

Discussion.

The PRESIDENT, in moving a vote of thanks to the Author, The President. remarked that the Paper was not only valuable in itself, as containing a very large amount of information collected with difficulty from many places, but was also valuable to engineers who had to do with overhead lines, in that it set forth suggestions—non-official suggestions though they were—as to what those lines might be in future, and submitted for frank discussion the outline of a system which the Board of Trade thought of issuing. It was much to the advantage of engineers generally, and to the credit of the Board of Trade that, through the Author, that method had been adopted, and that the system could be discussed from every point of view before it actually became an official set of regulations by which all engineers had to abide.

The AUTHOR remarked that since the Paper was written English The Author. overhead lines had been subjected to severe tests. At the beginning of 1907 there were about 40 miles of overhead line erected, and they had stood the very severe snowstorm at Christmas, 1906, without a single mishap. Since then, 10 to 15 miles more had been erected, which, with lines in process of construction, had weathered the recent very severe gale without a single mishap. He thought that spoke highly for the kind of work that was being done. The Author then exhibited a series of lantern-slides descriptive of existing transmission-lines, and demonstrated upon a model the result of cutting a line carried on flexible poles.

Mr. C. H. MERZ remarked that he had had to put down many Mr. Merz. cables where he would rather have put up overhead lines, partly owing to the difficulty of getting wayleaves, and partly on account of the large number of roads and wires that had to be taken care of in putting up overhead lines. He thought The Institution was greatly indebted to the Author, because the question was a very important one, now that the distribution of power over considerable areas would have to be undertaken. The cost of cables as compared with pole-lines was really about 3 to 1 if any large amount of power had to be conveyed. For long distances a cable might cost £2,000 or £3,000 per mile; so that if pole-lines could be erected on any extensive scale it would mean a large reduction in the capital account, which of course was really the chief question in all problems of power-distribution. With smaller powers the saving was not so

Mr. Merz. large. That brought him to the most important point in the transmission of electrical energy by overhead wires, namely, that the system was much more suitable for transmission than for distribution. Distribution entailed tapping the wires at different points, which further entailed terminal poles and other expensive arrangements. It might further be deduced that overhead wires would never be used as much in England as abroad, because the distances were so much shorter; in this country it would be always more a question of distributing electrical energy than of transmitting it. At the same time, great saving might be effected by the use of overhead wires. At first sight, when going into the question of taking a transmission-line through a district, it generally appeared that an overhead line should be used, but, on going into the matter further, it would be found that there were many roads to be crossed, there were Post-Office wires in the way, and landlords were difficult; and in many cases overhead lines which at first looked very promising had to be abandoned. Those difficulties in the end increased the price to the consumer, and it was to be hoped that with a Liberal Government in power it might be possible some day to get compulsory wayleaves over private property. The question of steel versus wood had been carefully considered in the work he had carried out, and he agreed with the Author in his preference for wood for all ordinary English lines, although he did not know whether he would agree that the wooden pole would last so much longer than the steel pole. Recently in the neighbourhood of Zürich he had seen some handsome concrete poles, and he thought that was a form of construction which should be carefully considered. The concrete pole was cheaper than the iron pole, it needed no painting, and it was certainly more sightly than a wooden pole. The Author's graphical illustration of the use of flexible poles was very interesting. Mr. Merz did not wish to suggest that the mathematical calculation of the stresses on the poles was not quite a good guide as to what should be done in practice; but he did not know that it quite took into account the jerk which, in the case of a wooden pole, would certainly seem to be the most serious strain that could be put upon it. Sudden breakage of the wires in a span caused a severe jerk to the neighbouring poles, and probably the calculations could hardly be made on the final position which the pole assumed. Guarding was certainly a great trouble, but it had to be done if the line crossed telegraph- and telephone-wires. He hoped that in time the Post Office would meet engineers more than they had done already—and they had been very good in discussing things—in regard to putting the telegraph-lines underground. Certainly, so far as the power-

companies were concerned they would be very glad to pay any expense incurred, and he thought it must be easier for the Post Office to put their wires underground than for engineers to divert a heavy transmission-line. He understood there were difficulties in the way, from increased capacity due to the wires being turned into cables for short distances; but already telegraph-wires through large towns ran for many miles underground, and therefore it would seem that there could not be much objection to putting them underground for a few additional yards.

Mr. JOHN GAVEY observed that his experience related rather to the construction and maintenance of telegraph-wires than to transmission-lines, but the two subjects were so akin that perhaps what was said of one might apply in a measure to the other. He desired first to correct a small error in the Paper which was due to careless editing in his own office. Referring to the second paragraph on p. 187, while both copper and iron wires were erected with a nominal factor of safety of 4, the statement that during a great breakdown a factor of safety equal to about 32 had been reached before the wires broke down, applied to iron wires, not copper. The iron wires used in those days had an elongation, due to ductility and elasticity, of about 10 to 13 per cent. The copper now used by the Post Office had an elongation that did not exceed 1 per cent., and the same data would not apply. With regard to the use of the weight per mile for describing conductors, instead of gauges or diameters, the Post Office adopted the weight per mile before the standard wire-gauge had been formulated, and when every manufacturer had his own wire-gauge. The use of the weight per mile was of considerable service for telegraphs in saving calculation; the weight per mile indicated at once the quantity required, and consequently enabled the cost of railway-carriage and cartage to be quickly determined; and the resistance of the conductor was found roughly by dividing the weight per mile by, for approximate results, the figure 900; or, more accurately, by 875.5, the weight of the ohm-mile. With regard to aluminium, he had had some interesting experience of the use of aluminium wire 7 or 8 years ago, when about 16 miles were put up in the Potteries for telegraphs, in lieu of copper wire. After being up for a few months the wires were broken in every span by the first heavy gale of wind. Sections were tested, and it was found that the tensile strength was practically unimpaired. The wire was repaired and suspended again, and the same thing occurred. The breaking-stress of the original wires varied from 340 lbs. to 365 lbs., and the normal stress with which the wires were suspended was 35 lbs. at the insulator, at 40° F.; and yet

