Discussion.

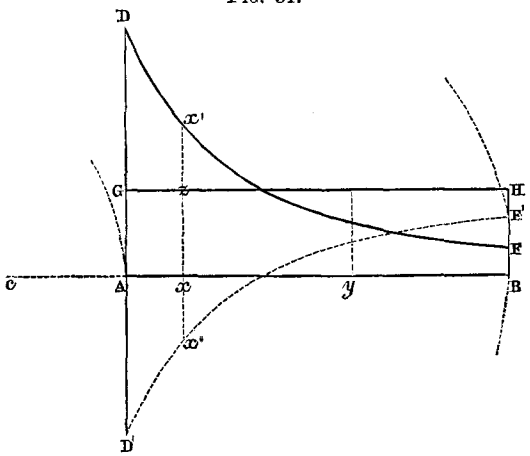
Sir J. W. Bazalgette.

Sir J. W. BAZALGETTE, C.B., President, said the subject to which the attention of the members had been drawn was one of peculiar interest at the present time, and the Author in bringing it before them had evidently bestowed upon it much thought and labour, and he was quite sure they would agree in voting him thanks for the very able manner in which he had introduced his views and supported them by mathematical calculations.

Mr. Longridge.

Mr. LONGRIDGE said the principle upon which his investigations rested was very analogous to the second law of motion; it was, in fact, this: that when two or more strains acted upon a body at the same point, the aggregate effect was simply the algebraical

FIG. 31.



sum of the separate effects of the separate strains. To apply this to the problem of finding the laying-on strain at any point, so that when under a given internal force the coil should be uniformly strained throughout. Putting aside the question of the core, in Fig. 31—

Let A B be the thickness of the coil;
ρ the inner radius C A;
R the outer radius C B;

then, under the action of an internal force f_0 and external force zero, the tension of the wire at x, if put on without internal tension, would be represented by the ordinate $x x'$ of the well-

known curve D E. But it was required that the tension at x and at every other part under fire should be $x\,z$, a constant quantity. It was evident, therefore, that from the tension at every ordinate must be subtracted a quantity $z\,x'$ equal to the difference between $x\,x'$ and A G, or the part at x must be in an initial state of compression $x\,x'' = x\,x' - x\,z$ when the gun was at rest. If therefore the curve D' E' was drawn similar to D E, with G H as the axis of abscissas, evidently this was the initial state of the strained coil which, when f_0 was applied internally, would give the uniform strains of the line G H. But the problem was to find the tension with which any wire, at y for instance, should be put on, in order that when all the rest of the wire was put on the tension at x should be exactly $x\,x''$. By the formula the normal force in the finished coil could be found which was exerted at y by all the coils between y and B upon the remaining coils between y and A, which call ϕ. Now it was clear that the condition at x was not altered if all the coils were removed between y and B, and were replaced by the normal force ϕ. Consequently an expression could be obtained for the tension at x in which the effect of the force ϕ might appear by itself, and if this was called a function of the other variables ρ' R' &c., it would be of the form Mr. Longridge

$$\phi,\ f_{,}\ (\rho'\ \mathrm{R}'\ \&c.),$$

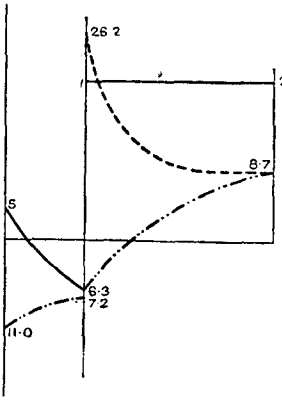
and the whole tension at x would be of the form

$$t_x = f_{,}\ (\rho,\ \mathrm{R},\ \mathrm{C}\,x\ \mathrm{C}\,y\ \&c.) + \phi\, f_{,,}\ (\rho'\ \mathrm{R}'\ \&c.),$$

the latter part representing exclusively the effect of the normal force ϕ. If then in the expression thus obtained ϕ was made = 0, the result would be the state of strain at x in the remainder of the coil when at rest, and the coils external to y removed. In this expression, if x be made = y, the state of strain of the outside or last wire laid on at the distance A y from A was obtained, and this was of course the laying-on tension at y which was required to be found. That was the principle on which the formula had been constructed. Of course it was impossible to do more than simply explain the principle; but he thought it could be understood. There were one or two remarks which he should like to make. One was with respect to the great importance of having a thin core. He had prepared Fig. 32, in which the core was double the thickness of all the others—4 inches, instead of 2 inches; in that there was for the first wire a laying-on tension of 26 tons instead of 2·87 tons, and the compression of the coil at rest was 11 instead of 4·6 tons.

Mr. Longridge. Thus there was a great improvement in having the thin core; in fact, if the external coil was put on a core of no thickness there would be no pressure between them. That was, of course, impossible; but the same object might be accomplished, if desirable, by a construction which he need not now describe. He could make a gun with a thickness of core of either 2 inches or 4 inches, in which when the gun was complete there would be no tension upon the core, even when fired; the whole tension would be thrown upon the coil. There were one or two remarks he wished to make upon Captain Schultz's gun. If the wire was put on with a uniform tension of 45 tons per square inch, and if its elastic limit extended so far. Fig. 24 would represent the state of the gun. Under fire it would be strained to 53·43 tons on the outside and 30·87 on the inside of the coil, whilst the steel core would absolutely feel no tensile strain. It would have 0·7 ton compression on the inside, 6·3 tons compression on the outside under fire; 38·7 tons compression on the inside, and 26·29 tons on the inside when at rest, consequently the core would be of no use, supposing it were put on as it was stated in the report above mentioned. On the other hand, assuming the elastic limit of the wire to be 22 tons, and that the tension under fire should never exceed that limit, it could be calculated what should be the laying-on tension; it would be 13·7 tons per square inch. Under those conditions the outside of the wire would be strained to 22 tons, and the inside to 17·79; and for the core, the inside strain would be 14·17 under fire, and 10·79 tons compression at rest (Fig. 25, Appendix). This showed the enormous difference it made whether the wire was put on with the proper calculated tension or whether it was put on haphazard. The other diagrams, Figs. 26 and 27, represented the gun of Sir William Armstrong. In the first case it was supposed that there was a uniform laying-on tension of 10 tons; Fig. 26 represented the strains which would then take place; Fig. 27 represented it with a laying-on tension of 20 tons; and Fig. 28 represented what he called the particular tension for that gun, that was the uniform tension which would strain equally the coils both of the inside and the outside. Fig. 29 represented what he thought was the

FIG. 32.



