

### Discussion.

**Mr. Bruce.** **MR. G. B. BRUCE**, President, said he thought the members, having heard the Paper, would, no doubt, agree with him in thinking that the Author had succeeded in laying before them a new application of power on a large scale in a thoroughly able, practical, and workman-like manner.

**Mr. Ellington.** **MR. E. B. ELLINGTON** desired to add a word with reference to the historical aspect of the question. Since the Paper was written he had ascertained that the first proposal to carry out a scheme of that kind in London was as long ago as 1858, and it would be interesting to the members to know that **Mr. Bruce**, the President, was the Engineer acting on behalf of the Company. The area then proposed to be served was along both sides of the river from Blackfriars Bridge towards the mouth, and he believed that the only reason why the works were not carried out was that arrangements could not well be made with the Water Companies. He was happy to say that the Water Companies had not regarded the enterprise described in the Paper with disfavour.

**Prof. Robinson.** **PROFESSOR HENRY ROBINSON** said the subject of the Paper was one in which he had himself taken part, having in 1877 brought before the Institution a description of works at Hull for a similar distribution of power.<sup>1</sup> He ventured then to predict that the principle of power co-operation would gradually gain favour with the business part of the public. At an early period, before his connection with the works at Hull, but subsequent to the time when the President was connected with the matter, he had more than once met a number of consumers of power in the City, with a view of promoting a company like the London Hydraulic Power Company. But the difficulty was not merely with the Water Companies, which had been referred to by the Author, but the fact that the consumers of power failed to appreciate the advantages of co-operation. There was great reluctance to place entire dependence upon one main, when each consumer had his own independent installation of steam-power. The fact that this reluctance had been overcome was a matter for satisfaction, and he felt sure that, in time, not only would hydraulic power be extended as a means of transmitting energy for various purposes, but that other systems which were now in vogue would come

<sup>1</sup> Minutes of Proceedings Inst. C.E. vol. xlix. p. 1.

more and more to the front. That opened a wide field of interest to engineers, and he hoped before long to lay before the Institution the results of works which Mr. Sturgeon and he were now carrying out for supplying compressed air on a similar principle of power co-operation at Birmingham. There was, he believed, an opening for both means of transmitting power. As a member of Lord Armstrong's staff twenty-five years ago, his old love was for hydraulic power, and although there was a certain amount of rivalry between the two systems, there was a field for both. In some cases, where it was desired to work expansively, hydraulic power was not so suitable as compressed air. In practice, the skilful decision of independent experts would enable the right place to be chosen for the right means of transmitting energy. He should be glad if the Author would state what amount of capital had been expended on the plant, and what upon the installation of engine-power and the mains. The balance-lift referred to by the Author was a useful appliance, but there were many others which could be worked from hydraulic mains, and he hoped that those who had had experience of machinery of that nature would describe them for the benefit of the members.

Mr. F. E. DUCKHAM said he was in favour of marine engines working direct single-acting pumps for the production of hydraulic power; he had both in use, though not in the same machine; he had marine engines in one place, and direct single-acting pumps in another; but were he to design another engine for hydraulic-power, he should be inclined to use direct single-acting pumps in combination with a marine engine. He should be glad to know what advantage, if any, the Author found from the arrangement adopted, namely, three steam-cylinders, one high-pressure and two low-pressure, taking their power on the up- and on the down-stroke, and three pumps working with the down-stroke only. He would suggest that it might be better to have an ordinary compound marine engine with one high-pressure and one low-pressure cylinder, and to prolong the piston-rods through the top and the bottom covers of those cylinders, connecting each piston with two plain plungers in two direct single-acting pumps; so that whether the pistons were on the up- or on the down-stroke, they would have the same work to do without transmitting power from one piston to the other pump through the crank-shaft. The Author had calculated 5 per cent. as slip to be allowed in taking water from the tank and forcing it into the main. An engine at Millwall Docks, having four direct single-acting pumps, had been tested, and it was found that the amount of slip in the pumps was very

Mr. Duckham, small indeed. The water gauged by measurement in the tank was practically the same as that measured by areas and the stroke of the rams. The Author had adopted self-feeding boilers with small coal, and he too had done the same. The advantages of self-acting stokers working with small coal, as compared with stoking by hand, had, however, not been mentioned. That was, perhaps, because the Author had commenced with mechanical stokers. The engines with which Mr. Duckham was connected were at first hand-fired, working with Babington coals at 14s. or 15s. per ton. After that McDougall's stokers were substituted, enabling small coal to be used at 9s. or 10s. per ton. It was found that the actual quantity of coals consumed per 1,000 gallons of water forced into the main was very nearly the same. The saving, therefore, by the mechanical stokers was the difference in price between the hard steam-coal and the small coal, and he need not say that this soon paid for the mechanical stokers. At the Falcon Wharf it appeared to have been necessary to filter the water. He could understand that it might be advantageous to filter water for passing through other people's machinery; but he had not found that hydraulic machines suffered much by using Thames water pumped direct without filtration. Occasionally some whitebait, little eels, and other small fry were found in the water, but that, however bad for the fry, did not affect the machinery. He did not know whether at Blackfriars there was any difference in the character of the water, whether there was more grit in it, rendering it necessary to have a filtering apparatus. The stop-valve mentioned in the Paper was an ingenious one, but he had not found it necessary to adopt any other than the old and more simple pattern, which two men could conveniently turn up or down without any such auxiliary arrangement as the Author had mentioned. If really needful to reduce the labour of opening and closing, he thought a by-pass might be used by which to equalize the pressure, or there might be such an arrangement as he had seen in Cumberland where low-pressure water was used—a little piston on the spindle of the valve, which would lower or raise the valve by the water-pressure. He had designed a relief-valve which acted very well. In external appearance the apparatus was like a Stilton cheese placed on top of a flat American one. Internally the upper portion was an open-top cylinder fitted with a cup-leather piston having an area of 30 inches; a mitre-valve, with an area of 29 inches, fitted on the same piston-rod, and had a seat on the bottom of the cylinder. Therefore with water at 720 lbs. pressure per square inch, ad-

mitted between the piston and the valve, the lifting power was Mr. Duckham that due to the difference in area multiplied by the pressure per inch, or, say, 720 lbs. The lower portion of the apparatus was fitted with a piston upon the same rod; this had a net area of, say, 72 inches; between the valve and this piston there was a pipe ascending to the water-tank, or otherwise. A head in this pipe equal to 10 lbs. per square inch, placed the apparatus in equilibrium. An increase of 1 lb., or 10 per cent., kept the valve on its seat with the normal pressure in the hydraulic pipe; but whenever that pressure rose to, say, 800 lbs., the valve was lifted and the water escaped freely past it. With regard to hydraulic lifts, he might refer to a lifting turn-table at Millwall Dock, for moving corn-laden wagons from one line of rails to another at a different elevation, and at right-angles to that on which the wagon might be. The lifting-press had two spiral grooves on the outside of its cylinder; a collar with friction-rollers fitted into these grooves, and was fixed to the framework of the upper table; consequently, as the ram of the cylinder was lifting the table it turned it round to the angle necessary to meet the other line at a proper elevation. It was a most convenient method, and used for lifting trucks of 20 tons weight. He was indebted to Mr. C. R. Parkes, Assoc. M. Inst. C.E., for co-operation in the production of this useful machine.

Mr. J. STURGEON understood that for an expenditure of £150,000 Mr. Sturgeon. only 800 gross HP. had been obtained at the Falcon Wharf station. He mentioned the matter because the Author had stated his belief that any idea of supplying power from the central station at rates much below those of the London Hydraulic Power Company would be chimerical. The figures given were equal to £187 per gross HP., or £375 per net delivered HP., at the Author's estimate of 50 per cent. all-round efficiency. In the Birmingham scheme the contracts were for providing 6,000 HP. at the central station for the same amount of money, viz., £150,000. In other words, the capital cost with compressed air was only £25 per gross HP., as against £187 on the hydraulic system, which was an excess of £162 per gross HP. for the latter. The interest on that excess was about equal to what was proposed to be charged to the consumers in Birmingham. Taking the all-round efficiency of compressed air at the very low rate of 33 per cent., the capital charge would be £75 per delivered HP. against £375 on the hydraulic system, the interest on the excess being thus £15 per HP. per annum. Out of the £150,000 to be expended at Birmingham, £100,000 was for constructive work; and, allowing 6 per cent. for repairs, wear and

Mr. Sturgeon, tear, and depreciation, that amounted to about £1 per gross HP., or £3 per net HP. per annum under that head. The Author had not stated how much of the £150,000 capital had been expended on constructive works which had to be maintained. He therefore could not estimate exactly what would be the rate per HP. for maintenance, &c.; but taking it at the same proportion as in Birmingham, namely, £100,000, it would be £7 10s. per gross HP., and £15 per net HP., as against £1 and £3 respectively with compressed air. He was speaking not from estimates only, but from actual contracts. Thus, in the two items of maintenance and interest on capital outlay, the hydraulic system was saddled with a charge of £27 per HP. per annum in excess of the compressed-air system. These first charges in the case of the hydraulic system, before coming upon the question of working expenses, were so large, and so small an amount of HP. was provided, that he did not see how it could possibly approach the compressed-air system in economy.

Mr. Bryan. Mr. W. B. BRYAN said it might modify Mr. Sturgeon's opinion if he were told that in laying a 6-inch pipe in the City the cost of disturbing the road was nearly £2,000 per mile. He had seen the pumping-station at the Falcon Wharf, and he could testify to the great forethought and care with which everything had been executed, from the pumping of the water from the Thames to its filtration and delivery into the accumulators. The pumping-engines appeared to him to be most efficient and suitable for the very varying power required. Fifteen years ago he was Engineer to a Corporation in the North, and he had to be present at an official trial of one of Shand and Mason's steam fire-engines, which had three steam-cylinders and three water-cylinders, with direct connection between the steam-pistons and pump-plungers, and a small shaft and cranks at 120°. He was much struck with the way in which the engine worked from the highest to the lowest speeds; and the London Hydraulic Power Company's engines on the same principle worked quite as smoothly. There was no doubt that the transmission of power by water at high pressure was one of the most economical modes that could be adopted; although compressed air and electricity had both fair fields for their application. Nine or ten years ago he had a troublesome case in dealing with some sewage from a district which had been newly incorporated by an extension of the Borough of Blackburn, and this new district lay 24 feet below the sewage outfall leading from the precipitation works to the farms. It would have been difficult to obtain land to put down a pumping-station with a

