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On the Conversion and Rifling of Cast-Iron Ordnance, and on Chilled White Iron Projectiles

Major William Palliser Unattached, late 18th Hussars

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Evening Meeting.

Monday, March 18th, 1867.

MAJOR-GENERAL J. T. BOILEAU, R.E., F.R.S., in the Chair.

NAMES of MEMBERS who joined the Institution between the 4th and 18th March, 1867.

LIFE.

Murray, John George, Lieutenant R.A. 9l.

ANNUAL.

Ellis, C. D. C., Maj. 60th Roy. Rifles. 1l.	Farquharson, M. H., Lieut. R.M.L.I. 1l.
Edmunds, Charles, Rear-Admiral. 1l.	Crickmer, Charles James, Lieut. Durham
Hill, the Rev. Pascoe Grenfell, Chaplain, R.N.	Art. Mil. 1l.
Crawford, H. P. R. F., Lieut. H.M. Madras Staff Corps. 1l.	Osborne, Eric Willoughby, Ensign 91st Highlanders. 1l.
	Hotham, Charles F., Captain R.N. 1l.

ON THE CONVERSION AND RIFLING OF CAST-IRON ORDNANCE, AND ON CHILLED WHITE IRON PROJECTILES.

By Major WILLIAM PALLISER, Unattached, late 18th Hussars.

I propose to divide my remarks this evening into three headings. I. The rifling of heavy cannon lined with soft wrought-iron coiled barrels. II. The converting and utilizing of our existing cast-iron ordnance. III. Chilled white iron projectiles. The third heading, properly, is not included in the subject announced for this evening, but since it treats of a materiel which has been largely introduced into the Service, I trust a short notice may not be unacceptable to you.

I shall begin by asking you to be good enough to follow me through what in another place have been lately termed some "Autobiographical reminiscences" as I am anxious to show how working at certain subjects, enabled me to observe wants and defects, and how the experience of these wants and defects induced me to turn my attention to supply and remedy them.

I. *Rifling of Heavy Cannon.*

Some time during the year 1853, I happened to hear it stated that the impossibility of rifling heavy cannon was an universally admitted fact. I had previously made many experiments with cross-bows from which I had shot arrows, bolts, bullets, and even small shot, and had thereby acquired a smattering of the flight of projectiles. In consequence of this knowledge, I believed that an elongated shot could be made to fly point foremost from a smooth-bore gun, by causing its

centre of gravity to be placed in front of the centre of the resistance of the atmosphere. This idea has since, and I believe had previously suggested itself to many others. I began by firing a variety of these shells from an ordinary smooth-bore fowling piece, and after a time attained considerable success. These small shells had percussion caps on their points, and invariably exploded against a wooden target at 100 yards distance. I next fired some similar shells out of a cast-iron gun—either a 4-pounder or a 6-pounder—at Dalkey Island from the main land, a distance of about 700 yards. Most of these shells exploded on striking. As, however, they weighed about three times as much as the round shot which the gun was intended to fire, it was believed that their weight might burst the gun, and hence it was always fired with a slow burning fuze, which gave us time to run away and get under cover. I submitted these shells to the Ordnance Select Committee, and they were tried by them during the month of August, 1854, at Shoeburyness, which place was at that time in its infancy. The results were unfavourable, owing to the great amount of windage which I was desired to allow, and which at that time was thought to be necessary. The shells remained point foremost during their flight, but they wobbled very much, and their range was very bad. I have since satisfied myself by further experiments, that great range and accuracy can be obtained with accurately fitting shells with heavy heads, but since there are insuperable objections to mechanically fitting projectiles, and since all difficulties connected with the rifling of cannon, which confers such extraordinary range and accuracy have since been overcome, there would appear to be no object for continuing experiments of this kind, excepting as an interesting scientific enquiry. Fig. 1, Plate VI, illustrates the shells which were fired at Shoeburyness in 1854. Some had helical flanges upon their surface, in order that the pressure of the air upon them might cause the shells to rotate. These flanges, however, confer no advantages. Like all inventors, I was at that time much impressed with the value of my invention, but I perceived that if it were necessary to run under cover every time they were fired, these wonderful projectiles could not be introduced into the service, and hence it was that my attention was turned, at that early period, towards the construction of strong cannon. I had previously watched the manufacture of twist, or, as they have since been called, “coiled” wrought-iron barrels at the forges of Messrs. Truelock and Harris, gunmakers, of Dublin, and had learned from them the great strength derived from this process of manufacture, and I commenced my experiments by casting several small cannon round wrought-iron twist barrels, in the same manner as I still propose to construct heavy guns. By this time, I began to doubt the truth of the statement, that heavy cannon could not be rifled. The letters given below show the precise dates of the experiments :—*

* No. 1.

Gun Manufactory, 233, High Holborn, W.C., Feb. 24, 1866.

SIR,—I beg to hand you the statement of the pieces of barrel I have rifled for you for insertion into cannon, and of the blasting fuze and cartridges, &c., I made

Fig. 1.

Scale $\frac{1}{4}$.

*Palliser's percussion Shell with Gun Metal
false head fired by Ordnance Select Committee
August 1854 from Smooth bore 9 Pz.*

Fig. 2.

*Original Sketch received from
Lieut. Palliser in Sept. 1855
by Andrew Murray Esq. R.M.
Dockyard, Portsmouth.*

A. D. ... one inch
D. E. ... six inches
A. B. ... eight inches
B. C. ... twelve inches
a. b. ... 13 inches
c. d. ... 13 inches

Fac Simile of original Sketch dated Malta Oct. 23rd 1855.

Fig. 3.

A. B. 20	D. E. 2
A. C. 6	a. b. 12
A. D. 1	c. d. 12

*x. x. Round Copper Plugs screwed through the Shell, diameter 1 inch
total length 2.5 outside the shell 5 inch.*

Shortly afterwards, the bursting of several 13-inch mortars at the bombardment of Sweaburg turned the attention of many towards constructing stronger guns; and many patents were, in consequence, taken out with that object. I found my small guns so strong that I could not burst them, and now I turned my attention to rifling. Not having sufficient mechanical appliances for rifling guns, I cast several small mortars over sand cores which had the rifling in relief upon their surface, and thus formed the grooves in the mortar. I tried in this manner two or three degrees of rapidity of spiral, and finally made a 6-inch mortar rifled with three grooves. Unfortunately it burst in proof. I,

for you at the time. I am prepared to state that I understood from you that you wanted me to procure and rifle you pieces of gun barrels, for the purpose of inserting in cannon, and that I rifled you three or four pieces in 1851.

I have the honour to be, Sir, your obedient servant,

JOHN W. P. FIELD.

No. 2.

Major Palliser bought of Parker, Field, and Sons.

1851.

July 26. Rifled a barrel twice.

Aug. 1. Powder magazine.

Coil of fuze.

2. Rifled a musket barrel.

1 lb. powder.

11. 1 lb. powder.

17. 1 lb. powder.

Sept. 22. 1 coil blasting fuze.

Rifled a barrel.

Oct. 5. 3 lbs. powder, T.P.

7. 1 do. do.

3 yards blasting fuze.

20. 2 lbs. powder.

5 yards fuze.

The above is a correct extract from our books.

JOHN W. P. FIELD.

Feb. 26, 1866.

for Parker, Field, and Sons.

No. 3.

W. Palliser, Esq., to S. H. Seager.

108, St. Martin's-lane, W.C., Oct. 20, 1851.

1851.

Oct. 20. To making in oak a large-size model
ship's gun-carriage complete..... £2 1 9

31. To making in oak a large-size model of
field-piece carriage..... 5 6 3

£7 8 0

The above is a correct extract from our books.

July 14, 1866.

T. T., for S. H. SEAGER.

No. 4.

15, Gate-street, Lincoln's Inn-fields.

SIR,—On referring to our books, we find that we finished turning a model cannon

however, made another, which was fired by Capt. Sir Thomas Maitland; now the Earl of Lauderdale, on board Her Majesty's ship "Excellent," during the month of August, 1855. The shells employed, had iron flanges cast on them to take into the grooves; these flanges were faced with strips of copper, attached by means of screws. The copper strips were, however, blown off, and could be seen falling into the water. The shooting, however, was indifferent, owing to there having been too much windage. By the kind permission of Admiral Sir Thomas Cochrane, Port Admiral, and Admiral Martin, Superintendent of the Dockyard, the mortar was bored up to a 7-inch, and again rifled with three grooves.

The mortar having been re-rifled with a slotting machine, the grooves were of unequal depth and did not follow the curved surface of the bore. The long flanges on the shells would in consequence not load, and I was obliged to shorten them, until they became mere studs of iron. The windage was reduced to about $\cdot 05$ of an inch, and, so far as could be judged, by firing down a range, covered with water, the practice was very good. One thing was noticed, namely, the tendency of the shells to deflect to the right. The fact of the iron studs on the shells cutting the rifle grooves was observed, and further that the

for you on the 10th November, 1851. The cannon was of cast iron, cast over an internal tube of wrought iron.

We are, Sir, yours faithfully,
CLARK AND Co., Engineers.

Captain Palliser to Clark and Co.

1851.

Nov. 10. To turning and finishing a cannon, painting, &c. £2 2 0

No. 5.

I, Charles Moritz, engineer, do hereby certify that I finished turning this gun for Captain Palliser on or before the 10th of November, 1851, and I can also identify the gun, both by the pattern and by having filled up with lead some blow-holes caused by faulty casting. The gun is made of cast iron, cast over an internal tube of wrought iron.

Signed, 17th day of September, 1863.
39, Lamb's Conduit-street, W.C.

CHARLES MORITZ.

Witness, Edmund Taylor, 7, Russell-terrace, N.W.

No. 6.

British Museum, May 26, 1866.

MY DEAR PALLISER,—I have much pleasure in stating that, during the year 1854, you were living with me in my chambers at 13, Gt. street, Lincoln's Inn-fields, and that, during the summer and autumn of that year you were occupied in making small guns, by casting the barrels over a central tube of wrought iron. On one occasion in the beginning of October, I went with you to Erith and witnessed some of your experiments with them. Towards the end of November, 1854, you left me, and went to Dublin.

I am sincerely yours,
WM. S. W. VAUX,
Keeper of the Coins and Medals, British Museum.

Major Palliser, &c.

greatest injury was done at the bottom of the grooves where the shells first began to move.

My first plan to obviate this was to countersink copper strips in the shot, as shown in Fig. 2. I am indebted to Mr. Andrew Murray, Chief Engineer of Portsmouth Dockyard, for the originals of these drawings. I went down to Portsmouth a couple of years ago, and asked him whether he had any record of my experiments, when he produced from a drawer my letters and drawings, which he had carefully docketed and dated; he also took me to a heap of old iron rubbish, from under which he produced the 7-inch rifled mortar itself. This mortar is at present on the gun wharf at Woolwich, in charge of Captain Gordon, C.B., Principal Superintendent of Stores. It is probably the first heavy piece of ordnance ever rifled on the French system.

If any one will take the trouble to look at the grooves of the mortar, he will see how they have been cut by the iron studs of the shells. I should mention that the shells weighed between 60 and 70 lbs., that the mortar was fired with 4 lbs. of powder, and that a few rounds were fired with only 1 lb. in order to watch the flight of the shell. I well remember that their flight was perfectly steady, that the shells appeared like humming-tops as they passed through the air, and further, that their axes always remained tangents to their trajectories, *i.e.*, that the shells descended with their points foremost. I have often since been surprised to see it stated in scientific works that the axis of an elongated rifled shot remains during its entire flight parallel with the axis of the gun from which it was fired.

I sailed for Malta in H.M.S. "Urgent," the day after the last experiment which took place, on Saturday, Sept. 29, 1855.* We had only left Portsmouth some twelve hours when we burst our steam-pipe, and had to put back into Plymouth for repairs. I wrote from that place the following letter to Mr. Murray, which contains my first proposal for an increasing spiral. My letter is only dated Devonport, Monday. But I am able to fix its date as Mr. Murray has written upon it, "Answered Thursday 4th Oct., 1855."

"I send you a drawing of the mortar sent. If you notice the groove you will see there are two pairs of parallel lines, one pair are straight, the others are supposed to represent the turn beginning by degrees and at last getting into the direct deflection; if the latter could be easily done I should prefer it, as the shell would then be turned by degrees, and not receive the full wrench at the first shock of the powder."

My next letter, dated Malta, Oct. 23rd, 1855, contained a more advanced drawing (Fig. 3.) of the studding system. It says,—"I enclose you a small plan of the shell for a 12-inch mortar, which I think

* Since reading this paper, I have received the following letter, which confirms the accuracy of my dates. The postmark on the envelope, Sept. 30, 1855, shows that the mortar was fired Sept. 29th. "H.M.S. Urgent, Sunday. My dear Vaux,—The mortar was quite successful yesterday, and I have applied to the Admiralty for leave to have one made like it, only of 13-inch bore, and Sir Thomas Maitland will recommend its being done. We sail in an hour. . . . Mr. Murray, the Chief Engineer, will undertake the manufacture of it. There is a man waiting to take the letter on shore, so I must say, good-bye. Yours sincerely,—William Palliser."

would be quite large enough, as the conical 12-inch shell would be larger and heavier than the 13-inch now in use."