Mr. Longridge.

best possible tension for this gun, inasmuch as it strained both the wire and coil to the same extent, 20 tons per square inch. The laying-on tension was 12·7 tons per square inch, and that was the gun which he had compared as of equal strength with that represented in Fig. 30. To demonstrate how a gun might be constructed of the same strength as that of Sir William Armstrong's, he had prepared diagram Fig. 30, showing a cast-iron core with 2 inches less thickness of wire upon it, that was to say, the total thickness of the gun was 2 inches less than Sir William Armstrong's. That gun would be strained 20 tons uniformly throughout, laying-on tension 7·1 and 6·75 tons, tension on core 7·4, and maximum compression at rest 6·1 tons per square inch; therefore that gun, 2 inches thinner than the other, would be one of equal strength. Further details respecting these guns had been given in the Appendix. With regard to the question of heating, he must cry *peccavi*. He had expressed strong opinions that the actual heating from the gases had very little to do with the heating of guns, and stated that, in his opinion, it was more due to the conversion of energy than to heat. He had investigated that at considerable length, and found where he made the mistake; he had calculated upon the heat which was imparted by contact, and left out the important effect of radiant heat. He found, taking this into account from the best data he could get, that something like 80 per cent. of the heat arose from the effect of radiant heat; the rest of the amount was due partly to the friction of the gases and the projectile, and partly, as he supposed, to the conversion of energy, but that conversion of energy was comparatively small. From heat it was probably 80 per cent.; friction of gases and shot about 12 or 15 per cent.; and from conversion of energy no more than 5 or 8 per cent.; so that he was wrong altogether in what he stated formerly. The details of these investigations would be found in his book, which would shortly be published. He had only one other remark to make, and that was with regard to what he had said about powder—that slow-burning powder was simply a device for weak guns. Colonel Brackenbury, Superintendent Royal Gunpowder Factory, in a Paper read recently at the Royal United Service Institution,[1] on "Gunpowder considered as the Spirit of Artillery," said: "We constantly hear that a gun has been produced which will do this or that, yet it is not the gun which does it, but the gunpowder. The gun is only a tube to concentrate the action of the powder and guide

[1] Journal of the Royal United Service Institution, vol. xxviii., p. 379.

Mr. Longridge. the projectile. There is not a single gun actually adopted for service in any country which is not, by its weakness, a hindrance to the full action of the 'Spirit of Artillery.' When gun-makers say, as they frequently do, that their gun will produce a certain effect 'provided that a suitable powder be found for it,' they mean 'provided that the strength of the gunpowder be restrained, "cribbed, cabined and confined" to suit the weakness of the gun.' We sometimes see in human life a great and strong spirit tear to pieces a feeble frame which contains it, and we do not say 'What a pity that the spirit is so strong,' but rather 'How sad that the body is so weak.' In the case of artillery we are always subduing and taming the spirit instead of strengthening the body. This may be necessary under existing circumstances, but, if so, the circumstances are unfortunate, and stand in the way of getting the most value out of the Spirit of Artillery." He entirely concurred with Colonel Brackenbury's remarks, and his object had been to show how to make a gun with which to conquer gunpowder.

Colonel Maitland. Colonel MAITLAND, R.A., Superintendent of the Royal Gun Factories, said, as regarded the powder question he did not quite agree with his fellow-superintendent, Colonel Brackenbury. He found that powder-makers generally liked very strong guns because they did not make their powder very regular or keep it under control; but he thought by working together they had attained with their slow-burning powder a very great deal more energy per ton of gun, which was the simplest way of measuring it, than was ever done with the quick-burning powder. If that theory was right, why should they not at once take gun-cotton? That would be the next step; if they could once control that, it would be much better than powder, taking up much less space for an equal amount of gas. With regard to the construction of these guns he thought the Author had given up experimenting with them, when he gave the lecture at the Society of Arts, but the Author had since informed him that he had not done so. In that lecture Colonel Maitland mentioned that he understood the longitudinal strength had not been fully provided for by the Author, and he must confess that he did not see where the longitudinal strength came in. He should not like to stand behind that gun (Fig. 22). The trunnions appeared to have no means of attachment, though no doubt that could be provided for, and the breech would certainly come away, because there was scarcely anything to hold it. Captain Schultz's 34-centimetre gun gave way longitudinally the first time it was fired. It was made not exactly on that principle;

it had twelve large bolts, 6 or 7 inches in diameter, placed round the gun from trunnion to breech. The first time it was fired six sharp cracks were heard, and it was found that six bolts had gone, so that the longitudinal strength must be more looked after than had hitherto been done by those who advocated the very large employment of wire. As to the gun which burst on board the "Daring," many guns of exactly the same nature had been fired many hundred rounds, and that particular gun had been fired about one hundred and sixty rounds. The gas corroded the material which was wrought-iron welded together in a weak place, and there were unfortunately two very bad welds in the gun nearly over one another. When the gas got into the interior it acted, of course on a larger surface, and the breech of the gun was blown off. He did not think it could be fairly said that it was theoretically weak, because there were so many hundreds of guns, of similar construction, which had been fired thousands of rounds. He did not know that there was any other point he need enlarge upon. As soon as the Author's book came out he would thoroughly go into it, and would try what could be done with wire put on on his principle, and he was sure the country would be very much indebted to him if it turned out to be successful. Colonel Maitland.

Mr. J. A. LONGRIDGE thought some misapprehension might be avoided if he was allowed to point out on Fig. 22 his proposed method of getting longitudinal strength. The inner part was the inner tube or core, and the black was the wire coil. Then came the outer jacket or casing, which extended from the breech to the trunnions, and was continued forward to the muzzle of the gun. In the 13-inch gun it was proposed to make this outer jacket 6½ inches thick between the breech and trunnions, of cast-iron,—the jackets were made thick to give weight to the gun, and protection to the wire, and had nothing to do with the circumferential strength of the gun. It was to give the weight required on account of the recoil, and to afford protection to the wire. Between the trunnions and the breech it had also to furnish longitudinal strength. Supposing that the inner tube and wire coil was slipped in from the end, then the heavy steel ring, which carried the breech-plug, was screwed into the outer casing; it did not touch the inner tube nor the wire. A small space was left between them, so that the inner tube was perfectly free to expand without bringing any strain upon the outer casing. The ring was held to the casing by the internal and external screw. These had fully the same length as the breech-plug, and a greatly increased diameter. There were two of them, and the breech-plug Mr. Longridge.

