in France, and Mr. Galbraith had sent him, Mr. Dalrymple-Hay, over to Paris to examine the shields which were being constructed there, and some actually at work, but there was no clay-stopping system. There was simply an extension of the cutting edge, an umbrella arrangement, where the men could go and work. Mr. Mott referred also to the revolving of the hooded shield and thought it would be exceedingly inconvenient if it revolved at 45°. Everybody knew that. The shield actually did revolve, like every other shield, about 2 inches or 3 inches, but that did not matter. The work could be done just as well. Mr. Francis Fox had been good enough to refer to a matter which he, Mr. Dalrymple-Hay, felt very much. He purposely mentioned Mr. Greathead's name in the Paper, because he felt they were all indebted to that gentleman. In fact, he maintained they were simply copying what he had told them to do. His object in mentioning the Greathead shield as such was because it was an absolute copy of what was done on the South London Railway. There was nothing new. His feeling was that if Mr. Greathead had never been born the Institution would not have been discussing the Paper that evening.

Mr. Jenkin.

Mr. B. M. JENKIN, in reply, said, in reference to the compounding of the dynamos as affecting injuriously the lighting of the stations and trains, only about a quarter of the series turns on the dynamos were used, and even with that it was found that the compounding was really a disadvantage; the variations in load were so rapid that the machines could not follow them. The volts lagged behind the current so much as really to make the pressure more unsteady when compounding than when working simply with shunt machines. Professor Forbes' suggestion that it might be better to use accumulators in the train was not altogether a good one. If the lighting could be made satisfactory without any additional apparatus, by simply tapping off the main supply, Mr. Jenkin. everyone would agree it was simpler, and saved the nuisance of accumulators, which was very great. The suggestion of a time automatic might be appropriate for alternating currents, but in the present case it would put the whole of the lights out in the trains and stations, and he did not think anybody would like to try it with continuous currents. The use of a locomotive instead of the arrangement of the two motor-cars, would make the trains very much heavier. Taking the weight of four trailer-cars, the train would weigh, loaded, 84 tons. In addition to that the locomotive would weigh something like 55 tons to get the same adhesion on the rails, which would make the total weight of the train 139 tons instead of 105 tons, or an increase in weight of 32 per cent. That, of course, meant additional power and cost of coal. Mr. Hudleston had said that that really was not a serious matter, but, in addition to that, it increased the size of the plant necessary at the station, and the size of the feeders; in fact, it increased the whole apparatus for working the trains, and therefore was certainly not desirable. The question of shunting at the City would also be complicated by the use of locomotives. Reference had been made by several speakers to the pushing and pulling as being a possible cause of the wear on the rails. Dr. Kennedy had already gone very fully into that, showing that practically no difference could be found when experimenting with the two halves of the train. Dr. Kennedy had referred to a difference of $1\frac{1}{2}$ per cent. between the pushing and pulling; that was only in the time taken to run the complete journey, and was really caused by the driver when pushing the train, being at the rear end of the train, and not able to see so well what he was doing as when he was at the front end. After getting over the slight variations at starting, the time curves plotted on a distance base lay absolutely parallel, that was to say, when the driver got on to the grades he ran at exactly the same speed up the incline whether he was pushing or pulling, which meant that the train-resistance was identical in the two cases, as far as it could be measured. The experiments made really calibrated the ammeters, because it was found in one case that the readings were lower in one cab when pushing and pulling than they were in the other cab, showing that it was due to a slight difference in the ammeter. The man drove the train with extreme accuracy. In two out of the three tests on the down line, he ran, when pulling, in 5 minutes 43 seconds, and repeated it in 5 minutes 43 seconds. In pushing he ran in 5 minutes 48 seconds, and repeated that exactly on the second run. So that the difference in driving was exceed-

Mr. Jenkin.

