Mr. Butter. conclusions in respect to it must therefore be of a purely speculative character. Mr. White had shown by reference to various experiments that it could not be so great as had been imagined; it must be borne in mind that this cause operated, although in a less degree, in the case of R. L. G. as well as in that of pebble powder, so that to account for the difference of one-third in their respective energies a much larger proportion than one-third of the energy of recoil of pebble powder must be due to the back pressure of the liberated gas, and considering how small, comparatively with what it had been in the bore, this was to begin with, and how rapidly, by free expansion in the air, it would cease, it could scarcely be seriously maintained that the full difference was due to this cause alone, although he admitted it must have an important bearing upon it. It was needless to consider the effect of the resistances of friction and of air upon the shot and the gun respectively, as these had been generally accepted. Looking then at the whole question from the point of view of the physical conditions which would appear to govern it, he thought no grounds existed for the confidence with which Professor Unwin and Mr. Bousfield maintained the entire sufficiency of existing mathematical expressions to meet the case; and that there was ample justification for the introduction of some constant, to meet the unknown quantities, into existing mathematical formulæ. He was not disposed to defend himself from the charge of a misapplication of mathematical expressions to any greater extent than he had done. That relating to "inertia" was the most serious, and no doubt arose on the part of his critics from not fully realising the conditions he had in view when he used the expression.

Correspondence.

Mr. Bashforth. Mr. F. BASHFORTH remarked that there could be no doubt that great advantage would result from the introduction of some elastic material between the gun and carriage of field guns, provided the invention were simple and not peculiarly liable to be damaged on service. He thought a good result would have to be worked out by trial, because so little was known about the action of gunpowder. As to the kind of action of exploding powder on the gun, he believed it was for the most part correctly treated by Hutton, Didion, &c., in their accounts of the gun pendulum. There could be no doubt that, if it were possible to apply a pressure $P—p$ to the breech of a gun at all times equal to pressure P of the exploding powder on the base of the bore, less p the forward pressure of the studs, &c., the gun would be prevented from recoiling. Mr. Bashforth.

But next to nothing was known about the pressure of exploding powder in the bore of a gun. He could not, therefore, agree with the Author that Researches on Explosives had settled all questions relating to the action of powder-pressures on the projectile with a completeness that left nothing to be desired. So far as the "projectile" itself was concerned, that was found by measuring the initial velocity of the shot. But the long and costly series of experiments was undertaken with a view to discover the action of powder-pressure on the gun. And, so far as he could understand the results arrived at, there was an enormous variation in the pressures exerted by the exploding powder on the gun, even when the shot had the same muzzle velocity and was fired with the same charge from the same gun. The experiments appeared to point to the conclusion that powder fired under apparently like conditions was liable to enormous variations in the stress it threw upon the gun. He was, therefore, not surprised to find Sir W. Armstrong declaring (16th March, 1880) that "nothing, in fact, wants investigation so much as this powder question, and until we arrive at more definite conclusions we cannot hope to be altogether free from accident."[1] And this was said after the failure of one of his 100-ton guns, although its strength was far beyond what a normal pressure would demand. Of course the recoil of a field gun would depend upon the nature of the ground on which it was placed, and, when the gun was fired, there would be an impulse given to the carriage by the gun, and another by the ground. He had often recommended experiments to determine the law of recoil of the gun similar to those mentioned in the Paper, but in vain. The gun ought to be left as free as possible to recoil, and the curves ought to be traced with a diamond point. He was disposed to think this would give the best attainable law of pressure on the base of the bore when any gun was fired, unless an experimental gun could be constructed on Captain Morgan's plan, which would reduce the mass of the part set in motion, and so give the law of recoil better.

Mr. G. Canet was unable to agree with the Author's novel ideas on the recoil of guns, as they were contrary to mechanical principles and facts. If left unchallenged, the Author's theory might lead into error those who had to investigate the delicate problem of the recoil of guns. Mr. Canet.

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[1] *Vide* Proceedings of the Royal Artillery Institution, vol. xi., p. 197.

Mr. Canet. The formula of the velocity of recoil, deduced from the equality of momenta, had never been right, as some factors had been left out of account; but as these factors were not generally of great importance at the beginning of the recoil, the velocity of recoil calculated by this formula was not very far from the truth. However, it must not be forgotten that this velocity was that of the gun and carriage when the projectile left the muzzle. It was not the same as regarded the maximum velocity of recoil; it was obvious that when the projectile had left the gun, the powder gases continued their action on the bottom of the bore till they were expanded to the atmospheric pressure, and the velocity of recoil increased more or less according to the resistances opposed to the motion of the gun. In order to design properly carriages strong enough for the work they had to perform, without more weight than was just required, it was important to understand thoroughly the action of the powder-pressure on the gun and carriage, which might be considered as part of the gun when there was no play on the trunnion-bearings. The Author seemed to think that inertia was such a special resistance that, on account of its great mass and the short time during which the pressure acted, "the gun was not directly obedient in its motion of recoil to the variations of powder-pressure, but stored up the total work of the pressures to be afterwards developed in one complete dynamic effort." Inertia was nothing of the kind. It was the resistance that a body at rest or in motion opposed to a change in its velocity, so that as long as the gun did not move there was no inertia to overcome, and at first the powder-pressure had only to overcome the ordinary resistances such as gravity, friction, &c. It followed that the recoil must begin nearly at the same moment as the shot moved, because as soon as the powder was ignited the pressure increased very rapidly to what was required to push the shot and the gun, as shown by the curves (Plate 2, Fig. 1). When a shot was deformed in the bore of a gun, it was not due to inertia, but to a pressure too great for the metal of the shot to withstand. This had been proved by some experiments made at Calais in 1872, to find the influence of the centre of gravity of common shells on the flight of projectiles; some lead had been run into the shells to bring them to weight, when it was found that the base of the shells was considerably set up by the firing. When sand was used instead of lead, the shells came out of the gun without injury. The inertia was the same in both cases, but the lead could not sustain the powder-pressures without expanding, and this deformed the cast iron of the shell. What

Mr. Canet.

was then the action of powder in the bore of guns? The powder-pressure had not only to act on the masses of the projectile, gun, and carriage, but it had to overcome various resistances, viz., the forcing of the projectile through the rifling against the atmosphere, and the friction of the carriage on the slide, the gravity and the resistance of the brake. Let d and B be these variable resistances, and the following formula would give the velocity of recoil V of the gun and carriage when the projectile left the muzzle :—

$$V = \frac{\left(w + \frac{w'}{2}\right)}{W} v + f(d, B) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (a)$$

w and w^1 being the weights of the projectile and charge, W that of the gun and carriage, and v the velocity of the projectile when it left the muzzle, which was less than the initial velocity, because the powder gases acted also a certain time on the projectile when out of the gun. As the maximum velocity of recoil would depend so much on the resistance of the brake, it would be impossible to lay down a definite rule for all cases, but it would be something in the shape of formula (a), the coefficient half of w^1 being replaced by a variable one β depending on the nature of the powder.