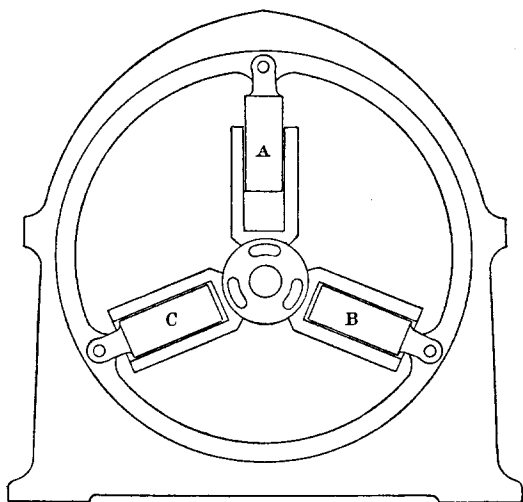
chimney, and a hydraulic pumping-station was designed by Mr. Bryan himself, the engines to be actuated by pressure from the town mains. The pressure in the mains was 125 lbs. to the square inch. The engines were made by Messrs. Easton and Anderson, and they had worked automatically from that time to the present, and had given no trouble whatever. Those little engines were capable of raising 1,000,000 gallons in twenty-four hours 24 feet high. They were fixed in a chamber 24 feet long by 9 feet wide, lined with glazed bricks, this chamber being placed under a footpath in a main road. At the Lea Bridge pumping-station of the East London Water-works Company a considerable amount of filtered water was formerly run to waste, by draining off, in order to clean the filter-beds. It seemed a pity to lose the water, and he accordingly designed a direct-acting pumping-engine to raise it about 10 feet with pressure from the existing mains. It raised 1,000,000 gallons a day, and worked efficiently and automatically. A difficulty arose in taking the pressure from the 4-inch pipe to the engine; the opening and the closing of the valve caused such a shock in the mains that he had to make a new arrangement to prevent it. The main being about 1,200 feet long, the flow of water into a cylinder 5 inches in diameter caused an enormous velocity, which being checked suddenly, caused the main to burst. To get over the difficulty, he adopted the following arrangement. An ordinary 4-inch sluice-cock had a hydraulic cylinder  $6\frac{1}{2}$  inches in diameter attached to the cover. The piston and plunger were coupled direct to the cock-door. The piston was  $6\frac{1}{2}$  inches in diameter and the plunger 4 inches, and the stroke was about  $4\frac{1}{2}$  inches. There was always pressure on the plunger side, there being a direct connection to the main. The communication to the piston side was through a small gun-metal three-way cock, the passages being about  $\frac{1}{2}$  inch in diameter. On the rising of a float a tumbler threw over the three-way cock opening the piston side to exhaust, and as the water escaped very slowly, the main cock was also opened very slowly. When the reservoir was pumped down the float sank to a tappet and threw over the tumbler and the three-way cock, shutting the exhaust and opening the pressure to the piston. The piston, being greater in area than the plunger, forced the water on the plunger side back into the main, and so gently closed the valve, thus entirely preventing concussion, by bringing the long column of water in the 4-inch main gradually to rest. At the Company's works water-power was used for several other purposes. There was a small turbine for driving Roots' blowers for the different forges, and the

Mr. Bryan. scrapers of the "economizers" were driven by hydraulic engines. The Author had mentioned that the duty of the engines could scarcely be compared with that of waterworks engines. He might compliment him on having got a duty of 80,000,000, which was a very fair amount. He was not a believer in the excessive duties which pumping-engines were sometimes said to be doing. At the present moment the East London Waterworks Company had some triple-expansion engines finished similar to those of the Author. Mr. Duckham had suggested putting a ram on the top of the cylinders, so as to make them double-acting. In the engines which Mr. Bryan had designed, about one-half of the power required to force the water was obtained simply by the weight of the connecting-rods, the plungers, and the piston, so that the engine was really double-acting. With regard to mechanical stokers, he had used those of three different makers, and he was sorry to say, that with the intermittent work that the waterworks company had to do, pumping direct into a district, they were very difficult to manage; so difficult, indeed, that he had been cautioned several times, and once fined £10 for the smoke caused by mechanical-stoking, and the three different systems had to be disused. With reference to the ordinary sluice-cocks mentioned by Mr. Duckham as suitable for high pressures, he had himself used them for pressures in a water main as high as 300 lbs. on the square inch, the difficulty of opening the main valve being got over by simply using a small by-pass, which was put into operation prior to the opening of the large cock. Mr. Duckham had also said that the use of water could not be compared with systems where expansive working could be used. Some time ago he had obtained one of Mr. Rigg's engines, which worked in such a way as to use water in equivalent proportion to the power required and governing itself, and he thought that this would open a very great field for employing water-power as economically as engines that could be used expansively. He considered Mr. Greathead's injector hydrant most effective for the purpose for which it was designed.

Mr. Rigg. MR. ARTHUR RIGG remarked that the Author had mentioned the requirements of a hydraulic engine for producing the best results from water-pressure in the mains, and he had stated that "what is required is a good durable engine with an automatic regulation of consumption of power-water according to the various demands on the engine." That was a perfectly accurate description. The Author had also mentioned an engine that Mr. Rigg had invented, with the object of producing the result to which he had referred.

It was totally different from any other engine hitherto constructed, Mr. Rigg. and had been working regularly for eighteen months, driven by water, by steam, and by compressed air, and it appeared to have behaved exceedingly well under all those conditions. There was a hydraulic engine running in the City of London driven from the mains, which the London Hydraulic Power Company supplied at 700 lbs. pressure, and it drove a dynamo producing one hundred lights. By using the engine as a meter, it took 33 gallons a minute to drive these lights, which was 80 per cent. duty, taking eight 16-candle glow lights as equivalent to 1 HP. As shown by Fig. 10, this hydraulic engine was provided with three

FIG. 10.



cylinders, all of which turned around their own centre, while the main wheel carrying their pistons turned round a different centre; the eccentricity between these two representing the length of the crank, which was, as it were, ideal. The stroke of each piston was determined by the length of crank, as usual; and it measured twice this eccentricity. For hydraulic engines, three cylinders were chosen, because pressure was continued during the entire stroke; and an equal tangential-driving effort was thus secured; but for steam-engines it was preferred to have four cylinders, because of alterations in pressure induced through expansion. Any slight variations were easily corrected by the engine itself, which constituted a sufficient fly-wheel, and the dynamo to which refer-

Mr. Rigg. ence had been made was driven at 700 revolutions with the utmost regularity while the engine made 240 revolutions, and no variation could be perceived in the lights produced. The engine had been run at 700 or 800 revolutions per minute; in fact, there was not the least difficulty in working a hydraulic engine with a good pressure at almost any speed. With steam, the engines had been driven at about 2,000 revolutions without any vibration worth mentioning. With compressed air, one of the engines had run without difficulty for two or three hours at 800 revolutions per minute with 60 lbs. pressure, and without any sign of ice in the exhaust. In Fig. 10 it would be seen that the cylinder marked A had its ram fully out; and at the exactly opposite position, the same ram would be close to the bottom of the cylinder. At B and C the other rams were approaching or receding from the bottom of their respective strokes. There were three ports, one connecting with each cylinder, and as they all turned round each was presented in turn before an inlet and exhaust opening of proper angular length and in suitable position, so that water was admitted on the left-hand side, and exhausted on the right-hand, and as the cylinder turned the pressure drove it round. To regulate the speed of the engine with the governor, it was necessary to adjust the stroke by moving the centres. If the two centres were coincident no movement would occur, but by moving the centres the required result was produced; and should it be desired to reverse the engine, the direction of the centres could be changed. If the engine were provided with a governor, the speed could be regulated uniformly, but as long as there was no governor the result of shortening the stroke was to increase the speed. It could be regulated to any speed, from a crawling movement to full speed. The power of reversing was very useful in the case of a capstan, there being no difficulty in running at a high speed in either direction; and barges or the largest ships were moved without difficulty. The model exhibited did about as much work as one man would care to do for long; and it, or others of the same size, were very successful in driving sewing machines, knife-cleaning machines, ventilating fans, &c. The stopping and starting of this engine was remarkably well under control, as there was no fly-wheel continuing the movement after the water-supply had been cut off; and there was no reasonable limit to its size. Thus this engine fulfilled the desiderata required, being able to give the high duty of 80 per cent., and no doubt more, while running at such speeds at high pressures as had been hitherto impossible. To these advantages might be added the capability of exact regulation,

whereby no more water was used than was required for the work Mr. Rigg. being done, or overcoming the resistance encountered.

Mr. R. H. THORPE observed that there could be no doubt that Mr. Thorpe. the London Hydraulic Power Company had conferred a great benefit on London, and in, perhaps, the majority of cases, it was better to take the power from its mains, and pay the moderate charges asked, than to attempt to generate power on the spot. But there were instances in which that was not the case; as, for example, in a city office-building in Warnford Court, opposite the Stock Exchange, in which there were three "Standard hydraulic elevators" daily at work. The Author, in giving examples of types of lift made at The Hydraulic Engineering Works, Chester, had stated that the machine at Palace Chambers was making four hundred to five hundred trips per day, and he gave that as the greatest number of trips with which he was acquainted for one lift in any office-building. At Warnford Court two small machines were making three thousand one hundred and eleven trips per week, and a large machine one thousand four hundred and forty-one trips per week. Those were full, not average trips. The height of the lifts was 50 feet. He had a statement of the cost of working the elevators at Warnford Court. Bearing in mind the cost of the coal, the cost of the man, and allowing rather more than a shilling per day for oil and waste, taking into consideration also that the water evaporated cost nothing, because it came from the well on the premises, and that the space was valueless, allowing further 7 per cent. depreciation on the cost of the pumping-plant, and 5 per cent. interest on the cost of that plant, and adding interest on the cost of the deep well from which the water was taken, the cost per week amounted to £6 19s. 8d. This service made the building perfectly independent of the Water Company. As water rate the company would have been justified in charging no less than £350 per annum. At £6 per week there was a sum of 19s. 8d. as the total cost of working those lifts, and that worked out at 0·052d. per trip; whereas, if hydraulic power had been used, the cost of the trip, with a consumption of 8 gallons of water, would have been 0·192d. per trip. If the power had been used for the lifts, by far the larger portion of the expense would have still existed, as the man and the greater part of the machinery would have been required for the deep-well service. Of course that was an exceptional case; but it showed that it was not always better to use hydraulic power than to generate power on the premises. It also proved that where steam-power was available it would be better and cheaper to put down a low-pressure pumping-plant, and

Mr. Thorpe. work with low-pressure machines, than to work with high-pressure machines from the hydraulic power of the Company's main. In small installations low pressure could be generated and used with less loss from friction than high pressure. In New York City, most of the buildings were heated by boilers during the winter, and there was a man to look after those boilers in the large and important office-buildings. That might, perhaps, be the reason why low pressure was so largely used in New York; not that high pressure was not known, for the American Elevator Company had built a number of machines working at 450 lbs. per square inch. Taking the case of a gas-engine, he might refer to the machine at 4, Mansion House Buildings, where the cost of running per day was 22.1d. at 2s. 9d. per 1,000 feet of gas. The elevator was making three hundred and eighty-five trips per day. Allowing 1s. 5d. per day (about £20 a year) for depreciation of plant, that worked out at 0.102d. per trip. Using power-water, and taking 3 gallons at 4s. per 1,000 gallons, the cost would be 0.14d. per trip. At Warnford Court, the calculated cost of power-water had been taken at 2s. per 1,000 gallons, at Mansion House Buildings at 4s. per 1,000. Of course, at Mansion House Buildings, the man who had to be on the premises looked after the gas-engine. If he had to be employed for the elevator service only, it would be a question at once of using power-water. He was prepared to admit that in the majority of cases for single installations, power-water could be employed with the greatest advantage. He desired to refer to the remarks made in the Paper on the question of safety appliances with regard to suspended lifts. The Author had taken, as a typical example of the best class of lift which was made, the lifts running at the Hotel Métropole, which, from the Author's figures, would perform work equal to about 50 per cent. of the power used. The maximum speed of those machines was 180 feet per minute, and he assumed that that speed was not with a full load, but with a light load. With such a machine as the Standard Hydraulic Elevator, there would be no difficulty in getting the maximum speed with a full load, if so large a margin as 50 per cent. were allowed. The Author had stated that suspended lifts were fitted with safety appliances of a very varied character, and that most of them failed in practice. He had also stated that he had no knowledge of any appliances which could be expected to act under all circumstances. Mr. Thorpe took exception to that statement, because no one knew better than the Author that the numerous machines which Otis Brothers and Co., of New York, had built must be carrying every day more than two million passengers,

and yet no accident had ever occurred by which a passenger Mr. Thorpe had been injured. The Author had stated that there had been some controversy as to whether the ram-lift was the simplest and safest type, but, he added that, as a matter of theory, there appeared to be no room for any real difference of opinion on the subject. He was glad that the matter had been referred to as one of theory; but, as a matter of practice, the Otis lift had been proved beyond doubt to be perfectly safe. The fact that the record was unbroken was worth any amount of theory. The extent to which the Author was wedded to the ram-lift could be seen from his statement, referring to ram-lifts counterbalanced with weights and chains: "the Author has no doubt that, even when so used, the ram is the best possible safety appliance; but the greatest safety in lifts is to be obtained by the general adoption of the simple ram without any balance-chains or counter-weights." The majority of the accidents to ram-lifts had happened by the giving way of the counterbalance or its connections. The Author further stated: "suspended passenger lifts will, however, continue to be used," showing, as he thought, a want of confidence that the ram-lift would keep the place in the public mind that it had once occupied. He did not wish to detract from the merits of the ram as made by the Author with its hydraulic balance, of which he was so justly proud; but at best the hydraulic balance could not be considered as anything more than an ingenious contrivance to get over the defects of a clumsy machine. He hoped that before two years had passed the members of the Institution would visit the forthcoming Paris Exhibition, and there have an opportunity of seeing lifts at work, larger, and travelling to a greater height, than any yet attempted. They would then also have an opportunity of judging whether any other system could be applied to that important service.

