Correspondence.

Dr. Dudley. Dr. P. H. DUDLEY, of New York, remarked that comparison of some of the earlier formulas given in Appendix II. with those put forward in the Paper, sufficed to show that the formulas deduced by the Author from his recent experiments on modern rolling stock and permanent way of an English railway, accorded more nearly with present practice than the older formulas, particularly at low and at high speeds. The installation of so many high-speed trains in various countries had long since demonstrated the unreliability of the older formulas. The present conditions of service were not only better than formerly, but the elaborate and extensive tests, so well planned and executed, had enabled the Author to analyse the data collected more completely than usual, and to express them by more reliable formulas for the conditions of the tests. The conditions upon the English railways were so stable as to the construction of the equipment and track, that tests upon train-resistance should be conducted with great care, as in this case; for the results would be reliable for many years, until important changes in construction were made. Yet, as the Author indicated, each test was liable to vary in result from causes which did not come under construction or system, and many tests must be made to ascertain the mean result. It was, however, important to know the maximum conditions of operation, for they had to be provided for directly and indirectly in practice, and when they were known the causes were more likely to be ascertained. The freedom from, or the amount of, dust or grit on the rail-surface was an important factor in the rolling resistance, particularly of a long train. The Author pointed out that the results obtained would be modified by rolling stock of different wheel-bases. This was found to be true in the United States in both passenger and goods service, the load upon the axles being an important factor as well. For mineral traffic with cars having a capacity of 80,000 lbs. or 100,000 lbs., the wheel-base of the trucks had been increased, while the spacing between the trucks had been decreased from the former light cars. On 85-lb. rails, having a moment of inertia of 32 (in inch units), a few tests under moving loaded cars of 80,000 lbs. capacity at 15 miles per hour, had shown a continuous depression of the rails, sleepers, ballast, and road-bed for the entire train. The specific deflections in the rails under the wheels were

Dr. Dudley. the largest, but decidedly less than was usually the case under similar wheel-loads where the wheel spacing was sufficiently long for the rails to be relieved of strain in the centre between the trucks. The rails formed practically a continuous girder for the entire train, and a few tests had indicated a reduction in train-resistance. Coal-trains of 2,800 tons to 3,000 tons were drawn by American locomotives round 4° to 10° curves and even ½ per cent. ascending gradient on a tangent. On the New York Central and Hudson River Railroad there were several trains daily of 3,000 tons to 4,000 tons drawn by American locomotives, the number of cars ranging from seventy-five to ninety. The investigations upon the atmospheric resistance were very complete, and showed that while not as great as formerly supposed, it formed a large percentage of the total resistance at high speeds. It was by no means constant, but was one of the variable elements. The "method of experimenting" described at p. 161 was similar to the one he had used many years since for short runs. The speed for each second was indicated, so that the acceleration and retardation of the dynamometer-car could be ascertained for any instant. Mechanism should be provided to show the movement of the locomotives due to the irregular application of the steam; for this, together with the joints and undulations in the track, contributed to the oscillations in the "tractive-effort diagram." The formulas and curves therefrom, shown in *Fig. 11*, indicated what must be the case, viz., that the resistance increased with some power of the speed; and the ratio determined by the Author would be a welcome contribution to the subject. Comparing the resistances per train shown in *Fig. 11* with American trains of nearly similar weight and length, but of quite different construction, the resistance of the American three-car train of about the same weight but one-third shorter would be higher per ton. Comparing the Author's ten-coach train, 542 feet long, weighing 489,916 lbs., with the American six-car train, 460 feet to 475 feet in length, weighing 480,000 lbs. to 600,000 lbs., the resistance of the latter would be less per ton. The resistance of American trains of eight cars to fifteen cars, and of 800,000 lbs. to 1,500,000 lbs. weight, had been found to be less per ton for speeds between 40 miles and 65 miles per hour. The weight, as well as the length of the train, seemed to be a factor in reducing the resistance of American trains per ton. The conditions were, however, so different, that a larger variation in results must be expected when the weight was considered. The great reduction to train-resistance in America in the past few years had been due in putting stiffer rails in the tracks, quite as much as to improve-

Dr. Dudley. ments in rolling stock. In fact, the former had permitted the latter.