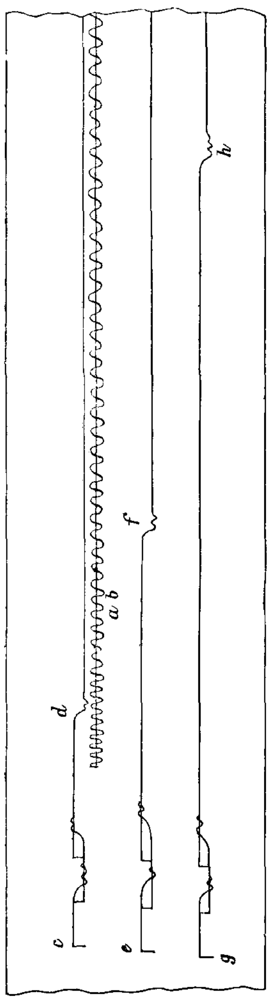
He had seen some rounds fired with compressors wrongly set, when there was no recoil; it was obvious there was no velocity of recoil. In formula (a) $\frac{(w + \beta w^1) v}{W}$ would be equal to minus function (d, B) and therefore

$$V = O$$

while with the Author's formula V would always have the same value, which was impossible. So much being said for the theoretical part of the question, it remained to be shown that what he contended for was not contrary to facts. The Author had brought forward a certain number of experiments which he was afraid could not be entirely relied upon, on account of the very rough apparatus which had been used. An eminent officer of the French Marine Artillery, Colonel Sebert, had devised, to study the recoil of guns and the motion of projectiles, very ingenious apparatus, and he was certain the results of experiments carried on with that apparatus would leave no doubt as to the effect of powder-pressure on guns. The apparatus used by Colonel Sebert to find the law of recoil was very simple. It was called a

Mr. Canet. "velocimetre." It consisted of a steel riband attached to the carriage, and pulled with it when it recoiled; it had therefore the same motion as the carriage. Over this riband were placed, in a fixed position, a tuning-fork and a series of little electric markers, which were electro-magnets, the armature of which carried a pen. When the current passing through the electro-magnet was broken, the pen moved sideways. To the tuning-fork was also attached a pen, and it was kept electrically in vibration. It was used for measuring the time from the number of vibrations it made per second. The surface of the riband was blackened with lampblack, and the pens of the markers and tuning-fork rested on it. When the carriage recoiled, the pen of the vibrating tuning-fork drew a sinuous line on the riband, and the pens of the markers drew straight lines, till the current passing in each marker was broken, when the line deviated. These markers were made to register on the riband the moment the shot left the muzzle, and when it passed through a certain number of screens. The full size diagram on the riband was as shown in Fig. 4. Supposing the tuning-fork vibrated one thousand times in a second, the carriage moved from *a* to *b* in one-thousandth of a second; it was therefore easy to deduce the velocities of recoil at any point; *c d*, *e f*, *g h* would be the lengths the carriage had recoiled when the projectile left the muzzle, and when it passed through the screens, and the time would be given by the number of vibrations of the tuning-fork. By a special contrivance the markers were made to act at the beginning of the recoil in order to be able to measure the time lost in the moving of the pens, time which had to be taken into account. He had selected a few amongst

Fig. 4.



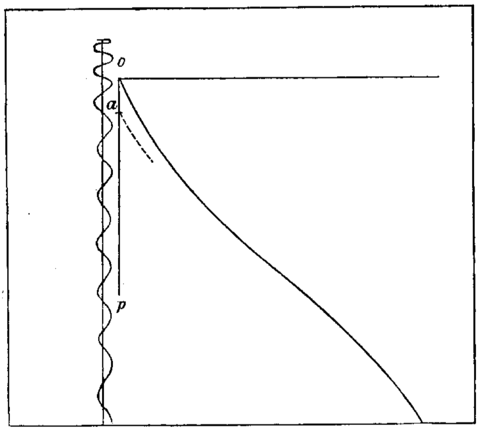
the numerous experiments carried out by Colonel Sebert; they Mr. Canet. showed the results obtained with a 24-centimetre ($9\frac{1}{2}$ inch) gun, weighing $15\frac{1}{2}$ tons, mounted on a hydraulic carriage weighing 19 cwt.

Date of Experiments.	Weight of Projectile.	Weight of Charge.	Initial Velocity of Projectile.	Velocity of Recoil when the Shot left the Muzzle.		Velocity of Recoil Maximum Measured.	Length of Recoil.
				Measured.	Calculated from Formula (*a*).		
1878.	Lbs.	Lbs.	Feet-sec.	Feet-sec.	Feet-sec.	Feet-sec.	Inches.
17 August .	315·0	61·729	1,494	13·60	14·04	16·84	38·9
17 „ .	315·1	,,	1,490	13·70	14·00	14·96	24·1
6 June .	315·9	,,	1,477	13·45	13·91	14·44	15·6
28 „ .	317·5	52·911	1,354	12·22	12·65	15·62	32·4
28 „ .	316·8	,,	1,338	12·27	12·47	15·55	31·9
6 „ .	317·9	,,	1,370	12·07	12·81	13·79	38·0
17 August .	316·8	44·092	1,222	10·68	11·23	11·75	16·1
17 „ .	314·2	,,	1,217	10·95	11·11	13·52	27·8
29 June .	317·4	,,	1,220	10·84	11·24	13·91	28·2
29 „ .	317·5	35·274	1,057	9·42	9·62	11·56	24·3
29 „ .	317·5	,,	1,059	9·34	9·64	11·67	24·2
29 „ .	316·8	,,	1,068	9·50	9·70	11·75	44·9
29 „ .	316·8	26·455	892	7·63	8·00	9·33	20·1
29 „ .	317·5	17·637	689	5·72	6·11	6·69	22·6

The hydraulic compressors had valves loaded with springs. He had calculated from formula (a) the velocity of recoil when the projectile left the muzzle, but he could not take into account $f(d, B)$ as that function was not known. He should, however, expect when there was a powerful brake, that the influence of d was less than that of B, so that V calculated from (a) must be too great. He should anticipate the reverse when there was no brake, or when a Woolwich buffer was used, as it did not give any resistance before the carriage had recoiled a certain distance. It would be seen from the Table that it was impossible to give a formula to represent the maximum velocity of recoil, as it varied according to the setting of the compressor and the quantity of air that might have got into the hydraulic cylinders. When there was no air in the cylinders the maximum velocity decreased as the recoils got shorter. Colonel Sebert found that with the 61·73 lbs. charge the time of travel of the projectile through the bore was 0·012 second, while the velocity of the carriage increased during 0·030 second. When there was no brake it increased during 0·041 second. In that case the carriage had recoiled 1·2 inch when the shot left the muzzle, and 7·9 inches when the carriage had its greatest velocity of recoil; the projectile

Mr. Canet. was then 16 yards off the muzzle. To prove that the recoil began as soon as the projectile moved, Colonel Sebert used an "accelerograph," which consisted of a plunger moving in a plug screwed

Fig. 5.



into the walls of the gun over the chamber, like a vent-piece. This plunger, which had a certain weight, carried on its top a flat vertical surface blackened with lampblack. The plunger was acted on by the powder-gases exactly like the shot. In front of the flat surface was a guide, along which a pen could be drawn by a spring as soon as it was released by the recoil of the gun. The powder-pressure caused the plunger to be shot up, and if the pen did not move, the line drawn by the pen on the blackened surface would be parallel to the axis of the plunger; but as soon as the recoil began the pen moved, say to the right, drawing a curved line on the surface of the accelerograph. It would be seen from Fig. 5, which was full size, that this curve commenced at the starting-point of the pen; this showed conclusively that the recoil of the gun began as soon as the plunger; or, in other words, as soon as the shot moved. Should it not be so the curve would begin on a point a of the vertical line $o\,p$, when the plunger would have been shot up of the quantity $o\,a$.

As to the elastic field-carriage proposed by the Author, it afforded him great pleasure to put on record that a similar carriage was designed nearly three years ago by Mr. J. Vavasseur, M. Inst. C.E., to whom artillerists were indebted for many other valuable inventions extensively used. The description given by the Author seemed sufficient to explain the Vavasseur field-carriage. Plate 5, Mr. Canet.

Fig., 1 showed a longitudinal section through the axis of the hydraulic compressor, the gun being in its firing position. The piston of the hydraulic compressor was pierced with two holes; in its central part was inserted a circular valve with holes corresponding with those of the piston. This valve had two projecting studs, which entered special grooves cut in the cylinder. During recoil the valve turned round gradually, closing the orifices. The dimensions of the holes were such that the resistance of the compressor was uniform during recoil. Fig. 4 showed the carriage ready to change its position during action, and Fig. 5 showed the gun in its travelling position; all sudden concussions were prevented, as the gun rested on springs *o* and buffer *p*. A greater portion of the weight of the gun was brought on the limber. No doubt if it were desired to increase much the velocity of field guns, the carriages now in service would not stand the work, and it would be necessary to use a carriage similar to that proposed by Mr. Vavasseur or the Author.

Mr. Davey.