The following is an extract from a third letter, dated Camp Notre Dame, Malta, Nov. 20, 1855. "I am making a model 2·5 inch diameter of bore, which I shall send home if it answers; the grooves have a terminal turn of ·6 inch in a foot, but the initial turn is so slight as to be barely perceptible; this goes on increasing till it arrives at the maximum turn as above. I am afraid this is badly expressed, but I think you will understand what I mean. You were quite right in supposing those to be plugs of a mixture of copper and brass, to be screwed into the shell to fit in the grooves. I think they will be quite strong enough to stand the violence of the explosion, and also of the friction. I am not quite confident that ·6 inch a-foot will be sufficient turn for the grooves, but I am decidedly of opinion that it will; and it would be a great advantage if it were, for two reasons—first, it diminishes the friction on the grooves, and the less rapidly the shell rotates, the less will be the deflection to the right.* I also think that ·25 of an inch will be sufficient depth for the grooves, as it will weaken the mortar less,† and likewise cause a less deflection to the right. I would on no account have a greater windage than ·05 of an inch, and would like to have it less if they will allow it at Woolwich."

Now a turn of ·6 inch in one foot is the same as a turn of 6 inches in 10 feet. In a 12-inch rifled gun this amounts to about one turn in 63 diameters. You will then observe that I proposed a 12-inch rifle with ·05 inch windage, a spiral of 1 turn in about 63 diameters, and gun-metal studs screwed into the shells to take the rifling. I find from Capt. Noble's Report, in 1865, on Ballistic Experiments, page 9, on the initial velocity of projectiles fired from the 600-pounder muzzle-loading rifled gun, that the windage for cast-iron shot is ·05 inch, for steel shell it is ·06 inch, and that the spiral is 1 turn in 65 calibres. The windage at present adopted in our service is ·05 of an inch over the studs and ·08 over the body of the shot, and I think the latter might with advantage be reduced to ·05.

I am still of opinion, notwithstanding all the experience that has since been obtained in rifling, that I was right as regards windage, spiral, material of studs, and their mode of attachment as then proposed for a heavy rifled mortar, designed to fire shells of about two diameters in length and containing large bursting charges, and I propose shortly to bring forward such a mortar for trial. I am anxious, however, that it should be well understood that I do not intend by this statement to interfere with the independent enquiries of others who may have been led to somewhat similar conclusions, especially those of Sir William Armstrong, to whose gun I have alluded, and who has so liberally assisted me of late in constructing guns and carrying out my experiments. My object in making this detailed statement has been to show that upwards of twelve years ago I had worked hard

* This sentence shows that we had noticed the tendency of the rifled mortar shell to deflect to the right.—W.P.

† The grooves in my first mortar were deep. It burst right along the grooves, and thus showed me that deep grooves were a source of weakness.—W.P.

at this subject, and to enable you to judge of the progress I had made in it at that time.

On my return to England in 1856, I resumed my experiments by making and rifling several small cannon lined with coiled barrels, and firing copper-studded shot from them; and in January, 1857, I again submitted this system of rifling to the Ordnance Select Committee. Owing to circumstances connected with my profession I had neither time nor opportunity thoroughly to go into the subject until the year 1862, when, owing to a severe kick which I received from a horse, I was placed for several months on the dismounted list, and was thus able to devote my leisure time to making a more extended series of experiments, as well as to compiling a treatise on compound ordnance, which I submitted to the Ordnance Select Committee on or about the 12th November, 1862.

In that treatise I proposed the addition of a small leading stud, in order to combine the advantages of an increasing spiral with those of a double bearing. The theory of the advantages conferred by the accelerated spiral is thus described in page 54:—

"First. If the accelerations of a projectile, from its first starting from a state of rest until it left the muzzle of a gun, were uniform, *i.e.* if equal increments of velocity were added in equal times, then would a straight line inclined at the required angle be the form of groove that would by a uniform pressure gradually accumulate the angular velocity in the shot during its passage out of the gun. For since the increments of velocity in the shot were assumed equal for equal times, the pressure that produced them would always be uniform; and since the pressure on the driving edges of the rifling is always proportional to the pressure that moves the shot, it will be uniform also.

"Secondly. If the velocity with which the shot moved were uniform, *i.e.* if it started off at once with a finite velocity which is not increased during its passage out of the gun, then it will be evident by the former reasoning that the required angular velocity would be uniformly accumulated by a parabolic curve.*

"Thirdly. If, however, as is actually the case, the projectile suddenly starts off with a high initial velocity, and that this velocity is further accelerated during the passage of the shot out of the gun, it will be seen that the rifling that will cause a constant tangential pressure will be shown by a curve lying between the straight line and the parabola."†

"The spiral which I propose, is such, that were the bore of the gun laid out flat, the grooves would become arcs of a circle, whose radius would be determined by the length of the bore of the gun, and the final angular velocity required.

"The arc will, therefore, be constructed in the following manner:

"Given A B († Fig. 7, Plate viii), the length of the barrel to be rifled, and α the final angle of the rifling, at B draw B O perpendicular to A B

* Mr. Twisden pointed out to me that the curve would be a parabola.—W.P.

† The direct, or unaccelerated rifling, causes too great a wrench when the shot first starts, and the parabolic curve does the same when the shot approaches the muzzle.—W.P.

‡ Fig. 9, Plate v in treatise.—Ed.

and make B O of such length that $\frac{A B}{B O} = \tan \alpha$. With O as centre

and O B radius describe the arc B D D', then B D will be the required curve since a tangent to the arc at D will make an angle with A B $= \alpha$; should it be desired that for a short distance towards the muzzle the spiral should not increase, the tangent D T will give the straight line."

The object of the "differential studding," as Mr. John Penn has aptly termed them, is described at page 75 of the same treatise.

"I at first experienced some difficulty in combining a shot with a double bearing and an accelerated spiral; for since the angle at which the grooves are inclined is continually increasing, we should have the gun trying to turn the fore part of a rigid shot faster than the hinder part, which would be impossible.

"This object is attained (*Fig. 6, Plate vii) by making the rear stud larger than the front one; thus at starting the three studs in rear do all the work of turning the shot, since E E' is the driving edge of the groove when the shot first commences to move. This work, however, is inconsiderable, as the angle of the turn at first is zero. As, however, the shot travels up the bore, the friction will wear down the rear studs, and the assistance of those in front will thereby be gradually called in.

"For a short distance towards the muzzle the rifling will become straight lines, at which place, since the common tangents to the bearing points on the circumferences of the studs become parallel to the driving edges of the grooves, the work will be equally distributed amongst all the studs, and thus the shot, prior to leaving the gun, will be steadied at six points—three in front and three in rear of its centre of gravity. The rear studs will be made large enough to fill the grooves; the size of the front studs will be determined thus: draw A A' a tangent to the larger stud at C, making an angle A' A H equal to the final angle of the rifling. From O, the centre of the rear stud, draw O O', making angle O' O H equal half the angle A' A H. It will readily be seen that a circle described with any point O', along O O', as centre, and the perpendicular O' P let fall upon B B' as radius, will touch D D', and that the shot will freely enter the gun, and that the bearing edges of the studs will all press equally on the driving edges of the grooves as the shot approaches the muzzle."

In this pamphlet I proposed a gun rifled with 3 grooves and an accelerated spiral of which the terminal pitch should be an angle of 5° , *i.e.*, 1 turn in 37 calibres. I fixed upon this ultimate pitch as it was the one which had been adopted by Sir William Armstrong, for the turn of the uniform rifling of his 7-inch breech-loading gun.

Some time after this, the Ordnance Select Committee rifled a gun with three grooves and an accelerated spiral to fire a projectile which had been adopted in the French service, namely a shell with single studs round the centre of gravity (see Fig. 4, Plate vii). This gun was included in the competitive trial which commenced on the 28th June, 1864. Some one, I don't know who, proposed putting in a second small stud in rear (see Fig. 5, Plate vii). This was but a bad imitation of my previous proposal.

* Fig. 3, Plate v in treatise.—Ed.

Iron Stud with
Zinc face.

Fig. 4.

French Shot or first supply fired
from three grooved Woolwich rifled
Gun.

Fig. 5.

Shot of the 2nd supply fired from
3 grooved Woolwich rifled Gun with
small Stud attached in the wrong
place.

Fig. 6.

Palliser's Shot, or 3rd supply
fired from 3 grooved Woolwich
rifled Gun which won the
competitive trial.

Fig. 10.

Fig. 8.

Fig. 9

Fig. 7.

The Ordnance Select Committee, however, tried both methods of studding from an Armstrong muzzle-loading gun, which for the sake of distinction was termed the "French" gun. Both methods of studding turned out failures, the zinc studs which no doubt may have answered well in the French cast-iron guns, fired with low charges and weak powder, were blown off or destroyed by the shock of the large charges of our strong English powder, and the gun made the worst practice of the three remaining in the competition.

I was now invited by the Ordnance Select Committee to send in the shot I had proposed in my pamphlet of November, 1862, and which, as I have shown, were shot perfected from my original proposal of 1855. As soon as these shot (Fig. 6, Plate vii) were tried, the gun came out by itself and beat all the others. I shall now denote this gun as No. 1. The relative accuracy of the three guns which remained towards the end of the contest is given as follows, in a Report published for the House of Commons, July 4, 1865.

No. 1.	Mean difference of range	27.2 yards.
	Mean reduced deflection	3.6 "
No. 2.	Mean difference of range	38.3 "
	Mean reduced deflection	7.4 "
No. 3.	Mean difference of range	47.6 "
	Mean reduced deflection	6.7 "

Their respective parallelograms of error would be, No. 1, 78 square yards; No. 2, 283 square yards; No. 3, 319 square yards. That is to say that the shooting of No. 1 gun, firing shot studded on my plan, was about three or four times as good as the shooting of the other two guns. The practice of No. 1 gun was very good, when it is remembered that the 7-inch shot were short, since they weighed only 100 lbs. and were solid, and that the windage amounted to 8-hundredths of an inch. This system of rifling has since been experimentally worked out and perfected by the Ordnance Select Committee, and to accomplish this end many long and carefully conducted experiments have been made by them. The system, as now perfected by them, has been adopted into the service for the rifling of our heavy muzzle-loading guns, and by direction of Earl de Grey, late Secretary of State for War, has been denominated the "Woolwich" system of rifling.

II.—*Converting and Utilizing Cast-Iron Ordnance.*

I propose to utilize existing cast-iron guns in two ways. First, to bore up and line with a coiled wrought-iron rifled barrel those cast-iron guns whose size and pattern will admit of their conversion into rifled guns suited to the requirements of modern warfare.—Secondly. To melt up and recast the others—round similar wrought-iron barrels—into rifled compound guns of the required dimensions.

Having, as previously stated, made up my mind, during the year 1862, once more to resume my enquiries, I determined to place the subject in such a manner before the authorities as would ensure a trial, viz., to submit my plans in a finished state, to accompany them with the

results and specimens of previous experiments as well as with a theoretical treatise corroborated by the calculations of eminent mathematicians, and to produce a rifled gun which had been fired in public, and which could be fired again. I accordingly sought and obtained friendly assistance from Andrew Hart, LL.D., Senior Fellow of Trinity College, Dublin; and also from the Rev. John Twisden, M.A., of Trinity College, Cambridge, and Professor of Mathematics at the Staff College. The calculations independently contributed by those gentlemen to my Treatise on Compound Ordnance will be found at the end of this paper, and it will be interesting to observe how exactly they agree with each other in their conclusions and how exactly those conclusions agree with the practical results of the experiments which will be herein detailed.

I commenced by making a gun similar to the 10-inch cast-iron shell gun of the service—to about $\frac{1}{4}$ scale—and lining it with a coiled wrought-iron barrel. This gun I tested to destruction with increasing charges. I regret that the record of its endurance test, which was very severe, has been lost. The barrel which was rifled had been made in two lengths which were screwed together. The object of this arrangement was to stop the rifling at such a point as to leave a smooth-bore chamber. The first intimation of failure was the separation of the barrel at the joint, and subsequently the casing was broken off. I derived much encouragement by finding that the barrel itself did not burst, Fig. 12, Plate ix. Next, in order to demonstrate the necessity for employing a barrel of *coiled* wrought iron, I made the gun, shewn in Fig. 11. The cast-iron portion of that gun was run round a barrel formed out of a solid bar of the best wrought iron, and bored into a tube. This gun burst at the second round with a charge of only 4 oz. of powder and a shot of $2\frac{1}{2}$ lbs. weight.

I may here mention that subsequent to this experiment a large number of wrought-iron guns were lined with solid forged tubes. This was done on account of the difficulties at that time experienced, in making sound coiled barrels. The flaws or bad welds in coiled barrels always run circumferentially and although they are no doubt eyesores they are in reality of but little importance. Further the iron used at that time in the manufacture of coiled tubes was of too hard and steely a nature to weld well. This hard iron was deemed necessary in order to resist the crushing force of the powder. Such, however, is not the case, and it is found that soft ductile iron, which I proposed* for making coiled tubes, welds very perfectly, and further that it is set up and rendered dense by a couple of heavy proof rounds. The effect of these rounds is, slightly to bulge the bore at the seat of the charge, and I, therefore, submit my large guns to a severe "setting out" proof before they are fine-bored. The finishing cut thus removes the bulge, and it has now been proved that no further bulge is caused by firing service charges. It has since been conclusively proved that all solid forged barrels are liable to split, and in consequence, it has

* I should wish the innermost tube to be constructed of the softest and most ductile wrought iron, such as Bradley (L.) Charcoal Iron.—Treatise on Compound Ordnance, Jan., 1863, page 17.—W.P.

