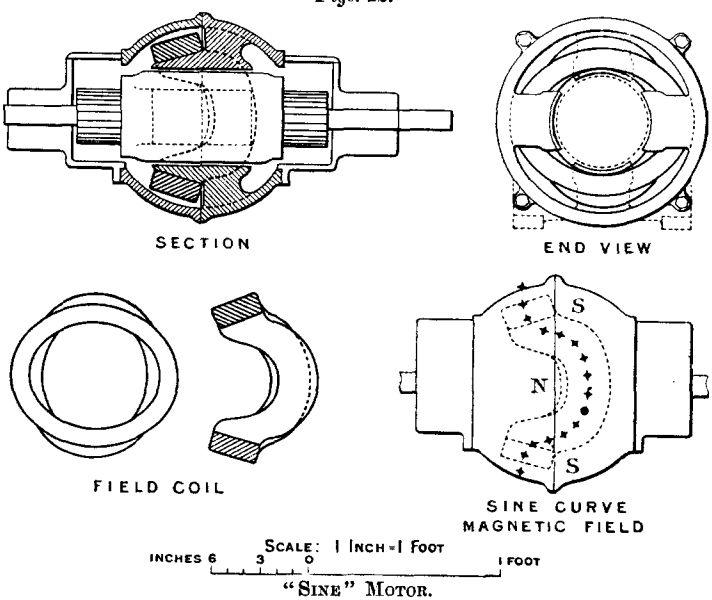
Discussion.

The President. The PRESIDENT, in proposing a vote of thanks to the Author, remarked that the Paper was interesting to the members not only as engineers but as citizens, because the development of the automobile was likely to be far-reaching in its effects.

The Author. The AUTHOR described a new motor which he had devised for electric automobiles. It was a four-pole motor, spherical in shape, with the iron casing carrying the poles divided in the centre into two halves, each half having two poles, and the two halves with their poles interspacing when placed together.

Figs. 42.



"SINE" MOTOR.

A single field-coil of special form was used for magnetizing the four poles. A front and side view of this coil were shown in *Figs. 42*, and the coil in position, relatively to the poles, was shown in the section. The coil was wound directly on a ball mould, or spherical former, or alternatively was first wound as a simple ring, and afterwards pressed or moulded into the required form, having two curved indentations alternating with curved raised parts, sinuous in shape, hence the name "sine motor." This coil was placed in position on one half of the iron casing, partly embracing and including the two poles on the

The Author.

magnetizing sphere of the coil, the other half of the iron casing with its two poles fitting into the depressions of the coil, and in turn being also included in the magnetizing sphere of the coil. The one coil magnetized the four poles alternately in two pairs, N.N. and S.S. It was found that this one magnetizing field-coil was only about one-half the weight of the four separate coils ordinarily used in a four-pole motor, and the C^2R loss was approximately only one-half. The sine-curve magnetic field (*Figs. 42*) allowed a reduction of the iron casing of 1 to 0·6, with a proportionately reduced weight, and a feature which he submitted was of the greatest importance was that the resultant direction of the field-coil and current being parallel and opposite to the current in the armature-coil windings, the point of commutation was thereby more defined, and a sparking limit, or permissible ampere stream, double that usually calculated for salient pole motors with separate coil windings, was obtained with the "sine motor," with fixed brushes, for rotation in either direction. Consequently a very light electric motor having a great output and high efficiency was the result. A "sine motor" with a double-wound armature and two commutators (*Figs. 42*) gave 6 B.HP., and weighed only 190 lbs.; the exciting energy was 70 watts, the efficiency 87·5 per cent. These results and the sparkless commutation were of considerable advantage in a motor intended for use in an electric automobile. He had been testing this motor for 2 or 3 years past, and as it had not been described before, he had thought it would be interesting to show it in connection with the Paper. He would like to add a few words on the usefulness of the electric automobile. As an auxiliary to electric supply-stations, and to electric railways and tramways, it seemed to him to have a great future. He had felt somewhat diffident in bringing the subject before the Institution, on account of its novel character, and he had had a little doubt as to whether it would be acceptable; but he thought the subject would become of great importance, although it was still in its infancy. From a sanitary point of view, and from the point of view of the transport engineer, the use of electric automobiles would be one of the most serious questions of the near future. Having recently had occasion to inquire into the cost of horse-drawn mails from London, he had ascertained that ten mail-coaches were driven out of London every night, to various towns, and travelled a total distance of 380 miles; and the cost of conveyance worked out at 6*d.* per ton-mile, the weight of the vehicle and the driver being included in the calculation. In the examples of Table V. the total

The Author. cost per ton-mile for the horse-drawn vehicles worked out at 6·1*d.* in both instances; and it was a curious coincidence that the actual cost of carrying the mails by horse-drawn vehicles worked out at practically the same figure. As would also be seen from Table V., the cost per ton-mile for electric vehicles was about one-half of that. The Post Office had recently made trials of electric vehicles. The Pioneer Electric Power Company were running an electric mail between London and Redhill, a distance of about 21 miles, which had been fairly successful. The Post Office had also tried an Opperman electric vehicle in London from the south-western district office to Battersea. The vehicle had been running experimentally for 12 weeks, and was reported to have been highly successful. Hence it seemed that, if more energy and attention were given to the subject, electric vehicles could and would be successful for such purposes. He had given in the Paper some particulars as to the watt-hours per ton-mile on electric railways. Taking 83·8 watt-hours per ton-mile, as given by Dr. Kennedy, for the City and South London Railway, and a tractive resistance of 12 lbs. per ton, the energy-consumption of road-vehicles, reduced to the same tractive resistance, was found to be less than one-half, namely, 32 watt-hours per ton-mile: which showed the economy of self-contained electric vehicles. The reasons for the economy were, that there were not the heavy capital charges, the cables, and the sub-stations of electric tramways and railways, and the vehicles had not to be made strong enough to bear the strains of pushing and pulling incurred by coupled vehicles. The recent interesting and able Paper on electrical traction on railways,[1] presented to the Institution by Messrs. Mordey and Jenkin, had been followed by a Paper on electric tramways[2]; and he had now completed the series by dealing with electric automobiles, which would serve where the other systems stopped, and would carry goods and passengers from the ends of electric tramways into districts where it would not pay to put down lines. He thought he had shown that such vehicles could be made economical and practical. As mentioned in the Paper, the weight of the batteries had been reduced considerably within the past 5 or 6 years, and in that respect electric cars now compared favourably with petrol and steam cars. The average weight of a petrol car varied between about 10 cwt. and 25 cwt.; a good petrol car would weigh about 17½ cwt. to

[1] Minutes of Proceedings Inst. C.E., vol. cxlix. p. 40.
[2] *Ibid*, vol. cli. p. 39.