Mr. Lart. Mr. F. A. LART observed that the results arrived at and the deductions therefrom seemed to be somewhat inconclusive, as in previous investigations of this complicated subject. In any such investigations—as the Author himself admitted—there were so many varying influences to be taken into account, and so many unexpected and contradictory influences intervened, that any really practical, useful, or conclusive deductions or formulas were hardly to be expected. He thought the only measure of train-resistance which could be taken into account was the practical and unerring demonstration of the dynamometer, the records of which represented the total resistance of all kinds overcome by the power of the engine, and, in fact, its brake-horse-power. All theories as to the numerous resistances said to have been recorded by, or estimated from, the rather crude instruments or measurements of the Author, seemed to be valueless; they conflicted markedly with similar experiments and theories of previous investigators, though no doubt all such results contained a certain, if doubtful, measure of truth. But they were absolutely useless as bases for any particular or general formulas. The conditions under which the Author had experimented were probably as unsatisfactory as could be imagined, in regard to the lines over which the trains had been run, the varying and local conditions of wind and weather, and the periods of the trials and their discontinuity. It was all the more to the credit of the Author and his assistants that these trials had been so carefully and persistently carried out. Such trials, in fact, if they were to lead to any practical, conclusive and useful results, would have to be carried out on a much more extensive and exhaustive scale, if only to average the enormous variety of conditions met with, than would be possible on such a line as the Lancashire and Yorkshire Railway. There existed at Crewe the most valuable collection of train-resistance records that had ever been acquired, and these were especially reliable as being the simple records of the Crewe dynamometer-car, combined with brief notes of wind and weather, profile of the road travelled over, speed and load. They had been taken for a number of years by Mr. Webb, as a practice, with all classes of engines and trains, every variety of load, over all kinds of roads, and under all possible atmospheric conditions. It was much to be wished that some exhaustive study and public record of these Crewe dynamometer-trials could be made. Some points in the Author's wind-experiments were of much interest, and suggestive of many questions and theories. As regarded the area of head-resistance, this was usually taken, for purposes of calculation, as the maximum cross-sectional area of the train. But the Author's experiments showed, as had been previously noted, that with a head wind (taking the most symmetrical case) there was a large area round the sides and top of the front of each coach subject to practically the same wind-resistance as acted on the cross-sectional area of the train, which was equivalent to the combined velocities of the head wind and the train. The experiments with paper thrown out of the car-roof, falling between the two car-bodies, and then being carried through the window at the back of the car to the front end of the interior, were most interesting as showing the strength of the induced draught. This must have been considerable to carry the paper through the body of inert air filling the car, but there did not seem to have been any barometric measurement of this back-pressure on the car, nor of the back-pressure or partial vacuum (if any) at the back of the last coach on the train. This would possibly have afforded interesting information as to whether the induced draught immediately surrounding the train acted in an analogous way to the stream of water set in motion by a moving vessel. It was well known—and ships were, or should be, designed with this fact in view—that the resistance of a ship through the water was largely compensated by the induced flow of water acting on the sides, and more particularly on the "run" or stern of the vessel. It seemed safe to assume that a train in motion was similarly assisted, and some of the return air-currents noticed in the Author's experiments clearly proved this to some extent at least, which, with careful and efficient measurement, might be found to be considerable. The Author admitted that his experiments and results were inconclusive, if only on account of their being those of summer and generally favourable conditions. When a pupil at Crewe, Mr. Lart had recorded the locomotive coal-consumption and expenses for both train- and engine-miles for 12 consecutive months for the entire London and North Western Railway system, and having done so had averaged everything, in detail and generally, for passenger and goods, winter and summer, northern and southern division, and so on. The results had been interesting and valuable, indicating very clearly the greater train-resistances encountered in winter than in summer, and on the hilly northern division than on the comparatively level southern division of the line. On the point of axle-friction, the Author's experiments showed once more the superiority of oil-pad over grease lubrication. In

Mr. Lart.