ingly small, and he thought the tests could be taken as fairly conclusive that there was no difference in the friction when pushing or pulling. With reference to the train-resistance, Mr. McMahon had already gone fully into the subject, and as far as it could be calculated from the experiments made, all Mr. McMahon said was absolutely right, and such saving as was suggested by Professor Carus-Wilson could not be attributed really to the roller-bearings. The calculated train-resistance varied enormously, and depended on the accuracy of the readings. Working it out from the different curves, it varied from 28 lbs. per ton to 5 lbs. per ton. That really meant that the speeds were not absolutely right, or that it was not quite certain whether the speed was being accelerated or slightly retarded. It was, however, difficult to measure such things when running fast in a tunnel, and any slight inaccuracy would make a large difference in the figures. Again, the motor efficiency had to be estimated, and it was not possible to be perfectly certain as to the amperes and volts, and unless much more accurate tests were made than it was possible to carry out on the Waterloo and City Railway, it would be rash to calculate the advantage of roller-bearings. In some experiments made the train was started from rest and run down the grade without any current on at all to see if a figure could be obtained with regard to train-resistance. The train-resistance in this case was from $9\frac{1}{2}$ lbs. to $10\frac{1}{2}$ lbs. per ton. Mr. Siemens had already referred to the question of the power of the motors, and certainly they were of ample power even with the very much increased weight of the trains. It should be remembered that the motors were designed for a certain weight of train and for certain conditions of working. It was stated that the run from station to station had to be done in a certain time, and that a certain speed was allowed round the curves. Given these conditions, the contractor designed a motor to suit them, and from the experiments made it appeared that the motors would have been ample with considerable power to spare. But when the line was started certain new conditions were imposed, therefore it could not be expected that the motors would be rightly designed for the new conditions. They could not be designed both for a high speed and a low speed, and it was rather hard on the motors to criticise them as not being right for the new conditions which the contractors knew nothing about when they were designing them. Professor Carus-Wilson went into considerable detail as to how the motors might be modified to make them suitable. That was a matter which, if left to the contractors, they would be able to do very well for

Mr. Jenkin. themselves. To show that the motors could do the work he might refer to *Fig. 28* (p. 94), which showed a train going up the 1 in 60 at 12 miles an hour, but with the four motors, two in series and two in parallel. When doing that they were only developing 28 kilowatts per motor, as compared with a full load of 50 kilowatts, which meant that the power developed was only 57 per cent. of the full power that the motors could develop at their normal full load. The current was rather larger, but not the power. The motors were over-loaded 12½ per cent. as far as the current was concerned, but they were only working at half their proper voltage, so that the power which was developed was only 57 per cent. *Fig. 22* showed a train weighing about 92 tons running up the 1 in 60 grade at 20 miles an hour, taking 400 amperes at 500 volts, or 50 kilowatts per motor. From these figures it could easily be seen that the motors would have taken a 72-ton train up the 1 in 60 grade at about 25·6 miles per hour when developing 50 kilowatts each, and a train weighing 105 tons at about 22 miles an hour up the same grade when developing 62·5 kilowatts; that is, with a load of only 25 per cent. above the normal for an increased weight of train equal to 45 per cent. Messrs. Siemens therefore really made the motors of very ample power for the conditions given them originally.

Several speakers had alluded to the design of the motors, controllers and other parts of the plant, and to the working of the line, as if the conditions under which the line had now to be worked were known when the plant was being designed. This, however, was not the case, and there had as yet not been an opportunity to alter the designs to meet the new conditions. The tests were made in order to ascertain in what direction these alterations should be made. It was with a view to showing the great effect produced by the new conditions and to obtaining a discussion on these points that the Author had given the results of the tests in his paper. He was extremely gratified that so thorough a discussion had been the result, and that it had been the means of bringing out a number of important points which he was sure would be of value, not only to those responsible for the improvement of the plant to meet the new conditions on the Waterloo and City Railway, but also to those interested in similar lines elsewhere.