20 cwt.; electric cars could be obtained weighing 19½ cwt. to 20 cwt. He had not touched in the Paper upon the many other kinds of batteries, motors and carriages, which were probably known to the members. There was a combined petrol and electric motor and many others, which he hoped would be described by engineers who were more familiar with them than he was. The Author.

Mr. A. B. CHATWOOD remarked that he had lately had to design some electric automobiles for a firm of steel-merchants, and it might perhaps be interesting if he described why electric vehicles had been insisted on instead of steam-lorries. In this case, a steam-lorry could not be obtained which had the flat top necessary for carrying long girders, the duty for which these lorries were intended. The insurance companies, too, had something to say in the matter. He had advised one firm, in the first instance, to order steam-lorries; but on making inquiries they had found that, as a rule, the insurance companies would not allow them to be used for cotton carrying. The district in which he lived was full of cotton-mills, and he believed the companies would not allow either petrol-lorries or steam-lorries to enter such mills to load. He did not know yet whether they would allow electric lorries to do so; but if they would, there was a large field, at all events in the south of Lancashire, for heavy lorries. He questioned the necessity, at the present day, of using a spring connection between the motor and the underframe. He did not see why motors with slotted armatures could not be built capable of standing any shock to which they would be exposed; in fact, he thought the motors that were being built would stand such shocks. The shock sustained by the motors of an electric automobile would not be as severe as that of an electric tramcar taking points. Another feature of design, which was of great importance and was mentioned in the Paper, was the rigid connection between the front and back wheels, instead of trusting to springs. One curious fact had transpired in connection with the lorries he had referred to, which was not brought out by any of the diagrams in the Paper, namely, that it was essential that the front axle should be able to turn through a right angle, so as to become parallel with the axis of the lorry; because, in delivering goods, these lorries had to go into narrow alleys, and turn sharp corners. The horses of horse-lorries sometimes had to be taken out, and the lorries manœuvred round. In South Lancashire, therefore, there seemed to be a greater opening for heavy lorries, carrying loads of 4 to 6 tons, than for the pleasure automobile. The lorries he had referred to were intended to carry a 5-ton load; Mr. Chatwood.

Mr. Chatwood. their weight was approximately 5 tons, including the batteries, which weighed about 30 cwt.; they were intended to run a maximum of 30 miles, and to be capable of running at 8 miles per hour, which was just twice the speed allowed by law.

Prof. Ayrton. Professor W. E. AYRTON considered that the Paper was an interesting one, on an interesting subject; and in view of the previous failures of accumulator-traction on common roads, he thought it had required a great deal of courage on the part of the Author to attack the problem practically as he had done, and to give the results obtained by himself and by others. In view of the fact that practically all the uses of electric accumulators for public, as distinct from private, electric traction had been failures, it was necessary to be an enthusiast in order to tackle the question. The Author was an enthusiast: and were not enthusiasts apt to be a little rosy in their views of what could be done? For example, the Author said that the watt-hour storage-capacities per pound of a complete cell, given on p. 10, were the values stated by the manufacturers. Manufacturers also were enthusiasts, and looked at the matter from an optimistic point of view. In the case of the Fulmen accumulator, which had been so much used in France, it was stated that 11 watt-hours storage-capacity per pound of complete cell could be obtained. The results of the prolonged series of trials of various accumulators made by the Automobile Club of France in 1899, however, showed (p. 11) that with this cell 101·9 total kilowatt-hours were obtained in ninety-eight successive discharges of a battery weighing 148·5 lbs. If those figures were worked out they would not come to 11 watt-hours, but to less than 7 watt-hours per pound. He was inclined to think that the storage-capacity of accumulators was much over-rated. From time to time many kinds of cells had been sent to him to be tested, but he had never obtained such figures as were frequently claimed for their storage-capacities. For instance, the manufacturers of the Rosenthal cell gave 15 watt-hours per pound; he had not tested that particular cell, but he had never obtained such a figure with any cell; about 8 watt-hours was the highest he had ever obtained over a long series of charges and discharges. That made a great difference in an estimate of the distance it was possible to run with an accumulator in a motor-car; because if there was less storage-capacity for a given weight, and it was necessary to go a certain distance, the weight would have to be increased, which meant increasing the output of the battery per mile in order to propel that weight, and therefore led to a still further weight of cells having to be carried. At the beginning of the Paper an

interesting account of the different kinds of batteries was given. On p. 6 a battery was mentioned wherein zinc with peroxide of lead was used, and the Author stated that this battery had the advantage that it could be charged quickly, and the whole energy could be stored in an hour or two. No doubt that was true; but it might be imagined from the statement that only that kind of battery, having zinc, could be quickly charged. In order to test that particular point, a series of experiments had been carried out in his laboratory, in 1898, the results of which had been communicated to the British Association in the same year. Accumulators were usually charged with a comparatively small current, a current much less than might be put through them—the current, for example, that they were discharged with. The particular accumulator tested in the investigation had been a Tudor cell—rather a small cell with only five plates—the rated current for charging being 20 amperes. It had occurred to him to try the effect of applying a constant potential difference instead of charging the cell for some hours with a constant current of 20 amperes. When charged with this constant current, the potential difference between the terminals per cell had risen from 2 volts to 2·55 volts. It had taken 206 minutes to put in 152 watt-hours. The question was, what would happen if practically the final potential difference were started with—if instead of allowing the potential difference to rise slowly from 2 volts to 2·55 volts, the current being kept constant, 2·55 volts were applied to start with, and the potential difference were kept constant at this value? Of course, relatively the current became enormous—over 160 amperes at the start. A large number of tests had been made in two distinct ways. He believed in testing cells only when a certain cycle of charging and discharging was carried out over and over again for weeks, until the cell had got into an absolutely steady condition. Single charges and discharges of cells told nothing: they might show that the cell was bad, but nothing else. The cell had first been charged and discharged, in the ordinary way, about forty-five times, until the charging-curves had become perfectly regular, and identical for successive charges and discharges. Having thus been got into a normal state for constant current, the cell had then been charged and discharged about forty-five times with a constant potential difference. It had been found that a larger number of watt-hours—that was, more energy—could be put into the cell in 1 hour when it was charged in that way than in 206 minutes when charged in the other way: with the advantage also that during the 1 hour's charge at 2·55 volts

