PHILOSOPHICAL

TRANSACTIONS.

I. *Description of a Percussion Shell, to be fired horizontally from a common gun. By Lieutenant Colonel* Miller, *late of the Rifle Brigade, and now unattached. Communicated by* R. I. Murchison, *Esq. F. R. S.*

Read November 16 and 23, 1826.

Before proceeding to describe this shell, it may be necessary to say a few words on the theory of rifles, with which its construction is intimately connected.

It is a principle now universally admitted, that the irregularity in the flight of shot arises from the inequality in the specific gravities of their sides, and the action of the air upon the inequalities of their surfaces. These imperfections it is impossible to guard against in casting; for although the mould may be constructed with mathematical exactness, yet the metal which is poured into it is known to occupy a larger space when hot than when cold, and is found by experience generally to contract unequally, as the process of cooling proceeds. The same mould will accordingly be found to cast shot of different sizes, and hardly ever a perfect sphere.

In a ball fired from a rifle, these imperfections are corrected by the spiral or rotatory motion of the ball round its axis, by which means any inequalities that may exist in its sides are continually shifting round the axis during the flight, and the course of the projectile is continued straight forward.

The spiral motion itself has hitherto been generally supposed to be communicated to a rifle ball, by the grooves which are made in the barrel of the gun. The following reasons, however, incline me to think that the spiral motion is given to the ball, not only by the direction it receives from the grooves of the barrel at the moment of discharge, but also by the action of the air upon the indentations in the ball itself, which the grooves of the barrel have made, when the ball is pressed against them in loading.

1. The grooves of a rifle run obliquely, making from $\frac{1}{4}$ turn or twist, to $1\frac{3}{4}$ in the length of the barrel. The diameter of the ball being somewhat greater than that of the bore, the ball requires to be driven down with considerable force, following the grooves, and receiving their impression as it descends. The ball therefore is a male, and the barrel a female screw, and unless the ball receive the impression of the grooves, it never acquires the spiral motion. This is ascertained by firing balls into a bank of hard earth, so as to flatten them a little. Unless the indentations made by the grooves of the rifle are distinctly perceptible round the edges of the balls, proving them to have struck end foremost, they never hit the mark with the necessary accuracy. If the balls are too small, and it is attempted to remedy this defect by using very thick patches, however tight they may be rammed down, they never answer the purpose intended.

2. When a rifle is fired at a moderate range, say from 100 to 300 yards, it is found that the accuracy of fire is maintained without any perceptible diminution; from which it may be inferred, that the spiral motion is maintained undiminished also. If, again, a rifle is fired at an elevation producing its greatest range, which is about $37\frac{1}{2}°$, its fire will not be so accurate as that of a plain barrel. The reason I conceive to be, that when the ball is at the summit of its flight, where it changes the direction of its course the most rapidly, the grooves have not sufficient length to enable the air to act upon them while the ball is forming the curve, so as to keep the axis and line of flight in one, by which means the position of the ball is suddenly changed, the spiral motion lost, and it continues to fly afterwards with great irregularity.

3. According to the calculation made by Mr. Robins, vol. i. p. 133, ed. 1761, the resistance of the air to a shot passing through it with a velocity of 1550 feet in a second, is equal to 120 times the weight of the shot. Dr. Robison, when treating of projectiles, in his Elements of Natural Philosophy, supposes that this resistance may be increased to 138 times the weight of the shot. But supposing it to be much below what it has been estimated at by either of those gentlemen, it is difficult to believe that a quarter of a revolution in the barrel can communicate to the ball a rotatory motion, which it has to maintain for hundreds of yards against this enormous pressure. And as this pressure falls obliquely on the grooves of the ball, I believe it to be the sustaining cause of the spiral motion.

4. So easy is it to communicate the spiral motion, that a grooved leaden ball will acquire it, in falling perpendicularly

through a roll of paper, or a gun barrel, merely from its own weight pressing against the air, so as to be distinctly visible to the eye. If the bottom of the tube is closed to prevent the air from escaping, it will be easily ascertained when the ball possesses the spiral motion, and when it does not do so, from the peculiar sound it makes against the sides of the tube.