Mr. Gavey. an ordinary gale of wind broke every span. He thought there must be some unexplained reason for the fact, for even though the wire were blown out at an angle of 45° , it was impossible to conceive that the breaking-stress had been reached. He therefore had some sections brought into the stores and cut into 36-foot lengths, which were hung vertically and weighted. The first section broke at 300 lbs., after $\frac{1}{2}$ hour's stress; the next broke at 280 lbs. after 5 hours; the next at 240 lbs. after 118 hours; the next at 220 lbs. after 525 hours. He thought that pointed to the fact that the failure was due largely to fatigue. He could hardly think it was due to the fatigue of the whole length of the wire; but in the early days there were difficulties in the manufacture, and the wire being probably not of uniform character throughout, the fatigue gradually affected the weaker places and caused fracture at relatively low stresses. He did not wish to dwell on that point, as no doubt the manufacture of aluminium wire had been improved since; he only referred to it because it was a matter to be borne in mind in considering the use of aluminium wire for overhead conductors. He was quite at one with the Author on the absolute necessity for elasticity in structures carrying transmission-lines. He had seen very many cases where accumulations of snow, combined with a gale of wind, had strained heavy telegraph-wires to such a degree that, but for the elasticity of the line, the stretching of the stays, and the yielding of the soil, miles of line would have been blown down which otherwise remained practically intact. They had been a little deformed, but had not cost much to put right. With regard to the causes of breakdown, reference had been made to the factor of safety used by the Post Office. He had never known a case of an extensive breakdown due to wind alone. The causes of breakdown that affected Post Office wires, and would probably affect transmission-lines, were, first, a combination of snow and wind, and, secondly, the falling of trees. When snow fell and the temperature was above the freezing-point, the wet snow adhered to the wires and accumulated till it had attained a diameter of 3 inches or $3\frac{1}{2}$ inches, and under such conditions, if even a moderate gale of wind arose, something had to give way. Heavy gales of wind in the autumn, when the leaves were on the trees, caused many trees to fall, and no line, either for power-transmission or for telegraphs, would withstand such stresses. Another cause, less frequent, might arise in mountainous regions. He had a case in South Wales where the line crossed a hill 1,000 feet high, and every winter the wires came down. Mist and fog were driven across the wires and froze on them until the diameter was

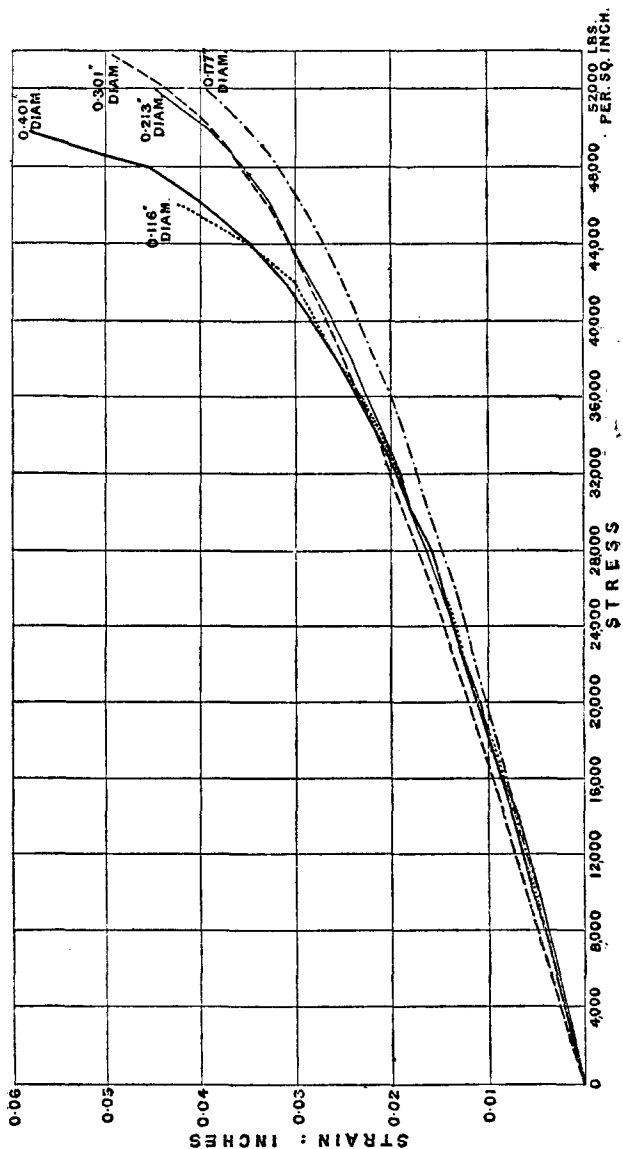
2 inches to $3\frac{1}{2}$ inches, and then something gave way, either the wires, Mr. Gavey. the arms, the supports, or the poles themselves. He had shortened the spans and increased the sag without effect; either the wires broke or they became twisted in an inextricable mass. He had given it up at last and put the wires underground, although even then he had been beaten, because in the following summer the turf caught fire and burned the cable. He had had cause to consider deeply the best means of guarding ordinary telegraph- and telephone-wires by means of cradles or otherwise, and occasionally he had had doubts as to whether it would be better to earth the cradle or to insulate it. Unquestionably, if an excellent earth could be provided, the proper thing was to earth the cradle; but in chalky or rocky soils the ordinary earth provided on a telegraph-line might vary in resistance from 5 or 10 ohms up to 500 or 600 ohms. If the resistance was high he was afraid the earthed wire itself and the guard would reach a very dangerous voltage and cause damage. Before trusting to the earth being effective, the actual resistance of the earth in all cases should be tested. With regard to Mr. Merz's remark as to placing telegraphs underground, he never hesitated to do so in order to avoid dangers from overhead structures, but the difficulty was with the telephones. At present, owing to the necessity for protecting telephone-wires from tramway and other moderate power-circuits, heat-coils and fuses had to be put in, which very materially increased the resistance of the lines. Between London and Glasgow there were lines which weighed 400 lbs. per mile, and owing to the interposition of the resistances the effective resistance had been reduced to the equivalent of 300 lbs. per mile, or, in other words, 25 per cent. of the speaking-capacity of those wires had been lost. To add the static capacity due to innumerable lengths of underground work would be so serious that he was afraid it might not be possible to ultimately speak over the wires for the distances for which they were provided.