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Prof. Ayrton. there was no gassing. The other questions to be decided had been, of course, whether the efficiency of the arrangement was lowered, and whether the cell was damaged. With constant current (for 3 hours), the energy efficiency of the cell had been 81 per cent.: whereas with charging at constant potential difference for 1 hour the efficiency had been 71 per cent. The efficiency had thus been about 10 per cent. lower; but both the amount of energy put in and the amount of energy got out in the discharge had been a good deal higher. Whether the cell had been charged at constant current, as in the first series of tests, or with constant potential difference, as in the second series, it had been discharged in exactly the same way; so that the results were quite comparable. It had been found that with constant potential difference 226 watt-hours were put in, as compared with 152 watt-hours when charging with constant current, 163 watt-hours being got out as compared with 123 watt-hours; so that under the latter conditions not only had more energy been put in but more energy had been got out, and the cell had had a greater storage-capacity, although its efficiency had been less. The question had then arisen whether the cell had been damaged by the forty-five charges and discharges with the constant potential difference, starting with 160 amperes instead of 20 amperes. The experimenter had therefore at the end gone back to the first set of tests, namely, charging with constant current, in order to ascertain the possibility of repeating the original observations. It had been found that this could be done; and there had been no sign whatever of the cell having been damaged. Although tested in 1898, the identical Tudor cell was still in use; which was the best proof that the treatment described had not damaged it. He did not know whether it was generally realized that a cell could be charged in that way, diminishing the time to less than one-third, and increasing not only the energy put in, but also the energy got out in the subsequent discharge. In addition to the many cells described by the Author for traction purposes he would like to mention one which Mr. Fithian, who was now with the Tudor Company, had worked out when studying under him. He had obtained a number of figures in relation to the working of this cell, but as he had had only about $1\frac{1}{2}$ year's experience of it, he would not place them before the members yet. The cell was made in the following manner. First there was a thin sheet of ebonite, with perforations in it. It was quite possible, when that was put into a proper mould, to cast lead round it, and to have lead pieces across, so that the thin sheet of ebonite was interlaced with lead. That could be done without burning the

ebonite, although at first sight it might be thought that the ebonite would be damaged. The plate was then pasted in the ordinary way; and as the foundation of the plate consisted of a substance which was not acted on by acid, the plate never fell to pieces. The great trouble in accumulators, especially with heavy discharges, was that after a short time the plates crumbled to pieces. That had never happened in this particular cell, within the $1\frac{1}{2}$ year's experience already obtained. So far as that experience went, the result arrived at was that a plate made in the way he had described seemed to be extremely durable. He would like to see this kind of plate tested by a prolonged period of hard work in an accumulator motor-car. Hitherto that had not been done; the tests had all been made in the laboratory. The important point of the question of the fall in efficiency was dealt with on p. 11, where the Author spoke of a cell weighing 67·2 lbs. having a durability of 3,000 ton-miles, and losing only 10 per cent. of its efficiency. These figures were very good, and were far better than those obtained in the trials made by the French Automobile Club. As the Author said, cells had improved greatly since the tests made in 1899; but at the same time it was worth while examining the results quoted. The cell referred to as giving 1 HP.-hour for 67·2 lbs. weight needed about 11·1 watt-hours per pound. That meant a large storage-capacity to start with. Consequently, if 100 watt-hours per ton-mile were taken, as was done by the Author on p. 11, 3,000 ton-miles meant about four hundred full discharges, so that in four hundred full discharges the efficiency of the cell fell only 10 per cent. But the Fulmen cell in the Table on the same page, which had been one of the most successful cells in the trials made in Paris in 1899, had had only ninety-eight discharges instead of four hundred, and had lost 14 per cent. in efficiency. While therefore a cell was required which with four hundred full discharges would lose only 10 per cent. of its efficiency, one of the best of the cells in the Paris tests had had only ninety-eight full discharges, and had lost 14 per cent. in efficiency. He was afraid he would be considered rather a "wet blanket"; but it had unfortunately been his lot during the past few years to be a wet blanket to many proposals to start accumulator traction. At a discussion[1] in 1897, at the starting of the London Electric Cab Company, he had given reasons for his belief that the Company would be a failure, but he had ended by saying that nobody was more anxious and no one would be happier

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[1] Journal Institution Electrical Engineers, vol. xxvi. p. 689.

Prof. Ayrton. to be proved wrong than he himself. On p. 5 the Author spoke of 86 watt-hours per ton-mile as required by an electric vehicle on a level road, and on p. 30 he said it was possible to run electric vehicles on a good level road with an expenditure of only 50 watt-hours per ton-mile. The actual results with the cabs of the London Electric Cab Company, which had made a long trial with many cabs, were the following. The weight of the cab, as mentioned in the Paper, had been a little over 2 tons, including everything except the two passengers and the driver, making the total weight about $2\frac{1}{4}$ tons. The accumulators had given 80 volts pressure; the current on good level paving had been 30 amperes, which had risen to 50 amperes on a rough road. That meant that between 2,400 watts and 3,600 watts had been developed, whereas going up-hill the power had been 8,000 watts. Assuming a speed of 6 miles per hour, and weight of cab $2\frac{1}{4}$ tons, the figures came to about 230 watt-hours per ton-mile. That was the figure which had been found absolutely necessary in the vehicles of the London Electric Cab Company, instead of the small figures of 50 watt-hours and 86 watt-hours per ton-mile, given in the Paper. With regard to the resistance of a vehicle with pneumatic tires, a number of careful experiments had been made by some of his students in order to find the pull necessary to drag a Beeston Humber bicycle in good order, with Dunlop-Welch tires, and a Humber block chain. The bicycle had had one person on it, and had been pulled by another person on a second bicycle. The draw-bar pull and the speed had been carefully measured. The speed had varied between about 3 miles and 18 miles per hour; and the tractive effort required had been found to be about 32 lbs. per ton on concrete, 49 lbs. per ton on macadam, and 43 lbs. per ton on wood blocks. Taking 41 lbs. per ton weight on a fairly level road as the mean, that gave almost exactly the same as the Author's higher figure of 86 watt-hours per ton; but in so doing no allowance was made in the bicycle trials for loss of power in the motor and in the gearing. The second bicycle had been pulled by the first; it had not been propelled by a motor, with its gearing and consequent loss of power. If power required to cover these losses were added, considerably more than 50 watt-hours or 86 watt-hours per ton-mile would be found to be necessary. In Table IV. one case showed 145 watt-hours per ton-mile, while at the bottom of the same column another case went down to 84 watt-hours per ton-mile: he would much like to have been present when the last figure was measured. Lastly, he wished to deal with one other point, namely, the reason for the failure of the