5. If it is asserted, that the spiral motion in a rifle ball is sustained *solely* by the impulse it receives from the barrel, I am aware of no proof that can be produced in support of that opinion, either from analogy or experiment. If, on the other hand, we suppose it to be a motion, both *produced* and sustained by the action of the air, it will be in strict accordance with the effect the air is known to produce in all similar cases. Among other familiar instances may be given that of the arrow, the windmill, the shuttlecock, the smoke-jack, a window ventilator, and a grooved paper cylinder drawn through the air. And it may be observed of the arrow, shuttlecock, and cylinder, that each revolves in equal distances of air, whatever their velocity may be, and the spiral motion is maintained undiminished to the end of the flight.

Having been led to infer from the above-mentioned reasons, that the spiral motion is in all cases, both produced and sustained by the action of the air; and believing it to be impossible to reconcile theory and experiment upon any other principle, the next idea that suggested itself, was the possibility of giving the spiral motion to grooved shot, when fired from a plain barrel. The same thought appears to have occurred to Mr. ROBINS sometime before his death, about the year 1745; for, in a memorandum found among his papers, he observes, when speaking of rifles, and the rotatory motion of the ball, " I have made some experiments on *simpler* methods of performing this, and applicable to iron bullets. My success as yet has not been what I could wish, but it has however been sufficient to encourage a farther prosecution, which, if I shall ever pursue farther, I know not." vol. i. p. 317. That eminent mathematician has left us no clue to discover what his plan was; but in his tracts, he dwells so much on the effects which the resistance of the air is capable of producing on the flight of shot, that one can hardly fail to be impressed with the idea, that it must have been in some way or other connected with that medium.

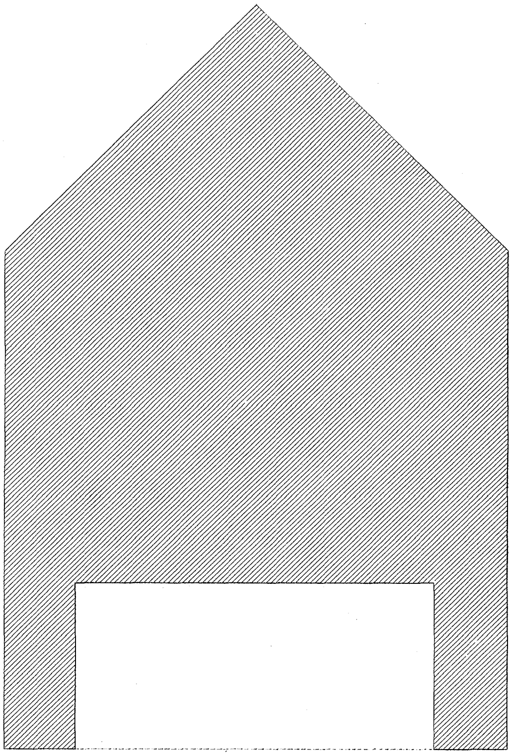
I shall now proceed to give a brief account of the experiments that have been made for the purpose of attaining the object in view. The first difficulty which presented itself, was that of applying the principle to shot of a spherical figure. The utter hopelessness of getting the air to act in the way desired, upon shot of this shape, soon led me to prefer the cylindrical to the spherical form, and it is to the improvement of that figure of shot accordingly, my subsequent endeavours have been directed.

My first experiments were made merely for amusement, for the purpose of shooting seals and sea-birds, in Bantry Bay, during the summer of 1821. Though not very successful, they were repeated from time to time as opportunity offered.