Mr. HENRY DAVEY observed that the Institution was indebted to the Author for submitting the forces and strains of recoil to direct experiment, the only satisfactory way of dealing with the problem. The Author first gave the formula derived from the accepted equation for the equality of momenta after impact,

$$\left(V = \frac{v\,w}{W}\right),$$

for ascertaining the maximum velocity of recoil. He then proceeded to state certain propositions as being usually accepted as true; viz., that the force of recoil could not exceed the maximum powder-pressure on the bottom of the bore, even in the case of holding the gun rigidly immovable; and that, while slow-burning powders might increase the length of recoil, the intensity was less in the same proportion as the powder-pressure inside the bore. But he also said that these views depended for their truth upon directly opposite conceptions of the nature of recoil. Now there was certainly ambiguity in the enunciation of the propositions. First, the term force of recoil was evidently intended to mean the same thing as intensity in the second proposition. If the terms were, as Mr. Davey believed they were, intended to mean the force resisted by the gun in the line of fire, when held perfectly immovable, it was difficult to see that the propositions were not true. If the gun were immovable, it was incapable of accumulating energy, because it could not acquire velocity. As regarded the application of the equation for the equality of momenta in deter-

Mr. Davey. mining recoil, he thought the Author was right in questioning its accuracy. The impact of the explosion took place in the breach of the gun, and its first effect was to compress the metal forming the breech, next to set up a high tension throughout the gun; and should the motion of the gun commence before the shot had left the bore, then the effect of the recoil would be augmented by direct powder-pressure acting between two moving bodies. Evidently, from the electric experiment alluded to by the Author, the gun did begin to move before the shot left the muzzle; and it would be interesting to have more conclusive proof of this, because he did not think the observations by so-called instantaneous photography could be relied on. He considered the Author was wrong in saying that the energy of recoil was due to the sudden liberation of stored-up work, rather than the direct action of powder-pressure, since the latter had ceased before motion in the gun was set up. It appeared to Mr. Davey that the reason why the energy of recoil with slow-burning powder was greater than that with quick-burning powder was that, in the former case at all events, the powder-pressure had not ceased before motion in the gun was set up. The observed increase in the length of recoil, consequent on the use of pebble powder as compared with R. L. G. powder, might be accounted for partially by the fact that with the pebble powder the maximum velocity of recoil was attained later than in the other case, and as a longer space was passed over in accumulating the energy, the sum of the spaces passed over during the accumulation and dispersion must necessarily be longer. In other words, the path of recoil might be divided into two parts: first, that traversed whilst the velocity of recoil was increasing; and the other, that traversed in bringing the gun to rest. The slower the powder was burned the longer would be the first part, and therefore the longer the whole. The Author had given no indication of the methods employed in eliminating the errors incidental to the mode of carrying out the experiments; such an error, for instance, as that due to the difference between the friction of rest and of motion. The hydraulic buffer appeared to be an excellent method of reducing the force which would be otherwise brought to bear on the carriage, by causing the inertia to be overcome gradually instead of suddenly.

Prof. Greenhill. Professor A. G. Greenhill observed that the facts and the results of the experiments, brought forward by the Author in the Paper, showed the insufficiency of the ordinary data for calculating the velocity of recoil and the strains due to its action. Although at first sight it might appear that the experiments exhibited a

Prof. Greenhill.

violation of the third law of motion, "action and reaction are equal and opposite," yet this apparent discrepancy was useful in directing attention to phenomena which had hitherto been considered insignificant and unimportant in comparison with those which had usually been taken into account. With the ordinary hypotheses employed, the gun and carriage were considered to form one rigid body, and the recoil was supposed to take place as if the gun were fired from a smooth horizontal platform. On these hypotheses the momentum of recoil was equal to the momentum of the shot at the instant the shot was escaping from the muzzle, and the centre of gravity of the gun and shot had not moved up to that moment. But the old experiments with the ballistic pendulum, performed by Dr. Hutton, proved that the momentum of the recoil was greater than the momentum of the shot, and the discrepancy must be accounted for principally in the motion imparted to the air at the muzzle by the flash of the discharge of powder. When it was considered how far the flash would extend, particularly with slow-burning powder, and that the weight of 13 cubic feet of air was 1 lb., it would easily be seen that it was no exaggeration to suppose that an amount of momentum might be communicated to the air equivalent to from one-third to one-half the momentum of the shot, so that the velocity of recoil was from one-third to one-half time greater than it would be if calculated from the principle of the equality for momenta of the gun and the shot. The experiments adduced by the Author proved, however, that to obtain a true idea of the nature of recoil in its action on the gun-carriage, and in the means which must be employed to control the recoil, the old hypotheses of perfect rigidity must be abandoned. The Author had spoken of the elastic yielding of the shot; but this effect he should consider unimportant compared with the elastic yielding of the gun, in consequence of the greater relative length of the gun. It was this elastic yielding which made time such an important element in overcoming inertia. To take the simplest instance, reversing the conditions of the discharge of a gun, and imagining two elastic cylinders of equal cross-section to impinge directly, then, on the hypothesis of perfect elasticity, the shorter cylinder (which must be taken to represent the shot) rebounded without vibration, and the time of impact was the time a longitudinal vibration took to traverse twice the length of the shorter cylinder; while in the longer cylinder (representing the gun) a wave twice the length of the shorter cylinder was propagated backwards and forwards, causing a worm-like progression of the longer cylinder. Of course in practice the imper-

Prof. Greenhill fect elasticity of the materials speedily destroyed this wave-action, leaving eventually, after a certain time, the resultant momentum as calculated on the hypothesis of perfect rigidity. This gradual destruction of vibration was beautifully exhibited in the records produced by the Author. To measure the recoil accurately the endeavour should be made to exaggerate its amount. The model produced by Sir Frederick Bramwell would doubtless afford interesting results in this way. Another method of increasing the recoil and measuring its amount would be to suspend the gun alone, without any carriage, by two equal parallel vertical chains 6 or 7 feet long, and then the gun after firing would recoil parallel to itself, and the velocity of recoil would be eight times the square root of the height ascended in feet. If the gun was free to revolve in the collars by which it was suspended, then the rotation communicated to the gun, in consequence of the rifling, could be measured and would afford additional interesting results. A gun freely suspended in this manner, firing blank charges, would give better indications of the effect of the discharge of the powder in the air than a gun fired from the ordinary carriage, when a certain amount of friction had to be overcome before any motion would take place.

Prof. Jenkin. Professor FLEEMING JENKIN observed that the Author had brought forward a curious fact, viz., the inequality of recoil observed when different powders were employed to give one and the same velocity to shot of a given weight. The only explanation which occurred to him as possible was, that the velocity of the products of combustion issuing from the gun must be very different in the two cases, although the velocity of the shot was the same. This at least would be a *vera causa* sufficient to account for some difference in the recoil. The data given in the Paper were insufficient to show whether the cause now suggested would produce the full effect described.

The explanation suggested by the Author appeared quite inconsistent with the well-established and fundamental laws of applied mechanics. The equality of momenta in opposite directions was a principle too well established by reason and experiment to be overthrown by any apparent contradiction; it was, indeed, obvious that the Author was not fully conversant with kinetics; this was shown in many places by the language employed. Thus it was stated: "Recoil, then, is due to a purely dynamic force, the resultant of the sum of all the powder-pressures." Professor Jenkin was not aware that there were two kinds of force, one dynamic and the other of some other nature; nor could he conceive how the summation of all the powder pressures was meant to be effected. The Author was also greatly mistaken in supposing that by lengthening the bore of the gun the work of recoil would be made more and more nearly equal to the energy acquired by the shot. Prof. Jenkin.