London Electric Cab Company. Obviously every one who had dealings with accumulators and road traction would like to know that. Various explanations had been given at the public board meeting, one attributing it to the sensitiveness of the drivers, who had been too much ridiculed by their friends, because there were no horses in the cabs. On a previous occasion he had mentioned publicly the cause of the company's failure, and he presumed there would be no objection to his repeating it. The cells, of the Faure-King type, had been maintained by the Electrical Power Storage Company. Before the signing of the contract, that company had offered the London Electric Cab Company two alternatives. If the Cab Company was willing to discharge its cells every other day, and to have them charged on alternate days, the Electrical Power Storage Company was willing to maintain them up to a certain fraction of their original capacity, for a payment of 10 per cent. per annum on the original cost. But if the Cab Company wished to discharge them every day—which was what they had elected to do—and to have them charged each night, then the payment under the contract was to be 20 per cent. per annum on the original cost. One proviso had been put in, to which the Cab Company had paid absolutely no attention; no doubt they had thought it was a sort of laboratory matter, an insignificant thing, which to an important undertaking like the London Electric Cab Company did not matter at all. This little detail had been the stipulation that any cell allowed to discharge so that the E.M.F. between the terminals fell below 1·8 volt, should not come within the contract. The first cases had been all right; as the cells had lost their storage-capacity, the Electrical Power Storage Company had renewed the plates. But after a time cabs had come in in which the cells had obviously been discharged until the E.M.F. between the terminals was less than 1·8 volt. The company had said at once that such cabs were outside the contract, and quite rightly so; and gradually cab after cab had gone outside the contract, until at last all of them had been in that position. He referred to that matter because he was not aware—although he would be glad to be told that he was mistaken—that in any electric vehicle propelled by accumulators the driver had a means of knowing when the E.M.F. per cell had fallen to 1·8 volt; he had no alarm bell, or anything of that kind. It might be asked what harm there was in allowing the voltage to fall below 1·8 volt? That subject had also been investigated in his laboratory in 1889; the problem being to ascertain to what voltage it was possible to allow the cell to fall without causing

Prof. Ayrton.

Prof. Ayrton. damage, charging and discharging it between definite voltage limits. There had been absolutely nothing to guide the experimenters. First of all 1·55 volt had been used, and then 1·6 volt; but after a time the cells had been found to be rapidly losing their capacity. Finally the fact had been arrived at that if the voltage was allowed to fall below 1·8 volt, the capacity of the cell diminished rapidly.[1] Although he had not been aware of it, the problem had been attacked at the same time by Professor L. Duncan and Mr. H. Wiegand in Baltimore; and they had published,[2] almost simultaneously, the same answer. Every accumulator company now put in its contracts the stipulation that they would not maintain the cells at a given rate, unless that limit of voltage was never reached. The reason why the effect was so disastrous if the voltage fell below 1·8 volt was simple. Such a fall in the voltage meant that there was not enough sulphuric acid: instead of sulphate being formed on the plate, and instead of the double sulphation theory of the working of the cell holding, there was soluble hydrated lead oxide, which wandered about in the cell and was turned into *detached* sulphate. Not being on the plates, the detached sulphate could not be reduced in the next charge, and the consequence was that the capacity fell rapidly; and, as had been found in the experiments referred to, a deposit of $PbO_2 + PbSO_4$ fell to the bottom of the cell, and the plates became disintegrated. He urged that, in order to obtain success with accumulator-traction, the same precautions must be used as were taken in the laboratory and in the central station. The cells must not be allowed to discharge below 1·8 volt. An indicator must therefore be put in front of the driver, which rang a bell or other signal, some time before the danger-limit was reached; and the driver should be given to understand that, if he did not come back to the charging-station when the bell rang, his dismissal awaited him on his return.

Mr. Clarkson. Mr. T. CLARKSON entirely agreed with Professor Ayrton's comment on the Author's rosy views. Perhaps it was not surprising that such opinions should be held by electricians or electric automobilists; but surely the same opinions might be held by a steam or a petrol automobilist. At the present time it was not unreasonable to say that the electric automobile might be regarded as the petted child of automobilism; it was unable to compete on level terms with either steam or petrol cars. Special conditions, shorter

[1] Journal Institution Electrical Engineers, vol. xix. p. 561.

[2] Transactions American Institute Electrical Engineers, vol. vi. p. 217.

distances, had to be provided in all competitions: and there could scarcely be anything more absurd than that, in weighing electric automobiles, the competitor was allowed to leave out the weight of the accumulator, whereas in weighing a steam or petrol car the competitor had to weigh everything. The Author stated early in the Paper that tours of over 1,000 miles had been made satisfactorily, but nothing was said about the degree of satisfaction; the assertion was evidently meant to be taken as a proof that electric automobiles were suitable for general touring purposes. He did not think a single such example was very conclusive. He had been present at the time of the tour to which the Author referred, and had seen something of the car's journeyings. It could fairly be said that it had run very satisfactorily, if it was regarded from the point of view of keeping within the speed-limit of 12 miles per hour: it had certainly been a law-abiding car, for he had never seen it run at more than 12 miles per hour, unless perhaps when going downhill. But the general opinion of other automobilists who had witnessed its performance seemed to be that it might be described as a kind of overgrown insect crawling over the face of the earth and sucking the blood of every colliery it came across. That beautiful white-painted carriage, having to go to collieries to re-charge, was given as an example of pleasant touring; although it was subsequently said in the Paper that charging-stations were now becoming very numerous, and no difficulty was experienced on that score. But how would an electric carriage compare with a steam or petrol car under such conditions as had been formulated for the forthcoming September trials of the Automobile Club? A committee of representative manufacturers had drawn up conditions, and it had been suggested that a fair trial of the cars could be made only by confining them strictly, at the end of each day, to a reserved enclosure. Immediately they came back from the trial, the cars must not be touched: no cleaning or replenishing or repairs ought to be done. Next morning, before anything could be done in the way of replenishment, adjustment, or repairs, an observer should take his seat on the car, and after a signal was given the car could be repaired; but every minute occupied in the replenishing, adjustment, or cleaning, counted one mark against the car until it was ready to move under its own power. Could an electric car compete with either of the other kinds under such conditions? He thought it would be agreed that at the present time the electric carriage could not be considered to compare with petrol or steam carriages for general purposes. He

Mr. Clarkson.