Mr. E. W. MONKHOUSE observed that he had placed on the wall a stress-strain diagram (*Fig. 24*), for various sizes of hard-drawn ordinary commercial copper, the samples of which had been obtained from the British Insulated Wire Company without telling them what they were to be used for. The diagram showed the results of the testing of some of the samples, taking every other one. The curious thing about the tests was that taking the top bunch of wires, the elastic limit, the limit of proportionality, of all of them, was almost exactly 38,000 lbs. It was not shown very distinctly upon the diagram because there was no very clear limit: it had been found by observing when the elongation began to increase for a

Mr. Monk-
house.

Mr. Monk-
house. given additional stress. The Author said that a factor of safety of

Fig. 24.



about 5 seemed to be reasonable for hard-drawn copper wire, but Mr. Monkhouse would like to know whether the Author proposed

to take that factor on the limit of elasticity or on the ultimate breaking-load of the particular wire, because it made a great difference. If taken on the elastic limit of wires such as those shown in the diagram it really meant that it was not practicable to hang them up at all, because the poles would be very close together. Mr. Gavey had spoken about the percentage elongation of copper wire, and the Author suggested that not less than 15 per cent. should be specified; and on p. 187 it was said that the Engineering Standards Committee had laid down a certain rule to determine what was meant by hard-drawn copper wire, and had defined it as that which would not elongate more than 1 per cent. without fracture. Was actual elastic elongation or permanent elongation to be taken? If permanent elongation, it was a very difficult thing to get any two wires, or any two specimens of the same size of wire, to give the same permanent elongation. He had some results of measurements made on the same wires that he had used in plotting *Fig. 24*, and taking No. 1 S.W.G., the permanent elongation, exclusive of the fracture, varied from 0.1 per cent. to 0.5 per cent. On a No. 7 S.W.G. wire it varied from 0.6 per cent. to 0.1 per cent. On No. 9 S.W.G. it varied from 0.5 to 0, that was, there was no permanent elongation at all on one specimen. On p. 189 the Author, speaking of wind-pressure, said that the Post-Office practice was to allow 17 lbs. per square foot at a resultant point 22 feet above the ground. He was there talking of wires, but probably he meant it to apply to the calculation for poles, as it did not seem to matter what height above the ground the wire was. Again, the Author said that 30 lbs. per square foot would be a suitable wind-pressure to allow on wires. Mr. Monkhouse had recently had to design a line for a foreign country and had been told to allow 50 lbs., although he thought 30 lbs. was sufficient. With regard to cradles, the regulations, if there were to be any, should be amended, at any rate for abroad. He had just received a regulation which said that the cradle was to be three times the width of the transmission-line. That was not unreasonable when there were only three wires on a pole, but when there were six wires, or nine wires in the form of a pyramid, three wires on the top and six wires below on one bracket, three times the width of the transmission-line was absurd. In the first case the total width of the cradle might be something like 6 feet, but in the other case it would be 16 feet. If 2 feet outside the wires were sufficient in the one case he did not see why it should not be so in the other. The Author suggested that, until some further experience had been gained, work which would not warrant the use of at least No. 7 S.W.G.

Mr. Monk-house. had better be carried out by underground cable. That might be so generally, but where expense had to be closely considered it was rather a hard condition. He thought the German rule given on p. 191 with regard to insulation on wires was excellent, because ordinary insulation put on overhead wires for extra-high-tension work was absolutely useless.

Mr. Sparks. MR. CHARLES P. SPARKS had had no experience of transmission-lines at the pressures mentioned by the Author, but in the last few years he had had experience of distributing on overhead wires at a pressure of 3,000 volts. In a colliery-district in South Wales one scheme of transmission-lines involved about 12 miles of route, or about 45 miles of conductor, and he disagreed with the view that overhead wires were only generally advisable for transmission. In colliery-districts underground cables were a source of great difficulty; there was a creepage going on in the soil, and it was very difficult to prevent cables from being drawn apart or joints from being thrown out, which resulted in frequent failures. The overhead line, at any rate in his experience, had proved quite reliable. With regard to safety, such lines were generally put in isolated positions. In the case he was speaking of, the lines were on private property except where they crossed public roads, and there special precautions were taken with cradles. Several types of cradles had been used, but either the deep U or the box had proved a source of difficulty owing to the wind tending to blow the cradle in contact with the wires. The form shown in *Fig. 11* (p. 203) had proved the most reliable in use. The Author alluded to the cradle being a source of danger owing to the difficulty with snow. Fortunately, with the pressure always on the line, two things tended to keep the transmission-line free; first, the heating of the wire, although slight, was sufficient to prevent accumulation of snow, and secondly, repulsion took place to the drier particles of snow. The risk of failure of the lines was extremely small. Insulator-failures in spans of 40 yards were practically unknown. The only source of danger was the small boy on the public highway. The cross arms supporting insulators should be of metal, earthed. With reference to screens, he preferred the earthed screen to the insulated one. The screen was earthed at each pole by running down a wire which was coiled round the base of the pole. When the lines were first put into use it was found the circuit-breakers at the station were pulled out if the line was connected to the guard-screens earthed in that way. With regard to the size of the wire, he thought the members were much indebted to the Author for *Fig. 3* (p. 190). In his own experience wires between No. 4 and No. 7 had been used solid, and the diagram showed that the limit