Mr. Lart. this connection his own experience had led him to the conclusion that the narrow steps now universally used for carriage and pad-lubricated journals, especially if they were wholly or partially of white-metal, were not suitable for heavily-weighted journals, or journals of large diameter, such as tender-journals, as these constantly heated and fired, and had to be kept in good order by means of surreptitious grease stolen from wagon axle-boxes, or by liberal supplies of tallow. Such heating was a serious matter when white metal was present. Skin- or surface-friction was probably not a serious factor in train-resistance at moderate and high speeds, as a train carried with it, at its own velocity, an envelope of air which had merely an imperceptible rolling friction with the surrounding atmosphere. The question of train-resistance was becoming serious in view of the narrow limits, now practically reached, in the size and power of British locomotives, and of the development of these necessitated by the increasing weight of trains. The increase of speed on British railways had been checked for a number of years, owing to the rapid and excessive development of carriage-stock, chiefly on the lines of those public nuisances known as corridor-coach trains. The Pullman car in this country had, fortunately, by the good sense of the public and of the railway authorities, made practically no advance since its first introduction in the seventies. But only slightly less clumsy, inconvenient, and uncomfortable, and rapidly rivalling it in unprofitable dead weight, was the latest development of corridor-, dining-, and sleeping-saloons. Possibly in a short time one or two billiard- and concert-saloons might be provided on trains. These coaches were, unfortunately, merely typical examples of the prevailing "megalomania" and craze for Americanism. They were opposed to the simple, decent, unostentatious ideas of British comfort; their tare was utterly disproportionate to their gross weight and carrying capacity, and they were not only excessively expensive to build, but also to maintain and to run. An experienced engine-driver placed blindfold on his engine could tell at once, when he had started, if there was a corridor-, a dining- or a sleeping-saloon on the train, and also if there were eight-wheeled or twelve-wheeled bogie-coaches. When the train consisted entirely of such coaches, it was not surprising that pilot-engines were required, and bank-engines up Shap, or that engines which could easily and economically handle a train of ordinary six-wheeled or four-wheeled bogie-carriages, carrying the same complement of passengers and luggage, were incapable of keeping time with such dead loads, were so heavy on coal and oil, and required such frequent repairs. The frictional murmur of the eight or twelve journals of such coaches might be very soothing to drowsy passengers, but such music was discord to practical and common-sense engineers and shareholders. But for oil-pad lubrication it would not be possible to load journals in this way, and it could not be good for the structure of a coach, or for the unfortunate journals, or for the permanent way, that one-half of the journals, that was, those along one side of the coach or train, should carry three-fifths of the load, and the other side two-fifths. He had frequently been a passenger, both on the engine and in the train, by the 11.50 P.M. from Euston to Carlisle, a train composed entirely of the heaviest corridor- and sleeping-cars; this train usually made good time to Crewe in all weathers, where it took on two engines for the Carlisle run. A short time ago this train, having twenty-two coaches, reckoning six wheels per coach, which was $6 \times 22 = 132$ carriage-journals, had failed to reach Shap summit by about 85 yards; the rail had been rather greasy owing to an early October morning fog, and a delay of 45 minutes had ensued, with the brakes hard on, until a bank-engine had arrived from Tebay to help the train on to the summit. In his somewhat extensive locomotive and passenger experience over this road, such a stoppage had never previously happened; but with the ordinary day corridor-trains composed of eight-wheeled bogie-coaches, he had sometimes almost stopped dead in going up Shap, and even Grayrigg, with a perfectly dry rail, and in the summer months. The expenditure of coal in taking these corridor-trains up the Preston-Carlisle road amounted to not less than 50 per cent. more than on other parts of the line. The earnings per mile of these trains, with their clumsy, pseudo-luxurious fittings and ornamental attendants of the largest size and least usefulness, must be very low indeed. The comparatively short distances run in this country did not necessitate such heavy trains, and there was no need whatever for any coach to run with more than eight journals; the twelve-wheeled bogies of dining- and sleeping-cars were necessitated simply by their enormous tare and not by their carrying capacity. It would considerably reduce the coal-, oil- and tallow-consumption of passenger engines, and the lubricating-oil used on passenger coaches in this country if a return could be made to the old six-wheeled compartment coaches, though he did not advocate this, provided a moderate-sized four-wheeled bogie compartment coach was used. These six-wheeled coaches pulled extremely lightly, even round curves, and ran quietly; they were also much steadier than the super-sensitively hung corridor Mr. Lart.

Mr. Lart. bogie-coaches which were in a constant and uncomfortable state of vibration due to the short periods of oscillation in all directions set up by every disturbance in the rails, and by every moderate gust of wind. These oscillations being chiefly transverse were to some extent dangerous, and were also productive of much flange-friction.

Mr. Price-Williams. Mr. R. PRICE-WILLIAMS remarked that the series of experiments carried out by the Author with great completeness and judgment on the Lancashire and Yorkshire Railway appeared to have had for their main object the determination of the amount of resistance which trains alone, apart from the engine and tender, were subjected to when passing through the atmosphere at different speeds, and more especially when, in addition to being subjected to what might be termed the normal resistance of a still atmosphere, the vehicles had to encounter head and side winds, which, as the experiments conclusively proved, largely increased the resistance to the train. The effect of the latter, however, could not but be regarded as of an exceptional character, and as one which, although provision should be made for it in working the traffic, did not directly bear upon the question of normal train-resistance, the main factors of which were the resistance of the atmosphere in a normal or quiescent state, the axle-friction and the friction resulting from the oscillations of the vehicles. Attention was drawn in the Paper, however, to a significant fact, which had a very important bearing upon this question of train-resistance, viz., that the resistance per ton of the locomotive was considerably higher than that of the carriages, and also that the engine-resistance increased at a higher rate (p. 168). Having regard to this admission, it was evident that however correctly the formula $R = 2 \cdot 5 + \frac{V^{\frac{5}{3}}}{50 \cdot 8 + 0 \cdot 0278\, L}$ might apply to a train of carriages under circumstances such as those described in the Paper, it would not apply to the train including the engine and tender. In most of the train-resistance formulas cited by the Author, what might be termed the normal resistance of the atmosphere was assumed to increase as the square of the speed; and this was abundantly confirmed by the shape of the curves for the resistances obtained from the various formulas, as shown in the diagram, *Fig. 41*. As regarded the axle-friction, the results of Mr. Beauchamp Tower's experiments (to the great value of which fitting allusion was made in the Paper) conclusively proved that it varied very little with the speed; and by adopting his coefficient of 1·65 lb. per ton as an average, the results of the coasting-experiments with the two trains fitted with brass and white-metal bearings respectively, graphically recorded in Fig. 33, Plate 3, afforded reliable means of ascertaining what the actual amount of train-resistance was in the case of those two trains allowed to gravitate from a state of rest down the long steep gradient of 1 in 82 at Langho Bank, the length of which was shown to be about 16,800 feet, corresponding to a gravitating height of 204·88 feet, and to a speed of 78·32 miles per hour, which, but for the resistance of the air and friction which gravity took no account of, would have been acquired at the foot of that gradient. The actual speed, however, attained by both these trains, as scaled from the diagram, was about $56\frac{2}{3}$ miles per hour. This speed at the foot of the gradient would correspond to a vertical height $\frac{V^2}{2g} = 107\cdot2$ feet, which, deducted from the actual height of the gradient would leave 97·68 feet, the height due to the force of gravity expended in overcoming the resistances of the air and the axle- and other friction during the descent to the foot of the gradient with uniform acceleration. Mr. Price-Williams.