Mr. R. W. PEREGRINE BIRCH wished to ask if the London Mr. Birch. Hydraulic Power Company had found it desirable or practicable to persuade consumers of power to start their own accumulators. It appeared to him that an accumulator on the consumer's side of the machine would be worth a great deal more than an accumulator at the public station. Of course, it would be a very small one, say 5 to 25 gallons capacity. He should like to know if there was any reason against it, or whether it would not be of great advantage? The Author had stated, "it would appear, from certain observations that have been made, that the pressure is

Mr. Birch. better maintained at all parts of the system when there is a considerable demand upon the mains for power." He was sure that the Author did not mean that the maximum power was better maintained, but that the power available was more even. It was clear that when there was a great draft upon the mains, the head at the points of delivery must be less, but he thought there was an equally good reason why the head should be more constant than it otherwise would be, namely, that when there was a great draft on the main, it meant that the four hundred or five hundred lifts were going up and down at very short intervals, and then the combined power required would be much more even than if they went up and down at longer intervals.

Mr. Latham. Mr. BALDWIN LATHAM regarded the Paper as a valuable contribution to the knowledge of hydraulics, especially since some doubts had been recently thrown upon the question as to whether when water-pressure increased, the friction due to the movement of such water did not also increase. The Author's experiment, with reference to two accumulators at two distant points at opposite ends of long lengths of main supplying definite quantities of water, showed conclusively that there was no more friction with high-pressure water than with low, and the formula which was applicable to low pressure was equally applicable to high pressure. That was very important, and it cleared away many of the doubts which had been raised on the subject. There were, however, some points in the Paper on which he should like the Author to throw additional light. He had made use of the expression "divining-rod," referring to it elsewhere as a "sound-ing-rod." "Divining-rod" was an unfortunate expression. Some persons still believed that water could be found by the divining-rod, which consisted simply of a forked twig (generally a hazel twig), held in the hands by a person who walked about with it, in order to discover where water in the ground was to be found. It was a very old device; and it might be imagined that the Author had himself been using it in order to discover leakages. He presumed that it was nothing more than a kind of stethoscope, which had been introduced into water-works in order to find out, by the sound of the escaping water, the leakages or the valves that might be open. A question had also been mooted as to the relative efficiency of transmitting power by air and by water. He had himself much experience in this subject, and it was a question that had been discussed in the Institution in many forms. For example, in many sewage-works air was now used for

compressing sewage-sludge. Recently a Paper by Mr. Crimp had Mr. Latham. been read,<sup>1</sup> in which it was shown that, under a pressure of about 75 lbs. at the maximum (of course, very much less calculated throughout the whole of the operation), the efficiency by the use of air-power did not give more than 16 or 17 per cent. of duty. That, as a rule, was what was obtained in sewage-works where the air-compressors were located close to the work they had to perform; but where the work was at a considerable distance from the compressor the loss was decidedly greater. It was quite true that in conveying the same volume of water through mains of the same size the friction of the water was greater than that of air, as friction depended upon the density or the weight of the fluid. But from the fact that air-pressures were so much smaller than water-pressures, that the absolute amount of power depended also upon the bulk of the material used, and that owing to the large volume of air necessary to produce the same results, the power behind it to overcome the resistance being as the cube of the quantity, it was clear that air was not economical as an agent for transmitting power. Then water was a medium which was at once available for the purpose of transmitting power. There was nothing to do but to pump water, it having the properties of a rigid substance; a given pressure could be applied at one end of a main, and it was instantly transmitted to the other. It was not so with air; for when air was pumped under pressure, heat was generated, which tended to expand the air, and the consequence was that it was necessary to get rid of a larger bulk of air than was originally pumped, and the higher the pressure the greater the loss arising from the generation of heat, as the whole of this heat was lost owing to the cooling that subsequently took place, which reduced the bulk that had been pumped at high pressure. Every attempt to compress air isothermally, or by cooling air as heat developed, had only been partially successful. He had recently in a number of cases been using high-pressure water for transmitting power for automatically pumping sewage. At Friern Barnet, for instance, he was transmitting power from the sewage-works to a point a mile distant, and lifting the sewage of an isolated district 55 feet high into the gravitation sewers. The great advantage of using water for that purpose was, that the water employed as power was afterwards conveyed to an altitude of 100 feet above the pumps, distributed to self-acting flushing tanks, and made available for flushing the sewers. The volume of water so used was

<sup>1</sup> Minutes of Proceedings Inst. C.E. vol. lxxxviii. p. 175.

Mr. Latham, such that the cost, if bought from the Water Company, would not only pay for the whole of the fuel, but for the engine-drivers' wages at the works, including power for all purposes; whereas only a small part of the power was transmitted. Another instance in which he was carrying out a similar distribution of hydraulic power was the district of Esher, Thames Ditton, and Long Ditton, the latter place being farthest down the River Thames. Adjoining Long Ditton was the populous neighbourhood of Surbiton, the lowest part of which was occupied by the works of two of the large London Water Companies, and it was impossible to get rid of the sewage by natural gravitation in that direction, nor was there any space in Surbiton available for its disposal. Under these circumstances the sewage was conveyed to the higher part of Esher, for which purpose three automatic pumping-stations had been provided. The inclination of the sewers was against the fall of the district, and at certain points lifts were introduced, by which means the sewage was finally conveyed to the works, where it was pumped by steam-power. The men at the sewage-works controlled the whole of the operations of the separate hydraulic pumping-stations. The high-pressure water, which transmitted the power to the automatic pumping-station, was intended to have a pressure of 600 lbs. to the square inch. As the sewage fell in the automatic pump chambers, there was a float arrangement in the chamber which began to slow, and if it fell below a certain level it entirely stopped the machine. If there was little work the accumulator rose, and the men knew that there was little work to do. The accumulators were in direct connection with, and controlled the speed of the engines, so that the whole work was automatic, and the men employed at the sewage works did the whole of the pumping. Two sets of automatic pumps were fixed in one chamber, and they were so arranged that the floats were at different levels, so that if one pump was overpowered the second would come into work automatically. The water, after use, was sent into self-acting flushing-tanks which filled very slowly, and when full the contents were rapidly discharged into the sewers. There was, therefore, a saving of the cost of buying all the water in that district for flushing purposes, for which 1s. per 1,000 gallons would otherwise have to be paid. As it cost nothing like that amount to pump the high-pressure water, the power was being transmitted, and all the pumping done practically for nothing. In the other instance to which he had referred, the plan had been at work for twelve months with the most satisfactory results; and the saving was

greater, as water was more expensive to buy there than in the Mr. Latham. Esher district.

Mr. HENRY DAVEY said the Author had been careful to explain Mr. Davey. that his success had largely, if not entirely, depended on the special nature of the operations which had to be performed. The machines worked from the hydraulic mains were chiefly lifting-machines, to which hydraulic power was especially adapted, and it was difficult to conceive that any better or more mechanical system could be devised for applying power to such machines. The field of discussion had been rather widened by taking into consideration the general question of the distribution of power; otherwise he should be reluctant to offer the few remarks he was about to make. It had been hinted that the work done by the London Hydraulic Power Company might have been more economically accomplished by the use of compressed air. In the first place, he did not see how air-pressure could be applied to the majority of the machines which were worked from the mains. It might, of course, be employed in the little engine of Mr. Rigg's. It evidently could not be done as a rule without some extra mechanical appliance. He had been fortunate enough to have the opportunity of giving the efficiency of hydraulic transmission, and of transmission by compressed air, under almost identical circumstances, and the members might be interested in knowing the results of the trials. At the Newstead Colliery a large air-compressing plant was put down to work the underground hauling and pumping-machinery, and several very careful trials were made to ascertain the actual efficiency obtained. The power applied on the surface was 185 indicated HP. There were no means of taking the efficiency from a brake and ascertaining the work done by the engine underground. Only indicator diagrams could be taken; but on comparing the indicator diagrams from the engine doing the work underground with the indicator diagrams from the motive-power engines on the surface, when using 35 lbs. pressure above the atmosphere, an efficiency of 24 per cent. only was obtained. The efficiency would certainly have been much larger, but to what extent it was difficult to say, if the air had been used expansively. It was not so used; it was employed in direct-acting hauling engines without expansion gear. It should be understood that that was an instance of using air non-expansively. Experiments were then made to ascertain what would be the difference in the efficiency by increasing the pressure. Increasing the pressure 50 lbs. above the atmosphere, the efficiency was reduced to 14 per cent. He should not have given the example but for the purpose of comparing it

Mr. Davey, with the efficiency obtained with hydraulic power working under precisely similar conditions, namely, with direct-acting pumps and with an engine with no expansive action. At a large colliery at Marseilles<sup>1</sup> he had to put down similar machinery on the hydraulic plan—surface machinery for working the hauling engines and pumps underground. The surface engine indicated 229 HP., and the efficiency in water raised to the surface by the hydraulic pumps, and measured in a tank, was 54.2 per cent. That was in a twenty-four hours' trial. Thus, comparing the two systems, there was more than double the efficiency in the case of hydraulic transmission. He was satisfied that for the purposes to which hydraulic power was applied from the Hydraulic Company's mains the efficiency was double what it would be if compressed air were used. The effective water pressure at Marseilles was almost identical with that of the Hydraulic Company's mains, namely, rather over 700 lbs. per square inch. He had often tested the efficiency of small hydraulic machines by indicating the power-cylinder and indicating the cylinder of the engine doing the work; and the usual efficiencies obtained in that way were from 75 to 80 per cent., the actual efficiencies being, of course, a little less, varying with the tightness of the machine. In connection with the question of the general transmission of power, he had made one or two calculations. Some time ago, in Leeds, he mooted the question of supplying cheap illuminating gas for the distribution of power, and he was convinced that it would be almost, if not quite, the most economical system if, as might be expected, a further development of the gas-engine was attainable; but taking the gas-engine as it stood, he found that a gas-main of a given size would convey, in 18-candle ordinary illuminating gas, ten times the amount of power with the same frictional loss as would be transmitted by compressed air at 40 lbs. pressure; and if the pressure of gas was increased (which was not advisable) to 40 lbs., there would be nearly thirty times the power through the same mains. As to its commercial efficiency, Messrs. Crossley had stated that their engine gave about 1 HP. for 20 cubic feet of 18-candle-power gas; and, as in Leeds, the cost of 18-candle-power gas was 1s. 9d. per 1,000 cubic feet, that would be 50 indicated HP. for 1s. 9d. Taking coal at 8s. per ton, with an engine burning 8 lbs. of that coal per indicated HP. the cost came out exactly the same. So that, for driving small engines, it appeared to him that in a system of general dis-

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<sup>1</sup> Minutes of Proceedings Inst. C.E. vol. lxxxiv. p. 513.

tribution there was great hope for the gas system, especially as no great degree of purification would be necessary. Cheap gas, such as would be required for the purpose, might, he thought, be supplied at from 1s. to 1s. 9d. per 1,000 cubic feet in towns near coal-fields. Captain Shaw.