of No. 7 was a safe and practical limit. With a smaller wire the length of the span had to be decreased, which increased the cost of transmission; and he thought it would be found that No. 7 was really a very practicable limit. Above No. 4 all conductors were stranded. The heaviest line he had put up had a cross section of 0·2 square inch, and he had no experience above that. Insulation on overhead wires, he thought, was a source of positive danger and should be prohibited. Another matter which had to be considered in connection with overhead lines was lightning, and with steel masts an overhead earthed wire was necessary. That was a source of some danger, because if the earth-wire broke at any time and fell on transmission-lines it stopped the supply. He himself preferred timber poles, only using steel masts at points of special strain; and in that case there was no necessity to have the earthed overhead wire. The position of the line with reference to the contour of the ground was of great importance. If a transmission-line was taken over the top of a mountain, or a high hill, the chances of the line being struck by lightning were very great, even in winter time; whereas, by keeping well below the brow of the hill the danger was averted. He agreed that transmission-lines should be kept away from trees, because in that way another source of great danger was avoided.

Mr. C. J. GREENE stated that Callender's Cable and Construction Company had put up a large number of overhead lines, and at many points, either for crossing Post-Office wires or for other reasons, they had had to put them underground; and he thought there was little doubt that one of the points of weakness in an overhead system was where contact was made with an underground system. It had been very difficult to get suitable apparatus for making the connection. He exhibited some dividing-boxes which in practice had satisfactorily solved the difficulty. One was a three-phase box, such as had been working for 2 years on 11,000 volts, both in the heat of summer and during the recent severe winter. The three-core cable was brought up the pole in a wrought-iron pipe, and entered the box at the bottom, where the armouring was clamped, so as to take the weight of the cable up the pole. The three cores were then split out inside the box, the whole box was filled with compound, and joined to the three cores were the three leads going out to the three-phase line. The joint to the three-phase line was in every case made of solid trolley-wire, because if it was made of stranded wire there was a likelihood of water running down the strands into the box. Therefore, whether the conductors themselves were stranded or not, a solid wire was always preferred for making this connection. His firm used corrugated high-tension

Mr. Greene. porcelain, which would easily withstand 11,000 volts, and to keep the corrugations dry there was a large high-tension porcelain cap which fitted immediately over. In order to keep the box dry, a small annular space was filled with either compound or sulphur cement, and as a further protection a small disk of spun copper was soldered on to the bottom of the choking-coil, so that there was no danger whatever of water getting inside the box. The leads in every case were coiled round to form the choking-coil between the overhead mains and the underground mains, and, whenever connected to any long length of underground main lightning-arresters, were fitted in parallel. Another form of box shown was for a two-core cable, for connecting a two-phase circuit to a two-phase overhead line. With regard to the insulator, in getting out the scheme the kind of insulator was left, as a rule, to the contractors tendering, and he was inclined to think that consulting engineers should specify the size and type of insulator they required, otherwise contractors were all tendering on different lines. The variation between the standard insulators of British and of foreign manufacture was very wide. For example, for 10,000 volts, the American standard insulator was $4\frac{1}{4}$ inches high by $4\frac{1}{4}$ inches in diameter; the Swedish was 5 inches high by $4\frac{1}{4}$ inches in diameter; the Italian was $5\frac{3}{4}$ inches high by $5\frac{1}{2}$ inches in diameter; and the English was 7 inches high and 7 inches in diameter. He exhibited an insulator which had been working in Lancashire for the last 2 years with very satisfactory results, at 11,000 volts. In addition to the insulator, there was a clip for fastening the transmission-wire on to the insulator. In Post-Office wires he thought the difficulty of binding a wire to the insulator was very small; with heavy transmission-wires varying from 0.1 to 0.2 square inch in section some special means had to be adopted, and the clip seemed to solve the problem fairly well, but not quite. He thought the insulator he showed was capable of much more than 11,000 volts working-pressure, and might be used at any pressure up to 20,000 volts. Every speaker so far had expressed the opinion that wooden poles were essentially the best to use, and he thought probably that with poles it was purely a question of cost. When short spans of 50 yards were used, the wooden pole was essentially the pole to be adopted, and the steel lattice pole was out of the question. It was only at 100 yards span and more that the steel lattice pole was able to hold its own. In the tests made by Messrs. Wade very interesting results had been arrived at, and he believed they had definitely shown what the relative strengths of an **A** pole and a single pole were, a thing which he did not think could

have been foretold from theoretical considerations. As he understood the results of the tests, the strength of an **A** pole was about $4\frac{1}{2}$ times that of a single pole of the same diameter at the ground-level, provided the splay of the **A** pole was correct. For commercial purposes it might be taken that, for **A** poles up to 40 feet in length over-all, the ratio of the splay at the ground-level should be about one-eighth of the over-all height of the pole. When the pole was so constructed it was found that to withstand a pull of 400 lbs. at the top with a factor of safety of 10 on an ordinary 32-foot pole, a single pole would require a diameter of about $11\frac{1}{2}$ inches at the ground-level. An **A** pole would be about 7 inches in diameter at the ground-level, and the ratio of cost between the single pole and an **A** pole of equivalent strength was about 2 to 1. With much heavier pulls such as were liable to arise on overhead transmission-lines, say 1000 lbs., the diameter of a single pole at the ground-level would be about 16 inches and of an **A** pole $9\frac{1}{2}$ inches. In that case the ratio of the cost of the single pole to the **A** pole was about $4\frac{1}{2}$ to 1. Therefore with wooden poles the single pole was out of the question and **A** poles would have to be used. In these tests the results were rather unfavourable to the pole, because the pole had been tested in a horizontal position, and the compression member had naturally tended to drop out of the horizontal plane; with the result that the pole showed signs of weakening sooner than it would have done if tested vertically. To overcome the trouble of the buckling of the compression member, he was inclined to think that instead of having the cross-bolt halfway down the pole, as in *Fig. 7*, it would be better to have two light angle-bars, in which case, if the pole tended to twist out of the plane of the paper, the web of one angle-bar would be in compression and the web of the other in tension, and that would resist the tendency of the compression member to buckle. With regard to wind-pressure, the factor of safety specified by the Author was 5 at 22° F. and a wind-pressure of 30 lbs. per square foot. If both the wind-pressure and the temperature were to be specified, a special Table would be required, and he had searched text-books and Post-Office Regulations in vain to find a table which gave variation in wind-pressure with variations in temperature. If a table was used in erecting a line, the working engineer must have not only his thermometer to measure the temperature, but also a wind-gauge to measure the pressure on the wire; otherwise he would not know what tension to put on his dynamometer. Taking the case of a 50-yard span of 0.05-square inch solid hard drawn conductor, in which he assumed the breaking strength to be 25 tons per square inch, which seemed to be a reasonable figure,