Fig. 11

Fig. 12

Fig. 13

Fig. 14

Fig. 15

Fig. 16

Fig. 21

Fig. 20

Fig. 19

Fig. 18

Fig. 17

been found necessary to bore them all out and to replace them with coiled tubes.

After making and destroying several other guns, I made a rifled gun $1\frac{1}{2}$ inches in bore, which I fired during the month of October, 1862, down the range at the Pigeon House Fort, Dublin, in the presence of Colonel Blane, A.A.G., and Colonel Phillpotts, commanding the Artillery. I then took my guns and models over to the Ordnance Select Committee, and at the same time submitted my Treatise on Compound Ordnance. The Committee at once decided upon giving my system a trial and placed a 68-pounder cast-iron gun of 95 cwt. at my disposal.

They decided that I should be allowed to convert their gun, which was of 8 inches calibre, into a 9-inch smooth-bore lined gun. Before doing this I made the following inductive experiment, for I had not previously constructed a similarly proportioned gun. I made three models of the 68-pounder 8-inch gun, accurately to the scale of 1-8th; one of these was a plain cast-iron model of the gun itself; the second was made of a forging of the best wrought iron but not coiled; the third was made of cast iron and lined with a coiled barrel 1-8th of an inch thick, it was 1-inch in bore; and thus represented, to scale 1-8th, the 68-pounder gun converted by means of a barrel two inches thick into a 9-inch gun. The programme I laid down for each gun was as follows:—

Charge Round. oz.	Weight of Cylinder in oz.
1 .. 1	12
1 .. 1	24
1 .. 1	36
1 .. 1	48

Then repeat the programme with a charge of 2 oz.; then with 3 oz.; and lastly with 4 oz. The cast-iron gun burst at the 4th round, viz:—1 oz. of powder and a cylinder of 48 oz. The wrought-iron and the lined gun each completed the test. They were then submitted to the following test, viz:—They were loaded with 1 oz. of powder and an iron bar which accurately fitted the bore and projected beyond the muzzle of the gun. The breech of the gun was placed against a cylinder of about 1,000 lbs. weight, and a cylinder of 200 lbs. weight was laid against the end of the bar which projected; the wrought-iron gun burst at the first round, but the cast lined iron actually blew the cylinder of 200 lbs. weight right against the opposite side of the cell. The gun was then loaded with 2 oz. of powder and the test repeated, when it burst.

The reason for my giving the details of an experiment made on a scale so small that some consider it to be, in consequence, worthless, is, that I attach the greatest importance to such inductive experiments in which care is taken that all conditions be strictly proportional and all sources of error eliminated, and I think that one reason why experiments made on a small scale, carry so little weight is, because apparently trifling elements are apt to be overlooked and conditions allowed to creep in which vitiate the comparisons. In order to convert the 68-

pounder into a 9-inch gun. It became necessary to bore it up until a ring of cast iron only one inch thick was left near the muzzle, and some people thought that the "jar" or "vibration," or "concussion," or some such indefinite cause would break the cast iron at that place. But since the metal at the muzzle of the model gun had been only 1-8th of an inch thick, and as nothing of the kind had occurred, I carried out my proposal.

In the early part of the year 1863, the 68-pounder 9-inch gun was completed in the Royal Gun Factories, and it passed through its "test to destruction" without bursting. This test consisted of 100 rounds of 16 lbs. of powder and cylinders increasing every 10 rounds, by the weight of one sixty-eight pound shot. Thus the first ten projectiles weighed each 68lbs.; the second ten 136lbs.; the third ten 204 lbs., and so on, the last ten weighing each 680 lbs. The recoil was very violent; and smashed several carriages. The gun was then suspended in iron slings, these were also broken, and the gun flung itself out of them. It pitched muzzle foremost on the ground which was paved with large stones. The muzzle uprooted some of these and buried itself to a depth of about two feet in the earth, but suffered no injury whatever. When the test was completed, it was found that the lining in the gun had been fissured, or, as it is technically termed "guttered" in front of the seat of the powder; these fissures were upwards of half an inch in depth, and were caused in the following manner. A difference of 15-hundredths of an inch had been allowed between the diameter of the cylinders and that of the bore of the gun. When loaded, the cylinders lay on the lower part of the bore and thus left a lunated space between its upper surface and that of the bore of the gun. When the gun was fired, the heavy cylinders at first moved slowly off, and thus the inflamed gas rushed through this vacant space and eat away the iron of the tube immediately in front of the charge. In this state the gun was then put through a second test with 32 lbs. of powder, and in consequence of the additional 16 lbs. lying under the injured—I may say destroyed portion of the barrel—the gun burst at the 7th round with a shot of 200 lbs. weight and 32 lbs. of powder.

The next gun, to which I shall allude, was a 68-pounder, converted into a 7-inch rifled gun by means of two tubes one within the other; the object being that when the inner tube had been destroyed by continuous firing, there might still be a gun to fall back on, which was lined with a stout coiled wrought-iron barrel. For if the inner barrel 1 inch thick were to split, we should still have a lined 9-inch smooth-bore gun left, and the great strength of such a gun has just been shown.

The following is extracted from the Report of the Ordnance Select Committee upon its trial.

"Between the 8th October, 1864, and the 16th January, 1865, the gun went through 300 rounds, viz., 20 rounds of 12 lbs., 40 rounds of 20 lbs., and 740 rounds of 16 lbs., and projectiles of 100 lbs. weight. At the 750th round, a crack was observed passing from the bottom of the bore in the direction of the muzzle about 1 inch to the right of the vent, and in the prolongation of the upper groove of rifling; 50 rounds

were then fired without causing much apparent change in the character of the crack, completing in all 800 rounds.

"The A tube is split longitudinally and apparently through, in all about 33 inches in length.

"They (the Committee) are of opinion that the result of the trial is more favourable to the system than if the gun had fired a larger number of rounds and then burst with violence without giving warning. No rifled gun has as yet fired so many rounds with such large charges, and the accident which has led to the suspension of the experiment might to all appearance as well occur to the inner tube of any wrought iron gun. It is probable that the split was first caused by the groove becoming guttered, and that this guttering was accelerated by the use of the round-bottomed shells, a form which would favour the entry of the gas into the grooves before the shells had sensibly moved."

Now the truth of the conjecture of the Committee has since received abundant proof by the splitting of the barrels of several wrought-iron guns. The first instance being that of the steel barrel in the wrought-iron gun rifled on a similar plan, viz., the French system which split about six months afterwards.

I think that the importance of the performance of my gun in having fired 50 rounds with a split 33 inches long running down the powder chamber and through the inner, or A tube, cannot be too strongly dwelt upon. The A tube was subsequently removed by cutting three grooves quite through it. The three segments thus came away from the B tube, which although blackened and covered with dirt by the powder was ascertained to be quite uninjured. The experiment proved the great value of a thin A tube which prevents a crack from becoming deep, and also the value of a stout B tube to prevent explosive bursting when the inner tube shall have been destroyed by continuous firing. The fact of the 7-inch wrought-iron gun having repeatedly penetrated the Warrior Target with chilled white-iron shot and shell of 115 lbs. weight and only 13 lbs. of powder, and of the 6.3-inch wrought-iron gun having done so also with only 12 lbs. of powder, and an 80lbs. shot of the same kind, has added great importance to this experiment which took place three years ago.

My last experiment of endurance was made with a 32-pounder gun of 58 cwt. This gun was one of 8, which on the proposal of General Lefroy, President of the Select Committee, were converted by Sir W. Armstrong and Co., into 64 and 56-pounder rifled guns on my plans, in order to determine various details in rifling, amount of charge, sighting, etc., previous to their introduction into the service. These guns have all got a hole through the cascable—a plan of Sir William Armstrong—for the purpose of giving intimation of any escape of gas. The guns were all converted by this firm, and I have to acknowledge the friendly and valuable assistance they have afforded me. An escape of gas was observed at proof through the breech of one of these guns, and it was in consequence rejected. I have no doubt, that had I asked to be allowed to remedy this defect, my request would have been granted, but since for the sake of economy some alterations had been made in the manufacture I had previously adopted in the 7-inch gun, I was

anxious to test this gun to destruction, and I therefore withdrew it. Before describing its test I may mention that the service charge for similar guns will probably be between $6\frac{1}{2}$ and 8 lbs. of powder, and common shell of 61 lbs. weight, and that they will have battering charges of probably 14 lbs. of powder. I mention this to enable you to estimate the severity of the test, which was as follows:—2 rounds, 16 lbs. powder and 150 lbs. shot; 10 rounds, 20 lbs., 100 lbs. shot; 5 rounds, 10 lbs., and 5 rounds 16 lbs. of powder and 64 lbs. shell. These shells were purposely burst in the gun; they were filled with $4\frac{1}{2}$ lbs. of powder, their fuzes were taken out, and they were loaded with their fuze holes towards the powder. The flash of the discharge thus entered the shell and burst it in the gun. The effects of these explosions were merely to scratch and scrape the bore in various places but they did not in any way interfere with subsequent facility of loading. Next 10 rounds, 16 lbs. of powder and shot of 64 lbs. rammed down only so far as to leave air spaces between the powder and shot varying from 5 inches to 25 inches in length. These rounds produced no apparent effect, 71 rounds were then fired with cylinders of 50, 100, 150 lbs. weight, and charges 10, 15, 25 and 30 lbs. of powder. At last the gun failed under a charge of 30 lbs., and a cylinder of 150 lbs. weight. The casing cracked but no explosive burst occurred. The gun was then cut open and it was ascertained that the wrought-iron barrel was quite sound although considerably bulged. I may mention that the fore-sight was screwed through the casing and caused a large hole in it. The great length of the 30-lb. cartridge brought the strain under the fore-sight where the metal of the gun was also reduced in thickness, and the casing split through this hole.

In judging of these tests the strength of our English powder should not be lost sight of; for most of the cast-iron guns which were previously rifled, burst with a very limited number of rounds, with charges varying from only 5 to 8 lbs. of powder, and shot of between 50 and 65 lbs. weight. Most of these guns were supplied by the Lowmoor Company; I understand, however, that the Italians fire 17 lbs. of powder, and rifled steel shot of 110 lbs. weight from similarly rifled cast-iron guns of the same calibre which they also obtained from Lowmoor. It is certain that one such charge of our English powder would blow them to pieces. I do not mean to infer that the Italians, French, and Americans could not make as strong and even stronger powder than ours, but the fact is that since they do not possess such strong guns as ours, they simply use a weaker powder which is suited to the capabilities of their ordnance.

The bursting of so many cast-iron rifled guns with such small charges, had naturally caused great distrust in this country to the employment of that material, and I have in consequence had to overcome a very strong prejudice. I am anxious, however, to impress upon this Meeting, 1stly, that the guns which I advocate are not strengthened cast-iron guns and that they should be designated coiled wrought-iron guns encased in cast iron; 2ndly, that the interior or heart of the gun is of vital importance, and that if this be composed of coiled wrought-

iron it matters but little whether the outside be composed of wrought-iron, steel, or cast iron.

I shall trouble you with only a few words upon the method of constructing new guns, which I think can be done in the cheapest as well as the quickest manner by running the metal round the barrels. It has taken many years and required many careful experiments to enable me to ascertain the various causes of unsoundness to which this mode of manufacture is liable, but I think I may say with confidence that they have now been all completely overcome. This small gun is a specimen of one nature of unsoundness. Here is another in which the tube is quite loose inside the casing. This section of a gun illustrates the fact of these difficulties having been overcome. It is 3 inches in bore and weighs 8 cwt., and is similar in these respects to the 12-pounder field gun of the service. The following is an extract from a letter I received from the Ordnance Select Committee, dated March 3, 1865, relative to its trial:—

“The test of your 3-inch compound gun has been completed, and the gun remains apparently unaltered. It has fired—

			Cylinder's weight.
“ 10 rounds, charge $1\frac{1}{2}$ lbs.	..	..	24 lbs.
“ 10 ” ” ”	..	..	48 lbs.
“ 10 ” ” ”	..	..	72 lbs.
“ 20 ” ” ”	..	..	96 lbs.”

This* gun was subsequently bisected and you will notice that the mechanical fit of the cast-iron casing round the wrought-iron barrel is quite perfect.

My latest experiment in connection with this mode of construction has been with a 9-inch muzzle-loading gun rifled on the “Woolwich” system. The gun was made for me by Sir W. Armstrong and Co. The manufacture of the wrought-iron portion was carried out by Mr. George Rendel, and the casting was performed by Captain Noble. The successful issue is in a great measure due to the care and skill with which those gentlemen carried out the operation. The gun was first tested at Woolwich in a smooth-bore state by firing 20 rounds with cylinders of 250 lbs. weight. The first 18 rounds being with 43 lbs., and the last two with 55-lb. charges of powder. It was then sent back to Elswick and rifled on the Woolwich system, and on its return to Woolwich it was again proved with two rounds of 55 lbs. of powder and shot of 250 lbs. weight, and then completed the programme allotted to it, of 87 rounds of 45 lbs. powder and 250 lbs. shot. It so happened that the inner barrel of this gun was very defective, although it is right to state, that it is the only defective barrel out of upwards of a dozen which the Elswick Ordnance Company have made for my guns.