Captain EYRE M. SHAW, C.B., observed that there was only one small branch of the subject of which he had any special knowledge. Wherever the pipes referred to were laid, the inventor believed that he would be able to assist the mains in the streets in proximity, and had brought the matter before him on two or three occasions. About six years ago he had witnessed an experiment with Mr. Greathead's injector-hydrants at the Albert Dock. There was underground an ordinary water-pipe under a pressure of 15 lbs. per square inch; there was an engine-house close by with 750 lbs. pressure at the accumulator and 700 lbs. at the hydrant per square inch. When the water was turned on from the water company's main with the small pressure of 15 lbs. it rose, with a 1-inch jet, to a height of about 25 feet, which would of course be of very little use for extinguishing fire. When high-pressure water was added, the jet immediately rose to more than double the height, producing a stream of about 60 feet. That was done on a very small scale, but he had since watched with great care the development of it; it did not, however, appear sufficient to have it brought under the prominent notice of the body with which he was connected. All that was proved was the possibility, by driving water at a high pressure into a pipe containing water at a low pressure, to increase the power for the purpose of extinguishing fires. Yesterday, in consequence of what he had heard, he asked to see another experiment, which was much more satisfactory. In the part of London where he lived, close to the pumping establishment of the London Hydraulic Power Company, the normal pressure in the mains was about 40 lbs. per square inch. A hose was screwed to a hydrant close to the gate of the yard in which the Company did its work, and the water rose through the atmosphere to a height of 40 or 50 feet. The high pressure was then turned on through a  $\frac{3}{8}$ -inch opening. The water at the compressor stood at a pressure of 730 lbs., and as the hydrant was close to the gate it might be assumed that it stood at about the same pressure there. The moment that the high-pressure water was added the stream rose to a height of 90 or 100 feet, which was most satisfactory in every way, and would have been as useful as any fire-engine for extinguishing a fire. It had been proved that wherever the pipes lay in close proximity to ordinary low-pressure pipes, or even pipes without pressure, by

Captain Shaw. turning on one of the injector-hydrants a result would be produced just as satisfactory as could be expected from any single fire-engine. There were, he understood, 30 miles of mains in London, and a considerable length in other cities; and it was to be hoped that some means might be found for bringing those who had water under high pressure into communication with the public authorities, so that they might be able on reasonable terms to make arrangements to take advantage of so excellent an invention.

Prof. Lupton. Professor ARNOLD LUPTON thought the Paper marked an era in engineering in regard to power distribution. There could be no doubt that what was taking place in London was only a type of what was taking place in other towns. For years past efforts had been made in New York to establish a system of power distribution by means of steam, and electricians had been working hard to introduce a similar system by electricity. In Paris there was one by means of air; and in Switzerland he had seen various schemes of power distribution on foot at Geneva, Zurich and Schaffhausen. The scheme now being developed in London, which had its germ at Hull, was becoming one of the great factors of the day, and he, for one, who had known the Hydraulic Power Company for many years, was glad to see that its efforts were appreciated. That great scheme with a capital of £150,000, supplying, he believed, six hundred customers or more, was only the beginning of what would ultimately be accomplished in London. It was, of course, a small thing compared with the greatness of the City. Six hundred customers formed a very small number out of four millions of inhabitants; though he believed that when the advantages of the system of power distribution became more known, the six hundred would be multiplied by one hundred, and then perhaps by another ten. But he believed the Author would have to modify some of his ideas before that ultimate development took place. The Author said he thought it chimerical to suppose that any system of power distribution could be adopted by which the charge could be less than 2*d.* per HP. per hour. That was rather a high cost for the use of power continuously. Of course many persons who had steam-power of their own were paying more than 2*d.* per HP. for every hour's work got out of the steam-engine. That had been demonstrated at Birmingham and had been confirmed; an exhaustive inquiry on the point had brought out the fact that in some cases, where fuel was cheaper than in London, people were producing steam-power themselves, and using it at a cost approaching 3*d.* per HP. per hour. The question was whether it was possible to reduce the 2*d.* per HP. per hour. Professor

Lupton thought it was possible, and an investigation of the Prof. Lupton. Author's figures would show that it was much more probable than he seemed to imagine. He had mentioned 4*d.* per HP. per hour as the price at which he should like to supply power, and at which he was supplying it. How was that 4*d.* made up? Certainly not all profit. There was a capital of £150,000; but as the engines were capable of developing 800 HP., and they had actually worked up to about 500 HP. as a maximum, what was the capital charge upon the power supplied? Taking it to be 800 HP., the capital charge was very great. The power mentioned was 800 HP. at the works. A great authority on hydraulics had expressed an opinion that about 50 per cent. might be expected at the user's engines. Mr. Davey had given 54 per cent. as the useful effect in a ram at Marseilles, where the pipe was very short, and where the pressure in the pipe was exactly adjusted to the single pump actuated. At 50 per cent., and assuming 800 HP. developed at the works, there was about 400 HP. as the possible maximum used by the consumer. The interest and depreciation would amount to £33 per annum per HP., which came to about 2½*d.* per HP. per hour, taking the working hours of the day, or three thousand working hours per annum. With those figures it was intelligible that the Author could not see the possibility of reducing the charge below 2*d.* He would suggest, however, that the cost might be reduced by merely increasing the out-put. If a mine yielded 100 tons of coal a day the cost would be so much per ton, but if the production were increased to 1,000 tons it would be much less. In like manner, if the Author would multiply 800 HP. by 10, he would find that the total expenditure would not be much increased. The cost of taking up the streets would be much the same; the increased diameter of the pipes would not make much difference in the capital account, which, instead of being an overwhelming item, would be brought into subordination, the working cost being then the main item. The working cost, however, need not be so great. The HP. for forcing any fluid through the pipes should not cost more than ½*d.* per HP. per hour, including all the items of expenditure properly belonging to the engines. The power ought to be produced for 1*d.* including all costs. The difficulty was to effect the distribution at a moderate cost, but he thought it could be done. The Paper, while useful and replete with information, omitted one or two items which, perhaps, the Author would supply. He had hoped to find some figures showing the actual friction of water through this great length of pipes, but there were none. The Author had

Prof. Lupton. certainly said that he could send water through the whole circuit of the pipes with a 20-foot head, but at what velocity? It might be inferred from the Paper that there was a pressure of 750 lbs. per square inch at the accumulator at the works where the engines were, and of only 700 lbs. at the far end, where the lifts were working. If, then, the friction was 50 lbs. per square inch in the pipes, when the maximum service was equal to 500 indicated HP. at the engines, there would be, calculating by the ordinary rules, 125 lbs. friction if the whole 800 HP. were delivered. Some interesting information was given in the Paper as to the efficiency of the machines. The bulk of the machines, however, were hydraulic lifts, and it was absolutely impossible to tell what was the efficiency of a hydraulic lift. The lift was of a certain size, but no one could tell what was the load going up, unless experiments were made for the purpose. He therefore did not suppose the Author could give the average efficiency of the lifts. Some of the speakers had compared water with other means of transmitting power. It had been said that the friction of a fluid passing through a pipe varied as the cube of the velocity, and therefore compressed air could not be used; but that did not appear quite a matter of course. It was well known that compressed air was very largely used for transmitting power in this country, on the continent, and in the United States, both on the surface and under ground. Scores of thousands of HP. were at work in this country; in Michigan he had seen 500 HP. transmitted 3 miles by compressed air; in France he had seen 1,000 HP. of compressed air at one colliery; therefore the practical men who had erected the works had not at once seen the conclusion announced by hydraulic advocates. If it was true that the power required to overcome friction increased as the cube of the velocity, and if the diameters of the pipes and the velocities were chosen, it could be shown that one fluid had immensely more friction than another. He would assume that a certain amount of water was forced through a pipe under water-pressure, and an equal amount of power forced through a pipe of the same diameter under air-pressure; that the water-power was 700 lbs., and the compressed air was 45 lbs. Then, assuming that air was an inelastic material like water, there would be a greater quantity of air, and  $15\frac{1}{2}$  times greater velocity of the air— $15\frac{1}{2}$  cubed came to between 3,000 and 4,000. That had to be divided by the increased density of the water, and then the increased friction of the air was seen to be about 18 times that of the water. That calculation did not frighten the practical man, who, if he had a smattering of science, might know that

friction varied inversely as the fifth power of the diameter of the pipe; so that by slightly increasing the diameter, say substituting a  $10\frac{1}{2}$ -inch pipe for one of 6 inches, the friction could be reduced to the same as that of water. And what did it matter whether the pipe was 6 inches or  $10\frac{1}{2}$  inches in diameter? A  $10\frac{1}{2}$ -inch pipe at 45 lbs. pressure per square inch might be much cheaper than a 6-inch pipe at 700 lbs. A  $10\frac{1}{2}$ -inch pipe, with a lead joint, would occupy much less room than a 6-inch pipe, with the flanges shown in the Author's design, at the place where the joints were. That was taking the hydraulic advocates on their own ground; but he would go a little further than they always chose to go. With a hydraulic engine a certain amount of power was delivered into the pipes at the works, but before that power got to the consumer there were many reductions in it. Putting aside Mr. Rigg's ingenious engine, which had not yet been universally adopted, it was not found that hydraulic engines adapted themselves precisely to the work required; but when an engine was driven by an elastic fluid like air, the fluid necessarily adapted itself to the work to be done. An engineer designing works, or putting up an engine of any kind, always made it larger and more powerful, say 25 per cent., than was required for the maximum demands; but in daily work it was perhaps only performing half the maximum demand. There was, therefore, an inelastic fluid always pressing upon the piston, and the useful effect was only 40 per cent. of the power that would be got if all the power that reached the consumer was utilized; but as only 60 per cent. reached the consumer, only 24 per cent. of the power at the originating works could be utilized in this case. Then there was another side of the question. Air was not inelastic; it could be worked expansively, and its apparent power in the pipes increased one-third, so that, as a fact, instead of the velocity of air travelling through a pipe being  $15\frac{1}{2}$  times, it was only  $4\frac{1}{2}$  times the velocity of water, and owing to its less density the friction of the air, for a given amount of power used by the consumer, was less than half that of water for an equal diameter of pipe. So much for the theory. He did not think it was as simple as at first sight appeared to those who had not looked at the question all round. He had some experience of power transmission, and had found that if hydraulic engineers were asked the cost of a hydraulic engine and motor and pipes, and if then the cost was ascertained for the adoption of compressed air, it would be found that compressed air was the cheaper. That was the practical conclusion. He was by no means opposed to hydraulic power, which was excellent; but he was opposed to rather unnecessary

Prof. Lupton, statements condemning other systems. Mr. Davey had not the slightest doubt that the hydraulic system would give twice the useful effect of the compressed-air system, but he should like to have something more than that conviction. He thought the capital account of a works could be brought down, and it had been brought down in Birmingham to a comparatively small sum per HP.; he thought also that the working cost could be lowered so that power could be delivered to the consumers at a cost as low as 1*d.* per HP. per hour, and in towns where fuel was cheaper than in London he had no doubt, when the operations were on a very large scale, that it could be delivered to some customers at a profit for  $\frac{1}{2}$ *d.* per HP. per hour. It had been said that water was so convenient to use; it was always to be got. Fortunately, in this country, there were not many droughts; but water, as a rule, had to be paid for. Water was certainly convenient, and he did not object to what was said in praise of it; but what he objected to was the implication that air was scarce. In the town where he lived, he wanted some water, but he found there was a gentleman with prior rights, and who said: "The river is mine, and all the water that is in it." But no king who ever reigned had yet conferred a monopoly of the wind.