Mr. Longridge. was cut away for one-half of the threads, in order to draw the breech out; and it was evident that long before this gave way the breech-plug must be blown out. Experience had shown that cutting away one-half of the thread left sufficient strength to resist the full powder-pressure; therefore it was certain that if anything gave way, it must be the cast-iron between the breech and the trunnions. There the cast-iron was 6½ inches thick. Assuming a pressure of 30 tons per square inch on the inside of the gun, multiplied by the area, and dividing that by the annular area, the result would be a strain of 4 tons per square inch only upon the cast-iron. The cast-iron would never give way under that pressure. If it was thought too great a pressure, let the area be doubled and make it 2 tons. The thing was, to take all the longitudinal strain off the inner part of the gun, the function of which was to resist the bursting strain, and to put it on the outside, the function of which was to resist the longitudinal strain. That was the principle for which he had contended for the last thirty years. That was evidently an efficient and complete way; but there were other ways of doing it, some of which he had previously exhibited. He wished to say one word about the assertion that he made, that Captain Schultz had overcome the assumed difficulty, and to which Colonel Maitland replied that Captain Schultz's 34-centimetre gun had failed in the first round. In that gun, the connection between the trunnion and the breech was made by twelve bolts, not 7 inches and 8 inches in diameter, but 3¾ inches in diameter. Those bolts, when the gun was fired, naturally gave way. The aggregate area of those bolts was 132 inches; the aggregate area of the bore was 142 inches; consequently if a pressure of 20 tons were put on the inside, thus causing a sudden strain of 21½ tons per square inch upon those bolts, it was no wonder that they had given way. But there was another difficulty in that system, the same difficulty which Captain Blakeley found in the first gun that he made. It was impossible to get a uniform strain upon twelve bolts. The consequence was that one failed after the other, for the reason that they were strained far beyond their strength. He had been in correspondence with the late Captain Schultz, who told him that he perfectly agreed with him about the longitudinal strength, that he did not find the slightest difficulty about it, and in subsequent guns there had been no difficulty. He would add one word to what he had said with respect to the heating of the guns. When his book came out it would be seen that there was not the slightest cause for uneasiness with regard to the tension of the

wires. The effect of the heating was so exceedingly minute, that it was not of the least consequence. Mr. Longridge.

Mr. W. H. Barlow, Past President, remarked that it might be expected of him to say a few words on this matter, because during the last three years he had been rather continuously engaged upon it. He did not know that he need advert to that part of the subject with which the Paper opened, namely the theory —that had been pretty well thrashed out before. The Author referred to the investigations of his father, Professor Barlow, and said that they differed from those of Lamé, Rankine, and Hart considerably. No doubt they did differ considerably. He might state that his father's attention had been drawn to that subject not with reference to guns, but mainly in reference to Bramah presses. In his idea he had arrived at conclusions considerably greater than those come to by Lamé and Rankine as to the relation between the average stress upon the metal and the internal stress. Fortunately the departure that he made from what was now called the true theory was on the safe side, and the result was that the Bramah presses constructed upon his principle were perfectly safe and good, none ever failed, and that brought his formula into very great popularity. He was quite prepared to admit that the resulting value was in excess of what was necessary for a gun, and in that respect Lamé, Rankine, and Hart were more correct. They were, however, subject to a modification which had been pointed out by Dr. Hopkinson, and which tended backwards a little way towards what had been done by his father. A further modification was really required in investigating the gun, if the ring or cylinder which was called upon to bear the circumferential strain was also called upon to bear the longitudinal strain. In the case of the gun just described by the Author, that point did not arise, for he was not calling upon his wire casing to bear any part of the longitudinal stress of the gun. The theory of Lamé and Rankine was limited to the elastic action of the material. It was said in the Paper that Colonel Rosset considered accordingly that the greatest internal pressure should be that which lay between the extreme limit of elasticity in compression and the extreme limit of elasticity in tension. No doubt, acting upon the limited lines of the theory, he was quite correct. The Author thought that the limit of compression might be very largely exceeded, and spoke of a tube of cast iron which was compressed $\frac{1}{25}$th inch in diameter, whilst the limit of elasticity of the material would be reached with a reduction of $\frac{1}{400}$th inch of its diameter. That meant that it was com- Mr. Barlow.

Mr. Barlow. pressed to sixteen times its limit of elasticity in compression, and that appeared to be rather a large excess. But while the Author thought that this very large excess might be allowed in compression, he seemed to consider that no excess should be allowed in tension. He did qualify that opinion to a certain extent at p. 84 of the Paper, where, speaking of a hoop-gun, and of the case in which there might be a little excess of strain upon the outer portion of the gun, he said, "Now if it should so happen that the excess strain causes a permanent set just equal to the original excess shrinkage, it is clear that the gun has been put right, that is to say, into the condition under which it ought to have been built. Subsequent firing will not alter these conditions, for the simple reason that the strain of explosion no longer exceeds the elastic limit." He quite concurred with the Author in that, and thought it was a very sensible view. Sir William Armstrong, in speaking upon this subject some years ago, said, as the result of his experience, that very strict mathematical rules need not be adhered to; and he was not speaking there from any theory upon the subject, but was giving the result of a long experience in gun-making. Although a slight departure might be made from the strict mathematical condition, yet there was no doubt that the nearer these could be approached the better, and under those circumstances the members were entitled to give their particular thanks to the Author of the Paper, and to Mr. Brooks, who had assisted a good deal in the mathematical department, for the elaborate working out which they had given to the various cases put in the Paper of different actions of wire in the coating of guns.

There was one point, however, in the Paper which he should like to know more about. The wire was said to be of a quality which could be obtained to bear a stress of 100 tons to the inch before it broke; but the Paper implied that 20 tons per inch was the limit of elasticity of that wire.

Mr. Longridge. Mr. LONGRIDGE replied that he believed the elastic limit of such wire as would be used was about 20 tons, to which he limited every strain in the calculations he had made.

Mr. Barlow. Mr. BARLOW said experiments had been made upon this wire at the Arsenal, and although there were two cases in which a very low elastic limit had been displayed yet in the majority of the results the elastic limit was about 50 tons.

Mr. Longridge. Mr. LONGRIDGE observed that in that case he could make his limit 40 or 50 tons as the case might be.