Mr. Longridge. Mr. LONGRIDGE said he had considerable difficulty in following the Author in his reasoning on the nature of recoil, owing to his apparently vague ideas respecting the forces and their action. In the first place, the Author took exception to the simple formula, as he termed it, of the equality of moments $V W = v w$. Now, as this formula was the expression of a universal law, it could be only to its application that exception could properly be taken. The fact was that the work done by the force, *i.e.*, the powder-pressure, was not simply moving the shot and the gun. There was the compression of the air and its displacement, the friction of the gases through the tube of the gun, the friction of the rifled projectile and of the gun-carriage, the extension of the body of the gun between the breech end and the trunnions, and other work done, all of which ought to be taken into account in a strict consideration of the question, and it was easy to see how at any rate some of them would be affected by the greater or less sudden application of the force arising from the use of quick or slow-burning powder. As an instance of the vagueness of expression above alluded to, the Author said, "It is stated that the force of recoil cannot exceed the maximum powder-pressure." What was meant by the force of recoil? Recoil was an effect produced by a force, and that force was purely and simply the powder-pressure itself. No one conversant with mechanics could maintain that the amount of recoil was dependent upon the maximum powder-pressure. If the amount of recoil were measured by the weight moved, and its attendant resistances multiplied into the distance moved, which was the only true measure, then it was evident that this distance must depend upon the velocity imparted to the gun; and this velocity did not depend on the maximum pressure applied, but was represented by the integral of the pressure at any moment into the time of its action; it was, in fact, $\int p\,d\,t$, when p varied from instant to instant. It was, therefore, easy to see that with a slow-burning powder this integral might be much larger than with a quick-burning powder, although the value of p at some particular instant of time might be much larger in the latter than in the former. An analysis of the pressure and time-curves taken by the chronoscope would show this conclusively. In the next place, the Author said that the energy imparted to the

Mr. Longridge. shot was due to two actions, "the one being of the nature of completed pressure of impact, and the other, and by far the larger, a directly accelerating force." Now impact and pressure were one and the same thing, impact being simply a pressure of short duration applied very rapidly. It was as much an accelerating force as any other pressure. The powder-pressure began at zero, and were it not for the frictional resistance of the shot, and in a very minute degree from its elasticity, the motion of the shot would begin at the very same moment as the application of the pressure; but in reality the pressure must accumulate till it was equal to the resistance, and then motion began, and the force, like all other continually applied forces, accelerated the velocity of motion. It was the same with the gun. As soon as the pressure had accumulated so as to balance the resistance of the gun and its carriage, motion of the latter commenced, and if it was ascertained, by photography and electricity, that this motion only began when the shot was clear of the gun in the first instance, and when it was within 2 inches of the muzzle in the latter, it only showed that either the means of observation were imperfect, or that the pressure did not balance the resistances till the shot had attained these positions. If the gun really did not move till the shot was clear of the muzzle, it was difficult to imagine why it should move at all, except from the reaction of the escaping gases against the atmosphere. If when the shot left the muzzle the gun had not moved, it could only be because the work done on it had not exceeded the resistance. How then, apart from the reaction of the escaping gases, could motion take place afterwards? The Author spoke of the "energy of recoil . . . . due to the sudden liberation of stored-up work." How was this possible? He seemed to think it was stored up in the elasticity of the gun. Now this elasticity would be a force expended in stretching the gun between the breech and the trunnions, and this would be a force acting between two points of the same body in opposite directions. How could this give motion to the whole body? The Author contended that during the time the pressure was giving motion to the shot "it can only complete the wave of pressure in a mass one hundred and thirty-four times greater." That "this wave of pressure exhausts its action upon the elasticity of the mass of the gun, inducing a high degree of tension longitudinally; and . . . that the reaction of elasticity takes place in the absence of any opposing gas pressure, and in this respect resembles the pressure of impact of an inelastic body;" and a little further on, "the gun is not

Mr. Longridge.

directly obedient in its motion of recoil to the variations of powder-pressure, but stores up the total work of the pressures to be afterwards developed in one complete dynamic effort." According to this idea a body could be at rest in space, some portion of which was in a state of internal strain, the restoration of which internal strain to its normal state of equilibrium produced an accelerating motion through space of the whole body. Was this possible? If not, to what could be attributed the recoil which took place after the shot had left the gun? It would appear to be due simply to the reaction of the escaping gases. But, in fact, all the resistance to motion had at this time been balanced, and the gun and carriage were then perfectly free to move (if indeed they had not already moved, though such motion might not have been detected), and the unbalanced reaction of the gases during their escape had then only to move the unresisting gun and carriage, which it would probably do, through a much greater distance than the actual distance of recoil, were it not for the continued action of the frictional resistance of the gun-carriage.

Although differing entirely from the Author's views as to the action of the forces which produced recoil, Mr. Longridge considered great credit was due to the Author for his advocacy of an elastic medium, or the resistance of hydraulic flow for the purpose of absorbing a portion of the force which otherwise would be transmitted direct to the gun and carriage, and have to be counteracted by dead weight. By this system a large amount of force was absorbed in generating internal resistances, which did not tend to displace the body in space, and this was an immense advantage if the apparatus employed could be made so as not to impede the working of the gun, and not be subject to derangement or destruction, and the Author's efforts in this direction appeared to have been well conceived and efficiently carried into practice.

In a Paper read many years ago Mr. Longridge pointed out and advocated the introduction of an elastic medium between the gun and the gun-carriage,[1] and he was glad to find that the subject was now attracting serious attention, and was being ably carried into practical effect by the Author of the present Paper.

Mr. MacAvoy.

Mr. MacAvoy observed that any system of construction which would enable the force of recoil to be spread over a certain space, instead of allowing it to act suddenly, like a blow, would bring much less strain on the carriage, and would therefore enable its weight to be reduced. Now, as the Author's invention of the

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xix., p. 314.

Mr. MacAvoy. hydraulic buffer placed in the hands of engineers the means of depriving a heavy body in motion of its momentum, however great it might be, in a definite space and according to any desired law, there could be no doubt of its suitability to the purpose under consideration; but it was obvious that its value, compared with any other system, could only be determined by trial. With regard to the theoretical points dealt with in the Paper, those relating to the momentum of the gun and the propagation of the powder-pressure through its mass seemed to demand the chief attention. At first sight the deductions from the experiments appeared to be at variance with the usually accepted theory on impact. The early experiments on impact confirmed the laws deduced from the theoretical considerations; but the masses acted upon were generally such as to enable them to be regarded as heavy particles, and the pressures of impact on each body could then be taken as acting instantaneously throughout the mass. But in a heavy gun, the mass acted upon was so enormous that it seemed quite in accordance with the known action of other physical forces to assume that pressure, instead of acting suddenly on the whole mass, was propagated through it in a wave whose duration occupied a definite interval of time, and the motion of the whole mass would not then be apparent until the wave was completed. Now the time occupied by the shot in passing along the gun was a very small interval, and if this were about equal to that taken to complete the pressure-wave through the gun's mass, the interval said to elapse between the commencement of motion of the shot and that of the gun would, he thought, be satisfactorily accounted for.

In considering the momentum generated by the action of the powder, it was difficult to take any other view than that the total in each direction must be equal; for the pressures at any instant of time during the action must be equal and opposite, and if these pressures were conceived as acting on two masses perfectly free to move, as in the case of direct impact of two heavy particles moving freely in space, the effect would, no doubt, be strictly in accordance with theory; but when these pressures acted as they did in the bore of a gun, it seemed scarcely justifiable to assume it as a fact that the momentum imparted to the shot would be precisely equal to that imparted to the gun, seeing that the momentum generated by the powder in the direction of the shot might not be wholly expended on the shot, but that part of it might be expended in a manner which had not yet been taken into account.

The employment of quick-burning powder might be looked upon as producing, by its rapid conversion into gas, an effect approximating much more nearly to that of impact than would be the case when slow-burning powder was employed; and the effects in the latter case, although bearing a definite relation to those in the former, might still not be precisely equal as regarded the shot and gun. The results of the experiments referred to in the Paper appeared to confirm this. Mr. MacAvoy.

Whatever might be the theoretical conclusions on a question of this kind, it was evident that the facts of the case could only be determined by experiment; and supposing that the experiments already made on the motions of the gun and shot had been conducted in such a way as to leave no possible doubt of the accuracy of the results, then, if the usually accepted theoretical deductions did not agree with them, the only conclusion that could be come to was, either that the theory was wrong or that the whole of the conditions involved in the problem had not been taken into consideration. The latter was, in his opinion, the most advisable one to adopt. The object in view would then be to discover the whole of the conditions involved, and their respective values, so as to obtain a complete solution of the problem. The full consideration of so complicated a mechanical problem could not be done hurriedly. Much time must necessarily be occupied in the discussion of every point.

Dr. Pole. Dr. Pole thought it might be useful to state the manner in which recoil could be calculated according to the ordinary laws of mechanics, which it scarcely seemed necessary to depart from.