Mr. Price-  
Williams.

Mr. R. PRICE-WILLIAMS observed that shortly after the invention of the injector-hydrant, he induced Sir Henry Bessemer to accompany him to the Albert Docks, to witness an experiment similar to the one referred to by Captain Shaw, when Sir Henry remarked that "this great invention makes London safe from fire." In a discussion on the subject of the injector-hydrant, some years ago, Mr. Bateman, Past-President, objected that the time had not come for its adoption, as the construction of accumulators in different parts of the Metropolis, which it then involved, would prove too costly. A glance, however, at Plate 1, which showed the great extension of the London Hydraulic Power Company's system throughout the Metropolis, proved that this objection no longer existed; and now that Captain Shaw had expressed his approval of the injector-hydrant, he believed that London would soon be made safe from any great fire such as had destroyed Chicago. There were several points in connection with the results shown by Fig. 7 on which he should like further information, especially as to the probable economical effect of the cost of working to be expected from the extension of the system to other parts of the Metropolis. He thought such extension must necessarily tend to lessen the cost, and, within certain definable limits, to increase the present available average daily supply of hydraulic power

required for the engines, now to a large extent working intermittently, so as ultimately to approach, though it could never absolutely reach, the average shown by the line B. Mr. Price-Williams.

Mr. DUGALD CLERK wished to say a few words on the Author's comparison between gas power and hydraulic power. It was stated in the Paper that with equal flow in each of the five pipes the velocity would be 2·83 feet per second, amounting to 12,480 gallons of water per hour for each main. At 700 lbs. pressure 122 gallons were required to produce 1 indicated HP. for one hour, so that at that speed a 6-inch main was capable of transmitting about 100 indicated HP. But the loss of head in 1,000 yards was said to be 22·896 feet, or 114 feet in 5,000 yards. Thus in passing at the rate of 100 HP. through a 6-inch main there was a loss of head of 114 feet, or a little over 8 per cent. of the total power. That was fairly economical. But if 200 HP. passed through the main, the velocity would cause a loss, using the Author's formula, of about 30 per cent. at 5,000 yards; and if 300 HP. passed through, the loss would be 70 per cent., so that there would only be 30 per cent. of the power available for work, apart altogether from the loss of the engine. The Author, therefore, had done wisely in keeping the velocity at 2·83 feet per second. No doubt with that velocity fair efficiencies could be obtained from the main, but, as far as he could see, to render the extended distribution of hydraulic power possible, it would be necessary to have large mains, and thereby increase the expense. In the best tests, the engines gave  $178\frac{1}{2}$  HP., and the water pumped into the reservoirs indicated about 139 HP. At 2s. per 1,000 gallons of water a sum of 3d. per indicated HP. per hour was necessary on the hydraulic-power system, and supposing a very great efficiency in the hydraulic engine, at least 4d. would be required per brake HP. per hour. The following was the expenditure of one of his latest gas-engines in work at Birmingham:—

8 HP. CLERK GAS-ENGINE AT FULL POWER.

10 brake HP. required 240 cubic feet of gas per hour, say 13,000 cubic feet of gas per week of fifty-four hours:—

|                                                        | £     | s. | d. |
|--------------------------------------------------------|-------|----|----|
| Gas at 2s. 6d. per 1,000 cubic feet . . . . .          | 1     | 13 | 0  |
| Water, not more than 10 gallons per day, say . . . . . | 0     | 1  | 6  |
| Oil . . . . .                                          | 0     | 4  | 0  |
| Attendance . . . . .                                   | 0     | 3  | 0  |
|                                                        | <hr/> |    |    |
|                                                        | £2    | 1  | 6  |

This was 9·22d. per hour per 10 brake HP., or 0·92d. per brake HP. per hour including all expenditure.

Mr. Clerk. At half-power the engine used 138 cubic feet of gas per hour.

4 brake HP. on 138 cubic feet per hour, say, 7,400 cubic feet of gas per week of fifty-four hours:—

|                                              | £     | s. | d. |
|----------------------------------------------|-------|----|----|
| Gas at 2s. 6d. per 1,000 cubic feet. . . . . | 0     | 16 | 6  |
| Water . . . . .                              | 0     | 1  | 6  |
| Oil . . . . .                                | 0     | 3  | 0  |
| Attendance . . . . .                         | 0     | 3  | 0  |
|                                              | <hr/> |    |    |
|                                              | £1    | 4  | 0  |
|                                              | <hr/> |    |    |

This was 5·3d. per hour for 4 brake HP., or 1·3d. per brake HP. per hour with the engine only giving half-power.

He thought there was no chance of the hydraulic system approaching in economy anything like those figures.

Mr. Bodmer. Mr. G. R. BODMER asked whether the formula for the friction in the pipe was the result of experiment, or whether the Author had taken the usual coefficients? He wished also to know whether it had been found necessary, where the power was used for driving motors, to have a small accumulator in close proximity to the motor? Where the motors were single-acting, it might naturally be supposed that the work would scarcely be satisfactory without an accumulator very near the engine itself. Again, had the Author made any absolute tests of the water-meters used? For the measurement of water was one of the weak points in trials of hydraulic motors, whatever they might be. There was considerable scope for varying the efficiencies, according to the method in which the water was measured, unless very great care was taken. The Author had mentioned that a turbine had been tried in connection with the system, and it would be interesting to have a description of it. The chief objection to turbines with high pressure was that the circumferential velocity had to be very great in order to utilize the power with advantage; and, except in cases where dynamos were the machines driven, that was rather inconvenient, as the speed had to be brought down by gearing. He should like to know at least what system of turbine was being used. He believed that the only type suitable with very high pressures was the impulse turbine, where the water only acted on one or two vanes at once. A turbine used in that way had the advantage that it could be easily regulated. Some time ago he had contemplated having a turbine constructed to work in connection with the London Hydraulic Power Company's mains, and thought of applying the compound principle, which, it was well known, had been utilized in Mr. Parsons' steam-turbine, to reduce the speed; but on going further into the matter he came to the

conclusion that the efficiency would be very much reduced, owing Mr. Bodmer. to the necessity, after the water had left the first turbine, of collecting it, changing the direction, and bringing it into the second. As far as he was aware, for water-turbines the compound system had not been hitherto employed. He therefore abandoned the scheme, and he was confirmed in the wisdom of doing so after seeing Mr. Rigg's excellent motor, which he thought it would be difficult to beat by any turbine with the high pressures used. As a proof that impulse-turbines could be made to work with very high pressures he had particulars of a small wheel, constructed by a Continental firm to utilize a head of 1,800 feet, which had an outside diameter of  $14\frac{3}{4}$  inches, and ran at no less than 2,500 revolutions per minute; the head corresponding to 700 lbs. pressure per square inch was about 1,600 feet. He did not know what efficiency this motor gave; it was of the outward-flow impulse class with free deviation and horizontal shaft. He doubted very much whether the efficiency of turbines used with such a very great head would come anywhere near that of a reciprocating motor.

Sir FREDERICK BRAMWELL said there was only one remark that he Sir Frederick  
desired to make upon the Paper, and that one was hardly germane Bramwell.  
to the subject. The mode of obtaining a useful water-jet, in respect of which Captain Shaw had expressed an opinion, was very interesting on two grounds. One was that it demonstrated the interesting fact of the power of obtaining a jet from the compound source; the other cause of interest was that it added another instance of the manner in which electrical phenomena could be illustrated by those occurring in hydraulics. Those who took an interest in this latter science ought to see this apparatus at work; they would then witness the feeble result of turning on the small jet of the very high-pressure water, 700 lbs. to the square inch; then, stopping that jet, they would see the more forcible but still feeble result of turning on the water from the mains of the water company; and then, when this latter jet was flowing with the force due to the water from the mains of the water company only, they would witness the surprising effect produced by turning into it the small jet, which, although but a fraction of an inch in diameter, on passing through the large one communicated to that large jet an enormous energy in excess of that which it before possessed. The other ground on which this compound jet was to him of so much interest was, as he had said, its applicability as an electrical illustration. At the present time engineers had before them the growing problem of the transmission of electricity for

Sir Frederick Bramwell, lighting purposes from central stations; and they knew how that problem had been solved, in one case at all events, and probably it would be solved in a similar manner in other cases, namely, by the transmission of electricity at a very high electromotive force, at a force, probably, some twenty times that at which it would be used in the buildings where it was to be employed. By a suitable apparatus the electricity was made to diminish in intensity, and to have the energy represented by what he might call for convenience an increase in quantity. It appeared to him that whereas almost every previous electrical problem was capable of illustration by a corresponding hydraulic fact, this more recent electrical fact was also capable of illustration by hydraulic apparatus; and he looked upon the compound hydrant of Mr. Greathead, converting as it did the energy contained in a small quantity of very high-pressure water into the less force (if he might use the term), but multiplied into the greater quantity of water, thereby making an efficient jet—he looked upon it as illustrating most closely the way in which, for example, at the Carlton Club, electricity was received from the Grosvenor Gallery at 2,000 volts, and was converted into workable electricity within the building at 100.

Mr. Greathead. Mr. J. H. GREATHEAD observed that the discussion had to some extent turned on the comparative merits of air and water as distributing mediums of power. It appeared to him that in London, where the principal part of the power had to be employed for lifting purposes, there could be no doubt that hydraulic power was preferable to air. But in his opinion there was another reason why hydraulic power should be preferred, namely, the facility which it gave for the extinction of fire. In many cities, as in London, the water-supply had been arranged by the companies with a view of satisfying the requirements of their customers, and not with the view of the extinction of fire. In London, water had to be supplied gratuitously for the extinction of fire, and naturally water companies did not lay themselves out for that particular use of the water. It might be asked what was the importance of the supply of water for fire purposes. In London it was a matter of the utmost importance. Fires were growing at a rate very much faster than the population. In the last twenty years the population had increased about 37 per cent., while the number of fires had increased about 60 per cent. Then there was the question of the value of property at risk. In the last twenty years the value of insured property alone in London had almost doubled, and at the present time it amounted to £800,000,000, equal to the National Debt. The value of uninsured property might be

taken to be at least equal to that of the insured. It was, therefore, Mr. Greathead. obvious that Captain Shaw had a very serious responsibility; and he was naturally anxious to adopt the most approved appliances for the purpose of coping with fires. As far as Mr. Greathead had been able to obtain information, the amount of property actually destroyed by fire in London amounted to over £2,000,000 annually. How would the introduction of an efficient system of hydrants affect the destruction of property? It was only necessary to look for an answer to cases where efficient hydrants had been introduced. Mr. Bateman had stated that in Manchester after the introduction of high-pressure hydrants the loss from fire was reduced by six-sevenths; in other words, after the introduction of an efficient hydrant system the loss was one-seventh of what it had been previously. In Liverpool, according to Mr. Chadwick, the loss had been reduced to one-fourth of what it was previously. If the annual loss in London amounted to £2,000,000, and if the saving effected by an efficient system of hydrants was only one-fourth, or even one-tenth, of the saving effected in the places he had mentioned, it would amount to hundreds of thousands of pounds annually. It was obvious, therefore, that the question of an efficient system of hydrants in London was one of great moment. It might be asked, why not alter the general water-supply in London in order to fit it for the extinction of fires, as had been done in Liverpool and Manchester? The answer was this: In Liverpool and Manchester the supply was by gravitation, and the water as delivered had a natural pressure, whereas, in places like London, the whole of the water had to be pumped, and, of course, the water companies did not employ more power than was necessary for the purposes of their customers. It had been estimated, by the Engineer of the New River Company, that in order to pump all the water delivered to London, amounting to 150,000,000 gallons a day, to the additional height required to fit it for the extinction of fires, an expenditure would be incurred of at least £150,000 annually. In addition to that the general public would be hampered by the presence of an excessive pressure in many cases, and there would be also involved the re-laying of all the pipes and mains in London, and the construction of very heavy works. By the use of the hydrants which Captain Shaw had mentioned, the London Hydraulic Power Company's supply might be made available for producing jets of water from the ordinary water-mains as efficient as any that could be obtained either in Liverpool or Manchester, or in London by the use of fire-engines. It appeared to him, therefore, that the

Mr. Greathead. introduction of a general hydraulic-power supply with high-pressure hydrants, such as the Author had described, was a matter affecting the general public to an extent represented by a saving, if applied to the whole of London, of about £1,000,000 a year, a sum about equal to all the rates levied annually by the Metropolitan Board of Works. It was of very great importance to the public of London that such a system should be extended as far as possible; and he thought that the hydraulic system had, in that particular alone, merits far outweighing anything which could be said in favour of air as a distributor of power.