Mr. Greene. on an absolutely calm day there was nothing to be considered beyond the weight of the wire itself, which, in the case under consideration, was approximately 28·8 lbs. With a wind-pressure of 5 lbs. per square foot, which was officially designated as "a very high wind," there was 28·8 lbs. acting vertically downwards, and a horizontal wind-pressure of 9·4 lbs., and the resultant pressure on the span of wire came to 30 lbs.: and so on. When the pressure specified by the Author, 30 lbs. per square foot, was reached, which was the official "hurricane," there was 28·8 lbs. acting vertically downwards, and 56·5 lbs. wind-pressure, the resultant being 63·5 lbs. All tables he had seen took that resultant pressure as the basis on which to work. It was quite evident that the table could be worked to only when the gale was blowing. If the wires were erected on a calm day the tension on the dynamometer had to be reduced in the ratio of 63·5 to 28·8, which gave roughly half the tension on the dynamometer on a calm day. As the force of the wind increased to the degree mentioned, the tension rose to correspond to 63·5 lbs. load, which gave a factor of safety of 10 when the hurricane was blowing. He could not find any table that dealt with that point. On looking through the Post-Office tables he found they allowed a factor of safety of 4 at 22° F., but did not mention anything about wind-pressure. He presumed that factor of safety of 4 was taken on a calm day. If so, when 17 lbs. per square foot was reached, which was the maximum pressure according to the Post Office, the factor of safety dropped down to 1·97, and at 30 lbs. per square foot the factor dropped to 1·25. It would seem, therefore, that a factor of safety of 5 under those conditions was perhaps rather high.

Mr. Hudleston. Mr. F. HUDLESTON pointed out that in a gale causing a pressure of 30 lbs. per square foot a man could not possibly put up a wire.

Mr. Jenkin. Mr. BERNARD M. JENKIN thought that in connection with guarding the overhead wires by earthed cradles it was necessary to take into account the kind of "earth" existing at the generating-station. There were three methods possible: the solid earth at the neutral point of a three-phase system, an earth through a resistance, or no earth at all. The effects in the three cases would be different. In the first case a solid earth to the neutral point at the generating-station would of course produce the maximum effect in the way of a short-circuit current whenever any transmission-wires touched an earthed cradle or an earthed stay-wire, and under those conditions the difficulty of obtaining a good earth at the poles of the transmission-line was very much increased; it was necessary to carry

a much larger current, and any defect in the earth at the poles Mr. Jenkin. would therefore produce a much greater difference of potential along the earth and might give trouble in consequence. If, however, the neutral was earthed through a resistance, the short-circuit current was reduced to probably something like twice the full-load capacity of one transmission-line—to a figure that would open the circuit-breaker and no more. But with the neutral point of the system earthed through a resistance, it meant that when an earth was obtained outside, the other two phases were put to the full pressure away from earth, that was, the generator was strained, not to the normal pressure between the neutral point and the transmission-line, but to the full pressure. With a 10,000-volt transmission the strain on the machine would be 10,000 volts instead of 6,000. If an engineer was prepared to subject his plant to that strain it would almost seem advisable not to have any earth at all at the generating-station. Then the necessity of the return earth-wire no longer existed; for the point at which the transmission-line touched the earthed cradle went to earth potential, and there was no return current to take back to the generating-station, and no risk of a bad earth at the cradle or fault.

Mr. W. H. PATCHELL agreed that the question of lightning-Mr. Patchell arresters depended on the earthing at the station, but thought that sufficient attention had not been paid to the resistance put between the lightning-arrester and earth. He had had a good deal of experience with lightning-arresters and had found great trouble in getting a proper form of arrester. He used the horn type, but had been unable to get it satisfactory until one pole was faced with carbon, and then it had been necessary to establish the proper amount of resistance put between the lightning-arrester and earth. Of course in that case he had been dealing not so much with lightning as with surges set up by mishaps in the plant due to faulty handling, and matters of that sort, over which there was sometimes no control. Mr. C. P. Steinmetz, whose authority was second to none on this question, had said lately, before the American Institute of Electrical Engineers, that money spent on lightning-arresters would be better spent in diverting the line to a district where the lightning was not quite so prevalent. The information given in the Paper was of the utmost value and would help the industry greatly in guiding the Board of Trade as to what restrictions should be imposed. There were difficulties which were not always very evident. Mr. Gavey's ground had caught fire in the summer, and Mr. Sparks's ground had slipped. He himself was now putting a transmission-line over ground which he was told was, in places, on