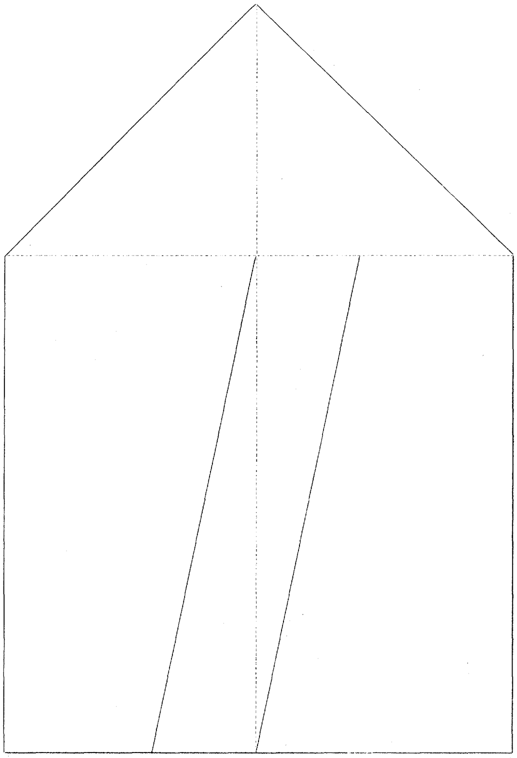
Hemispherical ends to the balls were thought of, and afterwards abandoned, as it was found desirable to dispose of the weight of the ball in such a manner as to give the greatest possible length to the sides. Grooves of various kinds were tried, and narrow ones were found not to answer. They must be of sufficient width to expose their sides, upon which the air presses, to its action throughout their length. For, if the air has not a free passage through them (Plate I. fig. 2) it will act as backwater on a mill-wheel. It is upon this principle that the blades of a windmill will not act if placed against a wall; and that rifles with very narrow grooves are found not to answer. In the beginning of 1822, some further experiments were made at Woolwich. On the first occasion, 10 grooved leaden musket balls were fired from a plain barrel through a target, at the distance of 100 yards. The balls were well finished, but heavier behind than before; and from the marks left by them in the target in passing through it, two of them appeared to have turned in their flight. From the circular holes left in the target by the others, they appeared to have passed through without turning. In the next experiment, balls of a somewhat better construction were employed. Several were fired at 40 yards, into a mass of boards and clay prepared for the purpose; and out of the number so fired, three or four were found in the exact position in which they lodged, all point foremost.

A grooved wooden shot was then fired six times from a $5\frac{1}{2}$ inch howitzer, against a bank, at 50 yards. This experiment distinctly pointed out the necessity of balancing the two extremities, as that which was heaviest showed an evident tendency to drop lower and lower during the flight.

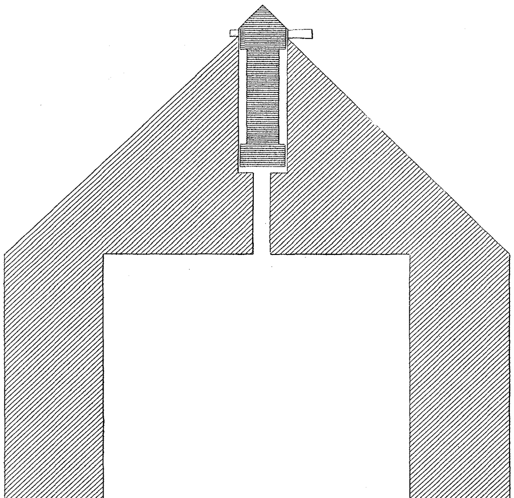
A wooden shot of the same form and proportions was then fired from the same gun, with a 3 lb. iron shot in its centre. This being properly balanced flew very steadily, hit the target, and then split without passing through it, but leaving



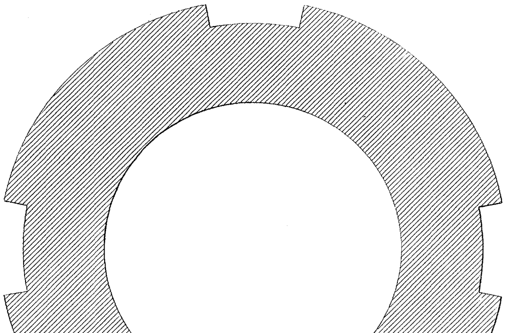
1. Vertical Section of Shot.



2. Obliquity of Grooves.



3. Vertical Section of Shell.



4. Horizontal Section of Shell.

a circular hole in the target, and a deep indentation on the cone, where it came in contact with the target.

During the following summer of 1823, I made several hundreds of experiments with grooved leaden musket-balls, fired from a plain barrel, at all ranges. When constructed with sufficient accuracy, they were found to fire very true, and to strike invariably point foremost. In order to balance them, the content of the cone, that of the cavity, and that of the part surrounding the cavity, must all three be equal, and the depth of the cavity must be equal to two-thirds of the height of the cone (Plate I. fig. 1.) The experiments with respect to twist, were found to correspond with those of rifles; that is, the velocity of the ball was found to diminish, in proportion as the twist was increased. In some of the balls used, the obliquity of the grooves was carried as high as a turn in 6 inches, which was found to diminish the velocity so much, that the person marking the shots repeatedly supposed the ball to have passed, before it reached the target. Numerous experiments were made during the same year, with wooden shot from a 24 pounder at the fort of Kinsale. They were found to range 400 and 500 yards; the largeness of their size rendered their position and flight easily perceptible to the eye; any imperfection in their construction was easily detected; and by firing them into the sea, each shot bore to be discharged a great many times before it became unserviceable. Others were afterwards fired by night with lighted fuses fixed in their sides, in order to mark their revolutions with greater distinctness. It was found that they possessed the spiral motion, and that it was maintained undiminished throughout their flight.