Mr. Barlow. Mr. BARLOW said of course that had its influence upon some of the observations made upon those designs. It varied of course very much in different qualities of wire; but he should say that

Mr. Barlow.

any wire possessing a strength of 100 tons to the inch, which showed anything like permanent set at 20 tons, was wire in an imperfect state of manufacture, and might by a little treatment be made into a wire of the sort he described. The Paper did not entertain the question of the thickness of the wire, and in that question was involved the extra strains that came upon the exterior of the wire compared with those which came on the interior. He had one word to say upon the subject of ballistics. The conditions put in the Paper were said to be calculated upon investigations made by Sir Frederick Abel and Captain Noble. He had not endeavoured to follow them out, but had compared the results in the Paper with what were known to be the results of chambered guns. A 13-inch chambered gun, something of the type shown in Fig. 21, with regard to its interior ring ought to develop about 30,000 foot-tons of energy with a pressure of 18 tons on the interior of the gun. There must be some cause for the difference between that and the results recorded in the Paper. He might mention examples of guns made at the Arsenal, or guns constructed by Sir William Armstrong. Comparing, for example, the energy with the cube of the diameter, which he found a convenient measure, the quantity amounted in one case to more than fourteen times the cube of the diameter, the cube of the diameter being given in inches, the energy in tons per foot, and that was with a pressure of $16\frac{1}{2}$ tons per square inch. In another case the same thing amounted to fifteen times the cube of the diameter with a pressure of $18\frac{1}{2}$ tons per square inch. The third case was that of Sir Joseph Whitworth's gun, weighing 20 tons—a chambered gun. The energy developed 9,786 tons, being 14·8 times the cube of the diameter. In another experiment with a 400-lb. projectile and 194 lbs. of powder, he got 16·7 the cube of the diameter; and in fact it might be taken that in well-proportioned chambered guns the energy in foot-tons was about equal to 15 times the cube of the diameter in inches, with a pressure not exceeding 18 tons per inch in the chamber. Of course the weight of a gun, so far as the weight required for strength, depended upon its pressure. In this particular case it was felt to be necessary to add weight to the gun beyond what was required for its strength; for he understood the Author added a cast-iron casing, which was in fact adding weight, the function of which was to diminish the recoil.

One word about the powder. There was a very large variety in the relation of the energy produced by a powder to the pressure in the gun; and looking through the various trials which he had remarked this relation differed as much as 50 per cent., depending upon the quality of the powder used in the same gun. The Author

Mr. Barlow. observed that slow-burning powder required larger charges and was not economical. That was quite true, but it produced apparently very good results as regarded the gun. The want of economy in the powder was not an important matter in respect to money. It was not important in fortresses where the powder could be easily stowed; it might become important in ships, and was certainly very important in field artillery where the powder had to be carried with the guns. That subject required and was receiving great attention. Then, for the interior of the tube the Author suggested cast-iron. Mr. Barlow did not think that cast iron would be capable of sustaining the effects of erosion which resulted from the firing of gunpowder. He had an opportunity of seeing casts taken from the mortars engaged in the bombardment of Sveaborg. Those guns had fired some one hundred and fifty rounds, and the result of erosion was such that after that they seemed to be capable of doing very little more. Other guns had stood five hundred rounds. He did not know that he need say more, excepting this; there had been, on the whole, a very great improvement some years back in artillery. He measured that improvement in this kind of way; namely, the energy developed by the gun as compared with the weight of the gun. Going back to the days of the old Woolwich Infant, about 350 to 450 tons of energy could be got out of 1 ton of gun. At the next stage, with breechloaders and somewhat longer guns, 450 to 550 tons of energy per ton of gun were reached. Then steel-hooped guns gave 550 to 600 tons of energy; and the wire guns, of which he had a very great opinion, would no doubt develop a higher state of things than that. It was quite true that as those energies were increased in proportion to the weight of the gun, they increased to a certain extent the difficulty of dealing with the recoil. But there were many excellent contrivances for that purpose; it was a separate study, and had been carried out in many ways, and he believed in time it would be very well done.

Sir Frederick Bramwell. Sir FREDERICK BRAMWELL, Vice-President, said he did not know that he could do better than follow his colleague, Mr. Barlow. It so happened that both of them, independently, had had their thoughts directed to the same two subjects, viz., the wire and the chambering. With respect to the reinforcing a tube by successive layers of wire or riband, he had in that Institution, many years ago, and elsewhere, frequently expressed the opinion that the system appeared to possess promises of success, such as entitled it to have the experiment tried upon a large and practical scale. That he was happy to know, was now being done in more places

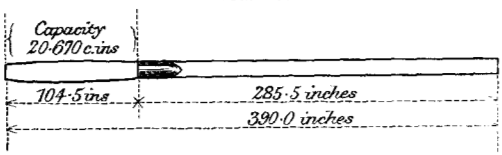
than one. Subject to one remark he would now leave the subject of the structure of the gun. The one remark he wished to make was this. As he followed the reading of the Paper, the Author, in all cases in his calculations, dealt with the wire or riband, as though either it were infinitely thin, or as though it were wound round about a tube of infinite radius; that was to say, the Author in every case treated the tensions upon the wire as though the wire were straight, and as though the tensions were not complicated by the convolutions of the wire round about a cylinder. Mr. Barlow just touched upon that point, and then left it, but Sir Frederick Bramwell wished to call attention to this, that in a by no means improbable case, viz., that of a 6-inch gun, having a tube 2 inches thick, giving 10 inches outside diameter, if the riband was $\frac{1}{16}$ inch thick, the extension of that riband on the outside beyond its neutral axis was $\frac{1}{1600}$ part. If it were the fact that the wire, such as was used for wire guns, extended $\frac{1}{8,000}$ part of its length for every ton tension per square inch, it followed, that if there was an extension of $\frac{1}{1600}$ part of its length, it amounted to an extension of 50 of these 8,000ths, and thereupon the whole of the Author's very delicate calculations were, as it appeared to him, neutralized by the fact he had neglected that the mere winding of a $\frac{1}{16}$-in. wire about a 10-inch cylinder, put on the outside of that wire, even if it were wound on with no retarding strain at all, a tension of 50 tons to the square inch; and that seemed to point to this, that the necessity of attending to the elastic limit could not be so great as the Author suggested it was; for if it were, the whole of these wires would be absolutely useless, in consequence, not of the tension at which they were put on, but of the mere tension which arose in bending them about a 10-inch cylinder. Further the very mode of manufacture of wire showed that it could not be crippled in the way in which the Author suggested, by passing the elastic limit. Consider in what way wire is manufactured? The nippers which lay hold of the end of the wire, are attached to the circumference of a drum, the thinned-down end of the wire is passed through the draw-hole, technically called the "triplet"; the end is attached to the nippers, and then the drum is set revolving. The drum draws the wire in a tangent, to the circle of the drum, it is true, but it is immediately coiled upon the drum under the strain that is requisite to bring it through the triplet; and thus, in the very outset, it must receive a bending, under the tension, which ought to destroy the integrity of the wire, if the elastic limit were such a critical point as was suggested. Practice showed that this could not

Sir Frederick Bramwell.