Mr. Clarkson. admitted at once that there was a field of usefulness for the electric carriage. For town service, within definite limits from its base of operations, it was eminently suitable, because there the conditions of working were not governed by questions of cost: people liked the electric automobile, and they would have it. The Author stated that an electric automobile was the only one in which the motor could be used as an effective brake. That was entirely wrong. Any one who had ridden upon a properly-constructed steam-carriage appreciated the immense braking-power of the compression of the engine. With an engine which was—as it ought to be for a steam-car—unbreakable, the easiest way of stopping was merely to pull over the reversing-lever, steam being shut off. That was the pleasantest way of pulling up the car, and it was done very quickly. The brake was not suddenly applied, although it appeared to be, the compressive effect being cumulative. The real question at the root of electric automobiles was the accumulator. Some years ago, Lord Salisbury, who had been experimenting on the subject, had remarked that Nature appeared to have conspired against the electric automobile, in having given practically only one element which could be used successfully in the construction of storage-batteries, a metal which possessed the great disadvantages of weight and weakness, whereas what was required was lightness and strength. All the ingenious arrangements shown in *Figs. 1–17* for utilizing lead and paste were so many ways of trying to make the best of a bad job. The materials available were poor. What hope there was of getting better materials he did not know; but until such were available he had little hope of the electric car superseding other kinds. On p. 10 the Author mentioned that particulars of the Edison cell could not be given. That cell had been referred to a few years ago as having solved once for all the question of road traffic. When the first announcement had been made, it had doubtless come as a tremendous shock to many who had been spending years and a good deal of money in investigating in other directions, to see their schemes vanish, and to picture the electric carriage superseding all others. But the shock had gradually subsided; the cell had not "materialized." Subsequent announcements had been made at various times; but with each announcement the cell had appeared to be weaker, until, at the last announcement, the cell had been so weak that it had failed to excite any apprehension. In common fairness it should be said that Mr. Edison gave to journalists the full credit of producing his last cell. He would like to give some comparative

figures with regard to the cost of running an electric and a steam car. The depreciation in efficiency of the cell was given in the Paper as 10 per cent. after doing 3,000 ton-miles. The depreciation in value was not given; but it appeared that the figures mentioned represented the effective life of the cell. The depreciation in value would therefore probably be 90 or 95 per cent.; but the Author did not say what the scrap value of the cell was. He had recently made some careful experiments in regard to depreciation on steam cars. After running 4,000 ton-miles, he had had an engine taken to pieces and carefully examined. The engine was made with large surfaces (most of them hardened), was thoroughly well lubricated, and was protected from grit and dust; and he had been delighted to find the surfaces in splendid condition. There had been practically no evidence of wear, and to all intents and purposes the engine had been as good as new, after running 4,000 ton-miles. He was satisfied that the steam-engine properly made would run 30,000 miles before needing repair, and then it could be put into good condition—made virtually as good as new—for about one-fifth of its first cost. That meant that the depreciation of the steam-engine, after running 3,000 ton-miles, would not be more than 2 per cent., as compared with 90 per cent. in the case of electric automobiles. Mr. Clarkson.

Colonel R. E. B. CROMPTON, C.B., remarked that, although the Paper was interesting and instructive and contained a mass of information of great use to every one connected with the electric automobile industry, it had been severely criticized. He admitted that, in some respects, the Author was over-sanguine; but he thought a middle course between the two sets of opinions was the safe one. Those who looked carefully into the matter would see that, for town use, at all events, the use of electric automobiles ought to be encouraged in every way, if it were only for the fact that they were motor-cars which could be driven by unskilled persons. Ladies could drive themselves, without the need of having any attendant; and moreover, sudden breakdowns were not liable to occur on electric cars. Sufficient warning was generally given that a car required attention, so that it was unlikely that people driving one would be stranded in the street. At present an increasing number of electric cars were to be seen in the streets of London. It would perhaps surprise Professor Ayrton to hear that the number now running was nearly thirty-fold the number owned by the London Electric Cab Company, about which he had spoken. That company had made an early and valuable experiment; and, although it had Col. Crompton.

Col. Crompton. failed, it had furnished an interesting object-lesson to all electrical engineers. He, like others, had studied the working of the company, and had found that, as was usual in such cases, its failure could not be ascribed to the accumulators, or to any one cause in particular. Defects in design, unsatisfactory charging-arrangements, and similar causes, had each contributed to the failure; nevertheless a gallant attempt had been made, and success had nearly been reached; and it must not be argued that similar attempts made at the present time would also be failures. It was believed that at present the cars now running in the streets of London were a commercial success; but the number in London was small compared with those to be seen in the streets of Paris. In that city recently he had been struck by the fact that quite a large proportion of theatre-goers who used carriages used electric automobiles. In his opinion there was every reason to encourage the use of electric vehicles. The supply of electricity for charging them was a very important matter to the electric-supply companies, as it enabled them to utilize their entire plant during the hours of light load. It thus enabled them to spread their working-expenses over a larger output, and to reduce the average cost of the energy produced. In the end, it must also benefit the public, because it must lead to eventual reduction in prices, even for lighting. He believed that the use of electricity for driving electric automobiles might expand so greatly that it would double, or even quadruple, the load of lighting-stations, and would have a most important effect on their future. For that reason he thought shareholders and all interested in electric supply ought to encourage the electric automobile. He did not attach much weight to the arguments of Mr. Clarkson, who had made a strong case against the use of the electric automobile for long-distance running, because the subject under discussion was, he considered, directed principally to the use of electric automobiles within towns, as a means of reducing the number of horses, and the consequent manure, slush and mud in the streets, which attend the use of horse-haulage. The engineering question, which would govern the commercial one apparently, was whether it was necessary to wait for a new form of accumulator from Edison or any one else. Were not the well-known accumulators at present fitted in the electric cars, such as had been made for years past with ordinary pasted plates, good enough for the purpose, provided that proper organization were adopted so as to secure their cheap and easy maintenance? He believed this could be done. He agreed with the Author that the time had