If a force f was applied during a very small period of time dt, to a body free to move, whose mass $= m$, it would give it a certain increment of velocity determined by the equation $mdv = fdt$. Let then ϕ represent the elastic force of the powder per square foot, acting against the shot, and a = area of bore, then the force urging the shot forward $= a\,\phi$. But from this had to be deducted the pressure of the atmosphere, which call $a\,h$; the force necessary to produce rotation, and the friction of the shot and gas-check. The two latter might be combined in one symbol $= k$. Then the effective force applied to move the shot $= a\,\phi - a\,h - k$.

Let w represent the weight of the shot, then $\frac{w}{g} = m$, and $\frac{w}{g}\,dv = (a\,\phi - a\,h - k)\,dt$. If t was the time elapsing from the starting of the shot till its exit from the muzzle, then (neglecting the resistance of the air)

$$\left.\begin{matrix}\text{Muzzle velocity}\\ \text{of shot}\end{matrix}\right\} = v = \frac{g}{w} a \int_0^t \phi\,dt - \frac{g}{w}(a\,h + k)\,t \quad . \quad . \quad . \quad (1.)$$

ϕ being expressed as a function of t.

Dr. Pole. Now, as the same forces acted during the same time in an opposite direction against the bottom of the barrel, it was only necessary to substitute for w in the above equation the quantity W, representing the weight of the gun, plus such parts of the carriage as moved with it, to give

$$\left.\begin{array}{l}\text{Velocity of recoil due}\\ \quad\text{to the action against}\\ \quad\text{the shot}\end{array}\right\} = \frac{g}{W}\, a \int_o^t \phi\, dt - \frac{g}{W}\,(a\,h + k)\,t.$$

But this was not all: not only the shot, but also the charge, which was of considerable weight, had to be set in forward motion, and according to the often-cited law of Newton, whatever force was necessary to produce this motion must react against the end of the barrel, and would consequently aid the recoil. Let this force be represented by γ, acting through a time τ; then the increase of velocity of recoil due to it would be $= \frac{g}{W}\gamma\,\tau$.

During the time that the shot was travelling along the barrel, the motion of the charge increased with it, and the mean velocity of the latter might be assumed to be half that of the shot. But as soon as the shot left the muzzle the imprisoned gases, being in a state of very high elasticity, flashed out into the atmosphere with great force, and with greatly increased velocity. Let the velocity of exit of the gases at the muzzle be represented by v_1, and let the mean velocity of the charge at that moment be assumed $= \frac{1}{2}\,v_1$. If then c = weight of charge, the quantity $\gamma\,\tau$ would be equal to $\frac{c}{2\,g}\,v_1$; and the increment of recoil $= \frac{g}{W} \times \frac{c}{2\,g}\,v_1$. Hence, finally,

$$\left.\begin{array}{l}\text{Total velocity}\\ \quad\text{of recoil}\end{array}\right. = V = \frac{g}{W}\left\{ a \int_o^t \phi\, dt - (ah + k)\,t + \frac{c}{2\,g}\,v_1 \right\} \quad \text{(II.)[1]}$$

An example of the practical application of these formulæ might be taken from the data furnished for the 10-inch gun, with pebble powder, in Messrs. Noble and Abel's Paper already cited. The quantities were w = 300 lbs.; c = 70 lbs.; $a = 0\cdot545$ square foot;

[1] If the velocity of exit of the gases were taken the same as the muzzle velocity of the shot, *i.e.* $v_1 = v$, a comparison of equations I. and II. would make

$$\frac{V}{v} = \frac{w + \frac{1}{2}\,c}{W}.$$

This was the ordinary rule; but it evidently gave the recoil too small, as it neglected the large further impulse given to the gases after the shot was out of the way.

$h = 2{,}116$ lbs. per square foot. The total time t, of travel of the shot in the barrel was $\frac{1}{80}$ of a second. As to the integral $\int \phi \, dt$, there was a difficulty in giving any general algebraical expression for it with reasonable simplicity, on account of the exceedingly complicated mode of variation of the powder-pressure; but it could be calculated numerically, in its definite form, from Table X. and Plates 19 and 20. The value came out, in lbs. × seconds, for 1 square foot area = 26,660. In regard to k, the first element, namely the force necessary to give the shot rotation, might be easily calculated; for, making r = radius of shot, and n = number of rotations per second, then, by the ordinary rule founded on the moment of inertia, Dr. Pole.

$$\text{Work of rotation} = \frac{w}{g} \pi^2 n^2 r^2,$$

and the mean force acting on the base of the shot to produce this, with a final twist of one turn in 40 calibres = 3,400 lbs. The friction of the shot depended on the practical arrangements adopted, but it might be calculated approximately by aid of the principles laid down in Captain Noble's Paper in the "Philosophical Magazine."[1] For the twist there given, with a 300-lb. shot, it might be estimated at about 9,000 lbs. Hence $k = 12{,}400$.

Applying these quantities in the first place to equation I., the muzzle velocity of the shot came out = 1,540 feet per second, the actual measured velocity being 1,527 feet.

The calculation might be effected by another mode. If s represented the space passed through by the shot before quitting the muzzle, then, according to the law of *vis viva*,

$$v^2 = \frac{2g}{w}\left\{ a \int_o^s \phi \, ds - (ah + k) s \right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(III.)}$$

ϕ being expressed in terms of the space and not of the time. This integral might be also calculated numerically from Noble and Abel's Paper, and the result was

$$v = 1{,}534 \text{ feet per second.}$$

The correspondence of these estimations, in a case where the whole action occupied only $\frac{1}{80}$ of a second, appeared to justify the modes of calculation used.

To work out equation II. it was necessary to find the value of

[1] March, 1873. Vol. xlv., fourth series, p. 204.

Dr. Pole. the quantity v_1, *i.e.* the velocity with which the gases would rush into the atmosphere after the shot was gone. This might be estimated according to the usual laws of gaseous motion, knowing the pressure and density, which were to be found from Noble and Abel's data. The determination could not be very precise for various reasons; but it appeared probable that the velocity of exit might amount to three times the muzzle velocity of the shot, or say 4,600 feet per second. Using this quantity, equation II. became

$$V = \frac{626,000.}{W}$$

To complete the determination it was necessary to know the weight of the portion of the carriage which recoiled along with the gun; this was not given, and it might vary considerably according to the material and design of carriage used. For the gun alone, weighing 18 tons, the velocity of the recoil would come out 15·5 feet per second; if the recoiling portion of the carriage were put at say one-sixth additional, making W = 21 tons, then

$$V = 13 \cdot 3 \text{ feet per second,}$$

which would probably not be far from the actual value.

In Fig. 2 Mr. Butter had given three curves of recoil of the 10-inch gun with pebble powder, which showed a velocity, maintained through some distance, of about 14 feet per second; but as no particulars were given of the weight of shot or charge, or of the recoiling portion of the carriage, it was not possible to compare this with the calculation; and moreover, it was not professed that the apparatus was very accurate.

If the assumption that $v_1 = 3\,v$, were taken as generally applicable, the following simple formula would result, and probably this might be adopted in the absence of a better one.

$$\text{Velocity of recoil} = \text{vel. of shot} \times \frac{w + \frac{3}{2}c}{W}.$$

There were some other points of interest that might be mentioned.

The *work* stored in the forward motion of the shot was, according to the ordinary rule,

$$u = \frac{w}{2\,g}\,v^2 = 10,860,000 \text{ foot-lbs.}$$

That stored in the recoil of the gun and carriage was (W being taken as 21 tons)— Dr. Pole.

$$V = \frac{W V^2}{2 g} = 129{,}000 \text{ foot-lbs.}$$

It was also interesting to inquire what amount of motion would be given to the gun, by the recoil, during the time the shot was travelling along the barrel. While the shot was moving forward, the gun (assuming it to be of perfectly rigid material) moved slightly backwards, so that if s and S represented the space moved over by each respectively, $s + S$ would be = the total travel in the barrel. The space S was somewhat difficult to determine; but it might be approximated to as follows.