Sir Frederick Bramwell.

be so, because there were now a great many wire guns made, and he could not help thinking, that in some occult way, the evils which the Author predicted must arise, if the elastic limit were passed, were not produced, for if they were, it would be impossible to make an efficient gun, upon the Author's own system, a conclusion at which Sir Frederick Bramwell would be very sorry to arrive. The other point upon which he wished to speak was the question of chambering. This was treated at p. 105 of the Paper where the Author contrasted the ballistics of a chambered gun, with those of an unchambered gun of equal diameter, and within 4 inches of the same length, the chambered gun using 500 lbs. of powder, and the unchambered gun 413 lbs. The result at which the Author arrived, was that the chambered gun would give a total energy of 17,317 foot-tons, while the unchambered gun, with 87 lbs. less of powder, would give a total energy of 30,103 foot-tons. That was an excess of more than 12,000 foot-tons. He believed that this conclusion at which the Author had arrived was due to an error in his calculation. He would say unfeignedly, that if he found himself differing from the Author in a matter of calculation, he believed it but too commonly arose from this: that the Author was right and he wrong. But in this particular instance, although he had the fear of this solution of their differences before him, he could not help suggesting, the Author had made a mistake. He would endeavour to show at all events, why he thought the Author was wrong. He would ask the members to be good enough to look at three diagrams, Figs. 33, 34, and 35. Fig. 33 showed roughly

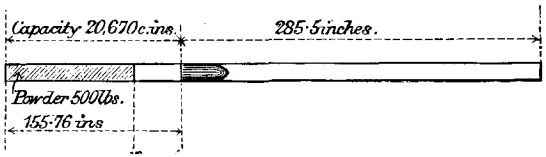
FIG. 33.



the Armstrong chambered gun. The length of the chamber was 104·5 inches; the length of the bore beyond the chamber 285·5 inches; making the total length 390 inches, the capacity of the chamber being, as before stated, 20,670 cubic inches. The Author said that chamber was equal, and Sir Frederick Bramwell agreed with him, to a length of the gun with a 13-inch bore of 155·76. On Fig. 34 he had lengthened the gun the difference between 155·76 and 104·5, viz., 51·26, so as to give in an unchambered 13-inch gun, the same capacity of the powder

chamber, viz., 20,670 inches, as was shown in the chambered gun. He had repeated the Author's calculation upon the diagram, and it was as follows:— Sir Frederick Bramwell.

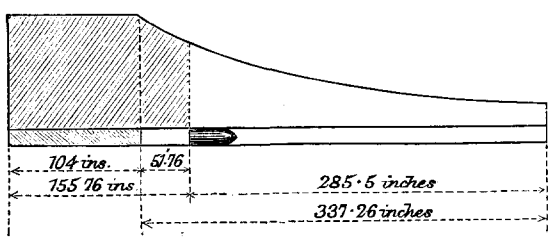
FIG. 34.



$$1 + \frac{\text{Length of Bore. 390 inches.} - \text{Length of Chamber. 104·5 inches.}}{\text{155·76 inches. Length of 13-inch bore equal to capacity of powder-chamber.}} = 2{\cdot}832 \text{ number of expansions.}$$

Then the Author took from Noble and Abel's Paper, that with 2·832 expansions the ballistic effect was 66·386 foot-tons per pound of powder, and from that he deducted the value of the expansion 1·42; that was to say the value of the expansion of the powder from the space it occupied at a gravimetric density of 1 into the contents of the powder-chamber; this value was 28·348 foot-tons per lb. of powder, and deducting that from 66·386 it left 38·038, the total work in foot-tons for 1 lb. of powder, so that for 500 lbs. he obtained 19,019 foot-tons as the total work of the gun. Now he did think that the Author had

FIG. 35.



$$1 + \frac{\text{Length of Gun from end of Powder. 337·26 inches.}}{\text{104 inches Length of Powder.}} = 4{\cdot}2 \text{ number of expansions.}$$

made a mistake, and that he would find he had in effect deducted the loss by the expansion 1·42, twice over, once in the outset in arriving at his number of expansions, and the second time

Sir Frederick Bramwell.

as a deduction from the effect of that number of expansions. He would ask the meeting to consider the diagram, Fig. 35, which he put forward as showing the mode in which in his judgment the expansion ought to be calculated. This as would be seen gave an expansion of 4·2 times. The value of 4·2 was 84·176 foot-tons per lb. of powder, from which, deducting the 8·348 there remained 55·828, as the value in foot-tons for each lb. of powder, as the factor, which multiplied by 500 lbs. gave as the value of that gun a total energy of 27,914, or in round numbers 28,000 foot-tons, in lieu of the Author's 19,000. Mr. Barlow had shown that the chambered guns actually made of that size had 30,000 foot-tons total energy; Sir Frederick Bramwell arrived at 28,000, while the Author estimated the effect at only 19,000. He did really in this instance believe that the Author was wrong and that he was right, and he thought he had pointed out the nature of the mistake. The Author had treated his own gun similarly unfavourably, but as he proposed to use powder at a gravimetric density of $\frac{9}{10}$, instead of the gravimetric density of somewhere about $\frac{7}{10}$, the error of his mode of treatment did not make anything like the same difference in his gun as it made in this, and therefore if Sir Frederick Bramwell was right it altered very much indeed his comparison of 19,000 tons in the one case as against 28,000 in the other.

Mr. Atkinson.

Mr. W. Atkinson said Mr. Barlow had referred to experiments on the strength of wire, and he assumed that an extensive series had been tried. The late Sir William Siemens had tried some experiments on the elastic limit of steel wire, and had come to the conclusion that it was capable of a kind of education, namely, if wire that would break with a weight 1 was subjected to something less than the weight 1, and this was allowed to remain a considerable time, then a weight which exceeded 1 might be put on, and so on until the wire at last would bear a considerably higher strain than at first. He did not know whether the Author could give some information upon that point, because it seemed to bear in a very important manner upon the question of the building up of guns by wire under continual tension. If the Author constructed his gun with the wire under tension, and that wire acquired additional strength by being under that condition for a time, in a short period the whole relation of the gun would be changed.

Mr. Barlow.

Mr. Barlow said a paragraph in the Paper bore strictly upon the point just mentioned. It was this, "Colonel Rosset states, that up to a certain point the elongations were proportional to the

stresses, but beyond that, they increased rapidly, and in a varying proportion, and that when in excess of the elastic limit, permanent elongations remain after the strains are removed." That was the first effect; it was followed by this, "when the bar is again submitted to tension it is found that the permanent elongations do not begin so soon as before, and that consequently the elastic limit of the material has been increased"—that was the tension of which Mr. Atkinson spoke—"though the modulus of elasticity remains practically the same." Therefore the condition of putting what might be termed a permanent set of moderate extent was that the elastic limit of the material was increased and the modulus of elasticity remained the same, and from his observations he thought Colonel Rosset was quite right on that point. Mr. Barlow.