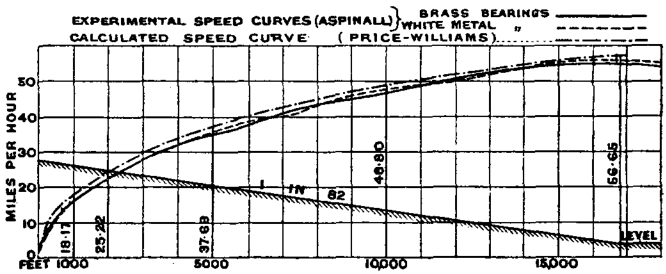
The force of gravity acting down the incline was $\frac{2{,}240}{82} = 27\cdot32$ lbs. per ton. The frictional resistances due to a fall of 97·68 feet in 16,800 feet were equivalent to a resisting force of $\frac{97\cdot68 \times 2{,}240}{16{,}800} = 13\cdot02$ lbs. per ton; the difference, 14·30 lbs. per ton, being the force exerted in acceleration. The speeds actually acquired by these two trains, which corresponded very closely, were shown in Fig. 33, Plate 3, at every 1,000 feet, and, as the following calculations (based on the assumption that the resistance of the atmosphere increased as the square of the speed) showed, they agreed almost exactly with what would result under such conditions after deducting 1·65 lb. per ton for the resistance due to axle-friction. The resistance of the air alone, according to D. K. Clark's formula was $\frac{V^2}{171}$ lbs. per ton, when V was in miles per hour. Thus, at 60 miles per hour, the air-resistance by this formula was 21 lbs. per ton. If v was taken in feet per second the speed in the formula became—

$$\frac{V^2}{171}\left(\frac{3{,}600}{5{,}280}\right)^2 = \frac{v^2}{368} \text{ lbs. per ton.}$$

By applying this coefficient, means were afforded with the following formula of calculating the speed at the different distances shown

Mr. Price-Williams. on the gradient, after making deductions in respect of the air-resistance and the axle- and other friction; and he had shown by a chain line in *Fig. 63*, which was a reproduction of a portion of the Author's Fig. 33, the curve for the calculated speed, which

Fig. 63.



corresponded in a remarkable way with that recorded during the experiments; and he thought the results of these two particular coasting-experiments down Langho Bank bore striking testimony to the correctness of D. K. Clark's formula for air-resistance, viz., $R_w = \frac{V^2}{171}$.

FORMULA FOR CALCULATING THE SPEED OF TRAINS, INCLUDING ENGINE AND TENDER ON A 1 IN 82 GRADIENT.

Let TP be the force of gravity down the incline after deducting the resistance due to axle-friction, which may be taken at 1·65 lb. per ton, according to Beauchamp Tower's experiments.

Then, since the incline in this case is 1 in 82,

$$TP = \frac{2{,}240}{82} - 1{\cdot}65 = 25{\cdot}67 \text{ lbs. per ton.}$$

Let Kv^2 be the air-resistance where, according to Clark's formula, $K = \frac{1}{368}$.

Also let $m = \frac{2{,}240}{32{\cdot}2}$ be the mass of 1 ton in absolute units. $\epsilon = 2{\cdot}7183$. If a train descends the gradient a distance s, increasing in speed from v_0 to v_1 feet per second, it can be shown that

$$v_1^2 = \frac{TP}{K} - \frac{\frac{TP}{K} - v_0^2}{\epsilon^{\frac{2Ks}{m}}}.$$

Let

$$\frac{TP}{K} = a^2,$$

and let

$$\epsilon^{\frac{2Ks}{m}} = \frac{1}{N};$$

then the formula may be written

$$v_1^2 = a^2 + N(v_0^2 - a^2)$$
$$= N v_0^2 + (1 - N) a^2.$$

Mr. Price-Williams.

But in this case

$$a^2 = 25 \cdot 67 \times 368 = 9446 \cdot 6;$$

also

$$\frac{2 \mathrm{K} s}{m} = \frac{2 \times 32 \cdot 2 \times 5}{2,240 \times 368} = \frac{s}{12,800}.$$

and

$$\mathrm{N} = \frac{1}{\epsilon^{\frac{s}{12,800}}}.$$

Example of Calculation of N.

ϵ	Log ϵ.	Log of Log ϵ.	Log.	
2·718282	0·1342945	$\bar{1}$·6377843		
	log s = log 1000 =	3·0000000		
		2·6377843		
	Log 12800 =	4·1072100		
		$\bar{2}$·5305743	0·0339292	1·081257 = Number.
		Complete Log	$\bar{1}$·9660708	0·92485 = Reciprocal.