Having, as I conceived, conclusively ascertained by experiment, that the spiral motion may be communicated to a grooved cylindrical ball fired from a plain barrel, it occurred to me, that by the help of this principle, shells might be so constructed as to explode by percussion. The plan I have adopted for this purpose will easily be understood by an examination of Plate I. fig. 3. A round peg is placed in the apex of the cone, working in a cylinder, and a pellet of percussion powder is placed under the peg, and over the vent which communicates with the cavity of the shell. By this means, as soon as the point of the peg strikes against any hard substance, it slides in and ignites the percussion powder, which instantly communicates with the bursting charge. The cross pin is employed merely by way of precaution, and is removed as soon as the shell is put into the muzzle of the gun, which is then rammed home with a hollow-headed ramrod.

The first four shells of this construction which were tried, were made partly of iron, but principally of wood, and fired from a 24 pounder against one of the bastions of Kinsale fort, at somewhat more than 100 yards. All of them exploded upon coming in contact with the fort, the splinters flying to a great height in the air. One exploded against a rock at the distance of about 200 yards, and several, fired at a longer range, missed the object. Experiments were afterwards made with iron shells, fired from a 6 pounder, and the first were by no means successful. The shells were cast a great deal too thin, so that a considerable proportion of them exploded in the gun, and we did not succeed once in hitting a target at 240 yards. It may here be noticed as a circumstance well known, that shells are apt to explode in firing, either from being too thin, or from a portion of sand remaining in the chamber after casting, which produces ignition from the concussion of the powder. Notwithstanding all the care that can be taken, this sometimes occurs in action; but as the propelling charge is much greater than the bursting one, the splinters are carried forward, without injury to the gunners.

The second day's experiments, made from the same gun, were more successful. The shells weighed 7 lbs. 2 oz., and the bursting charge was five oz. Eight were fired at a wooden target 8 inches thick, placed immediately in front of a soft slate rock. Several were fired through the target at 60 yards. Seven out of the eight succeeded. The eighth burst in firing. On examining the result, it was found that the explosions had produced a much greater effect upon the rock than upon the target. The target was then placed in an open situation near the sea, and two shells fired through it. It was then observed that the explosions fell behind it, and the splinters were carried several hundred yards into the sea. One shell fired into the sea with 14 oz. of powder, and at an elevation of 6°, appeared to range about 1100 yards.

In the course of the third day's experiments, several still exploded in firing. One however succeeded very well against a thicker target, and two, fired across the bay, exploded against the old castle, one at 800, and the other at 850 yards.

The next experiments were carried on at Leith Fort in the end of 1823. The shells used weighed 10 lbs., the bursting charge 7 oz., and were fired from a 9 pounder, with a charge of 1 lb. Two casks filled with sand and stones, and about 4 feet each in diameter, were placed on the sea shore at low-water mark, and a target 4 feet square, and 15 inches thick, made of old ship timber, was placed between them, and backed with sand and stones. Four shells were fired at this, at 180 yards; two of them missed, and the third exploded in one of the casks, the splinters passing out at the other side, and carrying part of the contents of the cask along with them. The fourth struck the target in the centre, and blew it to pieces, leaving an opening in it upwards of 2 feet in diameter. Several of the planks of which it was made were cut asunder, and one of them was blown backwards 12 or 15 feet.

In the next day's experiments, a target was placed at the same range, but being made of decayed timber, and backed with sand only, the effect was by no means so perceptible as on the day preceding. Several exploded between the target and the sand, without doing much execution. Four passed over the target, and ricochéd along the water for several hundred yards. It was observed that they kept circling to the right, in consequence of the grooves running in that direction. One was found in the sand under the target, cone foremost, but without the peg; and another exploded about 20 yards from the gun. From this circumstance, the necessity of adopting some contrivance for keeping the pegs firm in their position became apparent, and also of making them air-tight, in order that the compressed air might not produce ignition. The range was this day tried against that of a round shot fired from the same gun, and the two were reckoned by the artillery officers present to be as nearly as possible equal, $1\frac{1}{2}$ lb. of good powder giving the same range both with shot and shell, as 3 lbs. of that used by the Ordnance.