Mr. W. H. PREECE thought he could speak with some little knowledge of the behaviour of wire under different circumstances and under different stresses. He had had occasion at different times to examine the quality and condition of wire that had been submitted to tensions for a good many years. Not very long ago some wire that had been erected forty years was subjected to very careful examination, and it was found that although the wire had been exposed to the atmosphere during all that time, under considerable stress, it retained precisely the same strength that it possessed when it was first erected. Of course that wire had been subjected to very different conditions and to very different stresses to those wires dealt with in the Paper. He did not pretend to know anything about guns, but he did know a little about wires, and the way in which wire conducted itself under different conditions, and he should like to ask the Author one or two questions, because he was bound to confess that a careful listening to the Paper had not convinced him that wire as at present produced was competent to withstand the stresses to which a gun was subjected. The Author suggested that the wire should be laid in coils round the gun under very severe tension, a tension that closely approached the limit of elasticity of the wire; and after the wire had been subjected to this tension it had to undergo some rather rough usage. It had to be enfolded in a cast-iron casing, it had to be subjected to heat, and it had to undergo considerable molecular change. Steel wire was in existence that would stand a stress of 100 tons on the square inch, but if that wire was subjected to heat, or to any annealing process, its tensile strength would be very much diminished, and he should expect to find that if wire with a tensile strength of 100 tons per square inch was subjected to the rough usage of thermal and Mr. Preece.

Mr. Preece. mechanical appliances, its original strength would be very considerably diminished. The Author and Mr. Brooks in their calculation had concluded that the wire retained its original strength, but Mr. Preece doubted very much whether that would be the case. The wire was coiled around the gun, and was subject to a very considerable tensile force in the direction of its length. The wire was coiled around the core, and by taking one portion of one spiral each coil might be regarded as a ring. Suppose a sudden explosion of gunpowder to occur in the chamber exerting a pressure of 30 tons on the square inch, then the effect of a pressure of 30 tons on the square inch would be to distort that ring, and, in fact, to form a ring of greater diameter. Now if in the process of construction that wire had been formed into a ring with a tension closely approaching its limit of elasticity, he should assume that when it was subjected to a pressure of 30 tons on the square inch, in which it would be subject to a distortion which would be practically an elongation, the wire would then be under a strain exceeding its tensile strength and burst. The Author had spoken of the influence of drawing upon the wire. He said, "Let now this wire be drawn down to half its diameter, it will bear at least the same strain per square inch, although it has undergone a very large change of form." That was perfectly true; the wire, in being drawn down, not only retained its strength per square inch, but absolutely had its strength increased. But the Author added, "Mere change of form does not necessarily imply reduction of strength; in fact, in the case of wire-drawing it considerably increases it, and the action of the normal forces on a wire in a gun-coil is simply a case of wire-drawing." He was bound to confess that he must join conclusions with the Author on that point. Such an action as the simple distension of the coil was not at all analogous to the action involved in wire-drawing as explained by Sir Frederick Bramwell. There the wire was drawn through a hole, and in the process of drawing through the hole there was a considerable compression of the molecules, and the result was a considerable accession of strength. Under mere extension, as in breaking a wire, there was a reduction in the diameter without a compensating effect of a compression of molecules, and the result was the wire got weaker and weaker, while in the act of drawing it got stronger and stronger.

Mr. Beaumont. Mr. W. W. BEAUMONT wished to direct attention to the credit due to Dr. Hart with reference to the fundamental formula with which the stresses in ring-structures were obtained. He noticed that several names besides that of Dr. Hart were mentioned,

Mr. Beaumont.

but one name well known in the Institution, viz., that of the late Mr. Robert Mallet, M. Inst. C.E., had not been mentioned; and it was only due to Mr. Mallet to state his belief that he was the first to make use of and really complete for Dr. Hart that mathematical investigation, which would not have been brought out but for him.[1] Sir Frederick Bramwell had mentioned the difference in the various laminæ which might be used in any thickness of wire when bent and subjected to a stress such as that to which that wire would be, and he had mentioned that the Author had treated the compression of the wire in the gun as though the wire were of infinite thinness. He believed on the theorem of Lagrange which he had mentioned in a Paper read before the Institution,[2] it would be found that the difference in the stresses throughout the different parts of a section of wire so bent could be found. Sir William Armstrong had pointed out at the Southampton meeting of the British Association[3] that it was necessary to take into consideration the fact that very much greater tensile stresses would be thrown upon the exterior layer of a wire, unless of infinite thinness, than upon the inner one; and it had been suggested since then the wire might be drawn in such a way that, when wound round the gun, it should have the same tension throughout the whole of its section. It was proposed that this should be done by drawing the wire, as a last process, through a die, which should consist in the upper part of a rubbing die in the ordinary way, and in the lower part of a wheel; the wire, supposing it to be a riband wire as was chosen by Sir William Armstrong, would then pass over the roller and would not on that side have its texture in any way altered; while the upper part passing under pressure through the fixed die would be compressed, or rather, it would be elongated. Of course it would be necessary to cause the wire to come from that die nearly of the same diameter that it would afterwards have to take when coiled on the gun. The Author, referring to a 3-inch gun made some time ago, said that the interior of the tube of that gun was cast-iron, and he mentioned that during the coiling of the wire the core decreased in diameter $\frac{1}{25}$ inch. He remarked that that was very much greater than the elastic compression of the material, and came to the conclusion that in the form of a

[1] "On the Physical Conditions involved in the Construction of Artillery," 1856.

[2] Minutes of Proceedings Inst. C.E., vol. xlvii., p. 45.

[3] Report, 1882, p. 398.

Mr. Beaumont. tube the cast-iron or any material might be compressed much more than its elastic compression. With reference to that point he should like to ask if, when that gun was fired, the compressive stress, which resulted in decreasing the diameter of the tube, continued. It would seem the decrease in the diameter to that extent indicated destructive compression of the material, because, as far as he knew, although the Author mentioned that he supposed the decrease in the diameter of the tube was due to the condensation of the iron, he did not think it had been found that iron was really compressed in that way. He believed when cylinders were subjected to a change of form in that way their specific gravity was not altered; and, if that was the case, then the compression in the tube must be immense, and when the gun was fired it might have been expected that the decrease in the diameter would be considerable. The material of the tube being free to flow inwards, compressive stress greater than that necessary to cause deformation would be dissipated until the stress fell to near about the elastic limit of the materials. Perhaps the Author would state whether that was so or not. The Author had quoted Clavarino, and said: "Clavarino has put forth an opinion that the strength of a gun is limited not by the tension of the material, but by its extension. It amounts in fact to this, that the extension, say of a wire, by the joint action of the longitudinal and the lateral strains, fixes the limit of strain which the wire can resist. He says: 'If the elongation (caused by the three forces) equals that which is produced at the limit of elasticity by simple traction, then the prism is on the point of undergoing a change of form, although the force acting in the direction of elongation may not equal the resistance at the elastic limit.'" The Author objected to that paragraph, thinking it altogether at variance with the facts, but why he objected to it was not apparent, nor was it at all clear what was meant by the paragraph previous to the quotation. He should like to ask the Author what he intended by that paragraph. Clavarino's statement was to the effect that permanent elongation might take place under orthogonal stresses, though the stress in direction of elongation was below the elastic limit.