Mr. Kilgour. Mr. G. KILGOUR was at the present time studying the question of the transmission and distribution of power, with the view of its application to the working of certain gold mines in South Africa, and had found so many apparent disadvantages inherent to the use of water rather than air, that he took the opportunity of ventilating those disadvantages, more in the hope that the Author might in his reply dissipate them than in a controversial spirit. To make those difficulties readily understood, he would refer to Fig. 11, which showed broadly the three cases that were met in questions of power transmission; the first, where both prime and the driven motors were about the same level (as was the case in the work under discussion), the second where the driven was below the prime motor as in shafts, and the third where (as obtained in a particular case which he was studying) the driven would be above the prime motor. In the first of those cases the disadvantage of using so heavy a medium as water did not apply, and the Author had, wisely it appeared to him, preferred to work at the high pressure of 750 lbs. per square inch. This plan, although necessitating absolutely tight joints, avoided the dilemma of loss by friction that less pressure and consequent greater velocity must cause, or the cost of larger mains, and he therefore selected that case (the most favourable for water) for his first comparison, which would be found in the annexed Table.

COMPARATIVE COST of the TRANSMISSION of POWER on a LEVEL or DOWNHILL.

*Data.*

| Water (London)—                   |  | Air (Birmingham)—                   |  |
|-----------------------------------|--|-------------------------------------|--|
| Cost £150,000, expended HP. = 800 |  | Cost £150,000, expended HP. = 6,000 |  |
| Delivered HP. 50 per cent. = 400  |  | Delivered HP. 25 per cent. = 1,500  |  |

*Reduced to Common Unit. Delivered HP. 1,000.*

Working hours, 3,000 per annum; coal, 2 lbs. per HP. per hour, 10s. per ton.  
Interest and depreciation, 10 per cent.

Working expenses and maintenance, £10,000 per annum.

Cost, £375,000, expended HP. 2,000. Cost, £100,000, expended HP. 4,000.

*Estimate of Comparative Cost of Results.*

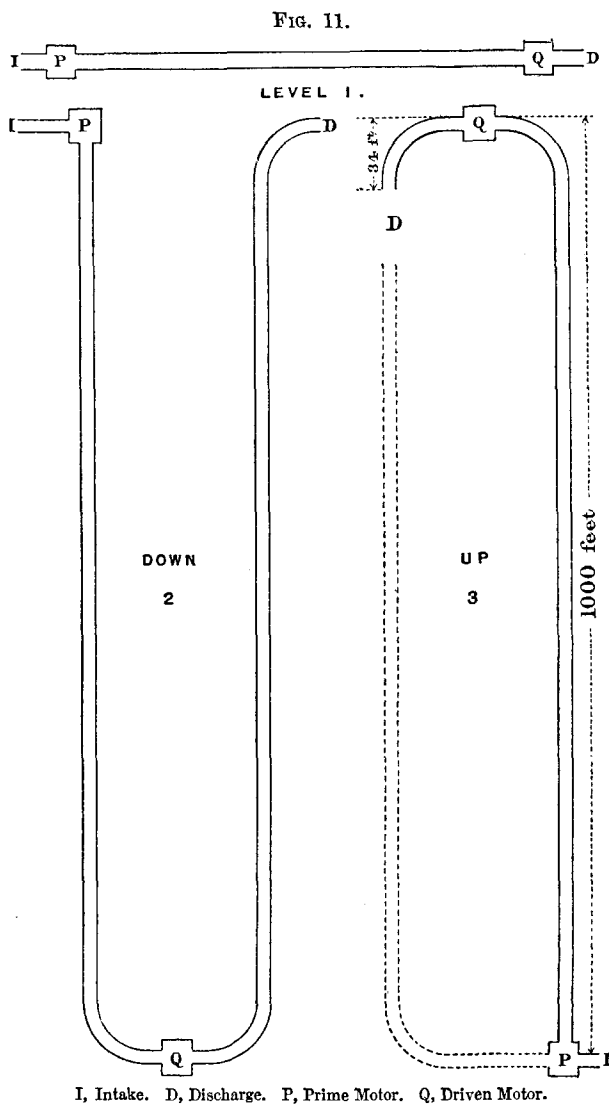
Mr. Kilgour.

|                                                      | £.             |                                                      | £.             |
|------------------------------------------------------|----------------|------------------------------------------------------|----------------|
| 10 per cent. on £375,000 . . .                       | 37,500         | 10 per cent. on £100,000 . . .                       | 10,000         |
| Working expenses and main-<br>tenance (common) . . . | 10,000         | Working expenses and main-<br>tenance (common) . . . | 10,000         |
| 5,400 tons coal at 10s. . .                          | 2,700          | 10,800 tons coal at 10s. . .                         | 5,400          |
| Total . . .                                          | <u>£50,200</u> | Total . . .                                          | <u>£25,000</u> |

showing the cost of air-transmission about one-half that of water where coal was 10s. per ton; but only 42 per cent. where water-power was available as the prime motor.

Here he had adopted in the case of water the Author's figures of cost, which probably included compensation for land, &c., and in the case of air those of the contracts for the Birmingham works, in which such compensation was included. Interest, depreciation, and working expenses were taken at the same ratio in each case; the hours of work per annum and the cost per ton of coal were made the same; whilst in both cases the consumption of coal in the prime motors was taken at the high rate of 2 lbs. per HP. per hour. The coefficient of useful effect in the water transmission at the driven motors he took at the Author's lower estimate, namely, 50 per cent., a figure that he thought he would find little difficulty in realizing; but although a good deal of information was available in the case of air as ascertained from the works at the St. Gothard, the Mont Cenis, and other tunnels, and more recently at the Forth Bridge, notes of which had been kindly supplied to him, he had practically taken the coefficient of useful effect for air from his own calculations. These showed that, with a pressure in the mains of, say, 50 lbs. per square inch, should isothermal compression be employed at the prime motor, with full expansion and reheating of the air to 200° at the driven motor, 60 per cent. ought to be obtained; but that with adiabatic compression at the prime, and without expansion or heating at the driven, motor it would scarcely do to reckon on more than 25 per cent., and that, the very lowest, was the coefficient he had adopted. He was aware that Mr. Davey only succeeded in getting 14 per cent., and indeed there was no reason to doubt that machinery might be devised that would return as low as 5 per cent.; but that was not the question under consideration. To obtain good economic results, air should be treated not only expansively at the driven, but also, if he might be allowed to coin a word, compressively at the prime, motor. He now converted these figures in both cases to a common unit of 1,000 HP. beneficial; and the result, to summarise briefly, was, as would be seen by the

Mr. Kilgour. Table, that where coal must be employed, at a cost of 10s. per ton (the Author's figures, he believed), power could be transmitted by



air at one-half the price that it would be were water used; but that where some natural force, such as a stream, was available, air

could claim an advantage of 60 per cent. And now, turning to case Mr. Kilgour. 2, where the driven was below the prime motor, there was a further disadvantage, since a return set of mains had to be provided to get the water out of the shaft, the friction was just doubled, and the benefit of the escaping air as a ventilating and cooling agent was lost. But case 3 was the one that he had specially to deal with. Here the source of power was a large and rapid stream, leaping down a rocky bed deadly with fever, capable of supplying power far in excess of that required. At some distance, with intervening broken ground, was the elevated and healthy plateau, say 1,000 feet above, where were the workings, the mills, machinery, and workmen's cabins, and where, during the dry months, the water-supply was little more than was required for the mill-tables and tailings, domestic purposes, &c. Here the driven motors must be placed, and an inspection of Fig. 11 would show that to obtain 800 lbs. to the square inch at the works would necessitate the enormous pressure of over 1,200 lbs. per square inch at the prime motor, and consequent largely increased expense of installation. Doubtless, by means of a costly down-pipe, the descending water might be utilized at the prime motor, but as more force was there already than required, that would be a doubtful advantage; whilst at the top there was as much water as wanted. The air system in such a case was free from that disability. He hoped he had made it clear why he considered that, with every factor in its favour, the cost of transmitting power by water would be double that of the same power transmitted by air; whilst under the circumstances he had just detailed, and which were those obtaining in the mineral districts of the Transvaal, a vast field for such appliances, water lay under a four- or five-fold disadvantage when compared with air.

LORD ARMSTRONG, C.B., Past President, said he certainly thought the Paper was calculated to give a great impulse to the principle which he had described and advocated. It was now more than half a century since he first directed his attention to the utilization of water pressure and its transmission for mechanical purposes. He did it then as an amateur. Like most amateurs he was an enthusiast, and his enthusiasm led him to anticipate the time when the practice would be widely extended, and would be used in populous centres for the distribution of power, but more especially for fluctuating and intermittent purposes, just as had been realized. His views were at that time regarded as dreams, but it was now a great pleasure to him to find that they had been fulfilled. But while water pressure had been rapidly

Lord Arm-  
strong.