The mode in which a coiled barrel is made is as follows;—a bar of iron is wound round a mandril, and then welded into a tube about 18 inches long; a certain number of these lengths are then welded

* This gun is now in the Museum of the Institution.—ED.

together end to end, and form the barrel. The coils which formed the second length at the breech end of this barrel were imperfectly welded, and in consequence were separated one from another. Still very little apparent change was caused in these flaws by the test to which the gun was subjected, and I submit that the success of a gun, whose barrel was full of flaws in the powder chamber, argues well for the success of similar guns when lined with sound barrels. Further, I think it will be conceded that having made and successfully fired a 9-inch gun with charges of 45 lbs. of powder, I have proved *a fortiori*, that 8-inch and 7-inch guns which fire respectively battering charges of only 30 and 22 lbs. of powder, as well as the great majority of our guns which are of smaller calibres, which fire smaller charges, and which are therefore exposed to lesser strains, can all be constructed upon the same system.

I have since sent the 9-inch gun to the Paris Exhibition, as I am anxious that it should be publicly recorded that the first large rifled gun constructed on a principle which I feel confident will shortly become universal, was made in this country.

There are two ways in which a gun can be burst, viz.,—by the bursting of the barrel or by the end being blown off. I have hitherto treated of the first mode of bursting, and I shall now say a few words on the second. In an ordinary cast-iron gun, the whole longitudinal pressure acts upon the end of the bore; if the bore be 8 inches in diameter, this pressure will, in round numbers, be distributed upon 50 square inches; if, however, the gun be bored up to 13 inches and lined with a barrel $2\frac{1}{2}$ inches thick, the longitudinal pressure will act upon 50 square inches as before, but it will be transferred to a surface of about 130 square inches; and thus the longitudinal strength of the gun becomes more than doubled. In fact every way of regarding the subject shows that the circumferential strength should be applied internally, and that the longitudinal strength should be borne by the outside, and this is precisely the reverse of the principle on which the wrought-iron guns of the service are made.

Care must be taken that there be no sudden alteration of figure, or rather, that the longitudinal strength be not suddenly weakened at any one place. The method at first pursued in the construction of muzzle-loading wrought-iron guns, was to introduce the interior barrel through the breech piece and then screw in the breech plug or cascable behind it. It will be evident that the plug to close the hole, must be larger than the barrel which passed through that hole, and in consequence that the screw thread to receive that plug or cascable had to be cut out of the substance of the gun. This arrangement defined a markedly weak place in the breech of the gun. Now, had the breech to sustain only a statical or gradually applied pressure, this diminution of longitudinal strength would not have been of the slightest importance. When, however, the pressure becomes a blow more sudden and more rapidly applied than any which we can conceive a hammer to give, this difference of strength leads to fatal consequences. I shall endeavour to illustrate this fact by applying sudden or impulsive pressure to some screw bolts. Some of these are made in the ordinary manner, i.e., the

screw thread is cut out of the substance of the bolt, others have screw threads in relief upon the shank like the bolts which I proposed for the attachment of armour plates.

[Major Palliser here placed on the table an iron apparatus, in the form of a tripod, with a vertical rod suspended from the apex, up and down which a perforated mass of iron, weighing about a quarter of a cwt., could move freely. He then produced two bolts, and went on to say:—

“ This one is an ordinary screw bolt such as is in general use. It is a bar of iron tapped at the end. It screws into this nut. The other bolt is tapped with the same screw tap, but it differs from the first in this respect, that the shank of the bolt is reduced until the thread is left in relief upon it. Now, if these two screw bolts were subjected to a gradually applied pressure, the result would be, that the first bolt would bear a greater weight than the other, inasmuch as the sectional area of the screwed part is somewhat larger than the sectional area of the reduced part. I shall try the ordinary bolt, subjected to a sudden pressure, and if I am not mistaken, the weight falling upon it will break it off at once at the screw part.”

Major Palliser here screwed the bolt on to the lower end of the vertical rod, and allowed the weight to fall upon it suddenly, the result was that the nut was broken off by the shock. A second experiment with the same description of bolt was attended with a similar result. He then tried the second description of bolt, the bolt with the reduced shank, and the effect was very different. Instead of breaking off under the violence of the blow the iron was simply drawn out, and the blow being repeated several times, the shank became so weak that, at last, it broke in two at the thinnest part.]

I submitted the results of similar experiments to the Select Committee in the early part of 1863, and the original method of closing the breeches of the muzzle-loading guns, has in consequence been altered by them, and inner tubes have ever since been inserted into wrought-iron guns from the front.

III. *Chilled White-Iron Projectiles.*

This small target (Plate viii, fig. 10), is the one upon which I made my first experiments with chilled shot. This is the gun from which they were fired, and these are some of the shot themselves. I am afraid I have already detained you too long and shall therefore only say a few words more. The bore of the gun is $\frac{3}{4}$ inch in diameter. The target is composed of a wood backing three inches thick faced with two wrought-iron plates, the upper one $\frac{1}{2}$, the lower one $\frac{3}{4}$ inch thick. The plates are secured with through bolts reduced in their shanks to the lesser diameter of the screwed part. The gun thus represented to scale $\frac{1}{2}$ a sixty-eight pounder converted into a 6 inch rifle gun, and the target represented to the same scale, 24 inches of wood backing faced with plates respectively 4 and 6 inches thick. The experiments were made in Woolwich Arsenal. The projectiles weighed 5½ ounces each.

Date of Firing.	Number of Round. See Pl. viii, Fig. 10.	Charge in Ounces.	Thickness of Plate.	Nature of Projectiles.	Result.
1863 May 14th	1	1	Inch $\frac{1}{2}$	Wrought-iron Shot, faced with steel; conical head	Penetrated Plate only.
"	2	"	$\frac{1}{2}$	Wrought-iron Shot, round head	Plate indented.
"	3	1 $\frac{1}{2}$	$\frac{3}{4}$	Wrought-iron Shot, faced with steel, flat head	Plate indented; mark of steel ring left in Plate. (See fig. 15, plate ix.)
"	4	"	$\frac{3}{4}$	Wrought-iron Shot, round head	Plate slightly indented. (See fig. 16, plate ix.)
"	5	"	$\frac{1}{2}$	Wrought-iron Shot, round head	Plate indented.
"	6	"	$\frac{1}{2}$	Wrought-iron Shot, faced with steel, conical head	Penetrated Plate only.
May 21st	7	1	$\frac{1}{2}$	White-iron chilled Shot, conoidal head	Target completely penetrated; the Shot was subsequently dug out of the earth in rear. It was quite unaltered in shape, with exception of the small tail (to receive the lead) being broken off. (See figs. 13 and 14, plate ix.)
"	8	"	$\frac{1}{2}$ & $\frac{3}{4}$	White-iron chilled Shot, conoidal head	Struck on edge of thick Plate and glanced; deep indent through Plate.
"	9	"	$\frac{3}{4}$	White-iron chilled Shot, conoidal head	Penetrated Plate only; the head of the Shot, which was subsequently extracted, was perfect. (See fig. 17, plate ix.)
"	10	"	$\frac{1}{2}$	White-iron chilled Shot, flat head	Penetrated Plate only and broke into pieces.
"	11	1 $\frac{1}{2}$	$\frac{3}{4}$	White-iron chilled Shot, conoidal head	Penetrated Plate only; the head of the Shot, which was subsequently extracted, was perfect.
May 25th	12	1	$\frac{3}{4}$	Wrought-iron Shot with steel ring in front, flat head.	Indented the Plate the depth of the steel ring. (See fig. 15, plate ix.)
"	13	"	$\frac{3}{4}$	White-iron chilled Shot, flat-headed	Shot broke into pieces against the Plate, which it slightly indented.
"	14	"	$\frac{1}{2}$	White-iron chilled Shot, flat-headed	Penetrated Plate only.
"	15	"	$\frac{1}{2}$	White-iron chilled Shot, conoidal head	Penetrated Target completely; the Shot was subsequently dug out of the earth in rear. It was quite unaltered in shape, with exception of the small tail (to receive the lead) which was broken off. (See fig. 18, plate ix.)

In considering the relative effects of the several Projectiles, particular attention is called to the thickness of the Plate which was struck.

The result of this experiment showed me that a penetration at all events equal to that of any steel could be obtained by the use of *conical-headed* chilled shot, could those of the larger sizes be rendered as hard by the chilling process as these small ones had been made. On the 12th and 13th of November, 1863, some ogival-headed chilled shot and shell (for shape of head see Fig. 19, Plate ix) were fired from a 12-pounder breech-loading gun against 2½-inch plates at Shoeburyness. The results, although they surprised others who were present at the experiment, disappointed me, and I at once perceived that the iron which had answered so well in the very small shot, was not suited to those of larger natures. On my return to my regiment at Norwich, I made a series of experiments at Messrs. Riches and Watts' foundry there, until I obtained large shot of precisely the same nature as the small ones, viz., of chilled white iron. I now, however, encountered a serious difficulty. The Ordnance Select Committee having hitherto carried out all the competitive trials of the steel shot of various makers from the 7-inch breech-loading gun of the Service, it was determined to continue the experiments with my shot from the same gun for the purpose of obtaining comparable results. We now found that the chilled white-iron shot cracked and fell into pieces during the process of lead coating, for the sudden and great changes of temperature, necessitated thereby, split the highly tempered mass, as hot water does a glass. We therefore had to institute the most careful experiments in the Royal Laboratory until we got a shot hard enough to penetrate and yet soft enough not to crack in leading.

From the time, however, that I was allowed to fire shot from the muzzle-loading gun, all my difficulties ceased.

Fig. 19, Plate ix, is a copy of a photograph of the head of a 12-pr. chilled white-iron shot, which penetrated a 2½-inch plate and buried itself 2 feet 8 inches in the earth in rear, on the 29th September, 1864. Fig. 20 is a copy of a photograph of a 7-inch shell, which, filled with sand, weighed 115 lbs., and fired at 70 yards distance with a reduced charge of 13 lbs. of powder, completely penetrated "the 'Warrior' target." Fig. 21 is a copy of a photograph of a 9-inch shell, weight 250 lbs., which, with a charge of 23 lbs. of powder, and fired at an angle of 74°, penetrated "the 'Warrior' target" at 200 yards distance, and burst after penetration. The full charges of the 7 and 9-inch rifle guns being respectively 22 lbs. and 43 lbs., the reduced charges of 12 lbs. and 23 lbs. were calculated to represent a distance of upwards of 1½ miles.

The following table shows the relative powers of penetration of various natures of projectiles referred to the "Warrior" target as a standard:—

None of these did penetrate the "Warrior" Target at 200 yards.	{	10½-inch cast-iron round shot of 150 lbs. fired with 50 lbs. of powder.
		9-inch steel round shot of 115 lbs. fired with 25 lbs. of powder.
		7-inch steel shell round-headed of 100 lbs. fired with 25 lbs. of powder.

<p>These have penetrated the "Warrior" at 200 yards.</p>	{	<p>7-inch ogival-headed white-iron chilled shot or shell, fired with any charge from the service battering charge of 22 lbs. down to one of 13 lbs. inclusive.</p> <p>6·3-inch chilled shot and shell of 80 lbs. fired with 14 lbs., or even 12½ lbs.</p>
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In conclusion I would observe that I have no personal interest whatever in penetrating anybody's target, and that so long as my projectiles make deeper indents than those made by any other projectiles, I am perfectly satisfied, so far as I am myself concerned. On public grounds, however, I hold it to be a source of satisfaction that the guns have beaten the targets. I am of opinion that the more destructive weapons of offence become as compared with moveable appliances for affording immediate protection, the greater will be the superiority of those acting on the defence, and *vice versa*. I believe this theory is quite general, whether applied to a few men armed with that destructive weapon of offence, the Snider breech-loader, defending themselves under cover of a parapet from the attack of superior numbers advancing across the open, or to the regular attack and defence of fortresses,* or to the attack of armour-plated ships upon coast defences.

As the question at present stands, our rifled cannon could easily beat off the attack of an iron-clad fleet upon any of our maritime fortresses, but should protective appliances be able to defy those of offence, iron-clad ships would be enabled, during any temporary absence of our own fleet, to bombard in security, and at their leisure, those dockyards and fortresses, such as Malta, Portsmouth, and Gibraltar, which lie on the sea coast.

Looking to the great wealth of this country, our extended commerce and isolated position, it will, I think, be admitted that any war in which we may have the misfortune hereafter to be engaged, will most probably be a war of defence on our part, and therefore anything that conduces to the efficiency of defensive warfare, will contribute to the security and welfare of this country.

APPENDIX.

ANDREW HART, LL.D., Senior Fellow Trinity College, Dublin, and the Rev. JOHN TWISDEN, M.A., Professor of Mathematics, contributed the following mathematical papers to my Treatise on Compound Ordnance in 1862.

* Colonel Sir William Denison, K.C.B., R. E., in a letter to Colonel Harness, C.B. R.E., "On the influence of rifled cannon, and small arms on the Attack and Defence," (Professional papers of the corps of Royal Engineers, vol. xii, page 4), says "it is needless to press the comparison farther; it appears to me that the balance of advantage preponderates on the side of the defence; that the siege of any given place would take longer time under existing circumstances, than when the arms used were the musket and the 24-pounder, and the loss to the besieger would be greater."—W.P.

Dr. Hart's Investigations.

This formula of Barlow rests on the assumption that the area of each transverse section is unchanged by internal pressure; in other words, that no transverse pressure applied to iron will alter either its density or its length, or, at least, that one of these effects will so far counteract the other as to leave the area of the transverse section unchanged. As a general proposition, this is (to say the least) highly improbable; and although in the particular case of the cylinder it may be nearly true, yet it should not be assumed as an axiom.