Mr. Baker. Mr. B. BAKER said there was one little point of difference between the Author and Sir Frederick Bramwell that might be reconciled, and that was with reference to the part of the Paper where the Author assumed the modulus of elasticity of the wire in all these calculations to be 22,000 tons. Sir Frederick Bramwell's calculations of the stresses resulting from coiling the wire

implied a modulus of 8,000 tons, or a difference of $2\frac{3}{4}$ to 1. The effect would be that Sir Frederick Bramwell's 50 tons, which he considered due to bending the wire, would be brought up to 130 tons. The elastic limit would thus be considerably exceeded, unless indeed the wire were of the highest quality and had been previously stretched. He should like to ask where the Author had got wire with 22,000 tons modulus. He thought that about 12,000 to 13,000 tons would be a happy medium in this case. The question was a small one and did not affect the theory of wire-guns, though it did affect the Author's diagrams and numerical results. Mr. Baker.

Mr. J. A. LONGRIDGE, in reply, said, speaking of the question of gunpowder, which had been referred to by Colonel Maitland, his argument throughout the Paper had been that powder-makers had been retrograding in the manufacture of gunpowder for the last twenty-five or thirty years. They had been making weak gunpowder to suit weak guns, and as corroborative of that he read a paragraph from Colonel Brackenbury's recent Paper which supported his view. Colonel Maitland said if strong powder was required why not take gun-cotton. That was exactly the question which he put to Colonel Maitland about two hours previously, when he asked whether the authorities ought not to try to moderate the action of gun-cotton instead of trying to weaken that of gunpowder. He mentioned to him that Baron Lenk many years ago in Austria had, as he was informed, succeeded in regulating the action of gun-cotton not only for small arms but for artillery. How far he had succeeded he could not pretend to say, but he was quite sure that if it could be done, gun-cotton would be far superior to gunpowder, not only in being less bulky, but also in avoiding that dreadful nuisance of smoke. How it would be possible to carry on naval actions now that it was proposed to have charges of powder equal to half the weight of the shot, he did not know; how, looking at the nuisance of smoke, the enemy were to be seen, he could not say; but irrespective of the question of smoke, he felt sure that if gun-cotton or any other material could be produced stronger instead of weaker than gunpowder, all that was necessary was to try to make the guns strong enough to govern it. That he was certain could be done. He was sure that by the application of wire he could make a gun which would resist an internal strain of 50 to 60 tons per square inch, which should be as safe as the present guns with an internal strain of 15 tons per square inch. The investigations which he had carried out would, he thought, prove that to Mr. Longridge.

Mr. Longridge. demonstration. It remained with those who had the power, such as the great establishments at Woolwich, at Elswick, or elsewhere, to experiment, not on a tentative process, but upon the lines now set before them on strict mathematical evidence. If any gun-maker was disposed to consider the question, Mr. Longridge's services were at his complete and free disposal. He should be most happy to give every information either to those at Woolwich or Elswick, or to Mr. Vavasseur, M. Inst. C.E., or any one else who would seriously go into the question, and he felt sure that if one-thousandth part of the money which had been spent in other experiments had been applied to wire-gun experiments, wire guns would have been in a very different position from what they now were. In his Paper he referred to the "Daring" gun. Colonel Maitland said that many guns of the same nature as the "Daring" had fired hundreds of rounds, and would continue to do so. That was perfectly true, and Mr. Longridge had said as much in the Paper; he said the gun might fire hundreds of rounds, but it was beginning to fail from the commencement, and sooner or later it would give way, and to that opinion he still held. How was it if these guns were perfectly safe that, immediately the accident took place, orders had been issued that they were only to be fired with reduced charges? He was very happy to hear from Mr. Barlow that wire could be got with an elastic limit of 50 tons. He had not been aware of that, and therefore preferred to be well within the mark, and in all his calculations to take it as 20 tons. If 50 could be had so much the better for his wire gun. Some remarks had been made by Mr. Barlow and Sir Frederick Bramwell about the strains induced in the wire by the act of coiling it about a core, and the same question had previously been raised by Sir William Armstrong at the Southampton meeting of the British Association. This was a point which the Author had not lost sight of, but being of minor importance, and considering the length of the Paper, he had not referred to it therein. Sir Frederick Bramwell, taking the case of a 10-inch core wrapped round with $\frac{1}{16}$-inch wire, argued, that if the wire were put on with no tension, it would, by the act of coiling on, be strained to 50 tons per square inch at the outer circumference. This would probably be true if two conditions existed; first, that the limit of elasticity was equal to or exceeded 50 tons per square inch, and second, that the wire, previous to laying on, was a straight wire of indefinite length. In reality it was not so. The wire as used was already in the form of a coil, and in that state was free from internal strain. Were it

otherwise, were it in tension on one side of the neutral axis, and consequently in compression on the other side, it would necessarily straighten itself. The extra strain brought on in coiling on the gun, was only that due to the difference of the radius of the drum on which the wire was coiled, and that of the coil when upon the core, and this might be manipulated indefinitely. This question would be found dealt with more at length in the Author's forthcoming work; at present he would only add that the extra strain from coiling did not give rise to any difficulty in the construction of the guns. He should not think in a 6-inch gun of putting on a $\frac{1}{16}$-inch wire for the inner coils, but he should prefer $\frac{1}{40}$-inch wire. Even with a $\frac{1}{16}$-inch wire the strain did not exist to the extent that Sir Frederick Bramwell thought. This very question of special elasticity which Colonel Rosset drew attention to, and which it was very desirable should be thoroughly investigated, showed that the wire was permanently stretched, but it did not retain the force with which it was stretched; it could at the very most retain the stretch of its elastic limit. The question had never been lost sight of, but it practically amounted to such a very small matter, that it was no real objection in the case of large guns. As to the question of erosion, rifled cast-iron guns were things of every day. The French artillery consisted almost entirely of rifled cast-iron guns. It was true the French were making some exceptional special guns, in which they did not seem to have much confidence, with steel tubes, but the great bulk of the artillery was cast-iron. So also was the American and Italian. The question of erosion was embarrassing with these large charges, on account of the enormous amount of powder which, being to a great extent an inert material, formed a fluid mass, and rushed along the gun. No doubt erosion was an inconvenience, and must diminish to a certain extent the life of the gun, but he would rather take care of the life of the men than the life of the gun. If the gun got unserviceable, nothing could be easier than to retube it, but he believed that erosion could be very greatly done away with by means of gas-checks; at any rate, he maintained that the question of erosion was quite beside the mark, inasmuch as nearly every other country was using cast-iron for the inside. Mr. Barlow, whilst not challenging the Author's calculation of the ballistic effort of Sir William Armstrong's 13-inch gun (Fig. 21), spoke of comparing the results with what he said was known to be the results of chambered guns. He said a 13-inch chambered gun, something of the type shown in Fig. 21, ought to develop about 30,000 foot-tons of energy with a

Mr. Longridge.