Col. Crompton.

come when, if the matter were put into capable hands, and carried out on a sufficiently large and well-organized scale, the use of electric automobiles would be a great commercial success. Public services of vehicles, private carriages, tradesmen's carts and wagons could all be driven by electricity at a price considerably below what they cost for horseflesh, and in addition would offer very considerable sanitary advantages, cleanliness, and extra speed. He repeated that it was now a question of organization; all that was required was a system of interchangeable accumulators, with battery-charging stations at which an empty set could be exchanged for a fully charged set. Whether the carriages were privately owned, or were hired from a company, it would be necessary that they should all be made to take accumulator-boxes of a standard size. If there were twenty or thirty charging-stations spread over London, the user of an electric automobile would never be far away from one of them, so that if he noticed that his battery was running down he could exchange it, and then continue his journey. Up to the present, attempts had been made to increase the life of accumulators and to make them more durable: what was now wanted was a thoroughly organized system of repairing and maintaining them, so that they might be kept as good as new at a small cost. Material and labour for accumulator-repairs were not expensive, and by improved organization alone the cost of these repairs could be reduced to a low figure; so that he thought the future was hopeful. With regard to the Paper itself, there were some statements in it which required explanation by the Author. He had taken the trouble to check some of the figures given, and he agreed with Professor Ayrton that the watt-hours per ton-mile given in Table III. were somewhat astonishing. It was a pity that any of the figures should be overstated. He thought there must be some error in them. He had spent a good deal of thought lately on traction problems, and had always considered the electric automobile to afford one of the best methods of measuring tractive power absorbed by automobiles on highways, as the varying resistance was always accompanied by a movement of the needle of the ammeter: moreover, by putting a meter on the car it was possible to integrate the power required over any length of time. He had hoped that the figures given by the Author would throw some light on a matter in which he, personally, was much interested, namely, the power absorbed by air-resistance at speeds exceeding 10 miles per hour; and also that it would give some indication of the extra power required on an undulating as compared

Col. Crompton. with a practically level road. As the Author stated, when descending a hill the car did not give back the whole of the power that had been used in ascending; consequently he had expected that the integrated power ought to show that a car running on an undulating road required a larger average draw-bar pull than one travelling on the level, just as if it had a continuous gradient against it. He found, however, in working out the figures in Table III. of the Appendix, that they varied among themselves to such an extent as to render it impossible to get concordant results from them. In the body of the Paper were shown some interesting methods of transmitting the power to the two wheels, and he thought users of cars would be much interested in the simple method of avoiding the use of differential gear shown in *Fig. 23*, where the armature drove one wheel and the field-magnet drove the other; but in this figure there was something wanting, for as far as the illustration went it would show that one wheel would be driven forward and the other backward unless there was some means of reversing the movement of one wheel. The statement made (p. 23) on the authority of Dr. Luxenberg, that increasing the diameter of the wheels from 2 feet 6 inches up to 5 feet would effect a saving of 40 per cent. in the pull, required confirmation. He thought it must be an exaggeration. Experiments were being carried out by Professor Hele-Shaw with the apparatus provided by the British Association Committee for measuring tractive pull, and he did not think that increase of diameter showed such a large decrease in the pull as was stated by Dr. Luxenberg.

Prof. Ayrton. Professor AYRTON remarked that Colonel Crompton's observations had been directed rather to a contrast between accumulator-cars and horsed vehicles; while he himself had had in mind the subject of the Paper, which was rather a contrast between accumulator-cars and petrol and steam cars. It was stated on p. 30, in reference to the cost of running electric vehicles, "This cost will compare favourably with that for any other kind of self-propelled carriage; and renders electric propulsion on roads, with its advantages already enumerated, more promising than any other system of motor-carriages." He would be glad to know whether Colonel Crompton thought that, including renewals and maintenance, the cost of running accumulators-cars was such as to render them more promising than any other kind of motor-carriage.

Col. Crompton. Colonel CROMPTON replied in the affirmative, observing that he considered electric automobiles had a very good chance, especially under such conditions as would obtain in the case of a private

family. Supposing, for instance, that the wife desired to do an afternoon's calling, he thought it could be done in an accumulator motor-car at a cheaper rate than the 15*s.* an afternoon charged for a carriage. The car could be driven by the ladies themselves, thereby saving the driver's wages. The saving in wages was much greater than the slight extra running-cost of repairs and electrical energy on the one side, over petrol and repairs on the other. Assuming that a driver received 35*s.* per week, his wages must be divided by the number of times the carriage was taken out, and as it would probably not go out every day, it would be fair to take 6*s.* or 7*s.* for an average day's work. That 6*s.* or 7*s.* would be entirely saved in the case of accumulator-cars. There was no doubt that ladies could drive accumulator-cars; they only had to turn a handle, ring a bell, and start and stop the car, and there was nothing to get out of order: whereas, on the other hand, it could not be said that, as a rule, ladies could be trusted with either petrol cars or steam cars. Col. Crompton.

Mr. P. W. NORTHEY considered that the Paper contained useful data. Such data, however, took a certain amount of time to collect, and in the meantime improvements in electric automobiles were being rapidly made. It was asserted in the Paper, in connection with zinc as a negative electrode in accumulators, that porous pots were necessary. He did not think that was so; because, although such pots had been used on a fairly large scale in one case, he thought they were a source of danger if the zinc, by forming a tree across, could be deposited on the inner side of the pot, against the oxidized lead paste. That gave rise to a serious difficulty, and the cell could not be put right without a great deal of trouble. He found in practice that a large space was necessary between the positive and zinc negative electrodes. With regard to gearing, it was stated that worm-gearing was quite inefficient, and for that reason, and because it was not easily reversible, it was held to be of no account. He quite agreed that nearly all text-books abused worm-gearing as inefficient compared with other gears, and no doubt it had been inefficient at the time of the publication of those text-books; but at the present time such gear was very different from what it had been some years ago. Worm-gearing had now been improved, and was wonderfully efficient compared with the best forms of spur-gearing used in electrical vehicles. So long as the thread, pitch, etc., of the worm were properly designed, nothing better could be desired from the point of view of reversibility. A good test to apply to a carriage with worm-gearing was its power of recuperation. Mr. Northey.