The more commonly received theory is, that the extension or compression of iron in any direction is proportional to the force which acts in that direction; and the following calculation, which I made some years ago, is based on that theory. The result, as will be seen, is that the strain on any lamina of the cylinder is to the strain on the external lamina as the sum of the squares of the diameters of the two laminæ to double the square of the diameter of the smaller one.

Let r be the radius of one of the cylindrical laminæ of which the tube is composed, and let dr be its thickness (the length of the tube being unity); also let p be the total internal pressure on this lamina, and $p-dr$ the reaction of the lamina immediately exterior to it. It is obvious that the difference of these two forces tends to stretch the lamina, and therefore to increase its radius. Let δr be the extension of the radius, and k the modulus of elasticity (or the ratio of the extending force to the extension), and we have

$$\frac{dp}{2\pi dr} = k \frac{\delta r}{r} \quad (1)$$

But since this same lamina is compressed in the direction of its thickness by the two opposing forces p and $p-dr$, its thickness will be reduced by a quantity $d\delta r$ proportional to the compressing force; that is to say,

$$\frac{p}{2\pi r} = k \frac{d\delta r}{dr} \quad (2)$$

(I assume that the modulus of the resistance to compression is equal to that of resistance to extension.)

Multiplying these two equations, we get—

$$\frac{p dp}{4\pi^2} = k^2 \delta r. d\delta r \quad (3)$$

Whence, by integration, if R be the radius of the external surface where $p = 0$

$$\frac{p^2}{4\pi^2} = k^2 \{(\delta r)^2 - (\delta R)^2\} \quad (4)$$

and, eliminating p between equations (2) and (4)—

$$\frac{d\delta r}{\{(\delta r)^2 - (\delta R)^2\}^{\frac{1}{2}}} = \frac{dr}{r}$$

whence, by a second integration—

$$\delta r - \sqrt{(\delta r)^2 - (\delta R)^2} = cr$$

and, eliminating c by the condition that when $r = R$, $\delta r = \delta R$, we have finally—

$$\frac{\delta r}{\delta R} = \frac{1}{2} \frac{r}{R} + \frac{1}{2} \frac{R}{r} = \frac{R^2 + r^2}{2 R r} \quad (5)$$

that is to say, the extension of any lamina is to the extension of the external surface as the sum of the squares of the radii to double their product; but the strains are proportional to the extensions divided by the lengths, that is, as the sum of the squares of the radii to double the square of the lesser radius r . Q.E.D.

In this reasoning it is assumed that the normal compression and the tangential extension are each proportional to the force which acts in its direction, and that a compression or extension in one direction does not cause any change of dimensions in a direction perpendicular to the force. This is manifestly false in ductile bodies, and is probably inaccurate even within the limits of elasticity. This error, however, is in the opposite direction to that of Barlow, before alluded to, and it is probable that the true law is intermediate between the two hypotheses, and that so far as they agree in results they may be safely relied on.

Returning to the equations, we find, by elimination between (4) and (5), and supposing r to be the radius of the inner surface of the tube, that the total internal pressure is

$$p = 2\pi k \frac{R^2 - r^2}{R^2 + r^2} \delta r$$

and as fracture will take place as soon as $\frac{\delta r}{r}$ reaches a certain limit ϵ ,

it follows that the total internal pressure must be less than

$$2\pi r \epsilon k \frac{R^2 - r^2}{R^2 + r^2} \quad (6)$$

or that the pressure per square inch must be less than

$$\epsilon k \frac{R^2 - r^2}{R^2 + r^2}$$

where it is also to be observed, that the value of k is probably less than the coefficient of elasticity given in the tables, on account of the error in the hypothesis which I have already mentioned. Differentiating the expression (6), we find the condition that a tube of given external diameter shall sustain the greatest possible amount of internal pressure, viz.—

$$R^4 - 4R^2r^2 - r^4 = 0$$

whence

$$\frac{r}{R} = (\sqrt{5} - 2)^{\frac{1}{2}} = \cdot 486$$

If one cylinder be inserted into another so as to fit accurately without initial pressure, and if r' be the radius of the surface of contact, and k, k' the moduli of elasticity of the outer and inner cylinders, then it is clear that the state of tension of the inner cylinder will depend on the pressure at the surface of contact, which is $2\pi k \frac{R^2 - r'^2}{R^2 + r'^2} \delta r'$; and that

it will be unaltered by changing k and R to k' and R' , provided that $k' \frac{R'^2 - r'^2}{R'^2 + r'^2}$ retains its value; that is to say, if

$$R'^2 = \frac{(k' + k) R^2 + (k' - k) r'^2}{(k' + k) r'^2 + (k' - k) R^2} r'^2$$

Accordingly the strength of the compound tube will be the same as of a simple tube composed of the inner material, with an external radius equal to the above value of R' , observing that $\frac{\delta r'}{r'}$ must not exceed the limit of elasticity of the inner tube, and that $\frac{\delta r'}{r'}$ which is similarly determined, must not exceed that of the outer tube.

Revd. John Twissden's Investigations.

There are two ways in which a gun may be destroyed—viz., by the bursting of the barrel, or by the end being blown off.

I shall in the first place, consider the former of these, reserving for another place my remarks on the latter.

The force by which the shot is propelled and the gun destroyed, if it be destroyed, is the pressure due to the expansion of the gases formed by the ignition of the gunpowder; and this pressure must be of the same nature as that produced by any other gas in a state of compression; but its capacity to destroy the gun will be affected by its sudden application, by the rapid change it undergoes in magnitude, owing to its expansion, and by the shortness of the time during which its action continued.

The first point for investigation is this:—Given a cylinder filled with a fluid and subjected to a pressure of p lbs. per square inch to determine the strain and the enlargement of the radius caused by that pressure at any point of the substance of the cylinder: for the sake of distinctness, we shall consider a portion of the cylinder whose axis is one inch long.*

* In this investigation, it is supposed that, where the gun consists of two concentric cylinders, they fit exactly, but neither exercises any strain on the other, except when it is subjected to internal pressure.

(1) If we suppose the internal radius of the cylinder to be r , and the thickness of its substance to be very small, then it is well known that, if any small portion of it be taken, it is stretched by two opposite tangential forces whose ultimate value τ is given by the equation

$$\tau = pr \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

and if δr is the increase of the radius due to p , we have

$$\frac{\delta r}{r} = \frac{pr}{Et} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where E is the modulus of elasticity and t the thickness of the cylinder, or the difference between its external and internal radii.

(2) Now let us suppose the external radius (π) to differ sensibly from the internal radius (ρ), but the substance of the cylinder to consist of one homogeneous material: conceive the substance to be made up of an indefinitely great number of cylindrical laminæ; let ρ , and $\rho + d\rho$ be the internal and external radii of one of these laminæ, and let π be the pressure per square inch transmitted to its interior surface, then part of π will be transmitted to the next lamina, and part will be employed in stretching the lamina thus increasing its internal radius from ρ to $\rho + \delta\rho$, let $\pi + d\pi$ be the pressure per square inch transmitted to the next lamina. Now $\pi + d\pi$ being spread over a larger

area will be equivalent to $(\pi + d\pi) \frac{\rho + d\rho}{\rho}$ on the inner surface of the lamina, and therefore the part of π employed in stretching the lamina is

$$\pi - (\pi + d\pi) \frac{\rho + d\rho}{\rho};$$

and therefore the tension of that lamina (by equation 1) is

$$\pi\rho - (\pi + d\pi)(\rho + d\rho)$$

which ultimately equals

$$-(\rho d\pi + \pi d\rho)$$

or

$$-d. \pi\rho$$

Hence by equation (2) observing that $t = d\rho$, we have

$$-\frac{d. \pi\rho}{E. d\rho} = \frac{\delta\rho}{\rho} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Now if all the radii of the laminæ were enlarged by the same amount, the external radius would become

$$\rho + d\rho + \delta\rho.$$

But if there is any variation in the enlargement of the several radii, it would become

$$\rho + d\rho + \delta\rho + d.\delta\rho$$

Now each lamina is compressed by the pressure transmitted to it; consequently

$$d.\delta\rho = - \frac{\pi d\rho}{E} \quad . \quad . \quad . \quad . \quad (4)$$

By multiplying (3) and (4) we obtain

$$\pi\rho d.\pi\rho - E^2 \delta\rho d.\delta\rho \\ \therefore (\pi\rho)^2 = E^2 (\delta\rho)^2 + c$$

but when $\rho = R$, $\pi = 0$ and $\delta\rho = \delta R$.

$$\therefore (\pi\rho)^2 = E^2 \left((\delta\rho)^2 - (\delta R)^2 \right) \quad . \quad . \quad . \quad (5)$$

Eliminate π between (4) and (5), and we obtain

$$\frac{d.\delta\rho}{\sqrt{(\delta\rho)^2 - (\delta R)^2}} = \frac{d\rho}{\rho}$$

Integrating, and remembering that when

$\rho = R$, $\delta\rho = \delta R$, we have*

$$\frac{\delta\rho}{\delta R} = \frac{1}{2} \left(\frac{\rho}{R} + \frac{R}{\rho} \right) \quad . \quad . \quad . \quad (6)$$

Eliminating $\delta\rho$ from (5) and (6), we obtain

$$\pi\rho = \frac{E\delta R}{2} \left(\frac{R}{\rho} + \frac{\rho}{R} \right) \quad . \quad . \quad . \quad (7)$$

Now let δr be the extension of the inmost lamina we have from (6)

$$\delta r = \frac{\delta R}{2} \cdot \left(\frac{R}{r} - \frac{r}{R} \right) \quad . \quad . \quad . \quad (8)$$

and

$$r = \frac{E\delta R}{2} \left(\frac{R}{r} - \frac{r}{R} \right)$$

therefore eliminating $R\delta$, we obtain

$$r = \frac{E\delta r}{r} \left(\frac{R^2 - r^2}{R^2 + r^2} \right) \quad . \quad . \quad . \quad . \quad (9)$$

(3) The more usual method of treating the question is, to neglect the compression and to consider that the total area of the transverse

* Formula (6) was communicated by A. S. Hart, Esq.

be $\frac{2}{16}(1 + \frac{1}{178})$, $\frac{2}{33}(1 + \frac{1}{178})$, $\frac{2}{50}(1 + \frac{1}{178})$, $\frac{2}{67}(1 + \frac{1}{178})$, $\frac{2}{84}(1 + \frac{1}{178})$, $\frac{2}{101}(1 + \frac{1}{178})$, $\frac{2}{118}(1 + \frac{1}{178})$, $\frac{2}{135}(1 + \frac{1}{178})$, $\frac{2}{152}(1 + \frac{1}{178})$.

It is plain from both these series of numbers that, when the inmost lamina is stretched as much as is consistent with safety, the lamina which is only two inches farther from the centre is only stretched the $\frac{2}{3}$ or $\frac{2}{35}(1 + \frac{1}{178})$, say about $\frac{2}{3}$ th of what it can be stretched with safety, while those near the outside of the gun are not stretched $\frac{1}{10}$ th or $\frac{1}{13}$ th part as much as they might be stretched with safety, and all their remaining strength is useless.

It may be remarked that the factor in Hart's formula, $\frac{R^2 + \rho^2}{R^2 + r^2}$ will

be but little greater than unity for the laminæ near the bore, and, since ρ must be less than R , must always be less than 2; from hence it will follow that the strain on the successive laminæ is distributed very nearly according to Barlow's formula.

(5) There is another conclusion deducible from Barlow's formula. Let us suppose the bore of the gun to be increased till its radius is x , and suppose the metal removed to be replaced by an incompressible substance which offers no resistance whatever to extension; under these circumstances the force of the explosion is the same as before, and it is now supported by the part of the iron that has been left; and it can be easily proved that the gun will be stronger than it was before, so long as the remaining thickness of the iron is greater than the radius of the bore.

Since the lining transmits the pressure after the manner of a solid, the pressure per square inch on the internal surface of the iron is

reduced to $\frac{Pr}{x}$, hence from formula (13) we obtain

$$\frac{Pr}{x} = \frac{E\delta x}{x} \left(\frac{1}{x} - \frac{1}{R} \right) \quad . \quad . \quad . \quad (16)$$

Now the ultimate strength of a gun is measured by the pressure which stretches the inmost lamina to the bursting point; hence if r' and r'' are the ultimate strengths of the two guns, r' will be the value of r from equation (13), when

$$\frac{r\delta r}{r} = T$$

the tenacity, and r'' the value of r from equation (16), for which

$$\frac{E\delta x}{x} = T;$$

hence

$$r' = T. \frac{R - r}{R}$$

and

$$\frac{P'' r}{x} = T \frac{R-x}{R}$$

therefore

$$\frac{P'}{P''} = \frac{x(R-x)}{r(R-r)}$$

and $P'' > P'$ so long as $Rx - x^2 > Rr - r^2$, or so long as x is less than $R - r$. The value of x for which P'' is the greatest possible, is clearly $\frac{1}{2}R$. If it were possible to remove the iron from the interior of the gun above cited, and replace it in the manner proposed, the gun would be as strong with only 3 inches of iron as it was with 10 inches, and with $6\frac{1}{2}$ inches of iron it would be stronger than with 10 inches in the proportion of about 7:5, i.e., according to Barlow's formula. If Hart's formulae are employed, similar results,* though much more complicated, are obtained—which in the case of the gun cited lead to a nearly identical result, viz., that the gun is stronger with any thickness of metal not less than 3.2 inches, and is strongest when its thickness is reduced to 6.32 inches.