Mr. Longridge. pressure of 18 tons on the interior of the gun; but he did not say that it had actually done so. It was not possible for the Author to argue against what a gun ought to do, nor could he say what it really would do, as Mr. Barlow did not give the weight of the charge of powder; but he had no hesitation in saying, that with a charge of 500 lbs. of powder in the chamber of the gun, Fig. 21, it was impossible for anything like 30,000 tons energy to be developed. He confessed that he could not follow Mr. Barlow's comparison between the energy and the cube of the diameter of the bore. He could not conceive the relation that there was between them in any possible way, and therefore could draw no conclusion from the figures which Mr. Barlow had submitted. Neither did he think that the proportion between the energy and the weight of a gun was a matter worthy of consideration. He could make his gun as light as he chose. If the recoil could be done away with he would reduce the weight of the gun as much as was desired. It was simply in order to avoid the inconvenience of recoil that he gave that weight, but he gave it with a material costing about £5 a ton instead of the enormously expensive steel and iron which was put on to such guns as that represented in Fig. 21. Mr. Barlow had remarked, that economy of powder was not a very important matter with regard to money. Perhaps not, although in firing large guns with projectiles weighing 1,000 lbs. the difference between 200 lbs. of powder and 500 lbs. would amount to a pretty large sum; but there were other considerations, and amongst them the amount of smoke which such enormous charges would give out, the inconvenience of such large cartridges, and the difficulty of transport and storage. Mr. Barlow had again referred to Professor Barlow's theory, and admitted that it differed from the true theory as given by Messrs. Brooks, Lamé, Rankine, and Hart, who had all arrived, independently of each other, at the same formula. He also remarked that Sir William Armstrong said, as the result of his experience, strict mathematical rules should not be adhered to, and that this was not speaking from any theory, but was the result of a very long experience in gun-making, and Mr. Barlow referred to a passage in the Paper, as to some extent supporting this view. Now the passage in question simply referred to a possibly exceptional case, in which by chance the permanent set was exactly equal to the excess error in tension, and must not be taken as in any way supporting Sir William Armstrong's contention. Coming to Sir Frederick Bramwell's calculation with respect to these two guns, he would give what he had said his most careful considera-

tion; and if he found that Sir Frederick Bramwell was right, as he very often was, nobody would have greater pleasure than he in correcting the matter. All he could say at present was that his calculation followed exactly in the lines given by Captain Noble and Sir Frederick Abel, in which they took a precisely similar case, and worked it out according to their Tables. He followed exactly on their method, and did not pay particular attention to it, thinking that such high authorities as they were must be right. Mr. Preece appeared to have misunderstood the Paper. He said that the Author suggested that the wire should be laid on in coils under very severe tension, closely approaching the limit of elasticity of the wire. The object of the Paper was, on the contrary, to determine the laying-on tension, so that when supplemented by the strain from the powder-pressure, it should never exceed the elastic limit. The diagrams in the Paper showing the conditions of a gun when the wire was laid on with a high initial tension, were placed there expressly to show the pernicious effect of a high laying-on tension, and not to show how a gun might be made. Mr. Preece had fallen into another mistake in supposing that after the wire had been put on it was subjected to rough usage. He said it had to be encased in a cast-iron casing and subjected to heat. The operation of putting the coil into the outer case was very simple, it involved no rough usage, and the coil was not subjected to any heat. With reference to the action of compression upon the small 3-inch gun, he had been asked by Mr. W. W. Beaumont if he measured the gun after it had been fired. He had not done so. It had been fired a great many times, and was apparently as perfect now as ever it was. There were no signs of erosion or fracture, or cracks, or anything of the sort. Mr. Beaumont was mistaken in thinking that cylinders when subjected to change of form in that way, did not alter their specific gravity. They did alter their specific gravity. Mr. Beaumont had reproached the Author with having omitted Mr. Robert Mallet's name. The Author did not mention Mr. Mallet because he was speaking of those who had investigated this question mathematically, and Mr. Mallet in his book expressly stated that it was Dr. Hart who made the investigations for him. As to the modulus of elasticity which he had taken, which Mr. Baker stated differed widely from that assumed by Sir Frederick Bramwell, he did not go very particularly into what really was the modulus of elasticity of the best steel wire, for it was beyond his personal knowledge. He had taken those figures from various documents in his possession, chiefly from the U.S.A. Ordnance

Mr. Longridge.

Mr. Longridge. reports, which contained a great number of experiments upon that subject. Steel wire no doubt had been and could be obtained with a modulus of 22,000 tons, but that did not at all affect the general question; it merely affected the value of the "c," which was one of the constants introduced into the formula. The formula was in such a general form that any modulus of elasticity, any radius of core or coil, and any dimension of gun, could be adopted. It would give the exact strain with which to lay on the wire if a uniform tension under fire were desired; or if uniform tension in laying it on was the object, another formula would give the exact strain under fire and at rest. It was perfectly general in form, and he sincerely hoped that the gun-makers would give it full and fair consideration, and put it to practical proof, instead of continuing to construct wire-guns by a tentative process. It was gratifying after thirty years to find that the views he then expressed as to the value of wire were being recognized; but it was grievous at the same time to believe that what was being done, and had been done up to the present time, had not been guided by theoretical and scientific considerations, but by a tentative process.

Mr. Woods. Mr. EDWARD WOODS, Vice-President, said all would agree that the Author had made a valuable contribution to the science of the construction of guns, and it must be gratifying to him to see that the subject was now receiving attention from those conversant with the details of the manufacture of ordnance. All present would join in the wish that the experiments now being made would be carried out to the Author's satisfaction, and would show the value of the system which he had been advocating.

Correspondence.

Mr. Longridge. Mr. LONGRIDGE observed that Sir Frederick Bramwell had taken exception to the calculation at p. 106 of the Paper, which represented the comparative power of the two guns, as obtained from Table XI., according to Noble and Abel's approximate method, detailed at p. 240 "Researches on Expansions;" that was to say,

	Foot-tons.
Chambered gun, 500 lbs. powder	17,357
Unchambered „ 413 „ „	30,103

Sir Frederick Bramwell had challenged these figures, and found by his own method of using the Tables, an energy for the chambered gun with 500 lbs. = 26,357 foot-tons. The Author,