Mr. Northey. He had compared gears on several cars going downhill under known conditions, and had found the power of recuperation with the tangent screw, if anything, better than with the spur-gearing. If the car was stationary, and it was desired to push it along by hand, there would not be any sticking between the worm-wheel and the worm of such improved gearing. Shunt-wound motors were favoured in the Paper, chiefly for purposes of recuperation, but in practice he thought it was a pity that the great advantages of the series machine should be set aside for the sake of recuperating only. With a series machine the starting-torque must always be greater than it could be under similar conditions with a shunt machine, unless with the latter complicated switches for variously arranging the field-coils were provided; and it was very easy to produce any desired combination with a series winding, either for variable field-strength or for purposes of recuperation. The Author's double-wound armature seemed to be the very thing that was wanted. He thought two motors would be the best means of driving an electrical vehicle, if they were not two separate pieces of apparatus with two sets of gearing; that was to say, if the advantages of the two motors could be obtained in a single machine. He was not at all afraid of the mechanical differential gear; he thought it was one of the most efficient and satisfactory devices on automobiles of standard design; but the great advantage of a double-wound armature or two electrical machines was that if the two halves were thrown into series, a better hill-climber was obtained, than with one motor and half the voltage of the battery, which should be an equivalent thing. He found that all cells in series and one motor was the only combination which was of any use for climbing hills; but it should not be so. On p. 27 the Author, for purposes of calculation, assumed an accumulator weighing 6 cwt. and capable of driving itself 250 miles; he then suggested that if the carriage to carry the accumulator also weighed 6 cwt. it would be propelled 125 miles, or half the distance. But the Author had not taken the varying discharge-rates into account throughout. By the time that battery had been loaded to three times its own weight, the discharge-rate, which might be almost three times as heavy, would have seriously affected the energy-capacity. The development of electric automobiles had been greatly hampered by want of understanding of their limitations. Many comparisons had been made between petrol, steam, and electric cars; but at the present time it was quite useless to make such comparisons. There was nothing to touch an electrical vehicle for strictly

town work, and nothing to touch a steam or petrol vehicle for touring; but he firmly believed that in the near future a mixed system of electricity and petrol—a system in which a petrol-motor would drive one dynamo on the vehicle, and that machine would be at one time a generator and at another time a motor—would be a very important development of the industry. Colonel Crompton's remarks were extremely encouraging, but Professor Ayrton and Mr. Clarkson had taken a pessimistic view of the situation. He would like to ask how Professor Ayrton would arrive at his tell-tale for indicating the limit of 1·8 volt; because when running along a level road a battery might read 1·9 volt, whereas directly the same battery, a moment or two later, was taken up a hill of 1 in 10, the discharge-rate might be increased fivefold, and the difference of potential be as little as 1·7 volt per cell, which would be a false indication to the driver. With a little experience, the driver of an electric automobile could tell to within a few watt-hours the amount of energy remaining in the battery; if he could not do so he ought to get dismissed. Mr. Northey.

Mr. L. H. Rugg remarked that, as the Author had referred to worm-gearing, he had taken the opportunity of exhibiting on the table a worm-gear which had been successfully employed on the Lanchester petrol car. The gear shown had run several hundred miles. It would be noticed that there was but little wear; in fact, Mr. Lanchester had informed him that a similar gear had run for 10,000 miles with scarcely less efficiency than the one exhibited. The ratio of the worm to the wheel was 5 to 1; the worm was of hard steel, and the worm-wheel of phosphor-bronze. The interesting point was that the angle of the worm was as much as 45°, and with such an angle the worm could be driven backwards without the slightest difficulty. In regard to tractive resistance on roads, he had recently had the permission of the London Road Car Company to make some experiments with a view to ascertain the initial pull required to start one of their vehicles on various surfaces. The results were:—39 lbs. per ton for asphalt; 49½ lbs. per ton for wood-paving; and 104 lbs. per ton for dry macadam. In each case the road had been perfectly level, and the experiment had been conducted under the most favourable conditions. On asphalt which was a trifle greasy the initial starting pull had been found to be nearly 150 lbs. per ton, although the experiments had been conducted on a level road. The vehicle experimented on was an ordinary London Road Car omnibus, weighing 1 ton 18¾ cwt., and fitted with iron tires. Mr. Rugg

Mr. W. Worby Beaumont asked Mr. Rugg to explain the nature Mr. Beaumont.

Mr. Beaumont. of the dynamometer or apparatus with which he had measured the pull, because the figures mentioned, as to the pull required on wet asphalt compared with dry asphalt, seemed to suggest that the movement of the horses caused sudden jerks which differed from the slower pull when the road was dry; and that would explain to a large extent the wide difference between the 150 lbs. and the 39 lbs. per ton which Mr. Rugg had stated to be required to start the omnibus on dry asphalt.

Mr. Rugg. Mr. RUGG replied that he had made a mistake in giving the figure as 150 lbs.; it should be 79 lbs. In making the experiments the horses had been taken out on each occasion, and the initial pull, which had been put on gradually by three men in each case, had been taken by a graduated spring-balance which belonged to Dr. Kennedy, and which he thought might be taken to be fairly accurate.