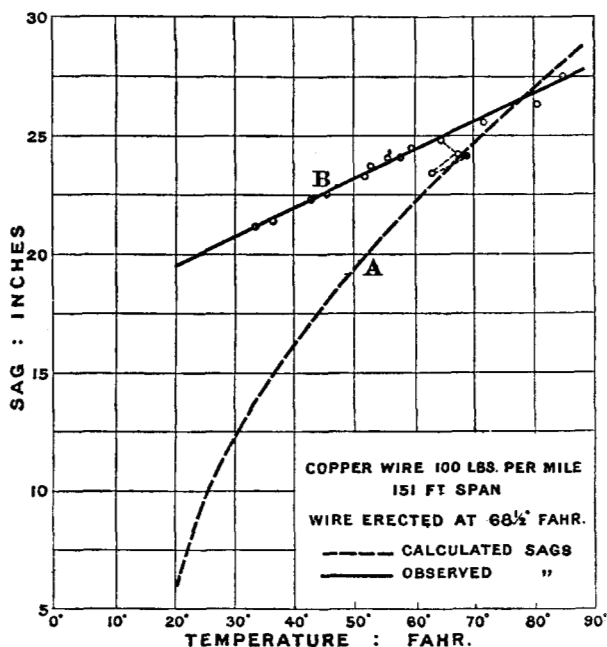
Mr. Patchell. fire all the year round. On the question of gauges, the Standard Wire Gauge gave no information if the gauge-table was lost. The circular mil, which the Author said was a strange American notion, was much too small, but it did give definite information, because if the circular mils of a wire were known its diameter was known. He wished to put in a word for No. 8 gauge, as it had done yeoman service in early electric-lighting days for arc-lighting, and he thought it might come in for transmission-lines. The Author said that joints were taboo as on trolley-wires, but Mr. Patchell did not quite see that the cases were parallel. The great objection to the joint in the trolley-wire was the trolley jumping over it, but that objection did not hold in the case of transmission-lines, and he did not see why a sound mechanical joint should be avoided. The Mexican poles were a good instance of the relative value of wooden poles and steel poles. The engineers responsible for the line had stated that it was impossible to use wooden poles on account of the number required and the cost of freight, and in that particular case it had paid to use long spans and put up steel poles. He might supplement the figures given by the Author in regard to *Fig. 4*. There were 101 miles of the **A** pole with 400-foot spans, and of the **H** pole there were 170 miles with spans up to 1,000 feet. The steel pole was used also on the line to Toronto, where, owing to the troubles with sleet, the span was only 400 feet. That showed the modifications which had to be made in the pole-line on account of climate. On the same line, where the transmission-line met the Niagara power-house, there were three different forms of lightning-arrester. On the question of wooden arms and pins, he had seen pins in Montreal which worked very well in the country, but in railway-yards the insulators arched over and the pins were charred deeply. That was due simply to the carbon from the locomotives being deposited on the insulators and arms. He thought the question of guards and spacing between wires might be overdone. It seemed fairly well established that the wires swung synchronously, and it was therefore practicable to allow less distance between the wires than would be possible if the wires clashed. Experience in America seemed to show that the wires might be run fairly close together, dependence being placed on their swinging synchronously. The steps taken to guard against breakdowns depended on the job; in some work it was possible to take a risk that was absolutely prohibited in other work. At the same time, the engineer could not be bound to 16-foot cradles or untold distance between the wires. The line from Niagara into Buffalo had been shut down once, though not through the wires blowing together; the patrol found

two pieces of something black which it was believed had once been Mr. Patchell.
two crows who had an altercation from adjoining wires. At the St. Louis Engineering Congress it was stated that one company alone had turned out, in 60,000-volt transforming plant, 971 transformers, aggregating 228,000 kilowatts, with a maximum of 2,500 kilowatts in an individual transformer. A Californian company had upwards of 700 miles working at 50,000 volts pressure. Those figures showed that work could be carried on with what might be termed reliable safety with high-tension overhead transmission.

Mr. FRANK GILL observed that he was not quite clear as to the Mr. Gill.
view the Author took of the elasticity of copper wire; on p. 189 he apparently ignored it, but later on, in dealing with the graphical method, elasticity in the wire was apparently allowed for. If the common method of calculating sags and stresses of line-wires (in which no account was taken of the elasticity of the material) were employed, the results were perhaps good enough, and possibly no very great harm was done, but the tables gave no idea as to what was really occurring, and the word "calculation" ought not to be used when these tables were applied. The National Telephone Company had found these tables very unsatisfactory, largely because they led to unduly slack spans, and consequently some attention had been given to the matter. In addition to calculations taking account of elasticity, a number of experimental observations had been made on specially erected wires, and he would give some of the results obtained. *Fig. 25* (p. 236) showed two curves of sag of copper wire, weighing 100 lbs. per mile ($0\cdot004914$ square inch section), erected at $68\frac{1}{2}^{\circ}$ F. on a span 151 feet long. Curve A gave the sags from the table as usually calculated for a factor of safety of 3 at 20° , and ignoring elasticity. Curve B gave the sags as they actually were at various temperatures on the wire erected in accordance with the table, and showed clearly the actual observations made. The Post-Office instructions quoted by the Author said, concerning the deliberate ignoring of elasticity, that at low temperatures the actual sags would be somewhat greater than those shown in the table. Comparing A and B at 30° , the actual sag was over 60 per cent. more than calculated, the figures being $20\cdot75$ inches actual against $12\cdot5$ inches calculated. In fact, the two curves had nothing in common except at one temperature, 78° . It was when the tensions in the wire were investigated, however, that the full error made by ignoring elasticity was appreciated. *Fig. 26* showed the tension in a bronze wire weighing 40 lbs. per mile. The calculations were by the usual formulas, ignoring elasticity, the factor of safety being 3 at 20° , and

Mr. Gill, the wire was erected on a 151-foot span at $73\cdot25^{\circ}$. A showed the tension which the calculations said would be found, and B showed what was actually observed. At low temperatures the erroneous nature of these calculations was very strongly brought out; at 34° the stress, instead of being 20 lbs., was only $14\cdot5$ lbs.; and at 20° , instead of being 66 lbs., one-third of the breaking weight, it was only $15\cdot5$ lbs. If now the temperature fell to 10° or lower, the factor of safety having been taken at 3 at 20° , the calculations said