Lord Arm-  
strong.

developing, it had met with a formidable rival in electricity. He had in his own private capacity—and still, as formerly, working as an amateur—employed both electricity and water pressure on his own property for various purposes, and he thought he was in a position to form some judgment as to the future of each. He felt satisfied that in point of safety, controllability, and adaptability to various purposes, electricity had little chance of ever rising to the level of hydraulic power. Moreover, the difficulty about the accumulation of electric power was such, that he could see no prospect whatever of its ever attaining the same simplicity and efficiency as had been attained by the hydraulic accumulator. Of course it might be said that electricity was only in its infancy, and he was inclined to think, and there was every reason to expect, that it would undergo very rapid development in regard to its dynamic application. He was, however, far from believing that water pressure, combined with the accumulator system, had yet reached its maximum development. The application of pressure derived from accumulators had hitherto been limited to direct pressure, and scarcely any attempt had yet been made to apply the turbine principle to the high pressures supplied by accumulators. The Hon. Charles Parsons had, as the members were no doubt aware, designed a steam-turbine which revolved at 10,000 revolutions per minute, and was coupled direct with a dynamo, which was of course worked at the same velocity. The objection which naturally suggested itself to the application of the turbine principle was the inconvenience of the high velocities; but if that velocity could be accomplished by steam, what reason could be assigned why it should not be accomplished by water? He did not mean to say that a turbine of any existing pattern could be driven with a pressure derived from accumulators. It would require very considerable modifications; but he had reason to believe that the obstacles were not by any means insurmountable. In designing a high-pressure turbine it would be necessary to eliminate leakage, because the quantity of water that would be used was so small that leakage, even of very small amount, would be a very serious objection. But that could be overcome. Then, again, it should be as nearly as possible without friction, because at high velocities the loss by friction even of very low intensity would be very serious. Belts, or anything that would produce heavy pressures, should be avoided. But he thought it within the bounds of practicability that a turbine might be constructed to work with any pressure up to the limits usually supplied by

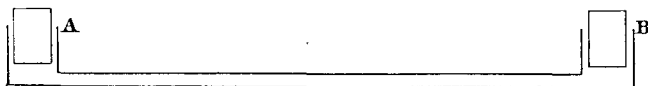
accumulators. Besides, there were alternatives. Sir Frederick Lord Armstrong had been just discoursing upon the reduction of electricity of a high tension and its conversion into a current of larger volume at a lower tension, and he had justly said that the same thing could be done with water. If it should turn out that the pressure of the accumulator was beyond the limit that could be practically applied to turbines, that very principle of reduction was available for the purpose of converting the tension of an extremely high tension current of water into a current of lower tension and of greater volume, which might operate in the manner of a continuous circulation, and thus drive the machine upon the turbine principle with a lower pressure and at a lower velocity. Of course there was also always a loss in the conversion of energy from one form or degree of tension into another. Sir Frederick Bramwell said that in the case of electricity, the loss in transformation was only about 5 per cent. Now the analogy in this respect between an electric current and a hydraulic current was so close that, with equally perfect apparatus, the loss might be expected to be equally small in both cases. Then, again, there were various forms of other machines which had never been utilized or tried with the high-pressure system. There were reaction machines, as exemplified in the old Barker's mill, various forms of impulse-machines, tangent turbines, and things of that kind, in which the power obtained, although not equal in efficiency to what was obtained from the true turbine, would be very considerable, and rank equal to any direct-acting water-pressure engine, and would yield the effect with very much lower axial velocity than the turbine. Only consider what an immense advantage it would be if machines of that character could be driven by those high pressures; there would then be a machine capable of supplying electricity for the lighting of an ordinary house within the compass probably of a small time-piece; the dynamo, judging from those produced by Mr. Parsons, would be equally compact; all the objections to steam and gas would be avoided; and, if machines of that character could be brought to perfection and utilized in that way, an immense impetus would be given to electric lighting, as well as to the use of hydraulic pressure, and the obstacles now experienced would be avoided. He was too old, and had had too much to do with inventions and their troubles and disappointments, to enter upon any new investigation of that kind; but he thought that the subjects he had mentioned presented a most promising field for inventors to operate in, and he hoped to see the day when some action would be taken in that direction.

Mr. Emden. Mr. WALTER EMDEN would only say a few words on what he thought to be one of the uses to which a force of the kind described could be applied. He had had to deal with public buildings, such as theatres, and had seen a good deal of the danger arising from fire, especially in connection with the stage. He had given his attention to the system known on the Continent as the *Asphaleia* system, where only hydraulic power was used for working the stage. The present form of stage was two hundred or three hundred years old. The stage was full of timber in every part, both above and below, and was very liable to be burnt. If that vast quantity of timber could be done away with, the public would be in greater safety, and a considerable advance would be made in stage appliances. The main reason against the use of machinery on the stage was the cost of working. If, however, the power could be obtained by simply turning on a tap in the way described, the rams might be worked so as to move every portion of the stage, and the power might be easily adapted to many or all theatre purposes. He was greatly interested in a system by which power could be transmitted all over London, and used easily and cheaply by theatrical managers, and he had no doubt that the Author's method of transmitting power would cause an entire revolution in such matters. The present system was as bad as it could be; any improvement would be an advantage; but an improvement which brought water at high pressure on to the stage would be of great importance, not only for working the machinery, but also for extinguishing fires.

Prof. Unwin. Professor W. C. UNWIN desired to point out an essential difference between the use of air and of water in the transmission of power, which seemed to have been overlooked in the discussion, and partly, where it might least have been expected, in connection with the Birmingham scheme. The discussion had turned on the question as to whether or not the loss of power in the mains was greater in the case of water, or in the case of air. In any way, that was a question somewhat unimportant, because he found that, even with the Author's scheme, power could be transmitted to a distance of something like 8 miles, at the velocity used, with a loss of only 10 per cent.; but he would point out that, even in that respect, air had an essential advantage. He would take a more extreme case than the one in question. Consider, first, a hydraulic system. Let  $u$  cubic feet of water, at a pressure  $p$ , be forced into a main by a pump at A (Fig. 12). Let the main be so long that at the motor B half the pressure was expended in friction. Then, apart from the efficiencies of the pump and motor, the work

expended at A would be  $p u$ , while the energy available at B Prof. Unwin. would be only half  $p u$ , one-half the energy having been wasted in friction in the main. Next, consider an air system. It appeared from the Papers of the Birmingham scheme that even there the fact had been overlooked that, with an expansive fluid like air, the case was totally different. There had been experience enough of the flow of air along mains to know that, when air flowed along a rough main expending power in friction, it flowed at a nearly constant temperature; consequently the volume of air varied inversely as the pressure. Hence, if, as before,  $u$  cubic feet of air were forced in at A at a pressure  $p$ , the work expended would be proportional to  $p u$ . At B, with a pressure of half  $p$ , the volume of the air would be  $2 u$ ; so the energy available for the motor would be proportional to  $p u$ , there being no loss due to friction in the main between A and B. Hence it appeared that, in the distribution of power to great distances, air had a distinct advantage in this, that the friction in the main was not directly a source of loss of energy. In an air-distribution there would be greater freedom in the choice of the size of main. It might seem

FIG. 12.



paradoxical, but in an air-main no energy was directly lost by friction. Indirectly a fall of pressure in the main might cause a diminution of the efficiency of the compressor or the motor. But this secondary loss would not counterbalance entirely the advantage possessed by an expansive fluid, that it increased in volume in consequence of the fall of pressure, and the heat generated by friction. Going a step further, he found that with a pressure of 750 lbs. to the square inch, with a velocity of about 3 feet per second in the mains (which he imagined to be as much as would be generally adopted with water), the 6-inch main would carry about 90 utilizable HP., that was, power which could be developed at the motor, supposing that no great amount of power was expended in friction in the mains. The efficiency of the air-compressing pump and the air-motor was less than that of the water-pump and the water-motor. In that respect the air system was inferior to the water system. Considered as a means of converting power at a central station into power at consumers' motors, he thought air was inferior to water. But with a very light fluid like air, and taking the velocity of the air in the



The energy utilizable in a motor, if there were no fall of pressure in the mains, would be  $a b m d$ . Hence the fall of pressure in the mains affected the efficiency of the arrangement as a whole, in the ratio of  $f g h d$  to  $a b m d$ . Fig. 13 was drawn to scale for air compressed to 60 lbs. (absolute), losing 30 lbs. by friction in the mains, and then working a motor which discharged into the atmosphere. Prof. Unwin.

Mr. C. R. PARKES wished to ask a question with reference to the divining-rod for detecting leakage in the pipes. He presumed that it was a metal rod with a diaphragm for an ear-piece, the point of the rod being applied to the place where leakage was suspected. Having made experiments in a different direction, to which he need not refer, he wished to ask whether the Author had tried a similar apparatus with a T-piece at the end made to fit the teeth, or the forehead. He had found that the nerves of the head, and especially of the teeth, could detect slight vibrations far better than the ears alone could do. Having fitted many machines for hydraulic supplies in London, he had found that the inequalities of pressure were considerable, and if a machine was designed for a certain maximum power, it necessitated making the machine or ram much larger than it would be if the pressure were more constant. His impression was that if there were more accumulators the pressure would be more constant. That raised another point, as to fitting machines such as cranes with multiple powers, to which the Author had not made much reference, and he would like to know what appliances he recommended for the purpose. It was a great point with consumers to use as little water as possible, and if they wanted to lift small bales and big bales they would like to use water in proportion. His firm had manufactured hydraulic cranes for many years, and had made various kinds of machinery, save-water appliances, for that purpose. At the present time an internal and external ram were recommended for small cranes; but for large cranes that was not very satisfactory; and for cranes of 30 cwt. or 2 tons or upwards he recommended two distinct cylinders, each cylinder having its own valves, pipes, chains, &c., the chains being carried up over two separate jib-head sheaves, and working side by side, but distinct from one another. This was called a compound crane. At first sight it might seem an expensive kind of machine, but in practice it had been found very economical. In lifting and discharging a cargo, the time was not taken up in the mere lifting and turning the crane so much as in slinging the packages and preparing the goods for it. With the machine to which he had referred, and which had been extensively applied to cranes, one chain would lift a large package; and while that Mr. Parkes.

Mr. Parkes. was being done a smaller package would be slung and then lifted after the first, the same turning-power doing for both. With a 2-ton crane there would be one cylinder of 25 cwt. and the other of 15 cwt.; and if it was wanted to lift the maximum weight of 2 tons, the two chains would be put together. The only point to be observed was that the chain of the smaller cylinder had to be rather stronger than would otherwise be the case. As a proof of the economy and dispatch obtained by that arrangement, he might mention that at Cardiff last week the s.s. "South Cambria," with 3,900 tons general cargo on board, was dispatched in ten and a-half hours by four cranes, leaving a margin of twenty-six hours over the usual time allowed for that quantity of cargo. He believed that that was the quickest delivery of general cargo on record.

Mr. Cowper. Mr. E. A. COWPER thought the question of transmitting power to a distance with the least loss was an important one, and he agreed with Professor Unwin that whatever loss of pressure there was from friction through the main, in the case of water, was so much loss of power, as water was inelastic. But he did not quite agree with Professor Unwin in the way he stated the case for air, which, being elastic, was greatly compressed in the compressing-pump, and raised in temperature by such compression, which heat it quickly lost in the mains in the earth. These, of course, would be at or near the temperature of the earth, and would control the temperature of the air within, whether compressed or expanded. If, however, the main was so long that the pressure of the compressed air was reduced to one-half of that at which it entered the main, there was so much less pressure to start with in the motor, and the indicator figure produced would be far lighter than the indicator figure produced from the full pressure of air. He therefore thought that in transmitting power by compressed air to long distances, there would be great loss from friction. But for shorter distances, say for 1 mile, which would cover the distance from the central station to many manufactories in Birmingham, the reduction in pressure by friction would be but small; thus a 14-inch pipe would convey about 631 HP., there being 45 lbs. pressure of air at the central station, and a loss of only 5 lbs. per square inch caused by friction through the main, always supposing that the motor at the end was arranged for such pressure, and to use the air as expansively as possible, that was expanding about two and a half times. In advocating the use of compressed air, or water under pressure, for the transmission of very large amounts of power, some people went possibly too far,

and hence there was a danger of a good system being condemned. Mr. Cowper. For instance, water under pressure, as had been described in the Paper, was an excellent arrangement for distributing power to a certain extent, and it was extremely valuable for lifts, hoists, cranes, and other small apparatus, where it was comparatively a matter of indifference whether the cost was  $\frac{1}{2}d.$  or  $2d.$  per HP. per hour; but the system would be far too costly for manufacturers requiring 80 or 100 HP. continuously, and it was not proposed for such cases. Moreover, there would not be room in the streets for mains to supply manufacturers generally. The system would be extremely valuable for the hydrants that had been described. The observations of Sir Frederick Bramwell showed that the more those high-pressure mains could be used, the more easily could fires be extinguished, because there was already a quantity of water in the low-pressure mains, and the high-pressure would make it valuable for useful work, by giving it pressure. The fact that fires generally occurred at night would leave the full use of the high-pressure mains available for the purpose in case of fire.