For

1st length	=	1,000 feet:	N	= 0·92485
2nd ,,	=	1,000 ,,	,,	= 0·92485
3rd ,,	=	3,000 ,,	,,	= 0·79106
4th ,,	=	5,000 ,,	,,	= 0·67666
5th ,,	=	6,800 ,,	,,	= 0·58787
Total ,,	=	16,800 ,,	,,	= 0·26914

Application of Formula.

FIRST LENGTH ON GRADIENT, 1,000 FEET. (N FOR 1,000 FEET = 0·92485.)

Then by formula,

$$v_1^2 = \mathrm{N}\, v_0^2 + (1 - \mathrm{N})\, a^2,$$
$$= 0 \cdot 92485 \times \overline{0}|^2 + (1 - 0 \cdot 92485)\ 9446 \cdot 6,$$
$$= \quad + 0 \cdot 07515 \times 9446 \cdot 6,$$
$$= \quad + 709 \cdot 91,$$
$$v_1 = \sqrt{709 \cdot 91} = 26 \cdot 64 \text{ feet per second } (18 \cdot 17 \text{ miles per hour}).$$

SECOND LENGTH, 1,000 FEET.

$$v_1^2 = 0 \cdot 92485 \times \overline{26 \cdot 64}|^2 + (1 - 0 \cdot 92485)\ 9446 \cdot 6,$$
$$= 0 \cdot 92485 \times 709 \cdot 91 + 0 \cdot 07515 \times 9446 \cdot 6,$$
$$= 656 \cdot 63 + 709 \cdot 91,$$
$$= 1366 \cdot 54,$$
$$v_1 = \sqrt{1366 \cdot 54} = 36 \cdot 97 \text{ feet per second } (25 \cdot 22 \text{ miles per hour}).$$

THIRD LENGTH, 3,000 FEET. (N FOR 3,000 FEET = 0·791065.)

$$v_1^2 = 0 \cdot 791065 \times \overline{36 \cdot 97}|^2 + (1 - 0 \cdot 791065)\ 9446 \cdot 6,$$
$$= 0 \cdot 791065 \times 1366 \cdot 54 + 0 \cdot 208935 \times 9446 \cdot 6,$$
$$= 1081 + 1973 \cdot 8,$$
$$= 3054 \cdot 8,$$
$$v_1 = \sqrt{3054 \cdot 8} = 55 \cdot 27 \text{ feet per second } (37 \cdot 69 \text{ miles per hour}).$$

Mr. Price-Williams.

FOURTH LENGTH, 5,000 FEET. (N FOR 5,000 FEET = 0·67663.)

$$v_1^2 = 0·67663 \times \overline{55·27}|^2 + (1 - 0·67663)\ 9446·6,$$
$$= 0·67663 \times 3054·8 + 0·32337 \times 9446·6,$$
$$= 2067 + 3054·8,$$
$$= 5121·8,$$
$$v_1 = \sqrt{5121·8} = 71·57 \text{ feet per second } (48·80 \text{ miles per hour}).$$

FIFTH LENGTH, 6,800 FEET. (N FOR 6,800 FEET = 0·58787.)

$$v_1^2 = 0·58787 \times \overline{71·57}|^2 + (1 - 0·58787)\ 9446·6,$$
$$= 0·58787 \times 5121·8 + 0·41213 \times 9446·6,$$
$$= 3011·0 + 3893·2,$$
$$= 6904·2,$$
$$v_1 = \sqrt{6904·2} = 83·09 \text{ feet per second } (56·65 \text{ miles per hour}).$$

CHECK CALCULATION. TOTAL LENGTH OF GRADIENT 1 IN 82 = 16,800 FEET. (N = 0·26914.)

$$v_1^2 = \text{N}\, v_0^2 + (1 - \text{N})\, a^2,$$
$$= 0·26914 \times \overline{0}|^2 + (1 - 0·26914)\ 9446·6,$$
$$= \qquad + 0·73086 \times 9446·6,$$
$$= 6904·1,$$
$$v_1 = \sqrt{6904·1} = 83·09 \text{ feet per second } (56·65 \text{ miles per hour}).$$

He had found from an application of this formula to some of the experiments given in the Papers by Messrs. Stroudley, Adams and Pettigrew, and Walter Smith on this subject, that the results arrived at all tended to confirm the correctness of the conclusion that the resistance of the atmosphere increased as the square of the speed.