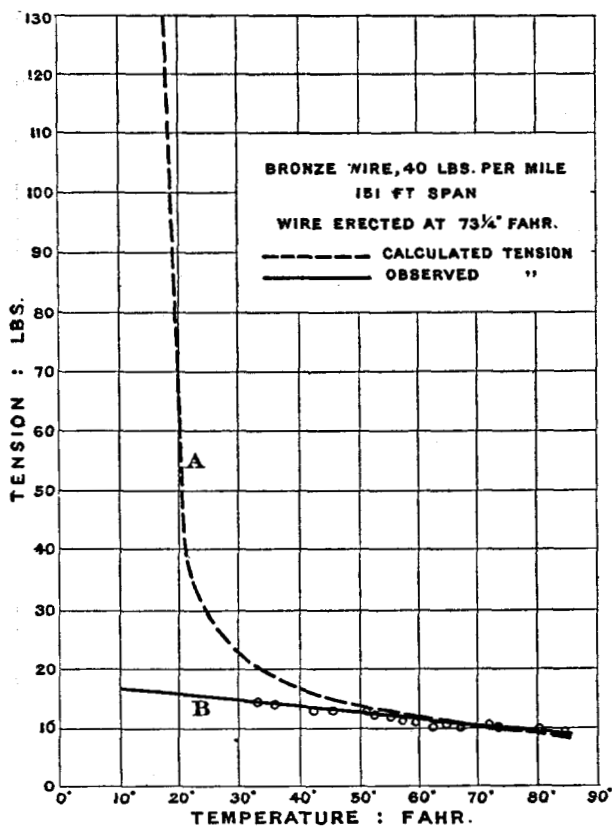
Fig. 25.



that the wire would break, but as deduced from the observations shown on Fig. 26, B (there had not been an opportunity of observing lower than 34°), the stress would actually be $16\cdot5$ lbs. If any attempt were made by transmission-engineers to carry these misleading figures into the design of the line, and poles and stays were planned accordingly, considerable unnecessary cost would result. There was no reason that he knew of why elasticity should be ignored, and the inclusion of it led not only to a fair approach to accuracy, but also to simplified erection. Professor B. Hopkinson

had given ¹ a method of calculation, and the following results were Mr. Gill. based on his formulas, the work having been done by Mr. J. F. Coote of the National Telephone Company. *Fig. 27* showed the sags on two spans of copper wire, 100 lbs. per mile (0.004914 square inch section), erected at 69°, one being 151 feet and the other 256 feet. The calculations included elasticity, and were for a factor of safety of

Fig. 26.

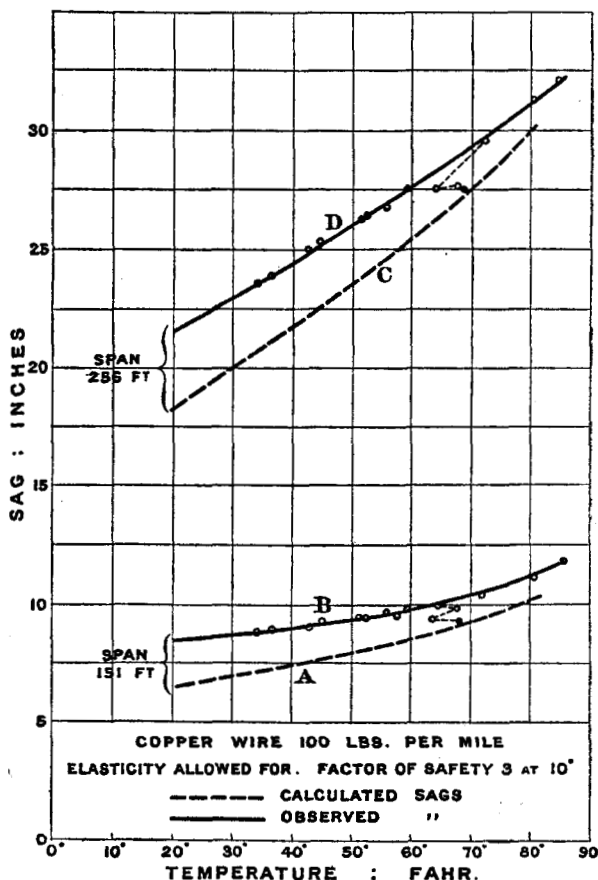


3 at 10°. Curve A showed the calculated and B the observed sags on the shorter span; C and D showed the same on the longer span. On the shorter span at 30° the sag as deduced was 1.75 inch more than calculated, the difference varying from 2 inches to 1.25 inch

¹ "Sag and Strain in Trolley-Wires." *The Electrician*, vol. xlv (1901), p. 501.

Mr. Gill. between 20° and 60° . On the longer span at 30° the sag was 3 inches more than calculated, and the difference between 20° and 60° varied from 3.25 inches to 2.25 inches. With regard to this difference between the calculated and observed figures, even when elasticity had been allowed for, copper and bronze wires appeared to

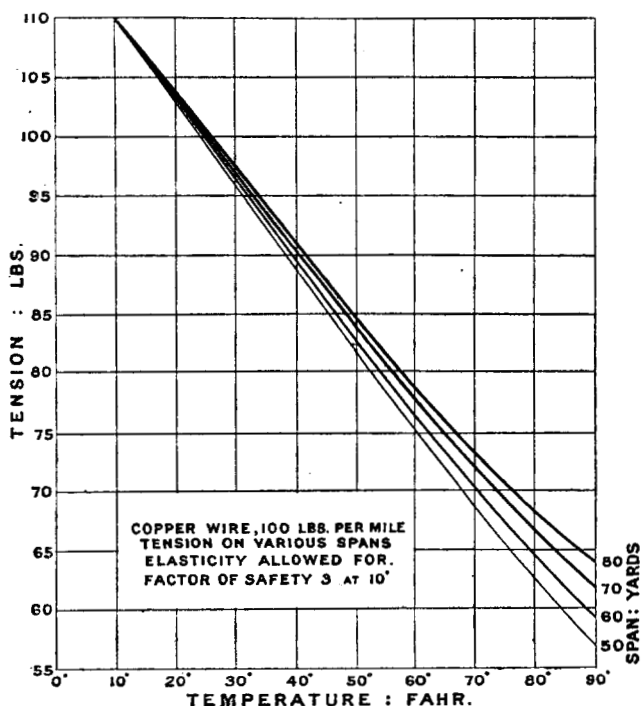
Fig. 27.