Mr. E. B. ELLINGTON in reply, said he had listened with very Mr. Ellington great interest to the discussion, and he might observe at once that nothing had been said which led him to think it would have been better to have supplied compressed air rather than hydraulic power in London. But bearing in mind what Mr. Cowper had said, he wished to remind the members that he had never advocated the supply of hydraulic power for continuous driving-engines to any large extent. Reference had been made to the Hydraulic Power Works established at Hull in 1875, as having pioneered those described in the Paper. The Hull undertaking was the first of the kind actually carried out, though, as he had already stated, Acts of Parliament had been obtained previously for London. He might, however, be permitted to say that the Hull Works originated with himself, and that he had always had the control of the undertaking, which was of an experimental character. The success in London was, he believed, largely due to the experience he had gained in Hull during his seven years' conduct of the enterprise there previous to the carrying out of the London works. He had no desire to show any want of appreciation of the work done by Professor Robinson, who had acted as Engineer during the construction of the first portion of the works at Hull; but it seemed to him that the observations made were liable to misconstruction without this explanation. Mr. Sturgeon had referred to the very great cost, as he thought, of the supply in London, as compared with the HP. he had

Mr. Ellington. put down at Birmingham; but he ventured to submit that the two sets of figures could not be compared. There were no data given showing how the £150,000 proposed to be spent in Birmingham was made up, but he believed that this outlay only included 5 or 6 miles of mains as against 27 miles laid in London; and the conditions under which the mains had to be laid in the streets of London were so different from Birmingham, and altogether the systems were so distinct, that they could hardly be compared upon that basis. It was quite possible that in Birmingham the first cost per HP. would be less; but that was hardly the question. Looking into the figures of the air scheme at Birmingham it seemed to him that the revenue that could be derived from the HP. provided in London, say 1,000 HP., would most likely equal the revenue that could be derived from 6,000 HP. in Birmingham; and 6,000 HP. could not possibly be worked at the same cost as 1,000 by the hydraulic system. The efficiency of the pumping-engines had been shown to be 80 per cent., and the efficiency of the air-compressing-engines was less than that, taking into account the loss of heat in compressing air, so that, supposing that compressed-air plant cost less, there was a large margin of working expenses to make up for any saving in that respect. But he did not think that Mr. Sturgeon really meant his figures to be taken seriously, because at the British Association at Birmingham in 1886 he had gravely stated that the cost of air-power was about one-tenth that of hydraulic-power on the basis of the Hydraulic Company's lowest charges. The efficiency of compressed air was estimated by Mr. Sturgeon at from 31 to 84 per cent.; but how were the high efficiencies obtained? They could only be obtained, if at all, by re-heating the air. The importance of taking into account the cost of heating air, in order to allow it to be expanded, was seen by the fact that it took 1 HP. to compress 2 cubic feet of air to 45 lbs. pressure, or say, 16,500 foot-lbs. of work. The heating of air up to a temperature of 320°, which was the temperature proposed for the most economical results, took 15,700 foot-lbs. of work, and yet the cost of that heating was not taken into account. The figures which he had given, and the opinion he had expressed that it would not answer under the circumstances existing in London to supply the public at less than 2d. per HP. per hour, were really confirmed by the advocates of compressed air, because he found that, taking only 300 cubic feet of air per HP. per hour, that worked out, at the Birmingham rate of 5d. per 1,000 cubic feet, to £16 5s. per annum for two thousand six hundred hours' work, which, allowing for the

necessary extra cost in London, nearly approached his own Mr. Ellington. estimate of £20. The cost of 5*d.* per 1,000 cubic feet of compressed air at 45 lbs. (60 absolute) was comparable to about 6½*d.* per 1,000 gallons for hydraulic power. He failed to see from his own experience in London, or the experience of other users of hydraulic power, how it was likely that that power could be supplied with profit at such a rate. There certainly was no reason for supposing that the cost of obtaining compressed air in the mains would be less per HP. than by the hydraulic system. He believed that in the estimate he had given, he had fully discounted the effect of any probable increase by the extension of the system in London. There had been a good deal said by various speakers upon the relative sizes of pipes required to convey power by hydraulic pressure and by compressed air. Professor Unwin had made the somewhat startling statement that air flowed along mains without loss by friction. It was clear, however, from the context that Professor Unwin meant something very different from the interpretation which would be ordinarily placed upon his words; because he was careful to explain that the fall of pressure which occurred during the flow of air along mains did reduce in practice the efficiency of the motor. But surely, this loss of efficiency being caused by the friction in the mains, it could not be right in any sense to say that there was no loss in transmission. It was admitted that the friction in the mains caused a fall of pressure both in the case of air and of water, and that fall of pressure, it appeared to him, was a direct loss caused by friction. No doubt the consequences arising from the fall of pressure were different in the two cases. He thought the demonstration used by Professor Unwin was liable to misconception. The expression  $pu$  in the two cases of air and of water did not, as it appeared to him, represent the same thing. Strictly speaking, the power-water had no energy; it simply acted as a flexible connection between the pistons A and B, Fig. 12. In the case of air,  $pu$  represented energy in the air itself, but being a constant assuming isothermal flow, was unusable. The usable energy in the compressed air had two elements, one corresponding to the expression  $pu$  used by Professor Unwin for water transmission, and being equal to the work done in pushing the volume of air into the main after compression, the other element being the work done in isothermally compressing the air from the atmospheric pressure to the main pressure. This latter was the only utilizable energy contained in the air itself. The remainder of the work done by the air was not by virtue of its expansive

Mr. Ellington. property, but was simply a connecting link between the prime mover and the motor, exactly as in the case of water or the pump-plunger itself. The fact of isothermal flow in air-mains, on which Professor Unwin's reasoning was based, seemed to require further experimental confirmation. In practice, the air in a long length of main, as pointed out by Mr. Cowper, would remain at the temperature of the surrounding ground, unless specially protected, and whether the air abstracted, or whether it diffused heat, would obviously depend on a number of highly variable circumstances. In calculating the HP. that could be transmitted through a 6-inch main by air and by water, Professor Unwin had assumed a much higher comparative efficiency in the motor for air than for water, and, however much theoretical considerations might support Professor Unwin's conclusions, it appeared to him unlikely that more HP. could be delivered in practice through a 6-inch main by air at 45 lbs. above the atmosphere than by water at 750 lbs. pressure. The interesting experiment at Birmingham would furnish the opportunity of setting at rest this and other matters connected with compressed air, on which at present there was a considerable difference of opinion. His remarks on the maintenance of the pressure in the mains had been rightly interpreted by Mr. Birch. There were some instances of accumulators, formerly required in connection with private pumping-plant now disused, having remained at work when the public power was taken. Mr. Parkes had also referred to the question of accumulators and variation of pressure; but investigation, following reports of insufficiency of power, had always shown, so far, that the fittings or machinery were at fault. What irregularities of pressure there were in the mains were more than covered by the margin of pressure supplied over and above the stipulated amount. A part of the discussion had been occupied with matters relating to the machinery used by consumers of the power. Mr. Rigg had given some interesting particulars about his engine. He should have liked to have had the full data of the trials made to determine its efficiency, stated to be 80 per cent. He felt very doubtful as to the accuracy of this value; if correct, it was a result in which Mr. Rigg was to be congratulated. On behalf of the Company he represented, Mr. Thorpe had spoken strongly in favour of the suspended type of lift as used in America, and had taken exception to the remarks in the Paper, advocating the greater safety of ram-lifts. He was still of opinion, however, that both theory and practice supported his views in this respect. He recognised the

value of recent improvements in the best suspended lifts as now made; but he was on sure ground in maintaining that the extended adoption of the suspended principle for passenger-lifts would tend to increase the number of accidents. Fortunately, the large majority of accidents to the machinery of lifts were unattended with serious consequences to life or limb. Mr. Thorpe referred to accidents that had happened to ram-lifts, when fitted with overhead counter-balance chains and weights; but these were not true ram-lifts, the ram in such lifts really serving as a safety apparatus. The fact that accidents had happened to them was a confirmation of the unreliability of the best safety appliances. What he was anxious to insist on was that, in the absence of special difficulties, it was better to use the simple ram as being, under equal conditions of design and manufacture, both safer and simpler than any suspended lift that could be constructed. There had been some remarks as to the limits within which hydraulic power could be supplied with advantage as compared with private plant upon the premises of users, and the case of Warnford Court had been cited as an illustration of the economy of providing pumping-plant, whether at high or low pressure, as compared with the cost of hydraulic power. But, on referring to the figures, he found the supposed economy was only obtained by crediting the full amount of the possible rating charges of the New River Company for the supply of the building, which was actually supplied by an artesian well. The cost was stated to be £363 per annum, or £6 19s. 8d. per week, and the amount that would have been charged by the New River Company was put at £350 per annum, and the difference was the only charge debited to the working of the lifts. Of course on that basis a very good result could be shown. The cost of pumping from the well being only about a tenth part of the total cost of the power used on the premises, 10 per cent. of the total cost should be the only amount credited to pumping water for domestic purposes; and, if that correction were made, the cost of private pumping would come out at 0·327d. per trip, as against 0·192d. for hydraulic power. The deep-well pumps could be worked by hydraulic power, and the heavy expenses mentioned by Mr. Thorpe would be saved. A much better case, therefore, would have to be made out against the want of economy in the public supply. Even large installations could be supplied with advantage by the Hydraulic Power Company, and the power was being taken in cases where as much as 100 HP. was required to work the lifts and cranes. Mr. Price-Williams was quite correct in assuming from

Mr. Ellington.

Mr. Ellington. Fig. 7 that the greater the total supply the nearer the line A would approach the line B; but, owing to intermittent demands for power, the theoretical minimum cost of supply which might be said to be represented by the line B could never be reached. It was the want of the recognition of the effect of intermittent work in increasing the cost of supply which was at the bottom of a good deal of the criticism that had been offered. It was hardly necessary to give a detailed reply to all the remarks on this point. The fact that the power had been so largely used within so short a period was a strong confirmation of the economy claimed for the system. Mr. Dugald Clerk allowed nothing in his estimate of gas-power for interest, wear and tear, depreciation, space occupied or for the time running light, all items which were comparatively very small with the hydraulic system, and which threw the advantage to the hydraulic side for intermittent work and small power. Mr. Kilgour had given what purported to be a table of comparative cost; but his figures were purely hypothetical. He took a mere estimate, including only a few miles of main of the Birmingham Works, and compared it with four years actual expenditure in London, including 27 miles of mains laid in crowded streets. He entirely forgot that the mains were sufficient for any extensions of supply through the medium of additional pumping stations. Then he put the working expenses and maintenance the same for both, though twice the power for air had to be maintained for the same amount delivered. He had no doubt at all that the cost of air per HP. delivered over an equal area in London would be more than double the cost of hydraulic power. Nevertheless, he had no hesitation in expressing his opinion that in the second case, in which Mr. Kilgour had requested information, air, as being required for ventilation, was a better agent than water. In the third case mentioned it would probably not be advantageous to use either water or air; it would be better to employ electricity as a means of transmission. He quite agreed with Lord Armstrong that, notwithstanding all the formidable rivals of hydraulic power which had appeared upon the scene, there was no fear about its being able to maintain the pre-eminence it had already acquired in so many directions, and that there was ground for expectation of a still greater development in the future.