Allusion had been made on several sides to the limited space available for the motors on the cars, and it had been suggested that larger motors could not be got in. It was, however, not necessary to adopt gearing to overcome this difficulty, as the method employed on the Central London Railway locomotives of carrying the magnets entirely from the bogie frames, if it proved satisfactory, could as easily be used on motor-car bogies. This would allow the armature to be lengthened, as the magnet bearings on the motor shaft would be done away with. Another method would be to place the bogie in a motor car further forward and in front of the cab. This would be exactly equivalent to cutting a locomotive in half and fixing it rigidly to the front end of the motor car, which would have the advantage of using half the weight of the motor car to obtain the necessary adhesion. In a similar way it would, no doubt, be possible to design a train with one, or even two, motors on each carriage in a train, as the end platforms could be raised to allow room for the motors beneath them. Where a train was made up of first, second and third class smoking and non-smoking carriages it was not essential—in fact it was undesirable—that the passengers should be able to walk all along the train, except in the case of a breakdown, when it might be necessary to get out at the end of a train on to the line. With a single large side door, or two side doors, one at each end of each carriage, probably a better arrangement would be obtained than with platforms at the ends for entering and leaving the train. The great difficulty that had to be met in such a line as the Waterloo and City, and, in fact, in all similar lines in London, was the great rush of traffic in the morning and evening, and the multiple-unit system certainly had the great advantage of enabling the trains to be quickly and easily increased in size at these times, without the waste of energy of hauling heavy, empty trains in the middle of the day, or the delays of shunting which occur with a train hauled by locomotives. Mr. Jenkin.

One of the most serious effects on the working of the Waterloo and City Railway produced by the reduction in speed at the curves had been that the trains took 6 minutes instead of $3\frac{1}{2}$ or 4 minutes to complete the journey. The speed fixed the number of trains per hour for a given headway. Thus, with a 6 minutes service there would be ten trains per hour, which with trains carrying 204 passengers was equivalent to a carrying capacity of the line of 5508 seat-miles per hour running at an average speed of $13\frac{1}{2}$ miles per hour. With a $3\frac{1}{2}$ minutes service there would be seventeen trains per hour and 9364 seat-miles per hour, running at an average speed of 23 miles per hour to keep the same headway. As had already been shown, with the higher speed the switchback principle reduced the energy per ton-mile, and the actual energy to work the seventeen trains would probably only be about 10 per cent. more than the energy for the ten trains. In addition to this, the passengers would have the advantage of being carried

Mr. Jenkin. at 23 miles an hour instead of at 13½ miles an hour. Professor Forbes suggested that no very great speed was required, and that the supply of trains was amply sufficient as it was. But on considering the matter from the above point of view, and bearing in mind what Mr. Eustace Thomas said had been his experience of actually travelling on the line every day, it certainly appeared that the lower speed of working had had a very serious effect on the economy, capacity and comfort of the line. This granted, the next thing was to consider the best thing to be done under the circumstances.