Let V_o express the velocity of recoil of the gun, the instant before the shot left the muzzle, and let F = the mean pressure on the base of the barrel during the whole travel. Then

$$F\,S = \frac{W}{2 g} V_o^2.$$

Estimating the quantities F and V_o by approximate practical methods, the quantity S came out

$$= 0 \cdot 071 \text{ foot.}$$

So that supposing the total path of the shot in the barrel to be 10 feet, the shot really moved 9·929 feet forward, and the gun 0·071 foot backward. This very small recoil might easily be overlooked if not very carefully watched for, and it was possible it might be diminished, as Mr. Butter had suggested, by the temporary storing of work in the elasticity of the material.

A summary of the various amounts of work in this example might be added:—

	Foot-tons.
Work applied in giving effective propulsion to the shot .	4,890
In overcoming the pressure of the atmosphere against it.	5
In giving it rotation	15
In overcoming its friction against the barrel	40
In giving recoil to the gun and its accompanying part of the carriage	58
	5,008

This, however, did not include the work expended in giving motion to the products of the charge, which was a very large addition, and might be roughly estimated at 3,400 foot-tons.

The total work here developed by the powder would therefore be = 8,400 foot-tons, or 120 foot-tons per lb. of charge, equal to about one-fourth the total theoretical power of the powder.

Mr. Butter. Mr. BUTTER, in reply to the correspondence, observed that the discussion had been useful in proving that the majority of mathematicians had given little attention to the action of the forces producing recoil, and so far justified the production of his Paper, which had also been useful in drawing into one focus various facts and observations bearing upon the subject. No doubt the adverse criticism of most of the mathematicians was due to their having made no effort to judge his expressions and deductions from his point of view of the conditions of the problem, and they had attacked his statements on the basis of their own ideal conditions; whereas, if he were wrong, it would be in the enunciation of his conditions, and these had mostly passed unnoticed, except by Professor Greenhill and Mr. MacAvoy, who, in their observations, had fully realised them, and had given due value to the effect of the gradual propagation of pressure through masses, upon the time at which motion of the whole mass was effected, and this was the basis of all his deductions. Mr. Bashforth's proposition of preventing recoil by opposing a pressure at the breech of a gun equal to that of the maximum powder-pressure on the bottom of the bore was no doubt accurate, but as guns were usually held at the trunnions, and thus admitted of an extension of the material between the trunnions and the breech, it was evident that if such extension occurred, motion to a part of the mass would be set up, and the resulting pressure on the trunnions would be greater than the total powder-pressure at the bottom of the bore, as had been conceded by Sir F. Bramwell. This extension of the mass of the gun had constituted one of the main elements of Mr. Butter's argument, and it was difficult to see how it could be denied; and if it were accepted, it would not only at once meet the objection of Mr. Bashforth, but would also explain the results of the experiments of Colonel Sebert, brought forward by Mr. Canet, from which it was sought to be maintained that the gun and shot commenced their motion simultaneously; whereas the experiment only proved that the breech end of the gun and the shot did so, and this was precisely in accordance with his own statements. The delicate, and in most respects conclusive experiments on recoil, carried out by Colonel Sebert in France, were unknown to him previous to writing the Paper; but nevertheless he thought there was less in them to have led to any considerable modification of his views, had he known of them, than Mr. Canet assumed; on the contrary, they confirmed in a remarkable degree all the really important points he had advanced. For example, with respect to the universal use in this country of the formula of the equality of

Mr. Butter.

momenta for finding the velocity of recoil, he had shown the necessity of the introduction into it of a constant, depending upon the kind of powder employed, and Mr. Canet, with all Colonel Sebert's results before him, had done the same; and it would appear from the Table and data given by Mr. Canet that Mr. Butter's formula would almost exactly meet the case. Again, he had from his observations drawn the conclusion that the recoil of the gun gradually attained its maximum after several inches of motion, and Colonel Sebert's experiments exactly confirmed this view, most important with regard to his calculations relative to the elastic field carriage; and further, he had asserted that recoil of the gun, as a whole, was not developed until the shot was near the muzzle, and this was so far confirmed, practically, by the experiments of Colonel Sebert, who proved that while the time of travel of the shot along the bore was 0·012 second, the time occupied in fully developing recoil was 0·041 second, or nearly four times as great; and whereas when the shot left the bore, the gun had only recoiled 1·2 inch, it did not attain its maximum velocity until it had passed over 7·9 inches. It appeared, therefore, that while they might differ as to the causes of the facts, which was after all of little importance, they agreed remarkably closely as to the facts themselves, so closely, indeed, that it was a matter of sincere pleasure to him to observe his main propositions so fully corroborated. He could not but express his surprise that Mr. Canet should have failed to have noticed this accordance between their results, unless on the supposition that his hostility to the theoretical views of the Paper rendered him indifferent to all other portions of it. With regard to his attack upon the theory, his definition of "inertia" was a singular one, but was sufficiently answered in Mr. Butter's reply to Mr. Bousfield. With respect to his statement that the velocity of recoil was 0 when the resistance was infinite, of course this must be so, but it was difficult to conceive how an infinite resistance could be practically set up. This was sought to be accomplished recently in the case of a 4-ton gun, which, in spite of a solid backing of iron and stone, embedded against a large bank of earth, recoiled 2 inches at the trunnions; this recoil could not have been detected but by careful automatic registry, as the gun immediately regained its normal position, the recoil being solely due to the compression and subsequent restitution by means of its elasticity, of the mass of the backing. With regard to the independent invention, by Mr. Vavasseur, of a field carriage for the French army of a similar kind to his, it was to be accounted for only on the ground that both took such interest in developing

Mr. Butter. to the utmost the use of the hydraulic buffer, that when a reduction in the weight of field carriages became desirable, it was natural that each one should turn to this appliance as affording the best chance of enabling such reduction to be made. Once on this line of thought, it was inevitable that some degree of similarity should be developed in the designs; he was quite content to know that his design was original, and to concede the same to Mr. Vavasseur. A few observations had been made by Professor Fleeming Jenkin which he felt bound to notice. What he had already said concerning the causes of a disturbance of true equality of momenta, in answer to Professor Unwin, would constitute a sufficient answer to Professor Jenkin on this subject, whose statement that he was not acquainted with kinetics because he had used certain terms which to the modern, exacting system, seemed inexact, was, to say the least, a little uncharitable. It was presumed the definition of force, as that which produced or tended to produce motion, was still a canon of faith, and that in statics the word force was still admitted; if this were so, then there was force associated with motion, and force which was only pressure, because it was in equilibrium with some other force; and although the abstract idea of force rendered it possible to conceive of only one kind, yet in practice nothing was more common than to speak of force, when acting as a pressure, as "statical force," and when associated with motion as "dynamical force." At any rate, when he found that the late Dr. Whewell, Hon. M. Inst. C.E., used the expression, "statical forces are called pressures," he presumed that Whewell would be considered equally unacquainted with kineties, and he was quite content to be condemned in such company. Mr. White had evidently not viewed this matter in the same light as Professor Jenkin. The latter gentleman also stated he could not see how the "summation of all the powder-pressures was meant to be effected." If he would endeavour to realise the conditions which Mr. Butter considered to be associated with the peculiar problem of the discharge of a gun, he would see that the powder-pressures, acting only in the first stage upon the elasticity of the mass of the gun, became stored up in the general compression of the material, and afterwards, by restitution, acting against whatever resistances there might be, developed that force of recoil which he had incurred the Professor's disapprobation by terming dynamic. He was more justified in dissenting from the idea of the gun under any circumstances of discharge developing an energy approaching that of the shot, because this was not a different shade of meaning given to mere words, as were the other objections, but one of principle.

This, however, was, from Mr. Butter's point of view, possible; for, if time were allowed for the powder-pressure to complete its action upon the shot, the latter would have attained to such an enormous velocity in the same direction as that of the expansion of the gas, that when the pressure of the latter had practically ceased, so far as the shot was concerned, it would be very considerable upon the gun, which was moving at a comparatively slow rate. Now it was possible, looking to the peculiar character of the products of combustion and the nature of their action, that the far greater velocity of the shot during the later stages of movement in the bores of ordinary guns, at which time the shot was moving rapidly in the same direction as the waves of pressure, might result in a greater actual pressure upon the gun than the shot, and this was so far borne out by observation that it was a well-known fact that the crusher-gauges in the gun always registered a higher pressure than did those in the base of the shot; there would appear, therefore, to be grounds for believing that the reactions by which, in ordinary impact and pressures of a similar kind, the action was maintained uniform throughout at each instant, might admit, from the causes stated, of giving to the gun a higher degree of momentum, by prolonging the action, than to the shot. The fact was, the nature and action of discharge, so far as the gun was concerned, were so complex, and demanded so many careful observations before anything of a reliable nature could be determined, that a strict mathematical deduction regarding this question was at present impossible, as Mr. Bashforth had stated. In the meantime mathematicians need not be so sensitively jealous of their various laws and expressions; it was merely a question of their correct application. They had regarded the discharge of a gun as a simple question of impact, whereas it was a far more complicated action. Mr. Butter.