(6) The foregoing investigation is based upon a supposition which can never be realised, viz., that the lining of the gun is an incompressible solid, and one that offers no resistance to extension. We will now examine the case in which the gun consists of two cylinders, one fitting the other exactly; we will denote by r the internal radius of the outer cylinder, by r' and E' the moduli of elasticity of the inner and outer cylinder respectively, and we will use the same notation in other respects as before.

We will treat this question on Barlow's principle, i.e., we shall have the two fundamental equations,

$$\rho \delta \rho = r \delta r = r' \delta r' = R \delta R$$

and

$$-\frac{d\pi\rho}{d\rho} = E' \frac{r\delta r}{\rho^2}$$

integrating and remembering, that

$$\pi = P' \text{ when } \rho = r$$

we have

$$Pr - \pi\rho = E'r\delta r \left(\frac{1}{r} - \frac{1}{\rho} \right)$$

* If the internal radius of the original gun is increased to x , the gun will be strengthened so long as

$$x(R^2 + r^2) < R \{ \sqrt{R^4 + R^2 r^2 - r^4} - Rr \}$$

and its strength is greatest when

$$x = 0.485.R$$

i.e., according to Hart's principle.

whence, if P' is the pressure per square inch transmitted to the inner surface of the outer cylinder, we have

$$Pr - P'r' = E'r\delta r \left(\frac{1}{r} - \frac{1}{R} \right)$$

But equation (13) gives us, remembering that $r\delta r' = r'\delta r$

$$P'r' = E''r\delta r \left(\frac{1}{r'} - \frac{1}{R} \right)$$

and therefore

$$Pr = r\delta r \left\{ E' \left(\frac{1}{r} - \frac{1}{r'} \right) + E'' \left(\frac{1}{r'} - \frac{1}{R} \right) \right\} \quad (17)$$

or

$$Pr = r'\delta r' \left\{ E' \left(\frac{1}{r} - \frac{1}{r'} \right) + E'' \left(\frac{1}{r'} - \frac{1}{R} \right) \right\} \quad (18)$$

NOTE.—Deductions can be made from Hart's principle in a similar manner, but complicated equations are obtained.

This last equation will enable us to institute a direct comparison between the method of strengthening a gun by encasing it in wrought iron, and that which seeks to effect the same object, by lining it with wrought iron; the difference will be most conveniently exhibited by a numerical example.

(7) Take a cast-iron gun of calibre 6 inches and thickness of metal 10 inches, convert it into a gun whose calibre shall be 10 inches; required (1st) the thickness of the wrought-iron casing, (2nd) the thickness of the wrought-iron lining which must be applied, so that under the same internal pressure per square inch it may be as strong as it was before its calibre was enlarged.

For the sake of simplicity, I shall assume that the modulus of elasticity of wrought iron is double that of cast iron, which is, on the average, nearly the case.

(a) For the gun of 6 inches calibre we have (13)—

$$P = \frac{E\delta^2}{r} \left(\frac{R-r}{R} \right)$$

where $r = 3$ and $R = 13$; for the second gun we have (since $E'' = 2E' = 2E$) from (17)

$$P = \frac{E\delta r'}{r} \cdot r \left\{ \left(\frac{1}{r} - \frac{1}{r'} \right) + 2 \left(\frac{1}{r'} - \frac{1}{R} \right) \right\}$$

where $r = 5$, $r' = 13$, and R is the external radius; now P and E are the same in both formulæ, and, the inmost lamina being of cast iron, the weakest point in both guns will be equally tried if $\frac{\delta r}{r}$ in both are equal. Now on substituting numerical values, the first formula gives

$$p = \frac{E\delta r}{r} \cdot \frac{10}{13}$$

the second gives

$$p = \frac{E\delta r}{r} \cdot 5 \left(\frac{1}{5} + \frac{1}{13} - \frac{2}{r} \right)$$

Hence

$$\frac{10}{13} = 1 + \frac{5}{13} - \frac{10}{r}$$

$$\frac{10}{r} = \frac{8}{13} \text{ and } r = \frac{130}{8} = 16\frac{1}{4}$$

or the wrought-iron casing must be $3\frac{1}{4}$ inches thick.

(b) Let us suppose x to denote the external radius of the wrought-iron lining; in this case the condition of equal strength will be that the inmost lamina of cast iron shall be equally strained in both cases: hence, as before, we have for the first gun—

$$p = \frac{E\delta r}{r} \cdot \frac{10}{13}$$

and for the second gun—

$$pr = x\delta x \left\{ E' \left(\frac{1}{r} - \frac{1}{x} \right) + E'' \left(\frac{1}{x} - \frac{1}{r} \right) \right\}$$

were $r=5$, $R=13$ and $E'=2E''=2E$

$$\therefore p \cdot 5 = \frac{E\delta x}{x} \cdot x^2 \left\{ 2 \left(\frac{1}{5} - \frac{1}{x} \right) + \frac{1}{x} - \frac{1}{13} \right\}$$

the condition of equal strength being

$$\frac{\delta r}{r} = \frac{\delta x}{x}$$

Hence we have for the determination of x the equation

$$x^2 \left(\frac{2}{5} - \frac{1}{x} - \frac{1}{13} \right) = \frac{50}{13}$$

$$\therefore x = 5.33.$$

Whence the thickness of the iron lining is about $\frac{1}{3}$ of an inch. *A lining $\frac{1}{3}$ of an inch thick on the inside rendering the gun as strong as a casing $3\frac{1}{4}$ -inch thick.*

If we solve the above question, supposing a is the internal and r the external radius of the original cast-iron gun, and if we suppose that the bore is to be increased to r , then if τ is the thickness of the wrought-iron casing, we shall have

$$T = R \frac{r-a}{r+a} \quad . \quad . \quad . \quad . \quad . \quad . \quad 19)$$

and if t is the thickness of the wrought-iron lining, a general value for t can be easily found, but it is complicated; however, in all practical cases we have very approximately*

$$t = (r - a) \frac{r}{3R - 2r} \quad . \quad . \quad . \quad . \quad . \quad (20)$$

(8) I will now apply these formulæ to another case. Let there be a cast-iron gun whose internal radius is a , and external radius is b , and another gun consisting of a wrought-iron tube, whose internal and external radii are r and r' respectively placed inside a cast-iron gun whose internal and external radii are r' and b , required to compare their ultimate strengths. The ultimate strength of the former is attained when the inmost lamina is stretched by a force equal to its tenacity (τ), i.e., when

$$\frac{E\delta a}{a} = T$$

Since the tenacity of wrought iron is at least four times that of cast iron, it follows that unless the wrought-iron tube had a thickness of more than half the calibre, the train transmitted on the cast iron would produce rupture before the wrought iron yielded. Now the wrought-iron tubes suggested in the present paper would never attain this thickness: hence the ultimate strength of the second gun will be attained when the inmost lamina of the cast iron is subjected to a strain equal to its tenacity, i.e., when

$$\frac{E\delta r'}{r'} = T$$

Hence if p and p' are the internal pressures producing the ultimate strains in the two cases, we have from (13)

$$P = T \frac{R - a}{R} \quad . \quad . \quad . \quad . \quad . \quad .$$

and from (18), remembering that $\mathbf{r}' = 2\mathbf{r}'' = 2\mathbf{e}$

$$P' = T \frac{r'^2}{r} \left(\frac{2}{r} - \frac{1}{r'} - \frac{1}{R} \right)$$

Hence the ratio of their ultimate strengths is

$$\frac{P'}{P} = \left(\frac{r'}{r}\right)^2 \frac{2R}{R-a} - \frac{r'}{r} \cdot \frac{R+r'}{R-a} \quad (21)$$

In this formula, since r is greater than r' , and r' than r , it is plain that the first term will ordinarily be much larger than the second; *e.g.*, take

* If we use formula (20) in the above example we obtain $t = \frac{1}{2}\%$, the exact value being 0.33. An inspection of equations (19) and (20) will show that in all practical cases T must be many times greater than t .

the cast-iron gun as before, and replace the inmost inch of metal by wrought iron, then $R = 13$, $r' = 4$, $r = a = 3$, and we shall find

$$P' : P :: 212 : 90 ;$$

or the mere substitution of one inch of wrought-iron for an inch of cast on the interior considerably more than doubles the strength of the gun.

If we enlarge the bore up to 13 inches, and then line it with wrought iron 1.5 inches thick, so that $R = 13$, $r' = 6.5$, $r = 5$, $a = 3$ we shall find $P' = 1.86 P$, or the gun's strength is nearly doubled, although its calibre is increased from 6 inches to 10 inches.

It can be easily shown that, if a cast-iron gun is cased in wrought iron, whose external radius is r' , the ratio of the ultimate strength of the gun will be given by the formula

$$\frac{P'}{P} = \frac{R}{R'} \cdot \frac{R' - r}{R - a} + \frac{r}{R'} \cdot \frac{R' - R}{R - a} \quad (22)$$

which shows that scarcely any thickness of wrought-iron casing will materially strengthen the gun; e.g. in the last example suppose the calibre increased to 10 inches, and the casing of wrought iron to be 4 inches thick, so that $r' = 17$, we shall find $P' : P :: 176 : 170$; or that the strength is scarcely increased. In fact if the thickness of the casing

is infinitely great, $\frac{P}{P'}$ only equals $\frac{R + r}{R - a}$, which is never much greater than unity.

THE CHAIRMAN: In this very interesting paper which you have heard from Major Palliser, there are doubtless many points upon which gentlemen present may wish to offer observations. All I would ask of you is, as the subject is a very wide one involving much detail, that you will be good enough to confine yourselves strictly to the subject of the paper.

Captain HARRISON, R.A.: There are two points in Major Palliser's interesting paper that it strikes me he did not allude to, and which, I think, are very important both as regards his system of guns and his system of projectiles. It is simply as to their relative cost. Major Palliser evidently, I think, proposes to utilise our cast-iron guns. We must take it for granted that his system will be infinitely cheaper than any system we have at present, if it is equally efficacious. But he also intimated that he proposed to make new guns on this principle. Now, I think it is very desirable, if Major Palliser can do so, that he should tell us what is the relative cost both of the conversion of our old cast-iron guns on the system he proposes, and also of making new guns on his principle. I think the same question applies to his very wonderful—I was going to say, discovery—it is hardly a discovery; but the success he has attained with these chilled projectiles, not only with shot but with shell, and the experiments with which, I have had the pleasure of witnessing from the very commencement, has been very great. He spoke of the satisfaction which everybody had at Shoeburyness, except himself, with the 12-lb. projectiles. I saw that experiment myself, and this is the first time I was at all aware that Major Palliser was dissatisfied. I can only say that if he was dissatisfied, I think he is very *exigeant*, because every one else present on the ground on that occasion was perfectly astonished; so much so, that it led at once to further experiments, which have gone on until the successful results that we see at the present time, have been attained. Not only have his projectiles supplanted steel shot, but we absolutely, find, with

regard to steel shell which were reported by the Iron-plate Committee as the only projectiles which were of use for attacking iron-clads, but which are of enormous cost even if we could obtain them of uniform quality, that we can now positively say that steel shell are no longer required, and that we shall simply have shell of chilled iron or white iron, whichever you may call it. But I think it is desirable that Major Palliser should tell us the relative cost of these projectiles; because, with the enormous number that will be required for this country, that becomes a very material question. There is only one other point which occurs to me; it is, that when Major Palliser began to show us that very striking experiment, with regard to the relative strength of those screw bolts, the result was so successful that it drove the thing out of his head, and he did not finish his explanation. Having also had the advantage of seeing the very earliest experiments with those bolts, which were originally submitted by Major Palliser to the Iron-plate Committee, and his earliest letter on the subject as recorded in the reports, I think that those bolts have not yet met with the reward that they deserve. For I must say that uninterruptedly they have been successful. I may be wrong, because I am not aware what decision has been come to, but I should be glad to hear that they have been adopted. The one objection that I have heard alleged against them is not a very strong one, which is, that they do not grip in the centre of the ship, that there is that narrow part. I imagine Major Palliser can tell us whether there is any way of obviating that, or whether it is a *bona fide* objection. That I think would also be interesting to us; and if he would be kind enough to say whether the system of stopping the breach of the breech guns is at all acted upon by the experiment which he began to show us.

Mr. BRAMWELL, C.E.: I do not know whether visitors at this Institution are allowed to speak. I have asked Major Palliser, and he tells me that they are.

The CHAIRMAN: Certainly.