Mr. Riches. Mr. T. HURRY RICHES remarked that he had not been quite able to reconcile the resistance as deduced from the Author's formulas with that indicated by the curves in *Fig. 36*. From that diagram the resistance at 50 miles per hour, taking the Author's curve, appeared to be about 12 lbs. per ton; and again, in *Fig. 34*, at 50 miles per hour, the total tractive resistance was shown as about 14 lbs. per ton; but by formula No. 2 (p. 165) he did not make the resistance anything like as great, and he was not quite clear as to why this should be. Perhaps the Author would explain this discrepancy. He had been struck by the Author's remarks on the influence of the wind-pressure upon a train, and they had recalled to his mind some experiments which he had seen carried out (and indeed had had something to do with) many years ago, having reference to the movements of bodies in liquids. The particular feature in those experiments which recurred to him was the difference in the resistance to the motion of a tapered body through water when the large end was leading, and when the small end was leading; and he remembered endeavouring to ascertain the reason why, in pulling the small end first, the effort to drag the pole through the water was much greater than when the large end was leading. It had been found that when the small end was first, the skin-friction had a tendency to propel the liquid in the same direction as the pole, while the resistance of the adjoining particles of water caused the particles which endeavoured to follow the pole to at once radiate from the pole, and apparently to increase the resistance to the moving body. On the other hand, when the pole was being pulled with the large end first, and as a consequence the space occupied by the rear end of the pole was less than that in front, the water rotated, and appeared to create a series of rollers which materially reduced the skin-friction and upon which, in fact, the pole advanced; whereas when the small end led there was no effect of this kind, but rather a tendency for the particles in front to be crowded by those being constantly propelled forward by the larger diameter of the pole in the rear. He mentioned this as having a bearing on the question of the influence of the wind, either the "natural" wind, as the Author termed it, or the current created by the train in transit, acting as a retarding influence upon the motion of the train. It appeared to him that the direction of the currents shown in *Fig. 30* was very much in harmony with the results of these experiments with liquids. Of course with air the influence would be somewhat modified because of the elasticity of the air, but it seemed to him that the spaces between the coaches were somewhat similar to the diminishing diameter of the pole when pulled with the large end first, and he thought there could be no doubt that the more closely the carriages were coupled together, the less would be the influence of the wind upon them. If a train was run with all the windows closed, he could conceive that the resistance would be found to be less than if it were run with its windows open, particularly if the windows were open on one side only. So far as the last vehicle in the train was concerned, there could not be a doubt that the rear of the vehicle had a large retarding influence, and this influence would no doubt be dependent on the strength of the wind blowing in the opposite direction to the advance of the train, as compared with the wind blowing in the direction in which the train was travelling. Therefore it seemed to him that if, instead of making cones in front of the locomotives, as had been done in some cases, a cone were fixed behind the last vehicle, and the train were coupled together as closely as possible, or even made a corridor-train so as to close altogether the openings between the coaches,

Mr. Riches.

Mr. Riches. then the resistance due to the air would, in that way, be reduced to a minimum. He thought that for high-speed trains of the future, this question was worth a great deal more consideration than it had had in the past.

Mr. Sauvage. Mr. E. SAUVAGE, of Paris, remarked that every one interested in railway engineering would feel a great obligation to the Author for instituting elaborate experiments on train-resistance, and giving a very complete account of these experiments. As mentioned in the Paper, the formulas given were necessarily approximate formulas only, as the resistance depended on several variable and not precisely defined factors. The numerous observations of wind-pressures and velocities were of special interest, as the data on this point were meagre, owing, no doubt, to the difficulty of making observations. Appendix II. would be of great use, and to the long list of formulas there collected might be added the following, in which the symbols had the same values as those in that Appendix:—

Authority.	Value of R.	Conditions.
Eastern Railway of France, 1880[1]	$0{\cdot}316\,V + 5{\cdot}245 - \frac{w}{88}$	Complete formula.
	$4{\cdot}09 + 0{\cdot}316\,V$	Reduced formula, generally sufficient.
Fink[2]	$5{\cdot}6 + 0{\cdot}00579\,V^2$	Favourable conditions.
	$8{\cdot}39 + 0{\cdot}0087\,V^2$	Unfavourable conditions.
Northern of France Railway[3]	$3{\cdot}248 + 0{\cdot}00463\,V^2$	Goods train of at least thirty wagons.
Desdouits[4]	$3{\cdot}355 + 0{\cdot}00405\,V^2$	V between 0 and 50 miles per hour.
	$3{\cdot}355 + 0{\cdot}0925\,V$	V between 19 and 63 miles per hour.
Von Rochl[5]	$0{\cdot}0112 + 0{\cdot}000001965\,V^3$	Locomotives.
	$0{\cdot}0056 + 0{\cdot}000001965\,V^3$	Trains only.

Mr. Smith. Mr. STEPHEN SMITH, of Edinburgh, observed that he had long been interested in the question of atmospheric resistance to trains, and the possibility of reducing it by shaping the front and rear of the train as a "wind-splitter." His views were corroborated by

[1] *Revue générale des Chemins de fer*, 1881, part ii. p. 13.

[2] Couche, "Voie, matériel roulant et exploitation technique des chemins de fer," vol. iii. p. 647. Paris. 1876.

[3] Deharme et Pulin, "Chemins de fer, Matériel roulant, Résistance des trains Traction," p. 125. Paris, 1895.

[4] *Ibid*, p. 127.

[5] *Ibid*, p. 155.

investigation of the data in the Paper. It was obvious that axle-friction and miscellaneous resistances, including that due to side winds, should be approximately constant per ton, but that the head-wind resistance at a given speed should be nearly the same, whatever the length of the train, and should therefore vary per ton inversely as the length and weight. The Author's formula Mr. Smith.