A valuable investigation had been contributed by Dr. Pole, but this was founded upon the assumed mathematical conditions, which might, or might not, be near the actual truth; and the simple formula for the velocity of recoil, at which he had ultimately arrived, differed but little from Mr. Butter's formula; in both formulæ an assumed constant was introduced into the expression for the equality of momenta, and it would be interesting to apply both to the case of the 43-ton gun, in order to compare their results. The values of the symbols were as followed:—

W (weight of gun and carriage) .	114,240 lbs.
v (velocity of projectile) . . .	1,850 feet per second.
w (weight of shot)	710 lbs.
c (weight of charge)	285 „

Mr. Butter. Taking first Dr. Pole's formula:—

$$V = v \times \frac{w + \frac{3}{2}c}{W}$$

$$= 1{,}850 \times \frac{710 + \frac{3}{2}(285)}{114{,}240} = 18 \cdot 4 \text{ feet per second.}$$

Turning now to his formula—

$$V = v \times \frac{w + c}{W} \times \sqrt{\tfrac{4}{3}}$$

$$= 1{,}850 \times \frac{710 + 285}{114{,}240} \times \sqrt{\tfrac{4}{3}} = 18 \cdot 7 \text{ feet per second.}$$

And now referring to the Paper (p. 20), it would be seen that the velocities had been arrived at by three different methods, namely:—

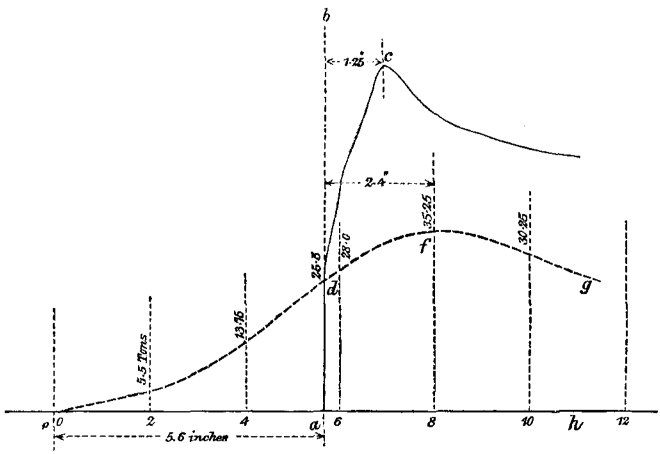
From the formula	18·7
„ „ time waves of the curves	18·6
„ „ actual observed work of recoil	19·0
Mean	18·8 nearly.

It would thus be seen that while the two formulæ gave very similar results, the one by Dr. Pole, as in the case of the 10-inch gun, appeared to indicate a velocity somewhat lower than was the actual fact.

Quite recently he had availed himself of an opportunity of making some experiments on the resistance of inertia and its effect upon elastic bodies, which he thought were of importance in this discussion, and he would therefore describe them.

He had constructed a frame in which a polished plate was made to move accurately in a vertical direction. This frame was fixed to the body of the proof carriage, Fig. 3, Plate 2; a stud fastened to the gun block, moved, as the gun recoiled, along a diagonal groove at the back of the plate, thus causing it to descend in a perfectly vertical line; a heavy frame on the ground, carried at its upper end a steel point which was kept by a spring in contact with the surface of the polished plate. Supposing that the body of the carriage remained at rest while the gun recoiled, the plate would descend and the steel point would make a vertical line; but when motion commenced in the carriage a curved line would be drawn. A number of experiments had been carried out with this apparatus, and gave, under the same conditions, uniform results; by applying it to different guns and thus varying the relations of the weights Mr. Butter. and velocities, some valuable data were obtained, but for the present purpose it would be sufficient to mention one instance as an example. The gun in this case was a 6-inch B. L. gun of 4 tons weight, firing a shot weighing 100 lbs. with a charge of 48 lbs. of powder; the highest velocity of the shot was 1,982 feet per second; the weight of the gun and its blocks was 92 cwt., and that of the carriage 176 cwt.; the former on recoil pressed the latter into motion with the force set up by the hydraulic buffers, and this force was measured by a pressure gauge at each round. The result was shewn in Fig. 6, which was one-half the size of the

Fig. 6.



actual records. By this it was evident that the carriage remained at rest while the plate fell a distance of *a d*, and to admit of this amount of fall, the gun moved horizontally through the space *e a* = 5·6 inches; at the point *d* the carriage began to move, and the steel point then became deflected from the straight line. When it reached *c*, the pressure caused by the resistance of the hydraulic buffer became so great that the whole carriage tilted upwards, causing the plate to describe the reverse curve as shown. The pressures acting upon the lower carriage to set it in motion were as stated on the various ordinates, and it would be seen that the pressure increased to 25·5 tons during the passage of the gun over the 5·6 inches, before the least motion was imparted to the carriage. This result he thought would assist greatly in making somewhat plainer the views he had advanced, and when carefully

Mr. Butter. considered must lead to some modification of the ideas on "inertia" which had been so freely advanced by Messrs. Bousfield, Canet, and other gentlemen, especially as the rails upon which the carriage rested had a decline of several degrees, which must have facilitated its starting into motion.

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29 November, 1881.

JAMES ABERNETHY, F.R.S.E., President,
in the Chair.

The discussion upon the Paper on "Forces and Strains of Recoil considered with Reference to the Elastic Field Gun-Carriage," by Mr. H. J. Butter, occupied the whole evening.

HYDRAULIC FIELD GUN CARRIAGES.

Fig : 1.

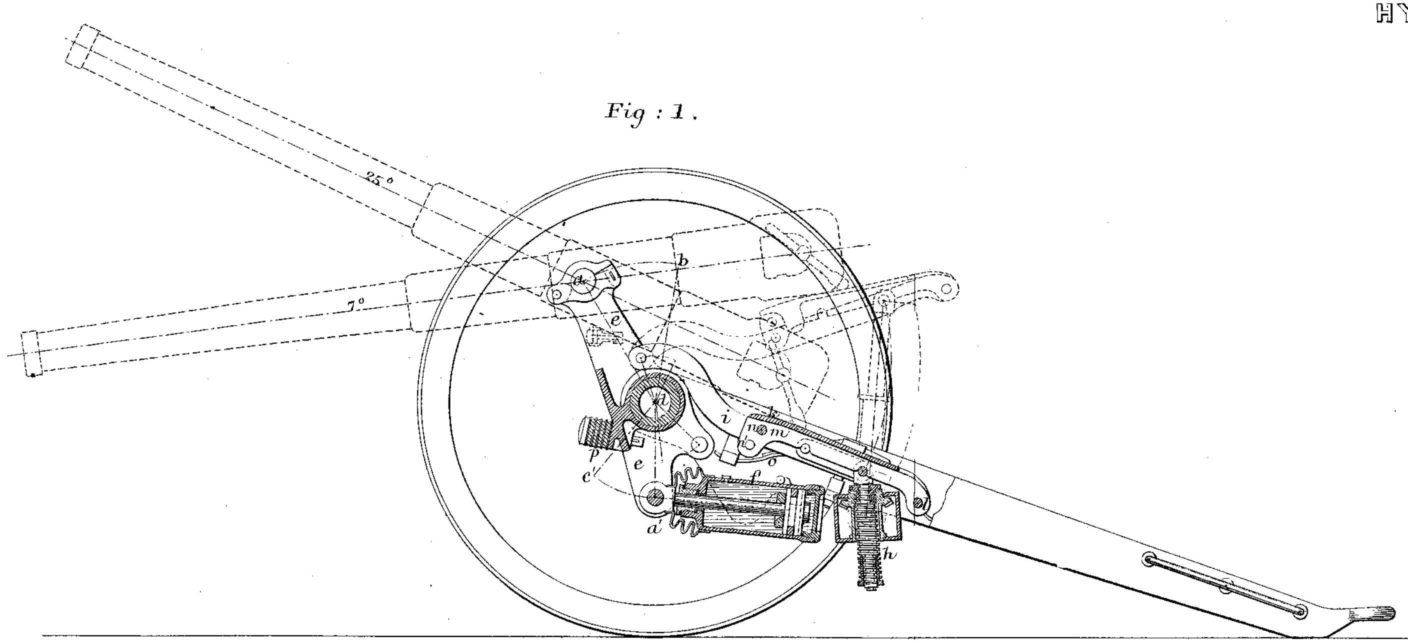


Fig : 3.