In the third day's experiments, the shells used were half an inch longer in the sides, and the twist reduced from 48 to 55 inches. The weight of each was 10½ lbs. including the bursting charge of 7½ oz., and they were fired with a charge of 1½ lb. The first was fired into the sea at 15° elevation, and as far as could be judged from the distance of the ships at anchor in the roads, ranged about 2200 yards. The next was fired at the Martello tower in the sea, at 6° elevation, and at a range of 1200 yards. It ricochéd from the water at about 1000 yards, and exploded against the tower. A two-feet thick target was then placed on the shore at about 110 yards, and 5 shells were fired at it. Three of them burst in it, and it was found that they had penetrated about 16 inches before the explosion took effect, and the splinters, after tearing away the back planks, passed into the sea like grape. Their range was then tried on Leith Sands, from a brass field piece. An empty shell weighing 9½ lbs, with a charge of 1½ lb. at 5° elevation, went 1330 yards: another weighing 10½ lbs. went only 1200 yards. It may be observed, that the cone of the former was sharper than that of the latter. Another weighing 10½ lbs. at 11° elevation, went 1820 yards. No wadding was used in any of the experiments either at Leith or Kinsale.

Some further experiments were made at Woolwich in April 1826, on the hull of a 28 gun ship. Part of the shells used were of the same construction as those last tried at Leith, the angle formed by the sides of the cone being 112°. In others it was raised to a right angle, which increased the length of the shell about half an inch. Their weight was about 11lbs. including the bursting charge of 8½ oz. A pasteboard wad, ⅓ of an inch thick, was put over the powder, and made to fit the gun with great exactness, so as to prevent the escape of any part of the charge by the windage. The ship was moored in the river with her broadside to the gun, which was a brass 9 pounder, placed on the shore, at a range of 330 yards. Ten shells were fired from this position, with a charge of 1$\frac{1}{2}$lb. Two struck the vessel without exploding; one of them passed through both its sides; the other was found on board, without the peg, and with a piece of wood jammed into the place the peg had occupied. This circumstance leaves no doubt that the peg had, in this case, come out in firing, and renders it probable that the same accident had occurred to the other also. One exploded in firing, and another went over the vessel; two struck the water, and afterwards lodged in the ship without exploding; the remaining four exploded *upon striking her.*

In the second day's experiments, the pegs were fixed more securely by having worsted twisted round them, so as to require a blow equal to a weight of 30 lbs. falling from a height of 3 inches, to produce ignition, and a slip of paper was pasted over each, so as effectually to prevent them from slipping out when the shell was discharged from the gun. The charge was this day increased to 1$\frac{3}{4}$lb. Thirteen rounds were fired at 330 yards: the gun was then retired to 450 yards, and 8 rounds more fired. Out of the 21 fired, 7 were cast so large that they stuck in the gun, and could not be rammed home. From these little could be expected, although two of them succeeded. One exploded in firing, and another on striking the water about 200 yards from the gun. One struck the water very near the ship, and exploded upon passing through the ship's side, a little above the water mark. Six struck the vessel, all of which exploded; the others either went too high or too low, and the whole of those that went too low, rose again from the water and lodged in the ship. Upon examining the vessel, it was found that the shells had passed through her side before the explosion took effect, and that the splinters had done more than usual execution. They had gone through a cast iron caboose, torn up part of the deck, thrown down great part of a wooden partition that ran along between decks, and some of them had lodged in the opposite side of the ship. One shell cut a strong chain cable in two, which was put round the vessel for the purpose of raising her, in the event of her being sunk, some of the splinters flying backwards on explosion, while the remainder passed through her side. Another fired from the farthest range, passed through the mainmast close to the deck, and set it on fire towards the centre, so as to render it necessary to cut part of it away before the fire could be extinguished.

In the third and last day's experiments, 10 of the longer shells were fired empty, at a very large target placed against the practice bank, from a brass gun, at a range of 800 yards, with a charge of $1\frac{3}{4}$ lb. of powder. The two first were fired at 3° elevation, and passed a great way over the bank. The remaining 8 were fired at $2\frac{3}{4}$° elevation; two of those also went over, 1 grazed short, 2 passed through the target, one of them after grazing 2 yards short, and the other 3 struck the bank not far from the target; the range therefore of the shells here used, when filled and fired at 3° elevation, may be about 1300 yards. One dug out of the bank appeared to have turned; two others, on being dug out, were found cone foremost, and another that passed through the target, left a hole perfectly circular, evidently showing that it had passed through horizontally. Four of the shorter shells were fired at 600 yards, but were found very inferior to the longer ones, both in range and accuracy of fire.