Mr. BRAMWELL: The last speaker has put some questions about the relative cost of the projectiles made of chilled iron, and of those made of steel. I may say that I had occasion to enquire into the subject, and I discovered this very striking fact, that a steel shell involves, in the first instance, a solid forging which requires to be bored out in order to make the shell cavity. It then requires to be turned externally, and have other work done to it. The result is, that the cost of the steel which is bored out, and made into mere waste turning, is as nearly as possible the whole cost of a Palliser shell of the same size and weight. That fact, I think, puts the question of relative cost into a very simple form. As regards the operation of the bolts for fastening the armour-plates, I, as an engineer, was extremely interested in the result that was developed by the use of these bolts. We are aware that in machinery it is requisite to avoid all sudden changes of form; and Engineers who know their business, take care to specify that there shall not be any small collar, or other abrupt change of form in any piece of iron exposed to motion or vibration; because, if there be, it is a mere question of time as to fracture ensuing. Ensnue it must, if there be an abrupt change of form. I have had very many marked cases come before me in my experience. One of the strongest, probably, was the case of a fly wheel shaft, eighteen inches in diameter, which after working twelve years, broke from no other cause than from having a sudden projection upon it of half an inch on each side. That which has been known to Engineers as a bare fact in the construction of shaft and similar machinery, Major Palliser has certainly applied in the most successful manner to these bolts. When you come to consider the reason of it, I think it is obvious; now that we have been told by Major Palliser how to do it, we may find out the theory. The theory of it, I presume, is this: that when the target is struck, there is a certain amount of momentum which has to be consumed in some way. It may be consumed in elongating a bolt which has two different sections, and where the change from the large to the small section may be very abrupt. The fact is when you pass from the small to the large (I can hardly explain it without a diagram, but I will not be at the pains of doing that) the small section, where it has to endeavour to stretch the large, has the whole force of the shot accumulating at that one point; whereas if you have the shank of the bolt equally small with the bottom, the thread of the bolt is equally capable of extension; and

thereby, the extension of the bolt takes place equally throughout, and the momentum of the shot is consumed in that extension. In fact we saw that when the tripod was put on the table, the elasticity of the table did that which is done by the bolt itself. I think that is the theory of that which Major Palliser has so well brought before us. As regards the projectiles themselves, I was extremely interested with this: viz., that when those projectiles were fired, and broke up as they did in portions, although the points frequently passed through and were entirely uninjured, as they are now, if you picked up the portions that passed through, and laid your hand upon the fractured metal, not upon the outside which had been in the neighbourhood of the target, but on the interior portion, it was barely warm; but if you picked up pieces of a steel shell that had failed to pass through and had broken up, they would burn your hand. The conclusion is obvious, that in the chilled shell there has been no work consumed in altering the form of the shell; but the whole work has been consumed in destroying the target. In the steel shell, the form of the shell had been altered; you could detect it by the eye and by measurement, but even could you not have done so, the test of warmth told you that there had been a work done in the shell in changing its form, and therefore, the shell could not perform the work which it had to do, namely, to penetrate the target.

Captain R. A. E. SCOTT, R.N.: As nobody else seems inclined to rise, I wish to make a few remarks upon the subject. America is now building a large number of wooden corvettes. The vessels of this country will have to be prepared for all eventualities. I need not indicate the powers whom we are *not* to fear, but whom we are still to be prepared for. Now, it is at present in contemplation to lessen the heavy weighting of plated ships, and it has been more than once put forward, that vessels should carry half the amount of ammunition which is at present put on board, and that the remainder of the ammunition should be taken in transports, and supplied abroad. If that be done there will be a saving in weight; but it would still be of great consequence to have projectiles that will be good at all times. If you take a chilled shot, however good it may be against an armour-plated ship, especially when fired at right angles, that chilled shot will be of little or no use, comparatively, in firing through the side of an unarmoured vessel. What you want is steel shell of *large powder capacity*. These chilled projectiles have not that advantage. The chilled projectiles, thanks to Major Palliser and others who have devoted much attention to the subject, are good in attacking an iron-clad ship. But as I have said before in this hall, with respect to steel, you can temper it, so as to be tough. The thinner steel is, the better you can temper it. I believe, with the same amount of attention, and the same means of knowledge given to our steel manufacture, which Major Palliser has applied to chilled shot, that it would result in a cheap steel shell. I may mention that Mr. Whitworth is at the present time making steel shell which have been very *even* in their results, and are somewhat cheaply made; and much more still may be expected in that direction. To my own mind the experiments that have been made in firing angularly at plates (and we may be tolerably sure that that will be the general way in which we shall engage at sea we shall scarcely ever fire at right angles), have not been satisfactory. I see that they are manufacturing at Woolwich at the present time seven-inch chilled shot. I believe there are no chilled shot of seven inches being manufactured. I see that the chilled shell for the nine-inch gun which is being manufactured only holds 21 lbs. 13 oz. of powder. That is certainly, a very small amount, indeed. You want a very much larger amount; and it is steel alone that will not break up with the thinness of shell necessary to carry that large amount. There is another point:—The chilled shell require studs, or some other means of bearing them. The shell that were sent out to Halifax the other day were certainly not covered over, and the studs were smashed up. I know that they can be put in cases or boxes, but in time of war, when large numbers of shell are carried from one place to another, you will never be able to pack them in that way. That was one of the difficulties of the lead-coated shot before, and it is one of the difficulties that we shall get into with stud shot hereafter. I will now turn to the question of strengthening the cast-iron guns. What we want is not only a gun that will stand its charge on being fired, but a gun that will not break up when it is fired at. There is a very

brittle metal outside, which is exceedingly thin. A strong metal is put inside; and as long as that metal is not extended, so as to rest against the cast iron, your gun is secure. But how do you know when it will not extend so as to bear against the outer cast-iron casing? I am not aware of any way in which you can test it. I believe if the firing were continuous that you would find your gun going; especially, if you left off firing in cold weather, and began again in warm weather. I believe the bursting of guns with the present large charges to be a very serious matter; it might result in the loss of an action. Certainly, we could not afford to take on board ship a gun that might burst when fired, or break up when struck by a hostile shot. There is another point I would mention. As far as we have experience at the present time of coiled tubes, it is exceedingly difficult to weld them together so as to make a complete joint. When fired with high charges, the coils separate. When that gun of Sir William Armstrong, the 300-pounder, which afterwards blew its breech out, was proved, the coils changed in the proof; at each round there was an alteration in the inner tube. We know that there is great difficulty in welding an iron tube so as to make it stand for the interior of a gun, and you cannot put cast-iron outside a steel tube. The only gun that was tried, that was made in that way, burst at the first round. I believe it to be essential for the endurance of our guns that we should have a steel tube inside and the strongest metal we can put on over it. I regard the efforts that are now made at the Gun Factory, at Woolwich, as most satisfactory; and I think great credit is due to the Superintendent and his manager, Mr. Fraser, for the system of manufacture they have introduced, which is undoubtedly at the present time the best known. I do not think I need go particularly into the fact as to the competitive guns. I can only say that I dissent in toto about No. 1, No. 2, and No. 3; I do not wish to go into that. But as to the gaining twist, there is a great mistake usually made. It is said that your shot should start easily, and should then be whirled up. It happens that when you push your shot home, if you have an even twist, that the stud or bearing, or whatever it may be, is resting against the loading edge; and when the powder is acting upon it, it has a little space to move in, whether it is the 800th part of an inch, or whatever it may be, before it touches the bearing side of the groove, and, all danger is over as soon as the shot has moved. Therefore, I do not see the value of that argument as to the gaining twist, and it seems that Major Palliser himself has very great doubts on the matter. I think that great variations have been made in this rifling. When Captain Haig, the Assistant Secretary of the Ordnance Select Committee, assisted Major Palliser in rifling his gun, the rifle twist commenced not where the shot lay, but it was at that point very nearly half the amount of twist at which the rifling terminated. I observe that the Ordnance Select Committee are gradually working back to the even twist, and I have not the slightest doubt they will end there. Despite what Major Palliser has done, and he has shown some admirable experiments this evening, and is entitled to very great credit (nobody who has taken these things in hand but knows what great thought and attention they require, and must give Major Palliser full credit for everything he has done in that respect), I say despite all this, I dissent with respect to strengthening the cast-iron guns; and I dissent also with respect to introducing a chilled projectile without a much fuller trial of steel, which I am sure is the material we shall ultimately come to, just as we shall come to an even twist in rifling.

Captain TYLER, When Major Palliser replies, I hope he will be good enough to tell us something more about the chief points of his projectiles; and whether he has fixed upon any particular shape as being the best. Captain Scott referred to that subject to some extent. And perhaps he (Major Palliser) would go on to say whether he has tried flat-headed shot. I observe that the shot in some of those diagrams have round heads, and not pointed heads, such as those which have gone through the armour-plate. It will be very interesting to know what, in the course of the experiments, are the exact results obtained from different shaped heads to the shot. As I have understood hitherto, these pointed shot will go through the armour-plates more easily when they are fired directly at them; whereas the square-headed or round-headed shot will penetrate more easily than pointed shot when they are fired at an angle towards them. With regard to the bolts that Major Palliser has shown us,

the experiments were exceedingly interesting; and remind me, as they must have reminded Mr. Bramwell, who spoke so well on the subject, of the way in which axles have come to be made in railway engines and railway carriages. It was found when the axles were made with parallel sides that from the want of elasticity they broke rapidly and suddenly near the wheels; but by being made thinner and thinner in the middle, they at last arrived at a point when they were actually stronger than when they were thicker. Very much the same result occurs with these bolts of Major Palliser. By making them thinner at one part he really makes the whole bolt stronger than they would otherwise be. There was one point brought forward by Mr. Bramwell that I could not agree with; and that was with reference to the reason why these chilled shot penetrate so much better than the steel. Mr. Bramwell gave us a very lucid explanation upon that point, and told us how it was that the steel shot was much hotter than the chilled shot after it had struck the target; and he deduced from that fact that the steel shot had done its work in altering its own shape; while the chilled shot, as I understood him, had expended its work in penetrating the target. Now, I apprehend, that steel shot and chilled shot have both the same amount of work to do in penetrating a target. I did not quite understand how it could be, if there be an alteration of shape in the steel shot, why so much heat should be developed. I should like to know whether that has been satisfactorily ascertained from a great number of experiments, or whether there may have been some mistake about one accidental case. It is quite clear that steel shot may be made so very hard that almost no alteration of the shot would occur in striking a target, as is the case with chilled shot. Therefore, if we could get a little more information upon this subject, and perhaps Major Palliser will be able to give it to us, it would be very interesting.

Captain MOLOXY, R.A., Asst. Sup. of Royal Gun Factories: There is one point on which I hope Major Palliser will offer some explanation: that is, how he proposes to give the necessary strength to his compound guns in the longitudinal direction. The effect of the longitudinal strain, he has clearly explained, is to blow the breech off. It is in this direction his guns have always shown great weakness; and it is in this direction that, even in guns altogether of wrought-iron, there is a tendency to weakness. Major Palliser—I do not know that he proposes putting steel into his guns—puts a wrought-iron coiled barrel into a cast-iron casing. Wrought-iron coiled barrels cannot be made with solid ends; consequently the whole longitudinal strain, coming on the inserted cup or plug at the end of the bore, is at present resisted by the cast-iron casing alone. I hope that he will clearly explain how he proposes to strengthen guns in that direction.

Dr. TYNDALL, F.R.S.: I am exceedingly reluctant to add to the weight already put upon the shoulders of Major Palliser by adding to the questions proposed to him. I would beg permission to express the great gratification with which I have heard this paper this evening. I think the spirit in which this investigation has been conducted is the true spirit. He has gone on making his footing sure, basing himself on the sure ground of experiment, as he went on, making experiments on a small scale before he attempted experiments on a larger scale. I must say that the course he has pursued is such as will be justified by the experience of every scientific man accustomed to experimental research. Now, I dare say there are many persons present who would very much like to know the precise process by which those wonderful bolts have attained their present tenacity and rigidity. We hear of chilled shot; and I am equally persuaded there are many present who would like to hear from Major Palliser's own lips how this process of chilling is conducted. With reference to the observations that fell from Mr. Bramwell, respecting the amount of heat developed, no doubt when a projectile strikes a target, the total amount of heat developed by the stoppage of a certain amount of motion, is always the same. If the Palliser projectile goes through the target, and if a steel projectile of the same weight and velocity stops short and does not go through, there is a greater amount of heat developed at the target in the case of the steel, than of the Palliser projectile. There is no doubt of that. It depends entirely upon the amount of *vis viva* annihilation. Then the question arises, how is the heat distributed? That depends upon the comparative rigidity of the target and the projectile. If the

statements I have heard to-night are correct, the proportion of the total heat which comes to the share of the projectile is greater in the case of the steel projectile than in the case of the chilled shot. That would prove that the density and rigidity of the chilled projectile is of such a character as to throw the heat more upon the target than upon the projectile. I say that, as far as this goes, it is in favour of the chilled projectile.

Mr. BRAMWELL: I may say, for the information of the gentleman who asked that last question, in whose views I very much coincide, that I said studiously, if you put your hand upon the interior of the broken-up shot, the interior of the Palliser shot or shell had no heat that was at all harmful to the hand, while the steel shot or shell, owing to the change of shape that had taken place had the heat developed in its interior. Of course, with regard to the exterior of the shot, whether it were chilled shot or steel, its heat would be due to contact with the target.