experience a permanent extension, even when subjected to light loads. In the curves referred to, the first observation made directly the wire had been erected was marked; there were then three or four observations (which were connected to the initial observation by a dotted line showing the chronological order) made

during the stretching period, and after that the wire appeared to settle down to a regular behaviour. So far, this factor had not been brought into the calculation, except by giving it some weight in determining the factor of safety on which to calculate. Allowing for elasticity permitted simplified erection, because practically it ceased to be necessary to pay any attention to the length of the spans. Unless the temperature was very high and the variations in the lengths of the spans very great, the stresses in practical spans were so

Fig. 28.



much alike that all that was necessary was to observe the temperature and pull up the wires to the tension given in the table. The wire was pulled up through a number of spans at one time and permanently bound in afterwards; care was of course necessary that in terminating the wire it was not slacked out below the tension shown on the dynamometer. Fig. 28 showed the tensions in copper wire weighing 100 lbs. per mile for various temperatures and spans; the difference between the mean and the extreme did

Mr. Gill not exceed 3·2 per cent. at 70°, or 4·2 per cent. at 80°. Generally speaking, it was a great deal easier to regulate by tension than by sag; for example, in mountainous country or where there was difference of level, regulation by sag was troublesome, and the tensions given in *Fig. 28* might, he believed, be used with advantage instead of the tables referred to in the Paper. The factor of safety was 3 at 10°, and by projecting the curve to lower temperatures it was seen that the elastic limit of copper, taken at 27,500 lbs. per square inch (135 lbs. for 100-lb. wire), was not reached until the temperature had fallen to about 27° below zero F. Wires erected to these tensions had stood well, and as the Author pointed out, the effect of wind was greater on small than on large wires, so that Mr. Gill thought it would be found that these figures made ample allowance for wind. For copper wires of other weights the tensions were nearly proportional to the weight. With regard to the proposed regulations, he feared that any effort made to include the modulus of elasticity as provided in clause 3 would lead either to expense in special experiments or to erroneous figures being quoted. He had dealt at length with clause 5. He feared that the proposal to have no line-stays on straight runs, as provided in clause 12, would not prove satisfactory. Lines were constantly subjected to sudden stresses, as, for example, when a tree fell on and broke the wires. In the example given at the foot of p. 120, if the six wires were broken at once trouble might arise; but the matter went further than that. A line must be so designed as to face snow and wind, and if owing to both these causes the wires got near their breaking-point and then a breakage of all wires on one side occurred, the poles were almost sure to fall. The telegraph- and telephone-engineer had to decide whether, in the event of the worst conditions, his poles or his wires should be saved, and apparently the same would apply to power-transmission. He was sorry the Author provided nothing for the protection of wires such as those of the National Telephone Company. The method of crossing which appeared to be the most satisfactory was the short-span method, and this was the basis of the Post-Office design illustrated in *Figs. 13*.

The Author. The AUTHOR, in reply, was gratified that the discussion had elicited a good deal of information about the mechanical characteristics of copper wire, but he was not convinced that a wire so hard-drawn as to have an elongation of only 1 per cent. was more advantageous than one having greater ductility and a slightly lower ultimate breaking-strength. Mr. Monkhouse had asked whether it was proposed to take the factor of safety on the limit of elasticity

or on the ultimate breaking-load. The Author considered that the The Author. factor of safety was the ratio

$$\frac{\text{ultimate breaking-stress}}{\text{maximum normal working-stress}}.$$

He used the word "maximum" here to include the maximum wind-pressure at the minimum temperature (usually taken at 20° F.) and he added the word "normal" to indicate that it did not include a condition of partial wreck or collapse of the line, or extraordinary stress such as that due to a fallen tree. In further reply to the same speaker, the Author, who had had several years' experience of colonial life, deprecated that regulations made for the United Kingdom should be borrowed and applied to colonies and other places abroad where conditions were necessarily different. Mr. Greene had alluded to a pressure of 30 lbs. per square foot as the official "hurricane." A hurricane was defined by the Meteorological Office as a wind having a mean force exceeding 17 lbs. per square foot, or a mean velocity exceeding 75 miles an hour. It was estimated that the extreme velocity of gusts might reach 105 miles per hour, equivalent to 33 lbs. per square foot. Had the Author known when he was preparing the Paper that in Mr. Gill's opinion the ordinary tables gave no idea of what was really occurring, he would have been saved from a considerable amount of useless calculation. He had desisted from this when he was satisfied that the errors or suppressions were on the safe side. Mr. Gill's contribution on this subject appeared to be of great value. On p. 204 "telegraph- or telephone-wires" were mentioned, and the whole of that section was intended to apply to telephone-wires as well as to telegraph-wires, but perhaps more to telephone-wires, since it was often more difficult to place them underground than telegraph-wires.

Correspondence.

Mr. C. H. K. CHAMEN heartily congratulated the Author on the Mr. Chamen. very valuable and exhaustive Paper which he had brought before The Institution. The subject was one on which but few reliable data were available, and those who took part in the discussion were bound to speak of their own experience. He differed somewhat from the Author's conclusion that no overhead wire should be used of a smaller sectional area than 0·024 square inch. If so small a wire had a low tensile strength it must surely be better to decrease the span

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