Having detailed the experiments that have been made with percussion shells, as accurately as I can, and as fully as seems to be necessary, I shall now conclude with some observations connected with the subject.

So far as range and efficiency are concerned, the experiments have perhaps been as successful as could have been expected, in so novel an invention. With respect to accuracy of fire, I am fully sensible that much still remains to be done; and to those who ask why this most important object was not more completely attained before the discovery was submitted to the public, I beg leave to answer, that no invention in gunnery, so far as I am aware, either in former or more recent times, has ever been brought to perfection without the help of long continued and laborious experiments, which from their nature are so expensive, that they cannot be expected to be prosecuted at the cost of any individual. In the present instance, only one hundred and four shells have been fired altogether, eighty-five of which were filled with powder, and out of these, thirty-nine exploded upon striking the objects fired at. In the experiments made at Woolwich, on the Pheasant sloop of war, in the river, which are certainly the most important that have yet been made, only eleven succeeded out of thirty-one; no great number certainly, but at the same time enough to have destroyed the vessel, had they been heavy metal. The fire at present is sufficiently accurate for the range at which naval actions are generally fought, but the object in view is to make them available to the full extent of their range, and I shall accordingly point out the means by which I conceive this object may be very much facilitated. Considerable improvement may, I think, yet be made in the mode of casting them; for although the gentlemen of the Carron Company have bestowed great pains on those that were cast by them, it seldom happens in matters of this kind, that the most simple process is discovered in the first instance. They may also be turned in a lathe, by means of machinery, which their shape will allow them to be with great facility, and thus rendered perfectly cylindrical, and of the same size. In the course of the experiments that have been made, the shell has also been greatly improved by an addition to the length originally given to it. This might, *a priori*, have been expected, as its weight is increased, without increasing the resistance of the air; and by this alteration its range is found to be increased also. The accuracy of fire is also found to be greater, as the angle of departure is diminished. Hence, greater accuracy of fire may be expected from heavy guns than from light ones, the sides of the shells in the former being much longer than in the latter, while the windage in both is equal. The following construction of a shell for a 9 pounder, I consider as the best, so far as the experiments made will allow me to determine. In these proportions, the length of the sides is increased half an inch beyond that of any yet used, and the twist is reduced from 55 to 72 inches.

Length - - -	6,24 inches.
Diameter - -	4,16
Length of sides - - -	4,16
Height of cone - -	2,08
Depth of grooves - -	0,2
Width of ditto round the circumference	0,8
Length of peg - -	1,4
Diameter of ditto - -	0,4
Diameter of vent - -	0,15
Thickness of sides - -	0,85
Thickness of bottom - -	0,74
Diameter of chamber - -	2,46
Height of ditto - -	3,42
Windage - - -	0,04

In all the experiments already made, it has been observed that the line of fire is generally good, but that the shells which have missed the object, went almost invariably either too high or too low, which is exactly the result we might from theory expect, when their ends are not perfectly balanced. The method of proving whether their ends be exactly balanced, is by floating them in mercury, their specific gravity when filled being something less than half that of mercury. When properly balanced, they float horizontally, and the balance is not perfect until that is effected.

It is conceived that shells of this description might be used against towns and stockades, for battering in breach, and also in the field; but it is evidently in naval warfare that they would be most efficient, for the burning of shipping. That for a 24 pounder will weigh 30lbs. and contain $2\frac{1}{4}$ lbs. of powder, or what is reckoned better, powder and combustible matter in equal parts. The composition of portfire is recommended, as it burns with great intensity, and is not easily extinguished. It may be ground to powder, and mixed with the bursting charge. If a shell of this size exploded on board a ship of war, it would be difficult to extinguish it under any circumstances, and if it passed through near the water-mark, almost impossible. Under these circumstances, ships lying low in the water, might possibly have an advantage over larger ones, from being less exposed to the fire of an enemy.

If ever the weapon should be used in war, it is only to be hoped that it may have a fair and impartial trial; and if it stand the test, the consequences may be considerable.