Mr. MALLEY, C.E., F.R.S.: I think there has been a little misconception as to the importance of this question of heat. I happened to have been present myself on the 24th of October last, when the experiments were made to which Mr. Bramwell has alluded, when steel shell was fired along with a number of chilled shot and shell. I felt the fragments of both of them in my own hand. Those of the steel shell were undoubtedly colder—the portions that I took—than those of the chilled shot. But I attribute no importance to that one way or the other. If you attempt to estimate the relative values, the practical values of projectiles by refinements derived from questions of the amount of heat developed, you will go far astray. It is simply preposterous to talk of there being any superiority in the properties of chilled shot over those of steel projectiles on such grounds. It is a question of comparative price and practical utility, of convenience rather, in use as an artillery instrument. If you can make to the end of the chapter chilled shot cheaper than you can make steel, then I say by all means adopt them. My belief is, knowing something practically of the question in other directions, that the time will come, and is not very distant, when cast-steel shot or shell will be made quite as cheap as chilled ones. Steel shell are being made now quite as cheap, as far as my information as to their cost at Woolwich goes, as chilled shell, and they will be found, I believe, decidedly superior. We know pretty well what the co-efficient of cohesion is, and what the co-efficient of rigidity is in both. Now chilled cast-iron, means iron that is soft in the interior and hard on the outside. These shot which were tried on the 24th of October and produced such remarkable effects, and which I entertain a very high opinion of, were not in the proper acceptance of the word chilled shot. They were simply white cast-iron shot, and would have been much the same had they been cast in sand. If you can at the same price make cast-steel shot or shell, you will have a better projectile than any projectile you can make of chilled iron or cast white iron. There have been so many points brought forward to-night that it would be quite out of the question to attempt to refer to them in an orderly manner. But there is one point more which I think Captain Tyler alluded to, that I would remark upon; namely, as to the advantage obtained by the use of pointed projectiles compared with flat-headed projectiles. I was, myself, in company with Mr. Whitworth and several other persons, originally an advocate for flat-headed projectiles. I gave in evidence before the Iron-plate Committee my opinion as to what sort of flat-headed shot would be most likely to penetrate armour-plate. I believe I was entirely wrong. The first man, I believe the first man in Europe who on *a priori* principles showed that that view was wrong was no one in this country, but Professor Haughton, Fellow of Trinity College, University of Dublin, who in a paper published in the proceedings of the Royal Irish Academy, and as resulting from investigations made by him, predicted the fact that a shot having a conical point, or with an average angle of about 70 degrees, which is what has actually been come to at Woolwich, would, on principles that he had already applied to a totally different subject, viz., physical geology, be that which must necessarily penetrate armour-plate with the least expense of force. I believe that great merit is due to Major Palliser for having persistently hammered into the ears of the authorities that the hardest and densest and toughest material was that which would be the best for penetrating armour plate.

Dr. TYNDALL: Will you allow me to say one word with regard to the development of heat. Mr. Bramwell has said something about the contact. The heat as developed is entirely measured by the amount of motion stopped. If you take the velocity of the projectile just before it strikes the target, and, supposing it to pass through the target, if you take its velocity immediately after it has passed through, the difference between those two velocities is the measure of the heat produced. It may be a minute, or a second, or part of a second, it is entirely independent of time; it depends upon the amount of motion stopped in passing through the target.

Mr. MALLETT: In every case it is divided between the distortion of the shot and the distortion of the target.

The CHAIRMAN: If no other gentleman has any remarks to make, I will now call upon Major Palliser to reply.

Captain TYLER: Just allow me to say, that Dr. Tyndall has given us the proper theory as to the amount of heat that was developed in the case of shot passing through the target. Would he go on to state what occurs when the shot hits the target, and fails to pass through? In that case, the whole momentum of the shot must be turned into heat.

Major PALLISER: Captain Harrison asked me first as to the relative cost of the conversion of existing guns, and of the construction of a new gun of wrought iron. It is impossible for me to say what the relative cost would be, as I have been unable to ascertain the cost of a cast-iron gun converted, or what is the actual cost of a gun made entirely of wrought iron. But this much I will say, that in that 12½-ton gun of mine, there was an interior barrel of wrought iron which weighed 2½ tons, and that the expense of that barrel could not be more than the expense of the same amount of wrought iron in a wrought-iron gun. There remain, however, ten tons of metal—of cast iron which were run round the barrel in about one minute and a half; and I leave it to anybody to form their opinion as to the relative expense of casting a mass of cast iron like that in a couple of minutes—when we have the cast-iron already in our possession not costing us anything—and the cost of making, turning and boring rings, shrinking them one over the other, and thus gradually building up a wrought-iron gun. With regard to the relative cost of the projectiles, I think Mr. Bramwell has answered that. I believe the cost of chilled shot is very little more than the cost of what they call common shell—the ordinary cast-iron shell filled with powder. The fact is that the chilled shot are so cheap, that I believe they are going to use them in practice.*

Mr. MALLETT: Can Major Palliser tell us what is the actual cost in pounds sterling per ton for manufacturing, at Woolwich, the so-called chilled shell and shot?

Major PALLISER: I am not able to tell you that now; but I know that when they were first commenced, it was about £18 per ton. But we have got it lower than that now. One great advantage of the chilling process is, we find—at all events we feel pretty sure—that we shall be able to utilize the existing stock of cast-iron shot and shell in the manufacture of chilled shot, and then they will be very much cheaper. But Mr. Mallett has said that casting white-iron shot in sand is not different from casting one of these chilled shot. Now, I beg to say, that the first person who analysed a specimen of chilled shot was Professor Abel, the chemist of the War Department, in 1865. I asked him to analyse some portions of the chilled shot, and he did so, and he found they differed in no way in their component parts from ordinary white cast iron. Then, it occurred to me, if that is the case, there might be no objection to cast white-iron shot in sand. But it was found that the grain of such shot was very open. If that chilled shot were split open, the grain would present a most extraordinary appearance, and it is this intense hardness and closeness of grain which contributes much towards the superiority of the chilled shot.† This closeness of grain is caused by the violent contractions of the

* This question has since been decided in favor of using common shells in ordinary practice.—[Ed.]

† NOTE.—Subsequently communicated by Major Palliser. "A 7-inch, white iron shot, cast in sand, weighing 123½ lbs., has been lately fired at the "Warrior" target with a 15 lb. charge, and failed to penetrate it, while a chilled shot of 114 lbs.

exterior portions of the projectile which become suddenly solidified and compress the interior while still in a liquid state. In addition, the chilling process enables you to utilise a great quantity of iron which you otherwise could not. Further, the iron employed is made so intensely hard, that it cannot be turned; and you can cast the iron in an iron mould more accurately than you can cast it in sand, unless you go to the expense of dry loam moulding which is more expensive. Another advantage of the iron mould is the facility it affords for casting the stud holes in the shot. Altogether, the advantages conferred by the chilling process render it far superior to casting shot possessing similar properties in sand. In 1861* I pointed out that the whole discovery in these shot consisted in finding out that that *toughness*, on which Mr. Mallett has laid so great stress, was of no importance; and that all that was required was great hardness—or rather resistance to compression—combined with a form of head which would apply the pressure *gradually* to the shot. I believe that a blow is nothing more nor less than a severe pressure applied for a short time; that to flat-headed shot this pressure is *suddenly* applied, whereas to the conical or ogival-headed shot this pressure is *gradually* applied. If you refer to the Report of the Iron-plate Committee in 1865, and that of the Armstrong and Whitworth Committee, you will find they call attention to the great tendency of steel shot to break up on impact, and to the great care with which it was necessary to temper these shot. In fact, the Committee looked upon toughness as one of the most important elements in the shot. Captain Scott said that these shells had small capacity. I beg to say that shells of large capacity have just as good penetration as shells of small capacity at the direct target. At the inclined target they have not. At the inclined target the solid shot has better penetration than either kind of shell. But as far as firing at a direct target, or anything moderately direct, the shell of large capacity has a penetration equal to either the shell of small capacity or the solid shot. With regard to flat-headed steel shot, one of 250 lbs. was fired from a 9-inch rifled gun with 43 lbs. of powder at 200 yards distance at the 8-inch plated "Warrior" target; it made an indent $4\frac{1}{2}$ inches deep and rebounded from the plate; while a chilled shell of the same weight fired the same day from the same gun with the same charge, went right through the target and burst on the other side. I do not think it is necessary to say much about the liability of converted cast-iron guns to break up under continuous firing, when the first rifled lined gun I made was a 68-pounder converted into a 7-inch rifled gun and it fired 800 rounds without bursting. With regard to the uniform spiral and the increasing spiral, the very fact that Captain Scott has mentioned, that the shot at first hugs the loading edge of the groove and leaves a space of say the 800th part of an inch between the

weight, fired at a similar portion of the target, on the same day, with the same charge, and from the same gun, penetrated the target completely and tore away some supporting beams in rear."—[Ed.]

* *Vide* the following extract from Major Palliser's letter to *Mechanics' Magazine* of 22nd July, 1864:—

"At the time I first heard of Mr. Whitworth's tempered steel shot, I conjectured that the results he obtained were to be attributed as much to the hardness as to the toughness and tenacity of the material he employed. I had previously noticed in some experiments that I had made in casting iron round wrought-iron tubes, that, under certain conditions, the cast-iron was rendered very hard and unyielding where it came into contact with the cold wrought iron. I was aware that cast-iron would resist a far greater crushing force than wrought iron could, and putting these facts together, I thought it highly probable that if I cast an iron shot in a mould that would rapidly carry off the heat by conduction, and if at the same time I made the fore part of the shot of such a form as would convert the sudden shock of impact as much as possible into a uniformly increasing pressure, the brittle nature of the material would not be of much consequence. I accordingly made a model iron-plated target, a small rifled cannon, and cast some shot to prove the truth of my conjecture. At the time I commenced the experiment, I had never heard the expression "casting in chill." As soon as I had satisfied myself by experiment that the theory held good on a small scale, I sent the gun, target, and shot, last May twelve months, to the Ordnance Select Committee."—[Ed.]

surface of the stud and the driving edge of the groove, shows that when the shot first starts, it does not at once come in contact with the grooves. Therefore, the shot must move through a certain space before it meets with the sudden resistance of the inclined groove; and the amount of that sudden resistance would be measured by the initial angle of the rifling. What I mean is this: if that were a rifled groove, and this the flange on the shot (pointing out the different parts), as Captain Scott said, it hugs the loading edge. When fired, he says it does not immediately touch the driving edge. This is quite true. But what is the result. That flange, whose tendency is to go straight on in that direction, suddenly comes in contact with this uniform spiral groove, when the shot has not only received the first shock of the powder, but when a considerable amount of velocity has also been accumulated in it. The stud, or flange, therefore, strikes a violent blow against the groove. This is a matter of little importance with small guns; but when we come to use large projectiles fired with high velocities, you must have an increasing spiral groove. Why I lay particular stress upon this is, that I am an advocate for the coiled barrel, despite what anybody says. I say that the grooves in this soft material will not stand the shock of such a heavy body coming suddenly upon them. If you must have a uniform spiral, you must also have a great number of grooves, and a great number of studs for each groove, in order to distribute the pressure over a large bearing surface. If you want a large gun to fire heavy shot with a moderate number of studs on them, you must have the increasing spiral groove, and I see no objection to it whatever. With regard to the particular form of the head of the shell, it is what is called an ogival head, and is formed by the intersection of two arcs of a circle whose radius equals $1\frac{1}{2}$ diameters of the body of the shell. This form of head so far as our experience has gone, has penetrated better than anything else. With regard to solid shot, the Ordnance Select Committee have sacrificed a small amount of effective power in order to get a longer body and therefore better bearing in the gun, which gives increased accuracy of shooting. They have hitherto struck the head with a radius equal one diameter, but I believe in future they will take one and a quarter diameter. With regard to the seven-inch shells, I believe the reason seven-inch shot have been ordered was that the authorities were anxious to obtain at once something which they had found to be good, to adopt it at once, and to trust to experiments for further improvements. Next year, however, we shall have 7-inch shells.

The CHAIRMAN: A gentleman has asked how the shot are made?

Major PALLISER: The shot are made in this way. There is an iron mould which is in the form of the shot, and there are holes made in it in which sand studs are put; the metal is simply poured down through a hole in a sand top or covering—the sand studs in the mould, cast the holes in the shot to receive the gun metal studs, and the shot comes out practically finished, with the exception of putting the studs in and cleaning off any roughness, and painting.

The CHAIRMAN: Will you be kind enough to complete the explanation of the caseable of the gun?

Major PALLISER: If you notice, the breech of a gun is the converse of the screw bolt. A female thread is cut out of the body of the gun, which is precisely the converse of the male thread cut on the screw bolt. Hence, the sudden shock which comes here (pointing to the screw thread in the breech of the gun), gives a tendency to the gun to break here (see Fig. 8, Plate viii). And a gun did actually break off its breech at that place. This fact has been harped upon a great deal; and I think it only fair to state that the powder employed was of an excessively strong and violent character, and such powder has never been used since. It was what is called No. 2 powder; further the charge was fired at two places at once. That is to say, there was a vent towards the rear end of the charge, and a vent towards the front, and the large powder charge was fired simultaneously at both points by electricity.

The CHAIRMAN: I feel confident that I am expressing the wish of the meeting in returning to Major Palliser our warmest thanks for the very interesting paper which he has read to us. I have no doubt you were all remarkably struck with the successful progress of his experiments, as one after the other, they have by induc-

tion led to their present completeness. The success which has attended the progress of his experiments, is very remarkable as regards the facts connected with his projectiles. And although it may be that for wooden vessels chilled shot is not the particular missile most suited for offensive use, that is not the question which has been under consideration. It is the piercing of armour-plated vessels; and in attempting that, Major Palliser's success appears to have been complete. Many gentlemen have brought their great talents to bear on the subject of artillery, and have given the benefit of their knowledge to improve the offensive and defensive means of our country. Most of them have reaped but a barren reward for the practical issue of their experiments. I trust Major Palliser not only will rejoice in the knowledge, and feel satisfied with the reflection of having done so much, practically, for the good of his country, but that he may also reap what is more unusual, an adequate substantial reward, in the shape of a pecuniary grant from Government.