More than one speaker had suggested, as a remedy, the alteration of the signals so as to make it possible to run with a shorter headway between the trains. As pointed out by Major Cardew, the driver should know when leaving whether he had a clear road before him, in order to take advantage of the switchback system of working. This, however, meant that the whole run from station to station must be treated as one section in the block system, which at once made it impossible to start a second train before the first had arrived at the other end. The suggestion of an outer home signal would mean the placing of a signal on the up grade, which in the case of the down line was a grade of 1 in 60. This, of course, was not a good place at which to stop a train, on account of the power required to start it again. Since the trains had to be checked by the brakes on the down grade in any case, on account of the limitation of speed round the curves, the best arrangement would be to place the intermediate signal as near the sharp curve in each line as possible, in order to allow the driver to switch on the current at once if the line were clear, but at the same time in such a position as would allow it to be seen from as far off as possible. It should also be so placed that if the train were stopped the power required to start would not be excessive. Mr. Szlumper contended that the signals were correctly placed as being half-way between the two stations. This was quite right so far as dividing the line into equal sections was concerned, but in each case the signal was placed so near the end of the 9-chain curve as to make it impossible for the driver to see it until close to it, which made it necessary for him to approach it more slowly in order to be able to stop should it be against him. A much better position would be in the straight length of line in each tunnel where it passed under the river. If placed at the end furthest from the starting station, the driver would in each case be able to see the signal for a considerable time before reaching it. In the up tunnel he would be stopped on the level or on an up grade of only 1 in 800, and in the down tunnel on a down grade of 1 in 800 or on the level. Mr. Szlumper had pointed out that when a train had passed the advance starting signal another train could immediately follow from the rear station. This, the Author was afraid, had not been clearly explained in the Paper. About 300 feet past the advance starting signal in each tunnel there was a fouling bar, or tread beside the rail, which, on being depressed by the passing train, set the advance starting signal at danger behind the train, and at the same time released the lever at the starting station signal-box, by which the shunt-by signal could be pulled off to allow a second train to follow as far as the advance starting signal. By this means it was possible to reduce the headway to half the length of the line which would allow trains to be run every 3 minutes. In view of the fact that the trains could not be run through on the switchback principle but had to be slowed down near the bottom of the dip on account of the limited speed allowed on the sharp curves, this was certainly the best way of increasing the carrying capacity of the line, as it practically doubled the number of trains or seat-miles per hour. If, on the other hand, it had been possible to take advantage of the switchback method of working, it would have been essential to let the trains run through without any chance of being checked at the bottom of the dip, and signals arranged in this way would have been a mistake. When the actual working of the line in this way came to be considered, there was, of course, the difficulty of fitting the trains in at the scissors crossing at the City and at the cross-over road at Waterloo; but even with these difficulties a train could no doubt be started every $3\frac{1}{2}$ minutes or at most every 4 minutes. The average speed of each train would remain as with the present 6-minute service, but the carrying capacity would be increased. The only reason this had not already been done was the want of trains. There were only five trains at present, whereas seven would be the fewest with which the more frequent service could be run. This was a matter which no doubt would very soon be dealt with. Mr. Jenkin.

Major Cardew pointed out that the words "catch points" had been wrongly used. The Author was sorry for the mistake. What he had meant was that on the Waterloo and City line a train that ran past a signal at danger went at once on to the main line or crossing and might, therefore, cause an accident, whereas where there were sidings or more than one line of rails the points were usually, or could frequently be so arranged that the driver did not at once run into danger but had a certain amount of time

Mr. Jenkin. to find out his mistake. In the present case the opening of the automatic at once called the driver's attention to his mistake and assisted him in stopping the train.

Prof. Carus-Wilson had said that the three-step controller was an unnecessary complication in view of the small saving in power effected by the third step, which he estimated at only 2 per cent. He had, however, apparently only considered the saving when starting a train. There was a similar saving on slowing down at the scissors-crossing at the City. There was also a great saving in shunting. It would be seen from the Table at the end of the Paper that the energy taken for shunting at the Waterloo end of the line amounted to about 9 per cent. of the total energy of the round trip. With a two-step controller this energy would be doubled, twice the current at present used being taken in order to do the shunting in the same time, as each pair of motors would have to have the same current through them as was now passed through the four motors in series. The additional energy would be wasted in the resistances, it not being possible to shunt at a greater speed.

Mr. Eustace Thomas was surprised that more resistance-stops had not been provided in the controller between the positions with the motors two in series, two in parallel and with the four motors in parallel. These additional resistance-stops would certainly have been provided had it been contemplated, when designing the controller, that the motors would have had to be switched four in parallel when running at a low speed. As had already been pointed out, it was intended to work the line on the switchback principle, and in that case the train would have been running at considerably above the speed at which the motors could without difficulty be switched four in parallel, and such resistance-stops would only have been an additional complication and waste of time in working the controller. Probably it would be desirable under the new conditions not only to add such resistance-stops to the controller, but also to rewind the motors to run at a lower speed. If wound so as not to take more than their maximum current at a speed of about 12 miles to 15 miles an hour, it would allow the driver to switch the four motors in parallel immediately on leaving the five-chain curve. Mr. Heap had already pointed out the desirability of such an alteration.