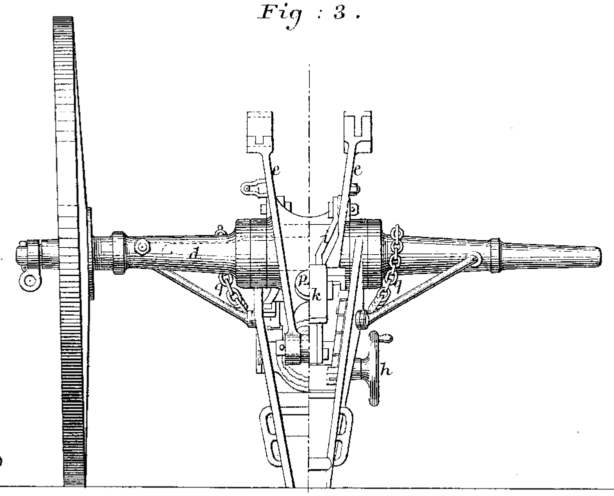


Fig : 4.

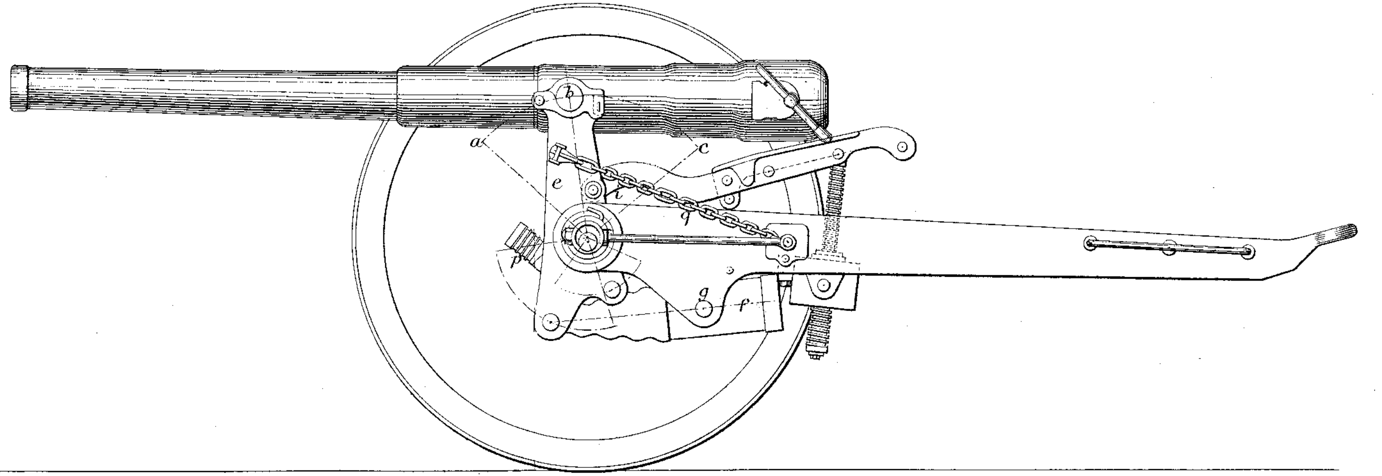


Fig : 2.

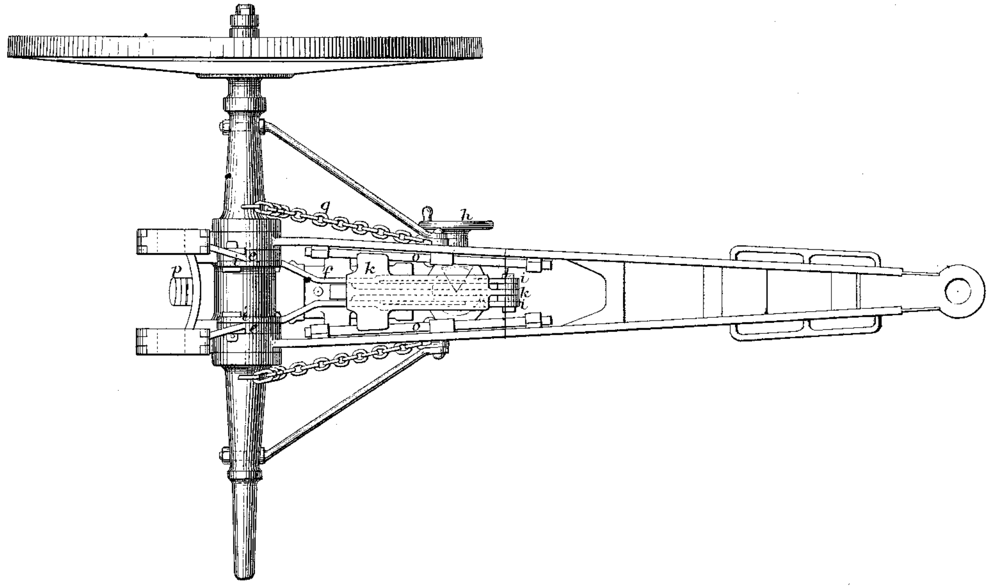
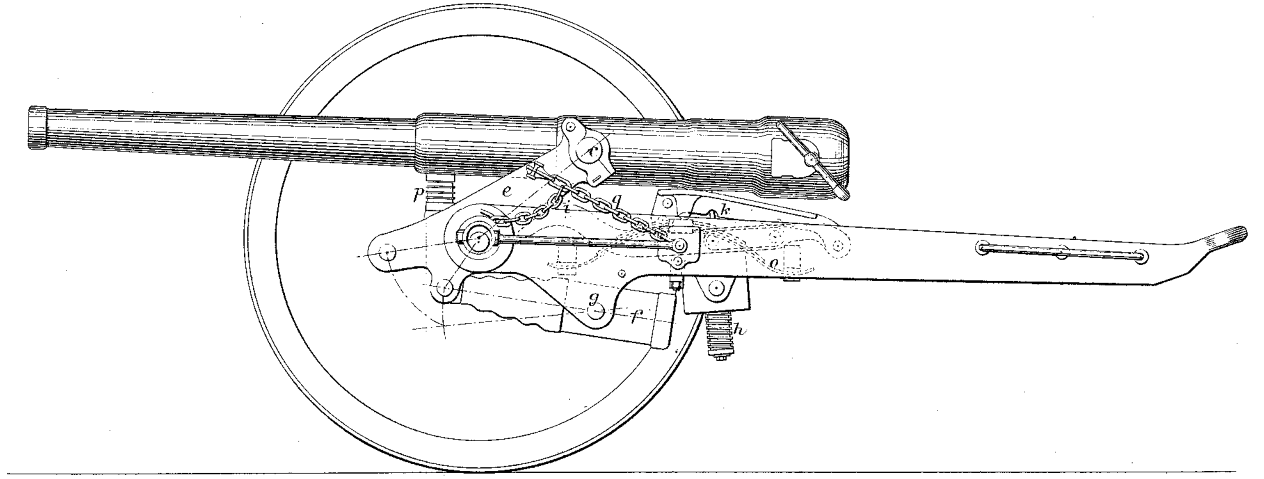


Fig : 5.



Scale of Feet.

12 6 0 1 2 3 4 5 10 15 20 25 Feet.

G. CANET, DELT

THOS KELL & SON, LITH. 40 KING ST COVENT GARDEN.