Mr. Drake. Mr. BERNARD DRAKE mentioned that, when in New York during the past year, he had been struck with the great preponderance of electric vehicles over petrol vehicles in the streets of that city. Ladies were constantly seen driving their own cars—a thing to which people in England had not been accustomed. The president of the company controlling the chief battery patents, which had been formed into a large Trust, had informed him that accumulator-traction for automobiles was extending rapidly. It was not claimed that the working-cost compared with that of the petrol motor, but on the score of convenience and reliability the electric vehicle was first. In the question of petrol versus electricity, the relative cost of power was a small item compared with the labour. Labour in the States was even more expensive than it was in England; and cars which could be driven by any one, and could be relied upon to make short journeys for shopping or calling purposes without hitch, were those which were finding most favour in New York. With regard to the batteries, he had found that pasted cells of one kind or another were now being chiefly used. He had seen but little difference between the batteries now being made in New York and those which he himself had made, according to Reckenzaun's method, as managing engineer of the Electrical Power Storage Company in 1886. The plates in these cells had been very thin; the active material had been much the same as at present, and the output had compared very favourably with that of the Fulmen battery or any of the other batteries for which figures were given in the Paper. In fact Mr. Reckenzaun appeared to have been altogether before his time. The gears which had been made to his designs at the

Power Storage Company's works had included a worm-gearing run in oil, as applied to the first tramcars made; and a number of tests made with this gearing had proved it to be highly efficient. In comparing electric cars and petrol cars, the main point was the ease with which the speed could be varied in the electric car. In a petrol car the variation of speed was a mechanical problem which had not yet been satisfactorily solved; whereas in the electrical car it had been worked out, and the speed could be varied with the greatest ease within wide limits. In the petrol car different sets of wheels had to be put into gear, and often the edges of the teeth were destroyed. It was necessary to be careful to get the speed right before changing the gear, otherwise a breakage occurred. The engineer of one of the largest automobile manufacturing companies had remarked that it was a question whether it would not really be worth while to have an engine running continuously and driving a dynamo, and to have two motors to drive the wheels, thus doing away with the gearing and the incessant trouble caused by it. In regard to Professor Ayrton's first point, about constant current *versus* constant voltage for charging, he thought both systems were incorrect, and that an intermediate course would yield a still better result. It was quite true that when batteries were empty they could be charged at a high rate without energy being wasted in producing gas or heat; but as the battery became charged the current required to be diminished to zero in order to get the maximum efficiency; if it was not diminished, heat and gas were generated, showing that energy was being wasted. If, however, batteries were charged at the maximum voltage when empty, the initial current was excessive, and in time the active material would be damaged. Probably the reason why Professor Ayrton had obtained better results with the constant voltage than with the constant current was that he had charged at 20 amperes, and had stopped at 20 amperes as soon as the voltage had risen to 2·55 volts. If he had gone on diminishing from 20 amperes to 15 amperes, 15 amperes to 10 amperes, and so on, he would probably have obtained the same capacity in both cases. With regard to the weight of accumulators, the tendency in America and elsewhere was to use accumulators for only short runs, and not to attempt to run any such distance as 100 miles. If accumulators to run at most 20 to 30 miles were used, the battery was easily carried, and gave quite efficient results; but if accumulators expected to run 100 miles were put into a car, excessive weight would have to be carried, which would be expensive to maintain: in addition to which the motors and framing would become clumsy. For electric auto- Mr. Drake.

Mr. Drake. mobiles, under the existing conditions, he therefore recommended that they should be of light weight for short runs, and be confined to town use, wherein they would do good service.

Dr. Kennedy. Dr. ALEX. B. W. KENNEDY remarked that, as a member of the public rather than as an engineer, he would like to mention a few points which had particularly struck him. He was in agreement with what Mr. Drake and other speakers had said, and was glad to emphasize the point that, for town work, electric cars were so much more comfortable than other kinds that their adoption on an extensive scale was by no means entirely a question of cost. He hoped the cost would be reduced later on; but he did not think that question arose at the present stage, if the price had been brought down to a reasonable figure. He was not quite sure he could say that it had; but, if not, he felt sure it would be in time. In the last column but one of Table V. the Author had given a price which worked out to a total cost of 14*s.* per day. That, he was afraid, was not in agreement with the cost of running an electric car to an ordinary member of the public at the present time. Perhaps the figure quoted would shortly represent the price at which the car could be run, and he hoped the Paper would hasten the advent of that happy time; but he thought it was worth putting on record in the discussion that so far as he knew, an electric carriage—say a landau to carry three or four persons—cost £600 or £700, and unless the owner agreed to keep it himself and took the responsibility of the batteries, he had to pay about £200 a year—he believed that was the figure quoted by one of the companies for its maintenance; in addition to which he had to pay his own driver. At that rate the car cost about 24*s.* per day. Even that sum had not been sufficient, and was not sufficient, to deter many people from running such a car rather than a pair of horses. He had no doubt whatever that, for town work especially, electrically-driven cars would be more and more used, and become more and more popular. He entirely agreed with Mr. Drake that at present the question of running electrical cars for 100 miles need not be considered. Perhaps he ought to say that he was not entirely disinterested in the matter, for the extensive use of electrical vehicles would, as Colonel Crompton had remarked, be an excellent thing for electric-supply companies; but he did not doubt that the time would come when they would be largely used.

Sir Frederick Bramwell. SIR FREDERICK BRAMWELL, Bart., Past-President, mentioned that when he had kept a pair-horse landau in London he had kept accounts, and thus he knew exactly what it had cost, after making

every allowance for stable, rent, one man's wages, and renewal of the carriage in perpetuity. He would always remember the figure because it was exactly £1 per day—as many pounds in the year as there were days. Sir Frederick Bramwell.

The AUTHOR in reply pointed out that Professor Ayrton's "four hundred full discharges" (p. 47) should be forty full discharges, there being an error in his deductions. Colonel Crompton had taken some exception to the watt-hours per ton-mile given in Table III. The figures had been gathered from published results of the trials; and, taking into account the different constructions, some vehicles with roller bearings and others without, and the differences in the tractive resistance at different times and on various roads, the Author believed the results could be taken as reliable. With this explanation, it would be easy to appreciate the reasons for the differences between the 230 watt-hours per ton-mile given by Professor Ayrton for the London Electric Cab Company's vehicles, and the 50 watt-hours and 86 watt-hours per ton-mile given in the Paper for vastly improved and much lighter vehicles. Mr. Fliess in some trials in New York, under exceptionally favourable conditions, had obtained a result of only 26 watt-hours per ton-mile, which was about half that anticipated by the Author. Mr. Northey's statement as to the efficiency of modern worm-gearing, which had been corroborated by Mr. Rugg, was most instructive, and met the Author's objections. He was much indebted to all those who had taken part in the discussion. He considered that Colonel Crompton's and Mr. Drake's championship of the electric automobile and their remarks and explanations fully answered the criticisms of Professor Ayrton and Mr. Clarkson; while all had added to the Paper and had materially increased the knowledge of its special subject. The Author.