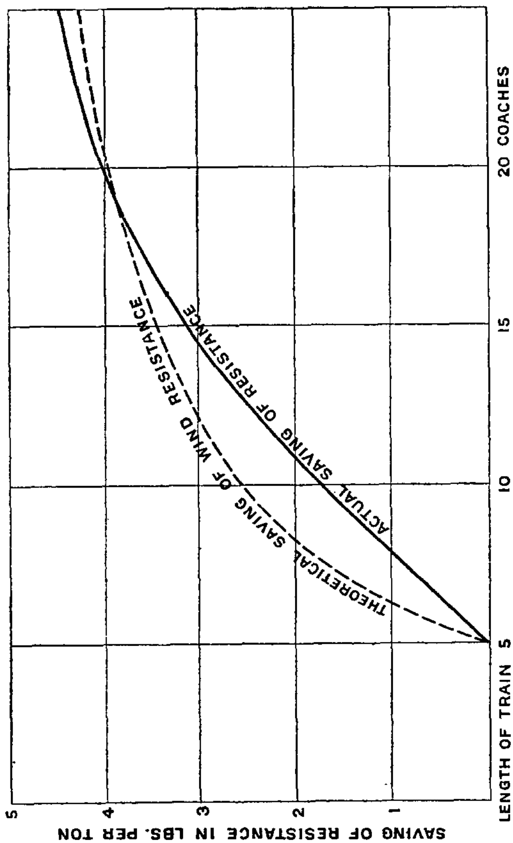


Fig. 64.

$R_w = 0{\cdot}003\ V^2$ agreed fairly closely with the theoretical value of the wind-pressure, viz., $R_w = 0{\cdot}0027\ V^2$, deducible from the simple formula for the dynamic head of fluids. With a speed of 60 miles per hour, the theoretical formula gave a wind-pressure of 9·72 lbs. per square foot, and taking the cross-sectional area of the train at 64 square feet, the total wind-resistance would be 622 lbs. Reducing this to pounds per ton for the various lengths

Mr. Smith. of train, it gave for the five-coach train, 5·4 lbs.; for the ten-coach train, 2·84 lbs.; for the fifteen-coach train, 1·93 lbs.; and for the twenty-coach train, 1·45 lbs., per ton; and the successive differences represent the saving of resistance theoretically effected in the longer trains. *Fig. 64* showed these differences plotted side by side with the actual differences in resistance at 60 miles per hour taken from the Author's Figs. 7–11. The actual saving of resistance at this speed was seen to be less than the theoretical saving up to a certain point, where the curves crossed, and this seemed to show that the miscellaneous resistances per ton increased up to a certain length of train, between eighteen coaches and nineteen coaches, and after that decreased. Transverse oscillation probably accounted for this, and a further comparison of similar curves for other speeds would likely show that at each speed there was a critical length of train for which the miscellaneous resistance was a maximum. The question of how far it might be possible to reduce the direct atmospheric resistance was one for practical experiment. In very long trains its relative importance became small; but in trains of medium length, at speeds approaching 60 miles per hour, it was by no means negligible, absorbing about 100 HP. In attempting to deal with it by shaping the ends of the train, the tail end was the more important, and he believed that it was quite possible to devise a simple and inexpensive portable pointed end, which could be easily removed, and would effect a considerable saving of power.

The Author. The AUTHOR, in reply to the Correspondence, observed that Dr. Dudley's remarks confirmed the results he had arrived at, but experiments had not been made to ascertain the effect on the resistance of the relation between the weight and the length of a train. Mr. Lart appeared to have a biased opinion of dynamometer-records. As already pointed out, in order to obtain anything like accurate results, it was essential that experiments should be made with a known load and over the same rails; not with a train of any description and a continually varying load, in the way many experiments were made. With regard to the locomotive coal-consumption and expenses being greater in winter than in summer, it was simply begging the question to say that because the consumption of fuel was heavier in winter the resistance was also greater, as there were a number of causes that would influence the consumption to a larger extent than would the difference in tractive resistance. He had already explained, in his reply to the Discussion, that the higher resistance of the engine, per ton, than of the carriages, referred only to the experiments mentioned at p. 168 of the Paper, and had undoubtedly been caused by compression of

The Author.

the air in the engine-cylinders when coasting. The conditions were not the same as when a locomotive was hauling a train. The calculations made by Mr. Price-Williams in regard to the two trains coasting down Whalley Bank were very misleading, on account of an erroneous deduction from D. K. Clark's formula. They were made on the assumption that the resistance of the atmosphere alone varied as $\frac{V^2}{171}$; which Mr. Price-Williams stated had been given by Clark as the resistance of the air alone. That was incorrect. Clark's formula for train-resistance, $R = 8 + \frac{V^2}{171}$, had been originally obtained from some experiments made by Mr. (afterwards Sir) Daniel Gooch in 1847 on the Bristol and Exeter Railway, of 7-foot gauge. Mr. Clark had stated that the total resistance was divisible into two parts; the constant and the variable resistance, of which the latter varied as the square of the speed. The constant resistance was due to the internal friction of wheels, axles and machinery; the variable resistance was due to the atmosphere, lateral oscillation and concussion, to vertical oscillations and concussions between the wheels and the rails due to imperfections of the permanent way, to the coning of the wheels, and to their consequent skidding on the rails at high speeds, and to other cognisable causes. Further, this formula gave the resistance of the engine, tender and train, while the coasting experiments down Whalley Bank had been made with carriages only; it would be seen therefore that proper comparison was out of all question. There were two curves on this bank, which would also affect the calculations. The experiment described in the Paper had been made chiefly to ascertain the relative frictional resistance of brass and of white-metal bearings, and the resistance deduced from it was not comparable with that obtained for the bogie-coaches, as each of these trains had been composed of seven six-wheeled coaches.[1] Mr. Riches had evidently not noticed that the diagrams from which he had taken his figures related to different trains, viz., *Fig. 34* to a five-coach train, 285 feet in length, and *Fig. 36* to a twenty-coach train, 1,057 feet in length. As the formula No. 55 (p. 192) had a denominator varying with the length of the train, it followed that the resistance of these trains would be different at