Mr. McMahon had pointed out how very much smaller the controllers were on the City and South London line than on the Waterloo and City line. This was, the Author believed, partly owing to the fact that those controllers had only to deal with two motors instead of four, and partly to the fact that the controller was not made to work backwards. That was to say, once the motors were in parallel the current had to be switched off before they could be put in series again. That simplified the design immensely. Such an arrangement would, however, be rather difficult to use when shunting with four motors. Mr. Jenkin.

With reference to the figures of the whole-day test, Mr. Heap had said that a fourth boiler which was working had not been mentioned. This boiler was entirely separated from the boilers used for the main plant, and only supplied steam to the pumps compressing the air for the brakes and to a steam-feed pump supplying the feed-water to this fourth boiler. The engines driving the stokers and the economiser scrapers obtained steam from the boiler, supplying steam to the main engines. The air-pumps were not adjusted to work economically, and the exhaust steam from them was being used to heat the offices, and so the coal and water to this boiler were left out of account altogether. It amounted, as Mr. Heap had stated, to about 10 per cent. of the total coal used if taken as all burnt during the time the trains were running. The fires were, however, made up in the evening, and no more coal added till after six next morning, which reduced the amount to about 5 per cent. A large part of this was taken to keep the fires going, and could be considered as used for banking. It certainly did not mean that the air-pumps took as much as 5 per cent. of the total energy to work the line. If they had been supplied with steam from the boilers on the main load they would certainly have increased the coal and water used, but by only a small amount. It had not been considered right to include the coal for a stand-by boiler, as this was not in any way essential to the working of the line. Mr. Eustace Thomas had referred to the number of engines used. Three was certainly more than was necessary, as had been shewn by the use of only two to run the heavy traffic in the evening. The engines were working non-condensing, and so could not develop their full overload power. Although the maximum load recorded had not been more than 330 kilowatts on that particular day, it might have been considerably more had anything gone a little wrong, and the full power of the two engines might then have been required. The Author quite agreed with what Mr. Thomas had said as to expansion-governing compared to throttle-governing, making it possible to overload an engine to a much greater extent.

Sir Douglas Fox, President, observed that the present was one of the best discussions that had taken place before the Institution. If anything were wanted to add to the apprecia- Sir Douglas Fox.

Sir Douglas Fox. tion of the Papers it had been supplied by the excellent replies made by the Authors. He had been very much impressed with the excellent character of the work that had been carried on in this very difficult case, where the railway had been shallow and was therefore exposed to many difficulties which did not arise when it was possible to go to a greater depth. He thought there were three things which would be found in future to improve the railway very much. One would be a station at Blackfriars, which would enable the Company to take a great deal of traffic in the middle of the day which at present they lost. The second would be passenger lifts, especially at the City end. He could not see why it should be attempted to carry on important traffic of that kind without their use, especially when, as in this instance, one of the stations was 62 feet below the surface—a very serious matter for middle-aged people. He did not think that matter rested on the shoulders of the Engineers, because he felt sure they would be up to date in such a matter when they had power to deal with it. He cited the one instance of Liverpool, for which he was responsible. There, over 100,000,000 of people had been carried from a depth of 80 feet during a period of 13 years, and there had never been an accident or a hitch of any kind, whilst the cost was infinitesimal as compared with the total cost of working the railway. Therefore he thought that, in carrying out railways for the amelioration of the difficulties of the traffic of London, the question of lifts should not be lost sight of. This question was in fact one of the main points that passengers might be brought quickly and safely from a considerable depth, thus keeping the construction of the tunnels well in the London clay, and below all surface rights. The third question he wished to refer to was that of ventilation. He did not think it should be at all assumed that, because there were no products of combustion in the tunnels, therefore there was no necessity for any artificial ventilation. He felt sure the line would be much more popular if there were some means of producing a more perfect circulation of air than there was at present on either the South London or the Waterloo and City Railway, and that could be readily done without great cost, because it was not a question of constantly changing the air as was the case where the products of combustion of locomotives had to be dealt with. The impression produced upon his mind during the three nights that the discussion had continued was that it had been of a most useful and practical kind, and he thought the Institution was very much indebted to the Authors for enabling it to take place.