[1] The Author is aware that Mr. Price-Williams does not agree with his conclusions in this matter, though he is unable to examine Mr. Price-Williams's objections in detail before the publication of this volume.

The Author. the same speed. The experiments showed that the resistance per ton decreased as the length of the train increased. By the formula given, the resistance per ton of a five-coach train at 50 miles per hour (viz., 14 lbs.) was exactly the same as that of a twenty-coach train at 60 miles per hour. As to experiments on the resistance of tapered bodies, there was considerable difference in the "suction" when cones were moved through liquids apex first or base first. Mr. Irminger, who had carried out a great many experiments on atmospheric resistance with bodies of various shapes, had found exactly the reverse of Mr. Riches's experience. Still, the length of the pole and the fact of the fluid being water instead of air might have some influence on the result. Mr. Irminger's results in the following modified form illustrated the effect on different surfaces :—

Shape of Body.	Total Resistance.	Percentage of Total Resistance due to "Pressure."	Percentage of Total Resistance due to "Suction."
	Per Cent.	Per Cent.	Per Cent.
Lamina	100	45	55
Cone, base foremost . . .	71	63	37
Cone, apex foremost . . .	42	14	86
Double cone (two cones base to base)	25	18	82

From this Table it would be seen that :—(*a*) When the wind was blowing against a plane, the suction at the rear accounted for 55 per cent. of the total resistance. (*b*) When the wind was blowing on the base of a cone, the total resistance was 29 per cent. less than with a plane of the same area; but the suction was only 37 per cent. of the total resistance. (*c*) When the wind was blowing on the apex of the cone, the suction at the rear was 86 per cent. of the total resistance; but the total resistance was 58 per cent. less than with a plane of the same area. (*d*) When the wind was blowing on a double cone, the suction accounted for 82 per cent. of the total resistance, although the total resistance was only 25 per cent. of that of a plane. These experiments showed that a cone offered 29 per cent. more resistance when the wind was blowing on the base than when it was blowing on the apex; but in the latter case the suction at the rear was 49 per cent. greater than when the wind impinged on the base; or, the resistance of a cone, base foremost, was chiefly due to the direct pressure. The resistance of a cone, apex foremost, was

29 per cent. less than in the former case, but the resistance was chiefly caused by the suction. It would be observed what a marked difference there was in the total resistance between the plane and the double cone, the latter offering the least resistance of any of these bodies—which was equivalent to fitting prows both at the front and at the rear of a train. There was no doubt that the resistance would be less if the carriage-windows were all closed, as the experiments described in the Paper showed that wind entered at both sides of a carriage, even if the natural wind was blowing on one side of the train only. The diagram given by Mr. Stephen Smith was very interesting, the difference between the two curves being no doubt due to the miscellaneous resistances. The critical point, viz., their intersection, would be found to correspond to a shorter train when a lower speed was taken. *The Author.*

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3 December, 1901.

CHARLES HAWKSLEY, President,
in the Chair.

It was announced that the following Candidates had been admitted as

Students.

James Dudley Ward Ball.
Alfred Charles Böcker.
Arthur Boyd, B.Sc. (*Sydney.*)
Fielding Charles Robert Hatley Boyd.
Alexander Brebner.
William Arthur Burton.
Frederick Jonathan Bywater.
Gerald Otley Case.
Chyn.
Robert George Clark.
Reginald Hawley Clarke.
William Alfred Collins.
Leonard William Colman.
Albert William Cook.
William Mark Cross.
Edward Cryer.
Harry Cunningham.
Martin Deacon.
William Roberts Devenish.
Harold Edward Ernest Draper.
Alexander Walker Duncanson.
Ronald William Edwards.
Bernard Everard, B.A. (*Cantab.*)
Jocelyn Herbert Fanshawe.
Herbert Nicholas Funnell.
Lawrence James Douglas Gibson, M.A., B.Sc. (*St. Andrews.*)
Harry Melville Griffiths.
Ernest Gunson.
John Parkinson Hamer.
John Alfred Hardie.
Alfred Richard Harris.
Ernest Charles Burgess Heden, B.A. (*Sydney.*)
Oliver Walter Hindley, B.A. (*Cantab.*)
Leslie Haywood Hounsfield.
Edgar Hoyle.
George Edward Hunt.
William Lionel Jenkins.
Frank Percy Jennings.
Laurence Joseph Kettle.
John Norman Lapage.
Alexander Henry Law, B.A., B.A.I. (*Dubl.*)